BEST PRACTICES FOR THE ASSESSMENT OF THE PUBLIC HEALTH EFFECTS OF NOISE FROM PROPOSED DEVELOPMENT PROJECTS

by

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Abstract

Governments and organizations around the world are increasingly considering public health as part of planning, assessment, and decision making processes for large development projects, such as new transportation corridors or industrial facilities. To date, there are no established or consistent methods for the consideration of environmental noise in assessment processes for these projects. The overarching objective of this thesis is to identify best practices for considering the public health effects of environmental noise when assessing the potential impacts of development projects. The term "noise impact assessment" (NIA) is proposed, including a framework adapted from human health risk assessment and health impact assessment processes.

Best practices for the NIA process were identified following a literature review in four key subject areas: (1) health effects of noise; (2) noise prediction/noise modeling; (3) practices in health impact assessment; and (4) practices in environmental impact assessment. Themes and lessons from the literature in each of the four key subject areas were identified and applied to the NIA framework. A total of thirteen best practices were identified.

In particular, this work emphasizes the importance of assessing health impacts themselves in addition to noise exposure. It identifies the "percent [of people] highly annoyed [by noise]" (%HA) and "percent [of people] highly sleep disturbed [by noise]" (%HSD) metrics as recommended quantitative and objective measures of the adverse health effects of noise appropriate for use in NIA. At the same time, this work recommends a flexible assessment approach that considers both objective and subjective, acoustical and non-acoustical factors that impact human health, including noise level, community context, and noise sensitivity. Finally, this thesis argues against noise management as an appropriate focus of any noise reduction strategy because it has limited potential to meaningfully change noise exposures.

While there is a broad literature relating to the health impacts of environmental noise, and numerous best practices for health impact assessment and human health risk assessment, this work is the first to bring these areas of research together and identify best practices for considering environmental noise in the assessment process for development projects.

Lay summary

Governments and organizations around the world are increasingly considering public health as part of planning, assessment, and decision making processes for development projects. To date, there are no established or consistent methods for the consideration of environmental noise in the assessment process for large development projects such as mines, bridges, or pipelines. The goal of this thesis is to identify best practices for considering the public health effects of environmental noise in the assessment process for development projects. This thesis proposes the term "noise impact assessment" (NIA) to describe this process, and presents a framework for NIA that is similar to other well-established assessment processes.

This thesis identifies thirteen best practices for considering the public health effects of environmental noise in the assessment process for development projects. Best practices were identified following a review of the literature in four key related subject areas, and applied to the NIA framework.

In particular, this work emphasizes the importance of assessing impacts on the full suite of health outcomes (annoyance, sleep disturbance, and cardiovascular outcomes) considering both objective measures (e.g. noise level) and subjective factors (e.g. community context). This thesis is the first to bring these areas of research together and to identify best practices for considering environmental noise in the assessment process for development projects.

Preface

This thesis is the original and unpublished work by the author.

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List of abbreviations

%HA	percent [of people] highly annoyed [by noise]
%HSD	percent [of people] highly sleep disturbed [by noise]
ANSI	American National Standards Institute
BC	British Columbia
dB	decibel
dBA	A-weighted decibel
EIA	environmental impact assessment
FICON	[United States] Federal Interagency Committee on Noise
HHRA	human health risk assessment
HIA	health impact assessment
Hz	hertz
ISO	International Organization for Standardization
LOAEL	lowest observable adverse effect level
NIA	noise impact assessment
WHO	World Health Organization

Glossary

$L_{90\%}$ or L90	$L_{90\%}$ or L90 is the sound level that is exceeded 90% of the time. $L_{90\%}$ is often used to measure and report background noise because it removes occasional noise peaks and events from the measure.
L_d or L_{day}	L_d or L_{day} is the equivalent continuous sound level measured during daytime hours from 7 am to 10 pm.
L_{den}	L_{den} is the equivalent continuous sound level measured over 24 hours with a 5 dB penalty assigned for the evening noise between 7 pm and 10 pm, and a 10 dB penalty for nighttime noise between 10 pm and 7 am.
L_{DN} or DNL	L_{DN} or DNL (day-night level) is the equivalent continuous sound level measured over 24 hours with a 10 dB penalty assigned for nighttime noise between 10 pm and 7 am. This metric was introduced to account for increased annoyance experienced during the night.
L_{eq}	L_{eq} is the equivalent continuous sound level measured over a specified period of time. The averaging period is often reported as a subscript. For example, a 16 hour averaging period would typically be reported as $L_{eq,16h}$
L_{max}	L_{max} is the maximum sound level, typically measured over a 1 second averaging period.
L_n or L_{night}	L_n or L_{night} is the equivalent continuous sound level measured during nighttime hours from 10 pm to 7 am.

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Chapter 1: Introduction

Governments and organizations around the world are increasingly considering public health as part of planning, assessment, and decision making processes for development projects. Noise is one of the many components of the environment that can affect human health, and inclusion of noise is necessary for a complete assessment of health impacts.

There are no established or consistent methods for considering environmental noise in assessment processes for development projects. This is likely driven by several factors. First, noise is a complex phenomenon and it is challenging to understand and reconcile information spanning different disciplines (e.g. physics, health, and psychology). Second, the human health effects of noise have received increasing attention in recent years but there is often a lag between research and the application of that research to policy and practice. Third, assessment processes such as health impact assessment (HIA), human health risk assessment (HHRA) and environmental impact assessment (EIA) are still evolving. Finally, assessments are usually undertaken by proponents of development projects and governments, rather than academe, so the outcomes and lessons from different assessment processes are not as widely available as they might be if they were led by researchers.

This goal of this thesis is to identify and describe best practices for the assessment of public health impacts from exposure to environmental noise generated by proposed development projects. It examines information, best practices, and challenges across different disciplines – physics/engineering, health sciences, and social sciences – and applies that information to an impact assessment framework. This thesis is intended to assist public health practitioners in understanding and conducting noise impact assessments for development projects.

This thesis relies on the work of others who have formed our current understanding of the relationship between noise and health. In particular, it builds on the foundation provided by: Dr. Wolfgang Babisch (Germany), who developed the prevailing theory of the pathway between noise and health outcomes; Dr. Theodore Schultz (United States), who developed the first dose-response curve which is now known as the "Schultz curve"; Dr. Henk Miedema and colleagues (the Netherlands), who developed the best available dose-response curves between noise and health; and Dr. David Michaud (Canada), who has put noise research specifically within the context of EIA within Canada. This thesis is the first to apply the breadth of research on the health effects of noise to an impact assessment model.

This work was undertaken within British Columbia (BC), Canada, and takes on a Canadian lens, particularly for the review of ways that environmental noise is typically considered (Chapter 3). While a review of the application of this research across jurisdictions is outside the scope of this thesis, many parts of this work will undoubtedly be applicable outside BC and Canada.

1.1 Noise impact assessment

Noise impact assessment (NIA) is a term that I have created to describe the process for assessing the public health impacts of environmental noise generated by proposed development projects. The proposed NIA process borrows concepts from both HIA and HHRA, but does not clearly fall into common definitions of either of those processes. For example, HHRAs are typically focused on assessing the health risks from a single hazard (which is similar to NIA), but HHRAs are also generic assessments conducted at the level of the substance and not a specific project (which is unlike NIA). On the other hand, HIAs are focused on assessing health impacts from a specific policy, program, or project (which is like NIA), but they are also more holistic than an assessment of a single hazard (which is unlike NIA). This thesis uses the NIA framework that I have adapted from both HHRA and HIA processes (Figure 1-1). The following is a description of the generic process, which is further developed as part of Chapter 4:

1. **Scoping:** Scoping is the exercise of defining the extent of the assessment and planning for the assessment. It includes identifying the relevant project-health interactions, and identifying the research methods to investigate those interactions.

2. **Baseline noise:** An understanding of the current noise in the area of a proposed project is necessary for an accurate prediction of noise once a project is underway. A complete description of the baseline noise includes a description of noise sources, noise level, noise character, as well as changes in those factors over time.

3. **Noise prediction:** Noise prediction is the process of predicting noise in the environment at a particular distance from its source, which can be any aspect of the development project (construction, ongoing operation, etc.). The outcome of predictive noise modeling is often a noise map with contours showing the dissipation of noise with distance from a source. The baseline noise step in combination with the noise prediction step can be considered the noise exposure assessment.

4. **Baseline health:** The baseline health step describes the existing health status in the local population surrounding a noise source. An understanding of the baseline health status is necessary in order to accurately predict how the local population will respond to additional noise from the project.

5. **Health effects assessment:** The health effects assessment uses information from the exposure assessment and describes health effects of the predicted noise exposures. Collectively, the baseline health and health effects assessment steps form the dose-response assessment.

6. **Mitigation:** The mitigation step applies measures to reduce or eliminate exposure and/or health effects.

7. **Significance assessment:** Significance refers to the value-based assessment of the magnitude and the severity of the health effect.

8. **Monitoring**: The final step in the NIA process is monitoring, and may include monitoring of the implementation of recommendations resulting from the assessment process, monitoring noise levels in the environment, and/or monitoring changes to health after a project is in operation.

In addition to HIA and HHRA, NIA can be distinguished from EIA. EIA is the process of assessing environmental impacts from proposed development projects, and can include human health impacts. In some circumstances, HIA and HHRA can form part of part of EIA. In this thesis, NIA can be considered one aspect of EIA.

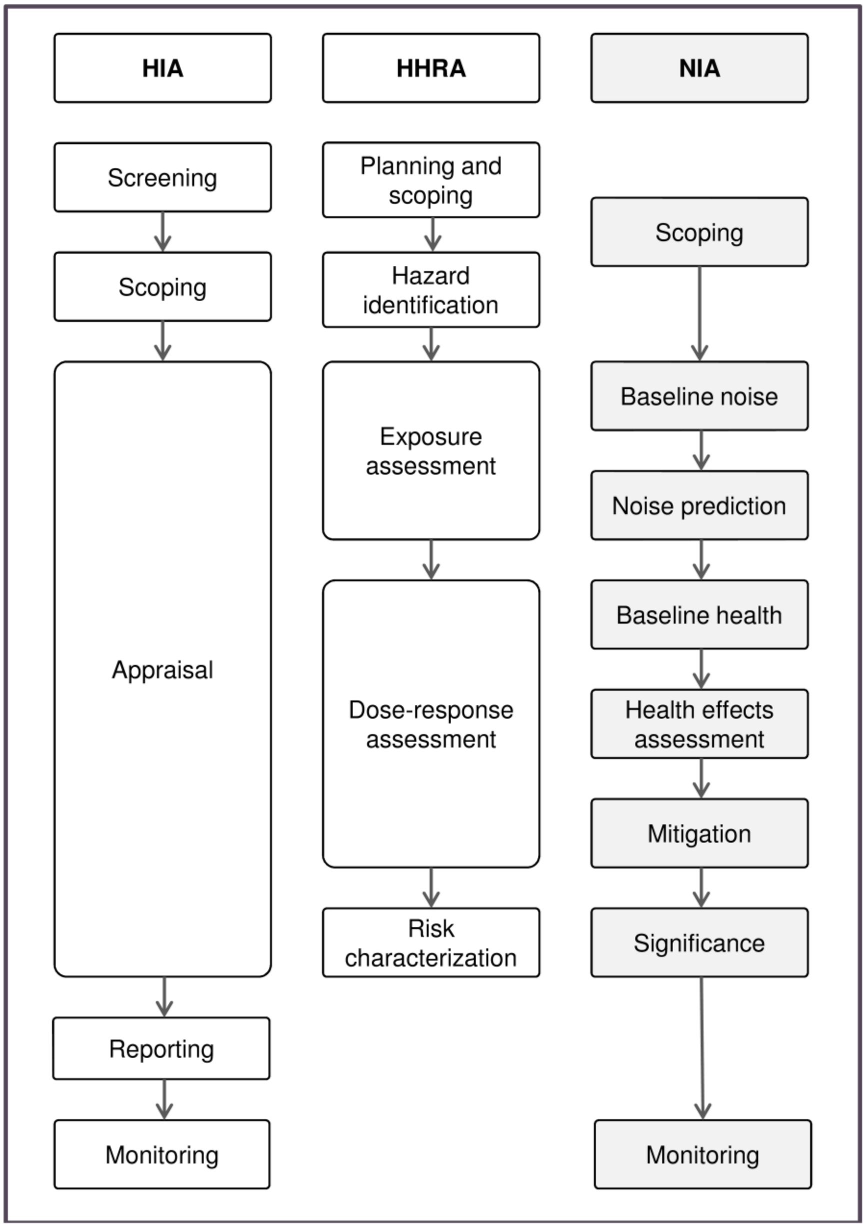

Figure 1-1: Comparison of the Health Impact Assessment (HIA), Human Health Risk Assessment (HHRA), and Noise Impact Assessment (NIA) processes[1,2]

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[1] The HIA process was adapted from the World Health Organization (114), the HHRA process was adapted from the United States Environmental Protection Agency (115), and the NIA process was adapted from both processes by the author.

[2] The comparison between steps in the HIA and HHRA processes is specific to the assessment of environmental noise from proposed development projects. The steps may not align in the same way for other hazards and applications of these assessment processes.

1.1.1 Context in British Columbia

In BC, proposed major projects such as mines, pipelines, transportation systems, and dams must undergo EIAs prior to project approval. The BC Environmental Assessment Act and Canadian Environmental Assessment Act form the foundation for EIA in BC, and identify the types of projects that require assessments. Under current provincial legislation, health is one of the five key “pillars” of the environment and HHRA and/or HIA may form part of EIA. Under federal legislation, the health of Aboriginal peoples only is considered as part of the federal assessment process.

Chapter 2: Background

2.1 Noise basics

2.1.1 Sound and noise

Sound waves are a type of pressure wave, caused by the oscillation (compressions and rarefactions) of molecules propagated in a medium such as air or water. Sound pressure waves are described by physical properties including their wavelength, frequency, period, amplitude, speed and direction.

When sound waves hit the eardrum, they cause the eardrum to vibrate, which is translated into the perception of sound by the auditory system. The average human auditory system can only hear sound waves with particular physical properties, including frequencies in the range of 20 to 20 000 hertz (Hz), and sound levels of at least 0 decibels (dB). Sound can also be described by the auditory sensation of hearing. Pitch corresponds to the frequency of the sound wave, volume corresponds to the amplitude of the sound wave, and temporal sequence corresponds to the "rise time" and whether the sound is intermittent or continuous.

Noise has been defined as undesirable sound and includes an inherently subjective component. Many anthropogenic sounds in the environment are considered to be undesirable, and therefore environmental noise includes sound from traffic, trains, airplanes, air conditioners, construction, industrial activities, etc. Natural sounds in the environment including those from birds, wildlife, rustling trees, or running water are not typically considered to be environmental noise because they are often desirable.

2.1.2 The decibel and A-weighted decibel

Sound level is measured using the decibel (dB). The decibel is a logarithmic ratio of the sound pressure level relative to the reference value of 2.0×10^{-5} Pascals, which is considered the threshold of human hearing.

The relationship between sound level, dose, and the human perception of sound level is important for health professionals but it is not intuitively understood. A 3 dB increase in sound level equates to a doubling of sound power, and therefore effective dose, but the change is barely perceptible to the human auditory system. A 10 dB increase is perceived as a doubling of sound level, but corresponds with 10 times the dose.

The human auditory system is not equally sensitive to sound at all frequencies. For example, a 50 dB sound at 125 Hz is perceived to be much quieter than a 50 dB sound at 1000 Hz. The A-weighted decibel (dBA) scale assigns a weight to each frequency band such that the sound level across all frequencies is perceived to be equally loud. With the exception of low-frequency sound, the majority of research on the human health effects of noise uses A-weighting to report sound levels because it better reflects the biological effects to humans. A-weighting strongly attenuates low-frequency sound, and not recommended to assess the biological effects of such exposures.

2.1.3 Noise metrics

Sound level often varies over time, so it is typically reported with a single decibel value known as the equivalent continuous sound level (L_{eq}). The L_{eq} takes into account the total sound energy over a period of time. With specific regard to environmental noise, the most common forms of a L_{eq} include L_{24h} (sound level equivalent over 24 hours), as well as L_{DN} and L_{den} (Table 2-1). While the following metrics do not distinguish between desirable sound and undesirable sound (i.e. noise), they are typically used to measure noise.

Table 2-1: Description of common sound metrics

Metric	Description
L_{eq}	L_{eq} is the equivalent continuous sound level measured over a specified period of time. The averaging period is often reported as a subscript. For example, a 16 hour averaging period would typically be reported as $L_{eq,16h}$
L_{max}	L_{max} is the maximum sound level, typically measured over a 1 second averaging period.
$L_{90\%}$ or L90	$L_{90\%}$ or L90 is the sound level that is exceeded 90% of the time. $L_{90\%}$ is often used to measure and report background noise because it removes occasional noise peaks and events from the measure.
L_d or L_{day}	L_d or L_{day} is the equivalent continuous sound level measured during daytime hours from 7 am to 10 pm.
L_n or L_{night}	L_n or L_{night} is the equivalent continuous sound level measured during nighttime hours from 10 pm to 7 am.
L_{DN} or DNL	L_{DN} or DNL (day-night level) is the equivalent continuous sound level measured over 24 hours with a 10 dB penalty assigned for nighttime noise between 10 pm and 7 am. This metric was introduced to account for increased annoyance experienced during the night.
L_{den}	L_{den} is the equivalent continuous sound level measured over 24 hours with a 5 dB penalty assigned for the evening noise between 7 pm and 10 pm, and a 10 dB penalty for nighttime noise between 10 pm and 7 am.

2.2 Characteristics of environmental noise

Noise can be characterized by physical characteristics including sound level, frequency, impulsivity, and tonality. Noise can also be characterized by the human perception of these physical features of sound, which is heavily influenced by psycho-social factors.

2.2.1 Sound level

The amplitude of the sound wave determines the sound level, which is perceived as the loudness. Typical sound levels range from less than 30 dB to around 140 dB (Table 2-2).

Table 2-2: Typical sound levels and associated human response

Source	Sound level (dB)	Typical response
n/a	0	Auditory threshold
Quiet bedroom at night	30	-
Conversational speech at 1 m	60	-
Shoulder of busy road at 5 m	80	-
Chainsaw at 1 m	110	Discomfort
Jackhammer	130	Pain threshold
Jet aircraft at 50 m	140	-

Note: Information adapted from Health Canada (1)

2.2.2 Frequency

Frequency refers to the number of times a sound wave cycles each second, and is measured in hertz (Hz) (1Hz = 1 cycle). Frequency is the property that determines the pitch of sound.

The typical young healthy person can hear sound in the range of 20 to 20 000 Hz, which is termed the auditory range (Table 2-3). Infrasound, which is low-frequency sound below 20 Hz, is not audible to humans but has received considerable attention in recent years because of the development of wind turbines. Infrasound may sometimes be perceived as vibration rather than audible sound. Ultrasound, which is high-frequency sound above the auditory range, is not widespread in the environment.

Table 2-3: Description of sound frequencies

Sound descriptor	Frequency (Hz)
Infrasound (inaudible)	< 20
Low-frequency (audible)	20 - 250
Medium-frequency (audible)	250 - 2000
High-frequency (audible)	2000 - 20 000
Ultrasound (inaudible)	> 20 000

Human speech uses frequencies of approximately 300-4000 Hz. High-frequency sounds are generally more annoying than moderate frequency sounds, even when measured in dBA (low-frequency sound is strongly attenuated by the A-weighted decibel). High-frequency sound can also mask low-frequency sound, which may contribute to the annoyance associated with high-frequency noise.

