The Calgary Airport Authority

Parallel Runway Project
Volume V – Item 13
Human Health Baseline Report

Report

The Calgary Airport Authority

Parallel Runway Project
Volume V - Item 13
Human Health Risk Assessment Interim Report

Prepared by:

AECOM
2540 Kensington Road NW 403 270 9200 tel
Calgary, AB, Canada T2N 3S3 403 270 0399 fax
www.aecom.com

Project Number:

60114017

Date:

June 2010

AECOM
2540 Kensington Road NW
Calgary, AB, Canada T2N 3S3
www.aecom.com
403 270 9200 tel
403 270 0399 fax

March 16, 2010

Project Number: 60114017

Peter Rudolf
Director Airfield Development
Calgary Airport Authority
2000 Airport Road N.E.
Calgary, AB
T2E 6WS

Dear Peter:

Re: Baseline Study – Human Health
Comprehensive Study Environmental Assessment
Parallel Runway Project 16L-34R - Runway Development Program

This report presents the results of the baseline study for Human Health conducted by AECOM Canada Ltd. for the Parallel Runway Project 16L-34R and connecting taxiways to be constructed at the Calgary International Airport in Alberta.

The report is part of the Comprehensive Study – Environmental Assessment and forms part of Volume V of that study.

If you have any questions concerning this report, please contact the undersigned at (403) 717-3498.

Sincerely,
AECOM Canada Ltd.

Barry Hawkins Project Manager
barry.hawkins@rwy-yyc.com

TJ:
Encl.
cc: File

Acronyms

Abbreviation	Full Text
ACNCC	Airport Community Noise Consultative Committee
ANISD	Aircraft noise induced sleep disturbance
ANSI	American National Standards Institute
APU	Auxiliary power units
the Authority	The Calgary Airport Authority
CEAA	Canadian Environmental Assessment Act
CO	Carbon monoxide
CO_2	Carbon dioxide
CS	Comprehensive Study
DETR	Department of Environment, Transport and the Regions
EA	Environmental Assessment
EEG	Electroencephalogram
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FICON	Federal Interagency Committee on Noise
HAPs	Hazardous air pollutants
HDS	Highly disturbed sleep
HHRA	Human Health Risk Assessment
IHD	Ischemic heart disease
ISVR	Institute for Sound and Vibration Research
LSD	Little sleep disturbed
LFN	Low Frequency Noise
LSA	Local Study Area
NA	Number of events above noise metric
NEF	Noise exposure forecast
NNI	Noise and number index
NO_2	Nitrogen dioxide
NPL	National Physical Laboratory
O_3	Ozone
PM	Particulate matter
PRP	Parallel Runway Project
RANCH	Road traffic and Aircraft Noise exposure and children's Cognition and Health
RSA	Regional Study Area
SD	Sleep disturbed
SEL	Sound exposure level
SO_2	Sulphur dioxide
TA	Time above noise metric
VC	Valued Component
VOC	Volatile organic compound
WHO	World Health Organization
YYC	Calgary International Airport

Symbol	Unit of Measure
cm	Centimetre
dB	Decibel
dBA	A-weighted decibel
L_{EQ}	Equivalent continuous noise level
L_{AEQ}	Equivalent continuous A-weighted sound pressure level
$L_{AEQ,t}$	Equivalent continuous A-weighted sound pressure level having the same energy as a fluctuating sound over a specified time period, t
L_{DEN}	Day-evening-night level
L_{MAX}	Maximum sound level
L_{AMAX}	Maximum A-weighted sound pressure level
$L_{AMAX,t}$	The maximum A-weighted sound pressure level recorded during a noise event or noise monitoring period – the sound level meter time-weighting (fast or slow) is normally stated
L_{DN}	Day-night noise level
L_{DNR}	Onset rate, adjusted day-night average
L_{NIGHT}	Total night-time sound energy
PM_{10}	Particles of 10 micrometers diameter or less
$PM_{2.5}$	Particles less than 2.5 micrometers diameter
$\mu g/m^3$	Microgram per cubic meter

Executive Summary

A formalized Human Health Risk Assessment (HHRA) is being completed as part of a Comprehensive Study (CS) of the proposed Parallel Runway Project (PRP) at Calgary International Airport (YYC). The CS is being prepared as part of an environmental assessment (EA) and approval process initiated by the Calgary Airport Authority (the Authority). The process parallels the EA process under the Canadian Environmental Assessment Act (CEAA).

Health concerns associated with aircraft noise and/or air emissions are typically important issues, especially in residential areas surrounding any major airport expansion and improvement project. Therefore human health has been selected as a priority Valued Component (VC) for the PRP EA. The purpose of the quantitative HHRA is to facilitate a better understanding of how the potential project could influence the health and well-being of people in the surrounding environs.

The HHRA should be read alongside the baseline studies and EA documentation for Noise and Air Quality as the conclusions about health risks, under baseline conditions or in the future (with or without the completion of the PRP) revolve mostly around the measured, modelled, and/or predicted outcomes describing exposure potential to either noise or airborne contaminants in areas surrounding the airport and proposed project footprint.

This interim report focuses on Problem Definition (summarizing stakeholder health concerns and provides a concrete strategy for addressing the issues raised) and Effects Assessment (presenting important decision criteria that are essentially thresholds of effects of the issues/stressors considered, beyond which risks to human health might need to be addressed through various risk management strategies). This report will form the basis for undertaking Exposure Assessment, Risk Characterization and Uncertainty Analysis.

Table of Contents

Figures

List of Tables

1. Introduction

This Interim Report discusses the formalized Human Health Risk Assessment (HHRA) that is being completed as part of a Comprehensive Study (CS) of the proposed Parallel Runway Project (PRP) at Calgary International Airport (YYC). The CS is being prepared as part of an environmental assessment (EA) and approval process initiated by the Calgary Airport Authority (the Authority). The process parallels the EA process under the *Canadian Environmental Assessment Act* (CEAA).

The proposed PRP consists of the following components:

- A 4267 m x 60 m runway (14,000 ft x 200 ft)
- Associated taxiways
- A perimeter road with security fencing
- Grading of workspace to the east of the proposed runway
- Visual navigation aids
- Electronic navigation aids
- A maintenance building
- A field electric centre
- Changes to airside/groundside roads necessitated by construction of the runway
- Closure of Barlow Trail between 48 Avenue and Airport Road
- A taxiway underpass (designated Taxiway J Underpass) servicing the airport's cargo area for airport service vehicles to pass under one of the taxiways
- Utility services to the runway including some changes to the airfield storm drainage system
- A taxiway underpass (designated Taxiway F Underpass)

Further details regarding the process and project can be found in Volume II, Chapter 5 of the CS.

Health concerns associated with aircraft noise and/or air emissions are typically important issues, especially in residential areas surrounding any major airport expansion and improvement project. Human health is selected as a priority Valued Component (VC) for the PRP EA. A formalized, quantitative HHRA is being completed to facilitate a better understanding of how the potential project could influence the health and well-being of people in the surrounding environs.

A series of baseline studies have been prepared in parallel with this interim HHRA report, describing the biophysical, socio-economic, and historical resource baseline conditions. A total of 13 baseline studies have been undertaken:

- Soils and Terrain
- Vegetation
- Surface Water and Aquatic Resources
- Wildlife and Wildlife Habitat
- Groundwater
- Transportation
- Land Use
- Noise
- Climate and Greenhouse Gases
- Air Quality
- Cultural Resources
- Socio-economics
- Human Health

The conclusions about health risks, under baseline (current or near future) conditions or in the future (year 2025, with or without the completion of the PRP), revolve mostly around the measured, modelled, and/or predicted outcomes describing exposure potential to either noise or airborne contaminants in areas surrounding the airport and proposed project footprint. The HHRA, therefore, should be read in concert with baseline studies and EA documentation for Noise and Air Quality.

The following sections describe the HHRA framework and the major components of an HHRA, which include the following:

- Problem Definition and Development of Conceptual Exposure Models
- Effects Assessment
- Exposure Assessment
- Risk Characterization
- Uncertainty Analysis

This interim report focuses on two of these five components; i.e. Problem Definition and Effects Assessment. The first of these – Problem Definition – summarizes stakeholder health concerns arising from a variety of sources, such as public consultation, and provides a concrete strategy for addressing the issues raised. The second major component addressed herein – Effects Assessment – presents important decision criteria that are essentially thresholds of effects for each of the issues/stressors considered, beyond which risks to human health might need to be addressed through various risk management strategies.

1.1 Defined Study Area

The formally defined study area for the health risk assessment is the same as the study areas selected for evaluation of air quality and noise issues. Unlike some project issues or VCs such as soil disturbance or loss, the study area extends outward from the proposed project footprint to encompass all areas where there is a potential for human exposures to noise or airborne contaminants at levels greater than the existing or expected future background (ambient) levels.

Noise (essentially undesired sound) propagates outward in the air from its sources as energy waves. While noise and vibrations can also propagate through other media such as soil, built structures or water, the human exposure associated with sound propagate in these media compared with air is trivial, for all but the lowest frequency events (low frequency noise: LFN; see Chapter 8 of ACRP, 2008a). Such propagation is generally overlooked or assigned a very low priority in the evaluation of airport noise health effects.

Airborne contaminants potentially arising from jet engine exhaust, other combustion sources, or dust suspension also propagate within the air. Since airborne transport of contaminants is the human exposure pathway of interest, the study area includes any area on the landscape where there is potential for increases in levels of airborne substances of interest beyond ambient levels.

While the overall area of interest potentially consists of any area in which noise and/or airborne contaminants could be higher than ambient levels, the health risk assessment focuses especially on areas surrounding airport lands where more sensitive human receptors are present over extended periods of time. This is described in more detail in the “Problem Definition” section below. The study area potentially includes, but is not necessarily limited to Skyview Ranch, Saddle Ridge, Martindale, Castleridge, Whitehorn, Rundle, Marlborough, Forest Heights, Forest Lawn, Albert Park, Mayland

Heights, Vista Heights, Harvest Hills and Coventry Hills. These are suggested areas of interest only, since the potential for elevations of noise or air quality variables above ambient conditions cannot be ascertained from pre-existing data.

As for other components of the EA, we consider human health risks and issues that might arise under baseline conditions and in the future (year 2025) with or without construction and operation of the PRP. In addition, health risks are considered during both the project construction phase and in the post-construction operational period.

