Using A Change In Percent Highly Annoyed With Noise As A Potential Health Effect Measure For Projects Under The *Canadian Environmental Assessment Act*

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ABSTRACT

Health Canada is in the process of developing a document, *Guidance for Environmental Assessment: Health Impacts of Noise (Guidance)* on how to assess noise impacts in environmental assessments. The guidance document is needed to assist Health Canada in providing consistent expert advice on the health effects of project noise, when requested under the *Canadian Environmental Assessment Act* (CEAA). Differences exist between various noise mitigation criteria used in environmental assessments from across Canada. Therefore, the first step for Health Canada to provide consistent advice is to establish quantitative criteria for adverse health effects as a function of project-related long-term changes in noise. The criteria should be based on scientific research that has demonstrated a reasonable cause-effect association between an adverse impact on public health and well-being and community noise exposure. This paper shows that: (i) there is a substantial amount of community-based social and socio-acoustic research and (ii) precedent from U.S., European and International standard and policy setting bodies, to justify the use of a change in percentage highly annoyed with noise (%HA_n) as one of the health endpoints for an environmental assessment. Furthermore, viewing high noise annoyance as an adverse health effect is consistent with Health Canada's definition of "health". This paper also shows that %HA_n is preferable as a long term endpoint than the use of noise complaints. To add to this, there have been recent nation-wide Canadian social surveys on high noise annoyance that further support its use as an adverse health effect to be considered in Canadian environmental assessments.

SOMMAIRE

Santé Canada est à développer un document, dont la première ébauche s'intitule *Guidance for Environmental Assessment : Health Impacts of Noise (Guidance)*, expliquant comment mesurer les effets du bruit dans le cadre des évaluations environnementales. Ce document est nécessaire à Santé Canada pour l'aider à donner des conseils éclairés cohérents relativement aux effets sur la santé du bruit engendré par différents projets, lorsque des questions lui sont posées à ce sujet en vertu de la *Loi canadienne sur l'évaluation environnementale*. Les critères de mitigation sur le bruit utilisés dans les évaluations environnementales diffèrent à l'échelle du pays. Par conséquent, pour fournir des conseils judicieux, Santé Canada doit d'abord définir des critères quantitatifs sur les effets indésirables sur la santé en fonction des changements à long terme de l'exposition au bruit engendré par des projets de construction. Les critères doivent être fondés sur des recherches scientifiques qui démontrent un lien de cause à effet entre, d'une part, un effet indésirable sur la santé publique et le bien-être, et de l'autre, une exposition de la communauté au bruit. Cet article indique i) qu'un grand nombre d'enquêtes sociales et socio-acoustiques sont réalisées dans les communautés et ii) que des autorités chargées de l'établissement des politiques et des normes américaines, européennes et internationales ont établi des précédents qui justifient le recours au changement du pourcentage de personnes très incommodées par le bruit (%HA_n) comme l'un des paramètres ultimes de santé dans le cadre d'une évaluation environnementale. De plus, le fait de considérer la nuisance par le bruit comme un effet indésirable sur la santé concorde avec la définition de la « santé » établie par Santé Canada. Cet article montre que le pourcentage de personnes très incommodées par le bruit (%HA_n) est un paramètre ultime à long terme plus pratique que l'utilisation des plaintes relatives au bruit. En outre, les résultats de récentes enquêtes sociales menées à l'échelle nationale sur la question de la nuisance par le bruit tendent à confirmer l'utilisation de ce paramètre comme effet indésirable sur la santé dans le cadre des évaluations environnementales au Canada.

1. INTRODUCTION

The Canadian Environmental Assessment Act (CEAA) [1] requires that certain projects undergo an environmental assessment before receiving federal government approval. The intent of the environmental assessment process is to ensure that actions are taken to promote sustainable development and to ensure that projects are not likely to cause significant adverse environmental effects. Environmental effects may include health effects from project related noise. In the implementation of the CEAA, Responsible Authorities (i.e. the federal authority responsible for a project's environmental assessment) are designated to make the critical decision as to whether the project is likely to cause significant adverse environmental effects. As noise is an issue in many projects, the Responsible Authorities may request specialist information and knowledge from Health Canada or other specialists, as prescribed under CEAA, [2,3] regarding the health effects of noise and the potential need for mitigation.

The nature of project noise varies widely. Transportation and industrial projects reviewed to date at Health Canada for noise effects involve the development of infrastructure. For transportation projects, examples have included: (i) the development, extension or widening of freeways, highways and arterial roadways, (ii) addition of railway lines and rail yards and (iii) building of new runways to major airports. These are generally done to increase capacity for greater road, rail and air transport operations, leading to a long term increase in these types of noises. New rail yards lead to long term increases in highly impulsive noise from shunting. Highly impulsive noise is characterized by ISO 1996-1 as "any source with highly impulsive characteristics and a high degree of intrusiveness" [4]. The examples provided in the ISO standard are small arms fire, hammering on metal or wood, nail guns, drop-hammer, pile driver, drop forging, punch presses, pneumatic hammering, pavement breaking, or metal impacts in rail-yard shunting operations.

Energy industry projects have included: (i)gas pipelines, with the low frequency noise (i.e. less than 100 Hz) from gas compressor stations being a particular concern, (ii)oil (including tar sand) refineries and tar sand mines which contain a mix of continuous, intermittent, highly impulsive and tonal noise (i.e., sound characterized by a single frequency component or narrow-band components that emerge audibly from the total sound [4]) as found in many other industrial facilities and (iii)wind turbine installations. Various other projects have included development of gold mines. One unusual, major environmental assessment involved the expansion of low flying military training flights, with its peculiar potential for short rise time and high sound level aircraft noise events in otherwise quiet rural areas.

Typically, but by no means always, public concerns about a project relate to the long term operational noise and this is often given precedence following general guidance on determination of the significance of an adverse effect for CEAA [2]. Project proponents will usually forecast project-related changes in the acoustical environment from the construction phase up to about 10-20 years after full-scale operations begin. Timescales of less than a year are normally not considered for operations. In our experience, there is no typical change in noise level that would characterize all of these projects; a broad range is found for project noise, from on the order of 30 decibels A-weighted (dBA) above the existing ambient to less than the existing ambient. Some of these changes may occur gradually as would be expected with an increase in road traffic volume as a result of highway widening, or rapidly from the expansion of an airport [5], or the building of a highway extension.

Sometimes construction noise can be very high and be of relatively long duration e.g., 1-2 years continuously or lasting for several months at a time (with winter breaks) over a period of a number of years. In these cases, it too, or alone, can be the focus of concern of residences in the vicinity of the project. Construction of tunnels, bridges and port facilities can involve pile driving, a highly impulsive noise but usually for no more than a few months at a time. Only where there is continuous construction for a significant fraction of a year is the proposed percentage highly annoyed criterion intended for use.

The need for the Guidance stemmed from Health Canada's reviews of a number of environmental assessments across Canada in which there were different mitigation criteria used to protect the public from project-related changes in noise, even if similar changes in noise environments were being assessed. Given these differences, and the large number and variety of environmental assessments on noise, one of the goals of the Guidance is to indicate how to assess noise impacts on health, including the basic information requirements for an environmental assessment. This should help ensure that an environmental assessment can provide a transparent, quantitative determination of the health effects arising in an average community from predicted project-related changes in noise. This enables comparisons with Provincial criteria for project noise, providing the potential for informed cooperation and coordinated action between the federal and provincial governments on the environmental assessments (one of the stated purposes of CEAA), at least with regard to noise issues.

