



Wind turbine noise perception, pathways and effects: a case study

Carmen ME Krogh^{a)}

Independent, Killaloe, Ontario, Canada, K0J 2A0

Roy D Jeffery^{b)}

Independent, Manitolin Island, Ontario, Canada, P0P 1K0

Jeff Aramini^{c)}

Intelligent Health Solutions, Fergus, Ontario, Canada, N1M 3S9

Brett Horner^{d)}

Independent, Killaloe, Ontario, Canada, K0J 2A0

In Ontario Canada wind turbines are being sited close to humans. Wind turbine noise is perceived to be more annoying than other equally loud sources of sound. This annoyance can contribute to stress related health impacts. An Ontario government commissioned report concludes a nontrivial percentage of exposed persons will be impacted. Our research documents some Ontarians living in the environs of wind turbines report experiencing physiological and psychological symptoms, reduced quality of life, degraded living conditions, and adverse social economic impacts including a loss of social justice. In some cases the effects resulted in families abandoning their homes. Others have negotiated financial agreements with wind energy developers. An Ontario Environmental Tribunal considered a wide body of evidence including expert witness testimony and found that wind turbines can harm humans if placed too close to residents. Peer reviewed literature, case reports, freedom of information documents and expert testimony will be presented which

^{a)} email: krogh@email.toast.net

^{b)} email: jeffery_07@sympatico.ca

^{c)} email: jeff_aramini@ihealthsolutions.net

^{d)} email: brett_horner@toast.net

support the conclusion that noise perception via the indirect pathway can result in serious negative effects.

1 INTRODUCTION

An increasing number of industrial wind turbines are being sited in close proximity to humans. Complaints are not uncommon from individuals exposed to wind turbine sound^{1,2}.

The Wind Turbine Noise (2011) post-conference report states,

“The main effect of daytime wind turbine noise is annoyance. The night time effect is sleep disturbance. These may lead to stress related illness in some people. Work is required in understanding why low levels of wind turbine noise may produce affects which are greater than might be expected from their levels³.”

This paper explores the effects which can result from human perception of wind turbine sound. Reviewed literature, case reports, freedom of information documents and expert testimony are presented which support the conclusion sound that is perceived and considered “unwanted” can result in serious negative effects.

2 WIND TURBINES CAN HARM HUMANS

A 2011 Ontario Environmental Review Tribunal found that wind turbines can harm humans if they are placed too close to residents⁴. In the United States a 2012 board of health resolution made a formal request for “...temporary emergency financial relocation assistance from the State of Wisconsin for those Brown County families that are suffering adverse health effects and undue hardships caused by the irresponsible placement of industrial wind turbines around their homes and property⁵.”

Some individuals living in the environs of wind turbines report experiencing adverse health effects including annoyance and/or sleep disturbance and/or stress related health impacts and/or reduced quality of life^{6,7,8,9,10,11,12,13,14}. In some cases the adverse effects have been severe enough that families have elected to abandon their homes.

Dr. Nina Pierpont documented symptoms reported by individuals exposed to wind turbines to include: sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic episodes associated with sensations of internal pulsation or quivering when awake or asleep¹⁵.

The American Wind Energy Association and Canadian Wind Energy Association sponsored a literature review which determined wind turbine symptoms documented by Dr. Pierpont “... are not new and have been published previously in the context of “annoyance”” and are the “... well-known stress effects of exposure to noise¹⁶ ...”. A coauthor of this literature review stated in a separate analysis: “I am happy to accept these symptoms, as they have been known to me for many years as the symptoms of extreme psychological stress from environmental noise, particularly low frequency noise ... what Pierpont describes is effects of annoyance by noise – a stress effect ... simply the well known effects of persistent, unwanted noise¹⁷ ...”. The contents of these two references were reaffirmed by witnesses testifying under oath during a 2011 Ontario Environmental Review Tribunal¹⁸.

Reports of wind turbine noise induced adverse health effects have been dismissed by some commentators including government authorities and other organizations. It has been suggested

that wind turbine sound pressure levels are not sufficient to cause health effects. This point of view fails to take into consideration that sound has multiple dimensions which can collectively affect human perception. Wind turbines produce sound that routinely exhibits a number of special characteristics which can impact human perception.

2.1 Definitions: Perception, Sound, Noise and Health

Perception can be defined as: "... awareness of one's environment through physical sensation¹⁹ ...". Human perception of sound can result in a number of responses which can be positive (music), negative (noise) or neutral. Presence of sound does not necessarily signify the presence of noise. "Physically, there is no distinction between sound and noise. Sound is a sensory perception and the complex pattern of sound waves is labeled noise, music, speech etc. Noise is thus defined as unwanted sound²⁰." Sound meters can assess sound; however, humans assess "noise". Sound becomes a risk to human health when it is considered to be noise.