The area of interest generally does not include lands within the Calgary International Airport (YYC) property boundary. In particular, it is assumed that most human exposures to airborne contaminants or noise within the YYC property boundary would be in association with occupational activities, both during construction or outside construction periods. Health risks associated with occupational exposures are beyond the scope of the HHRA, but our explicit assumption is that these can be effectively addressed through a variety of occupational risk management frameworks and measures.

The travelling public are temporary visitors to various areas within the YYC lands, within the terminal building, in parking lots, and hotel. Exposure to airborne contaminants or noise is already managed in these areas through a variety of engineered controls, and the proposed PRP should not substantially alter exposure levels relative to current conditions. Therefore, public health issues associated with visitations to publicly accessible parts of YYC lands are assumed to be insignificant and were not assessed as part of the PRP EA.

2. Overview of Human Health Risk Assessment Methods

HHRA is a decision-making tool that is intended to address the concerns of potentially affected individuals or parties, managers, planners, and regulators, through formal (ideally objective) analysis of three major elements:

1. The potential sources of various stressors, toxicants, or other possible hazards;
2. Individuals or groups of people that might be exposed; and
3. Potential routes or mechanisms of exposure.

Some of the conceptual models and metrics that underpin HHRA are based on scientific/technical knowledge; however, HHRA should be viewed as a consensus-building tool that relies on inputs about concerns from a generally non-technical audience. The prior agreement (either implicitly or explicitly) by stakeholders about the issues to be addressed is at least as important for the outcome of the risk assessment as various interpretations based on the current most scientific knowledge. Quantitative risk assessment is intended to be clear and transparent: Key assumptions and uncertainties should be clearly and formally documented.

HHRA is intended to address the following five major issues, each of which is a major constituent of the analysis:

1. Problem Definition: What are the issues of concern, and which are higher versus lower priority issues for further scrutiny?
2. Health Effects Assessment: For each risk driver, what are the lower limits of exposure that could lead to undesired health consequences? (Alternatively, at a given level of predicted or measured exposure, what is the level of health effect likely to be encountered?).

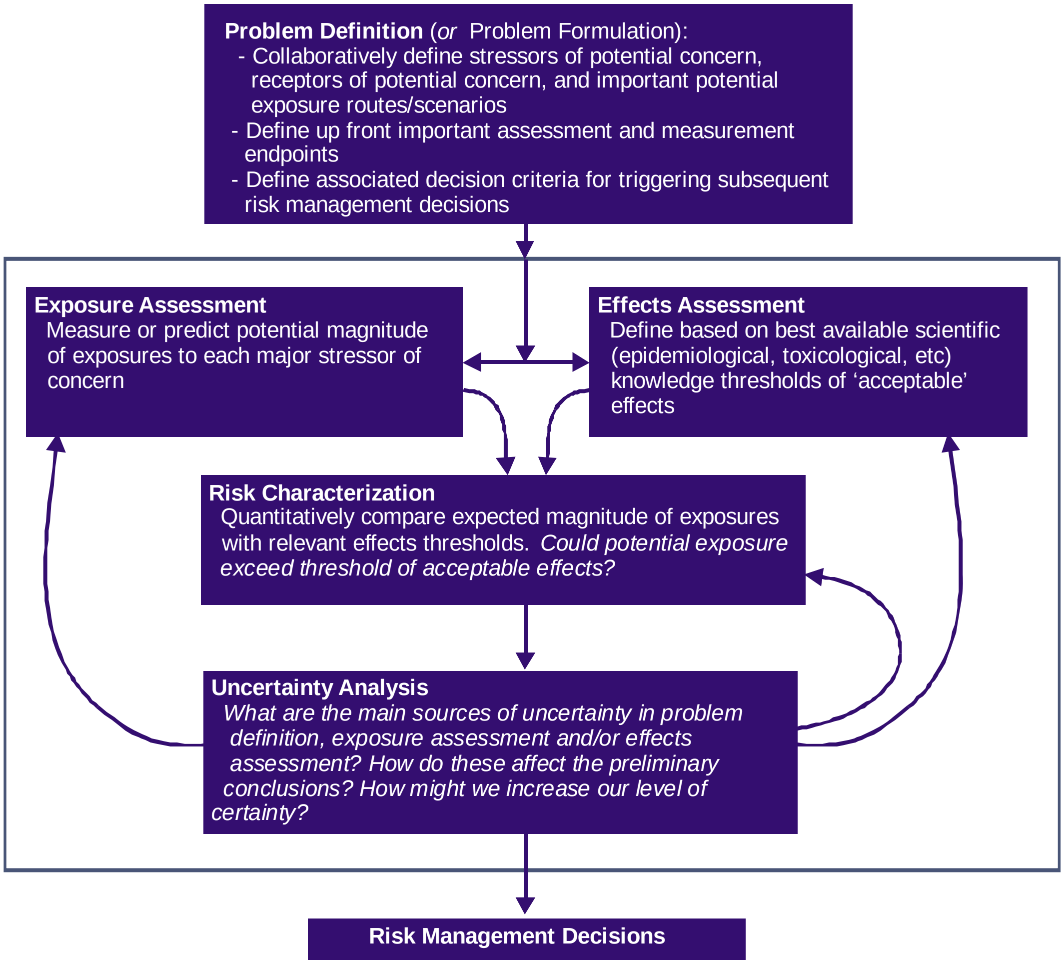
3. Exposure Assessment: For each type of potential stressor, toxicant, or other type of hazard (i.e., risk drivers) that might potentially arise from a situation or undertaking, who are the people (i.e., receptors) who might possibly be exposed, and at what magnitude or level?
4. Risk Characterization: Are potential health risks possible in light of the predicted (or measured) magnitude of exposure in comparison with expected thresholds for health effects?
5. Uncertainty Analysis: How certain are we about the information assembled to arrive at conclusions about health risk potential?

The various components of the HHRA, as commonly recognized by Health Canada, the World Health Organization (WHO), United States Environmental Protection Agency (EPA), and various other agencies, are illustrated in Figure 1. The particulars of the each component are described in more detail in subsequent sections in the context of the PRP.

HHRAs can provide useful information at a variety of levels. For example, a qualitative assessment is often useful for ruling out some concerns and focussing the HHRA on other issues. Negative health outcomes are plausible only to the extent that the source of a stressor, propagation or transport along an exposure route, and potentially affected people or VC co-occur. If any of the three elements are absent, then the underlying risk hypothesis is not plausible. By extension, predicted health risks can be mitigated by manipulating either of these three components or combinations thereof.

Where the possibility of risks has been qualitatively confirmed, it does not necessarily mean that there are unacceptable health risks. Health risk potential increases with an increase in the magnitude of exposure to one or more stressors or perturbations, and decisions about whether such increases are acceptable from a human health perspective are routinely made through comparison with thresholds of effects, beyond which adverse effects would be expected given the best available scientific/technical information.

Figure 1 The PRP Health Risk Assessment Model



This interim report provides a discussion of some of the earlier stages of quantitative HHRA for the specific purpose of catalyzing discussion and moving towards a consensus among the major interested parties. In particular, the following sections provide a preliminary Problem Definition that will be used to guide the completion of the HHRA, followed by a preliminary discussion of metrics and effects endpoints, against which predictions of noise and airborne contaminant exposures will be compared, en-route to deriving conclusions about health risks.

3. Problem Definition

The intent of the problem definition stage of HHRA is to define, through review and consultation, the list of issues of concern (stressors, toxicants, hazards, or other perturbations), potentially affected individuals, and exposure routes and other aspects of mechanistic connections between the issue of concern and humans. The information provided in the following subsections is based on:

1. a general review of environmental assessments, human health assessments, and various other case studies completed at other large airports in Canada, the United States, the European Union, and Australia;
2. documented correspondence between the Authority and other parties, including residents in surrounding neighbourhoods, the general public, local municipal authorities, and federal agencies such as Transport Canada;
3. long-standing interactions between the Authority and the Airport Community Noise Consultative Committee (ACNCC); and especially
4. oral and written feedback arising from three PRP public consultation meetings held in late April and early May, 2009.

3.1 Issues of Potential Concern

Two major issues invariably dominate concerns about human health at major airports: noise and air quality. Based on information obtained via the above-listed sources, health concerns arising from the PRP among residents of Calgary are first and foremost associated with aircraft noise. A much smaller proportion of people have expressed concern about air quality. No other major issues with regard to human health have been identified to date.

3.1.1 Community Noise

Airport noise arises from airside operations—which include engine run-up, take-off, landing, and overflights of various wide-bodied or narrow-bodied jets, propeller driven airplanes, and helicopters—and from groundside operations, primarily of maintenance vehicles (see Volume V, Chapter 8). The WHO (1999) defines community noise as follows:

> *"Community noise (also called environmental noise, residential noise or domestic noise) is defined as noise emitted from all sources except noise at the industrial workplace. Main sources of community noise include road, rail and air traffic; industries; construction and public work; and the neighbourhood."*

Community noise at airports comes primarily from aircraft approaching or taking off, from taxiing aircraft, and from engines that are running on the airfield (Edinburgh Noise Action Plan 2008-2013; May 2008). Engine noise comprises both the sound of the engine's moving parts and the sound of air expelled from the engine. However, aircraft noise also includes noise generated from air passing over the aircraft's airframe (landing gear, wings, and fuselage). The volume of noise created by aircraft varies according to their size and type, as well as the way that they are flown.

The Authority has monitored concerns of area residents to airport noise (YYC 2004). Between 300 and 400 noise complaints were lodged with the Authority in 2003 and 2004, the greatest number being received in August and the lowest number from November to January. Based on averages over four or more years, the highest number of complaints is received in the early hours of the morning (4 to 5 A.M.).

The most frequent concerns (37% in 2003 and 35% in 2004) were attributed to takeoffs of commercial jets, as opposed to arrivals, overflights, propeller type aircraft, or military flights. The Authority has also collected noise data since 1993 from 14 noise monitoring stations located near various flight paths. The data are useful in investigating complaints.

Community noise is measured in decibels (dB), which is the universally accepted measurement of sound amplitude or volume. Decibels are expressed on a logarithmic rather than arithmetic scale, since people may experience amplitudes that vary in volume between 1 and 100,000 units. As a result, perceivable sound volumes for humans are expressed within a more manageable scale of 20–120 dB. In addition, the human ear has greater sensitivity to a smaller range of sound frequencies than may be present, so noise is usually measured in A-weighted decibels (dBAs), which encapsulates the range of sounds that register most noticeably in the human ear.