Given that the advice pertains to another authority's (i.e., the Responsible Authority's) decision on the significance of an effect, the advice that Health Canada provides on the health effects of noise is generally based only on well-accepted scientific evidence for a link between noise exposure and health. Therefore, this paper provides a review and analysis of the hypothesis that a change in percentage highly annoyed with noise (%HA_n) can be used as one of the health effect measures in environmental assessments for noise. Only peer review papers as well as available guidance documents, reports and conference papers published in English and judged by the authors to be most influential and pertinent for this review have been included. The analysis examines the evidence for the following supporting arguments for the hypothesis: 1) community noise annoyance is consistent with definitions of a health endpoint, 2) the $\%HA_n$ has the potential to be linked with chronic stress and other health effects, 3) the $\%HA_n$ has support as the principal measure of community reaction to noise, 4) community noise annoyance, as measured by the $\%HA_n$ has a well-established dose-response relationship with day-night sound level (DNL) and day-evening-night (DENL) sound level, the main descriptors for assessing community noise impacts in the U.S.A. and in the European Union Environmental Noise Directive [6], respectively and 5) there is a precedent for a change in $\%HA_n$ to be used as a criterion for environmental assessment of noise.

Limitations to the use of $\%HA_n$ as the only health effect measure will also be discussed. Some limitations result from the fact that other health effects need to be taken into account and are not fully done so by the $\%HA_n$. There are also limitations to the $\%HA_n$ dose-response curve, which will be discussed. As discussed in subsequent sections, $\%HA_n$ dose response relationships have been identified in a number of meta-analyses of social surveys of community noise annoyance towards steady-state acoustical environments. A change in $\%HA_n$ refers to the difference in $\%HA_n$ between the steady-state noise environment with the project and the steady-state noise environment without the project. The change in $\%HA_n$ is not intended to assess the immediate response towards a project's initial change in noise levels, but to those which are projected to occur in the long-term, at which time any potential over-reaction to the initial change, particularly a step change, can be expected to reach a steady state. One might expect that an initial potential over-reaction may subside in the steady state if the community adapts to the change; learns to effectively cope with the change and/or relocates. However, Brown and van Kamp [7] have recently reviewed the literature on how annoyance changes with time and have suggested that an initial over-reaction towards a change in noise levels may occur and not necessarily subside with time. The authors concluded that more research that specifically targets change in annoyance is needed before this can be supported or refuted. The model proposed by Brown and van Kamp could be used in future studies to elucidate how community noise annoyance changes with time.

In a recent position paper on transportation noise and annoyance [8], prepared for the European Commission by an expert working group, source-specific dose response relationships are identified as being applicable to environmental health impact assessment, giving insight to the situation that is expected in the long term. However, the position paper also notes that these annoyance responses are not applicable to a particular individual or group of individuals because the large amount of scatter in the data produces large prediction intervals. The magnitude of the prediction interval for any single community has been analyzed by Schomer [9,10], Green and Fidell [11], Fidell and Schomer [12] and Fidell and Silvati [13]. For example, Fidell and Schomer [12] have quantified the prediction interval for a community at the 95% confidence level to be between 2% and 50% highly annoyed at a DNL sound level of 65 dBA.

With their estimated confidence intervals, as opposed to prediction intervals, the dose response relationships are applicable only as the average response for a large population of adults sampled from a number of communities from several developed nations. This can be interpreted as the response of an average adult population (community) with no response bias [11]. Put in another way, in the application to environmental assessment, where, usually, the only data provided are the sound levels in the presence and absence of the project, the $\%HA_n$ cannot be assumed to be representative of the particular community where the project is occurring, but rather to an average community. This is the only level of assessment that is technically feasible at this time. As discussed later, we have adjusted the relationship between DNL and $\%HA_n$ when an area is assumed to have a greater expectation for and value placed on peace and quiet. The currently unrealistic alternative would be to conduct a socio-acoustic survey for each environmental assessment so that non-acoustic variables could be accounted for in predicting $\%HA_n$. The potential for greater predictive power using community-based subjective adjustments has been proposed by Schomer [9], but not formally tested.

1.1 Defining "health"

Clearly, if one considers the definitions of "health", as put forth by the World Health Organization (WHO) [14], and fully adopted by Canadian federal, provincial and territorial governments [3], a high degree of community annoyance from noise constitutes an adverse health effect. The definitions are: "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" and, "the extent to which an individual or a group is able, on the one hand, to realize aspirations and to satisfy needs, and on the other, to change or cope with the environment".

Treating "high annoyance" towards community noise as a health impact is consistent with the definitions of "health". Although it could be argued that the accepted broad definition of "health" could provide a framework for considering any degree of annoyance to be applied to CEAA, lesser degrees can reasonably be judged to be excluded as CEAA is concerned with the Responsible Authorities' decision as to whether significant adverse health effects are likely to occur. General guidance on significance is provided by the Canadian Environmental Assessment Agency [2], which administers the CEAA. The Agency states: "Minor or inconsequential effects may not be significant. On the other hand, if the effects are major or catastrophic, the adverse environmental effects will be significant."

Clearly, to help the Responsible Authorities with their decision, Health Canada's advice regarding the potential need for noise mitigation could not reasonably use degrees of annoyance at the low to moderately annoyed range of the spectrum. There must also be some reason to consider the change in high annoyance with noise to be a major effect. Other policies or criteria descriptions provide the only reasoning via precedents.

1.2 Noise annoyance and stress

Presumably, the relevance to the CEAA of "high annoyance" would be enhanced if it was also found to be related to (or contribute to) other adverse physiological effects, potentially leading to conditions of disease or infirmity. Some evidence suggests that this may be the case (see discussion in [15,16]). The suggested mechanistic framework is as follows. "Annoyance" is recognized as a psychological state that represents a degree of mental distress towards (in this case) noise [15]. In greater magnitudes, chronic annoyance likely reflects an inability to cope with the noise. Chronic high annoyance with noise has the potential to increase one's allostatic load by constantly requiring that one adapts to the noise. The process of this adaptation is known as allostasis and the wear-and-tear that this on-going adaptation has on the body is known as allostatic load. Processes that lead to allostatic load can include ongoing exposure to multiple stressors (from mundane to major). In susceptible individuals, this could potentially lead to an increase in allostatic load, which may lead to reduced physical and mental health, including cardiovascular disease, sleep disorders, depression and anxiety [17-23].

Some of the quantifiable indices of allostatic load include systolic and diastolic blood pressure, epinephrine, norepinephrine, cortisol levels, waist-hip ratio, ratio of total cholesterol to high density lipoprotein levels [24-26]. It has been shown that lower allostatic load scores correlate with better physical and mental health [27]. The reader interested in a more thorough discussion on the concept of allostasis and allostatic load is referred to excellent reviews by McEwen [24-26].

There is a well-documented wide-scatter in the range of $\%HA_n$ [12,28,29] at any given noise level and the incidence of adverse physiological health effects attributed to noise [30-33], which together makes it exceedingly difficult to demonstrate a strong correlation between the expression of annoyance with noise and the prevalence of illness. Despite this, there are some clues in the literature that indicate high noise annoyance may increase one's risk of illness. First, there is evidence that exposure to rather mundane daily stressors (e.g. family arguments or work deadlines) can worsen one's health and subjective well-being [34]. Jacobs [35] recently showed that having a negative mood when confronted with minor daily stressors was associated with elevated cortisol [35]. Also, long term psychological stress has been shown to increase the risk of developing cardiovascular disease among men and women in the Atherosclerosis Risk in Communities study [23]. Also, the Cardiovascular Occupational Risk Factors Detection in Israel Study (CORDIS), which is both cross-sectional and longitudinal in design, has shown that high noise annoyance scores had a statistically significant additive impact on noise-associated increases in cholesterol levels (an index of allostatic load) [36]. These authors noted that special attention should be given to individuals highly annoyed, in studying the health effects of industrial noise. While the CORDIS study was concerned with industrial noise exposure, this does not minimize the finding that those who were highly annoyed by noise showed higher levels of plasma cholesterol levels. If self-reported long term high annoyance with noise in the industrial and community settings can be considered as a similar reaction, then it is plausible that the effect on allostatic load could be similar in the two settings.

Further support for the use of $\%HA_n$ being potentially related to physiological health effects is based on the findings of a recent WHO study on housing and health status [37,38]. This study, coined the Large Analysis and Review of European Housing and Health Status (LARES), showed that, after adjusting for several potential confounding variables, self-reported annoyance (at a level equivalent to highly annoyed) among adults (18-59 years) towards traffic noise was statistically associated with elevated relative risks (adjusted odds ratios (OR), 95% confidence intervals) for the prevalence of a variety of illnesses, as diagnosed by a physician. For example, two conditions were hypertension (OR, 1.42, CI approximately 0.35) and migraines (OR, 2.19, CI approximately 0.6). The LARES study also showed that the pattern for the prevalence of illness was similar for annoyance towards general neighbourhood noise.