The World Health Organization (WHO) definition of health has been accepted by many jurisdictions including the Canadian federal, provincial, and territorial governments and health officials²¹ : "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity²²." The WHO "... recognizes the enjoyment of the highest attainable standard of health as one of the fundamental rights of every human being²³."

2.2 Annoyance: A Serious Risk to Human Health

Annoyance has been defined as "... a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them²⁰..." or "Any sound that is perceived as irritating or a nuisance²⁰...".

Annoyance is acknowledged to be an adverse health effect^{24,25,26,27,28}. For chronically strong annoyance a causal chain exists between the three steps health – strong annoyance – increased morbidity²⁹. Symptoms associated with annoyance from various noise sources include stress, sleep disturbance, headaches, difficulty concentrating, irritability, fatigue, dizziness or vertigo, tinnitus, anxiety, heart ailments, and palpitation^{30,31,32}. Chronic severe annoyance induced by noise must be classified as a serious human health risk³³. Consultant reports prepared for wind energy developers discuss people who subjectively evaluated themselves as disturbed by noise and state, "Regardless of whether the perceived impacts by affected individuals are physiological or psychological in nature, they are a serious matter and are considered as adverse health effects^{64,65}."

2.3 Pathways of Health Effects

Noise induced hearing loss can result from high sound levels via the direct causal pathway. However sound need not be considered loud for it to adversely affect human health. Noise of a moderate level acts via an indirect pathway and can have health outcomes similar to those caused by high noise exposures on the direct pathway²³. Specific health effects in the indirect pathway include interference with communication; sleep disturbance effects; cardiovascular and psychophysiological effects; performance reduction effects; effects on social behaviour and annoyance²⁰.

2.4 Wind Turbine Sound and Perception

Wind turbines produce both mechanical and aerodynamic sound. The Canadian Wind Energy Association states: “Acceptable separation distances for sound are generally 300 to 600 m; at these distances, sound from the wind turbines is similar to a whisper³⁴”. Based on this it would appear reasonable to expect that wind turbine sound would not be easily perceived by humans and/or human response would be relatively neutral. However, studies have consistently documented wind turbine sound to be “...very easily perceived³⁵ ...” and more annoying than transportation noise or industrial noise at comparable sound pressure levels³⁶. Annoyance to wind turbine noise starts at wind turbine dBA sound pressure levels in the low 30’s and rises sharply at 35 dBA^{6,9,36,37}.

A 2006 report by The National Academy of Medicine (France)³⁸ comments that actions taken by private industry involve marketing, using techniques that sometimes lead them to downplay the inconvenience connected with proximity to wind turbines. The report also notes some individuals describe wind turbine noise as piercing, preoccupying, continually surprising because it is irregular in intensity, but also includes grating and incongruous sounds, which distract the attention or disturb rest. The spontaneous recurrence of these noises disturb the sleep, suddenly awakening the subject when the wind rises, or preventing the subject from going back to sleep.

In the United Kingdom subjective analyses describe wind turbine noise as “like a train that never gets there”, “distant helicopter”, “thudding”, “pulsating”, “thumping”, “rhythmical beat”, and “beating”³⁹. These wind turbine noise descriptions do not appear to be consistent with suggestions that sound from wind turbines “is similar to a whisper”.

2.5 Dimensions of Sound

Not all sounds are equal. Regulators and members of industry frequently concentrate on the sound pressure levels of a noise. Sound quality can be as important as quantity when assessing the health impacts of a noise source. “The capacity of a noise to induce annoyance depends upon many of its physical characteristics, including its sound pressure level and spectral characteristics, as well as the variations of these properties over time²⁰.”

The “...unique sound characteristics of wind farm noise and the different influences on the perception of this noise²⁸...” have been noted. Wind turbine sound has a number of special sound characteristics which are identified as plausible causes for reported health effects. These characteristics include amplitude modulation⁴⁰, audible low frequency noise,^{41, 44} infrasound⁴², tonal noise, impulse noise⁴³, and night time noise³⁶.

2.6 Fluctuating Sound is More Difficult to Ignore

Modern upwind wind turbines routinely produce an audible amplitude modulation which can disturb and be stressful. “A time varying sound is more annoying than a steady sound of the same average level and this is accounted for by reducing the permitted level of wind turbine noise⁴⁰.” “From various studies it follows that this modulation is equivalent in annoyance to the un-modulated sound at an approximately 5 dB higher level⁴⁵.”

Wind turbines also produce impulsive sound which can be unexpected and disturbing to residents^{37,43}.

2.7 Sound Need Not be Loud to Cause Harm

Modern wind turbines routinely produce audible and inaudible low frequency noise. For modern wind turbines it is "... beyond any doubt that the low-frequency part of the spectrum plays an important role in the noise at the neighbors⁴¹." In reference to wind turbines The Minnesota Department of Health concluded: "Most available evidence suggests that reported health effects are related to audible low frequency noise⁴⁴."