Frequency (pitch) is a physical characteristic of the sound itself, and should not be confused with the frequency (number of occurrences) of the noise event. In this thesis, frequency refers to the physical characteristic (pitch) of the sound measured in hertz unless otherwise specified as the frequency of the noise event.

2.2.3 Impulsivity

Impulsivity is a feature of the duration of the noise. Sound is typically considered impulsive if sound peaks are at least one second apart, and may also be characterized by a short rise-time, high sound level, and a changing sound character. Common impulsive sound sources include fireworks, blasting activity, and jackhammers. Impulsive noise is generally understood to be more annoying than non-impulsive noise of the same sound level. As a result, some noise guidelines recommend that a sound level "penalty" of between 2 and 12 dB be applied to the L_{eq} for impulsive sound (2).

2.2.4 Tonality

Tonality refers to the number of frequency bands in a noise. Tonal noise comprises a single frequency and could be described as a "flat" sound. On the opposite end of the tonality spectrum is "white noise" that comprises noise of an infinite number of frequency bands. As with impulsive noise, tonal noise is thought to be more annoying than non-tonal noise of the same sound level. Some noise guidelines recommend a sound level "penalty" of 3 to 10 dB be applied to the L_{eq} of tonal sound.

2.2.5 Characteristics of specific sound sources

2.2.5.1 Transportation noise

Aircraft noise is non-continuous and occurs as a series of noise events when an aircraft flies overhead or takes off. Noise from aircrafts is typically high-frequency and varies with time within the noise event. Research has generally shown that aircraft noise is more annoying than other transportation noise sources at the same sound level (3).

Traffic noise tends to be continuous noise. Light and heavy vehicles produce low- and medium-frequency noise while motorcycles produce medium- and high-frequency noise (4). Traffic noise is less annoying than aircraft noise but more annoying than rail noise at the same sound level (3). Traffic is an example of “anonymous noise” where the sound source is indistinguishable to the human ear (other examples include mechanical ventilation noise). The human health effects and dose-response behavior of different sources of anonymous noise are similar. Anonymous noise is distinct from “noise with character” which is discussed in the context of wind turbine noise in section 2.2.5.2.

Railway noise is non-continuous and occurs as a series of noise events when a train passes by. Railway noise is highly variable in both frequency (pitch) and noise level, and depends on the specific noise source and railway track. In general, railway noise is considered to be low-frequency noise, although trains also product “wheel squeal” associated with curved tracks and train whistles, which are high-frequency sounds. Railway noise is typically less annoying than both aircraft and traffic noise at the same sound level (3).

2.2.5.2 Wind turbine noise

Wind turbines produce low-frequency sound between 20 and 200 Hz within the auditory range, and infrasound, which is below the auditory range. The human health effects of infrasound have received more attention in recent years because of increasing development of wind farms and public attention to the effects from wind farms. Preliminary information suggests that low-frequency noise from wind farms may be more annoying than transportation noise at the same sound level (5).

Wind turbine noise (i.e. the repeated "whooshing" noise) is a good example of "noise with character" where the noise is distinct enough that it can be attributed to a specific noise source. The human response and human health effects associated with noise with character are considered specific to the noise source. As such, the human health effects and the dose-response curve for wind turbine noise overlaps with the curve for transportation noise, though they are also distinct.

2.3 Health effects of environmental noise

2.3.1 Methods

I adopted a two-stage search for this review. The first stage was a screening process with the objective of identifying the key health effects that have been investigated in peer-reviewed scientific literature. The second stage was a targeted literature search with the objective of identifying: recent systematic reviews on each health effect, a reasonable selection of primary research papers that reflect the active research in the subject area, and key papers that inform our current understanding of each health effect. This two-stage literature search allowed me to access papers relevant to my research question while limiting the number of search results.

2.3.1.1 Step 1: Identification of health effects for targeted literature search

The first stage was conducted by searching Medline for the words "noise" and either of "environmental," "transportation," "traffic," "aircraft," "train," "rail," or "industrial" in article titles. The search was further limited to English language papers published between January 1, 1996 and December 31, 2015. I reviewed abstracts to identify relevant studies. Health effects were selected for a targeted literature review if the preliminary literature search identified at least five studies investigating that health effect.

2.3.1.2 Step 2: Targeted literature search

I conducted a targeted literature search for each health effect identified as part of the screening process using EBSCOhost Online Research Databases. I used unique search terms for each health effect (Table 2-4), and limited my search to English language and scholarly papers published online between January 1, 2006 and December 31, 2015.

Depending on the number and nature of search results, I considered bringing forward papers identified during the preliminary literature search for consideration in the discussion for each health effect. In addition, a very limited number of additional papers were identified from unstructured search techniques. These well-cited papers were important in developing the current understanding of each health effect.

Table 2-4: Search terms for each structured literature search

Health effect	Words in article titles
Annoyance	“noise” not (“occupational” or “hospital) and (“annoyance” or “annoyed”)
Cardiovascular outcomes	“noise” not (“occupational” or “hospital) and (“hypertension” or “blood pressure” or “myocardial infarction” or “cardiovascular” or “heart disease” or “stroke”)
Sleep disturbance	“noise” not (“occupational” or “hospital) and “sleep”
Cognition	“noise” not (“occupational” or “hospital) and “cognition”
Mental health outcomes	“noise” not (“occupational” or “hospital) and (“psychiatric” or “mental health”)
Noise-induced hearing loss	words “noise” and (“hearing loss” or “hearing impairment”) not (“occupational” or “hospital”)
Obesity/diabetes	“noise” not (“occupational” or “hospital) and (“diabetes” or “obesity”)
Birth outcomes	“noise” not (“occupational” or “hospital”) and (“reproduction” or “reproductive” or “birth”)

2.3.2 Results

2.3.2.1 Step 1: Identification of health effects for targeted literature search

The following health effects were selected for a more detailed literature review (search results in parenthesis): cardiovascular outcomes (n = 101); annoyance (n = 74); sleep disturbance (n = 52); cognition (n = 33); mental health outcomes (n = 20); noise-induced hearing loss (n = 8); obesity/diabetes (n = 5); and birth outcomes (n=5) (Figure 2-1). Cardiovascular outcomes were further divided due to the quality and quantity of studies. The preliminary literature search also identified some papers investigating the associations between environmental noise and respiratory disorders (n = 4), breast cancer (n = 2), rheumatoid arthritis (n = 1), and immune responses (n = 1), but the evidence of an association was too sparse to warrant review in this thesis.

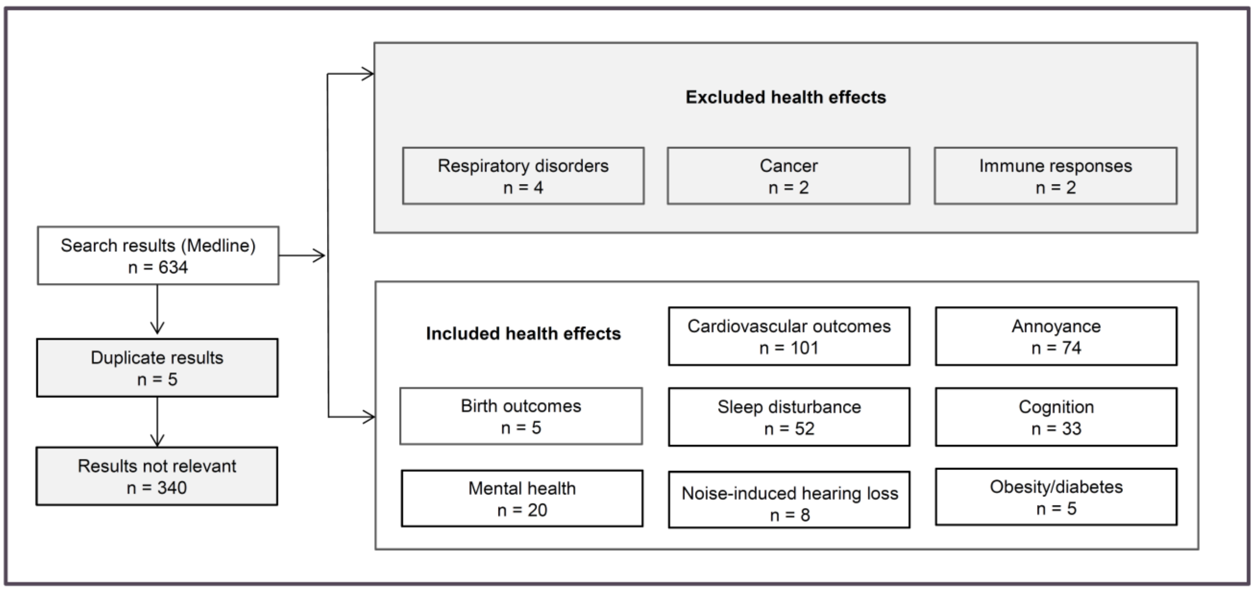

Figure 2-1: Search strategy and results for step 1: Identification of health effects for a targeted literature search

2.3.2.2 Step 2: Targeted literature search

Each targeted literature search for each health effect produced between 20 and 701 results (Table 2-5). Titles and abstracts were manually reviewed to identify relevant and good quality studies for discussion. Additional papers from the screening process were considered as part of the review where the search produced a limited number of results, or where there were additional well-cited papers that contribute to our current understanding of the relationship between noise and health (Table 2-5).

Table 2-5: Description of search results

Health effect	Search results	Papers identified through unstructured search	Papers identified through the screening process	Papers selected for review
Annoyance	142	3	0	24
Cardiovascular outcomes	180	0	0	31
Sleep disturbance	157	0	4	48
Cognition	21	0	0	33
Mental health outcomes	20	0	0	20
Noise-induced hearing loss	701	2	1	4
Obesity/diabetes	32	0	1	7
Birth outcomes	58	2	1	2

The papers selected for discussion were predominantly observational epidemiologic studies, supplemented by some experimental studies where appropriate (Table 2-6). The vast majority focused on the health effects of transportation noise sources (traffic, aircraft or rail noise), and very few investigated effects from non-transportation sources such as industry or wind farms.

Table 2-6: Description of papers selected for review

Health effect (N)	Reviews (N)	Study designs (N)	Noise source (N)
Annoyance (24)	None	Observational (21) Experimental (0)	Traffic (5) Rail (4) Combination (4) Wind farms (3) Aircraft (2) Other (3)
Cardiovascular outcomes (31)	Meta-analyses (2)	Observational (31) Experimental (0)	Traffic (24) Aircraft (11) Rail (5)
Sleep disturbance (48)	Review (10)	Observational (36) Experimental (8)	Traffic (18) Rail (16) Aircraft (10) Combination (2) Wind farms (1) Other (2)
Cognition (33)	None	Observational (30) Experimental (3)	Aircraft (21) Traffic (18) Rail (1)
Mental health outcomes (20)	Review (1)	Observational (20) Experimental (0)	Traffic (11) Aircraft (9) Other (1)
Noise-induced hearing loss (4)	None	Observational (2) Experimental (0) Other (2)	Aircraft (2) Combination (2)
Obesity/diabetes (7)	Meta-analysis (1)	Observational (7) Experimental (0)	Traffic (5) Aircraft (1) Combination (1)
Birth outcomes (2)	Review (2)	n/a	Combination (2)

2.3.3 Discussion

2.3.3.1 Pathways to health effects

Noise can affect health through a complex response involving both direct and indirect pathways. The prevailing hypothesis is that noise acts directly on the auditory system leading to sleep disturbance, and then indirectly through a psychological response in order to induce or exacerbate stress in exposed individuals (Figure 2-2). This indirect pathway is synonymous with the "general stress hypothesis" (6).

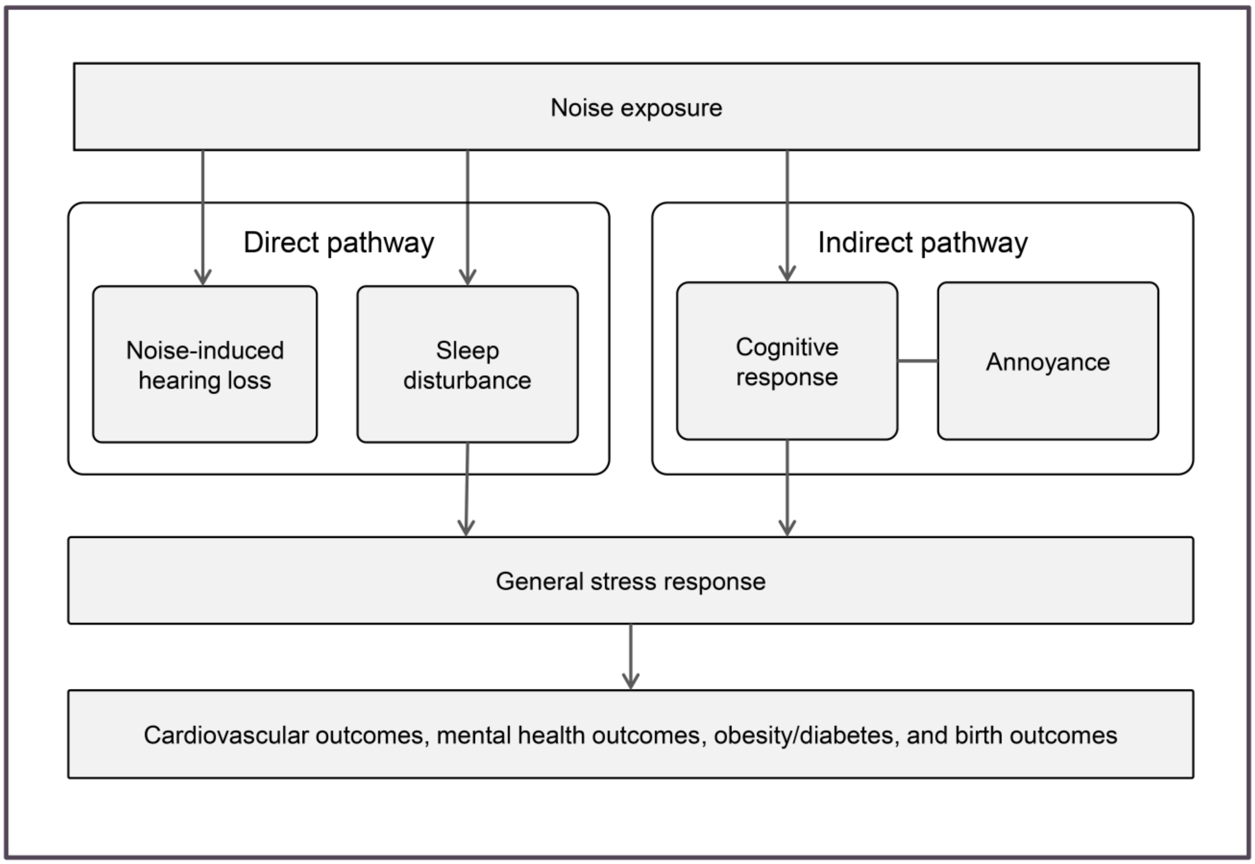

Figure 2-2: Pathway to health effects[3]

[3] Figure adapted from Babisch (6)

In the direct pathway, noise causes impulses in the auditory nerve that activate the reticular activating system, which is responsible for alertness and consciousness. Sleep disturbance as a result of noise exposure is believed to be a result of activation of the reticular activating system.

The general stress hypothesis proposes that noise induces or exacerbates stress in a non-specific way, which means that the biological effects of noise are the same as or similar to other physical and psychological stressors.

In support of the proposed model, both major stress pathways have been implicated in the noise-induced stress response (6,7). Activation of the hypothalamus - pituitary - adrenal axis releases glucocorticoids, including cortisol, from the adrenal cortex. Exposure to aircraft noise has been associated with increased cortisol in women (8,9), and men (9), while traffic noise has been associated with the same effect in adults (9) and children (10). High levels of cortisol have also been found in individuals exposed to noise during both waking (10) and following arousal from sleep (8).

Activation of the sympathetic - adrenal - medulla stimulates release of catecholamines (epinephrine and norepinephrine) from the adrenal medulla. Exposure to aircraft noise has been associated with increased noradrenaline in women (11), and exposure to traffic noise has been associated with increased noradrenaline in both sexes (9).

2.3.3.2 Annoyance

Noise annoyance is common in exposed individuals. Noise-related annoyance has been defined as “a feeling of resentment, displeasure, dissatisfaction, discomfort or offence when noise interferes with someone’s thoughts, feelings or actual activities” (12). Consistent with this, each of the 21 reviewed papers reported an association between some measure of noise and annoyance. Annoyance has also been proposed as a mediating variable between noise and other health outcomes (13).

The majority of literature on noise-related annoyance is on the acoustical and non-acoustical factors influencing annoyance. In general, as much as one third of the variance in noise annoyance can be explained by acoustical factors, while as much as another third can be explained by known non-acoustical factors such as time of day and noise sensitivity (14).

Acoustical factors influencing annoyance include average sound level (15–22), maximum sound level (23), frequency (18,21,24–26), duration of noise event (22), and number/frequency of noise events (20,27,28). Very preliminary research suggests that the maximum sound level or number of noise events may be the most important acoustical factors in noise annoyance (23,28).

Non-acoustical factors influencing noise annoyance include noise sensitivity (5,15,29–31), attitude towards the noise source (15,16,31), visibility of noise source (5), age (32,33), sex (33), time of day (15,30,31,33,34), perceived control over the noise source (31), trust in noise regulatory authorities (15,31), socio-economic status (17), and economic benefit (5). In Canada, community size and province were also found to influence annoyance (33). Time of day and self-reported noise sensitivity are frequently cited as the most important non-acoustical factors in determining annoyance.

Studies have shown that different sources of noise lead to different levels of annoyance in exposed individuals, and this is likely due to a combination of acoustical and non-acoustical factors. Preliminary information suggests that noise from wind farms is more annoying than transportation noise at the same noise level (5), and that industrial noise is less annoying than transportation noise (34). Research has consistently reported aircraft noise as most annoying among transportation noise sources, followed by traffic noise and then railway noise (3).

2.3.3.2.1 Relationship between noise-induced annoyance and health

Annoyance is thought to contribute to the noise-induced stress response that leads to physical health outcomes. It is clear that annoyance plays a role in the relationship between noise and physical health outcomes, but it is uncertain whether annoyance is on the causal pathway, acts as a mediator, or both. Some papers have found associations between annoyance and specific health outcomes (i.e. cardiovascular outcomes) (35). Other studies have found that annoyance plays a mediating role in the relationship between noise exposure and specific physical health outcomes (36).

In addition to the indirect role of annoyance, annoyance in itself can be considered a health effect. According to World Health Organization (WHO) definition of health as "a complete state of physical, mental and social well-being, and not merely the absence of disease or infirmity" (37), annoyance itself should be considered as a health effect.