It has also recently been shown [39] that, although road traffic noise overall was not associated with treatment for hypertension, when the authors investigated subgroups they did observe this association among females, but not males. When the analysis was restricted to those indicating they were annoyed by traffic noise (adjusted for gender, body mass index and age), the prevalence ratio for being treated for hypertension among annoyed males (but not females) increased as the equivalent Leq 24 traffic noise levels increased. The respective prevalence rates were 3.8%, 9.4% and 13.8% at traffic noise levels below 50dBA, between 50-54 dBA and above 55 dBA. The prevalence ratio of 1.7 was statistically significant for those above 55 dBA (95% CI 1.0-2.7).

It is also relevant to this discussion that the results from a recent nation-wide traffic noise survey conducted on a representative sample of more than 2500 respondents aged 15 years and older, showed that Canadian's indicated that their annoyance towards traffic noise had a perceived negative impact on their health. Although self-reported health status was not statistically related to %HA_n, subjects were asked a separate question to rank the impact that their annoyance towards road traffic noise had on their health. On a scale from 0 to 10, where 0 was equivalent to "no effect" and 10 was equivalent to "very strong effect," 39% of those who claimed they were highly annoyed by road traffic noise responded 7 and above. Those who were highly annoyed were significantly more likely to indicate that this high annoyance had a negative impact on their health compared to those who were less annoyed [40]. Unfortunately, this survey did not probe the health endpoints that Canadians felt were adversely impacted by high annoyance.

2. ASSESSING COMMUNITY NOISE IMPACTS IN THE U.S.A. WITHOUT %HA_n

Prior to the development of a relationship between %HA_n and DNL, assessment of community noise impacts focused primarily on complaint analysis and speech interference criteria. It is important to briefly review these, as a number of jurisdictions in Canada have noise criteria which appear to be traceable to these ways of assessing community noise impacts, apparently without consideration of %HA_n.

Rosenblith et al. [41] and Stevens et al. [42] studied the characteristics of community reaction resulting from changes in noise exposure. This constituted an analysis of about 20 complaint-based case studies that ultimately formed the "community noise rating" (CNR), which was the first attempt in the U.S. to adjust for a number of factors as a way of improving the prediction of community reaction to the noise level of an intruding source. These factors included: ambient noise levels, presence of tonal noise, the community's experience with the source and time of day. The decibel adjustments were typically made in 5 dB intervals based primarily on the researcher's intuition and limited ability to determine sound levels at a greater certainty than 5 dBA [43]. These adjustments were the basis for the normalized day-night sound level.

In 1972, the U.S. Noise Control Act was established. The Environmental Protection Agency's (EPA) "Levels" document was published in 1974 to support the mandate of the Noise Control Act [44]. As there were only a few large-scale social surveys on noise exposure and %HA_n, the EPA had, as its central aim, to identify sound levels that would protect public health and well-being using speech interference and complaints, rather than a measure of annoyance.

The noise complaint assessment in the "Levels" document was based on the results of 55 case studies of complaints plotted against day-night sound level (DNL)[1] and normalized DNL of the intruding noise. A recent discussion and summary of the normalized DNL correction factors has been given by Schomer (2002) [9]. The results for the normalized DNL of the intruding noise are shown in Figure 1. Two interpretations of the complaints data were provided. The first interpretation was that a "no reaction" response corresponded to a normalized outdoor DNL of 55 dBA for the intruding noise, whereas "widespread" complaints may be expected when the normalized DNL of the intruding noise exceeds the ambient DNL by approximately 5 dBA. The second interpretation was that the mean measured outdoor DNL level associated with "no reaction" was 55 dBA, for vigorous reaction it was 72 dBA and for three intermediate degrees of reaction, which included the "widespread" complaint category, the mean value was 62 dBA. The EPA also noted that there was no evidence in the 55 case studies of even sporadic complaints when the measured DNL was less than 50 dBA.

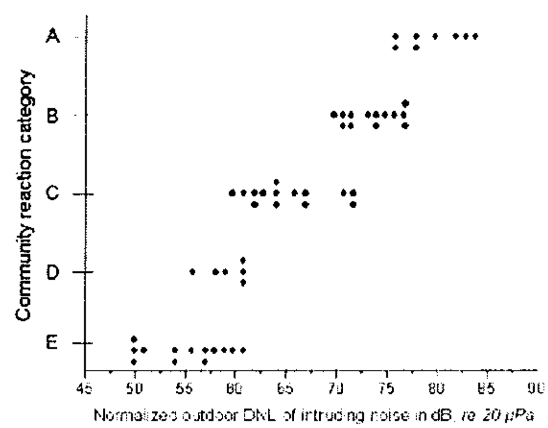

Figure 1. Adapted from the EPA *Levels* document [43] the figure shows the different levels of community reaction towards intruding noise plotted from 55 case studies as a function of the normalized DNL. Data points in the figure are normalized to: residential urban residual noise; some prior exposure; windows partially open; no pure tones or impulses. Community reaction categories: (A) vigorous community reaction; (B) severe threats of legal action or strong appeals to authorities to stop noise; (C) widespread complaints or single threat of legal action; (D) sporadic complaints; (E) no reaction although noise is generally noticeable.

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[1]DNL is a nighttime adjusted 24 hr equivalent continuous sound level (Leq), calculated from energy equivalent A-weighted day and nighttime sound levels with a 10 dB adjustment added to sound levels between 2200-0700.

Speech interference was also used by the EPA to recommend a 55 dBA DNL criterion level, which included a 5 dB margin of safety. This guidance was derived from laboratory-based studies on sentence intelligibility that involved steady, continuous sound. Then, using data for outdoor to indoor transmission loss and typical living room and bedroom absorption, it was found that the outdoor level that would permit (on average) 100% sentence intelligibility throughout a typical living room or bedroom with windows open was 60 dBA (this corresponded to 45 dBA indoors). Outdoors, this same level would allow at least 95% (satisfactory) sentence intelligibility when speaking in a normal voice up to 2 metres, according to the EPA "Levels" document [44].

The US Federal Highway Administration (FHWA) [45] uses noise abatement criteria which are partially based on speech interference. The criteria consider a traffic noise impact to occur when: 1) the projected traffic noise levels approach or exceed the FHWA noise abatement criteria (NAC) table, excerpts of which are provided in Table 1; or 2) the projected traffic noise levels substantially exceed (i.e., by 10 -15 dB) the existing noise levels in an area.

Table 1: Noise abatement criteria (NAC) hourly A-weighted sound level-decibels (dBA)

Leq(h)[2]	Descriptor of activity category
57 (outdoors)	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
67 (outdoors)	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals.
52 (indoors)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

The 52 dBA indoor level in Table 1 is well above that recommended in the ANSI standard [46] on acoustical criteria for learning spaces, such as classrooms. ANSI specifies a maximum indoor Leq (1hr) of 35 dBA for steady background sound levels in rooms between 283m^3 and 566m^3 and a reverberation time of 0.7sec. The recommended 35dBA limit may increase to 40 dBA depending on the contribution of transportation noise to the loudest 1hr period. The ANSI standard also specifies that C-weighted levels from building services and utilities (e.g. HVAC) shall not exceed the A-weighted criteria by more than 20 dB.

3. COMMUNITY REACTIONS TO NOISE

As noted above, a number of Canadian jurisdictions appear to consider either complaints or speech interference in the development of their noise mitigation criteria for environmental noise impacts and in some cases, both complaints and annoyance [47-52]. Therefore, it is important to trace the need ascertained for this health effect measure, compare it to other measures of community noise impact and review its level of acceptance in Canadian and international policy.

Around 1976, the U.S. Department of Housing and Urban Development (HUD) sponsored research to determine if self-reported annoyance could be the primary measure of long-term community reaction to noise. This led to the discovery (detailed in Section 5) of a preliminary relationship between %HA_n and DNL that suggested annoyance responses could be used in place of, or in addition to, complaints.