Annoyance from audible low-frequency noise is acknowledged to be more severe in general²⁰. Low-frequency noise does not need to be considered loud for it to cause annoyance and irritation³¹. Low-frequency noise causes immense suffering to those who are unfortunate to be sensitive to it³⁰ and chronic psychophysiological damage may result from long-term exposure to low-level low-frequency noise⁴⁶.

Wind turbines also produce inaudible low frequency noise and/or infrasound. It has been suggested sound you cannot hear cannot affect you. However, the human body can perceive and respond to sound which is below the hearing threshold. Research indicates "...non-aural physiological and psychological effects may be caused by levels of low frequency noise below the individual hearing threshold³²." It is estimated that sound levels of 60 dBG for frequencies from 5 to 50 Hz can stimulate the outer hair cells of the inner ear and "... it is scientifically possible that infrasound from wind turbines could affect people living nearby⁴²."

"Low-frequency noise may also produce vibrations and rattles as secondary effects²⁰." "People who are exposed to wind turbine noise inside buildings experience a much different acoustic environment than do those outside....They may actually be more disturbed by the noise inside their homes than they would be outside. ... One of the common ways that a person might sense the noise-induced excitation of a house is through structural vibrations. This mode of observation is particularly significant at low frequencies, below the threshold of normal hearing⁴⁷."

Ministry of Environment documents, obtained under a Freedom of Information Request, confirm that some Ontario wind turbines produce low frequency noise which was inaudible outside the home but audible inside and "...quite annoying to the occupants⁵²." Ontario does not have "... measurement procedures or criteria for addressing indoor noise intrusions due to wind turbines⁶¹...". It was proposed that Ontario wind energy developers be required to monitor and address perceptible infrasound (vibration) or low frequency noise⁴⁸. The Canadian Wind Energy Association has lobbied to have the proposed requirement for infrasound or low frequency noise monitoring removed⁴⁹.

2.8 Soundscapes, Masking and Perception

Land-use planning is vital to successful noise management. Modern urban and suburban planning recognizes that industrial parks are the appropriate location for industrial noise. Wind turbines present a rather unique situation where industrial noise is being introduced into predominately natural soundscapes with low ambient sound levels.

The Canadian Wind Energy Association suggests much of wind turbine blade sound "... is masked by the sound of the wind itself and of the accompanying sound of rustling leaves in nearby trees and scrubs⁵⁰." In response to suggestions "... background wind noise will cause some masking of the sound levels from the turbines ..." Health Canada states:

“These statements can be misleading as turbine noise is likely to be audible to the nearest receptors in the form of continuous low-level or intermittent swooshing, as well as low frequencies at approximately 50 Hertz. As such, Health Canada advises the following:

- o Please omit statements about noise masking as they can be misleading; and
- o Please ensure that nearby residents are informed that turbine noises may be audible in terms of a low-level continuous or intermittent swooshing, as well as at low frequencies around 50 Hertz⁵¹.”

Wind turbine sound is very easily perceived³⁵ and is difficult to mask^{6,36}. Human perception of a sound may be reduced if other masking sounds are present. “Masking, however, is a complex process. The human auditory system is uncannily good at separating signals from “background”. ... The rule of thumb that a noise can be considered masked if the signal is 10 dB below the background is only valid if the noises have the same frequency composition and if they actually occur at the same time²³.”

Wind turbine noise guidelines in Ontario permit noise limits of 40 to 51 dBA depending on wind speed. These limits typically are not below ambient sound levels as wind turbines in Ontario are usually sited in quiet rural soundscapes that can have ambient sound levels below 30 dBA⁵². Furthermore: “Wind turbines are generally located in areas devoid of trees and other large vegetation. Instead, ground cover usually consists of grass, sagebrush, plants, and low shrubs⁴⁷ ...”. Ontario is a northern climate with a relatively short growing season consequently much of the surrounding plant life is without foliage for a large percentage of the year.

An Ontarian who was adversely affected by wind turbine noise and who eventually reached a financial agreement with a wind energy developer describes the perception of wind turbine noise:

“... I will never hear natural wind again in our place. ... It doesn't matter if it's very windy out; moderate wind; low wind, it's always that rotating mechanical turbine, overrides the wind ... That's why we live in the country ... to enjoy the quiet and the maple trees ... rustling leaves and now that's all gone and people have to be aware the minute they put these in that's gone. It's gone for good and it will just sound like a great big factory⁶³ ...”

2.9 Wind Turbine Noise Limits

Over the past decade wind turbines have increased in size, electrical power output and the amount of sound they produce³⁷. At the same time wind turbine amplitude modulation and low frequency noise have become an increasingly significant part of the noise impact. “It must be anticipated that the problems with low-frequency noise will increase with even larger turbines⁴¹.”

Wind turbine compliance noise audits are typically based on an averaged “A”-weighted metric which is unsatisfactory for complaints of cyclical amplitude modulation and low frequency noise². Furthermore wind turbine noise guidelines typically do not address the lack of night time abatement.