Within the logarithmic A-weighted decibel scale, a three dBA decrease is barely perceptible to most people, while a five dBA decrease is clearly perceptible. Further, a decrease of ten dBA is perceived as being half as loud. For example, an event that generates 40 dBA of ambient noise is considered half as loud as an event or setting that generates 50 dBA of ambient noise.

Noise is complex, and specific effects of community noise may co-vary with different noise attributes, such as the instantaneous magnitude of a single loud event, the number of atypically loud events over a time span, the average continuous exposure to noise, or timing of a noisy event relative to various human activities, such as sleep, learning, or other attention-demanding activities.

Noise indices or metrics developed to characterize community noise can be classified into three different types (Jones and Cadoux, 2009):

1. Single event metrics: *Measurements taken to describe the noise occurring during one noise event, such as an aircraft overflight*.
2. Exposure metrics: *Used to provide a description of the type of noise exposure experienced over a given period of time*.
3. Supplementary metrics: Measurements often used in conjunction with the above, to provide a more meaningful depiction of the potential impact of noise exposure. For example, L_n is the A-weighted sound level exceeded for the *n*th percent of time. Another example is the Person Events Index, or PEI, which quantifies the number of people that would be affected by a single event noise level of specified magnitude. A PEI (70) describes the number of people affected by a single noise event greater than 70 dBA. A major disadvantage of the use of virtually all supplementary metrics is the lack of epidemiological data or other existing knowledge that would allow a comparison of the metric and health effects.

3.1.2 Airborne Pollutants

The operation of aircraft and airports can generate the same kinds of airborne contaminants as many other forms of road transportation and urban combustion emissions. Although much less is known about existing emission levels associated with aircraft operations and ground vehicle support at YYC than is known about aircraft noise, the Airport Cooperative Research Program (ACRP) provides three recent reviews of aircraft and airborne air pollutants (ACRP 2008b, c, d).

Air pollutants include particulate matter (PM), volatile organic compounds (VOCs), and other noxious compounds such as sulphur dioxide and oxides of nitrogen. As identified in the PRP Project Description and Scoping Document, the primary airborne pollutants of interest include the following:

- Total Suspended Particulates and Fine Particulate Matter (PM10, PM2.5)
- VOCs, with a focus on benzene
- Carbon Monoxide (CO)
- Nitrogen Dioxide (NO_2)
- Ozone (O_3)
- Sulphur Dioxide (SO_2)

Potentially important sources of airport-related PM emissions include aircraft engines, auxiliary power units (APUs), ground support equipment, construction vehicles and their activity, ground access vehicles (e.g., passenger cars, delivery and freight trucks), and stationary equipment. Within the immediate vicinity of the runway, the largest emission activities for VOCs are aircraft engine operation during idling and taxiing. For areas peripheral to the airport, however, source types for air pollutants cannot be generalized across airports, communities, or operating conditions.

A large variety of combustion-related VOCs have been documented in aircraft emissions, in addition to benzene. For example, ACRP (2008c) assesses potentially important "hazardous air pollutants" (HAPs) from aircraft operations. The list includes acrolein (propenal), formaldehyde, 1,3-butadiene, naphthalene, acetaldehyde, ethylbenzene, and propanal (propionaldehyde). Such HAPs are also produced from other internal combustion sources, including vehicular traffic.

When considering the above-listed HAPs and the larger suite of emitted HAPs, based on both relative emission rates and expected degree of human (mammalian) toxicity, benzene is among the highest priority. Therefore, benzene air quality data are considered to be a good surrogate for health impact potential for the larger suite of HAPs.

3.2 At-Risk Individuals and Groups

The assessment of future changes in air quality or community noise associated with the PRP will consider not just a resident of average physical health, but will focus on potentially sensitive individuals within the larger population and portions of the overall study area where such individuals might experience a higher level of project-related exposure than elsewhere. For assessment of health impacts associated with potential changes in air quality associated with the PRP, formally adopted health-based effects thresholds as promulgated by Health Canada, the WHO, United States EPA, California EPA, or other agencies generally consider the potentially higher sensitivity of developing children, the elderly, and other potentially sensitive individuals. The extent to which various formally adopted effects thresholds (Health Effects Assessment: next section) account for the possible greater sensitivity of various groups within the larger population is examined for each airborne contaminant of potential concern.

For assessing the potential impacts of changes in community noise associated with the PRP, various assessment endpoints, as specifically discussed below, are directed at sensitive components of the overall populace. In addition, the locations of facilities and residents that might house or temporarily accommodate children and toddlers (daycares), young learners (kindergartens, elementary and secondary schools), the elderly (nursing homes, old age homes, and extended care facilities), or individuals with impaired health (medical clinics and facilities) will be specifically identified, so that exposures in these locations can be specifically scrutinized.

4. Health Effects Assessment

4.1 Community Noise

4.1.1 Health Effects Hypotheses

The PRP Health Effects Assessment considers the epidemiological and scientific studies / reviews completed to date. There has been a major recent focus on evaluating the effects of community noise on human health - including noise associated with road traffic or aircraft operations. The conclusions from some studies have become widely accepted as a basis for predicting health outcomes in relation to proposed changes in airport operations (for example, Schulz 1978), while the possible implications of a few more recent associational studies are the basis of continuing debate (e.g., Jarup et al. 2005, 2008).

ACRP (2008a) and others (e.g., Harris 1997) provide a recent review of research and conclusions on the effects of aircraft noise developed since 1985. The various scientific effects studies regarding human health fall within the following noise effects categories:

- Cardiovascular effects
- Effects in developing children
- Annoyance
- Sleep disturbance
- Speech interference
- Effects of aviation noise on schools and learners

Several recent studies have suggested a significant association between some forms of long-term noise exposure and increased hypertension or other cardiovascular effects. For example, the World Health Organization (WHO, 1999) suggested a weak association between long-term environmental noise measured as ‘Equivalent Sound Measure’ (L_{AEQ}, where the ‘A’ denotes A-weighting) and hypertension:

> *“…the overall evidence suggests a weak association between long-term environmental noise exposure and hypertension, and no dose-response relationship could be established. …The overall conclusion is that the cardiovascular effects are associated with long-term exposure to L_{AEQ} 24-hr values in the range of 65-70 dB or more, for both air and road traffic noise. However, the associations are weak and the effect is somewhat stronger for ischemic heart disease than for hypertension.”*

Noise metrics such as L_{AEQ} (also routinely referred to as L_{EQ}) are discussed in more detail in Section 4.1.2.

No quantitative dose-response relationship could be developed at the time; however, based on the available data. Passchier-Vermeer and Passchier (2000) concluded from a review of the existing literature that noise exposure can induce hypertension (observed as an increase in the percentage of individuals with hypertension) and ischemic heart disease (IHD). The threshold for hypertension was estimated to correspond to a Day-Night Sound Level value (L_{DN}: Section 4.1.2) of 70 dBA. However, various studies on this issue have been criticized by some reviewers (Van Kempen et al. 2002) for not carrying out surveys in a systematic manner (which makes them prone to bias), and the tendency to not provide adequate measurement and reporting of noise exposure data. An interesting note is that cross-sectional or other studies have not revealed an association between noise exposure and either systolic or diastolic blood pressure.

Babisch (2006) reviewed the relationship between cardiovascular risk and transportation noise, based on 61 pre-existing epidemiological studies. It was hypothesized that repeated autonomic and endocrine responses can result in long-term functional and metabolic changes in individuals who experience elevated transportation noise exposures. Babisch concluded that “With respect to aircraft noise and hypertension, studies consistently show higher risks in higher exposed areas.” The author noted, however, that “statistical significance was rarely achieved”. Babisch nonetheless suggested an effect threshold for cardiovascular effects in the range or L_{DN} 60 dBA. For road traffic noise, an “exposure-response relationship” has been proposed, between noise level and risk of Myocardial infarction MI; indeed, this has been applied by Babisch to estimate the potential number of people at risk of cardiovascular effects from road traffic noise in Germany (Babisch 2006). However, for aircraft noise, there has been an insufficient number of adequate-quality studies on which to base such an exposure-response relationship. It has been argued that the relationship developed for Road Traffic Noise should be used as an “approximation” for aircraft noise; however, this assumption is still a major item for discussion amongst international experts in this field.

More recently, Jarup et al (2007) concluded that higher rates of hypertension are associated with increasing noise levels (HYENA study); however, the larger HYENA study indicated that there was a co-variation only for night-time aircraft noise. A major problem noted with the HYENA study is that the odds ratio associated with hypertension did not increase synoptically with night-time (L_{EQ} Night) exposure levels, but rather decreased at L_{EQ} Night levels greater than ~40 dBA.

In regard to the HYENA and similar studies, a very recent review by Babisch and van Kamp for the WHO led to the conclusion that:

> “*There is sufficient evidence for a positive relationship between aircraft noise and high blood pressure and the use of cardiovascular medication. However, no single common exposure-response relationship can be established for the association between aircraft noise and cardiovascular risk due to methodological differences between studies and the lack of continuous or semi-continuous (multi-categorical) noise data. For the same reason no answer can be given regarding possible effect thresholds.* “

Overall, the currently available knowledge strongly indicates a link between some indicators of cardiovascular disease (hypertension, IHD) and aircraft noise; however, the mathematical particulars or strength of the covariations cannot be adequately ascertained from the available studies. In particular, the identity, relative importance, and quantitative effects of a wide variety of possible contributing factors to hypertension or IHD have not been evaluated (unlike the case for annoyance and aircraft noise). While the possible linkage should not be ignored, the uncertainty associated with evaluation of health risks due to hypertension or IHD is too large in comparison with other health effects.

