

# Health Effects and Wind Turbines: A Review for Renewable Energy Approval (REA) Applications submitted Under Ontario Regulation 359/09



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May, 2011

### EXECUTIVE SUMMARY

Wind power has been identified as a clean renewable energy source that does not contribute to global warming and is without known emissions or harmful wastes. Although wind power has been harnessed as a source of power for several decades around the world, debate is ongoing with respect to the relationship between reported health effects and wind turbines, specifically in terms of audible and inaudible noise. People interested in this debate turn to two sources of information in order to make informed decisions: scientific peer-reviewed studies published in scientific journals and the popular literature and internet. The purpose of this report is to provide results of a review of the peer-reviewed scientific literature, government (medical) agency reports on wind turbine health effects, and the most prominent information found in the popular literature. We found that conclusions of the peer reviewed literature differ in some ways from the conclusions of the studies published in the popular literature. In the peer reviewed studies, wind turbine annoyance has been statistically associated with wind turbine noise, but found to be more strongly related to subjective factors like visual impact, attitude to wind turbines in general and sensitivity to noise. To date, no peer reviewed scientific journal articles have identified a causal link between people living in proximity to modern wind turbines, the noise (audible, low frequency noise, or infrasound) they emit and resulting physiological health effects. In the popular literature, self-reported health outcomes are related to distance from turbines and the claim is made that infrasound is the causative factor for the reported effects, even though sound pressure levels are not measured. What both types of studies have in common is the conclusion that wind turbines can be a source of annoyance for some people. The literature suggests that annoyance-related effects can be managed and mitigated through behavioural and cognitive behavioural interventions.



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## 1 INTRODUCTION

Wind power has been identified as a clean renewable energy source that does not contribute to global warming and is without known emissions or harmful wastes (WHO, 2004). Studies on public attitudes in Europe and Canada show strong support for the implementation of wind power (Devine-Wright, 2005). Indeed, wind power has become an integrated part of provincial energy strategies across Canada. In Ontario, the Ontario Power Authority has placed a great deal of emphasis on procuring what they term “renewable and cleaner sources of electricity”, such as wind (OPA, 2008).

Although wind has been harnessed as a source of electricity for several decades around the world, its widespread use as a significant source of energy in Ontario is relatively recent. As with the introduction of any new technology, concerns have been raised that it could lead to impacts on human health. These concerns are related to two primary issues: wind turbine design (i.e., electromagnetic frequencies from transmission lines, shadow flicker from rotor blades, ice throw from rotor blades and structural failure) and wind turbine noise (i.e., levels of audible noise, low frequency noise and infrasound). If left unchecked and unmanaged, it is possible that individually or cumulatively, these concerns could lead to potential health impacts. For example, high sound pressure levels (loudness) of audible noise (including low frequency) and infrasound have been associated with learning, sleep and cognitive disruptions as well as stress and anxiety (Leventhall, 2003; Kristiansen et al., 2009; Yuan et al., 2009; WHO Europe, 2009). Ice throw and structural failure could lead to physical injuries.

As a result of these issues, minimum setback distances have been established world-wide to reduce or avoid potential effects for people living in proximity to wind turbines. For example, under the Ontario Renewable Energy Approval (REA) Regulation (O. Reg. 359/09, as amended by O. Reg. 521/10), a minimum setback distance of 550 m must exist between the centre of the base of the wind turbine and the nearest noise receptor. This minimum setback distance was developed through noise modeling under worst-case conditions to give a conservative estimate of the required distance to attain a sound level of 40dB(A) (MOE, 2009). The World Health Organization (WHO) Europe Region has stated that 40 dB(A) corresponds to the sound from a quiet street in a residential area (WHO, 2009). Globally, rural residential noise limits are generally set at 35 to 55 dB(A) (Walsh, 2010). In addition, the industry has changed to minimize structural issues: for example, modern turbines are geared to sense blade imbalances due to ice build-up and will shut turbines down to prevent ice throw, and turbines have braking mechanisms to stop in the event of a short-circuit or when wind speeds are too high.

Regardless, some people and organizations have expressed concern about the potential of wind turbine projects to adversely affect the health of residents living nearby. Groups such as the Alliance to Protect Prince Edward County, Wind Concerns Ontario and The Society of Wind Vigilance play an important role throughout the planning and development of wind farms. Such organizations unite those with common concerns and speak as one voice to ensure that their concerns are heard by the general public, regulators and wind energy developers. In fact, The Society of Wind Vigilance sponsored the “First International Symposium-The Global Wind Industry and Adverse Health Effects: Loss of Social Justice?” in Picton, Ontario from October 29-31, 2010. Proceedings are available at [http://www.windvigilance.com/symp\\_2010\\_proceedings.aspx](http://www.windvigilance.com/symp_2010_proceedings.aspx). Numerous websites have been constructed by individuals or groups to support or oppose the development of wind farms. Often these websites state the perceived impacts on, or benefits to, human health to support the position(s) of the individual or group. The majority of information posted on these websites cannot, unfortunately, be traced back to a scientific, peer-reviewed source and is typically anecdotal in nature. In

some cases, the information contained on and propagated by internet websites and the media is not supported, or is even refuted, by scientific research. This serves to spread misconceptions about the potential impacts of wind energy on human health, which either fuels or diminishes opposition to wind farm development. In other cases, the information posted points to data gaps in the scientific literature that should be filled. Therefore it is difficult for the general public to ascertain which claims, from both sides of the issue can be substantiated by scientific evidence, are refuted by scientific evidence; and/or have no scientific evidence to either support or refute.

The purpose of this evaluation of potential health effects is not an attempt to discount the self-reported health issues of residents living near wind turbines. Rather, the purpose of this report is to provide results of a review of the peer-reviewed scientific literature, review of government (medical) agency reports on wind turbine health effects that can be used to draw conclusions about wind turbines and health effects using a weight-of-evidence approach.

## 2 POTENTIAL EFFECTS (NOISE, ANNOYANCE, EPILEPSY)

### 2.1 Peer-Reviewed Literature

Publication of scientific findings is the basis of scientific discourse, communication and debate. The peer review process is considered a fundamental tenet of quality control in scientific publishing. Once a research paper has been submitted to a journal for publication it is reviewed by external independent expert(s) in the field. The expert(s) review the validity, reliability and importance of the results and recommends that the manuscript be accepted, revised or rejected. This process ensures that the methods employed and the findings of the research receive a high level of scrutiny, such that an independent researcher could repeat the experiment or calculation of results, prior to their publication. This process seeks to ensure that the published research is of a high standard of quality, accurate, can be reproduced and demonstrates academic / professional integrity.

In order to assess peer-reviewed studies designed to test hypotheses about the association between potential health effects in humans and wind turbines, a review of the primary scientific literature was conducted. While this review did not strictly follow the evaluation process outlined in the “Cochrane Handbook for Systematic Reviews of Interventions, the standard for conducting information reviews in healthcare and pharmaceutical industries” (Higgins and Green, 2009), it was conducted in the spirit of the Cochrane systematic review, in that it was designed based on the principle that “science is cumulative”, and by considering all available evidence, decisions can be made that reflect the best science available.

To facilitate this review, combinations of key words (Table 1) were selected and entered into the Thomson Reuters (formerly ISI) Web of Knowledge<sup>SM</sup>. The Web of Knowledge<sup>SM</sup> is a database that covers over 10,000 high-impact journals (i.e., a measure of the number of times an article in a journal has been cited in a given period) in the sciences, social sciences, and arts and humanities, as well as international proceedings coverage for over 120,000 conferences. The Web of Knowledge<sup>SM</sup> comprises seven citation databases, two of which are relevant to the search: the Science Citation Index Expanded (SCI-Expanded) and the Social Sciences Citation Index (SSCI). The SCI-Expanded includes over 6,650 major journals across 150 scientific disciplines and includes all cited references captured from indexed articles. Coverage of the literature spans the year 1900 to the present. On average, 19,000 new records per week are added to the SCI-Expanded.

SSCI is a multidisciplinary index of the social sciences literature. SSCI includes over 1,950 journals across 50 social sciences disciplines from the year 1956 to the present. It averages 2,900 new records per week.

**Table 1: Key Words Selected for Primary Literature Database Search**

Annoyance	Noise
Environmental change	Sleep disturbance
Epilepsy	Stress
Health effect(s)	Wind farm(s)
Infrasound	Wind turbine(s)
Low frequency noise	Wind turbine syndrome
Neighborhood change	

Although hundreds of articles were found during the search, very few were related to the association between potential health effects and wind turbines. For example, numerous articles have been published about infrasound, but very few have been published about infrasound and wind turbines. Indeed, only fifteen articles, published between 2003 and 2011, were found relevant and are summarized below. These summaries may contain excerpts taken directly from the articles.