Psycho acoustic fundamentals present plausible explanation why wind turbine sound is easily perceived and found to be more annoying than transportation and other industrial noises. Setback distances and sound pressure limits should incorporate adjustments for the special sound characteristics of wind turbines. Some wind turbine proponents have lobbied regulators to; increase permitted noise levels for wind turbines, remove requirements to address low frequency noise, avoid penalties for amplitude modulation.

2.10 Wind Turbine Noise, Attitudes and Perception

Non participating neighbors reporting adverse effects from wind turbine noise have been characterized as being unreasonable complainers. In one example, an adversely affected family was reportedly accused of “exaggerating and overreacting⁵³”. Negative attitudes toward wind turbines have been suggested as a cause of noise complaints.

Non-acoustical factors may affect annoyance levels²⁰. Those “...who benefit economically from wind turbines have a significantly decreased risk of annoyance, despite exposure to similar sound levels³⁶.” However, there are a number of confounding factors which need to be considered. For example:

“Respondents that benefit will more usually have control: most or all of them have taken part in the decision to put up the turbines and they can stop them if they want. One respondent remarked that if a turbine close by caused too much noise for him or his neighbour, he stopped the turbine⁹.”

Individuals who benefit economically from wind energy projects typically are granted the opportunity to decide whether or not they wish to be exposed to noise and visual impacts in exchange for financial compensation. The following excerpts from two different Canadian hosting agreements indicate individuals who benefit financially from wind energy projects typically waive their right to complain about noise and other adverse effects:

“... in consideration of the Rent paid by the Lessee to the Lessor. ... the parties hereto covenant and agree ... Lessor grants and transfers to Lessee a non-exclusive License for audio, visual, view, light, flicker, noise, shadow, vibration, air turbulence, wake, electromagnetic, electrical and radio interference, and any other effects attributable to the Wind Power Facilities or activity located on the Leased Lands or on adjacent properties (“Effect License”)⁵⁵.”

“The Rent, in respect of the Specified Locations...represent compensation in full for...nuisance, noise, signal interference,..., casting of shadows and other inconveniences or damage...incurred by Lessor from the acts or omissions of Lessee⁵⁶.”

Negative effects are not limited to the property of those hosting wind turbines. Noise and other burdens of wind energy can cross property lines. At one Ontario wind project where there were noise complaints a number of homes were purchased from non participating residents by the wind energy developer and eventually resold for substantially lower prices⁵⁷. Disclosure by the wind energy developer to prospective purchasers states the operation of the wind turbine facilities

“...may affect the living environment of the Transferor and that the transferee will not be responsible or liable for, of and from any of the Transferor's complaints, claims, demands, suits, actions or causes of action of every kind known or unknown which may arise directly or indirectly from the Transferee's wind turbine facilities on the Leasehold Lands to the extent permitted by this Easement.”

The same disclosure also secures:

“... the right and privilege to permit heat, sound, vibration, shadow flickering of light, noise (including grey noise) or any other adverse effect or combination thereof resulting directly or indirectly from the operation of the Transferee's wind turbine facilities.”

It has also been stated: “Annoyance was strongly correlated with a negative attitude toward the visual impact of wind turbines on the landscape³⁶.” Once again confounding factors need to be considered.

Wind turbines can have noise and visual burdens⁴⁴. Visual burdens of wind turbines can include shadow flicker, light flicker and blade glint which can disturb residents and contribute to annoyance and stress. Furthermore:

“A free sight from the dwelling to one or more of the wind turbines also gives free way for the sound. In these cases the immission levels at the dwelling of the respondent were in accordance with the calculated levels, and not less due to hindrance of the sound propagation. When the sight of the wind farm is blocked, than the sound may be (partly) blocked too, leading to lower sound levels. This may explain the lower levels of annoyance. However, the enhanced probability for annoyance if the wind turbines were visible could also be due to a multimodal effect; the rotating blades of a wind turbine attracting the sight could increase the awareness of the sound and hence also the possibility of noise annoyance⁹.”

Researchers comment that attitudes towards wind turbines were initially positive and communities welcomed wind energy project for their perceived economic¹⁰ and/or environmental¹³ benefits. “The reported adverse impacts were unexpected¹².”

The following passage from one adversely affected individual in the United Kingdom describes their attitude towards wind turbines:

“Writing as someone who used to live 1km from a windfarm, and whose career has been involved in some way or other with public health. I make the following observations. We welcomed the wind farm, why would [*sic we*] not? We could not see the turbines from our home. We thought them to be admirable structures, a significant engineering achievement, and graceful in operation. We were completely and wholly unprepared for the noise and sleep deprivation that we immediately suffered from. None of my family have had problems sleeping before, but we did then, and being suddenly awoken in the early hours and being unable to get back to sleep night after night is very unpleasant, and rapidly makes normal day to day living almost impossible. It is well documented, and within the public domain that we tried (as other respondents have suggested) ear plugs, white noise machines, fans and medication. Nothing worked. Once we stopped sleeping at home, we were able to sleep normally again. We can sleep next to motorways, industrial sites, [*sic train*] stations and airports – but this was something else altogether. You do not habituate to it⁵⁴.”