Annoyance is the only health effect with a defined dose-response relationship, which forms the foundation for modern environmental noise research and policy. The evolution of the dose-response curves is important to our current understanding of the relationship between noise and health. Schultz (38) was the first to summarize the relationship between noise and annoyance in 1978 using 161 data points. The curve was updated in 1991 to include additional data (39), and soon after it was refined by Finegold et al. in 1994 (40) and adopted by the United States Federal Interagency Committee on Noise (FICON) for regulatory purposes. FICON still uses the 1994 curve, still commonly referred to as the "Schultz curve." Miedema and Vos (41) then produced a major update to the 1994 curve and produced three separate curves for each of aircraft, road and rail traffic noise. The Miedema and Vos curves predicted more annoyance at a given noise level than the Schultz curve. Most recently, Fidell and Silvati (42) updated the curve for aircraft only. While the academic community has largely accepted the Miedema and Vos curves as the most up-to-date and relevant, most modern standards still use outdated information. FICON still uses the 1994 Schultz curve as a guideline for the evaluation of annoyance from aircraft noise, and the International Organization for Standardization (ISO) 1996-1 (2003) and American National Standards Institute (ANSI) still use the original 1978 curve in their ISO 1996-1 (2003) and ANSI

S19.9-2005 standards. It is unclear why these organizations have not updated their documents to use the most up-to-date dose-response relationships.

2.3.3.3 Cardiovascular outcomes

The strongest evidence of an association between environmental noise and chronic cardiovascular outcomes is for transportation noise and heart disease. Recent epidemiologic studies and meta-analyses have found positive associations between both aircraft and traffic noise and heart diseases, which are described in the text below.

Of the ten recently published papers and meta-analyses that were identified through the targeted literature search, two meta-analyses (43,44) and six epidemiologic studies have concluded that there is strong evidence of an association between noise and cardiovascular outcomes. The strongest evidence comes from a prospective study that found a positive relationship between heart disease mortality and traffic noise in men after controlling for traffic-related air pollution (45). Three additional cross-sectional studies (46–48) and one ecological study (49) also found a positive association between transportation noise and heart disease. However, all of these studies were subject to uncertainty because the exposure assessments were completed using computer models or noise maps.

The strongest estimate for the association between environmental noise and heart disease reported in recent literature was an odds ratio (95% confidence interval) of 1.72 (1.36 – 2.19) per 5 dB increase in L_{den} traffic noise, although this was without controlling for traffic-related air pollution as a potential confounder (46). The relative risk of heart disease from noise exposure is more likely in the range of 1.06 to 1.08 per 10 dB increase in noise level (Table 2-7). There is some evidence of a threshold effect near 50 dBA and a stronger association in men, although these threshold and sex effects are not clearly understood (43,44).

Table 2-7: Effect estimates for the association between transportation noise and heart disease from meta-analyses published since 2005

Paper	Noise source	Relative risk estimate (95% confidence limit)	Threshold of effect
Vienneau et al. (44)	Aircraft and traffic	1.06 (1.03 - 1.09) per 10 dB increase in L_{den}	50 dB
Babisch (43)	Traffic	1.08 (1.04 - 1.13) per 10 dB increase in L_{DN}	52 dB

2.3.3.3.1 Hypertension

There was more recent literature investigating the association between environmental noise and hypertension than for heart disease, but the studies were not as rigorous. Nevertheless, there is evidence that environmental noise exposure contributes to hypertension. Twenty recent studies were identified through the literature search, including two meta-analyses (Table 2-8); fourteen of which support the hypothesis that that there is an association between transportation noise and hypertension. As with heart disease, effect estimates seem to be stronger in men (35,50–52), although a few studies have reported stronger effects in women (53,54). There is also evidence that the time of exposure may have an effect because nighttime noise has been more frequently correlated with hypertension than daytime noise (55), particularly for aircraft noise (51,56).

As with other epidemiologic studies of environmental noise, these studies were limited by uncertainty in the exposure assessments and cross-sectional study designs that are subject to bias. Only one prospective cohort was identified (35), and significant effects were only observed in men or individuals who reported being annoyed by noise. Better ways of classifying exposure and establishing the temporal sequence are needed to make more conclusive statements about causality.

Table 2-8: Effect estimates for the association between transportation noise and hypertension from meta-analyses published since 2010

Paper	Noise source	Odds ratio (95% confidence limit)
Yang et al. (52)	Aircraft	1.63 (1.14 – 2.23) with exposure
van Kempen and Babisch (57)	Traffic	1.03 (1.01 – 1.06) per 5 dB increase in LA,eq,16h

2.3.3.3.2 Other cardiovascular outcomes

Association between transportation noise and cardiovascular disease, myocardial infarction, stroke and heart failure is less established than for heart disease and hypertension. There have been a few studies investigating these associations, but given the conflicting results and mild associations observed, more studies are needed to support conclusions.

2.3.3.4 Sleep disturbance

Significant associations between noise and sleep disturbance have been observed in both observational and experimental study designs. However, the relationship between noise and self-reported sleep disturbance appears stronger than the relationship between noise and objective measures of sleep (58). Research has found associations between noise and awakening frequency, sleep time, and use of sleep medication (20,59,60). The maximum sound level and sound rise time have been more strongly associated with sleep disturbance than average sound level (61–63).

There is a clear pathway between noise exposure and sleep disturbance, and then between chronic poor sleep and adverse health outcomes. However, studies making the complete link between noise, sleep, and health outcomes are lacking. There is some evidence that nighttime noise exposure has a greater effect on cardiovascular outcomes than daytime or 24-hour noise exposure (51,55,56) and therefore sleep has been proposed as a mediating variable along the pathway between noise exposure and health outcomes (13).

As with other noise research, studies investigating the relationship between transportation noise and sleep disturbance are limited by uncertainty in the exposure assessments. One study found a weak correlation between nighttime outdoor measures of sound, which are used for most epidemiologic studies, and indoor noise, which better represents exposure (64).

There is also some literature on the effect of non-transportation noises on sleep, including neighborhood noise, animal noise, and noise from air conditioners. A recent review article found that non-transportation noise disrupted sleep in a similar way to aircraft noise, and that non-transportation noise from air conditioning or ventilation systems showed an effect on subjectively-measured sleep effects, but not objectively-measured sleep effects (65).

2.3.3.5 Cognition

One major cross-sectional study has investigated the effects of transportation noise on cognition in children. The Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health (RANCH) study found dose-dependent effect of aircraft noise on reading comprehension, and traffic noise on memory (66,67). Smaller studies have found effects on reading speed (68), reading comprehension (69), memory and recall tests (70,71), and motivational deficits (72). Children may be particularly sensitive to the cognitive effects of noise because they have more sensitive hearing than adults, they have reduced capacity to manage stressors, and they are at a critical development phase.

There are two effect pathways that have been proposed to explain the relationship between noise and cognition in children. Elevated stress may be the primary mechanism by which noise interferes with cognition in children as it does with other health outcomes in adults (73). Alternatively, children may attempt to "tune out" unwanted noise and, in doing so, ignore important sound (e.g. a teacher speaking) that contributes to learning and memory (66). Whether or not children "tune out" desirable sound has not been tested in any experimental study.

The effect of noise on cognition in adults is less studied, and only two papers were identified. Basner (74) found that exposure to nocturnal aircraft noise reduced reaction time in the laboratory, while Lee and Jeon (75) found that both road and ventilation noise impaired recall in the laboratory.

2.3.3.6 Mental health outcomes

There is some recent literature suggesting that exposure to environmental noise may contribute to anxiety and other psychiatric disorders. Two cross-sectional studies found significant associations between transportation noise and various psychiatric disorders, measured as self-reported anxiety (76) or anxiolytic medication use (77). In both cases, the associations were weak. However, another recent cross-sectional study and the only prospective cohort study on the topic found no association between psychotropic medication use (78) and depression or anxiety (79). Overall, literature on this topic has concluded that noise is not a contributor to psychiatric disorders, although exposure may contribute to anxiety or exacerbate symptoms in those already suffering from a mental disorder (79).

2.3.3.7 Noise-induced hearing loss

Noise-induced hearing loss is the temporary or permanent threshold shift (i.e. change in hearing threshold) that occurs following exposure to high noise levels. Noise-induced hearing loss is correlated with the total sound energy received, which is otherwise known as the noise dose. The “3 dB exchange rate” explains the relationship between sound level and dose; the dose associated with 73 dB is double that of 70 dB if the duration of exposure is the same. Therefore, short episodes of noise with a high sound level can contribute quite significantly to total sound energy received, and in turn, hearing loss.

The WHO, United States Environmental Protection Agency, and Health Canada recommended a maximum L_{eq} of 70 dBA for protection against noise-induced hearing loss (80,81). Neitzel (82) found that approximately 90% of study participants living in a major urban center were exposed to a L_{eq} above 70 dBA, and therefore, are at risk of noise-induced hearing loss. Slight threshold shifts are expected to occur in the average urban resident (83). Noise from subways, personal listening devices, and non-occupational use of power tools were identified as major contributors to the overall exposure (82,83).

Very few papers have investigated whether environmental noise leads to measurable noise-induced hearing loss, and this question has only been researched by a single investigator who has published two papers on the topic. Chen (84) used audiometry and found that children who attended a daycare facility close to the airport had higher hearing thresholds (pure tone average, high pure tone average, and threshold at 4 kHz) than children who lived farther from airports. The study was repeated for adults with similar results (85).

2.3.3.8 Obesity/diabetes

The relationship between noise and body mass index, weight, waist circumference, and metabolic outcomes including diabetes has recently received attention in the scientific literature. The strongest evidence of an association comes from a recent prospective study where a 10 dB increase in L_{den} traffic noise was associated with an increase in relative risk of incident diabetes after controlling for several confounding variables (86). However, a similar study investigating the association between diabetes and aircraft noise found no association (87). The only meta-analysis also found a significant association between L_{den} and risk of diabetes (88).

Very few studies have found an association between noise and obesity. One recent cross-sectional study found that road traffic was associated with increased waist circumference and odds of obesity (89), but other studies have found similar associations only in noise sensitive individuals (90). No studies reviewed found an association between noise and body mass index (87,89,90).

Three effect pathways have been proposed to explain the potential relationship between noise and diabetes (86). First, noise stimulates release of glucocorticoids as part of the generic stress response, and high levels of glucocorticoids can interfere with insulin metabolism. Second, noise impairs sleep, and impaired sleep quality and quantity have been linked to increased risk of type 2 diabetes. Finally, poor sleep can impair appetite regulation, which could result in weight gain and diabetes.

2.3.3.9 Birth outcomes

Two systematic reviews have been published since 2005 investigating the association between noise and reproductive outcomes. Hohmann (91) concluded that there was no association between chronic noise exposure and a range of pregnancy and birth outcomes including low birth weight, preterm birth and fetal growth. In contrast, Ristovska (92) concluded that there was enough evidence to support an association between noise exposure and the same pregnancy and birth outcomes. Despite using similar inclusion criteria and being published one year apart, Ristovska identified an additional occupational study and three additional environmental studies investigating the relationship, three of which found an association. These additional papers make the Ristovska review a stronger systematic review, and the evidence suggest that environmental noise exposure during pregnancy can lead to lower birth weights. However, the evidence is far from conclusive and we are only beginning to understand this area of potential health effects.

2.3.3.10 Sensitive populations

In general, noise-related annoyance with age follows an inverted u-shaped curve. The young and the old are typically less annoyed by noise than middle-aged adults after adjusting for noise level (32). Children, while less sensitive to noise-related annoyance, have been found to be sensitive to cognitive effects of noise (93). Children are the most sensitive receptor group for noise because of this sensitivity to cognitive effects and because they are at a critical development stage (93).

People of lower socio-economic status are another sensitive receptor group for noise. Consistent with exposures to other types of environmental contaminants, there is evidence that people of lower socioeconomic status are exposed to increased levels of noise, and may be more vulnerable to the adverse health effects from noise (94). For example, Dale (95) found that noise exposure was negatively associated with different socioeconomic indicators in Montreal, Canada.

Chapter 3: Typical NIA process in British Columbia

3.1 Introduction

In BC, the EIA process is a legislated procedure for assessing the environmental, health, economic, social and heritage impacts of proposed development projects. NIA typically forms part of the broader EIA process as part of the health “pillar” of the assessment. This chapter reviews recent EIAs in order to understand the current approach to NIA in BC. This chapter forms part of the foundation for Chapter 4, which describes best practices for the NIA process.

3.2 Methods

3.2.1 Project selection

I selected a subset of all projects assessed under the BC Environmental Assessment Act (SBC 2002) that had completed the EIA process by December 31, 2016. In order to get a good understanding of practices across different project types, I selected 20% of projects in each of the major categories using a random number generator (Table 3-1). The following categories were used: (1) mining; (2) hydroelectric power generation; (3) wind power generation; (4) gas-fired power generation; (5) petroleum and natural gas; (6) water management; (7) waste management; (8) transportation; (9) industrial; and (10) tourism.

The BC Environmental Assessment Office electronic Project Information Centre (e-PIC) website and associated website search tools was used to identify projects by date and type with one exception. The website grouped all electricity generation projects as one category (i.e. hydroelectric power generation, wind power generation and gas-fired power generation), so these projects were manually classified into one of the three categories listed above. It was important to divide this broader category into smaller categories because hydroelectric power and wind power generation projects have very different noise production.

Once projects were selected using the website search tools, I manually navigated the website folder structure to identify relevant documents for my review.

Table 3-1: Environmental Impact Assessment (EIA) projects selected for analysis

Project type	No. of projects total/ No. of projects reviewed	Project names
Mining	30/6	• Tulsequah Chief Mine • Kitsault Mine • Brucejack Mine • Eagle Rock Quarry • Galore Creek Mine • Giscome Quarry and Lime Plant
Hydroelectric power generation	23/5	• East Toba River Montrose Creek Hydroelectric • Forrest Kerr Hydroelectric • Mica Generation Station Unit 6 • Big Silver Creek Waterpower • Pingston Creek Hydroelectric
Wind power generation	8/2	• Cape Scott Wind Farm • Dokie Wind Energy
Gas-fired power generation	11/2	• Fort Nelson Electrical Generation • Mackenzie Green Energy Centre
Petroleum and natural gas	26/5	• Fortune Creek Gas • Cabin Gas Plant • Ring Border Gas Plant Expansion • Prince Rupert Gas Transmission • West Coast Connector Gas Transmission
Water management	14/3	• Chemainus Water Wells Supply • Bevan Avenue Wells • Vancouver Convention Center Expansion
Waste management	7/1	• Babkirk Secure Landfill

Project type	No. of projects total/ No. of projects reviewed	Project names
Transportation	10/2	• Canada Line (rapid transit) • Evergreen Line (rapid transit)
Industrial	4/1	• Peace Valley Oriented Strand Board (wood product manufacturing)
Tourism	3/1	• Garibaldi at Squamish (winter resort and ski hill)
Total	136/28	

Note that this is a review of the methods for NIAs of recent projects, and does not include a review of the legislation, policy or guidance that supports the assessment of each project.

3.2.2 Analysis

For each EIA, I manually accessed documents using the BC Environmental Assessment Office website. Given the considerable size of the documentation for each project (often thousands of pages), I used the table of contents and word searches, if available, in addition to a focused manual review to find relevant information. In most cases, all relevant information was found within the technical documentation submitted by proponents.

Information on how each project considered environmental noise in the assessment was recorded (Table 3-2). Only information about noise as it pertains to human health was recorded; information about noise as it relates to wildlife was outside the scope of the review. Some of the projects did not consider the impacts of environmental noise on human health, and therefore were not classified as NIAs.

Table 3-2: Information collected for each Environmental Impact Assessment (EIA)

Step	Information collected
Scoping	• Whether there was an assessment of environmental noise, or an assessment of effects to human health in general • The project phases included in the assessment
Baseline noise	• Presence of baseline data • Type of baseline data i.e. literature-based values or site-specific information • For literature-based values, the literature source • Noise metric(s) that were measured • Whether there was a characterization of daily or seasonal changes
Baseline health	• Whether there was any description of baseline health in the local population
Noise prediction	• Whether there was some quantitative prediction of noise • The propagation standard and noise modeling method used, if any • Noise metrics used for predictive modeling
Health effects assessment	• Whether there was a health effects assessment • Noise guidelines considered, if any • The specific health effects assessed, if any
Mitigation	• Presence of mitigation measures for noise • Type of mitigation measures, i.e. design or good practice type measures
Assessment of significance	• Presence of an assessment of significance for the health effects from noise • Criteria used to evaluate significance
Follow-up and monitoring	• Presence of a follow-up or monitoring program • Type of monitoring, i.e. noise monitoring, complaint monitoring, etc.

3.3 Results and discussion

3.3.1 Scoping

Scoping is the exercise of outlining the extent of the assessment, including whether or not the assessment considered the human health effects of noise. Among reviewed EIAs, the majority identified environmental noise as a potential effect (23/28 or 82%), and a smaller majority identified environmental noise as a potential effect to people (20/28 or 71%), but only half identified potential human health effects from noise (14/28 or 50%) (Table 3-3). Assessments that considered environmental noise but not its effects on people typically considered only its effects on wildlife. Assessments that considered effects to people but not human health typically considered effects on recreational land uses and property values. In some cases, the purpose of the noise assessment was unclear. All of the assessments that considered the public health effects of environmental noise accounted for both construction and operation activities. Construction and operation project noise is typically quite different, so their separate assessment is a best practice.

The fact that not all assessments identified potential effects to human health is not indicative of poorly completed EIAs, as many natural resource development projects are located in remote areas that are removed from people. However, I would expect that all assessments that identify potential effects to people, including recreation or property values, would also have the potential to affect public health given that annoyance is the mechanism by which noise would also affect recreation or property values. Therefore, the recognition of potential public health effects from noise could be improved among reviewed EIAs.

Table 3-3: Context for the assessment of environmental noise in reviewed Environmental Impact Assessments (EIAs)

Context	Number of EIAs out of 28 total	Percent of EIAs out of 100 total
Any context	23	82
Human context	20	71
Public health context	14	50

Both the industry type and year of assessment were associated with whether or not the assessment considered the public health effects of environmental noise. Assessments that were granted a decision between 2010 and 2016 were more likely to have assessed environmental noise from a public health context (8/12 or 67%) compared with assessments that received a decision before 2010 (5/16 or 31%). In addition, assessments for mining projects (4/6 or 67%), wind farm projects (2/2 or 100%) and transportation projects (2/2 or 100%) were more likely to have considered environmental noise in a public health context compared with hydroelectric generation projects (1/5 or 20%). Industry type may also be associated with proximity to people. For example, transportation projects are, by nature, likely to be located near to or along urban centers. In this analysis, both reviewed transportation projects were located in Metro Vancouver and therefore were close to large populations.

3.3.2 Baseline noise

The purpose of this step is to understand the existing noise environment, which informs both the prediction of the future noise environment and resulting public health effects. Assessments for all projects that identify potential effects of noise on human health should characterize the baseline noise environment; however, not all assessments did so. Only some assessments (11/20 or 55%) that considered potential human effects of noise characterized the baseline noise environment. Most of these completed site-specific surveys (8/11 or 72%), while some used literature-based values (4/11 or 36%) (Table 3-4). One assessment did both and verified the appropriateness of literature values by ompleting a site-specific survey. This leaves several assessments (9/20 or 45%) that did not describe the baseline noise environment. An understanding of the current noise environment is essential to the accurate prediction of the future noise environment and resulting human health effects. The absence of this baseline information calls into question the quality of the effects assessment, and the assessments for these nine projects were incomplete.