Although complaints were the primary measure of assessing community reaction to noise to the mid 1970's, official records showed that complaints tended to be in response to momentary noise events, often from limited households and primarily from noise contours considered to be acceptable acoustical living environments [28,53]. In addition, processing manually logged and unstructured complaints was problematic.

The %HA_n was recognized by HUD as reflecting a long-term integrated response resulting from the exposure to long term energy averaged noise levels and their ability to interfere with ongoing daily activities. Indeed, annoyance scores are correlated with responses to questions that specifically probe activity interference, other annoyance questions, coping strategies (e.g. window closing), and even complaints. Most importantly, these responses are correlated with noise levels [4,54]. In a recent nation-wide Canadian survey it was shown that %HA by road traffic noise was statistically related to: 1) increasing vocal effort during conversation outdoors, 2) interference with the ability to sleep, 3) interference with the ability to hear people, the TV and radio and 4) interference with reading and writing [40]. Several years ago, Job [55] reviewed the factors influencing the relationship between noise exposure and reaction. Reaction to noise included, but was not limited to annoyance. One of the more interesting findings from his study was that noise by itself failed to account for more than 29% of the variation in reaction and that attitude towards the source and noise sensitivity could explain as much, or more, of the variability in reaction than the noise did. It is unclear from Job's review however how much of the reaction was self-expressed annoyance, but there is little doubt that annoyance is influenced by variables other than noise.

[2] The worst hourly traffic noise impact is considered to occur when truck volumes and vehicle speeds are greatest.

Annoyance can lead to publicly expressed complaints, but the literature on this clearly shows that certain conditions must be present before complaints are made [54,56,57]. In their review of the factors that influence social surveys, Fields and Hall [54] noted that the validation of annoyance scales have been limited to various measures of self-report and therefore are susceptible to certain biases, including response bias, demand characteristics such as experimenter expectancies and social desirability. One caveat to self-report is that there can be a misunderstanding or confusion about the response scales. For instance, it is not at all straightforward that one can equate one's subjective feelings about a noise source, to either the adjectival response categories or the numerical rating scales (see below). Despite these concerns, it is generally agreed upon that it is possible to capture the subjective response towards community noise level on an annoyance scale that ranges from "not at all annoyed" to "very much or extremely annoyed" [29,58].

According to Fields and Hall [54], the conditions necessary for the emergence of individualized complaints are similar to those on a group level. A necessary, but insufficient factor on its own is dissatisfaction with the noise situation. There must also be a readily identifiable person/group that is viewed by the public as being responsible for the noise problem (e.g., airport authorities). Similarly, people must know *how* to register their complaint. It has been noted that when a telephone complaint number is publicized, complaints increase [59]. There must also be a belief that complaining will result in a positive change. A testament to this is the observation that in Australia 31% of the people surveyed who knew that they *could* complain indicated that they did not. The reason for this finding was the lack of confidence that complaining would bring about a change in the noise situation [54]. For complaints, but not annoyance, it is also important that a person or group feels that the noise is preventable. Fields and Hall [54] and Fields [60] also noted that research showed that a newly introduced source can dramatically increase complaints because it also provided an opportunity to express noise concerns about pre-existing sources. Complainants are more likely to be among the portion of the population characterized as being highly annoyed on social surveys, but they are still the minority of this group.

In the United States, complaints have been shown to be related to noise levels, but not as strongly as annoyance responses. While there appears to be little doubt that complaints do reflect an underlying existing noise problem, Fields and Hall [54] wrote:

"*...the accumulated body of research has led to the firm conclusion that complaint records are misleading indicators of the extent or causes of noise effects in populations... Official complaint records seriously underestimate the extent of noise effects. Surveys consistently show that many more people are disturbed by noise than complain.*" p18

Data prior to 1987 indicated that complaints were more strongly influenced by social status, occupation, income, and property value and were strongly impacted by the person's attitude towards the source. It was the more affluent neighborhoods that complained about aircraft noise, which likely reflected the stronger belief that their complaints would result in change [54]. Luz [53] also concluded that complaints do not necessarily increase with an increasing DNL.

There are other reasons that annoyance may be a preferable measure of community response to noise. These include the observations that complaints often: i) come from the same individuals or households, ii) tend to be in response to atypical noise events and iii) often arise from areas where community noise levels are considered acceptable living environments (see references in [54]). It should also be recalled that while 50 years ago, Rosenblith and Stevens [42] developed the CNR based on a systematic study of complaints, they clearly acknowledged the limitations to this as an approach to fully understanding the noise problem in a community:

"*Our information on the community response, however, is gleaned from comments on the number of telephoned complaints and the number of letters of complaint and from impressions of the severity of the disturbance voiced by the complainers. A carefully planned and executed opinion survey of communities exposed to noise would give much more precise data on the response. Such surveys are rarely made, however.*" p.65

The %HA_n has been accepted by two U.S. federal agencies as a potential noise impact [61,62] and is used in U.S. [63] and ISO [4] standards as such a measure. Noise annoyance is also referred to as a harmful effect by the European Union [6] and identified as one of the health effects of noise for which guideline levels have been set by the WHO [14]. Schomer [64] recently discussed noise annoyance criteria recommended by national and international organizations that set standards pertaining to community noise.

In Canada, some federal and provincial environmental noise criteria show some consistency with the use of annoyance. In British Columbia [52] and Quebec [50], the highway noise guidance appears to be based on a 6.5% change in HA_n. Transport Canada's land use guideline for aircraft noise recognizes that annoyance due to aircraft noise may start to occur within the Noise Exposure Forecast (NEF) 25[3] (approximate DNL 56.5 dBA) noise contour and that developers should be aware of this and inform all

[3] Canadian NEF is based on peak planning day, which has approximately 1.4 times the average number of operations per day. The DNL can be approximated by adding 31.5 dB to the Canadian NEF.

prospective tenants or purchasers of residential units within these boundaries. Within the NEF 30 and 35 noise contours, Transport Canada does not recommend that new residential projects take place [65]. However, they suggest that projects may be suitable in these areas if the Responsible Authority is satisfied that acoustical mitigation measures have been adequately incorporated into the building design of the development and that the developer is informed of the fact that, within these noise level contours, speech interference and annoyance resulting from aircraft noise exposure are "*...on average, established and growing at NEF 30 and very significant by NEF 35.*" The developer should also inform all prospective inhabitants of this as well.

4. USE OF DNL AS A MEASURE OF ENVIRONMENTAL NOISE

The DNL is one of the two descriptors (the other being day-evening-night sound level, DENL) for which a dose response relationship for $\%HA_n$ has been developed. Given that there remains some controversy surrounding its use, this section briefly describes some of the rationales in its favour and briefly compares it to DENL.

The DNL is a nighttime adjusted 24-hr Leq, which is typically evaluated over a long time period such as a year, or fraction of a year, so that it is useful for assessing long-term health effects. The nighttime adjustment is used to account for the expected increased annoyance due to noise-induced sleep disturbance and to the increased residential population at night relative to daytime by a factor of 2-3. Indeed, the most recent Canadian noise survey indicated that Canadians overwhelmingly want noise levels at night to be lower than at any other time period during the day [40]. In calculating the DNL (see footnote 3 above), noise levels at nighttime are artificially treated as though they were ten decibels greater than they actually are. There is no widely accepted rationale for setting the nighttime adjustment at 10 dB but the EPA "Levels" document suggests that in quiet areas the nighttime levels naturally drop by about 10 dB at night and this level of adjustment has been used with success in the US. Indeed, Shepherd [66] noted that the basis for the magnitude of the nighttime adjustment was based on the first aircraft noise study around the London Heathrow Airport, where it was found that daytime and nighttime community annoyance was nearly equal, even though nighttime noise levels dropped by about 10 dB. Likewise, the WHO has suggested nighttime noise guidelines for sleep disturbance in residences 10 dB below daytime/evening guidelines for serious annoyance [14]. A nighttime 10 dB adjustment in Canada is consistent with some provincial guidelines [48,51,52,67], although NEF contours are based on a +12 dB nighttime adjustment.