**van den Berg, G.P. 2003. Effects of the wind profile at night on wind turbine sound. *Journal of Sound and Vibration* 277:955–970**

In 2003 van den Berg published the results of a study designed to assess sound immission (noise affecting people opposed to emission which is noise from the turbine itself) from a 30MW, 17-turbine wind park (in Germany) at two locations (Location A: 400m from closest turbine; Location B: 1500 m from closest turbine) in neighboring residential areas in Holland. The study was conducted because residents living 500m or more from the park reacted strongly to the noise and residents up to 1900 m from the park expressed annoyance, especially during night-time periods. The sound was described as “a low pitched thumping sound with a repetition rate of about once a second (coinciding with the frequency of blades passing a turbine mast), not unlike distant pile driving, superimposed on a constant broadband ‘noisy’ sound”.

Between May 13 and June 22, 2002, sound immission measurements were made over 1435 hours, of which 417 hours were at night, within four months at two consecutive locations. Briefly, sound was measured with a type 1 sound level meter with a microphone 4.5 m above the ground and protected by a foam wind shield. Wind speed was measured at 2 and 10 m above the ground. Every second, wind speed and wind direction and A-weighted sound level was measured. At Location A, van den Berg found that wind turbine sound was the dominant sound in the environment 25% of the time and predominantly at night (72% of all 105 measurement hours) compared to during daytime (4% of 191 measurement hours). At location B, the turbine sound remained dominant for over one-third of the time at night (38% of 312 measurement hours). At Location A, the 5 minute equivalent immission sound levels (Leq5 min) ranged from roughly 25 dB(A) at a wind speed (at 10 m above ground) of 0 m/s to between roughly 35 and 50 dB(A) at a wind speed of between 4 and 6 m/s. At a wind speed of 8 m/s, Leq5 min was between 40 and 45 dB(A). At Location B, Leq5 min ranged from 20 to 35 dB(A) at a wind speed of 1 m/s, roughly 23 to 37 dB(A) between wind speeds of 4 and 6 m/s and between 27 and 33 dB(A) at speeds above 6 m/s.

Wind speed at hub height at night was found to be up to 2.6 times greater than predicted by the turbine operator possibly because noise modeling took surface roughness into account but not atmospheric stability, which varied between day and night. This caused a higher rotational speed of the wind turbines and

consequentially up to 15 dB(A) higher sound levels, relative to the same wind speed in daytime. The change in wind profile at night also resulted in lower ambient background levels than expected: at night the wind speed near the ground may be lower than expected from the speed at a height of 10m and a logarithmic wind profile, resulting in low levels of wind induced sound from vegetation.

The contrast between wind turbine and ambient sound levels was therefore more pronounced at night. At night the turbines caused a low pitched thumping sound superimposed on a broadband 'noisy' sound, the 'thumps' occurring at the rate at which blades pass a turbine tower. It appears that the characteristic, but usually small 'swishing' pulses that can be heard at the rate at which blades pass a turbine tower, coincide because turbines operate nearly synchronously. van den Berg concluded that the number and severity of noise complaints near the wind park were in part explained by the study findings: actual sound levels were considerably higher than predicted by the operator and wind turbines produced sound with an impulsive character.

**Pedersen, E. and K. Persson Waye. 2004. Perception and annoyance due to wind turbine noise – a dose–response relationship. *Journal of the Acoustical Society of America* 116:3460-3470**

In 2004 Pedersen and Persson Waye published the findings of their cross-sectional study performed in Sweden in 2000. The purpose of the study was to: evaluate the prevalence of annoyance due to wind turbine noise, to assess any dose–response relationships, and to determine if any interrelationships existed between noise annoyance and sound characteristics, as well as the influence of subjective variables such as attitude and noise sensitivity. Pedersen and Persson Waye delivered questionnaires to 627 households in five areas comprising 16 wind turbines. One week later questionnaires were collected: the response rate was 68.4% (n=351). For the participating households, A-weighted (dB(A)) sound pressure levels due to wind turbines were calculated using the sound propagation model for wind power plants adopted by the Swedish Environmental Protection Agency and verified by field measurements.

The questionnaire was divided into four sections. Briefly, the first had questions regarding housing and satisfaction with the living environment, including questions about degree of annoyance experienced outdoors and indoors and sensitivity to environmental factors. The second section had questions about wind turbines (noise, shadows, and disturbances), respondents' level of perception and annoyance, and verbal descriptors of sound and perceptual characteristics. The third section had questions about chronic health (e.g., diabetes, tinnitus, cardiovascular diseases), general well-being (e.g., headache, undue tiredness feeling tensed/stressed, irritable) and normal sleep habits (e.g., quality of sleep, whether or not sleep was disturbed by any noise source). The last section comprised questions on employment and working hours. Of import, the purpose of the study was masked in the questionnaire.

People assessed in the study fell into six sound categories: those living in areas of sound pressure levels <30.0, 30.0-32.5, 32.5-35.0, 35.0-37.5, 37.5-40.0, and >40.0 dB(A). Percent respondents in each category were similar and ranged from 60% (<30.0 dB(A)) to 78% (>40 dB(A)). Results of the study revealed that the proportion of respondents who noticed noise from wind turbines outdoors increased sharply from 39% (n=27) at sound category 30.0–32.5 dB(A) to 85% (n=53) at sound category 35.0–37.5 dB(A). The proportion of those annoyed by wind turbine noise outdoors also increased with higher sound category, at sound categories exceeding 35.0 dB(A). However, 20% of the 40 respondents living in sound category 37.5–40.0 dB(A) and 36% of the 25 respondents living in sound category >40.0 dB(A) were very annoyed by wind turbines. No respondent self-reported as annoyed at sound categories below 32.5 dB(A).

Among those who noticed wind turbine noise (n=223), 25% (n=47) reported that they were disturbed every day or almost every day. 17% of people were disturbed once or twice a week. Annoyance was most frequently reported when relaxing outdoors and at barbecue nights. 7% of respondents (n=25) were annoyed by noise from wind turbines indoors, and this was related to noise category. 23% (n=80) of respondents stated that they were disturbed in their sleep by noise. At lower sound categories, no respondents were disturbed in their sleep by wind turbine noise. Of the 128 respondents living at sound exposure above 35.0 dB(A), 16% (n=20) stated that they were disturbed in their sleep by wind turbine noise. Of the 351 people assessed, 26% (91) reported chronic health issues (e.g., diabetes, tinnitus, cardiovascular diseases), but these issues were not associated with noise levels.

Pedersen and Persson Waye revealed that attitude to visual impact, attitude to wind turbines in general, and sensitivity to noise were also related to the way people perceived noise from turbines. For example, 13% of the variance in annoyance from wind farms could be explained by noise and the odds that respondents would be annoyed by noise from wind turbines increased 1.87 times from one sound category to the next. When noise and attitude to visual impact was statistically assessed, 46% of the variance in annoyance from wind farms could be explained and the odds that respondents would be annoyed from wind turbines increased 5.05 times from one sound category to the next. Statistical analyses showed that while attitude to wind turbines in general and sensitivity to noise were also related to annoyance, visual effect was the most significant variable in terms of predicting annoyance.

Results of this study also showed that the proportions of respondents annoyed by wind turbine noise was higher than for other community noise sources (i.e., railways, road traffic and aircraft) at the same A-weighted sound pressure level and that the proportion of annoyed people increased more rapidly. Pedersen and Persson Waye suggest that these differences could be due to the rural environment where turbines are placed (where low background noise allows perception of noise sources when dB(A) is low), the intrusive characteristics of aerodynamic sound, and the impact of visual interference.

### **Leventhall, G. 2006. Infrasound from wind turbines – fact, fiction or deception? Canadian Acoustics 34:29-36**

In this paper Leventhall discusses infrasound in terms of what it is and how it is related to wind turbines. Leventhall states that the common assumption that “infrasound” is inaudible is incorrect, and that sound remains audible at frequencies well below 16Hz. Low frequency sound experienced at high sound pressure levels can have effects: people with both hearing ability and hearing loss (and with normal middle ears), exhibit aural pain at about 165dB at 2Hz, reducing to 145dB at 20Hz. Leventhall suggests that naturally occurring infrasound, in the range from about 0.01 Hz to 2Hz and at inaudible levels, is ubiquitous and comes from meteors, volcanic eruptions, ocean waves, wind and any effect which leads to slow oscillations of the air. Infrasound is also emitted from anthropogenic sources like explosions, combustion processes, slow speed fans and machinery.