Among those assessments that used literature to estimate baseline conditions, the most common cited literature includes the BC Oil and Gas Commission *BC Noise Control Guidelines* (96) and Alberta Energy Regulator *Directive 038: Noise Control* (97) , and the. One assessment estimated baseline conditions at 25 dBA but it did not describe how this was estimated. Assessments that adopted values from the literature included the more remote sites, which are expected to have lower ambient sound levels.

Assessments that included site-specific monitoring include those projects located near urban centers, such as the Canada Line and Evergreen Line. This is consistent with good practice due to the number of noise sources and potential for large daily and seasonal variability in urban areas. However, survey times ranged from 14 h to 48 h. This sampling time provides a snapshot of daily noise variability, but it does not provide a reliable picture of the day to day variability or any indication of seasonal variability.

Table 3-4: Source of baseline data used in Noise Impact Assessments (NIAs)

Source of baseline data	Number of NIAs out of 20	Percent of NIAs out of 100
Site-specific survey	8	40
Literature – Alberta Energy Regulator *Directive 038: Noise Control*	1	5
Literature – BC Oil and Gas Commission *BC Noise Control Guidelines*	2	10
Literature - Unknown	1	5
None	9	45

3.3.3 Noise prediction

Noise prediction is the exercise of estimating sound at a distance from source. A general heuristic is that noise energy dissipates at 6 dB per doubling of distance in the outdoor environment. There are a number of more advanced methods for predicting noise levels at a distance from source which consider a number of sound propagation factors including the shape of source, distance, topography, surface material, and other environmental factors, and I would consider these more advanced methods to be “sound modeling”.

Among the reviewed assessments that completed some effects assessment, a few did not do any sound prediction (3/20 or 15%) (Table 3-5). These assessments qualitatively described increased noise levels at the receptor locations, but did not do any sound prediction to support those qualitative descriptions. For these assessments without some exposure information, the conclusions on the nature of health effects were unsubstantiated.

Five assessments did some sort of quantitative prediction that would be considered noise prediction, but not full modeling (5/20 or 25%). This approach would be appropriate where there are large distances between sources and human receptors and where there is confidence that sound would dissipate before reaching any receptors. Ten assessments (10/20 or 50%) completed noise modeling. Five different standard methods were used (Table 3-5), and some assessments used more than one method to predict sound from different sources. The most common method (8/10 or 80%) was the International Organization for Standardization (ISO) 9613-2 method, typically modeled with the CadnaA software. The ISO is a major standards-setting organization, and the ISO 9613-2 standard describes the method of calculation for the attenuation of sound during propagation in an outdoor environment. One assessment (1/10 or 10%) used the *Nouvelle Methode de Prevision de Bruit* (NMPB-Routes 96) method, which is a French road traffic noise prediction method, but did not describe why this method was selected over other options. Similarly, another assessment used the German *Instruction for the Calculation of Aircraft Noise and for Noise Mapping* (ICAN 2009) method, but did not describe why it selected. Another assessment used the American models ANSI S12.17 *Impulse Sound Propagation for Environmental Noise Assessment* and ANSI S2.20 *Estimating Air Blast Characteristics for Single Point Explosions in Air, with a Guide to Evaluation of Atmospheric Propagation and Effects* for modeling blasting noise, but again did not describe why these models were the best choice. One assessment (1/10 or 10%) did not identify a sound prediction method but appeared to complete sound modeling. This made the critical review of the effects assessment impossible. Sound modeling should be the standard for NIAs, particularly where there are human receptors nearby. As with previous NIA steps, assessments completed between 2010 and 2016 were more likely to have completed noise modeling, which is an indicator of improving NIA practices.

Among reviewed assessments that completed full sound modeling, the models selected were not always appropriate for the nature of the noise sources. For example, assessments with blasting used the ISO 9613 standard, which is inappropriate for modeling noise from blasting. Given the number of different noise sources expected as part of any one project (road traffic, air traffic, blasting, processing, etc.), I would expect most assessments to use multiple models for the different noise sources. However, based on the review of publically available documentation it appeared that only some of the multiple noise sources were modeled for these projects.

Seven noise metrics used to model noise among the 20 reviewed projects (Table 3-6). The most common metrics were L_d and L_n. In general, the chosen noise metric adequately represented the anticipated nature of the noise. For example, assessments for both the light rail transit projects modeled the $L_{peak\ (event)}$ metric, as did the one assessment for helicopter noise. The notable exception was for wind farm projects, as neither of the two assessments modeled or assessed effects from low-frequency noise. Low-frequency noise has been identified as a concern for this type of project so the fact that reviewed NIAs did not consider it was a gap.

Table 3-5: Sound prediction standards used in reviewed Noise Impact Assessments (NIAs)

Sound prediction method	Number of NIAs out of 20	Percent of NIAs out of 100
None	4	21
Basic sound prediction	5	25
Unknown sound modeling	2	10
ISO 9613-2	8	42
NMPB-Routes 96	1	5
ICAN 2009	1	5
ANSI S12.17	1	5
ANSI S2.20	1	5

Table 3-6: Noise metrics modeled in reviewed Noise Impact Assessments (NIAs)

Metric	Number of NIAs out of 20	Percent of NIAs out of 100
None	4	21
$L_{eq,24h,A}$	3	16
L_d	6	31
L_n	6	31
L_{DN}	3	16
L_{peak} (event)	3	16
Low-frequency noise	1	7
L_{90}	1	5
Unknown	4	21

3.3.4 Baseline health

The purpose of characterizing baseline health in the local population is to get a better understanding of potential noise effects. A characterization of baseline health includes both the identification and description of potential sensitive receptor populations (e.g. residents at hospitals, children in daycares, etc.) and a description of the prevalence of those health conditions where there is sufficient evidence of an association, including cardiovascular outcomes.

Among reviewed NIAs, only one assessment (2/20 or 5%) characterized baseline health. This assessment reported information at the level of the local health service delivery area using self-reported perceived health information from the Canadian Community Health Survey. While information on self-reported perceived health status forms part of the context for the assessment and is better than no information, it is only indirectly related to the potential sensitivity of the local population to the effects of noise. Given that only one of the 20 NIAs presented any baseline health information, this step was very poorly completed.

The majority of NIAs (13/20 or 65%) identified the presence or absence of nearby receptors. For the remaining six assessments, it was unclear whether there were any nearby human receptors, and whether or not there could be any potential effects to public health. For these assessments, no information was provided on the potential sensitivity of the receptors.

3.3.5 Health effects assessment

3.3.5.1 Identification of potential health effects

The health effects assessment step in NIA takes the noise prediction information from the previous step and describes what that that noise exposure means for human health. There are a number of different approaches for translating that information.

Among the 20 reviewed NIAs that initially identified potential effects of noise on people, four NIAs (20%) did not complete a health effects assessment (Table 3-7). This means that they identified effects to land use, property values, or recreation, but not human health. Given that annoyance is the mechanism by which noise would affect such non-health outcomes, it would also be likely to affect health at the same levels.

One NIA completed a qualitative description of the effect of noise on health, without completing any type of noise prediction, doing any noise modeling, providing any exposure information, or giving rationale for why these steps were not completed. This project was located in a very remote area so it is possible that there was enough distance between the source and any receptors that it was possible to conclude no effects without the modeling step. If so, however, this information should have been presented and its absence calls into question the conclusions of the effects assessment.

Eight assessments considered noise exposure but did not carry that information through to a health effects assessment. These typically compared exposure with established guidelines that were assumed to be protective of human health. However, some of the established guidelines used explicitly state that they are not protective of human health (i.e. Alberta Energy Regulator *Directive 038: Noise Control*).

Nine assessments completed an evaluation of the effects of noise in human health. Annoyance was the most common health effect identified. Sleep disturbance and interference with speech communication were also identified by NIAs that also identified annoyance. In general, mining projects did a better job at identifying health effects, but there were no other trends across industry type.

Table 3-7: Health effects assessed as part of Noise Impact Assessments (NIAs)

Health effects assessment	Number of NIAs out of 20	Percent of NIAs out of 100
None	4	20
Exposure as a substitute for health	8	40
Health without exposure	1	5
Health effects	9	45
Annoyance	6	30
Sleep disturbance	4	20
Speech communication	2	10
Social behaviour as an indicator of mental health	1	5

3.3.5.2 Comparison with established guidelines

A typical part of the health effects assessment is comparison of the predicted noise/health effects against established guidelines. There are no regulatory limits for environmental noise across BC, so the assessments used 13 different standards and guidelines from other jurisdictions (Table 3-8). The BC Oil and Gas Commission (96), Alberta Energy Regulator (97), and Heath Canada guidelines were the most common.

Although none of the NIAs provided justification for the specific guidelines they applied as standards, most chose appropriate values. For example, the NIA for the Canada Line used the Canada Mortgage and Housing Corporation *Road and Rail Noise: Effects on Housing Guidelines*, WHO guidelines, and municipal bylaws for comparison. Use of municipal bylaws were appropriate due to local law, WHO guidelines were appropriate as a well-cited and health-based guideline, and Canada Mortgage and Housing Corporation guidelines were appropriate as they are Canadian, specific to residential land use, and they identify standard attenuation for noise in homes.

In other cases, the selection of guidelines was unclear and not justified. For example, the assessment for the Kitsault Mine Project referenced the Irish Environmental Protection Agency and World Bank guidelines for the effects assessment. The Irish Environmental Protection Agency was an odd choice because it does not propose a single guidance limit, but rather a high level strategic document that sets out procedures for the assessment of noise, including defining competent persons, measurement techniques, use of best available technology, and considerations for developing a noise management program. In addition, the World Bank guidelines were not a good choice given that they set noise limits for a number of specific industries (including manufacturing, processing and base metal mining) but they exclude molybdenum mining (the specific type of mine), and are only intended for application to World Bank-funded projects.

Table 3-8: Standards or guidelines used to evaluate effects from reviewed Noise Impact Assessments (NIAs)

Standard	Number of NIAs out of 20	Percent of NIAs out of 100
None	7	35
BC Oil and Gas Commission *Noise control guidelines* (2009)	4	20
Alberta Energy Regulator *Directive 038: Noise control* (2007)	2	10
Canada Mortgage and Housing Corporation - *Road and rail noise: Effects on housing* (1986)	1	5
Health Canada *Guidance for evaluating human health impacts in environmental assessment: Noise* (2011)	3	15
WHO *Night noise guidelines* (2009)	1	5
WHO *Guidelines for community noise* (1999)	2	10
Health and Welfare Canada *National guidelines for environmental noise control* (1989)	1	5
Irish Environmental Protection Agency *Guidance note for noise in relation to scheduled activities* (2006)	1	5
World Bank *Pollution prevention and abatement handbook* (1998)	1	5
Municipal bylaws (various)	2	10
Developed own	1	5

3.3.6 Mitigation

Measures to mitigate the health effects of noise can broadly be categorized as either design mitigation or management mitigation. Design mitigation includes strategies such as acoustical enclosures, use of a specific quiet technology, or locating noisy activities away from any receptors. Management mitigation includes good practice activities, such as maintaining equipment in good working order, considering noise in the selection of equipment, and other measures that are difficult to quantify or enforce but may meaningfully reduce the health effects from noise.

The majority of reviewed NIAs (16/20 or 80%) identified measures to mitigate the effects of environmental noise (Table 3-9). Most NIAs (11/20 or 55%) identified management plans as the only proposed measures to mitigate effects. Both of the assessments for transportation projects identified design and management mitigation measures, while all of the assessments for mining projects only identified management measures. There was no association between the type of mitigation measures and the time at which the projects were assessed.

Table 3-9: Types of mitigation measures identified for reviewed Noise Impact Assessments (NIAs)

Sound prediction method	Number of NIAs out of 20	Percent of NIAs out of 100
None	4	20
Management plans only	11	55
Design mitigation only	1	5
Design mitigation and management plans	4	20

3.3.7 Significance assessment

The significance of an effect determined by the magnitude and severity of the effect. Only 10 of the 20 NIAs concluded with an assessment of significance for the effects of noise on public health, and all concluded with a determination of no significance effects to the acoustic environment or human health, after consideration of measures to mitigate noise. These were all based on the exposure, and not the %HA or other measure.

Typically, a significant effect would be any effect in excess of a regulatory limit or, in the absence of a limit, a relevant guideline. Five of the NIAs (25%) went with this approach (Table 3-10), even though the specific guideline applied was not always clear. Two assessments (10%) went with a different approach and both, coincidently, predicted noise levels that would exceed relevant guidelines. In these cases, it appeared that the definition of significance was adjusted specifically to avoid a conclusion that there would be a significant effect to human health from exposure to noise.

Three alternative approaches to evaluating significance were also presented. The assessment for the Brucejack Gold Mine determined that a significant effect would exceed the guidelines by no more than 5 dBA; and the assessment for the Evergreen Line compared project noise levels with baseline, and defined significance as any increase in ambient sound by 5 dBA to 10 dBA over 1 h (recall that a 5 dBA difference would be perceptible to the human ear and that a 10 dBA difference would be perceived as a doubling of sound). The Mackenzie Green Energy Centre assessment adopted its own criteria and defined significance as 65 dBA L_{90}, and implied that it was an appropriate level for commercial land use, but did not specify the location for that measurement (i.e. at receptor location, fence line, etc.).

Table 3-10: Description of what a significant effect would be among reviewed Noise Impact Assessments (NIAs)

Description of a significant effect	Number of NIAs out of 20	Percent of NIAs out of 100
No description provided	10	50
Predicted noise level exceeds "regulatory limits"	2	10
Predicted noise level exceeds WHO guidelines by more than 5 dBA (55dBA at residences)	1	10
Predicted noise level exceeds BC Oil and Gas Commission guideline limits (L_n=40 dba)	2	10
Predicted noise level ambient by more than 5 dBA	1	5
Predicted noise level exceeds WHO guidelines at fenceline (55dBA)	1	5
Predicted noise level exceeds 10 dBA above ambient $L_{eq,1h}$	1	5

3.3.8 Follow-up and monitoring

Follow-up and monitoring refers to activities that will be implemented after the NIA to verify the outcome of the effects assessment and/or take additional measures to mitigation or manage effects. It can include further work to refine the predictions, monitoring of noise, monitoring of health, or monitoring of mitigation among other things.

Most of the NIAs (14/20 or 70%) did not identify any follow-up or monitoring of environmental noise or public health following the NIA (Table 3-11). Among those that did, the most common commitment was to monitor any noise complaints, and only a few of the assessments (3/20 or 15%) committed to monitoring noise directly. One made a commitment to monitoring noise only if required due to complaints, while another made a vague commitment to implement a noise monitoring program "if required". Neither of these assessments explained how many complaints or the nature of the complaints that would trigger additional noise monitoring, or what conditions would result in the "requirement" for a noise monitoring program. No assessments provided any detail about the noise monitoring, including location, frequency, duration, metrics, or use of the noise monitoring information.

Follow-up and monitoring activities were so sparse, that there did not appear to be any association between the follow-up and monitoring commitments and industry, nor between the follow-up and monitoring commitments and the recentness of the NIA.

Table 3-11: Follow-up and monitoring activities for environmental noise in reviewed Noise Impact Assessments (NIAs)

Description of follow-up and monitoring	Number of NIAs out of 20	Percent of NIAs out of 100
None	14	70
Any follow-up or monitoring activities	6	30
Monitoring of noise	3	15
Monitoring of noise complaints	6	30

3.3.9 Summary

Environmental noise is routinely assessed as part of the EIA process for proposed development projects. Among the assessments I reviewed, there was wide variability in approaches to baseline data collection and the effects assessment. However, mitigation measures, follow-up, and monitoring had little variability because they were generally limited to good practice mitigation measures and complaint monitoring. In addition, despite variable definitions of significance for environmental noise, there were no conclusions of a significant effect for any reviewed projects.

After evaluating each step in an EIA individually and then again as a whole (Table 3-12), I found that the assessment of environmental noise was missing key information that would support the conclusions. In particular, baseline noise and baseline health information were severely lacking, as was the characterization of effects to health itself and the description of adequate follow-up and monitoring commitments.

Table 3-12: Summary of Environmental Impact Assessment (EIA) process for all of the 28 projects randomly selected for review

Project name	Scoping	Baseline noise	Noise prediction	Baseline health	Health effects assessment	Mitigation	Significance of effects	Follow-up and monitoring
		Survey (S) or Literature (L)	Prediction (P) or Modeling (M)			Managem-ent (M) or Design (D)		Complaint (C) or Noise (N)
Totals	✓ – 20 ✗ – 8	S – 7 L – 3 Both – 1 None - 17	P – 6 M – 10 None - 12	✓ – 1 ✗ – 27	✓ – 11 ✗ – 17	D – 1 M – 11 Both – 4 None - 12	✓ – 12 ✗ – 16	C – 3 N – 1 Both – 2 None – 22
Mining projects								
Brucejack Gold Mine	✓	S, L	M	✗	✓	M	✓	C
Eagle Rock Quarry	✓	✗	P	✗	✗	M	✓	✗
Galore Creek Mine	✓	S	M	✗	✗	M	✗	✗

Project name	Scoping	Baseline noise	Noise prediction	Baseline health	Health effects assessment	Mitigation	Significance of effects	Follow-up and monitoring
Giscome Quarry and Lime Plant	✓	S	M	✗	✓	M	✓	✗
Kitsault Mine	✓	L	M	✓	✓	M	✓	✗
Tulsequah Chief Mine	✗	✗	✗	✗	✗	✗	✗	✗
Hydro energy projects								
East Toba River Montrose Creek Hydroelectric	✗	✗	✗	✗	✗	✗	✗	✗
Forrest Kerr Hydroelectric	✗	✗	✗	✗	✗	✗	✗	✗
Mica Generating Station 6	✓	✗	✗	✗	✗	✗	✗	✗
Big Silver Creek Waterpower	✓	✗	✗	✗	✗	✗	✓	✗
Pingston Creek Hydroelectric	✗	✗	✗	✗	✗	✗	✗	✗

Project name	Scoping	Baseline noise	Noise prediction	Baseline health	Health effects assessment	Mitigation	Significance of effects	Follow-up and monitoring
Wind energy projects								
Cape Scott Wind Farm	✓	×	P	×	×	×	×	N
Dokie Wind Farm	✓	×	M	×	✓	M	✓	×
Gas-fired electricity projects								
Fort Nelson Electrical Generation	✓	×	P	×	×	M	✓	×
Mackenzie Green Energy Centre	✓	S	P	×	×	D	×	×
Petroleum and natural gas projects								
Fortune Creek Gas	✓	L	P	×	✓	D; M	✓	C; N
Cabin Gas Plant	✓	×	M	×	✓	M	✓	×
Ring Border Gas Plant Expansion	×	×	×	×	×	×	×	×

Project name	Scoping	Baseline noise	Noise prediction	Baseline health	Health effects assessment	Mitigation	Significance of effects	Follow-up and monitoring
Prince Rupert Gas Transmission	✓	L	M	✗	✓	M	✓	C
West Coast Connector Gas Transmission	✓	L	M	✗	✓	M	✗	✗
Water management								
Chemainus Water Wells	✗	✗	✗	✗	✗	✗	✗	✗
Bevan Ave Wells	✗	✗	✗	✗	✗	✗	✗	✗
Vancouver Convention Center	✓	✗	P	✗	✓	M	✗	C; N
Waste management								
Babkirk Secure Landfill	✗	✗	✗	✗	✗	✗	✗	✗
Transportation								
Canada Line Rapid Transit	✓	S	M	✗	✓	D; M	✓	✗

Project name	Scoping	Baseline noise	Noise prediction	Baseline health	Health effects assessment	Mitigation	Significance of effects	Follow-up and monitoring
Evergreen Line	✓	S	M	×	✓	D; M	×	C
Industrial								
Peace Valley Oriented Strand Board	✓	S	×	×	×	D; M	✓	×
Tourist resorts								
Garibaldi at Squamish	✓	×	×	×	×	×	×	×

Note: The ✓ symbol indicates that the step was completed, while the × symbol indicates that the step was not completed

Chapter 4: Best practices

4.1 Introduction

This chapter identifies and describes best practices for the assessment of public health impacts from exposure to environmental noise from proposed development projects. It pulls together the information about the health effects of noise (Chapter 2), the current practices for NIA in BC (Chapter 3), as well as well as best practices for noise assessments and HIA. Best practices are presented sequentially using the NIA framework which was first presented in Chapter 1. This chapter is intended to guide project proponents in following best practices to conducting NIA, and assist public health practitioners in understanding and participating in NIAs for proposed development projects.