Some attention has been provided to the possible interactions between aviation noise and childhood development, including mental disorders and *in utero* development as indicated by low birth weights in children of exposed mothers. According to ACRP (2008d):

> *“Neither psychiatric disorders nor environmental factors showed any relationship to noise; however, psycho physiological parameters (e.g., heart rate and muscle tension) did demonstrate some relationship to noise. …*
>
> *……no association was found between personal noise exposure (measured in decibels) and birth weight…”*

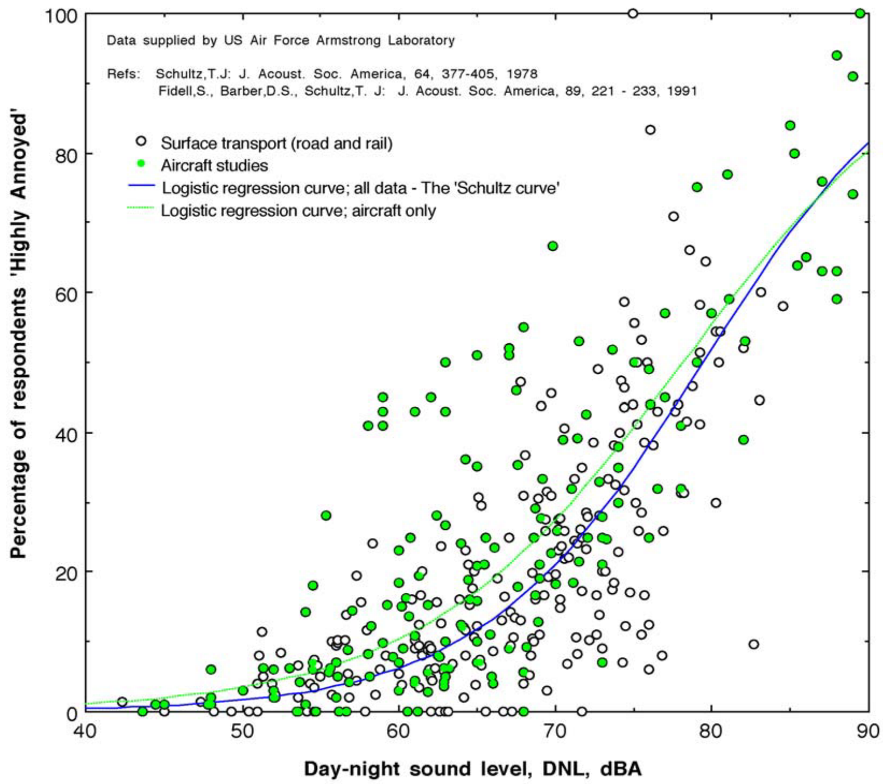
Based on the relative degree of consensus within the overall scientific and health community about the causal nature and strength of noise metrics, three health effects have been selected for the PRP health risk assessment: annoyance, sleep disturbance, and cognitive development of children. These health endpoints consider the strength of evidence (number of supporting studies, degree of certainty about the applicability of the proposed relationship to airport-related community noise, and importance of the effect level / type for human health) and availability of peer-reviewed, quantitative exposure-effect relationships..

4.1.1.1 Annoyance

The WHO (1999) guidelines for Community Noise provide a definition of noise annoyance as "a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them". Annoyance is a primary potential effect of aviation noise..The study of noise annoyance, however, is complicated by significant individual variability in annoyance response to the same level of the same sound, and to different noises; The same noise could be annoying to some people but acceptable to others. Measurement procedures of annoyance have been standardized internationally by agreement (e.g., International Organisation for Standardisation, 2003) across different cultures and languages. The methods involve individuals self reporting their response on an annoyance scale. The degree of annoyance in populations has generally been reported in terms of the percentages of that population who are ‘highly annoyed’, ‘moderately annoyed’, ‘a little annoyed’, or ‘not annoyed’. Research studies (Schultz 1978; Fidell, *et al.*, 1991; Miedema and Vos 1998; Fidell 2003; Fidell and Silvati 2004) on aircraft noise annoyance and disturbance over many decades has shown that, although average long-term effects (e.g., annoyance) can be determined by asking a representative sample to rate their individual annoyance on a categorical scale, these responses tend to be only weakly correlated to the degree of sound exposure (Figure 2). This modest correlation reflects very large differences between individuals’ reactions to the same noise (due to the modifying non-acoustic factors such as attitude to the noise maker, personality traits, perception of control over the noise, noise sensitivity, etc.) rather than a failure of experimental design. Consequently, aviation noise assessment criteria take into account typical “community responses” and are not capable of predicting or validating the reaction of individuals.

A strength of the longstanding focus on annoyance is that several researchers have evaluated the effects of various demographic variables on self-reported annoyance. For example, Miedema and Vos (1998) evaluated the quantitative influence on annoyance of sex, age, education level, occupational status, size of household, dependency on the noise source, use of the noise source, etc. along with two ‘attitudinal’ variables (noise sensitivity; fear of the noise source). The results indicate that fear and noise sensitization has a major influence on reported annoyance.

Figure 2 "The Schultz Curve" - % Person Highly Annoyed by Transportation Noise



Source – CAP 725 CAA Guidance on the Application of the Airspace Change Process Airspace Change Proposal - Environmental Requirements

The U.S. Federal Aviation Administration (FAA) guidance on aircraft noise annoyance thresholds is based on the Schultz Curve (Figure 2), which is based on social survey data published in 1978 that has been updated by Fidell et al. (1991). The expanded dataset and exposure–annoyance response model was adopted in 1992 by the U.S. Federal Interagency Committee on Noise (FICON) and subsequently became part of the American National Standards Institute (ANSI, 2006) standard on community responses to environmental noises.

Beyond North America, one of the most widely accepted exposure-annoyance relationships for aircraft noise is that developed by Meidema and Oudshoorn (2001), using the noise metric L_{DEN} (see section 4.1.2) as a predictor of annoyance. Their exposure-effect relationships were developed from a meta-analysis of 20 international studies, with separate analysis for each of road traffic, aircraft, and railways. The Meidema and Oudshoorn exposure-effect curves were subsequently recommended for noise assessment purposes by the European Commission (2002) (Environmental Noise Directive 2002/49/EC) and by the Environment Assessment Agency of the Netherlands (Kempen et al 2005).

Their exposure-effect equations for aircraft noise are:

$$\text{Percent Annoyed (\%A)} = 8.588 \times 10^{-6} (L_{DEN} - 37)^3 + 1.777 \times 10^{-2} (L_{DEN} - 37)^2 + 1.221 (L_{DEN} - 37) \quad \textbf{[1]}$$

$$\text{Percent Highly Annoyed (\%HA)} = -9.199 \times 10^{-5} (L_{DEN} - 42)^3 + 3.932 \times 10^{-2} (L_{DEN} - 42)^2 + 0.2939 (L_{DEN} - 42) \quad \textbf{[2]}$$

The authors also calculated 95% confidence intervals around these exposure response estimates.

4.1.1.2 Sleep Disturbance:

The current literature suggests that sleep disturbance due to noise can take two forms: (i) sleep interruption, resulting in fragmented sleep and overall loss of sleep, and (ii) modification of sleep patterns, typically resulting in altered sleep states and lesser amounts of deep sleep, which are replaced by lighter, more fitful sleep patterns. Acute responses might include changes in blood pressure and heart rate, taking a longer time to get to sleep, awakening, and acute annoyance. Such effects are generally experienced during a particular aircraft overflight event; however, individual acute events may have an aggregated influence over one night (termed ‘total night effects’) and even multiple nights (‘chronic effects’), resulting in sleep deprivation, sleep fragmentation, and changes in normal sleep cycles. Possible longer term consequences have been hypothesized to include impaired performance and a variety of other effects on physical and mental health.

According to the Health Council of the Netherlands (2004), there is sufficient strength of evidence to support a link between aircraft noise and shorter term repercussions of sleep disturbance, including changes in sleep state, electroencephalograph (EEG) indicators of awakening, onset of motility (noise-induced awakening or movement), cardiovascular change, and subject-registered awakening. Longer term effects for which there is sufficient strength of evidence include a prolongation of the sleep inception period (difficulty getting to sleep), insomnia, and drowsiness or fatigue during the day and evening. There is less evidence for effects such as changes in stress level hormones, depression, altered immunocompetence, impaired cognitive performance, increased irritability, annoyance, impaired social contacts, or occupational accidents. In these effects, a relationship between exposure and effect has been observed (in one or more studies), and a causal relationship is credible, but the possibility of coincidence, bias, or distortion cannot confidently be excluded.

Meidema and Vos (2004) completed a meta-analysis of nine sleep studies (based in France, the Netherlands, Switzerland, the U.K., and the USA) relating aircraft noise exposure levels to percentage of subjects that self-reported as being highly sleep disturbed (%HSD), sleep disturbed (%SD), or a little sleep disturbed (%LSD). The noise exposure metric used was total night-time sound energy (L_{NIGHT}). The equations describing the curvilinear fit through the meta-data were as follows:

$$\%HSD = 18.147 - 0.956\, L_{NIGHT} + 0.01482\, (L_{NIGHT})^2 \qquad \textbf{[3]}$$

$$\%SD = 13.714 - 0.807\, L_{NIGHT} + 0.01555\, (L_{NIGHT})^2 \qquad \textbf{[4]}$$

$$\%LSD = 4.465 - 0.411\, L_{NIGHT} + 0.01395\, (L_{NIGHT})^2 \qquad \textbf{[5]}$$

It is expected that various other effects would correlate with motility. Passchier-Vermeer (2003) reviewed noise exposure vs. sleep disturbance data for residents near Schiphol Airport, Netherlands and determined that:

$$\text{Percentage noise-induced awakenings} = -0.564 + 1.909*10^{-4}*(SEL_i)^2,$$

where SEL_i is the *indoor* Sound Exposure Level (see Table 1 for a description of SEL). The use of this equation, therefore, will require further conversion of outdoor SEL noise exposure estimates to indoor estimates, with the attendant assumptions.

In 1991-92, research for the Department of Transport in the UK into aviation noise impacts at night found that outdoor noise events below 90 dBA SEL (equivalent to approximately 80 dBA maximum sound level,

L_{MAX}: Table 1 are very unlikely to cause any increase in the normal rate of sleep disturbance, and that, for noise events in the range of 90-100 dBA SEL (80-95 dBA L_{MAX}), the likelihood of the average person being awakened by an aircraft noise event is about 1 in 75.