The publication of the EPA "Levels" document marked the beginning of the wide-spread usage by federal agencies in the U.S. of DNL as the metric of choice for describing noise impacts and setting noise criteria [61,62,68,69]. In the EU, the Environmental Noise Directive [6] uses the variant, DENL.

The DNL has been criticized because it does not account for different sound characteristics, such as tones or low frequencies; however, the same could be said for any energy equivalent metric, including the 24 hour Leq. Furthermore, a normalized or adjusted DNL can be used to predict annoyance towards steady-state sounds that contain audible tones (see discussion below and [4]). As with other metrics that are based on the A-weighting, the DNL has been criticized for underestimating the impact due to low frequency noise sources and not being able to account for rare loud events. On the other hand, a single 20-sec aircraft flyover with an Lmax of 95 dBA is equivalent to a daily DNL of 65 dBA. Thus, a typical single event will be taken into account by a daily DNL.

Some have also objected to the inflexible onset (2200-hr) of the nighttime penalty, even though this would likely be viewed by many as a good thing because it makes the onset of the "quiet time" predictable. On a physiological level, the concern over the inflexible onset time may be legitimate, but there is no doubt that people become less tolerant of intruding noise after a certain hour that tends to correspond to the time of day when most people would be going to sleep in order to attain somewhere around 8 hours of continuous sleep. By introducing a 5dB evening penalty, the DENL is more gradual, but it is not clear that the DENL is significantly superior to predicting the response to noise (at least for annoyance) than the DNL. For the reader interested in a detailed review of the historical development of DNL, Fidell and Schultz published a critical review of the DNL that goes beyond the scope of the present discussion [70].

5. ESTABLISHING THE DOSE-RESPONSE RELATIONSHIP FOR $\%HA_n$

Finegold has recently presented a thorough review of the historical development of the dose-response relationship for $\%HA_n$ up until 2002 [71]. Briefly, there are 4 clear phases of development of the ISO dose-response relationship for $\%HA_n$ [4]. These include the development of the original Schultz curve [29], two U.S. updates [72,73] and the transportation noise source dependent dose-response curves by Miedema and Vos [74]. These and other peer-reviewed articles for impulsive [75-81] and tonal [82-84] noise led to the current rating level synthesis of ISO 1996-1 [4]. More recently, a 5^{th} update has been provided by Fidell and Silvati [13], which used several curve fitting functions to describe the relationship between aircraft noise and $\%HA_n$. Depending on the assumptions made to fit the data, they found that a curve could miss data points of greatest interest (i.e., between 55-75 DNL). For example, when averaged in 5 dB bins, the Finegold et al [73] curve underestimated the mean $\%HA_n$ at all data points between 45 dBA DNL and 75 dBA DNL. Fidell and Silvati stated a preference for a theory-based prediction model originally presented by Green and Fidell [11]. They argued that such a model was more defensible than regression analyses because it requires less elaborate assumptions. Their analysis represents the most exhaustive approach to date, accounting for nearly 53,000 interviews across 326 sites.

Any dose-response function that has been derived by forcing a curve to fit data points that go beyond the actual data values should be interpreted with caution. It is more appropriate to fit the smoothest curve to the data points that are available without making any assumptions concerning values of $\%HA_n$ that have not been empirically validated. Thorough discussions on the introduction of bias resulting from various curve fitting approaches have been published by Schomer [10], Fidell and Silvati [13], Fidell and Schomer [12] and Fidell [28].

The functions shown in Figure 2 for $\%HA_n$ are some of the various dose-response functions developed for general transportation noise [29,72,73] and aircraft noise [4,6,11,13] as a function of DNL. They were developed from a multitude of socio-acoustic surveys. These surveys were designed to, as much as possible; assess annoyance as an integrated response to living in a steady-state environment and not to isolated events. Between two extreme anchors, varying degrees of annoyance could occupy four, five, six, seven or more categories that would either be named, or assigned a numerical value. One of the advantages to the use of numerical scales was that they readily subjected themselves to mathematical analyses.

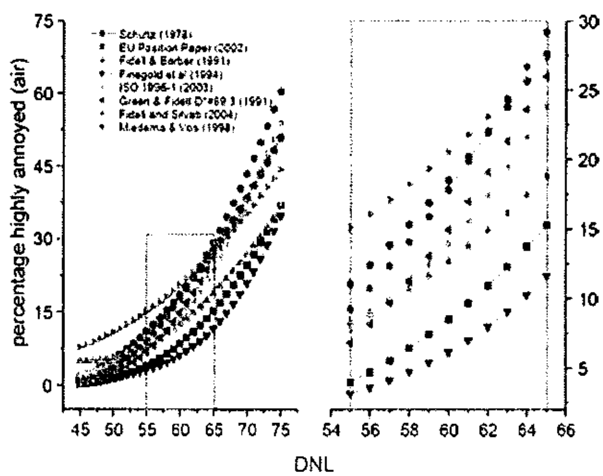

Figure 2. The Left panel shows the various dose-response functions for general transportation noise (Schultz 1978; Finegold et al. 1994; Fidell et al. 1991) and aircraft noise (EC 2002; Green and Fidell 1991; Fidell and Silvati 2004 logistic fit; Miedema & Vos, 1998; ISO 2003). The EC position paper endorses a DENL, which has been converted to DNL here by adding 0.6 dB to the DNL. The plotted ISO curve includes a 5dB adjustment for aircraft noise. The Right panel shows an exploded view of the DNL range, for the various dose-response functions, that is most applicable to environmental assessments.

The birth of socio-acoustic surveys included scales of annoyance that were generated from a combination of the subject's answers to a number of questions about activity interference or the spontaneous mention of noise as an annoying aspect of the environment. This non-standardized methodology meant that many of the social surveys were difficult to compare to one another and it was a challenge to characterize responses as belonging specifically to a high degree of annoyance (discussed below). The reader is referred to Fields and Hall [54] for a thorough discussion of the questions that have been used in the past to assess annoyance in social surveys.

Comparisons across studies showed that standardized annoyance questions were needed. This was the impetus for the publication of the ISO technical specification (TS) 15666 [58], which proposed two standardized questions to be used to assess annoyance. The questions have been translated (using forward and backward translation) into nine languages to facilitate international comparisons. The ISO/TS specifies two questions; one that has a 5-point adjectival and a second that has an 11 point numerical scale.

<u>Adjectival rating scale:</u>

Thinking about the last [12 months or so], when you are here at home, how much does noise from [noise source] bother, disturb or annoy you? *Not at all, Slightly, Moderately, Very, or Extremely*

<u>Numerical rating scale:</u>

This question is introduced with the following statement:
"This question uses a 0 to10 opinion scale for how much (source) noise bothers, disturbs or annoys you when you are here at home. If you are not at all annoyed choose 0; if you are extremely annoyed choose 10; if you are somewhere in between, choose a number between 0 and 10."

Question:

Thinking about the last [12 months or so], what number from 0 to 10 best shows how much you were bothered, disturbed or annoyed by [source] noise?

A substantial amount of research went into the development of these questions [85] so that responses were 1) indicative of a long-term integrated response to noise; 2) the respondent's own response; 3) pertinent to the noise experienced at the respondent's home; and 4) able to adequately capture a negative response. A more detailed description of these questions is provided in [58,85], including the rationale for the choice of wording and why both questions are required. These questions have been implemented world-wide and used in two national social surveys conducted in Canada to quantify the percentage of Canadians highly annoyed by traffic noise [40,86].

5.1 Source-dependent dose-response functions

Miedema and Vos [74] from the Environment Section of The Netherlands Organization for Applied Scientific Research Prevention and Health (TNO) in Leiden, The Netherlands have, over several years, built an archival database containing socio-acoustic surveys, conducted in Europe, North America and Australia, pertaining to transportation noise sources. The database contained, as of 1997, original data from 38 different studies with data from individual respondents in addition to 8 studies that were limited to group level data. In total, their new source-specific dose-response functions for transportation noise exposure and annoyance were based on 55 data sets from 45 different socio-acoustic surveys that contained 58 065 respondents, resulting in a total of 63 969 respondents since some would be counted more than once if they contributed to multiple data sets. This nearly doubled the amount of surveys used to generate the dose-response functions that preceded theirs [29,72,73].