In terms of wind turbines, infrasound is a component of the frequency spectrum, but found at low sound levels and only in the inaudible range. Leventhall suggests that there is insignificant infrasound from wind turbines and that attention should be focused on the audio frequency fluctuating swish, which some people may well find to be very disturbing and stressful, depending on its level.

### **Pedersen, E. and K. Persson Waye. 2007. Wind turbine noise, annoyance and self-reported health and well-being in different living environments. Occupational and Environmental Medicine 64:480-486**

Building on their 2004 paper, Pedersen and Persson Waye conducted a cross-sectional study in seven areas in Sweden across dissimilar terrain and different degrees of urbanisation. The objective of the study was to: evaluate the prevalence of perception and annoyance due to wind turbine noise among people living near the turbines and to study relations between noise and perception/annoyance, with focus on differences between living environments. 1309 questionnaires were sent to households in seven selected areas, three of which had wind turbines situated on flat ground (e.g., agricultural field) and four had turbines situated on ground that was hilly/rocky and comprised of trees and/or the altitude of the base of the wind turbine differed considerably from that of the dwellings nearby (called complex ground in the study). Three areas were classified as suburban; four as rural. The area and number of respondents sought was based on a statistical power analysis and, like their 2004 study, the purpose of the study was masked in the questionnaire.

Of the 1309 questionnaires delivered, 754 (57.6%) were satisfactorily completed and returned. The questionnaire consisted of questions about living conditions, reaction to possible sources of annoyance in the living environment, sensitivity to environmental factors, health and well-being. A-weighted (dB(A)) sound pressure levels due to wind turbines were calculated using the sound propagation model for wind power plants adopted by the Swedish Environmental Protection Agency.

One of the differences between this study and the one conducted in 2004 was the inclusion of the assessment of the influence of a tall object near the dwelling. This “vertical visual angle” was calculated for each respondent and defined as the angle between the horizontal plane and an imaginary line from a respondent’s house to the hub of the nearest wind turbine, expressed in degrees.

Perception of annoyance with wind turbine noise was statistically correlated with sound pressure level on the dB(A) scale ( $p < 0.001$ ). Of the 754 respondents, 307 (39%) noticed sound from wind turbines outside their dwelling (range of sound pressure level:  $< 32.5$ ,  $32.5-35.0$ ,  $35.0-37.5$ ,  $37.5-40.0$ , and  $> 40.0$  dB(A)) and the proportion of respondents who noticed sound increased almost linearly with increasing noise. In the  $37.5-40.0$  dB(A) range, 76% of the 71 respondents reported that they noticed sound from the wind turbines; 90% of respondents ( $n=18$ ) in the  $> 40.0$  dB(A) category noticed sound from the wind turbines. The odds of noticing sound increased by 30% for each increase in dB(A) category. Terrain did not statistically significantly influence the perception of noise but degrees of urbanization did: the odds that respondents would be annoyed by noise from wind turbines was 1.8 times more when living in rural vs. suburban environments. Further, respondents living in rural areas with complex ground were more likely to notice the sound than others.

In terms of annoyance, a total of 31 of the 754 respondents said they were annoyed by wind turbine noise. In the  $< 32.5$  to the  $37.5$  dB(A) category 3% to 4% of people said they were annoyed by wind turbine noise; in the  $37.5-40.0$  dB(A) category, 6% of the 71 respondents were annoyed; and in the  $> 40.0$  category, 15% of 20 of respondents said they were annoyed by wind turbine noise. In addition, of those 31 respondents who were annoyed by wind turbine noise, 36% reported that their sleep was disturbed by a noise source, compared with 9% among those 733 not noise annoyed.

Pedersen and Persson Waye concluded that “living in a rural landscape in contrast with an urbanised area enhanced the risk of perceiving wind turbine noise and, furthermore, the risk of annoyance. Type of terrain had no major influence on perception in urbanised areas; however, in a rural landscape, complex terrain substantively increased the risk”. One suggestion of the difference between rural and suburban areas is level of background sound and interestingly, perception and annoyance was associated with type of landscape, “indicating that the wind turbine noise interfered with personal expectations in a less urbanised area...”

pointing towards a personal factor related to the living environment". The authors also concluded that visual exposure enhances the negative associations with turbines when coupled with audible exposure. They also point out that their study showed that aesthetics play a role in annoyance: "respondents who think of wind turbines as ugly are more likely to appraise them as not belonging to the landscape and therefore feel annoyed".

**Keith, S.E., D.S. Michaud, and S.H.P. Bly. 2008. A proposal for evaluating the potential health effects of wind turbine noise for projects under the Canadian Environmental Assessment Act. *Journal of Low Frequency Noise, Vibration and Active Control* 27:253-265**

As a starting point for the development of a Health Canada guidance document on how to assess noise impacts in environmental assessments of wind turbine projects conducted under the Canadian Environmental Assessment Act (CEAA), Keith et al. published this report, the purpose of which was to provide criteria for evaluating the potential health effects of wind turbine noise. In the report Keith et al. propose that the predicted sound level from a wind turbine should not exceed 45 dB(A) at a sensitive receptor location (e.g., residences, hospitals, schools) situated in a quiet rural setting. The Health Canada definition of a quiet rural area is when the human made background sound levels are below 45 dB(A) during the day and 35 dB(A) during the night, and where population density is typically less than 8 dwellings/km<sup>2</sup>.

The authors go on to say that 45 dB(A) is below the World Health Organization guideline for sleep and speech disturbance, moderate annoyance and hearing impairment. Since publication of their study, the WHO Europe Region has released new Night Noise Guidelines for Europe (WHO, 2009): "The new limit is an annual average night exposure not exceeding 40 decibels (dB), corresponding to the sound from a quiet street in a residential area". It was acknowledged that in quiet rural areas there is a greater expectation for and value placed on peace and quiet, and this factor was taken into account when developing the proposed criteria. It is suggested that in these areas, predicted project sound levels should be adjusted by +10 dB(A). This criterion is also expected to protect against low frequency noise from wind turbines.

Based on literature review and calculations of the percentage of high annoyance, Keith et al. suggest that the proposed criterion value would lead to a 6.5% increase in the percentage of highly annoyed (%HA) people. The authors state that there will always be a small part of the population in quite rural areas that are highly annoyed by man-made sources of noise. When Keith et al. redo their calculations assuming that 1% of the population is expected to be highly annoyed, the sound level criteria is 43.3 dB(A).

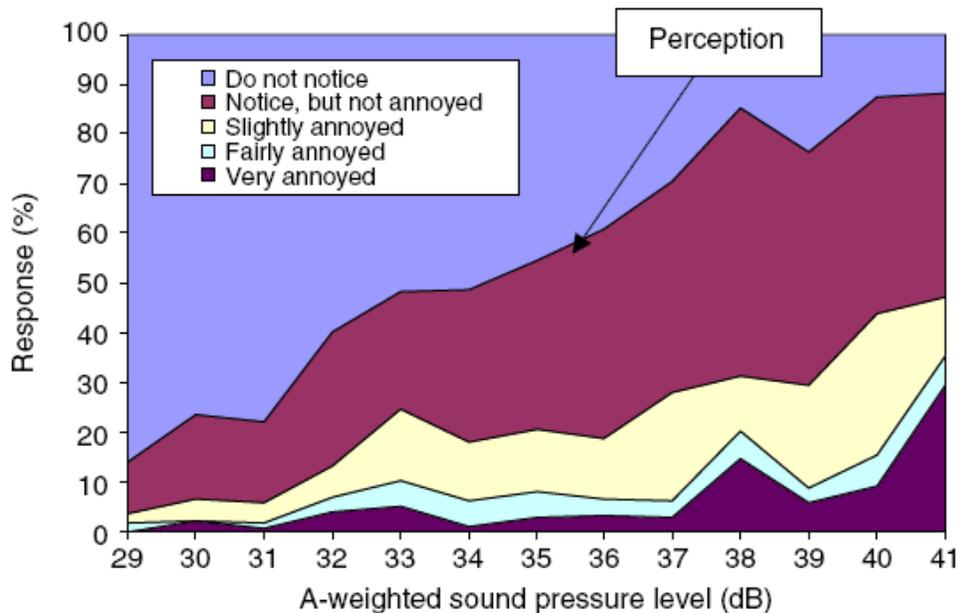
**Harding, G., Harding, P. and A. Wilkins. 2008. Wind turbines, flicker, and photosensitive epilepsy: Characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them. *Epilepsia* 49:1095-98**

Photosensitive epilepsy (PSE) occurs in one in 4,000 of the population. Because the rotating blades of wind turbines can produce shadow flicker, Harding et al. (2008) applied known parameters of the seizure-provoking effect of flicker (e.g., contrast, frequency) to wind turbine features to calculate the proportion of people liable to be at risk for seizures. Flicker from turbines that interrupt or reflect sunlight at frequencies greater than 3 Hz pose a potential risk of inducing photosensitive seizures at an incidence of 1.7 per 100,000 of the photosensitive population. The study found that seizure risk does not decrease significantly until distance from the turbine exceeds 100 times the hub height, a distance typically more than 4 km.