Another adversely affected individual from Ontario, Canada describes their attitudes towards wind turbines

“What I thought was they were going to be good for the environment, for the province, and Canada and the whole world really. ... I really didn't think they would be an issue. I just absolutely didn't and we had no cause for concern. ... I thought it was a good thing. The

neighbours hosting the turbines are awesome people I have absolutely no problem with them. I probably would have signed up for one too if I had the land mass⁵⁸.”

In both the above cases the affected individuals did not benefit economically yet they had positive attitudes towards wind energy and/or the visual impact of wind turbines. The families in both cases were adversely affected by the noise and both pursued legal avenues to resolve the issues. In both cases the families settled out of court with the respective wind energy developer. Both these agreements are reported to contain non disclosure agreements which prevent the parties from discussing specific details.

A number of wind turbine nuisance cases have been settled out of court with non disclosure agreements¹². Non disclosure agreements hinder opportunities to further understand what exactly the problem was and how to prevent it in the future.

2.11 Wind Turbines in Ontario and Expected Health Impacts

The introduction of wind turbines into Ontario, Canada is a relatively recent development. Ontario Ministry of Environment guidelines are based on an averaged “A”-weighted metric and permit noise of 40 dBA up to 51 dBA (formerly 53 dBA) depending on wind speed. Noise limits are measured at the façade of a receptor (i.e. home). Ontario does not have limits for wind turbine noise inside homes or elsewhere on private property. Until 2011 the Ontario Ministry of Environment did not have a scientifically accepted field methodology to measure wind turbine noise to determine compliance or non compliance with approval limits⁵⁹. In August 2011 the Ontario Ministry of Environment introduced a “Compliance Protocol for Wind Turbine Noise” which explicitly excludes consideration of “health effects”.

Ontario noise guidelines require a 5 dBA adjustment for other industrial noise that has amplitude modulation but not for wind turbines.⁶⁰

Sound studies commissioned by wind energy developers or community members, and investigations by Ontario Ministry of Environment personnel have been conducted at various sites in Ontario. Assessments at some Ontario projects have documented the wind turbine sound was tonal, contained low frequency components, and routinely produced an audible amplitude modulation.

Internal Ontario Ministry of Environment correspondence, obtained through a Freedom of Information Request, states “It appears compliance with the minimum setbacks and the noise study approach currently being used to approve the siting of WTGs will result or likely result in adverse effects⁵² ...”. In 2011 the Ontario Ministry of Environment released a consultant report which concludes the sound from wind turbines, at the levels experienced at typical receptor distances in Ontario, is “... expected to result in a nontrivial percentage of persons being highly annoyed ... research has shown that annoyance associated with sound from wind turbines can be expected to contribute to stress related health impacts in some persons⁶¹.”

There have been numerous noise and health complaints coinciding with the commencement of operations of some Ontario wind turbine projects. In response to the lack of vigilance monitoring in Ontario, volunteers established WindVOiCe in March 2009. WindVOiCe is a self reporting health survey which follows the principles of Health Canada’s Canada Vigilance Programs for reporting adverse events for prescription and nonprescription products, vaccines and other¹¹.

3 RESULTS

Reduced quality of life, sleeplessness and headaches are among the most common effects reported in other case studies⁴⁴. The most common effects reported in the WindVOiCe survey included altered quality of life, sleep disturbance, excessive tiredness, headaches, stress and distress. The predicted probability of health effects diminishes with increased separation distance between the wind turbine and the participant's property. Nissenbaum et al.¹⁰ also documented a reduction of sleep effects as wind turbine separation distances increased. These "effect versus distance relationships" are consistent with the physics of sound decay through absorption by ground and the atmosphere.

WindVOiCe catalogued other effects including migraines, hearing problems, tinnitus, heart palpitations, anxiety, and depression. WindVOiCe also collected comments which included participant descriptions of their perception of wind turbine noise and visual impacts such as shadow flicker. These comments provide insight into effects that unwanted sound as perceived by humans can have on individuals. One survey participant comments:

"The noise of the turbines is what bothers me. On a windy day, they can sound like a jet is coming right at you. They are much louder than we were led to believe they could be. In the summer when we have the windows open we have to sleep with the fans running to drownout the constant pulse of the windmills. In the winter, when it is windy, you can still hear & sometimes feel the pulsing of the windmills right through the walls⁶²."

A number of WindVOiCe participants comment the existing soundscape has been negatively altered by the wind turbine noise. Some report wind turbine noise is disturbing both outdoors and indoors. Intrusive, pulsating, swooshing, and humming are terms used to describe the noise.

Some of the adverse effects described by WindVOiCe participants include physiological and psychological symptoms, loss of enjoyment of property, and economic impacts. Some WindVOiCe participants also reported they are considering or have made significant alterations to their lifestyle including moving away.