To the extent possible, Miedema and Vos tried to address the concerns raised by Fields [54] in his review of the Fidell et al. [72] and Schultz [29] curves. This resulted in the elimination of several data sets used originally by Schultz [29] and Fidell et al. [72]. The minimum requirements concerning the relationship between DNL and $\%HA_n$ used in their research were 1) DNL (at the most exposed facade) and $\%HA_n$ had to pertain to one and the same source of transportation noise (air, road, or rail). Failure to meet this criteria resulted in the removal of 6 studies used in the analysis by Fidell et al. [72]; 2) $\%HA_n$ had to be derived from the response to a question about the general noise annoyance from the source concerned and not inferred based on rankings or activity interference. Nine of the published studies used by Fidell et al. [72] did not meet this criteria but Miedema and Vos had original data available to them from four of these nine surveys and were able to satisfy this criteria for these four; 3) the $\%HA_n$ had to be derived with a cut-off sufficiently close to 72 on a scale from 0 to 100 (they did not define what they meant by "sufficiently"). Failure to meet this criteria resulted in the elimination of five additional studies because the cut offs for three of them were 50, one was 60 and another was between 50 and 60. Using these inclusion criteria the dose-response functions included 22 of the 35 datasets originally used by Schultz [29] and Fidell et al. [72].

When DNL was not directly available, the authors calculated it by relying on certain models with some assumptions. Depending on the source, they used the: 1) event pattern model (air); 2) traffic intensity model (traffic); 3) stair case model (traffic); 4) Leq pattern model (air, road and rail). The DNL was divided into intervals of 5 dB to produce $\%HA_n$ as a function of DNL for each survey. If the 5 dB interval contained less than 100 cases, it was combined with the adjacent interval that had fewer observations. The authors repeated this step until every DNL interval contained at least 100 cases. For each mode of transportation, a quadratic ordinary least squares regression was carried out, weighing each point according to the number of observations on which it was based. Scores below 45 dBA DNL and above 75 dBA DNL were excluded from the analyses. The original fitting of the data showed that the threshold for high annoyance should be set at a DNL of 42 dBA. Subsequent analyses then forced the curves to zero at this threshold. Using multilevel modeling, the resulting $\%HA_n$ curves for each steady-state noise source, when 42 dBA was considered equal to 0 $\%HA_n$ were:

$$\text{Air: } = -0.02(DNL-42) + 0.0561(DNL-42)^2 \qquad \text{Eq.1}$$

$$\text{Road: } = 0.24(DNL-42) + 0.0277(DNL-42)^2 \qquad \text{Eq.2}$$

$$\text{Rail: } = 0.28(DNL-42) + 0.0085(DNL-42)^2 \qquad \text{Eq.3}$$

At a given exposure level, aircraft noise predicted the highest $\%HA_n$, followed by the noise from road traffic and rail traffic, respectively. The multilevel approach predicted greater aircraft annoyance at the high sound level than the least squares model. The authors also argued for the multilevel model because it more effectively accounted for the scatter in the data. It is only with this model that the 95% confidence intervals are mutually exclusive between the sources at high sound levels. The authors claim that the multilevel modeling results supported the contention that the three modes of transportation engendered different degrees of annoyance and should therefore be considered separately. Until this time, aircraft noise was considered to cause relatively higher annoyance than the other sources [11,73], but not to the extent that the data justified a separate function for it. Indeed, Finegold has objected to treating the sources differently because their differences are within the range of uncertainty in estimating noise exposures within and between studies (i.e., less than 5 dB). He also noted that source differences did not exist across the entire range of the curves and may only be apparent at sound levels that are very high (above 70 dBA DNL) [71]. While some of the studies used by Miedema and Vos directly compared aircraft noise to traffic noise (five studies) and three studies directly compared rail noise to road traffic noise, no studies directly compared annoyance from aircraft noise to annoyance from rail noise. The community response to aircraft noise is unknown while rail noise is present, and vice versa.

A relevant concern with respect to the different modes of traffic noise is that annoyance may be different when traffic is from a highway, local roads or arterial/district type roads that might be free flowing or interrupted. However, Miedema and Vos found no systematic differences between the road types (based on 19 datasets), beyond that which could be accounted for by variations in noise levels.

Miedema and Vos emphasized that, in their analysis, DNL was determined at the most exposed facade and therefore lower exposure to ground transportation noise could have led to the apparent differences in annoyance between these sources and aircraft. These potential exposure differences could be due to people ensuring their bedroom was as far away from the most exposed facade as possible. This could effectively reduce exposure to ground transportation without having an effect on aircraft noise exposure. Kryter [87] expressed a similar argument in his objections to the single function originally synthesized by Schultz [29], suggesting that annoyance towards aircraft noise should be higher. Kryter [87] reasoned that one's "effective noise exposure" is higher from a source that originates from above (and has a more spatially uniform transmission loss) compared to traffic, which would be influenced more by interfering structures [87] (see also [88,89]).

In the EU, the Environmental Noise Directive requires mapping of DENL. As a result, efforts have been made to standardize noise impact criteria in terms of this quantity. The DENL is defined as a 24 hr energy average of annually energy averaged daytime (0700-1900 hr), evening (1900-2300 hr), and night-time (2300-0700hr) sound levels. In the 24 hr energy average there is a 5 dB adjustment to noise in the evening and a 10 dB adjustment to noise in the night. Miedema and Oudshoorn [90] have used more sophisticated analytical methods to re-define the dose-response functions for transportation sources, using both DNL and DENL. Again, data outside the 45 dB DNL and 75 dB DNL were excluded because these authors considered annoyance at these extremes to be unreliable; due to uncertainty in noise data at the low end and the inclusion of what they called "survivors" at the high extremes. In this analysis, respondents that skipped specific annoyance questions because of their response on a filter question were included and assigned to the two lowest annoyance categories. Miedema and Oudshoom claimed that this minimized the risk of underestimating annoyance when filter questions were used. In total, this revised analysis was based on 27 081 aircraft respondents, from 19 studies, 19,172 road traffic respondents from 26 studies and 7,632 rail respondents from 8 studies. Their analyses for DENL and $\%HA_n$ have been published by the EU in a position paper on dose-response relationships between transportation noise and annoyance [8]. The resultant dose-response functions for transportation noise sources are as follows:

air: $-9.199 \times 10^{-5}(DENL-42)^3 + 3.932 \times 10^{-2}(DENL-42)^2 + 0.2939(DENL-42)$ Eq.4

road: $9.868 \times 10^{-4}(DENL-42)^3 - 1.436 \times 10^{-2}(DENL-42)^2 + 0.5118(DENL-42)$ Eq.5

rail: $7.239 \times 10^{-4}(DENL-42)^3 - 7.851 \times 10^{-3}(DENL-42)^2 + 0.1695(DENL-42)$ Eq.6

These functions are intended only for predicting annoyance on a population level to steady-state transportation noise sources. As discussed in the Introduction, these functions are *not* applicable to local, complaint-type situations or to the assessment of the short-term effects of a change of noise environment.

5.2 ISO and U.S. Standards

The ISO has published a standard [4] for assessment procedures for environmental noise, which can be done in terms of the $\%HA_n$. The relationship between the rating level (RL) and $\%HA_n$ is given by:

$$\%HAn = 100/[1+\exp(10.4-0.132*RL)] \quad \text{Eq.7}$$

The RL in Eq 7 is typically an adjusted DNL, with adjustments made depending on the type of noise source and source characteristics (e.g., tonality). The ISO standard specifies that the relationship for road traffic noise is obtained when RL equals DNL. The resulting curve nearly coincides with Schultz's original curve. If the RL is DNL with a +5dB aircraft noise adjustment, then the resulting ISO curve is quite similar to Fidell and Silvati's most recent logistic curve [13] for aircraft noise. Indeed, the meta-analysis by Green and Fidell [11] showed that, on average, people were more willing to report high annoyance towards aircraft noise than they were towards road and rail noise at the same sound level. The relative difference in the threshold for reporting high annoyance was found to be around 5 dB less for aircraft noise. The adjustment recommended for aircraft noise is +3 dB to + 6 dB in ISO 1996-1 [4].