Given that the risk of seizure does not decrease with viewing distance up to approximately 4 km from the turbine, it is critical that flash frequency is maintained at or below 3 Hz. For turbines with three blades, this translates to a maximum speed of rotation of 60 rpm, “the normal practice for large wind farms”. Harding et al. (2008) also noted that when several turbines are in line with the sun’s shadow, the flicker produced is from a combination of blades from different turbines, which can have a higher frequency than from a single turbine. However, these should all be below the 3.0 Hz from modern wind turbines.

**Pedersen, E. and K. Persson Waye. 2008. Wind turbines - low level noise sources interfering with restoration? Environmental Research Letters 3:1-5**

In this paper, Pedersen and Persson Waye summarize their previous work (2004, 2007) with the emphasis on perception, annoyance and consequences for restoration, defined as the degree to which an environment can aid recovery from mental fatigue and restoration of attentional capabilities. The hypothesis for their work was: low and moderate stressors such as wind turbine noise could have an impact on health. Based on the 1095 people involved in both studies, the proportion of respondents who noticed sound from wind turbines increased almost linearly with increasing sound pressure level (dB(A)), from roughly 5-15% noticing noise at 29 dB(A) to 45-90% noticing noise at 41 dB(A) (Figure 1). However, the proportion of respondents fairly annoyed or very annoyed remains quite level through the 29-37 dB(A) range and increases at noise levels above 37 dB(A), with peaks at 38 dB(A) and 41 dB(A). Of note, at 40 dB(A), the criteria for wind turbine noise in Ontario, less than 10% of the 1095 respondents were very annoyed and roughly 15% were fairly annoyed. Pedersen and Persson Waye indicate that this increase is not statistically significant.



**Figure 1:** Response to wind turbine noise in relation to A-weighted sound pressure levels outside the dwellings of the respondents (reproduced from Pedersen and Persson Waye 2008).

Swishing, whistling, resounding and pulsating/throbbing were the sound characteristics that were most highly correlated with annoyance by wind turbine noise among respondents who noticed the noise outside their dwellings. Respondents described wind turbines as environmentally friendly, necessary and efficient, but also described them as ugly. Annoyance with wind turbine noise was associated with a negative attitude toward wind turbines in general and toward their visual impact; however, only noise level and visual impact were statistically significantly related to annoyance ( $p < 0.001$ ), with visual impact being the variable most strongly associated with annoyance. Response to wind turbine noise was also correlated with the respondent's judgment of the possibility for recovery and regaining of strength in the current living place.

**Pedersen, E., L.R.-M. Hallberg, and Persson Waye, K. 2007. Living in the vicinity of wind turbines—a grounded theory study. *Qualitative Research in Psychology* 4: 49–63.**

The goal of this study was to gain a deeper understanding of how people living near wind turbines perceive and are affected by them, by following grounded theory, an inductive method for generating conceptual models and hypotheses for further testing. Fifteen participants took part in this study and were part of a previous study by Pedersen and Persson Waye (2004). Participants described “three main types of stimuli from the wind turbines: noise, flickering light, and rotor blade movement. The noise was often classified as a swishing sound, but throbbing, resounding, rattling, and howling were also used as descriptors. The flickering light was depicted by some as being like a strobe light. The movement was described as a constant rotation that always attracted attention, and that was more annoying in winter when there were no leaves on the trees to hide the rotor blades”. Noise was typically the dominating stimulus of disturbance.

Some people felt that “wind turbines led to feelings of intrusion into privacy” while others “felt that if one chooses to live in a rural area, one must accept disturbances typical of the countryside such as flies or odor from manure and hence also noise and shadows from wind turbines”.

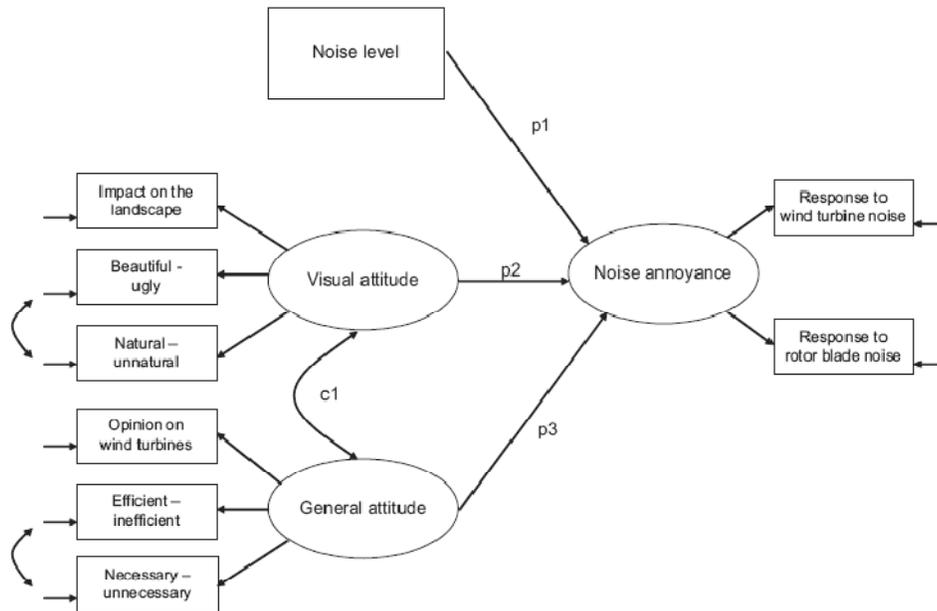
Findings indicated that the relationship between exposure and response is complex and possibly influenced by variables not yet identified, some of which are nonphysical. The notion that wind turbines are “intruders” is a finding not reported elsewhere. Pedersen et al. suggest that values about the living environment are important when the impacts of wind turbines are assessed, as values are firmly rooted within a personality and difficult to change.

**Pedersen, E. and P. Larsman. 2008. The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines. *Journal of Environmental Psychology* 28:379-89.**

Pedersen and Larsman conducted this study to assess visibility of the noise source (i.e., wind turbines), visual attitude and vertical visual angle (VVA) in different landscapes. This study follows up on the findings of previous work showing a relationship between noise annoyance in people living near wind turbines and the impact of visual factors as well as an individual's attitude toward noise (Pedersen and Nielsen 1994; Pedersen and Persson Waye 2004, 2007; Pedersen et al. 2007). It should be noted that Pedersen and Nielsen (1994) is a report written in Danish, for the Lydtekniske Institut in Denmark.

Data from studies conducted by Pedersen and Persson Waye (2004, 2007) were used as the basis of this study and a theoretic model built that takes into account the interactions amongst the factors tested, namely: noise level, response to turbine noise, response to rotor blade noise, impact on landscape (beautiful-ugly, natural-unnatural descriptors), evaluation of wind turbines (efficient-inefficient, necessary-unnecessary

descriptors) and vertical visual angle. These variables were categorized according to whether or not wind turbines were visible, if the terrain was flat or hilly/rocky and if turbines were found in built-up (suburban) or rural areas. These interactions have been illustrated in a conceptual model (Figure 2).



**Figure 2:** The structural equation model tested in the Pedersen and Larsmann study. “Noise level” refers to calculated sound pressure levels (dB(A)) outside the dwellings of the respondents due to wind turbine noise. Visual attitude, general attitude and noise annoyance are latent constructs. Regression weights (paths) are labelled “path 1 (p1)” to “path 3 (p3)” and the correlation between visual and general attitude is labelled “c1”. (reproduced from Pedersen and Larsmann 2008).