The objective of this chapter was to identify the best available practices for each step in the NIA process. Best practices were developed through two main processes. First, well-done aspects of the recently completed NIAs which were reviewed as part of Chapter 3 were recorded and brought forward. Second, lessons from the literature in three related subject areas were recorded (Appendix 2) and applied to the NIA framework. The three related subject areas were: (1) health effects of noise (reviewed as part of Chapter 2); (2) noise assessment (i.e. focused on the propagation of noise in the environment); and (3) best practices in HIA (Table 4-1). Professional judgement, including the application of public health principles, was used to identify the aspects of recently complete NIAs that were well-done and to identify of lessons from the literature.

Table 4-1: Summary of search strategy and results

Subject area	Search engine	Description of search	Description of search results
Health effects of noise	EBSCOhost	• See section 2.3.1	• See section 2.3.2 • Focused on academic studies on the health effects of noise
Noise assessment	Google	• Terms: environmental noise impact assessment guidelines • Date: December 27, 2016	• Search results (duplicates were removed by the search engine: 375 • Unique results (duplicates were manually removed): 190 • Focused on engineering methods for noise propagation in the outdoor environment
	Google	• Terms: environmental noise impact assessment methods • Date: December 27, 2016	• Search results (duplicates were removed by the search engine: 399 • Unique results (duplicates were manually removed): 3 • Focused on engineering methods for noise propagation in the outdoor environment
HIA	Google	• Terms: health impact assessment guidelines • Date: December 27, 2016	• Search results (duplicates were removed by search engine: 319 • Unique results (duplicates were manually removed): 66 • Focused on best practices for HIA, including checklists, frameworks, etc.

Subject area	Search engine	Description of search	Description of search results
	Google	• Terms: health impact assessment noise methods • Date: December 27, 2016	• Search results (duplicates were removed by the search engine: 299 • Unique results (duplicates were manually removed): 3 • Focused on best practices for HIA, including checklists, frameworks, etc.
EIA	n/a	• See section 3.1	• Focused on current practices for consideration of environmental noise in EIA

4.2 Review of best practices at each NIA step

4.2.1 Scoping

Scoping is the exercise of defining the scope of the assessment and planning for the assessment. It includes identifying the relevant project-health interactions, and identifying the research methods that will be used to investigate those health effects. As it relates to environmental noise, it is the process of determining whether there is a need to assess the public health effects of noise, identifying the components of the project that will be assessed, and identifying the geographic scope of the assessment.

Because of the widespread nature of noise, most assessments for proposed development projects should consider noise. Exceptions include assessments for projects in very remote locations where there is sufficient evidence that noise would dissipate to background levels prior to reaching either current and potential future receptors, or where limited noise is produced. Even so, the effects to on-site off-shift workers should be considered, if only quantitatively. When noise is included, NIAs should include a comprehensive inventory and assessment of noise sources from all components and phases of a project including noise from construction activities, blasting activities, and transportation of materials and personnel via road, rail, and aircraft. This approach ensures that noise sources are not missed. In general, the geographic scope of the assessment should be sufficiently large for noise to dissipate to background levels. This ensures that due consideration is given to any sensitive populations.

Key recommendation #1: NIAs should assess noise from all aspects of a project including all phases (e.g. construction, operation, maintenance, and decommissioning) and different sources (e.g. blasting, transportation of materials and personnel via road, rail, and aircraft).

4.2.2 Baseline noise

The characterization of the baseline noise should include a description of noise sources, noise level, noise character, as well as changes in those factors over time. An understanding of the baseline noise environment is necessary in order to accurately complete predictive noise modeling and understand the human health effects from a change to the noise environment.

The selection of noise metrics and the description of the baseline noise environment should consider seasonality, weather conditions, as well as the time of day and week. For example, summer months might be quieter because people often take vacations during the summer, weekdays are likely to be quieter than weekends because there are typically more commuters in urban centers during the week, and rush hour is likely to be noisier than other parts of the day. In addition, rain creates sound while snow dampens sound and both these weather conditions are associated with seasonality.

The description of the baseline noise environment should include noise metrics that reflect the current noise environment, and are likely to be affected by the proposed project. For example, if a proposed project is likely to create nighttime noise, L_{night} should be measured in order to assess sleep disturbance. If the current noise environment is influenced by passing trains or aircraft flyovers, L_{event} should be measured.

The work effort to understand the baseline noise in the local area should be commensurate with the level of health risk presented by noise. The most common method used among reviewed EIAs was the use of literature-based values to estimate the baseline noise in the local area surrounding a proposed project, which is a low-effort approach. Literature-based baseline noise estimates are appropriate where the risk to receptors is low, such as in remote environments where there are no existing anthropogenic noise sources, or where there are no nearby receptors.

Site-specific noise surveys capture the specific environmental conditions and reduce the uncertainty compared with literature-based baseline noise estimate. Site-specific noise surveys are appropriate where noise presents a higher health risk, given that the consequences of inaccurate baseline noise estimates are higher. Site-specific surveys are particularly encouraged in urban environments with multiple noise sources, in environments with wide variability in the noise profile, or where noise levels may already be unsatisfactory. A site-specific noise survey with a relatively short sampling period of 48 h may be appropriate for a project located just a couple of kilometers from receptors. A noise survey with continuous noise measurements for one year might be more appropriate for a major transportation project located in an urban center. For high-risk projects such as airports, the description of the baseline environment should also consider any information on noise complaints, if available from local governments or other large organizations.

Key recommendation #2: The effort to understand the baseline noise in the local area should be commensurate with the level of potential health risk presented by noise from the proposed project. Literature-based estimates of the baseline noise environment may be appropriate for assessments of low-risk projects, while site-specific noise surveys with a sampling period of up to one year may be appropriate for high-risk projects in urban centers.

4.2.3 Noise prediction

Noise prediction is the process of predicting noise in the environment at a particular distance from its source. The outcome of predictive noise modeling is often a map with contours showing the dissipation of noise with distance from a source.

Selection of the appropriate prediction method and/or model(s) should consider the type of noise being modeled, as well as distance to any receptors, topography, and meteorological conditions. The considerations that go into selection of an appropriate prediction method and/or model are largely an engineering discipline, and are outside the scope of this thesis. Public health practitioners should consult with an acousticals specialist to ensure that an appropriate method and model is used. In relation to health, the most important part this step is to ensure that the approach is appropriate for modeling noise from the specific noise source, and that modeling includes noise metrics that are relevant to health.

Noise models that are specifically designed for the noise source are preferred, where available. For example, wind farms should use a model specifically designed for wind farms because most other noise models are designed to model sound produced at the ground surface. Blasting noise should similarly be modeled using a method capable of capturing the highly impulsive nature of blasting noise.

In addition to selection of an appropriate noise model for the source, it is important to model noise metrics that are appropriate for predicting effects to health. For example, sleep disturbance from aircraft noise is correlated with the maximum noise level (L_{max}) and event sound level (L_{event}), so these metrics should be measured for an airport project in addition to the more common L_{dn}/L_{den} metrics, which are correlated with cardiovascular outcomes.

Note that most noise metrics and guidelines are based on outdoor noise. For example, the WHO *Night Noise Guidelines for Europe* threshold are based on outdoor noise and assume some outdoor-to-indoor loss of noise as nighttime exposure typically occurs indoors. However, some assessment metrics are based on indoor noise, and so the noise prediction exercise would need to consider outdoor-to-indoor transmission loss. Canada Mortgage and Housing Commission has established standard building attenuation levels for outdoor-to-indoor transmission loss (98) that can be used to calculate building transmission loss.

Key recommendation #3: Consult with an acoustical specialist to ensure that models and metrics are appropriate for the type(s) of noise covered by the assessment.

4.2.4 Baseline health

The baseline health status describes the current health status in the local population. The description should focus on the identification of potentially affected receptors, potentially sensitive receptors, and the baseline health of those receptors with respect to outcomes that are related to noise. An understanding of the baseline health status is necessary in order to properly understand how noise would affect the population. For example, a project near to an elementary school would affect a different population than a project near to an office building. Given the sensitivity of information on the health of individuals and groups, special attention should be provided to the protection of personal privacy during this step.

At a minimum, NIAs should identify the location of potentially affected receptors, and provide a description of the demographics of those receptors. Sensitive populations can be identified based on the location of community infrastructure including schools, daycare facilities, hospitals, and residential care homes. Given that different receptor groups are more vulnerable to the health effects from noise, a description of how each group might be sensitive to changes in the noise environment should be provided. Special attention should be given to children because they are the most sensitive receptor group with respect to noise because they are at a critical development stage.

Ideally, a description of the baseline health would include a description of the prevalence of health conditions related to noise, including cardiovascular outcomes, because those are the health conditions that additional exposures are likely to affect. However, there are ethical considerations around the collection and dissemination of this information, which limits the availability of information for use in NIA. Any information that is available would be accessible through local public health authorities for any given region, and the best practice would include consultation with these public health professionals. Useful information would include baseline health status of the local population, including prevalence of cardiovascular outcomes and obesity/diabetes. The description should also identify other vulnerabilities including age and sex. Given the very limited information available between noise and the other health effects identified in section 2.3.3 (i.e. mental health outcomes, noise-induced hearing loss, obesity/diabetes, and birth outcomes), and specific assessment of the prevalence of these health effects is not appropriate. It may be appropriate to keep some information in this step in the NIA confidential or to report aggregate information to protect privacy.

In addition to collecting information about baseline health, another benefit of consultation with public health authorities is to notify health authorities early in the process, which may translate to a greater involvement in the project planning process and collaboration on shared issues. If available, any existing information about noise complaints in the area should be considered as part of the characterization of baseline health status as noise complaints are driven, in part, by annoyance. Such information is likely to come from the relevant regional district or the Ministry of Environment.

Key recommendation #4: The description the local population and its baseline health should include basic demographic information by age, locations of potentially-affected schools, daycares, hospitals, and residential care facilities, and prevalence of cardiovascular outcomes and obesity/diabetes. Information on baseline health status should be collected directly from, or in consultation with, local public health authorities.

4.2.5 Health effects assessment

The health effects assessment uses information from the exposure assessment and translates that to the effects to health from that predicted noise exposure.

4.2.5.1 Distinguishing between noise exposure and health impacts

Any noise exposure in excess of the lowest observable adverse effect level (LOAEL) of approximately 40 dBA can be expected to have some adverse effects to health. The health effects from noise depend on the exposure levels, among other less objective factors. At any noise exposure level above the LOAEL, it is important to characterize the health effects of noise using the health impact itself (i.e. annoyance, cardiovascular outcomes, etc.), rather than the noise exposure level. It is the description of the health impact itself that has meaning to the lay audience. Overall, characterizing health effects using the health impact itself reduces the uncertainty associated with translating exposures into health effects.

Key recommendation #5: NIAs should characterize the health impacts of noise rather than using noise exposure as a substitute for those health impacts.

4.2.5.2 Annoyance

Annoyance is a good measure for use in NIA because we have a relatively good understanding of the dose-response relationship in adults. The threshold for noise related annoyance is approximately 42 dBA L_{den} (99), slightly above the overall LOAEL, which makes annoyance appropriately conservative for use in NIA.

The dose-response relationship between noise and annoyance was first described in the 1970s by Schultz and is currently best described by Miedema & Oudshoorn (2001) (see section 2.3.3.2.1 for a discussion of the evolution and current status of the dose-response curves). This dose-response relationship is more established for annoyance than any other health effect, and can be used to identify the "percent [of people] annoyed [by noise]" (%A) and the "percent [of people] highly annoyed [by noise]" (%HA) metric.

4.2.5.2.1 Assessment metric: Percent [of people] highly annoyed [by noise] (%HA)

Predicting the change in %HA is a well-established way to assess annoyance in NIA using the dose-response curves discussed above. The %HA metric has been used across jurisdictions to quantify health effects and inform decision making. In addition, Health Canada has recommended this approach for EIAs in Canada (100).

There are two major equations for the calculation of %HA, which are each based on two different dose-response relationships. The ISO 1996-1 (2003) and ANSI S19.9-2005 standards both identify the same equation based on the Schultz curve (Equation 1) while the European Commission has adopted a different equation based on the more recent Miedema and Oudshoorn curves (Equation 2, 3, and 4)(101).

There are a number of considerations that make each equation the best choice, depending on the nature of the noise source, noise character, and environment. The ISO/ANSI equation is intended to cover a variety of noise sources, and is not limited to transportation noise. It contains adjustment factors for different noise sources (i.e. aircraft), noise character (tonality, and impulsiveness), time of the day/week, and land use. The ISO/ANSI equation is more flexible than the European Commission equations and appropriate for use in a wider range of conditions and for noise from a variety of sources. In contrast, the European Commission has separate equations for road traffic, aircraft, and rail noise, but does provide any additional adjustment factors for other noise sources or contexts. For road traffic and aircraft noise, the European Commission equations generally predict higher annoyance than the ISO/ANSI equation (Table 4-2). Given that the European Commission equation is based on an updated and source-specific dataset, it should be used where it applies. However, the more generic ISO/ANSI equation should be used for noise other than transportation noise.

Equation 1: ISO/ANSI equation for %HA

$$\%HA = 100/(1 + e^{10.4-(0.132)(L_{dn})})$$

Equation 2: European Commission equation for %HA by road traffic noise

$$\%HA = (9.868)(10^{-4})(L_{dn} - 42)^3 - (1.436)(10^{-2})(L_{dn} - 42)^2 + (0.5118)(L_{dn} - 42)$$

Equation 3: European Commission equation for %HA by aircraft noise

$$\%HA = (9.199)(10^{-5})(L_{dn} - 42)^3 + (3.932)(10^{-2})(L_{dn} - 42)^2 + (0.2939)(L_{dn} - 42)$$

Equation 4: European Commission equation for %HA by rail noise

$$\%HA = (7.239)(10^{-4})(L_{dn} - 42)^3 - (7.851)(10^{-3})(L_{dn} - 42)^2 + (0.1695)(L_{dn} - 42)$$

The above equations can be used to predict the %HA based on predicted noise levels (L_{dn}). In addition to calculating %HA, population data should be used to calculate the number of people highly annoyed both before and after the project, and the change in number of people highly annoyed by noise. While the %HA metric speaks to the magnitude of the change to those people who are affected, the total number of people annoyed both before and after a project speaks to the magnitude of the health effect to the population.

Key recommendation #6: NIAs should include a quantitative assessment of noise on annoyance, including an estimate of the number of people highly annoyed before and after the project and the change in %HA using whichever of the European Commission or ISO/ANSI equations is most appropriate.

Table 4-2: Comparison of percent of people highly annoyed (%HA) using the International Organization for Standardization / American National Standards Institute and European Commission equations

	%HA					
	Road traffic		Aircraft		Rail	
L_{dn}	ISO/ANSI	European Commission	ISO/ANSI	European Commission	ISO/ANSI	European Commission
45	1.1	1.4	1.1	1.2	1.1	0.5
50	2.2	3.7	2.2	4.9	2.2	1.2
55	4.1	6.4	4.1	10.7	4.1	2.5
60	7.7	10.3	13.9	18.6	7.7	4.7
65	13.9	16.2	23.9	28.7	13.9	8.6
70	23.9	24.7	37.8	41.1	23.9	14.5
75	37.8	36.7	54.0	55.8	37.8	23.1

4.2.5.2.2 Use of %HA over "percent [of people] annoyed [by noise] (%A)

Calculating the %HA may not seem conservative for use in NIA in comparison with calculating the percent of people moderately or slightly annoyed by noise. In fact, there are equations for %A developed using the same datasets used for the %HA and these could be used instead of, or in addition to, the %HA metric.

The largest advantage of the %HA metric is that is more sensitive to minor changes in noise level at the higher noise levels that are typically of greater interest. On the other hand, %A is more sensitive to minor changes at lower noise levels that are typically of less interest. It is for this reason that %HA metric is recommended for use in NIA.

4.2.5.2.3 Limitations of the %HA metric

The %HA metric is an easy and quantitative measure for predicting annoyance in response to a project, but there are some limitations to its use. First, the dose-response relationships can be assumed to represent the average community, but they do not represent any one specific community. This relationship was developed from many socio-acoustic surveys across different countries, community sizes, and cultures and there is large variability within each study and across studies. As such, the actual %HA by project noise in any particular community may be above or below that predicted using the %HA metric. It may be appropriate to adjust this value is response to known sensitivities or resilience of the local population (see section 4.2.5.2.4). Second, the dose-response curves are only applicable to steady state, long term noise (i.e. after habituation). The %HA metric should not be used for short-term or intermittent noise such as construction or blasting noise. Third, the dose-response curves were developed from "typical" noise environments with between 45 and 75 dBA L_{dn}. As such, these curves and the %HA metric should not be used for very quiet or very noisy environments greater than 75 dBA L_{dn}.

4.2.5.2.4 Non-acoustical factors influencing annoyance

There is large individual and community variability in the human response to noise. In addition to acoustical variables influencing annoyance, there are many non-acoustical factors influencing annoyance that are not accounted for using the %HA metric. Individual response depends on age, noise sensitivity, visibility of the noise source, and economic benefit of the noise source, among other factors. Community response was found to vary with size and province within Canada (see section 2.3.3.2). Most variables, when considered individually, have an incremental effect on overall human response. Taken together, non-acoustical factors are believed to account for approximately one third of noise-related annoyance (14).

Given that non-acoustical factors play a large role in noise-related annoyance, it would seem important to consider and adjust predictions of annoyance in response to these factors. However, these individual and community-specific factors are very difficult to measure. The ISO/ANSI standard estimates that the expectation of "peace and quiet" in a quiet rural environment in addition to an unfamiliar sound source may lead to a difference of up to 15 dBA in noise annoyance between rural and urban communities (2,102).

Key recommendation #7: NIAs should include a qualitative description of how non-acoustical factors associated with both the project and the community may influence noise annoyance of the local community.

4.2.5.2.5 Implications of additional research

Recently, the "community tolerance level" (CTL, or L_{ct}) has been proposed as a constant to capture the non-acoustical factors that influence annoyance for a specific community and noise source (103–105). The community tolerance level can be calculated based on socio-acoustic surveys of annoyance. At present, the community tolerance level is an explanatory rather than predictive tool. However, future research may lead to development of socio-acoustic surveys that can be used as a predictive measure of community tolerance for use in NIA.