The use of the 90 dBA SEL criterion is in line with more recent findings, as presented in the Michaud et al paper published in 2007 on aircraft noise-induced sleep disturbance. This paper examined aircraft noise-induced sleep disturbance (AN-ISD). This literature review of field studies of AN-ISD since 1990 finds that the generalization of findings to population-level effects is complicated by individual differences among subjects, methodological and analytic differences among studies, and predictive relationships that account for only a small fraction of the variance in the relationship between noise exposure and sleep disturbance. Also, the available studies show that AN-ISD occurs more often during later than earlier parts of the night, indoor sound levels are more closely associated with sleep disturbance than outdoor measures, and spontaneous awakenings, or awakenings attributable to non-aircraft indoor noises, occur more often than awakenings attributed to aircraft noise. There is additional information about levels above 90 dBA SEL. However, the authors confirm that using any such relationship for predicting effects carries with it a level of uncertainty and implies that it is probably best viewed as a tool for comparing situations rather than for a clear indication of total numbers of people affected.

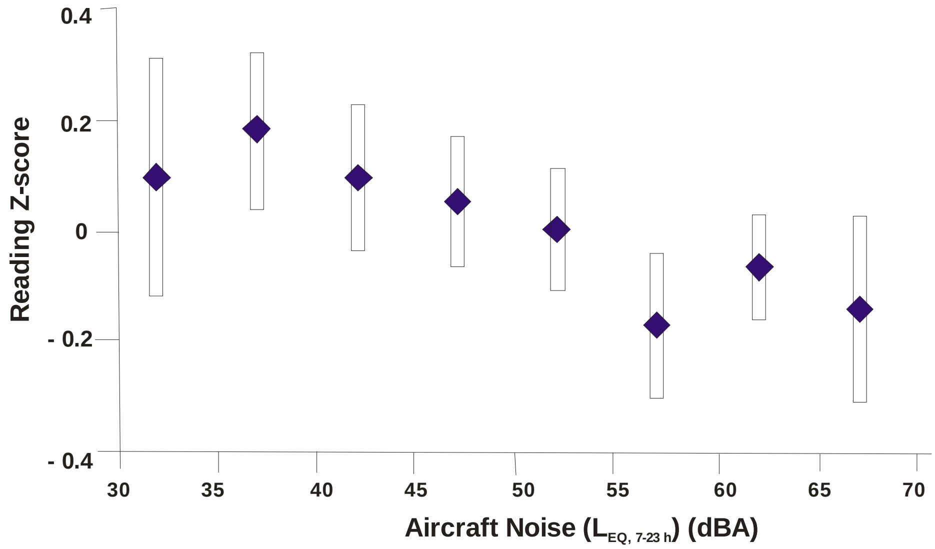
4.1.1.3 Cognitive Development of Children:

While the 90 dBA SEL level might be useful for assessing the effect of aircraft noise on sleep disturbance, much lower levels can affect children's cognitive development. The 2005 RANCH (Road traffic and Aircraft Noise exposure and children's Cognition and Health) study (http://www.wolfson.qmul.ac.uk/RANCH_Project/), provided evidence that young children living near airports lagged behind their classmates in reading by up to two months for a 5-dBA increase in aviation noise in their surroundings, at levels of 30 to 70 dBA (Stansfeld et al. 2003). Figure 3 is reproduced from the RANCH study. The study also associated aircraft noise with lowered reading comprehension, even after socio-economic differences were considered. The Munich Airport Study (Hygge et al. 2002) also demonstrated a positive relationship between aircraft noise levels and cognitive outcomes in a cohort of 326 nine to ten year olds (i.e., in reading, long-term memory, working memory, attention, and mental/health behaviours) (Staasten 2004). The metric of interest in the Munich study was $L_{AEQ,\ 24\ hr}$; in the RANCH study, it was $L_{AEQ,7\text{-}23\ hr.}$

The RANCH study is continuing and a numerical exposure – effects model of children's cognitive development has yet to be developed.

The relationship between aircraft noise and children's cognitive development cannot be defined too precisely. This is due in part to the fact that reading age cannot be quantified in units of less than one month duration using the Suffolk Reading Scale, which was used in the RANCH study. As well, there are uncertainties when measuring reading performance in the classroom, when translating actual test scores into 'reading age' and in estimating noise exposure. The noise-cognitive development relationship should be expressed in relatively coarse units if used to quantify effects on reading age, with an acknowledgement of the degree of uncertainty around individual numbers. The preliminary findings of the RANCH study, nonetheless will be used to guide the health risk assessment interpretations and conclusions.

Figure 3 Aircraft Noise Exposure Relationship for Reading Performance in 2,844 Nine to Ten Year Olds around Heathrow Airport, U.K



4.1.2 Community Noise Metrics

The ideal noise metric for assessment of aviation noise would:

- capture the absolute or peak noise level of the noise emission source;
- describe the duration the noise is audible at a specific location;
- indicate the degree to which the noise exceeds the ambient noise; measure how often the noise occurs;
- account for the different impacts of the over flight noise (for example, in relation to annoyance, sleep and activity disturbance, speech interference, etc.) ;
- be easily measured;
- be readily modeled and predicted; and
- be readily understood by non-specialists.

Unfortunately, no single noise metric has yet been developed that can meet all the above requirements. It is necessary, therefore, to select a primary noise metric that covers as many of the above attributes as possible, as well as supplementary metrics, which will address the remaining points above so that, cumulatively, the primary and supplementary metrics serve the need of the health risk assessment. The select primary and supplementary noise metrics are described below. In all cases, the metric assumes some simplification of A-weighted noise levels and fluctuations over time.

A brief summary of the broader range of metrics used in contemporary noise assessments worldwide is provided in the PRP Project Description and Scoping Document, and is provided here as well for context:

Table 1 Summary of Commonly Used Noise Metrics

Major Application	Metric	Brief Description	Unit	Relevant Time Period
Policy: Land Use Restrictions/Zoning Annoyance (percent highly annoyed: $\%HA_n$)	**L_{DN} (DNL)**	Day-Night Sound Level: developed using the FAA's Integrated Noise Model (INM). L_{DN} sums the individual noise events and averages over 24 hr, after including a 10-dB 'penalty' for events occurring between 2200 hr and 0700 hr.	dBA	24 hr
Policy: Land Use Restrictions/Zoning Annoyance (percent highly annoyed: $\%HA_n$)	[1]**NEF**	Noise Exposure Forecast: composed of the Effective Perceived Noise Level (EPNL) and Tone-corrected Perceived Level (PNLT).	dBA	24 hr
Sleep disturbance, speech interference	**L_{MAX}, L_{AMAX}**	Maximum Sound Level: highest A-weighted sound level during a distinct event	dBA	Dependent on event duration
Sleep disturbance	**SEL**	Sound Exposure Level: composite metric that captures both the intensity and duration. SEL approximates the net impact of an entire acoustic event, since it estimates on a logarithmic scale the total sound energy transmitted to a recipient during a specified event.	dBA	Dependent on event duration
	L_{EQ} = L_{AEQ}	Equivalent Sound Measure: cumulative noise metric based on steady state noise level over a defined period.	dBA	1 hr, 15 hr Day, 9 hr Night
	L_{DNR}	Onset-Rate Adjusted Day-Night Average Sound Level: L_{DN} metric adjusted to reflect sudden onset, or 'surprise' events. Designed to address sporadic, high-noise events such as military aircraft overflights.	dBA	Daily, monthly
	TA	Time Above Noise Metric: The amount of time that noise levels are greater than a given threshold.	Minutes/day	Daily
	NA	Number of Events Above Noise Metric: the number of noise events exceeding a given threshold	Events/day	Daily

Notes:

1) NEF contours are predictive estimates of noise transmission produced using a complex model advanced by the National Research Council and adopted by Transport Canada for use at all major Canadian airports. The NEF is based on data for aircraft type, runway geometry, flight paths, flight distance, number of day and night flights, activity increase/decrease, and aircraft fleet upgrading. These data are combined with study results from about two decades from the United States on community responses to noise. The NEF accounts for both physical noise levels and human noise perceptions, and is a numerical approximation of the accumulated perceived noise levels that would be perceived at a specific location around the airport on an average busy day. Since noise transmission characteristics have a spatially explicit character (i.e., are based on distance from a source and change in noise energy over distance), NEF contours can be developed around the airport.

Primary Noise Metric - Day-Night noise level (L_{DN}, or DNL): It is proposed that the primary noise index used to assess the noise impact of the parallel runway will be the Day-Night noise level (L_{DN}). This is a 24-hr L_{EQ} measure with a 10-dB weighting for any noise events occurring during night-time (22:00-07:00)[1], when it is considered that people's sensitivity to noise is heightened. There is a split of 15 hr for the daytime and 9 hr for night-time. No weightings are applied to the day and evening periods. This metric is currently used in the United States, Belgium, and New Zealand. The major effect evaluated using L_{DN} is annoyance.

Secondary Noise Metric - Noise Exposure Forecast (NEF): The Noise Exposure Forecast (NEF) descriptor was originally derived by the USA in the 1960s for commercial airports. It combines the sound level expressed in Effective Perceived Noise Level (EPNL) with the number of events. A trade-off factor of 16.7 is applied to night-time operations only (10 for daytime movements). Only events above a certain EPNL level are taken into account. NEF is used in Canada, Hong Kong, Spain, and Greece. A practical disadvantage of NEF is the difficulty of routine noise monitoring in EPNL.

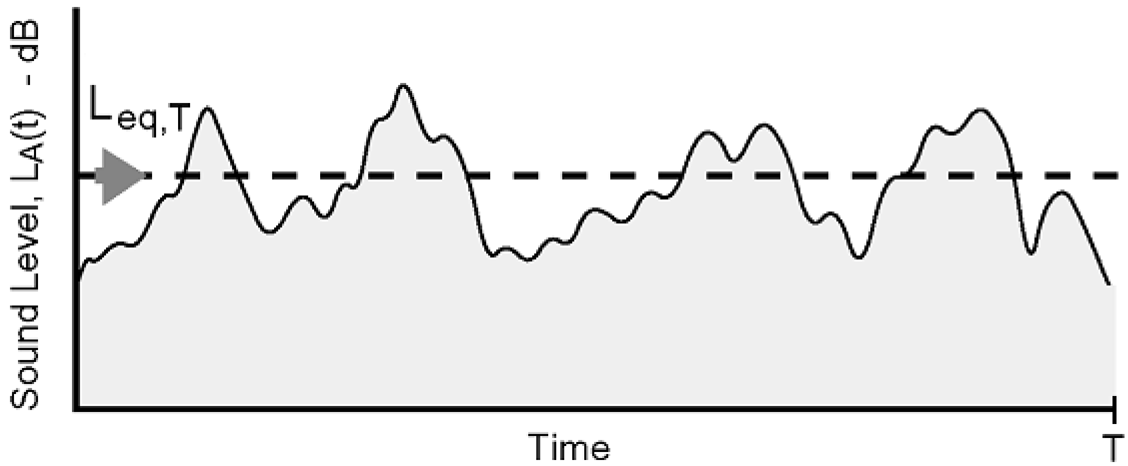
Secondary Noise Metric - L_{MAX}: The simplest measure of a noise event, such as the overflight of an aircraft, is the maximum sound level recorded – L_{MAX}. In many applications, a frequency weighting is applied to approximate the measurement to the response of the human ear. Most commonly, the A-weighting is used with the level termed L_{AMAX} and measured in dBA. For aircraft noise, it is common practice to measure L_{AMAX} (which is sometimes simply referred to as L_{MAX}), using the sound level meter's 'slow' response, which dampens the very rapid, largely random fluctuations of level (as opposed to the 'fast' response, which causes the meter to track them). Metrics that are based on L_{MAX} do not take into account the duration of the noise, and hence are possibly less representative of the disturbance due to the noise event. However, they are easier to measure and often much simpler for the public to understand. L_{AMAX} can be used to assess speech and activity interference, and impacts on children's cognitive development.