"Ministry of Environment correspondence ... describes how low frequency noise from Ontario IWT facilities resulted in annoyance, "sleep deprivation" and "uninhabitable" living conditions⁶⁰." "To escape the noise, some report resorting to sleeping in vehicles, tents, trailers, basements lined with mattresses, garages, and at relatives or friends' homes¹²."

To protect their health some Ontario home owners reporting adverse health effects due to wind turbines have elected to sell their home. In a number of cases adversely affected Ontarians have retained legal counsel and eventually negotiated financial agreements with the wind energy developer.

4 DISCUSSION AND CONCLUSIONS

The references presented in this paper support the conclusion that noise perception via the indirect pathway can result in serious negative effects. Health is one of the fundamental rights of every human being and includes complete physical, mental and social well-being. Noise is perceived sound which is evaluated to be "unwanted". Noise does not need to be considered loud for it to adversely affect human health. Noise can result in annoyance, sleep disturbance, stress related health impacts, reduced quality of life, degraded living conditions, and adverse social economic impacts. These effects can be psychologically mediated via the indirect pathway and can represent serious harm to human health.

Those responsible for the production and regulation of noise need to understand the risk to human health and adopt strategies to prevent harm. Psycho-acoustical impacts of the noise source must be assessed in context to the soundscape being affected. Noise limits should be based on the physical characteristics of the specific sound source. Sound pressure level, spectral characteristics, as well as the variations of these properties over time should be assessed when determining the capacity of a noise to induce health effects.

5 ACKNOWLEDGEMENTS

The author(s) received no financial support for the research, authorship, and/or publication of this paper.

6 REFERENCES

1. Hanning, C., & Evans, A., ‘Wind Turbine Noise’, *British Medical Journal*, BM J2012;344:e1527, (2012)
2. Richarz, W., Richarz, H., & Gambino T., *Correlating Very Low Frequency Sound Pulse To Audible Wind Turbine Sound*, Paper presented at the Fourth International Meeting on Wind Turbine Noise, Rome, Italy, (2011, April 12-14)
3. *Wind Turbine Noise Post Conference Report*, (2011)
Retrieved from
http://www.confweb.org/wtn2011/index.php?option=com_content&view=article&id=70:report&catid=35:information
4. *Erickson v. Director, Ministry of the Environment, Environmental Decision Case Nos. 10-121 and 10-122*, (2011, July) Retrieved from
<http://www.ert.gov.on.ca/english/decisions/index.htm>
5. Brown County Board of Health, *Resolution Requesting Emergency State Aid for Families Suffering Around Industrial Wind Turbines*, Brown County, Wisconsin, (2012, January)
6. Pedersen, E., & Persson Waye, K., “Perception and Annoyance Due To Wind Turbine Noise—A Dose Response Relationship”, *Journal of the Acoustical Society of America*, **116**, 3460-3470. (2004)
7. Harry, A., *Wind Turbines, Noise and Health*, (2007, February) Retrieved from
<http://www.wind-watch.org/documents/windturbines-noise-and-health/>
8. Phipps, R., Amati, M., McCoard, S., & Fisher, R. *Visual And Noise Effects Reported By Residents Living Close To Manawatu Wind Farms: Preliminary Survey Results*, (2007) Retrieved from <http://www.wind-watch.org/documents/visual-and-noise-effects-reported-by-residents-living-close-to-manawatu-wind-farms-preliminarysurvey-results/>
9. van den Berg, F., Pedersen, E., Bouma, J., & Bakker, R., *Project WINDFARM Perception: Visual And Acoustic Impact Of Wind Turbine Farms On Residents (Final Report FP6-2005-*

Science-and-Society-20, Specific Support Action, Project no. 044628), Groningen, Netherlands: University of Groningen and the University of Gothenburg, (2008)