4.2.5.3 Sleep disturbance

Among reviewed NIAs, sleep disturbance was identified as a health end point for some assessments. Sleep disturbance is a good measure for use in NIA because we have a general understanding of the dose-response relationship. Sleep disturbance occurs at lower noise levels than most other health effects (with the exception of annoyance), and is therefore appropriately conservative for use in NIA. Sleep disturbance should be measured separately from annoyance because they are linked to separate noise metrics.

The best available information on the dose-response relationship between noise and sleep outcomes currently comes from Europe, notably the expert working groups and WHO, which support the work of the European Commission in implementing the *Environmental Noise Directive*. Studies indicate that both the average nighttime noise level indicator (L_{night}) and maximum noise level indicator (L_{max}) are predictive of adverse effects to sleep. The WHO *Night Noise Guidelines for Europe* identify 40 dBA L_{night} as the LOAEL, which is considered protective of vulnerable populations. The guidelines further identify a sleep disturbance threshold of 42 dBA L_{max}, such that sleep disturbance can be expected to occur above these levels.

As described in section 2.3.3.4, sleep is believed to be a mediator in the relationship between noise and other health outcomes. The WHO *Night Noise Guidelines for Europe* identify a threshold of 50 dBA L_{night} which is based on the potential for nighttime noise to lead to medical conditions (specifically, myocardial infarction and hypertension), rather than sleep disturbance directly.

4.2.5.3.1 Assessment metric: Percent [of people] highly sleep disturbed [by nighttime noise] (%HSD)

The assessment method for sleep disturbance is very similar to the method for prediction of annoyance. However, this method is not routinely used in NIA in BC, presumably because the assessment of noise on sleep is not common.

There is only one equation for the calculation of "percent [of people] highly sleep disturbed [by nighttime noise]" (%HSD) for each transportation noise source (road, aircraft, and rail traffic) (Equation 5, 6, 7) (106):

Equation 5: Equation for %HSD by nighttime road traffic noise

$$\%HSD = 20.8 - 1.05(L_{night}) + (0.01486)(L_{night})^2$$

Equation 6: Equation for %HSD by nighttime aircraft noise

$$\%HSD = 18.147 - 0.956(L_{night}) + (0.01482)(L_{night})^2$$

Equation 7: Equation for %HSD by nighttime rail noise

$$\%HSD = 11.3 - 0.55(L_{night}) + (0.00759)(L_{night})^2$$

With the noise values from the predictive noise modeling, the above equations can be used to predict the %HSD. In addition, population data should be used to calculate the number of people highly sleep disturbed both before and after the project, and the change in number of people highly sleep disturbed by nighttime noise.

Key recommendation #8: NIAs should include a quantitative assessment of noise on sleep, including an estimate of the number of people highly sleep disturbed before and after the project, and the change in %HSD.

4.2.5.3.2 Limitations of using the %HSD metric

Similar to annoyance, the dose-response relationship used in the %HSD may represent the average community, but it does not represent any one specific community. As such, the actual %HSD by noise by a project in any particular community may be above or below that predicted using the %HSD metric. It may be appropriate to adjust this value or include a description of how this value is likely to apply given known sensitivities or resilience of the local population. The dose-response curves are only applicable to steady-state, long term noise (i.e. after habituation). As with the %HA function, the %HSD should not be used for short-term or intermittent noise. Finally, the dose-response curves were developed from and are valid for the typical noise levels in the environment, between 40 and 70 dBA.

4.2.5.4 Other health effects

NIAs reviewed in Chapter 3 mentioned annoyance, sleep disturbance, and changes to speech communication and social behaviour as health outcomes from exposure to noise, but no NIAs explicitly or implicitly recognized other cardiovascular outcomes, cognition, obesity/diabetes, or birth outcomes as potential health effects. NIAs should identify and consider the full suite of health effects of noise, including cardiovascular outcomes, sleep disturbance, cognition problems, mental health outcomes, noise-induced hearing loss, obesity/diabetes and birth outcomes for a rigorous assessment, particularly if there are sensitive populations nearby. Given that neither health professionals nor the public are necessarily familiar with the health effects associated with noise, this would facilitate public and expert participation in NIA.

The qualitative assessment should consider baseline levels of those health effects in the population, whether there are sensitive populations and the size of those populations, and whether there are other risk factors that may interact with noise and influence the overall risk of a population.

A quantitative assessment of noise on cardiovascular outcomes, sleep disturbance, cognition problems, mental health outcomes, noise induced hearing loss, obesity/diabetes and birth outcomes is not recommended. With the exception of cardiovascular outcomes (specifically, heart disease and hypertension), we do not have a good understanding of the quantitative relationship between environmental noise and these health effects. A quantitative assessment of annoyance and sleep disturbance should provide adequate information for public health protection.

Key recommendation #9: NIAs should include a qualitative assessment of noise on cardiovascular outcomes, cognition in children, mental health outcomes, obesity/diabetes, and birth outcomes. The qualitative assessment should focus on potential effects to sensitive receptor groups, including children.

4.2.6 Mitigation

The mitigation step identifies measures to reduce, or mitigate, the health effects of noise. These could include measures to reduce sound exposure, as well as measures to reduce the health effects of exposure. Mitigation is one of the most important steps in NIA because it is a tangible and useful outcome of the process.

This step might be done before or after the predictive noise modeling, depending on the stage at which the need or interest in mitigation measures is identified. Sometimes the need or interest in reducing noise is identified at outset and incorporated into project design and sometimes the need is not identified until after an understanding of the potential health effects.

4.2.6.1 Mitigation hierarchy

Mitigation measures can be divided into design mitigation such as relocation or rerouting of the project, or engineering mitigation such as replacement of one technology with a quiet technology, or construction of noise barriers.

A mitigation hierarchy refers to a prioritized set of mitigation options and, in some cases, alternatives are also included in the hierarchy. The hierarchy most frequently referenced in environmental science is: (1) avoidance; (2) mitigation; (3) compensation; whereby avoidance of an effect is the preferred option and compensation for an effect is least preferred option. The analogous hierarchy used in occupational hygiene is called the hierarchy of controls and is typically referenced as: (1) elimination; (2) engineering controls; (3) administrative controls; (4) personal protective equipment. For the purpose of NIA, a blend of these two mitigation hierarchies makes sense. The blended hierarchy focuses on the options that are most likely to be effective, while including all potential options that may reduce health effects associated with noise. This thesis proposes the following mitigation hierarchy in relation to environmental noise.

1. Elimination
2. Control at source
3. Engineering controls at distance
4. Non-acoustical mitigation
5. Noise management

As with both the hierarchies, elimination of noise or avoidance of the noise is preferred because it eliminates the uncertainty in the human response to noise. Elimination could include use of an alternative (e.g. use of electricity from the grid rather than power generation), moving a particularly noisy activity to an existing facility off-site, partial elimination of sound sources (e.g. using buses to transport workers to site rather than having workers drive personal vehicles). Given that noise is ubiquitous in our environment, elimination is probably not feasible in a majority of cases.

If elimination is not feasible, control of noise at or near the source is another good option. This could include selection of quiet technologies, installation of sound dampening materials, or construction of a sound barrier. Control at source provides a greater level of certainty compared with engineering controls at a distance because the propagation of sound in the environment is complex and introduces uncertainty in the modeling.

Engineering controls at a distance are generally limited to installation of sound barriers at some point between the noise source and people. There is uncertainty in the effectiveness of sound barriers because sound propagates in the environment, and this uncertainty is compounded by the uncertainty inherent to sound modelling. Finally, non-acoustical mitigation (see section 4.2.6.2), and noise management should be considered only after more effective noise mitigation is applied as a compliment to those measures. This recommendation receives special attention in the next section.

Management plans often provide the framework for implementation of mitigation measures, and may also include monitoring, follow-up, adaptive management, and reporting. Noise management activities should not be a substitute for mitigation, particularly where there is commitment to take any future mitigation and little responsibility to do anything with the monitoring data. If noise monitoring is to be useful, the purpose of monitoring should be described, and specific thresholds should be identified that would trigger additional actions or mitigation measures.

Key recommendation #10: The following mitigation hierarchy should be applied for the consideration of measures to mitigate effects from environmental noise: (1) elimination; (2) control at source; (3) engineering controls at a distance; (4) non-acoustical mitigation; and (5) noise management. NIAs should provide information in all areas.

4.2.6.2 Non-acoustical mitigation

An estimated one third of the variance in noise annoyance can be attributed to non-acoustical environmental factors (e.g. visibility of the noise source) and community and personal factors (e.g. economic benefits, trust in noise authorities, perceived control over noise source). Acoustical factors, such as noise level, tonality, and impulse account for another one third (14). While untested, it follows that measures to mitigate non-acoustical factors that influence annoyance could be effective, all reasonable efforts to reduce the health effects of noise are recommended.

There are a number of environmental, community, and personal factors that could mitigate annoyance from noise in adults. Note that these should only be considered after appropriate consideration of measures to reduce the noise. Environmental factors include placing key project components outside of view, and setbacks between the project and receptors. Community factors that could mitigate noise-induced annoyance include local hiring, establishing and maintaining a community liaison group and/or noise management group, establishing and following a complaint management procedure, and providing economic or other community benefit. Personal factors that could mitigate noise-induced annoyance include providing employment, providing economic or other personal benefit, and increasing the predictability of noise through a regular noise schedule or notification procedure. These environmental, community, and personal factors influence noise-induced annoyance, and therefore may assist in reducing noise-induced annoyance in adults. However, these factors would not successfully reduce the cognitive and learning effects in children, so they should only be used after considering other measures in the mitigation hierarchy.

4.2.7 Significance assessment

Significance refers to the value-based assessment of the magnitude and the severity of the health effect. In NIA, significance is not to be confused with statistical significance.

Two overarching principles should inform the assessment of the significance of effects to health. First, noise is ubiquitous in our environment, and incremental increases to exposure can be expected from most development projects. Some health regulations and guidelines are developed based on the principle of no adverse effects to people, particularly chemical exposures, but this is not realistic for noise. Noise is everywhere, and the human health effects of environmental noise are largely driven by cumulative exposures. The no observable adverse effect level (NOAEL) is unknown and even the LOAEL of approximately 40 dBA is challenging to meet in urban environments.

Second, NIA is an imprecise process. Noise is a complex physical phenomenon and there is uncertainty in every step of the process of predicting and assessing the health effects of noise. These uncertainties include: (1) the nature and level of sound produced; (2) propagation of sound outdoors; (3) any transmission loss from installation of acoustical barriers and building materials (4); the perception of sound by people; (5) subjective health outcomes (e.g. annoyance); and (6) the individuality of the any objective health outcomes (e.g. cardiovascular outcomes). Because of this compounded uncertainty, predictive processes such as NIA cannot draw conclusions based on precise changes to the noise environment. Instead, conclusions should be drawn based on more general changes to the noise environment, e.g. changes greater than 1-3 dBA.

4.2.7.1 Considerations in evaluating the significance of effects

As described in section 3.3.5.2, comparing predicted values with benchmarks/guidelines and/or ambient/baseline noise levels is a common approach to evaluating significance. Comparing predicted noise level with health-based benchmarks is an important part of evaluating the magnitude and significance of any noise effects. The WHO *Guidelines for Community Noise* are internationally recognized and health-based guidelines for noise exposure that should be considered in NIA (note that many guidelines including the Alberta Energy Regulator guidelines are not health-based). The exposure guidelines range from 30 dBA L_{night} (indoors) for sleep disturbance to 55 dBA (outdoor) for annoyance at a school or playground and 100 dBA $L_{eq,4h}$ (outdoors) for entertainment venues. They are useful benchmarks for noise in different environments, but form only part of the story.

Similar to the above, understanding the magnitude of the change to noise levels is important, but it is not enough to describe the magnitude of the health effect because the health effects of noise have a threshold. For example, in a rural environment with 35 dBA L_{eq}, a 10 dB increase in noise level would still be below the WHO guideline value of 50 dBA, but it would be perceived as a doubling in sound level by people, which could cause considerable annoyance to any receptors.

Another key factor that was omitted in each of the above approaches was the consideration of land use context, including urbanicity, proximity to sensitive populations, and presence of existing noise problems. The land use context is one way to measure the habituation and tolerance of residents to noise, as well as the sensitivity and vulnerability of the receptors. A lower noise exposure is appropriate for rural areas because of the expectations of residents about having a quiet environment. The same is true for projects in close proximity to schools, hospitals, or care facilities because of the sensitivity and vulnerability of receptors. In addition, there may be low public acceptance of very small changes to noise exposures if the area has existing chronic noise problems. For example, airport expansion projects may have a much larger impact on surrounding populations who are already annoyed by the existing noise.

Each of these three approaches should be considered together, rather in in isolation, as part of any conclusion with respect to the significance of a health effect. A description of how each factor was considered should be provided.

Key recommendation #11: The significance of any health effect of noise should be evaluated following consideration of relevant health-based noise exposure guidelines or benchmarks, the changes in the noise environment, and the context (both land use and sensitive populations). The WHO *Guidelines for Community Noise* are currently the best health-based guidelines available.

4.2.8 Monitoring

The final step in the NIA process is monitoring, and may include monitoring the implementation of recommendations resulting from the assessment process, monitoring noise levels in the environment, or monitoring changes to health after a project is in operation.

Many projects operate for many years, and within that time, the community and potential receptors surrounding it are likely to change. Monitoring provides a mechanism to objectively evaluate potential changes to the noise environment, and it is recommended wherever there is a potential opportunity to make changes that could improve the noise environment. Monitoring can track changes to the noise environment as a result of project or community changes, and it can be used to evaluate the success of potential mitigation measures. Noise monitoring is particularly important where predicted noise levels approach unacceptable levels because there is inherent uncertainty in noise propagation and modeling in outdoor environments.

4.2.8.1 Monitoring noise exposures over health effects

In theory, monitoring of health outcomes would focus on the health outcomes themselves (e.g. monitoring of annoyance or sleep disturbance in the population rather than noise levels) as this removes the uncertainty in the exposure-response relationship. However, this would be neither practical nor cost-effective for most health effects. The magnitude of the effect estimates for noise are so small that one would need a very large exposed population to accurately measure any change in health outcomes. In addition, there are long lag times for some outcomes, particularly cardiovascular diseases, and it would be undesirable to wait until those effects can be measured before taking action to prevent them. Monitoring of noise levels is an appropriate proxy for monitoring human health outcomes.

As with other steps of the NIA process, the monitoring effort should be commensurate with the potential for adverse health effects. In the past, noise monitoring has generally been limited to a couple of locations over a period of hours or days; and this may be appropriate for projects with low potential for health effects. Long-term noise monitoring and monitoring at multiple locations is becoming increasingly common, and would be appropriate for projects with a high potential for health effects, or for areas with noise problems. Noise monitoring networks are most often set up surrounding major airports, and they have also been established in select urban centers including in Gdansk, Poland (107); Pisa, Italy (108); and Dublin, Ireland (109). The cost and time required to set up a noise monitoring network as well as making the data available presents a challenge, so this would approach is recommended only for areas where adverse health effects are likely.

In some exceptional circumstances, monitoring of annoyance through socio-acoustic surveys could be appropriate. Exceptional circumstances could include projects that produce a lot of noise in urban environments, such as airports. To date, use of socio-acoustic surveys to characterize annoyance has been limited to academic studies of noise and annoyance. There is a well-established and standard survey protocol for measuring annoyance (ISO Technical Specification 15666:2003), but researchers have also piloted use of web-based surveys and social media (110), which are cheaper and therefore more likely to be proposed in NIA.

Key recommendation #12: Monitoring of noise levels is an appropriate proxy for monitoring human health outcomes after project completion. Monitoring of noise levels should be conducted for any projects where noise is anticipated to impact human health. A monitoring plan, including protocols for collection and analysis of monitoring data and identification of thresholds for implementation of additional measures, should be part of the NIA process.

4.2.8.2 Noise complaint monitoring

Historically, community tolerance to noise was evaluated using information from noise complaints. Information from complaints was the only information available before the development and use of socio-acoustic surveys. While complaint behavior is undoubtedly influenced by annoyance, it is also influenced by other social and psychological factors (111,112) and tends to underrepresent the health issue. Noise complaints can be considered a noise problem that is distinct from, but related to, noise annoyance.

The few NIAs that provided conceptual follow-up and monitoring programs included the commitment to establish a noise complaint monitoring program as part of the follow-up and monitoring plan but without any further discussion on how the information would be used. Given that a complaint records are likely to underrepresent actual annoyance, it cannot provide more than anecdotal data and cannot be used reliably to verify whether the effects assessment was accurate.

Key recommendation #13: Complaint monitoring can be used to support community engagement activities, but it should not the focus of a management program.

Chapter 5: Conclusions

This thesis presents a framework for the assessment of environmental noise from proposed development projects on human health, and identifies thirteen specific recommendations for any assessment. This is the first published work to do so, and it is also one of the first to look at best practices for noise in any related assessment framework including HIA and HHRA. While other researchers and consultants have completed assessments of the effects of noise on health from proposed development projects, nobody has published a framework to help proponents direct the assessment processes or to help public health authorities evaluate the quality of the assessment after completion.

Several of my recommendations are consistent with well-established and broader themes in science and in public health. For example, recommendation #1 speaks to the need to be comprehensive in assessments, and recommendations #6 and #8 suggest quantitative assessments where possible. Some of my recommendations pick up on emerging topics in public health and in noise, such as recommendation #5 which focuses on the need to assess effects to health rather than exposure, and recommendation #11 which identifies the need to give sufficient weight to noise context among more typical considerations such as noise levels. Recommendation #10 is unique in that it proposes non-acoustical mitigation as one potential way to reduce noise-induced annoyance, among other more established methods.

While not a specific goal of this thesis, one of the benefits of this work is that it contributes to the growing body of literature which describes acoustic concepts and summarizes and applies noise research for public health practitioners and other non-experts. Noise is an underrepresented hazard in the public health literature, and this work will help public health practitioners better understand how it affects human health.

5.1 Limitations

The major limitation to my work is that it is driven heavily by recently completed NIAs in BC. There are two major contributors to this limitation. First, Chapter 3 reviewed only recently-conducted NIAs in BC. Noise from development projects is an issue facing many other jurisdictions within Canada and internationally, and other jurisdictions are likely to have different areas of expertise based on their experience, legislative and policy focus, and community values. For example, the NIA process in Europe might be different because population density in Europe is much higher than it is in BC, which increases the potential for noise to be a problem. Further, the *Environmental Noise Directive* creates additional obligations of European Union countries to reduce environmental noise in certain situations. Second, I identified relatively few lessons as part of the supplementary literature searches in Chapter 4 that could be applied to my research objective because there is so little research in the NIA subject area.

Although the heavy focus on NIA in BC is a limitation, this work was specifically designed to improve NIA in BC and Canada. As both a student in environmental health and a professional in the field of EIA, I identified that there were a number of different approaches to NIA in BC, and I identified the need for a greater focus on effects to public health in general and the need for more consistency in the assessment of noise. While a review of NIA processes in other jurisdictions would further advance this work, the focus on BC also means that this work is most applicable to NIAs in BC.

5.2 Future research directions

The next step in this study would be to implement these best practices, by using these recommendations to design and guide a NIA for a proposed development project, and to report on the success and challenges of the implementation process. It would be particularly interesting to see how my untested recommendation to use non-acoustical mitigation, among other factors in the mitigation hierarchy, could be applied for different projects.