Secondary Noise Metric - Sound Exposure Level (SEL): The sound exposure level (SEL) of an aircraft noise event is the sound level, in dBA, of a one second burst of steady noise that contains the same total A-weighted sound energy as the whole event. In other words, it is the dBA value that would be measured if the entire event energy were uniformly compressed into a reference time of one second. SEL, therefore, can be higher than L_{MAX} for a noise event. SEL can be used to assess sleep disturbance.

Secondary Noise Metric - The Continuous Equivalent Noise Level (L_{EQ}): L_{EQ} can be defined as the hypothetical steady sound, which contains the same sound energy as the actual variable sound, over a defined measurement period (Figure 4). L_{EQ} is the most commonly used noise descriptor for all types of noise source, and for aircraft noise, its use is widespread across the world. L_{EQ} is most often measured on the A-weighted scale, and usually with the averaging time indicated in the format, giving for example the abbreviation L_{AEQ}, 16 hour. For a constant level sound event, the L_{EQ} remains unchanged if the duration is doubled, because the average energy is the same.

[1] Note that different jurisdiction or authorities may define the night time period differently. For example, WHO and NEF contours are based on a night-time weighting of noise events occurring between 2300 h and 0700 h.

Figure 4 Graphical Representation of L_{EQ} (from Jones and Cadoux, 2009)



$$L_{AEQ,T} = 10\ Lg\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}\frac{pa_2{}^2}{p_0{}^2}\,dt\right]$$

Where:

$L_{AEQ,T}$ is the equivalent continuous A-weighted sound pressure level, in decibels, determined over a time interval *T* starting at *t*1 and ending at *t*2;

*p*o is the reference sound pressure (20 kPa); and

*p*A (*t*) is the instantaneous A-weighted sound pressure of the sound signal.

In the term 10 X log10, the use of 10 as the coefficient gives an energetic summation of noise events; i.e. doubling the number of events increases the overall L_{Aeq} by 3 dB, since 10 X log10 = 3. This number coefficient is often referred to as the 'trade-off' factor, as it determines how many less noisy events can be 'traded' for events at a higher noise level.

L_{EQ} is a measure of average (A-weighted) sound energy, which involves no empirical adjustments other than the A frequency weighting. L_{EQ} can be relatively easily measured or calculated in a variety of ways. It is important to understand that the L_{EQ} index represents a logarithmic energy average rather than an arithmetic statistical average, since decibels are measured on a logarithmic scale. This is particularly important with respect to aircraft noise because of the wide variation in noise levels between noisier and quieter aircraft noise events. By means of an example, consider three noise events of noise levels 70, 80 and 90 dB. The arithmetic average is simply the sum divided by the number of events or 80 dB: but because a noise level of 90 dB has 100 times the noise energy of 70 dB and 10 times the noise energy of 80 dB, the logarithmic or energy average of these noise levels is approximately 86 dB. This means that, although the L_{EQ} is an average because it is energy based, it will tend to be biased toward the highest noise levels in the assessment period. The L_{EQ} can be used to asses overall impacts on noise annoyance and on children's cognitive development.

Other Metrics: Day-Evening-Night Level (L_{DEN}) is similar to L_{DN}, except that it essentially adds an extra weighting of 5 dB to aircraft noise levels occurring in the evening. It has three component parts: L_{day} measured over a 12-hr day period from 07:00 to 19:00 (the same as L_{EQ} for that period), $L_{evening}$ measured over a 4-hr evening period from 19:00 to 23:00, and L_{night} measured over an 8-hr night period from 23:00 to 07:00 (all times local). Countries currently using this metric include Denmark and Finland, and L_{DEN} is the metric specified for the environmental noise maps produced under the European Noise Directive (Directive 2002/49/EC). The default day/evening/night time periods in the EU Directive are 07:00 to 19:00, 19:00 to 23:00 and 23:00 to 07:00, but practitioners can shorten the evening period by one or two hours if they wish and can lengthen the day and/or the night period accordingly. The L_{DEN} can be used to assess annoyance and the impacts of noise on physical health.

Some working groups have recommended greater use of the "Time Above" (TA) noise metric, which is the amount of time that noise levels exceed a given threshold. Such a threshold can be defined in a variety of ways: for example, by reference to an L_{90} ambient, the 90^{th} percentile of noise levels under ambient conditions. A benefit of TA (L_{90}) is that it correlates in an approximate linear fashion with changes in number of aircraft operations (Hanscom Noise Workgroup recommendations, FICAN 2001 Airport Noise Forum; http://www.fican.org/pdf/HanscomNoise.pdf, accessed 31 October 2009). The number of events above (NA) a chosen threshold would be expected to similarly capture changes in the number of flights and associated activity. FICAN (2002) describes the N70 contour (or NA_{70dBA}), which depicts the number of individual events louder than 70 dBA on an average day. 70 dBA equates to a noise event likely to disturb conversation inside a house with the windows open. One weakness of N70 is that it treats a noise event of 70 dBA the same as one of 90 dBA; however, it is based on the concept that once a certain threshold is reached, the event becomes intrusive and the actual noise level is less important.

In summary, L_{EQ}-type indicators – those that provide an integrated (geometric mean) measure of noise energy over a pre-established time period (for example L_{EQ}, L_{DN}, L_{DEN}, L_{night}) - are widely used. They provide an integrated measure of the number of noise events, the noise energy, and the duration of those events. However, other noise indicators are useful in communicating the impact of aircraft noise and assessing specific impacts (for example $L_{MAX,}$ N70), but are subject to limitations and do not replace L_{EQ}-type indicators that remain the basis of aircraft noise impact assessment internationally.

4.1.3 Exposure Limits Adopted by Other Parties and Case Studies Based on Recent Environmental Assessments

In 1999, the WHO provided formal guidance on community noise thresholds for human health (Table 2). On October 8, 2009, WHO's European Office also issued "Night noise guidelines for Europe," which recommend that annual average night exposure to noise not exceed 40 dB $L_{night,outside}$, a noise metric that is also used by the European Union.

In 1998, the UK Department of Environment (DETR) requested that the National Physical Laboratory (NPL), together with the Institute of Sound and Vibration Research (ISVR) at Southampton University, review standards for assessing the health impact of environmental noise. The NPL/ISVR report concludes that the Guidelines for Community Noise published by the Karalinska Institute in 1995 (which went on to be adopted as the WHO Community Noise guidelines in 1999) are interpreted as taking such a precautionary approach, and that social, economic, political and historic factors are at least as important in setting noise criteria.

The NPL/ISVR report goes on to state that -

> *"In essence, the WHO guidelines represent a consensus view of international expert opinion on the lowest threshold noise levels below which the occurrence rates of particular effects can be assumed to be negligible. Exceedances of the WHO guideline values do not necessarily imply significant noise impact and, indeed, it may be that significant impacts do not occur until much higher degrees of noise exposure are reached. One difficulty here is the true importance of the different noise effects considered when placed in an overall context relating to quality of life, and the extent to which noise control might have excessive consequences in other areas of human experience."*

and:

> *"As such, it would be unwise to use the WHO guidelines as targets for any form of strategic assessment, since, given the prevalence of existing noise exposure at higher noise levels, there might be little opportunity for and little real need for any across the board major improvements. On the other hand, the most constructive use for the WHO guidelines will be to set thresholds above which greater attention should be paid to the various possibilities for noise control action when planning new developments. It is important to make clear at this point that exceedances do not necessarily imply an over-riding need for noise control, merely that the relative advantages and disadvantages of noise control action should be weighed in the balance. It is all a question of balance and mere exceedance of the WHO guidelines just starts to tip the scales."*

The above extracts from the NPL/ISVR report can be interpreted as meaning that if given the freedom to only consider noise impacts on or from a proposed development in isolation, without consideration of other planning, social, health and economic objectives; it may be desirable for none of the adverse effects of noise to occur. Significant drawbacks, therefore, of the WHO 1999 guidelines include the failure to consider the practicability of achieving any of the recommended noise levels or the consequences of achieving the recommended noise levels in terms of other planning, social, health, or economic objectives.

Table 2 Guideline Values for Community Noise in Specific Environments (excerpted from WHO 1999)

Specific Environment	Critical health effect(s)	L_{AEQ} (dBA)	Time base (hr)	$L_{AMAX\ fast}$ (dB)
Outdoor living area	Serious annoyance, daytime & evening Moderate annoyance, daytime & evening	55 50	16 16	- -
Dwelling, indoors Inside bedrooms	Speech intelligibility & moderate annoyance, daytime & evening Sleep-disturbance, night time	35 30	16 8	 45
Outside bedrooms	Sleep-disturbance (open window), outdoor values	45	8	60
School classrooms & pre-schools, indoors	Speech intelligibility, disturbance of information extraction, message communication	35	During class	-
Pre-school bedrooms, indoors	Sleep disturbance	30	Sleeping time	45
School, playground outdoor	Annoyance (external source)	55	During play	-
Hospital, wardrooms, indoors	Sleep disturbance, night time Sleep disturbance, daytime & evenings	30 30	8 16	40 -

Table 3 provides a brief summary of recently completed environmental assessments that involved the evaluation of health impacts from potential changes in community noise.