10. Nissenbaum, M, Aramini J, Hanning C., *Adverse Health Effects Of Industrial Wind Turbines: A Preliminary Report*, 10th International Congress on Noise as a Public Health Problem (ICBEN) 2011, London, UK. (2011, July) Retrieved from <http://www.windvigilance.com/about-adverse-health-effects/resource-centre>
11. Krogh, C., Gillis, L., Kouwen, N., & Aramini, J., “WindVOiCe, A Self-Reporting Survey: Adverse Health Effects, Industrial Wind Turbines, and the Need For Vigilance Monitoring” *Bulletin of Science Technology & Society*, **31**, 334-345, (2011)
12. Krogh, C., “Industrial Wind Turbine Development and Loss of Social Justice?” *Bulletin of Science Technology & Society*, **31**, 321-333, (2011)
13. Shepherd D, McBride D, Welch D, Dirks KN, Hill EM, Evaluating the Impact of Wind Turbine Noise on Health-Related Quality Of Life. *Noise Health* **13**:333-9.(2011)
14. Rand R., Ambrose S., Krogh C., Occupational Health and Industrial Wind Turbines: A Case Study, *Bulletin of Science Technology & Society*, **31**: 359,(2011)
15. Pierpont, N., *Wind Turbine Syndrome: A Report on a Natural Experiment*, Santa Fe, NM: K-Selected Books, (2009)
16. Colby, W. D., Dobie, R., Leventhall, G., Lipscomb, D. M., McCunney, R. J., Seilo, M. T., & Søndergaard, B., *Wind Turbine Sound and Health Effects: An Expert Panel Review*, Washington, DC: American Wind Energy Association and Canadian Wind Energy Association. (2009)
Retrieved from http://www.canwea.ca/pdf/talkwind/Wind_Turbine_Sound_and_Health_Effects.pdf
17. Leventhall, H. G., *Wind Turbine Syndrome: An Appraisal*. Testimony before the Public Service Commission of Wisconsin (PSC Ref#121877 20), (2009, October)
18. Erickson v. Director, Ministry of the Environment, Environmental Review Tribunal, Case Nos. 10-121 and 10-122, (Official Transcripts) Appeal of Renewable Energy Approval, Kent Breeze Corp. and MacLeod Windmill Project Inc. (Kent Breeze Wind Farms) c/o Suncor Energy Services Inc.
19. Webster’s New American Dictionary (1995)
20. Berglund, B., Lindvall, T., & Schwela, D. H., *Guidelines for Community Noise*, Geneva, Switzerland: World Health Organization, (1999)
21. Health Canada, *Canadian Handbook on Health Impact Assessment: Vol.1. The Basics. A Report Of The Federal/Provincial/Territorial Committee On Environmental And Occupational Health*, (2004)
Retrieved from <http://www.who.int/hia/tools/toolkit/whohia063/en/index>

22. World Health Organization, *Preamble To The Constitution Of The World Health Organization As Adopted By The International Health Conference, New York, 19-22 June, 1946; Signed On 22 July 1946 By The Representatives Of 61 States, (Official records of the World Health Organization, no. 2, p. 100)*, (1948, April 7)
23. World Health Organization, *Night Noise Guidelines For Europe*, (2009)
24. Health Canada, Community Noise Annoyance, *Its Your Health*, (2005, September)
25. Michaud, D. S., Keith, S. E., & McMurchy, D., “Noise Annoyance in Canada”, *Noise Health*, **7**, 39-47. (2005)
26. Pedersen, E., & Persson Waye, K., “Wind Turbine Noise, Annoyance and Self-Reported Health and Well Being in Different Living Environments”, *Occupational and Environmental Medicine*, **64**, 480-486, (2007) doi:10.1136/oem.2006.031039
27. Suter, A. H., *Noise and Its Effects*, Washington, DC: Administrative Conference of the United States, (1991) Retrieved from <http://www.nonoise.org/library/suter/suter.htm>
28. New South Wales. Parliament. Legislative Council. General Purpose Standing Committee No. 5, *Rural Wind Farms* (2009, December)
29. Niemann Dr Hildegard, Maschke Dr Christian, *LARES Final Report Noise Effects and Morbidity*, World Health Organization, (2004)
30. Leventhall, G. (with Pelmear, P., & Benton, S.), *A Review Of Published Research On Low Frequency Noise And Its Effects*, (2003)
Retrieved from <http://westminsterresearch.wmin.ac.uk/4141/>
31. DeGagne, D. C., & Lapka, S. D., “Incorporating Low Frequency Noise Legislation for the Energy Industry in Alberta, Canada”, *Journal of Low Frequency Noise, Vibration and Active Control*, **27**,105-120, (2008)
32. Schust, M., “Effects Of Low Frequency Noise Up To 100 Hz”, *Noise Health*, **6**, 73-85, (2004)
33. Maschke, C., & Niemann, A., “Health Effects Of Annoyance Induced By Neighbour Noise”, *Noise Control Engineering Journal*, **55**, 348-356, (2007)
34. The Canadian Wind Energy Association, *Responding to Concerns about Wind Energy*, (2009, January)
35. Pedersen, E., van den Berg, F., Bakker, R., Bouma, J., “Can Road Traffic Mask Sound from Wind Turbines? Response To Wind Turbine Sound At Different Levels Of Road Traffic Sound”, *Energy Policy*, **38**, 2520–2527, (2010)