ANSI [63] recommended an adjusted DNL in the same manner as the ISO standard [4] as the metric of choice for predicting community annoyance to long term noise from all types of environmental sounds in isolation or when combined.

It should be noted that there have been objections raised against the use of an adjusted or normalized noise metric with the argument that such adjustments only represent post-hoc "band-aid" solutions that do not serve to improve the predictive power between the adjusted DNL and the $\%HA_n$ [13,91]. This however is not entirely true and there are examples in the literature that show how very strong community opposition to aircraft operations could have been better anticipated if the predicted DNL was adjusted to account for factors like living in a quiet rural area and having little prior experience with aircraft noise [9]. In keeping with both the EPA and aforementioned ISO standard, Health Canada proposes a +10dB adjustment to the project sound level for assessing $\%HA_n$ when the project is to be undertaken in a quiet rural area.

6. USING A CHANGE IN %HA_N AS NOISE MITIGATION CRITERIA

The US Federal Transit Administration, (FTA) has a guidance manual [61] for characterizing impacts for all mass transit projects including, rapid, light or commuter rail, diesel/electric buses and their storage and maintenance yards. This guidance has been adopted by the US Federal Rail Administration (FRA) [62] for high speed rail projects. The guidance was adopted from a report prepared for the U.S. Department of Transportation (DoT), by Hanson et al [92]. The impacts are shown in Figure 3 as a function of noise levels from the new noise source *in combination* with the existing noise levels. The function differs with land use category. For land uses where people normally sleep and/or reside (category 2) the criterion for severe impact is based on an increase of 6.5% in %HA_n for baseline DNL values from 43 DNL to 77 DNL.

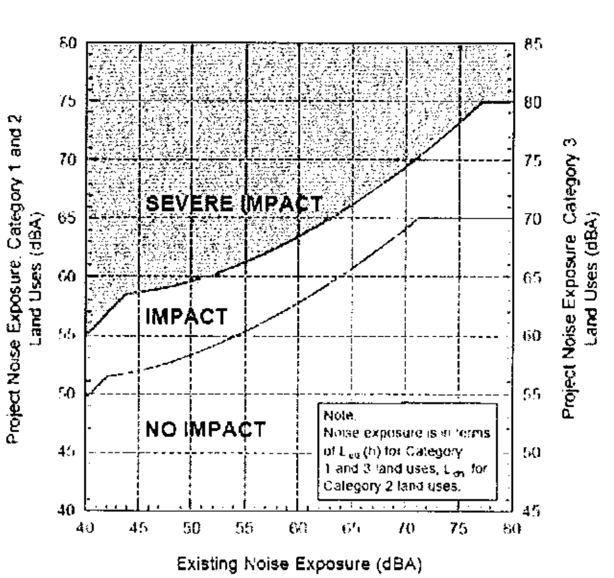

Figure 3. Plot originally presented by the US Federal Transit Administration [55] showing the magnitude of noise impact for various land use categories. For baseline DNL values from 43 DNL to 77 DNL, the "severe" noise impact reflects an increase in sound levels that equates to a 6.5% increase in the %HAn.

The rationale provided by Hanson et al. [92] for using a 6.5% increase in %HA_n as the threshold for a severe noise impact is as follows: 1) the onset of a normally unacceptable noise zone is defined by the US HUD [69] as a DNL of 65 dBA. This is also the threshold level at which the US FAA would consider noise mitigation as something that should be investigated; 2) The common use of a 5 dBA increase in DNL as the minimum required for a change in community reaction. This usage appears to be traceable to the finding in the US EPA "Levels" document regarding the changes in community reaction as a function of DNL and normalized DNL (see section 2); 3) the finding that a step from 60 DNL to 65 DNL corresponds to a change of about 6.5% in %HA_n according to Eq 7, at least for all sources and settings where adjustments do not apply (i.e., RL = DNL). Therefore the upper curve in Figure 3, from the ambient sound levels of 43 DNL to 77 DNL, is obtained using Eq 7 by solving for DNL when the increase in %HA_n is fixed at 6.5%.

Due to the non-linear nature of the dose-response relationship for %HA_n between 43 DNL and 77 DNL, the threshold for the increase in sound levels to achieve a severe impact becomes smaller as the baseline sound levels increase. Hanson et al. [92] indicated that:

"The justification for this is that people already exposed to high levels of noise will notice and be annoyed by only a small increase in the amount of noise in their community. In contrast, if the existing noise levels are quite low, a greater change in the community noise will be required for the equivalent level of annoyance." p. 3-7

Health Canada has used the change of 6.5% HA_n criterion in reviews of environmental assessments to indicate the potential severity of project noise impacts. In these reviews, the U.S. FTA criterion was extended to projects other than mass transit by assuming that the RL for mass transit projects is the same as for road traffic (i.e. DNL). For other projects, the RL adjustments for different sources provided in ISO 1996-1 [4] were used to determine the %HA_n. Application of the U.S. FTA criterion to quiet rural areas was also made using tentative adjustments of 10 dB. As noted above, ISO 1996-1 notes that research has shown that there is a greater expectation for and value placed on "peace and quiet" in quiet rural areas. This greater expectation for "peace and quiet" may be equivalent to a rating level adjustment of up to 10 dB.

In figure 4, sound level increases are shown as a function of initial sound levels from 45 dBA DNL to 75 dBA DNL. The sound level increases were determined for a corresponding increase in the %HA_n of 6.5%, using different dose-response relationships that have been applied to aircraft noise. Despite the differences in the %HA_n dose response curves in Figure 2, a 6.5% increase in %HA_n results in a similar decibel change for the 5 functions specific to aircraft noise [4,6,11,13,74]. For example, the sound level increases agree to within approximately 2-3 dBA. More variability is introduced by inclusion of the three functions [29,71,72] in which there are no distinctions between transportation noise sources. Moving from the highest to the lowest initial sound level, this variability is about 2-8 dBA.

In the FTA guidance manual [61], the %HA_n criterion is limited to a baseline sound level of 77 DNL because of the asymptotic nature of the dose-response relationship above this value. Also, HUD's site acceptability standards [69] for community noise indicated that beyond 75 dBA DNL, sites were considered unacceptable. For an existing DNL greater than 77 dBA, the FTA guidance manual considers the impact severe when the project DNL exceeds 75 dBA

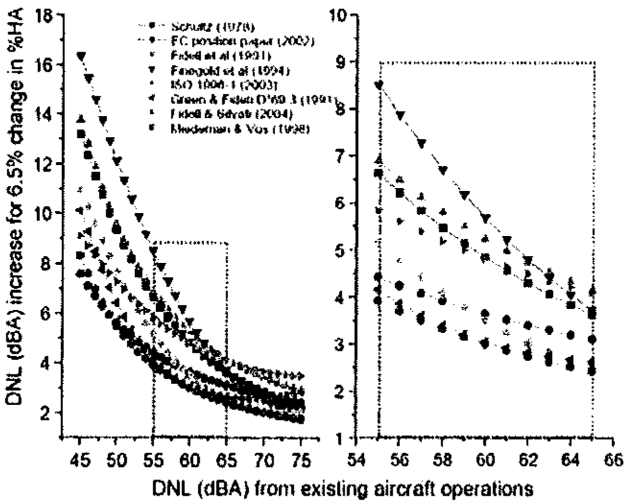

Figure 4. The Left panel shows sound level increases as a function of initial aircraft sound levels from 45 dBA DNL to 75 dBA DNL. The sound level increases are shown for a corresponding increase in the %HAn of 6.5%, using different dose-response relationships that have been applied to aircraft noise, including the ISO curve [48] with a +5dB adjustment for aircraft noise. The Right panel shows an exploded view of the DNL range for the various dose-response functions that is most applicable to environmental assessments.