Because VVA was strongly correlated with noise exposure, Pedersen and Larsman did not include it in the multivariable model. Rather, VVA was assessed separately using multiple linear regression. Overall, Pedersen and Larsman concluded that respondents in a landscape where wind turbines could be perceived as contrasting with their surroundings (i.e., flat areas) had a greater probability of noise annoyance than those in hilly areas (where turbines were not as obvious), regardless of sound pressure level, if they thought wind turbines were ugly, unnatural devices that would have a negative impact on the scenery. The enhanced negative response could be linked to aesthetic response, rather than to multi-modal effects of simultaneous auditory and visual stimulation. Moreover, VVA was associated with noise annoyance, especially for respondents who could see at least one wind turbine from their dwelling, if they were living in flat terrain and rural areas. Pedersen and Larsman suggest that these results underscore the importance of visual attitude towards the noise source when exploring response to environmental noise.

**Pedersen, E., F. van den Berg, R. Bakker, and J. Bouma, 2009. Response to noise from modern wind farms in The Netherlands. *J. Acoust. Soc. Am.* 126 (2): 634-643.**

Pedersen et al. published this study expanding on their previous works. This new study was based on the results of a 2007 field study conducted in the Netherlands with 725 respondents. Overall, results suggested that “wind turbine noise was more annoying than transportation noise or industrial noise at comparable levels, possibly due to specific sound properties such as a “swishing” quality, temporal variability, and lack of nighttime abatement”.

Pedersen et al. also showed, as before, that wind turbines being visible from a dwelling statistically significantly increased the risk of annoyance, and annoyance was correlated with a negative attitude toward the visual impact of wind turbines on the landscape. What was new was the finding that people who economically benefited from wind turbines had a significantly decreased level of annoyance compared to individuals that received no economic benefit, despite exposure to similar sound levels.

Different from previous studies was the finding that annoyance was highest in urban areas rather than rural ones. The authors hypothesized that this was because of “place attachment”, and inhabitants who may feel that turbines are not beneficial to the living environment tend to exhibit a negative reaction. Though not tested, this hypothesis is supported by the work of Pedersen et al. 2007.

**Pedersen, E., F. van den Berg, R. Bakker, and J. Bouma, 2010. Can road traffic mask the sound from wind turbines? Response to wind turbine sound at different levels of road traffic. *Energy Policy* 38: 2520-2527.**

In this paper, Pedersen et al. hypothesize that if high levels of background sound can reduce annoyance by masking the noise from a wind farm (either physically or cognitively), then turbines could cause less noise annoyance when placed next to motorways instead of in quiet agricultural areas. Accordingly, the objective of this study was to determine if “perception and annoyance with wind turbine sound is reduced when road traffic sound dominates the wind turbine sound.”

Data utilized for this study were those used by Pedersen et al. 2009, and are based on the results of a 2007 field study conducted in the Netherlands with 725 respondents. Noise levels in dB(A) outside of the homes of each respondent were calculated in accordance with ISO-9613 (1993) for a wind speed of 8m/s at 10 m height and a wind profile in a neutral atmosphere. Day–evening–night sound immission levels (Lden) from road, air and rail traffic were obtained from the Dutch National Institute for Public Health and the Environment (RIVM).

In general, the hypothesis was not supported by the available data. Indeed, “the relationships between sound levels and annoyance with the noise were in most cases separate for wind turbine and road traffic, respectively, and not interacting”. If anything, results of the study show that road traffic may provide a significant masking effect of wind farm noise in the 35–40 dB(A) range. However this only occurs when road traffic is 20 dB(A) louder than noise from the turbines, indicating that less noise annoyance as a result of wind farms would be expected if situated in areas where road traffic sound levels are in the 55–60 dB(A) range.

**Smedley, A.R.D., A.R. Webb, and A.J. Wilkins. 2010. Potential of wind turbines to elicit seizures under various meteorological conditions. *Epilepsia* 51: 1146-1151.**

The work published by Smedley et al. builds upon that by Harding et al. 2008 (who stated that flicker from turbines that interrupt or reflect sunlight at frequencies greater than 3 Hz pose a potential risk of inducing photosensitive seizures at an incidence of 1.7 per 100,000 of the photosensitive population). In that atmospheric effects that reduce shadow contrast are included in a model used to calculate the proportion of people liable to be at risk for seizures. The current view used by United Kingdom planning authorities is that “Flicker effects have been proven to occur only within ten rotor diameters of a turbine”.

Smedley et al. conclude that wind turbines rotate at a rate below that at which the flicker is likely to present a risk, but like Harding et al. 2008, suggest that there is a risk when flicker is more than three times per second. Moreover, for the scenarios considered in their assessment, Smedley et al. found that the “risk of wind turbine induced seizures is negligible at a distance more than about nine times the maximum height reached by the turbine blade”.

**Salt, A.N., and T.E. Hullar. 2010. Responses of the ear to low frequency sounds, infrasound and wind turbines. *Hearing Research* 268: 12-21**

Infrasound is produced by physiological processes like respiration, heartbeat and coughing, as well as man-made sources like air conditioning systems, vehicles, some industrial processes and wind turbines. Salt and Hullar suggest that “it is widely assumed that infrasound presented at an amplitude below what is audible has no influence on the ear”; in this paper Salt and Hullar summarize the results of previous studies that show a physiological response of the human ear to low frequency noise (LFN) and infrasound. At very low frequencies the outer hair cells (OHC) of the cochlea may be stimulated by sounds in the inaudible range. Salt and Hullar hypothesize that “if infrasound is affecting cells and structures at levels that cannot be heard this leads to the possibility that wind turbine noise could be influencing function or causing unfamiliar sensations”. These authors do not test this hypothesis in their paper but suggest the need for further research.

**Pedersen, E. 2011. Health aspects associated with wind turbine noise—Results from three field studies. *Noise Control Eng. J.* 59 (1), Jan-Feb: 47-53.**

The purpose of this study by Pedersen was to assess the relationship between wind turbine noise and possible adverse health effects based on three cross-sectional studies conducted in two areas on Sweden and one location in the Netherlands. One of the Swedish studies took place in a flat, rural landscape (SWE-00; n=351) while the other took place in suburban sites with hilly terrain (SWE-05; n=754). The study in the Netherlands was also in a flat landscape, but with different degrees of road traffic intensity (NL-07; n=725). The selection of study areas corresponds with previous work conducted by Pedersen and colleagues that have investigated the influence of terrain, different degrees of urbanisation and traffic on noise annoyance.

Questionnaires were mailed to people in the three areas to obtain information about annoyance and health effects in response to wind turbines noise. Pedersen included questions about several potential environmental stressors and did not allow participants to know that the focus of the study was on wind turbine noise. For each respondent, sound pressure levels (dB(A)) were calculated for nearby wind turbines. The questionnaires were designed to obtain information about people’s response to noise (i.e., annoyance), diseases or symptoms of impaired health (i.e., chronic disease, diabetes, high blood pressure, cardiovascular

disease, tinnitus, impaired hearing), stress symptoms (i.e., headache, undue tiredness, feeling tense or stressed, feeling irritable), and disturbed sleep (i.e., interruption of the sleep by any noise source). Answers were either given as “yes/no” or as: do not notice, notice, but not annoyed, slightly annoyed, rather annoyed, and very annoyed.

Results showed that the frequency of those annoyed was related to an increase in sound pressure level as shown by odds ratios (OR) with 95% confidence intervals (CI) greater than 1.0. Sleep interruption was associated with sound level in two of the three studies: in the SWE-00 and NL-07 studies, sleep disturbance was associated with levels of sound of approximately 40 dBA and 45 dBA, respectively. It should be noted that the effect of noise on sleep did not increase gradually with noise levels, but spiked at 40 dBA and 45 dBA, and these sound pressure levels corresponded with the recommended highest exposure levels in the two countries where the studies took place. Pedersen also showed that, after adjusting for noise level, many variables were related to annoyance itself: feeling tense or stressed, as well as irritable, were associated with noise annoyance in all three studies (OR and 95%CI > 1.0). Sleep interruption was associated with sound level and annoyance (OR and 95%CI > 1.0). In general, OR were greater in the SWE-00 and NL-7 studies (flat landscape) than the SWE-05 study (hilly).