36. Pedersen, E., Bakker, R., Bouma, J., & van den Berg, F., "Response To Noise From Modern Wind Farms In The Netherlands", *Journal of the Acoustical Society of America*, **126**, 634-643, (2009)
37. Shepherd D., Billington R., "Mitigating the Acoustic Impacts of Modern Technologies: Acoustic, Health, and Psychosocial Factors Informing Wind Farm Placement", *Bulletin of Science Technology & Society*, **31**: 389, (2011)
38. Chouard, C. H., *Le Retentissement Du Fonctionnement Des Éoliennes Sur La Santé De L'homme*, Académie Nationale De Médecine, (2006) (Unofficial translation from French reference)
39. Moorhouse, A., von Hünerbein, M.H., S., Piper, B., Adams, M., *Research into Aerodynamic Modulation of Wind Turbine Noise: Final Report*. Report by: University of Salford, Prepared for UK Department for Business Enterprise and Regulatory Reform (2007)
40. Leventhall, G., "Infrasound from Wind Turbines: Fact, Fiction or Deception", *Canadian Acoustics*, **34**, 29-36, (2006)
41. Møller, H., & Pedersen, C. S., "Low-Frequency Noise from Large Wind Turbines", *Journal of the Acoustical Society of America*, **129**, 3727-3744, (2011)
42. Salt, AN, and Kaltenbach, JA, "Infrasound From Wind Turbines Could Affect Humans", *Bulletin of Science Technology & Society*, **31**: 296, (2011)
43. Thorne, B. "The Problems With Noise Numbers For Wind Farm Noise Assessment" *Bulletin of Science, Technology & Society*, **31**, 262-290, (2011)
44. Minnesota Department of Health, *Public Health Impacts Of Wind Turbines*, (2009, May)
45. Pedersen, Eja, van den Berg, Frits, *Why Is Wind Turbine Noise Poorly Masked by Road Traffic Noise?* Inter Noise 2010, June 13-16, (2010)
46. Leventhall HG., "Low Frequency Noise And Annoyance", *Noise Health*; **6**:59-72, (2004)
47. Hubbard H. H., Sheppard K. P., *Wind Turbine Acoustics*, NASA Technical Paper 3057, DOE/ NASA/20320-77, (1990)
48. The Ontario Ministry of Environment, *Proposed Content for the Renewable Energy Approval Regulation under the Environmental Protection Act*, (2009, June 9)
49. The Canadian Wind Energy Association, *Environmental Bill of Rights Posting 010-6516 (Proposed Ministry of the Environment Regulations to Implement the Green Energy and Green Economy Act. 2009) – CanWEA's Supplemental Submission, EBR Comment ID 123788 EBR Signed Robert Hornung President*, (2009, July 24)
50. The Canadian Wind Energy Association, *The Sights and Sounds of Wind*, Fact Sheet, Retrieved from

http://www.canwea.ca/images/uploads/File/NRCan_-_Fact_Sheets/7_visual_sound.pdf

51. Health Canada, *Correspondence*, Safe Environments Program. Regions and Programs Branch, Health Canada, (2009, August 6) Retrieved from www.windvigilance.com
52. Ontario Ministry of Environment, *Internal Correspondence*, Obtained through Freedom to Information request, (2011)
53. *Couple Settle With Wind Farm Operators Over 'Unbearable Hum'*, *The Telegraph*, (2011, November 30)
Retrieved from <http://www.telegraph.co.uk/earth/environment/8925467/Couple-settle-with-wind-farm-operators-over-unbearable-hum.html>
54. Davis, Sarah Jane, "Wind Turbine Noise", *Posted comment British Medical Journal*, Retrieved from <http://www.bmj.com/content/344/bmj.e1527/rr/580518>
55. "Schedule "B", Lease Agreement for Wind Power, Canada
56. *Surface Lease for Wind Power Project*, Canada
57. Lansink Appraisals and Consulting, *Analyses of Purchases / Sales by Wind Turbine Controlled Corporations, Diminution in Land Value Injurious Affection*, (2012, January)
58. *Wind Turbines*, The Current CBC Radio One, (2009, April 14) Retrieved from <http://www.cbc.ca/thecurrent/episode/2009/04/14/april-14-2009/>
59. Ontario Ministry of Environment, *Correspondence ENV1283MC2009-4305*, (September 30, 2009)
60. Horner B, Jeffery R., Krogh C., "Literature Reviews On Wind Turbines And Health : Are They Enough?", *Bulletin of Science Technology & Society* **31**: 399, (2011)
61. Howe Gastmeier Chapnik Limited, *Low Frequency Noise and Infrasound Associated With Wind Turbine Generator Systems: A Literature Review*, (2010, December 10)
62. Krogh, C., Gillis, L., & Kouwen, N., *WindVOiCe, Wind Vigilance for Ontario Communities, "A Self-reporting Survey of Adverse Health Effects Associated with Industrial Wind Turbines: The Need for Vigilance*, (2011, March) Retrieved from http://www.windvigilance.com/windvoice_home/download-a-copy-of-windvoice-results
63. Personal Interview (2009), Retrieved from <http://www.wind-watch.org/video-melancthon-amaranth.php>
64. Jacques Whitford Stantec Limited, *Byran Wind Project Environmental Review Report, Prepared for SkyPower Corp.*, (2009, August 25)
65. Stantec Consulting Ltd., *Ostrander Point Wind Energy Design and Operations Report, Prepared for: Gilead Power Corporation*, (2010, September)