7. LIMITATIONS and ALTERNATIVES TO %HA$_N$

The use of a %HA$_n$ criterion is not the only published noise mitigation criterion that could be used for environmental assessment purposes. First and foremost, it is important to be aware of the usefulness of various existing federal, provincial and territorial Canadian noise mitigation criteria for environmental assessment and land use [47,49-52,65,93]. Other U.S. Federal criteria may also be useful. As noted above, the FHWA has its own criterion based primarily on speech interference but also on "substantial change" (i.e. 10-15 dB increase) in the noise environment, even when this change leads to sound levels which do not necessarily interfere significantly with speech. For highways and for DNL levels less than 43 dB without the project, the FTA changes its guidance to that of the U.S. FHWA using an increase of 15 dB [45] (see section 2).

An example where an extra criterion is necessary pertains to low frequency sounds, which readily induce rattle indoors. Using the ISO dose-response relationship for %HA$_n$, it is currently not possible to assess the potential magnitude of low frequency noise effects. To evaluate these impacts, separate proposals have been made [9,94,95].

International noise mitigation targets have been developed, which are based on lowest observed adverse effect levels. For example, the WHO guideline levels (also adopted by the World Bank Group [96]) indicate that to avoid serious annoyance during the daytime and evening, the 16-hr Leq should not exceed 55 dBA. The guideline level for serious annoyance has also been adopted by the Organization for Economic Cooperation and Development (OECD) in urban areas with a 5 dB lower value for rural communities. These guidelines do not specify how, or if, noise sources other than road traffic or non-tonal and non-impulsive industrial noise are accounted for.

The WHO also has guideline levels to avoid sleep disturbance. The 8 hr nighttime Leq within the bedroom should not exceed 30dBA for continuous sounds and the indoor A-weighted maximum sound level for single events should not exceed 45 dBA. To avoid speech interference, indoor sound levels should not exceed 35 dBA Leq, either 16 hours in residences, or during class time for schools. As discussed in Section 2, noise mitigation targets were also provided by the U.S. EPA based on dose response relationships for percent sentence intelligibility and equivalent continuous sound level for approximately steady noises [44]. A relatively new noise mitigation criterion based on sound exposure level (SEL) for an aircraft noise event and temporary speech interference has also been suggested [97].

Recently developed dose-response relationships for sleep disturbance appear to hold promise as complements to %HA$_n$ for impact assessment. These include dose-response relationships for self-reported percentage highly sleep disturbed from road and rail noise [98] and percent of behaviourally confirmed awakenings from aircraft noise events [99,100]. A recent analysis by Anderson and Miller [101] provided a method for predicting awakenings from aircraft operations. Their method is encouraging because it attempts to account for variables that are known to influence noise-induced awakenings, such as the number of noise events.

8. CONCLUDING REMARKS

There are a variety of Canadian, U.S. and international criteria and targets for noise mitigation with respect to environmental assessment and land use. As a result, there is a place for environmental assessments under CEAA to provide predictions of the magnitude of health effects due to project-related changes in community noise. This information should be grounded on science-based evidence.

There has been more than 50 years of social and socio-acoustical research that either directly or indirectly studied the impact that community noise has on annoyance. These studies have consistently showed that an increase in community noise level was associated with an increase in the percentage of the community indicating that they are highly annoyed. The relationship between noise levels and high annoyance is stronger than any other self-reported measure, including complaints. Defining high noise annoyance as an adverse health effect is certainly consistent with Health Canada's definition of what constitutes "health". New Canadian research on road traffic noise also shows a significant percentage of respondents have indicated that this high annoyance has a negative impact on their health [40].

Dose-response relationships for predicting high annoyance have a history of using DNL as the noise metric and have improved substantially over the years by incorporating adjustments into the DNL to account for variables that are unique to either the noise source and/or the exposed community. The culmination of these meta-analytic synthesis curves has been the publication of the ISO standard for predicting high annoyance using an adjusted DNL (i.e. rating level). This standard has been adopted without modification by CSA [102].

As discussed above, there are alternatives and important complements to the use of $\%HA_n$ in environmental assessments. However, it seems reasonable to conclude that a change in $\%HA_n$ can be used in environmental assessments as *one of* the measures of the magnitude of an adverse health effect caused by project related noise. This follows from the scientific evidence provided above, and the fact that $\%HA_n$ has been used to assess impact severity in environmental assessments in US government guidance documents.

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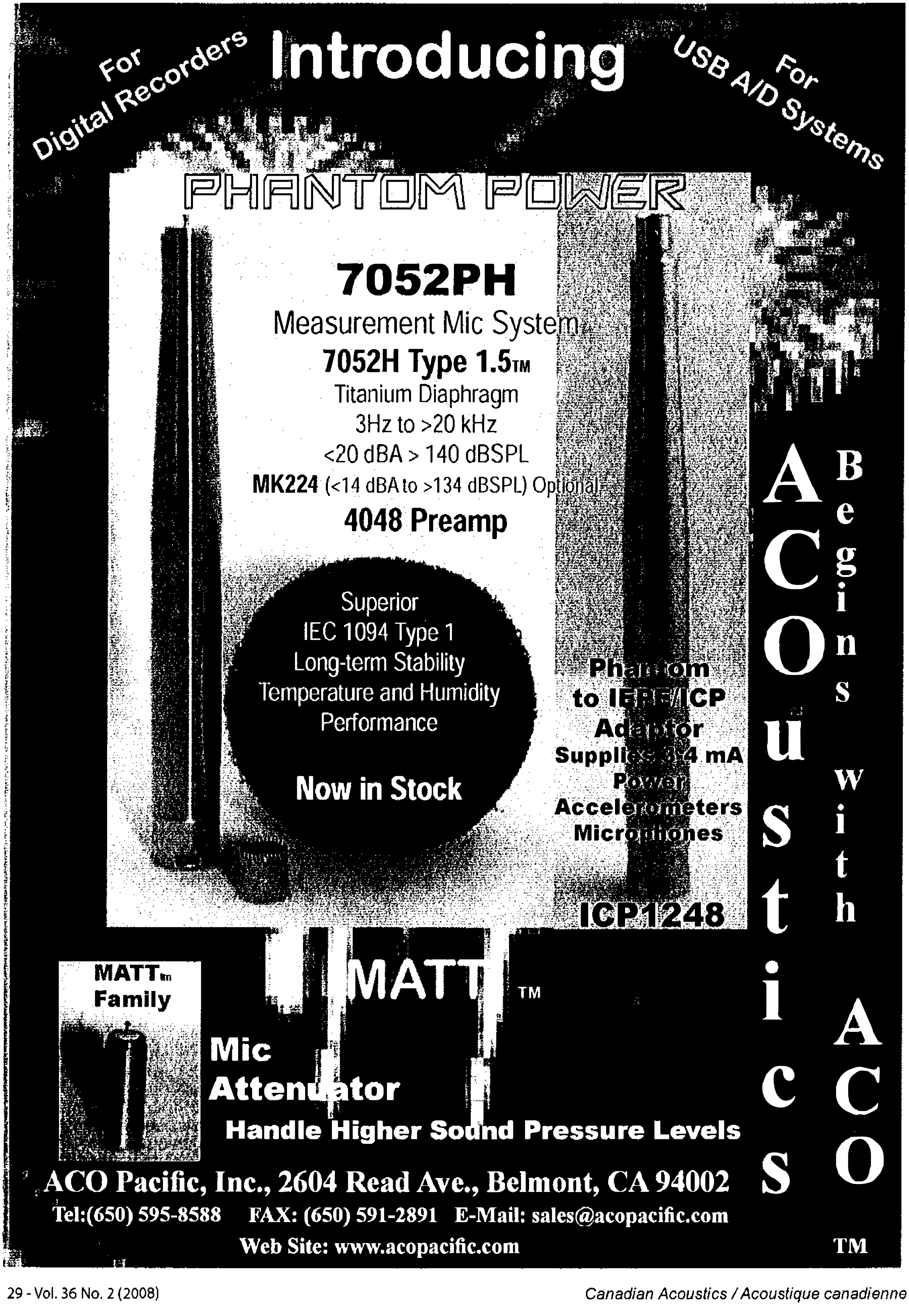
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