Though there are limitations to the study design (as acknowledged by Pedersen), results support those published in previous studies: that terrain is a variable that can be related to the way people respond to wind turbines and effects like stress are more strongly related to annoyance, and not wind turbine noise (e.g., Pedersen and Persson Waye, 2004; 2007; 2008; Pedersen and Larsman, 2008). Pedersen states that this is not to say that this result should be taken as evidence of a causal relationship between wind turbine noise and stress, mediated by annoyance, but rather explained by cognitive stress theory, in which an individual appraises an environmental stressor, such as noise, as beneficial or not, and behaves accordingly.

**O’Neal, R.D., Hellweg Jr., R.D., and Lampeter, R.M. 2011. Low frequency noise and infrasound from wind turbines. *Noise Control Eng. J.* 59 (2), March-April: 135-157**

To assess the possibility that the operation of wind turbines may create unacceptable levels of low frequency noise and infrasound, O’Neal et al. conducted a study (commissioned by a wind energy developer, NextEra Energy Resources, LLC) to: determine guidelines/standards used to evaluate low frequency sound and infrasound; to measure wind turbine noise outside and within nearby residences of turbines; and to compare the field results to the obtained guidelines and standards.

At the Horse Hollow Wind Farm in Taylor and Nolan Counties, Texas, broadband (A-weighted) and one-third octave band data (3.15 hertz to 20,000 hertz bands) were simultaneously collected from General Electric (GE) 1.5sle (1.5 MW) and Siemens SWT-2.3-93 (2.3 MW) wind turbines. Collection took place using two Norsonic Model Nor140 precision sound analyzers with a Norsonic-1209 Type 1 Preamplifier, a Norsonic-1225 half-inch microphone and a 7-inch Aco-Pacific untreated foam windscreen Model WS7. Data were collected outdoors and indoors over the course of one week under a variety of operational conditions at two distances from the nearest wind turbines: 305 meters and 457 meters.

Outdoor measurements were compared to criteria for audibility: disturbance using equivalent outdoor levels from the UK DEFRA (Department for Environment, Food, and Rural Affairs); for rattle and annoyance criteria as contained in ANSI (American National Standards Institute) S12.9/Part 4; for evaluating complaints of rattling using Japan Ministry of Environment guidance; and for perceptible vibration using equivalent outdoor levels from ANSI/ASA S12.2. Indoor measurements were compared to criteria for audibility: for disturbance

from UK DEFRA; for evaluating complaints of mental and physical discomfort using Japan Ministry of Environment guidance; and for suitability of bedrooms, hospitals and schools and perceptible vibration from ANSI/ASA S12.2.

O'Neal et al. found that the measured low frequency sound and infrasound at both distances (from both turbine types at maximum noise conditions) were less than the standards and criteria published by the cited agencies and organizations. The authors concluded that results of their study suggest that there should be no adverse public health effects from infrasound or low frequency noise at distances greater than 305 meters from the two wind turbine types measured.

### 2.2 Summary

What can be seen from these articles is that the relationship between wind turbines and human responses to them is extremely complex and influenced by numerous variables, the majority of which are nonphysical. What is clear is that some people living near wind turbines experience annoyance due to wind turbines. Swishing, whistling, resounding and pulsating/throbbing were the sound characteristics that were most highly correlated with annoyance by wind turbine noise among respondents who noticed the noise outside their dwellings. Some people are also disturbed in their sleep by wind turbines. Key points that have come out of these peer-reviewed studies are listed below.

1. People tend to notice sound from wind turbines almost linearly with increasing sound pressure level, from roughly 5-15% noticing noise at 29 dB(A) to 45-90% noticing noise at 41 dB(A).
2. Of people that notice sound from wind turbines, the proportion who are fairly annoyed or very annoyed remains quite level through the 29-37 dB(A) range (no more than roughly 5%) but increases at noise levels above 37 dB(A), with peaks at 38 dB(A) and 41 dB(A) where up to 30% of people may be very annoyed.
3. Noise annoyance is not only related to wind turbine noise itself, but also to subjective factors like attitude to visual impact (e.g., beautiful vs. ugly), attitude to wind turbines in general (benign vs. intruders) and sensitivity to noise. Noise annoyance related to wind turbines is also statistically related to whether or not people live in suburban or rural areas and landscape (flat vs. hilly/complex).
4. Visual impact has come out as a stronger predictor of noise annoyance than wind turbine noise itself.
5. People who economically benefit from wind turbines have significantly decreased levels of annoyance compared to individuals that received no economic benefit, despite exposure to similar sound levels.
6. Studies have shown that placement of wind turbines in already noisy areas rather than quiet ones can help mitigate noise annoyance.
7. Flicker from turbines that interrupt or reflect sunlight at frequencies greater than 3 Hz pose a potential risk of inducing photosensitive seizures at an incidence of 1.7 per 100,000 of the photosensitive population. The normal practice for large wind farms is for frequencies below this threshold.
8. Health Canada has proposed that the predicted sound level from a wind turbine should not exceed 45 dB(A) at a sensitive receptor location (e.g., residences, hospitals, schools) situated in a quiet rural setting. The proposed criterion value is expected to lead to a 6.5% increase in the percentage of highly annoyed people.

## 2.3 Popular Literature

Scientific studies peer reviewed and published in scientific journals are one way of disseminating information about wind turbines and health effects. The general public does not always have access to scientific journals and often receive information, and form opinions, from sources that are less accountable (e.g., popular literature and the internet). Numerous websites have been constructed by individuals or groups to support (e.g., David Suzuki, 2005; The Pembina Institute <http://www.pembina.org/re/wind-power-101>) or oppose (e.g., Wind Concerns Ontario <http://windconcernsontario.wordpress.com>; The Society of Wind Vigilance <http://www.windvigilance.com>) the development of wind turbine projects.

Often these websites state the perceived impacts on, or benefits to, human health to support the position(s) of the individual or group. The majority of information posted on these websites cannot, unfortunately, be traced back to a scientific, peer-reviewed sources and is typically anecdotal in nature. In some cases, the information contained on and propagated by internet websites and the media is not supported, or is even refuted, by scientific research. This serves to spread misconceptions about the potential impacts of wind energy on human health, which either increases or diminishes opposition to wind farm development. Therefore it is difficult for the general public to ascertain which claims from both sides of the issue are relevant and defensible.

There are a number of cases available on the internet (presented as reports or as slide presentations) suggesting a link between human health effects and wind turbines (e.g., works by Dr. Michael Nissenbaum conducted at Mars Hill and Vinalhaven Maine, Dr. Robert McMurtry and Carmen Krogh in Ontario, Lorrie Gillis, Carmen Krogh, and Dr. Nicholas Kouwen in Ontario). Authors of these studies have presented their findings in various forums (e.g., lectures, affidavits, public meetings). Dr. Nissenbaum evaluated 22 exposed adults (defined as living within 3500 ft of an arrangement of 28 1.5 MW wind turbines) and 27 unexposed (living about 3 miles away from the nearest turbine). In 2009, a book entitled *Wind Turbine Syndrome: A Report on a Natural Experiment* by Dr. Nina Pierpont, was self-published and describes “Wind Turbine Syndrome”, the clinical name Dr. Pierpont coined for the collection of symptoms reported to her by people residing near wind turbines. The book describes a case series study she conducted involving interviews of 10 families experiencing adverse health effects and who reside near wind turbines. Briefly, for these studies a limited number of people living near wind turbines were given questionnaires, and information about their health obtained. Generally, self-reported symptoms included sleep disturbance, headache, tinnitus (ringing in the ears), ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia (rapid heart rate), irritability, problems with concentration and memory, and panic episodes. These symptoms have been purported to be associated with proximity to wind turbines, and specifically, to the infrasound emitted by the turbines. Unlike the studies published in the peer-reviewed literature, the purpose of the studies was made clear to participants prior to undertaking questionnaires.

To date, these studies have not been subjected to scientific peer review and, given the venue for their distribution, it is extremely difficult to assess whether or not the information provided is reliable or valid. What is apparent is that these studies:

1. were not designed incorporating the fundamental principles of epidemiology;
2. do not contain noise measurements;
3. do not have adequate statistical representation of potential health effects;
4. provide limited rationale for the selection of study participants;

5. suffer from a small number of participants; and
6. suffer from a lack of objectivity, as authors are also known advocates who oppose wind turbines.