Another next step of this work would be to conduct a retroactive assessment of an NIA. This would evaluate the success of NIAs in predicting changes in noise and the resulting effects to health once a project is in operation. As briefly described in Chapter 3, this retroactive reflection in the form of follow-up and monitoring is a gap in the current NIA process in BC.

Finally, this work could be supplemented through the identification of case studies which demonstrate appropriate application of these best practices and recommendations. This thesis repeatedly describes the importance of the environmental context in the human response to noise. Some of my recommendations are high-level and leave many important decisions in the NIA process up to professional judgement. An inventory of case studies which describe the specific situation and considerations that went into decisions would assist public health practitioners looking for further clarity on these recommendations. For example, I have described in section 4.2.2 that it might be appropriate to conduct one year of continuous noise surveys for some high-risk situations, while skipping a site-specific noise in favor of using literature-based values from proxy sites might be appropriate in other situations. An inventory of case studies could describe the examples where low-effort baseline noise assessment were appropriate, and other examples where high-effort baseline noise assessment were appropriate. The examples should describe specific considerations and rationale for selecting the type and length of the baseline noise assessment.

References

1. Health Canada. A primer on noise. 2014 [cited 2015 Dec 15].Available from: https://www.canada.ca/en/health-canada/services/environmental-workplace-health/noise/wind-turbine-noise/primer-noise-environmental-workplace-health.html.

2. American National Standards Institute. ANSI S12.9-2005/Part 4 Quantities and procedure for description and measurement of environmental sound - Part 4: Noise assessment and prediction of long-term community response. 2005.

3. Miedema HM, Oudshoorn CG. Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Environ Health Perspect. 2001 [cited 2015 Dec 18];109(4):409–16. Available from: http://ehpnet1.niehs.nih.gov/docs/2001/109p409-416miedema/abstract.html.

4. Chang TY, Beelen R, Li SF, Chen TI, Lin YJ, Bao BY, Liu CS. Road traffic noise frequency and prevalent hypertension in Taichung, Taiwan: A cross-sectional study. J Environ Healh. 2014;13(1):37. doi: 10.1186/1476-069X-13-37.

5. Janssen SA., Vos H, Eisses AR, Pedersen E. A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources. J Acoust Soc Am. 2011;130(6):3746. doi: 10.1121/1.3653984.

6. Babisch W. The noise/stress concept, risk assessment and research needs. Noise Health. 2002 [cited 2015 Dec 15];4(16):1–11. Available from: http://www.noiseandhealth.org/text.asp?2002/4/16/1/31833.

7. Babisch W. Stress hormones in the research on cardiovascular effects of noise. Noise Health. 2003 [cited 2016 Jan 11];5(18):1–11. Available from: http://www.noiseandhealth.org/text.asp?2003/5/18/1/31824.

8. Selander J, Bluhm G, Theorell T, Pershagen G, Babisch W, Seiffert I, et al. Saliva cortisol and exposure to aircraft noise in six European countries. Environ Health Perspect. 2009;117(11):1713–7. doi: 10.1289/ehp.0900933.

9. Ising H, Braun C. Acute and chronic endocrine effects of noise: Review of the research conducted at the Institute for Water, Soil and Air Hygiene. Noise Health. 2000 [cited 2015 May 21];2(7):7–24. Available from: http://www.noiseandhealth.org/text.asp?2000/2/7/7/31745.

10. Evans GW, Lercher P, Meis M, Ising H, Kofler WW. Community noise exposure and stress in children. J Acoust Soc Am. 2001 [cited 2015 May 21];109(3):1023–7. Available from: http://www.ncbi.nlm.nih.gov/pubmed/11303916.

11. Babisch W, Fromme H, Beyer A, Ising H. Increased catecholamine levels in urine in subjects exposed to road traffic noise: the role of stress hormones in noise research. Environ Int. 2001 [cited 2015 May 29];26(7–8):475–81. Available from: https://www.ncbi.nlm.nih.gov/pubmed/11485215

12. Passchier-Vermeer, W; Passchier WF. Noise exposure and public health. Environ Health Perspect. 2000 [cited 2015 May 29];108:123–31. Available from: http.//ehpnetl.niehs.nih.gov/docs/2000/suppl-1/123-131passchier-vermeer/abstract.html.

13. Babisch W, Pershagen G, Selander J, Houthuijs D, Breugelmans O, Cadum E, et al. Noise annoyance - A modifier of the association between noise level and cardiovascular health? Sci Total Environ.2013;452–453:50–7. doi: 10.1016/j.scitotenv.2013.02.034.

14. Guski R. Personal and social variables as co-determinants of noise annoyance. Noise Health. 1999 [cited 2015 May 25];1(3):45–56. Available from: http://www.noiseandhealth.org/text.asp?1999/1/3/45/31714.

15. Pennig S, Schady A. Railway noise annoyance: exposure-response relationships and testing a theoretical model by structural equation analysis. Noise Health. 2014 [cited 2016 Apr 24];16(73):388–99. doi: 10.4103/1463-1741.144417.

16. Pawlaczyk-Łuszczyńska M, Dudarewicz A, Zaborowski K, Zamojska-Daniszewska M, Waszkowska M. Evaluation of annoyance from the wind turbine noise - A pilot study. Int J Occup Med Environ Health. 2014;27(3):364–88. doi: 10.2478/s13382-014-0252-1.

17. Méline J, Van Hulst A, Thomas F, Karusisi N, Chaix B. Transportation noise and annoyance related to road traffic in the French RECORD study. Int J Health Geogr. 2013;12:44. doi: 10.1186/1476-072X-12-44.

18. Kassess, C., Noll, A., Najdak P., Waubke, H. Effect of train type on annoyance and acoustical features of the rolling noise. J Acoust Soc Am. 2013;134(2):1071–81. doi: 10.1121/1.4812771.

19. Ali SAA. Study effects of school noise on learning achievement and annoyance in Assiut city, Egypt. Appl Acoust. 2013 Apr;74(4):602–6. doi: 10.1016/j.apacoust.2012.10.011

20. Pennig S, Quehl J, Mueller U, Rolny V, Maass H, Basner M, et al. Annoyance and self-reported sleep disturbance due to night-time railway noise examined in the field. J Acoust Soc Am. 2012;132(5):3109–17. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23145596.

21. Alayrac M, Marquis-Favre C, Viollon S, Morel J, Le Nost G. Annoyance from industrial noise: indicators for a wide variety of industrial sources. J Acoust Soc Am. 2010;128(3):1128–39. doi: 10.1121/1.3466855.

22. Ohshima T, Yamada I. Study on the effect of sound duration on the annoyance of helicopter noise by applying a technique of time compression and expansion of sound signals. Appl Acoust. 2009;70(9):1200–11. doi: 10.1016/j.apacoust.2009.03.006.

23. Seong Y, Lee S, Young Gwak D, Cho Y, Hong J, Lee S. An experimental study on annoyance scale for assessment of wind turbine noise. J Renew Sustain Energy;5(5):52008. doi: 10.1063/1.4821811.

24. Torija AJ, Flindell IH. Differences in subjective loudness and annoyance depending on the road traffic noise spectrum. J Acoust Soc Am [Internet]. 2014 Jan [cited 2016 Apr 24];135(1):1–4. Available from: http://www.ncbi.nlm.nih.gov/pubmed/24437739.

25. Huang Y, Di G, Zhu Y, Hong Y, Zhang B. Pair-wise comparison experiment on subjective annoyance rating of noise samples with different frequency spectrums but same A-weighted level. Appl Acoust. 2008;69(12):1205–11. doi: 10.1121/1.4842456.

26. Klein A, Marquis-Favre C, Weber R, Trollé A. Spectral and modulation indices for annoyance-relevant features of urban road single-vehicle pass-by noises. J Acoust Soc Am. 2015;137(3):1238–50. doi: 10.1121/1.4913769.

27. Aasvang GM, Overland B, Ursin R, Moum T. A field study of effects of road traffic and railway noise on polysomnographic sleep parameters. J Acoust Soc Am. 2011;129(6):3716–26. doi: 10.1121/1.3583547.

28. Bartels S, Márki F, Müller U. The influence of acoustical and non-acoustical factors on short-term annoyance due to aircraft noise in the field - The COSMA study. Sci Total Environ. 2015;538:834–43. doi: 10.1121/1.4913769.

29. Ryu JK, Jeon JY. Influence of noise sensitivity on annoyance of indoor and outdoor noises in residential buildings. Appl Acoust. 2011;72(6):336–40. doi: 10.1016/j.apacoust.2010.12.005.

30. Paunović K, Jakovljević B, Belojević G. Predictors of noise annoyance in noisy and quiet urban streets. Sci Total Environ. 2009;407(12):3707–11. doi: 10.1016/j.scitotenv.2009.02.033.

31. Laszlo HE, McRobie ES, Stansfeld SA, Hansell AL. Annoyance and other reaction measures to changes in noise exposure - a review. Sci Total Env. 2012;435–436:551–62. doi: 10.1016/j.scitotenv.2012.06.112.

32. Van Gerven PWM, Vos H, Van Boxtel MPJ, Janssen SA, Miedema HME. Annoyance from environmental noise across the lifespan. J Acoust Soc Am. J Acoust Soc Am; 2009;126(1):187–94. doi: 10.1121/1.3147510.

33. Michaud DS, Keith SE, McMurchy D. Annoyance and disturbance of daily activities from road traffic noise in Canada. J Acoust Soc Am. 2008;123(2):784–92. doi: 10.1121/1.2821984.

34. Pierrette M, Marquis-Favre C, Morel J, Rioux L, Vallet M, Viollon S., Moch A. Noise annoyance from industrial and road traffic combined noises: A survey and a total annoyance model comparison. J Environ Psychol. 2012;32(2):178–86. doi: 10.1016/j.jenvp.2012.01.006.

35. Eriksson C, Bluhm G, Hilding A, Östenson CG, Pershagen G. Aircraft noise and incidence of hypertension-Gender specific effects. Environ Res. 2010;110(8):764–72. doi: doi: 10.1016/j.envres.2010.09.001.

36. Akinseye OA, Williams SK, Seixas A, Pandi-perumal SR, Vallon J, Zizi F, et al. Sleep as a mediator in the pathway linking environmental factors to hypertension : A review of the literature. Int J Hypertens. 2015;2015(1). doi: 10.1155/2015/926414.

37. Grad FP. Preamble to the Constitution of WHO as adopted by the International Health Conference. Bull World Health Org. 2002 [cited 2016 Apr 29]; 80(12):98.-984. Available from: http://www.who.int/governance/eb/who_constitution_en.pdf.

38. Schultz TJ. Synthesis of social surveys on noise annoyance. J Acoust Soc Am. 1978;(64):377–405. doi: 10.1121/1.382013.

39. Fidell S, Barber D, Schultz TJ. Updating the dosage-effect relationship for the prevalence of annoyance due to transportation noise. J Acoust Soc Am. 1991;(89):221–33. doi: 10.1121/1.400504.

40. Finegold L, Harris C, von Gierke H. Community annoyance and sleep disturbance: Updated criteria for assessing the impact of general transportation noise on people. Noise Control Eng J. 1994 [cited 2016 Jun 1];(42):25–30. Available from: ftp://ftp.agl.faa.gov/Materials%20Released%20Related%20to%20the%20OM%20EIS/3-31-2005%20World%20Gateway%20Related%20Documents/1821_6.pdf.

41. Miedema HME, Vos H. Exposure-response relationships for transportation noise. J Acoust Soc Am. 1998;(104):3432–45. doi: 10.1121/1.423927.

42. Fidell S, Silvati L. Parsimonious alternatives to regression analysis for characterizing prevalence rates of aircraft noise annoyance. Noise Control Eng J. 2004;52(2):56–68. doi: 10.3397/1.2839741.

43. Babisch W. Updated exposure-response relationship between road traffic noise and coronary heart diseases: A meta-analysis. Noise Health; 2014 [cited 2015 May 6];16(68):1–9. Available from: http://www.noiseandhealth.org/text.asp?2014/16/68/1/127847.

44. Vienneau D, Schindler C, Perez L, Probst-Hensch N, Röösli M. The relationship between transportation noise exposure and ischemic heart disease: A meta-analysis. Environ Res. 2015;138:372–80. doi: 10.1016/j.envres.2015.02.023.

45. Gan WQ, Davies HW, Koehoorn M, Brauer M. Association of long-term exposure to community noise and traffic-related air pollution with coronary heart disease mortality. Am J Epidemiol. 2012;175(9):898–906. doi: 10.1093/aje/kwr424.

46. Banerjee D, Das PP, Foujdar A. Association between road traffic noise and prevalence of coronary heart disease. Environ Monit Assess. 2014;186(5):2885–93. doi: 10.1007/s10661-013-3587-3.

47. Floud S, Blangiardo M, Clark C, de Hoogh K, Babisch W, Houthuijs D, et al. Exposure to aircraft and road traffic noise and associations with heart disease and stroke in six European countries: A cross-sectional study. Environ Health. 2013;12:89. doi: 10.1186/1476-069X-12-89.

48. Hansell AL, Blangiardo M, Fortunato L, Floud S, de Hoogh K, Fecht D, et al. Aircraft noise and cardiovascular disease near Heathrow airport in London: Small area study. BMJ. 2013;347:f5432. doi: 10.1136/bmj.f5432

49. Evrard A-S, Bouaoun L, Champelovier P, Lambert J, Laumon B. Does exposure to aircraft noise increase the mortality from cardiovascular disease in the population living in the vicinity of airports? Results of an ecological study in France. Noise Health. 2015 [cited 2016 Apr 25];17(78):328–36. Available from: http://www.noiseandhealth.org/text.asp?2015/17/78/328/165058.

50. Barregard L, Bonde E, Ohrström E. Risk of hypertension from exposure to road traffic noise in a population-based sample. Occup Environ Med. 2009;66(6):410–5. doi: 10.1136/oem.2008.042804.

51. Jarup L, Babisch W, Houthuijs D, Pershagen G, Katsouyanni K, Cadum E, et al. Hypertension and exposure to noise near airports: The HYENA study. Environ Health Perspect. 2008;116(3):329–33. doi: 10.1289/ehp.10775.

52. Yang K, Cui Q, Huang D, Song X, Tian J, Wang Q. Is there an association between aircraft noise exposure and the incidence of hypertension? A meta-analysis of 16784 participants. Noise Health. 2015;17(75):93. Available from: doi: 10.4103/1463-1741.153400.

53. Banerjee D, Das PP, Fouzdar A. Urban residential road traffic noise and hypertension: A cross-sectional study of adult population. J Urban Health . 2014;91(6):1144–57. doi: 10.1007/s11524-014-9916-1.

54. Bluhm LG, Berglind N, Nordling E, Rosenlund M. Road traffic noise and hypertension. Occup Environ Med. 2007;64(2):122–6. doi: 10.1136/oem.2005.025866.

55. Weinmann T, Ehrenstein V, Von Kries R, Nowak D, Radon K. Subjective and objective personal noise exposure and hypertension: An epidemiologic approach. Int Arch Occup Environ Health. 2012;85(4):363–71. doi: 10.1007/s00420-011-0679-7.

56. Greiser E, Greiser C, Janhsen K. Night-time aircraft noise increases prevalence of prescriptions of antihypertensive and cardiovascular drugs irrespective of social class - The Cologne-Bonn Airport study. J Public Health. 2007;15(5):327–37. doi: 10.1007/s10389-007-0137-x.

57. van Kempen E, Babisch W. The quantitative relationship between road traffic noise and hypertension. J Hypertens. 2012;30(6):1075–86. doi: 10.1097/HJH.0b013e328352ac54.

58. Pirrera S, De Valck E, Cluydts R. Field study on the impact of nocturnal road traffic noise on sleep: The importance of in- and outdoor noise assessment, the bedroom location and nighttime noise disturbances. Sci Total Environ. 2014;500–501:84–90. doi: 10.1016/j.scitotenv.2014.08.061.

59. Frei P, Mohler E, Röösli M. Effect of nocturnal road traffic noise exposure and annoyance on objective and subjective sleep quality. Int J Hyg Environ Health. 2014;217(2–3):188–95. doi: 10.1016/j.ijheh.2013.04.003

60. Ohrstrom E, Hadzibajramovic E, Holmes M, Svensson H. Effects of road traffic noise on sleep: Studies on children and adults. J Environ Psychol. 2006;26(2):116–26. doi: 10.1016/j.jenvp.2006.06.004

61. Janssen SA, Centen MR, Vos H, van Kamp I. The effect of the number of aircraft noise events on sleep quality. Appl Acoust. 2014;84:9–16. doi: 10.1016/j.apacoust.2014.04.002

62. Elmenhorst E-M, Pennig S, Rolny V, Quehl J, Mueller U, Maaß H, et al. Examining nocturnal railway noise and aircraft noise in the field: Sleep, psychomotor performance, and annoyance. Sci Total Environ. 2012;424:48–56. doi: 10.1016/j.scitotenv.2012.02.024.

63. Basner M, Müller U, Elmenhorst E-M. Single and combined effects of air, road, and rail traffic noise on sleep and recuperation. Sleep. 2011 [cited 2016 Jun 2];34:11–23. Available from: https://www.ncbi.nlm.nih.gov/pubmed/21203365.

64. Pirrera S, De Valck E, Cluydts R. Nocturnal road traffic noise assessment and sleep research: The usefulness of different timeframes and in- and outdoor noise measurements. Appl Acoust. 2011;72(9):677–83. doi:10.1016/j.apacoust.2011.03.007.

65. Omlin S, Bauer GF, Brink M. Effects of noise from non-traffic-related ambient sources on sleep: review of the literature of 1990-2010. Noise Health. 2011;13(53):299–309. doi: 10.4103/1463-1741.82963.

66. Stansfeld SA, Berglund B, Clark C, Lopez-Barrio I, Fischer P, Ohrstrom E, et al. Aircraft and road traffic noise and children's cognition and health: A cross-national study. Lancet. 2005;365(9475):1942–9. doi: 10.1016/S0140-6736(05)66660-3.

67. Clark C, Crombie R, Head J, Van Kamp I, Van Kempen E, Stansfeld SA. Does traffic-related air pollution explain associations of aircraft and road traffic noise exposure on children's health and cognition? A secondary analysis of the United Kingdom sample from the RANCH project. Am J Epidemiol. 2012;176(4):327–37. doi: 10.1093/aje/kws012.

68. Ljung R, Sorqvist P, Hygge S. Effects of road traffic noise and irrelevant speech on children's reading and mathematical performance. Noise Health. 2009;11(45):194–8. doi: 10.4103/1463-1741.56212.

69. Haines MM, Stansfeld SA, Job RF, Berglund B, Head J. A follow-up study of effects of chronic aircraft noise exposure on child stress responses and cognition. Int J Epidemiol. 2001 [cited 2016 Jun 2];30(4):839–45. Available from: http://www.ncbi.nlm.nih.gov/pubmed/11511614.

70. Matsui T, Stansfeld S, Haines M, Head J. Children's cognition and aircraft noise exposure at home--the West London Schools Study. Noise Health. 2004 [cited 2016 Jun 2];7(25):49–58. Available from: http://www.noiseandhealth.org/text.asp?2004/7/25/49/31647 .

71. Hygge S, Boman E, Enmarker I. The effects of road traffic noise and meaningful irrelevant speech on different memory systems. Scand J Psychol. 2003;44(1):13–21. doi: 10.1111/1467-9450.00316.