Table 3 Examples of Decision Criteria Used in the Assessment of Noise Impacts for Other Projects

Study	Noise Metric	Decision Criteria	Comments
Edinburgh Airport Noise Action Plan 2008-2013 (May 2008)	L_{AEQ} dB L_{DEN}	57 dB	UK Government threshold for onset of significant annoyance affecting low levels of a population.
Brisbane, Australia, new Parallel Runway – Airspace Health Impact Assessment (2007)	L_{DEN} L_{NIGHT} and SEL (indoors) L_{EQ}	Change in % of potentially highly annoyed or moderately annoyed per equations [1][2], Section 4.1.1 Change in % of potentially sleep disturbed, per equations [3][4][5] of Section 4.1.1 Qualitative	Self-reported annoyance level Sleep disturbance Children's reading performance
URS (June 2007). Calgary International Airport Aircraft Engine Run-up Study	NEF	< NEF 30	"Under Transport Canada guidelines for airport noise compatibility, an exterior level of NEF 30 or less is considered acceptable for noise levels for residential neighbourhoods near airports."
U.S. Department of Transportation, Federal Aviation Administration (March 20, 2006), National Policy: Environmental Impacts: Policies and Procedures	L_{DN}	L_{DN} < 65 dB For - 65 dB < L_{DN} < 75 dB, Hospitals, nursing homes, churches, auditoriums, and concern halls should achieve a noise level reduction (NLR) of 25 to 30 dB.	"A significant noise impact would occur if analysis shows that the proposed action will cause noise sensitive areas to experience an increase in noise of DNL 1.5 dB or more at or above DNL 65 dB noise exposure when compared to the no action alternative for the same timeframe. For example, an increase from 63.5 dB to 65 dB is considered a significant impact."
Cranbrook, B.C., Airport Expansion Program, Environmental Assessment (2005)	L_{DN}	L_{DN} < 65 dB	"…several reviews of chronic health effects (i.e. cardiovascular disease, hypertension) from airport noise found that effects were possible from long-term exposure to 24-hour time averaged noise levels greater than 65-70 dBA." (Health Canada 2002). Health Canada's (2002) review concluded that "the available research does not support the contention that there is a significant risk of chronic stress and/or cardiovascular disease arising from long-term exposure to outdoor daily aircraft noise levels above 65 dBA". Nevertheless, 65 dBA remains a standard threshold for potential concerns over airport noise [65 dBA corresponds to a Noise Exposure Forecast (NEF) of about 33.

Study	Noise Metric	Decision Criteria	Comments
Sea to Sky Highway Environmental Assessment, Vol 3, Section C, Noise.	$L_{EQ.\ 24\ h}$	55 dBA Threshold of acceptability for road noise	"The CMHC in its document 'Road and Rail Noise: Effects on Housing' (NHA 5156 08/86) has identified an Leq(24) of 55 dBA as the threshold above which highway noise can begin to have impacts within residential areas… … due to interference with speech and sleep."
Vancouver International Airport Parallel Runway Project, Report of the Environmental Assessment Panel (2001)	NEF L_{DN} SEL L_{MAX}	< NEF 25 L_{DN} < 60 dBA	"…the Panel accepts b, 60 dBA as the criterion for assessing impact of noise on people." "…the Panel believes that a reasonable threshold for defining the spatial limits of aircraft noise impact would be an outdoor Lmax of 65 dBA, and a corresponding SEL of 75 dBA
Seattle Tacoma (SETAC) Final Supplemental Environmental Impact Statement for the Proposed Master Plan Update Documents (1997)	L_{DN}	L_{DN} < 65 dB % increase in predicted a real extent of L_{DN}>65 dB contour	Per FAA guidance, as at all major U.S. airports

4.1.4 Summary of Major Effects Endpoints and Noise Metrics Used in the Study

As discussed in Section 4.1.1 of this report, the major potential health effects associated with community noise selected for evaluation in the PRP environmental assessment, in order of priority, are:

- annoyance (percent of populace or households highly annoyed);
- sleep disturbance, based especially on night-time aircraft operations; and
- cognitive development in children.

Michaud et. al. (2008) published a paper entitled "*Using a change in percent highly annoyed with noise as a potential health effect measure for projects under the Canadian Environmental Assessment Act."* This is part of guidance being drafted by Health Canada for the purpose of providing consistent advice regarding noise-related health effects of projects proposed under the Act. According to Michaud et al., the viewing of a high degree of annoyance is consistent with Health Canada's definition of "health", and percent highly annoyed is the preferred alternative as a long-term health endpoint. A goal of the Health Canada deliberations is to *"establish quantitative criteria for adverse health effects as a function of project-related long-term changes in noise"* (Michaud et al. 2008). This paper provides an extensive review of the noise metrics and thresholds developed over the last two decades to predict percent highly annoyed (%HA_n), including a critical evaluation of dose-response relationships; however, no specific set of effects thresholds have yet been recommended by Health Canada. Nonetheless, the detailed analysis tends to indicate that using a change in %HA_n is an acceptable noise impact mitigation criterion, coupled with L_{DN} as an appropriate exposure metric. According to Michaud et al. (2008):

> *"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."*

Over the 45 to 75 dBA L_{DN} range, Michaud et al. found that sound level increases equating to an increase of 6.5% HA_n were very similar (within approximately 2 to 3 dBA) when calculated from mathematical relationships between annoyance and aircraft noise that were provided by Fidell and Silvati (2004), ISO (2003), Directive 2002/49/EC (2002), Miedema and Vos (1998), or Green and Fiddell (1991).

Overall, the noise effects and thresholds assessed in the PRP EIS are summarized in Table 4.

Table 4 Summary of Noise Descriptors and Decision Criteria Used in the Health Risk Assessment

Effect	Risk Threshold or Indicator
Annoyance	Number of individuals or households experiencing a change (increase or decrease) equivalent to 6.5% HA_n, as predicted from modelled (validated), spatially explicit L_{DN} levels
Sleep Disturbance	(1) 90 dBA SEL (see Michaud et al. 2007) (2) Number of individuals or households experiencing a change (increase or decrease) in sleep disturbance, based on Meidema and Vos (2004) equations (Section 4.1.1)
Cognitive Development in Children	Predicted change (increase or decrease) in noise exposure levels at facilities where children are routinely engaged in learning and development activities (day care centres, kindergartens, home-schooling, etc). (L_{DAY}, L_{AMAX})

4.2 Airborne Pollutants

As described in the PRP Project Description and Scoping Document, potential health effects associated with emission of air pollutants from airport operations will be assessed based on current operating conditions and in the future (2025), based on predicted emissions with or without completion of the PRP. Additional analyses will be focused on the construction phase of the project. The risk characterization for each major case will be based on comparing predicted airborne concentrations with human health effects thresholds as incorporated in the *National Air Quality Objectives, Alberta Ambient Air Monitoring Objectives and Guidelines* (2008) and other relevant sources as required.

A brief summary of the appropriate effects threshold for each contaminant of potential concern is in Table 5.

Table 5 Summary of Ambient Air Quality Objectives Used in the Health Risk Assessment

Airborne Contaminant	Risk Threshold Value	Source
Total Suspended Particulates	[1]Maximum Acceptable Level: 24-hr avg. – 120 µg/m^3 Annual avg. – 70 µg/m^3	National Ambient Air Quality Objectives (CCME 1999)
Fine Particulate Matter PM_{10} $PM_{2.5}$	Recommended Reference Level: 24-hr avg – 25 µg/m^3 Recommended Reference Level: 24-hr avg – 15 µg/m^3	National Air Quality Objectives for Particulate Matter (Health Canada 1998)

Airborne Contaminant	Risk Threshold Value	Source
Benzene	1-hr avg - 25 µg/m^3 Inhalation-based toxicity reference value associated with an incremental lifetime cancer risk of 1-in-100,000 3.03 µg/m^3 Chronic air concentration associated with a 1-in-100,000 cancer risk. 1.3 to 4.5 µg/m^3	Alberta Ambient Air Quality Objectives and Guidelines (2009) Health Canada (2004) USEPA IRIS
Carbon Monoxide (CO)	[1]Maximum Acceptable Level: 1 hr – 30 ppm (mg/m^3) 8 hr – 13 ppm (mg/m^3) [2]Maximum Tolerable Level: 8 hr – 17 ppm (mg/m^3)	National Air Quality Objectives for Carbon Monoxide (Health Canada 1994)
Nitrogen Dioxide (NO_2)	1-hr avg. - 400 µg/m^3 24-hr avg - 200 µg/m^3 Annual avg. – 60 µg/m^3	Alberta Ambient Air Quality Objectives and Guidelines (2009)
Ozone (O_3) (ground-level)	[3]Recommended Reference Level: -non-accidental mortality: Daily, 1-hr maximum - 20 ppb -respiratory hospitalization: Daily, 1–hr maximum - 25 ppb	National Air Quality Objectives for Ground level Ozone (Health Canada 1999)
Sulphur Dioxide (SO_2)	1-hr avg. – 450 µg/m^3 (pulmonary function) [1]Maximum Acceptable Level: 1-hr avg. – 900 µg/m^3 24-hr avg. – 300 µg/m^3 Annual avg. – 60 µg/m^3	Alberta Ambient Air Quality Objectives and Guidelines (2009) National Ambient Air Quality Objectives (CCME 1999)

Notes:

1) *The **maximum acceptable level** is intended to provide adequate protection against effects on soil, water, vegetation, materials, animals, visibility, and personal comfort and well-being.*

2) *The **maximum tolerable level** denotes time-based concentrations of air contaminants beyond which, owing to a diminishing margin of safety, appropriate action is required without delay to protect the health of the general population.*

3) *Health Canada (1999) notes "The ozone Reference Level is defined as an estimate of the lowest ambient concentration at which statistically significant increases in health responses have been detected. In general, Reference Levels should not be interpreted as thresholds for affects. In the case of ozone, most studies indicate a continuum of effect through all ambient levels examined, and adverse effects are expected below the Reference Level. However, the analysis performed here indicates that the statistical strength of the data below the identified Reference Levels is inadequate to provide quantification of effects at lower levels.*

5. Exposure Assessment

This section will be completed when outcomes of the air quality and noise modelling are available.

6. Risk Characterization and Uncertainty Analysis

This section will be completed when outcomes of the air quality and noise modelling are available.