Of note is that conclusions of the peer reviewed literature differ in some ways from the conclusions of the studies published in the popular literature. In the peer reviewed studies, annoyance tends to peak in the >35 dB(A) range but tends to be more strongly related to subjective factors like visual impact, attitude to wind turbines in general (benign vs. intruders) and sensitivity to noise rather than noise itself from turbines. In the popular literature, health outcomes tend to be more strongly related to distance from turbines and the claim that infrasound is the causative factor. Though sound pressure level in the peer reviewed studies was scaled to dB(A), infrasound is a component of the sound measurements and was inherently accounted for in the studies. What both types of studies have in common is the conclusion that wind turbines can be a source of annoyance for some people.

### 2.4 Governmental Agency Reports

A number of reviews of potential health effects associated with wind turbines have been written in recent years for governments and governmental agencies (WHO, 2004; National Research Council, 2007; Chatham-Kent Public Health Unit, 2008; Minnesota Department of Health, 2009; Chief Medical Officer of Health Ontario, 2010; Australian Government, National Health and Medical Research Council, 2010).

In June 2008, the Chatham Kent Public Health Unit of Chatham, Ontario published a review entitled "The Health Impact of Wind Turbines: A Review of the Current White, Grey, and Published Literature". This review was one of the first of its kind to be released and concludes with the statement "This paper concludes and concurs with the original quote from Chatham-Kent's Acting Medical Officer of Health, Dr. David Colby, "In summary, as long as the Ministry of Environment Guidelines for location criteria of wind farms are followed, it is my opinion that there will be negligible adverse health impacts on Chatham-Kent citizens. Although opposition to wind farms on aesthetic grounds is a legitimate point of view, opposition to wind farms on the basis of potential adverse health consequences is not justified by the evidence."

In May of 2010, the Chief Medical Officer of Health (CMOH) for Ontario released a report entitled "The Potential Health Impacts of Wind Turbines". Quoting directly from the Summary of the Review "The review concludes that while some people living near wind turbines report symptoms such as dizziness, headaches, and sleep disturbance, the scientific evidence available to date does not demonstrate a direct causal link between wind turbine noise and adverse health effects. The sound level from wind turbines at common residential setbacks is not sufficient to cause hearing impairment or other direct health effects, although some people may find it annoying." It is important to note that the CMOH for Ontario did not consider these reports of annoyance to be sufficient at this point to warrant medical consideration.

In July 2010, the National Health and Medical Research Council (NHMRC) of the Australian Government published "Wind Turbines and Health, A Rapid Review of the Evidence", in which they concluded "This review of the available evidence, including journal articles, surveys, literature reviews and government reports, supports the statement: There are no direct pathological health effects from wind farms and that any potential impact on humans can be minimised following existing planning guidelines." It should be noted that the Australian Senate, specifically the Community Affairs References Committee, is holding an inquiry into the social and economic impact of rural wind farms. Results of the inquiry are expected in a final report by 1 June 2011 (Australian Government, 2011).

It is important to recognize that of these reviews, all of which include medical doctors, none classified the self-reported annoyance issues of residents as a pathological medical entity. Overall, governmental health agencies agree that noise from wind turbines is not loud enough to cause hearing impairment and are not causally related to adverse effects, however, they acknowledge that wind turbines can be a source of annoyance and suggest that impacts can be minimized by following existing planning guidelines.

### 2.5 Annoyance

Studies on the health effects of wind turbines, both published and peer-reviewed and presented in the popular literature, tend to conclude that wind turbines can cause annoyance for some people. It has been hypothesized that the self reported health effects found in popular literature (e.g., sleep disturbance, headache, tinnitus (ringing in the ears), ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia (rapid heart rate), irritability, problems with concentration and memory, and panic episodes) are related to infrasound emitted from wind turbines. This hypothesis likely stems from studies that have proposed a relationship between biological effects and exposure to infrasound (e.g., Alves-Pereira and Branco, 2007).

Given the following points, however, it appears that the link between wind turbine-generated infrasound and health effects are not substantiated.

- Studies where biological effects were observed due to infrasound exposure were conducted at sound pressure levels (e.g., Leventhall, 2006; 145 dB and 165 dB; Yuan et al., 2009: 130 dB) much greater than what is produced by wind turbines.
- Infrasound is not unique to wind turbines but is ubiquitous in the environment due to natural and man-made sources, meaning that people living near wind turbines were exposed to infrasound prior to turbine operation (e.g., Leventhall, 2006).
- Peer reviewed and scientifically defensible studies suggest that annoyance and health effects are more strongly related to subjective factors like visual impact and attitude to wind turbines than to noise itself (both audible and inaudible [i.e., infrasound]) (e.g., papers by Pedersen and others).
- The self reported health effects are associated with numerous issues, many of which can be attributed to anxiety and annoyance. For example, Berglund and Hassmen. 1996 reported that infrasound (a component of low frequency sound) is emitted from road vehicles, aircraft, industrial machinery, artillery and mining explosions, air movement machinery including wind turbines, compressors, and air-conditioning units, and Leventhall 2006 reported that infrasound comes from natural sources like meteors, volcanic eruptions and ocean waves. Indeed, many mammals communicate using infrasound (e.g., Langbauer, 2000).
- Shargorodsky et al. (2010) published that roughly 50 million adults in the United States reported having tinnitus, which is statistically correlated (based on 14,178 participants) to age, racial/ethnic group, hypertension, history of smoking, loud leisure-time, firearm, and occupational noise, hearing impairment and generalized anxiety disorder (based on 2265 participants) identified using a World Health Organization Composite Diagnostic Interview. In fact, the odds of tinnitus being related to anxiety disorder was greatest for any of the variables tested. Folmer and Griest (2000), based on a study of 174 patients undergoing treatment for tinnitus at the Oregon Health Sciences University Tinnitus Clinic between 1994 and 1997, reported that insomnia is associated with greater severity of tinnitus. Insomnia is also associated with anxiety and annoyance. Bowling et al., 2006 described statistically that people's perceptions of neighbourhood environment can influence health. Perceptions

of problems in the area (e.g., noise, crime, air quality, rubbish/litter, traffic, and graffiti) were predictive of poorer health score.

- In their 2003 publication Henningsen and Priebe discuss the characteristics of “New Environmental Illness”, illnesses where patients strongly believe their symptoms are caused by environmental factors, even though symptoms are not consistent with empirical evidence and medically unexplained. A key component to such illnesses is the patient’s attitude toward the source of the environmental factor.

Given that annoyance appears to be more strongly related to visual cues and attitude than to noise itself, self reported health effects of people living near wind turbines are more likely attributed to physical manifestation from an annoyed state than from infrasound. This hypothesis is supported by the peer-reviewed literature pertaining to environmental stressors and health. What is more, health effects from annoyance can be mitigated through behavioural and cognitive behavioural interventions (Tazaki and Landlaw, 2006; Leventhall et al., 2008).

### 3 POTENTIAL EFFECTS (ICE SHED, STRAY VOLTAGE, EMF)

#### 3.1 Ice Shed

Another potential public health and safety issue could result from the accumulation of ice on the turbine blades. This can occur when specific conditions of temperature and humidity exist. This condition is not unique to wind turbines and has the potential to occur on any structure that is exposed to the elements. In Ontario, this condition is most likely to occur in the winter months in extreme weather events. Under these conditions the turbines may be subject to ice coating from freezing rain or interception of low clouds containing super-cooled rain. There are two potential hazards associated with ice accumulation on wind turbines:

- danger of falling ice that may accumulate on the turbine itself as a result of freeze-thaw of snow and ice; and
- throwing of ice from the moving turbine blades.

Falling ice from an immobile turbine does not differ from other tall structures like telecommunication towers, power lines, and antenna masts. The potential ground area affected by falling ice depends to a large extent on the blade position and the prevailing wind speed and direction. When a turbine tip is at its highest point (approximately 120 m), ice would fall within a width of approximately 85 m from the turbine base (Seifert et al., 2003). This is dependent upon wind speed and direction. Garrad Hassan Canada (2007) estimated that only very high winds may cause ice fragments of any significant mass to be blown beyond 50 m of the base of a modern, stationary 2 MW turbine. Operating staff and landowners are briefed on this situation; therefore the risk is considered minimal (Garrad Hassan Canada, 2007).

Wind turbines typically operate when the wind speed is within the range of 4 m/s to 25 m/s; when turbines are in operation they can accumulate ice on the rotor blades. Ice fragments which detach from the rotor blades can be thrown from the wind turbine; any fragments will land in the plane of the wind turbine rotor or downwind (Garrad Hassan Canada, 2007). Throwing distance varies depending upon the rotor azimuth, rotor speed, local radius, and wind speed. Also, the geometry of the ice fragments and its mass will affect the flight trajectory.