72. Mackensen SV, Bullinger M, Meis M, Evans GW, Hygge S. The psychological cost of aircraft noise for children. J Acoust Soc Am. 1999;105(2):1219. doi: 10.1121/1.425878.

73. van Kempen E, van Kamp I, Lebret E, Lammers J, Emmen H, Stansfeld S. Neurobehavioral effects of transportation noise in primary schoolchildren: A cross-sectional study. Environ Health. doi: 10.1186/1476-069X-9-25

74. Basner M, Elmenhorst E, Quehl J. Nocturnal air, road, and rail traffic noise and daytime cognitive. J Acoust Soc Am. 2015;135(1):213–22. doi: 10.1121/1.4842475.

75. Lee PJ, Jeon JY. Relating traffic, construction, and ventilation noise to cognitive performances and subjective perceptions. J Acoust Soc Am. 2013;134(4):2765–72. doi: 10.1121/1.4818776.

76. Hardoy MC, Carta MG, Marci AR, Carbone F, Cadeddu M, Kovess V, et al. Exposure to aircraft noise and risk of psychiatric disorders: The Elmas survey. Aircraft noise and psychiatric disorders. Soc Psychiatry Psychiatr Epidemiol. 2005;40(1):24–6. doi: 10.1007/s00127-005-0837-x.

77. Floud S, Vigna-Taglianti F, Hansell A, Blangiardo M, Houthuijs D, Breugelmans O, et al. Medication use in relation to noise from aircraft and road traffic in six European countries: results of the HYENA study. Occup Environ Med. 2011;68(7):518–24. doi: 10.1136/oem.2010.058586.

78. Halonen JI, Vahtera J, Stansfeld S, Yli-Tuomi T, Salo P, Pentti J, et al. Associations between nighttime traffic noise and sleep: The Finnish public sector study. Environ Health Perspect. 2012;120(10):1391–6. doi: 10.1289/ehp.1205026.

79. Gallacher J, Stansfeld S, Gallacher J, Babisch W, Shipley M. Road traffic noise and psychiatric disorder: Prospective findings from the Caerphilly Study. BMJ. 1996 [cited 2016 Jun 2];313:266–7. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2351704/.

80. Health Canada. It's your health: Noise-induced hearing loss. 2012 [cited 2016 June 23]. Available from: http://www.hc-sc.gc.ca/hl-vs/iyh-vsv/environ/hearing_loss-perte_audition-eng.php.

81. United States Environmental Protection Agency. Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety. 1974 [cited 2017 Jan 17]. Available from: https://nepis.epa.gov/Exe/ZyPDF.cgi/2000L3LN.PDF?Dockey=2000L3LN.PDF.

82. Neitzel RL, Gershon RRM, McAlexander TP, Magda LA, Pearson JM. Exposures to transit and other sources of noise among New York City residents. Environ Sci Technol. 2012;46(1):500–8. doi: 10.1021/es2025406.

83. Lewis RC, Gershon RRM, Neitzel RL. Estimation of permanent noise-induced hearing loss in an urban setting. Environ Sci Technol. 2013;47(12):6393–9. doi: 10.1021/es305161z.

84. Chen TJ, Chen SS. Effects of aircraft noise on hearing and auditory pathway function of school-age children. Int Arch Occup Environ Health. 1993;65:107–11. doi: 10.1007/BF00405728.

85. Chen TJ, Chen SS, Hsieh PY, Chiang HC. Auditory effects of aircraft noise on people living near an airport. Arch Environ Health. 1997;52(1):45–50. doi: http://doi.org/10.1080/00039899709603799.

86. Sørensen M, Andersen ZJ, Nordsborg RB, Becker T, Tjønneland A, Overvad K, et al. Long-Term Exposure to Road Traffic Noise and Incident Diabetes: A Cohort Study. Enviro Health Perspect. 2012;121(2):217–23. Available from: 10.1289/ehp.1205503.

87. Eriksson C, Hilding A, Pyko A, Bluhm G, Pershagen G, Ostenson C-G. Long-term aircraft noise exposure and body mass index, waist circumference, and type 2 diabetes: A prospective study. Environ Health Perspect. 2014;122(7):687–94. doi: 10.1289/ehp.1307115.

88. Dzhambov A. Long-term noise exposure and the risk for type 2 diabetes: A meta-analysis. Noise Health. 2015;17(74):23. doi: 10.4103/1463-1741.149571.

89. Pyko A, Eriksson C, Oftedal B, Hilding A, Östenson C-G, Krog NH, et al. Exposure to traffic noise and markers of obesity. Occup Environ Med. 2015;72(8):594–601. doi: 10.1136/oemed-2014-102516.

90. Oftedal B, Krog NH, Pyko A, Eriksson C, Graff-Iversen S, Haugen M, et al. Road traffic noise and markers of obesity - A population-based study. Environ Res. 2015;138:144–53. doi: 10.1016/j.envres.2015.01.011.

91. Hohmann C, Grabenhenrich L, de Kluizenaar Y, Tischer C, Heinrich J, Chen C-M, et al. Health effects of chronic noise exposure in pregnancy and childhood: A systematic review initiated by ENRIECO. Int J Hyg Environ Health. 2013;216(3):217–29. doi: 10.1016/j.ijheh.2012.06.001.

92. Ristovska G, Laszlo H, Hansell A. Reproductive outcomes associated with noise exposure - A systematic review of the literature. Int J Environ Res Public Health. 2014;11(8):7931–52. doi: 10.3390/ijerph110807931.

93. van Kamp I, Davies H. Noise and health in vulnerable groups: A review. Noise Health. 2013;15(64):153–9. doi: 10.4103/1463-1741.112361.

94. Science for Environmental Policy. Links between noise and air pollution and socioeconomic status. In-depth report produced for the European Commission. 2016 [cited 2017 Dec 2]. Available from: http://ec.europa.eu/environment/integration/research/newsalert/pdf/air_noise_pollution_socioeconomic_status_links_IR13_en.pdf.

95. Dale LM, Goudreau S, Perron S, Ragettli MS, Hatzopoulou M, Smargiassi A. Socioeconomic status and environmental noise exposure in Montreal, Canada. BMC Public Health. 2015;15:205. doi: 10.1186/s12889-015-1571-2.

96. British Columbia Oil and Gas Commission. British Columbia Noise Control Best Practices Guideline. 2009 [cited 2016 Jun 18]. Available from: https://www.bcogc.ca/node/11095/download.

97. Alberta Energy Regulator. Directive 038: Noise Control. 2013 [cited 2016 Jun 17]. Available from: https://www.aer.ca/documents/directives/Directive038.pdf

98. Canada Mortgage and Housing Corporation. Road and rail noise: Effects on housing. 1981 [cited 2016 Jul 29]. Available from: http://publications.gc.ca/collections/collection_2017/schl-cmhc/NH15-27-1981-eng.pdf.

99. European Environmental Agency. Good practice guide on noise exposure and potential health effects. 2010 [cited 2016 Jul 29]. Available from: https://publications.europa.eu/en/publication-detail/-/publication/c5ff590d-f2fd-47e1-b3f7-f8a1f987cf74/language-en.

100. Health Canada. Useful Information for Environmental Assessments. 2010 [cited 2016 May 16]. Available from: http://publications.gc.ca/collections/collection_2015/sc-hc/H128-1-10-599-eng.pdf.

101. European Commission. Position paper on dose response relationships. 2002 [cited 2016 Jul 29]. Available from: http://www.eukn.eu/fileadmin/Lib/files/EUKN/2010/1710-dose-effect.pdf

102. International Standards Organization. ISO 1996-1:2003 Acoustics - Description, measurement and assessment of environmental noise - Part 1: Basic quantities and assessment procedure. 2003.

103. Schomer P, Mestre V, Fidell S, Berry B, Gjestland T, Vallet M, et al. Role of community tolerance level (CTL) in predicting the prevalence of the annoyance of road and rail noise. J Acoust Soc Am. 2012;131(4):2772–86. doi: 10.1121/1.3688762.

104. Fidell S, Mestre V, Schomer P, Berry B, Gjestland T, Vallet M, et al. A first-principles model for estimating the prevalence of annoyance with aircraft noise exposure. J Acoust Soc Am. 2011;130(2):791. doi: 10.1121/1.3605673.

105. Taraldsen G, Gelderblom FB, Gjestland TT. How to measure community tolerance levels for noise. J Acoust Soc Am. 2016;140(1):692. doi: 10.1121/1.4959134.

106. Miedema HME, Passchier-Vermeer W, Vos H, Delft C. Elements for a position paper on night-time transportation noise and sleep-disturbance . TNO-Inro rapport 2002-59. 2002 [cited 2016 Jun 2]. Available from: http://ec.europa.eu/environment/noise/pdf/noisesleepdisturbance.pdf%5CnU:%5CHIA%5CENHIS2%5Cliteratur%5CL,,rm

107. Mioduszewski P, Ejsmont JA, Grabowski J, Karpiński D. Noise map validation by continuous noise monitoring. Appl Acoust. 2011;72(8):582–9. doi: 10.1016/j.apacoust.2011.01.012.

108. Vinci B, Tonacci A, Caudai C, Rosa P De, Nencini L, Pratali L. The SENSEable Pisa Project: Citizen-participation in monitoring acoustic climate of Mediterranean city centers. CLEAN – Soil, Air, Water. 2017;45(7). doi: 10.1002/clen.201600137.

109. Dublin City Council. Ambient Sound Monitoring Network - Annual Report 2015. n.d [cited 2017 Nov 20]. Available from: http://www.dublincity.ie/sites/default/files/content/WaterWasteEnvironment/NoiseMapsandActionPlans/Documents/AMBIENT%20SOUND%20MONITORING%20NETWORKAnnualReport2015Final.pdf

110. Silva B, Santos G, Eller R, Gjestland T. Annoyance survey by means of social media. J Acoust Soc Am. 2017;141(2):1019–26. doi: 10.1121/1.4976055.

111. Michaud DS, Bly SHP, Keith SE. Using and change in percent highly annoyed with noise as a potential health effect measure for projects under the Canadian Environmental Assessment Act [cited 2016 Sept 8]. Can Acoust. 2008;36(2):13–30. Available from: https://jcaa.caa-aca.ca/index.php/jcaa/article/view/2011.

112. Belojevic G, Jakovljevic B, Slepcevic V. Noise and mental performance: personality attributes and noise sensitivity. Noise Health. 2003 [cited 2017 Mar 11];6(21):77–89. Available from: http://www.noiseandhealth.org/text.asp?2003/6/21/77/31680.

113. Berglund B, Lindvall T, Schwela DH. WHO Guidelines for community noise. Geneva, Switzerland: World Health Organization; 1999. Available from: http://whqlibdoc.who.int/hq/1999/a68672.pdf.

114. World Health Organization. The HIA procedure. n.d. [cited 2017 Sep 23]. Available from: http://www.who.int/hia/tools/process/en/

115. United States Environmental Protection Agency. Human health risk assessment. 2016 [cited 2016 Sept 9]. Available from: https://www.epa.gov/risk/human-health-risk-assessment.

Appendix 1: Summary of key recommendations

The following is a consolidated summary of all recommendations contained within Chapter 4. It is presented here for ease of reference.

1. Noise Impact Assessments (NIAs) should assess noise from all aspects of a project including all phases (e.g. construction, operation, maintenance, and decommissioning) and different sources (e.g. blasting, transportation of materials and personnel via road, rail, and aircraft).

2. The effort to understand the baseline noise in the local area should be commensurate with the level of potential health risk presented by noise from the proposed project. Literature-based estimates of the baseline noise environment may be appropriate for assessments of low-risk projects, while site-specific noise surveys with a sampling period of up to one year may be appropriate for high-risk projects in urban centers.

3. Consult with an acoustical specialist to ensure that models and metrics are appropriate for the type(s) of noise covered by the assessment.

4. The description the local population and its baseline health should include basic demographic information by age, locations of potentially-affected schools, daycares, hospitals, and residential care facilities, and prevalence of cardiovascular outcomes and obesity/diabetes. Information on baseline health status should be collected directly from, or in consultation with, local public health authorities.

5. NIAs should characterize the health impacts of noise rather than using noise exposure as a substitute for those health impacts.

6. NIAs should include a quantitative assessment of noise on annoyance, including an estimate of the number of people highly annoyed before and after the project and the change in %HA using whichever of the European Commission or International Organization for Standardization / American National Standards Institute equations is most appropriate.

7. NIAs should include a qualitative description of how non-acoustical factors associated with both the project and the community may influence noise annoyance of the local community.

8. NIAs should include a quantitative assessment of noise on sleep, including an estimate of the number of people highly sleep disturbed before and after the project, and the change in percent [of people] highly sleep disturbed [by noise] (%HSD).

9. NIAs should include a qualitative assessment of noise on cardiovascular outcomes, cognition in children, mental health outcomes, obesity/diabetes, and birth outcomes. The qualitative assessment should focus on potential effects to sensitive receptor groups, including children.

10. The following mitigation hierarchy should be applied for the consideration of measures to mitigate effects from environmental noise: (1) elimination; (2) control at source; (3) engineering controls at a distance; (4) non-acoustical mitigation; and (5) noise management. NIAs should provide information in all areas.

11. The significance of any health effect of noise should be evaluated following consideration of relevant health-based noise exposure guidelines or benchmarks, the changes in the noise environment, and the context (both land use and sensitive populations). The World Health Organization (WHO) *Guidelines for Community Noise* are currently the best health-based guidelines available.

12. Monitoring of noise levels is an appropriate proxy for monitoring human health outcomes after project completion. Monitoring of noise levels should be conducted for any projects where noise is anticipated to impact human health. A monitoring plan, including protocols for collection and analysis of monitoring data and identification of thresholds for implementation of additional measures, should be part of the NIA process.

13. Complaint monitoring can be used to support community engagement activities, but it should not the focus of a management program.

Appendix 2: Lessons from the literature

The following are lessons and themes identified through review of the literature in each of four different subject areas that are most relevant to noise impact assessment (NIA): (1) health effects of noise; (2) noise assessments; (3) health impact assessment; and (4) environmental impact assessments (EIAs). These lessons and themes from the literature are presented according to each step in the NIA process.

Scoping

There were two major themes applicable to the scoping stage of NIA that were identified following a review of the literature. First, it was noted that the majority (58%) of NIAs in British Columbia (BC) identified and captured and assessed the health effects from noise in some manner. Second, the literature that is available and relevant is focused on scoping noise into NIA. The literature repeatedly speaks to the need for NIAs to consider noise at each phase of the project (construction, operation, etc.), and from each project component (transportation of materials to the site, processing or materials, etc.).

Baseline noise

The literature applicable to baseline noise was very sparse. Only one key theme was identified from the review of environmental impact assessments. Almost half of reviewed NIAs that included baseline information relied on literature-based values. For NIAs that did complete site-specific surveys, sampling times were very short (from 48 h to a maximum one month). Noise has large daily and seasonal variability as a result of natural (e.g. meteorological) and anthropogenic activities (e.g. traffic), and these sampling times are too short to capture seasonal variability in the acoustic environment.

Noise prediction

The lessons and themes from the literature came predominantly from the literature search on NIA. This literature area identified the importance of selecting the right noise propagation model. In particular, the noise model should consider source characteristics (e.g. height, directivity), distance to any nearby people (including ground attenuation), topography (i.e. blocking effects from uneven terrain), and meteorological considerations (e.g. wind speed, temperature). In addition, the selected model should be appropriate for modeling noise from the particular source. International Standards Organization (ISO) 9613-2 is widely used for transportation noise, while specific noise models have been developed for blasting, aircraft noise, wind farms, and others.

Baseline health

The health impact assessment literature spoke to the importance of identifying sensitive populations as part of assessments, although this was raised generally and in relation to other health pathways and not specifically related to noise. The health effects of noise literature identified the particular sensitivity of children to noise with respect to the cognition and learning. Only one reviewed NIA characterized baseline health status in the population surrounding a proposed project, and no assessments discussed the sensitivity of any nearby receptors.

Health effects assessment

There are several themes from all four subject areas that are applicable to the health effects assessment stage of NIA. First, the health effects of noise literature identified many health effects from noise that depend, in part, on the noise source. There is relatively good information about health effects from transportation noise (road traffic, rail and aircraft noise) but limited information about other types of noise (wind farms, blasting, military and other industrial noise).

Second, there is large individual and community variability in the human response to noise. This response depends on both acoustical and non-acoustical factors, which makes it particularly important to identify and assess effects to sensitive population. The need to assess effects to sensitive populations as raised in the health impact assessment literature in general, although it was not raised specifically in relation to noise.

Finally, some reviewed NIAs did not clearly identify whether it was being assessed because of effects to human health, animal health, or other. Many NIAs did not differentiate between noise exposure and health effects from that exposure. These NIAs appeared to rely on noise exposure as a substitute for protection of human health. Among those NIAs that identified and assessed effects to human health, annoyance was used as an assessment end point more than any other health effect. Sleep disturbance was also assessed for one reviewed NIA.

Mitigation

There are two major themes from the literature that are applicable to this step in the NIA process. First, the human response to noise depends on acoustical and non-acoustical factors such as placing project components outside of views. In addition, factors such as economic benefit, perceived control over noise source, and trust in noise authorities can influence annoyance.

Second, there is a heavy reliance on noise management plans as the sole mitigation measures among NIAs in BC. Very few projects identified engineering/design measures to reduce noise

Significance assessment

The concept of the significance of a health effect only exists within impact assessment. For this reason, lessons and themes can only be expected to be found within the health impact assessment and EIA literature areas; however, the health impact assessment literature search was silent on the concept of significance.

The most common approach to evaluations of significance among reviewed NIAs was to compare predicted values with regulatory benchmarks and/or guidelines, with the assumption that regulatory standards and/or guidelines are appropriate proxies for protection of human health. Most reviewed NIAs took on a variation of this approach for the assessment of the health effects of noise - 90% of projects compared predicted noise levels with a benchmark, and defined significance using some comparison of the two. For example, one NIA defined a significance effect as that where a predicted noise level exceeded the guideline by any amount, while another NIA defined a significant effect as that where a predicted noise level exceeded the guideline level by more than 5 dBA.

Another approach was to compare the predicted noise level with ambient/baseline noise levels and evaluated significance based on a comparison of the two. For example, one project defined a significant effect as that where a predicted noise level exceeds ambient by no more than 5 dBA, while another NIA defined a significant effect as that where a predicted noise level exceeded ambient by no more than 10 dBA.

In Canada, there are no national regulatory limits or guidelines for environmental noise. The most widely accepted and relevant health-based guidelines are the World Health Organization (WHO) *Guidelines for Community Noise* (113). While they are the most relevant, they are arguably limited in scope and outdated, so they should be used with caution. Since publication of the WHO *Guidelines for Community Noise* in 1999, there has been substantial research into the health effects of noise. In particular, there is now a better understanding of how noise affects children and how to quantify the relationship between noise and cardiovascular outcomes.

Follow-up and monitoring

There was only one major lesson from review of the literature that applies to this step in the NIA process. Noise management plans are widespread among reviewed NIAs in BC. The majority of reviewed NIAs (55%) identified a noise management plan as the sole mitigation measure for noise, despite the fact that management plans do not necessarily contain plans for mitigation. There were some NIAs that committed to establishing a noise complaint monitoring program as part of the follow-up and monitoring plan, but they did not provide any further discussion on how the information would be used. There was no description of other monitoring activities, or how monitoring information would be used.