7. References

ANSI, 2006. American National Standard Guidelines for the Preparation of Standard Procedures to Determine the Noise Emission from Sources. ANSI S12.1-1983

ACRP (Airport Cooperative Research Program), 2008a. Effects of Aircraft Noise: Research Update on Selected Topics. A Synthesis of Airport Practice. Report by Mestre, V. on behalf of the United States Federal Aviation Administration (FAA) and the Transportation Research Board. Washington, D.C. (www.TRB.org). 90 pp. (http://www.trb.org/Publications/Public/Blurbs/Effects_of_Aircraft_Noise_Research_Update_on_Selec_160286.aspx; accessed Sept. 22, 2009)

ACRP (Airport Cooperative Research Program), 2008b (December 12th). Summarizing and Interpreting Aircraft Gaseous and Particulate Emissions Data. 34 pp plus appendices. (http://www.trb.org/Publications/Public/Blurbs/Summarizing_and_Interpreting_Aircraft_Gaseous_and_160507; accessed Sept. 22, 2009).

ACRP (Airport Cooperative Research Program), 2008c (August 11th). Aircraft and Airport-Related Hazardous Air Pollutants: Research Needs and Analysis . 56 pp. (http://www.trb.org/Publications/Public/Blurbs/Aircraft_and_AirportRelated_Hazardous_Air_Pollutan_160113; accessed Sept. 22, 2009)

ACRP (Airport Cooperative Research Program), 2008d (July 16th). Research Needs Associated with Particulate Emissions at Airports. 33 pp plus appendices. (http://www.trb.org/Publications/Public/Blurbs/Research_Needs_Associated_with_Particulate_Emissio_160036; Accessed Sept. 22, 2009)

Babisch, W., 2006. Transportation Noise and Cardiovascular Risk. Review and Synthesis of Epidemiological Studies, Dose-effect Curve and Risk Estimation. UBA [Federal Environmental Agency] Report. (http://www.cowiprojects.com/noiseclassification/docs/Babisch_Transportation_Noise_Cardiovascular_risk_2997.pdf).

Babisch, W., 2000. Traffic noise and cardiovascular disease: epidemiological review and synthesis, *Noise Health* 2(8): 9-32.

Babisch, W. and van Kamp. 2008. Aircraft Noise and Health, in the Report of the WHO Working Group on "Evidence Review of Aircraft Noise and Health.

Directive 2002/49/EC, 2002, of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. Declaration by the Commission in the Conciliation Committee on the Directive relating to the assessment and management of environmental noise. Official Journal of the European Communities L189, 12-25.

BAA Edinburgh, 2008. Edinburgh Noise Action Plan 2008-2013.

FICAN, 2002. Federal Interagency Committee on Aviation Noise. The Use of Supplemental Noise Metrics in Aircraft Noise Analyses. 10 pp. (http://www.fican.org/pdf/supplemetal_metrics.pdf)

Fidell S. and L. Silvati, 2004. Parsimonious alternatives to regression analysis for characterizing prevalence rates of aircraft noise annoyance. *Noise Control Engineering Journal*, 52: 56-68.

Fidell S. 2003. The Schultz curve 25 years later: a research perspective. *J Acoust. Soc Am.*, 114: 3007-3015.

Fidell S. and L. Silvati, 2002. Social survey of community response to a step change in aircraft noise exposure. *J. Acoust. Soc. Am.*, 111: 200-209.

Fidell, S., D.S. Barger and T.J. Schulz, 1991. Updating a dose-effect relationship for the prevalence of annoyance due to general transportation noise. *J. Acoust. Soc. Am.* 89: 221-233.

Green DM and S. Fidell, 1991. Variability in the criterion for reporting annoyance in community noise surveys. *J. Acoust. Soc. Am.*, 89: 234-243.

Harris, C.S., 1997. The Effects of Noise on Health, Writ-Patterson Airforce Base, Ohio: Report AL/OE_TR-1997-0077.

Health Canada, 2002. Noise from Civilian Aircraft in the Vicinity of Airports – Implications for Human Health. I. Noise, Stress and Cardiovascular Disease. http://www.hc-sc.gc.ca/ewh-semt/pubs/noise-bruit/01hecs-secs256/index_e.html

Health Council of the Netherlands, 2004. The Influence of Night-time Noise on Sleep and Health. The Netherlands, Health Council of the Netherlands: Publication No. 2004/14E.

Hygge, S., 2003. Noise Exposure and Cognitive Performance-Children and the Elderly as Possible Risk Groups,. Technical report presented at the World Health Organisation meeting on noise and health indicators 07-09 April 2003, WHO Brussells, 1-19.

Hygge S. G.W. Evans and M. Bullinger, 2002. A prospective study of some effects of aircraft noise on cognitive performance in schoolchildren. *Psychological Science* 13: 469-474.

ISO, 2003. Acoustics-Description, measurement and assessment of environmental noise-Part 1: Basic quantities and assessment procedures. ISO 1996-1:2003(E).

Jarup, L., W. Babisch, D., Houthuijs *et al.,* 2008. Hypertension and exposure to noise near airports: the HYENA study. *Environmental Health Perspectives.* 116: 329-333.

Jarup L, M.L. Dudley, W. Babisch *et al.*., 2005. Hypertension and Exposure to Noise near Airports (HYENA): study design and noise exposure assessment. *Environmental Health Perspectives* 113:1473–1478.

Jones, K. and R. Cadoux, 2009. Metrics for Aircraft Noise. ERCD Report 0904, produced for the Aircraft Noise Monitoring Advisory Committee. 22 pp. (http://www.caa.co.uk/docs/33/ercd0904.pdf; accessed Sept 22, 2009).

Kempen, E van, B., Staatsen and I. van. Kamp, 2005. Selection and evaluation of exposure-effect-relationships for health impact assessment in the field of noise and health, Environment Assessment Agency, Bilthoven, RIVM report 630400001/2005.pp. 1-77.

Michaud, D.S., S.H.P. Bly and S.E. Keith, 2008. Using a change in percent highly annoyed with noise as a potential health effects measure for projects under the *Canadian Environmental Assessment Act*. *Canadian Acoustics*, 36: 13-28

Michaud, D., S. Fidell, K. Pearsons, K. Campbell and S. Keith, 2007. Review of field studies of aircraft noise-induced sleep disturbance. *Journal of the Acoustical Society of America*

Miedema H.M. and C.G. Oudshoorn, 2001. Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. *Environ. Health Perspect*., 109: 409-416.

Miedema H.M. and H. Vos, 2004. Self-reported sleep disturbance caused by aircraft noise. Delft, TNO, pp. 1-12.

Miedema H.M. and H. Vos, 1998. Exposure-response relationships for transportation noise. *J. Acoust. Soc. Am*., 104: 3432-3445.

NPL/ISVR - B Berry, I Flindell & N Porter - *Health Effect Based Noise Assessment Methods: A Review and Feasibility Study*, September 1998, Department for Environment, Food & Rural Affairs

Passchier-Vermeer, 2003. Night-time Noise Events and Awakening. Delft, TNO, pp. 1-47.

Passchier-Vermeer W, and W.F. Passchier, 2000. Noise exposure and public health. *Environ. Health Perspect*. 108 (suppl. 1):123-131.

Schulz, T. J., 1978. Synthesis of social surveys on noise annoyance. *J. Acoust. Soc. America*, 64, –377-405.,

Stansfeld S.A. and M.P. Matheson,. 2003. Noise pollution: non-auditory effects on health. *Br Med Bull* 68:243–257.

van Kempen E.E., H. Kruize, H.C. Boshuizen, C.B. Ameling, B.A. Staatsen and A..E. de Hollander AE. 2002. The association between noise exposure and blood pressure and ischaemic heart disease: A meta-analysis. *Environ Health Perspect.* 110:307–317.

WHO (World Health Organization), 1999. Guidelines for Community Noise. Birglund, B. *et al*., eds.159 pp. (http://www.who.int/docstore/peh/noise/guidelines2.html; accessed Sept. 22, 2009).

World Health Organisation [WHO] Working Group – Aircraft noise and health - *Chapter on Cardiovascular effects*, by Babisch and van Kamp - Version 2 Draft January 2008 – Appended to B F Berry 2008. Effect of noise on physical health risk in London. Report on Phase 1 – review of the topic. BEL Technical Report 2008-1. March 2008 http://www.london.gov.uk/mayor/strategies/noise/docs/technical-report1.pdf

YYC (Calgary Airport Authority), 2005. 2004 Annual Noise Report for the Calgary International Airport. 24 pp. (www.yyc.com/fts/getfile.cfm?FID=5982; accessed 22 Sept. 2009)

Statement of Qualifications and Limitations

The attached Report (the "Report") has been prepared by AECOM Canada Ltd. ("Consultant") for the benefit of the client ("Client") in accordance with the agreement between Consultant and Client, including the scope of work detailed therein (the "Agreement").

The information, data, recommendations and conclusions contained in the Report:

- are subject to the scope, schedule, and other constraints and limitations in the Agreement and the qualifications contained in the Report (the "Limitations")
- represent Consultant's professional judgement in light of the Limitations and industry standards for the preparation of similar reports
- may be based on information provided to Consultant which has not been independently verified
- have not been updated since the date of issuance of the Report and their accuracy is limited to the time period and circumstances in which they were collected, processed, made or issued
- must be read as a whole and sections thereof should not be read out of such context
- were prepared for the specific purposes described in the Report and the Agreement
- in the case of subsurface, environmental or geotechnical conditions, may be based on limited testing and on the assumption that such conditions are uniform and not variable either geographically or over time

Unless expressly stated to the contrary in the Report or the Agreement, Consultant:

- shall not be responsible for any events or circumstances that may have occurred since the date on which the Report was prepared or for any inaccuracies contained in information that was provided to Consultant
- agrees that the Report represents its professional judgement as described above for the specific purpose described in the Report and the Agreement, but Consultant makes no other representations with respect to the Report or any part thereof
- in the case of subsurface, environmental or geotechnical conditions, is not responsible for variability in such conditions geographically or over time

The Report is to be treated as confidential and may not be used or relied upon by third parties, except:

- as agreed by Consultant and Client
- as required by-law
- for use by governmental reviewing agencies

Any use of this Report is subject to this Statement of Qualifications and Limitations. Any damages arising from improper use of the Report or parts thereof shall be borne by the party making such use.

This Statement of Qualifications and Limitations is attached to and forms part of the Report.