Observations have shown that the ice fragments do not maintain their shape and immediately break into smaller fragments upon detaching from a blade. This would decrease the ice fragment's drag and potentially allow the ice fragment to be thrown greater distances. For human injury to result from wind turbine ice shed, several conditions would have to exist simultaneously (Garrad Hassan Canada, 2007):

- sustained weather condition conducive to icing;
- ice dislodging from the turbine blade;
- ice pieces large enough to remain intact through the air;
- ice traveling in a particular direction past setback guidelines; and,
- a person in the path of the ice as it lands.

A risk assessment methodology was developed by Garrad Hassan Canada and Partners, in conjunction with the Finnish Meteorological Institute and Deutsches Windenergie-Institut, as part of a research project on the implementation of Wind Energy in Cold Climates (WECO). Guidelines produced in the WECO project were based on a combination of numerical modelling and observations. The WECO database of observed ice fragments determined that recorded ice fragments are typically thrown to distances less than 125 m from the base of the turbine (Seifert et al., 2003).

Garrad Hassan Canada developed an Ontario-specific risk assessment methodology for ice shed based on the findings of the WECO project. Modelling was undertaken to determine the probability of an ice fragment landing within one square metre of ground area, as a function of distance from the turbine. The model result determined that the critical ice shed distance would be approximately 220 m from a turbine. At distances greater than 220 m, the probability of ice shed reaching ground level at a mass that would cause injury decreases rapidly. The critical distance can effectively be regarded as a "safe" distance, beyond which there is a negligible risk of injury from ice shed (Garrad Hassan Canada, 2007).

Example calculations were presented in the Garrad Hassan Canada (2007) report, using data representative of a typical wind farm project in rural southern Ontario. Risks to a fixed dwelling, vehicle travelling on a road, and individual person from being struck by an ice fragment thrown from an operating wind turbine were modelled, with the following results:

- fixed dwelling: equivalent to 1 strike per 500,000 years;
- vehicle travelling on a road: equivalent to 1 strike per 260,000 years; and,
- individual person: equivalent to 1 strike in 137,500,000 years.

These predictions seem markedly low; however, it is due to the fact that icing events are limited to only a few days per year. For example, Vestas Canada, which maintains turbines across Canada, has experienced no incidents related to falling ice in Canada (Jacques Whitford, 2006). Ice shed from the former Ontario Hydro's first wind turbine was monitored during its first six years of operation, with ice shed reported to have occurred thirteen times. The furthest ice fragment was recorded to be less than 100 m from the turbine (Garrad Hassan Canada, 2007).

### 3.2 Stray Voltage

Stray voltage results from an overflow of current traveling through the ground, and is manifested as an elevated voltage being developed between the neutral and ground wires. If a human touches two pieces of equipment that are at different voltage levels, a small electric current passes through the person and could have an adverse affect on their health if the voltage were strong enough. Stray voltage is not unique to wind farms and Hydro One is attempting to address stray voltage where it is a result of poor or faulty farm wiring, improper grounding of older Hydro One distribution lines (hydro lines connected to a farm/house), and other on and off farm sources. Stray voltage can be easily prevented through proper wiring practices, such as appropriate insulation, and can be easily measured and eliminated by qualified professionals should it occur.

### 3.3 Electromagnetic Fields (EMF)

To date, the largest evaluation of EMF and human health has been carried out in the United States by the Electric and Magnetic Fields Research and Public Information Dissemination (EMF RAPID) Program. Led by the National Institute of Environmental Health Sciences (NIEHS) of the National Institutes of Health and the Department of Energy, the EMF RAPID Program was a six-year project (ending in 1999) designed to provide scientific evidence to determine whether exposure to EMF could result in a potential risk to human health (EMF RAPID, 2002).

Overall, the EMF RAPID Program concluded that the body of scientific evidence linking human health risk from EMF exposure is weak. No consistent pattern of biological effects from exposure to EMF had emerged from laboratory studies with animals or with cells. However, epidemiological studies (i.e. studies of disease incidence in human populations) indicated a potential association with EMF exposure to a potential small increased risk of leukemia occurrence in children and chronic lymphocytic leukemia in occupationally exposed adults. They did not report at what EMF levels this causation would be expected to occur.

The Federal-Provincial-Territorial Radiation Protection Committee – Canada (FPTRPC) is comprised of a forum of delegates from the Canadian Nuclear Safety Commission, Health Canada - Radiation Protection Bureau, and the Provincial and Territorial Radiation Protection Programs (FPTRPC, 2009). In 2005, the FPTRPC released a review of all relevant scientific information reported in refereed journals with regard to EMF exposure, published from 1998 to 2002. The report concluded that laboratory research has shown that EMF at extremely low frequencies (ELF) can interact with biological systems. However,

- results to date have not provided conclusive evidence that these fields cause adverse health effects in humans, such as cancer;
- epidemiological studies have not established an association between exposure to ELF EMF and the development of cancer in adults; and
- the evidence associating cancer in children with exposure to ELF EMF remains inconclusive.

The FPTRPC's position on the potential link between childhood leukemia and exposure to EMF is stated thus: "It is the opinion of FPTRPC that the epidemiological evidence to date is not strong enough to justify a conclusion that EMF in Canadian homes, regardless of locations from power lines, cause leukemia in children." -- FPTRPC Response Statement to the Issue of Power-Frequency Magnetic Fields and Childhood Leukemia – Issued on January 20, 2005

Health Canada has reviewed numerous studies related to ELF EMF exposure and concluded that electrical devices and power lines can induce weak electric currents to flow through the human body. However, these currents are much smaller than those produced naturally by one's brain, nerves, and heart, and are not associated with any known health risks (Health Canada, 2004). Health Canada scientists are aware that some studies have suggested a possible link between exposure to ELF fields and certain types of childhood cancer. However, they determined that when all of the studies are evaluated, the evidence of such a link appears to be very weak (Health Canada, 2004) and no threshold values could be established.

In 2004, the International Agency for Research on Cancer (IARC) reported that there is "limited evidence" that ELF magnetic field exposure could result in childhood leukemia (at exposure levels above 0.4  $\mu$ T or 4 mG in a pooled analysis based on 9 well conducted studies), and "inadequate evidence" for any other link between human health effects and exposure to EMF (WHO, 2004). Although a causal relationship between ELF and childhood leukemia had not been established (i.e., no clear evidence exists that indicates that ELF causes childhood leukemia), conflicting results of epidemiology studies indicated a higher incidence of childhood leukemia in children with higher exposure to ELF. ELF was therefore classified as "a possible human carcinogen". New laboratory (animal and in vitro) and epidemiological data evaluated since the 2004 classification by IARC showed no evidence that EMF causes cancer in animals or humans; however, enough uncertainty still existed in the epidemiology studies that the classification remained unchanged in their 2007 review (WHO, 2007).

The consensus among agencies and the literature reviewed is that:

- available evidence is not strong enough to conclude that EMF causes cancer in children or occupationally exposed adults;
- there is insufficient evidence linking EMF to any other human health effects; and,
- more studies are needed to draw firm conclusions.

## 4 CONCLUSIONS

To date, no peer reviewed scientific journal articles have been retrieved or reviewed that identified a causal link between people living in proximity to modern wind turbines, the noise (audible, low frequency noise, or infrasound) they emit and resulting physiological health effects. Both peer-reviewed and popular literature reports suggest that some people can be annoyed by wind turbine noise. Peer-reviewed studies suggest that annoyance is more strongly related to subjective factors like visual impact, attitude to wind turbines in general (benign vs. intrusive) and sensitivity to noise rather than noise itself from turbines. In the popular literature, self-reported health outcomes are related to distance from turbines and the claim is made that infrasound is the causative factor for the reported effects, even though sound pressure levels are not measured. Moreover, self reported health effects can be associated with numerous issues, not just wind turbines. What both types of studies have in common is the conclusion that wind turbines can be a source of annoyance for some people. The literature suggests that annoyance-related effects can be managed and mitigated through behavioural and cognitive behavioural interventions.

## 5 CLOSURE

This report may not be relied upon by any other person or entity without the express written consent of Stantec Consulting Ltd. Any use that a third party may make of this report, or any reliance on decisions made based on it, are the responsibility of such third parties. The information and conclusions contained in this report are based upon work undertaken by trained professional and technical staff in accordance with generally accepted engineering and scientific practices current at the time the work was performed. Conclusions and recommendations presented in this report should not be construed as legal advice.

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