



Wind Turbine Noise & Human Health: A Review of the Scientific Literature

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Summary

Since 1997, 67 utility scale wind turbines with 149 megawatts of capacity have been installed at five locations in Vermont: Searsburg, Deerfield, Georgia, Lowell, and Sheffield. The Vermont Department of Health reviewed recent scientific publications to better understand whether wind turbine noise poses a risk to public health. The Department's findings are summarized below.

1. At noise levels studied, there was no evidence of a direct effect of wind turbine noise on any of the health outcomes considered.
2. As wind turbine noise levels increase, the proportion of community members reporting that they are highly annoyed by the wind turbine noise also increases.
3. Although wind turbine noise itself was not associated with any direct health effect, annoyance attributed to wind turbine noise by respondents was associated with migraines, dizziness, tinnitus, chronic pain, hair cortisol concentrations (an indicator of stress), blood pressure, and self-reported sleep quality.
4. Efforts to minimize annoyance should address both noise and non-noise related factors. In order to minimize annoyance attributed to noise, an annual limit of 35 dBA coupled with community engagement could be considered. Community engagement could help to address prior attitudes toward wind turbine development, identify vulnerable populations and address concerns about visual annoyance (for example blinking aircraft warning lights), physical safety, and equitable distribution of economic benefits.

1. Introduction

The aim of this literature review is to assess the current state of the science with regards to the potential human health impacts of the noise from wind turbines. This review provides an update to an earlier review completed in 2010, entitled “Potential Impact on the Public’s Health from Sound Associated with Wind Turbine Facilities” (Vermont Department of Health 2010).

The main development since the 2010 Health Department report was published is the completion of Health Canada’s Community Noise and Health Study. This study of 1,011 people living in Ontario and 294 people living on Prince Edward Island was funded by the Canadian government. This study is the largest and most thorough examination of the potential health effects of wind turbine noise conducted to date. Of note, the Health Canada study verified modeled wind turbine noise levels with sound power measurements, including for low frequency sound (Keith, Feder et al. 2016). The study also used objective measures of stress and cardiovascular health (Michaud, Feder et al. 2016b), and sleep quality (Michaud, Feder et al. 2015) to complement the self-reported annoyance, sleep, quality of life, and health information that is routinely collected in epidemiological studies of the potential health effects of wind turbines.

2. Methods

The studies discussed below were selected based on the following criteria: 1) that they investigate potential health impacts of wind turbine noise, and 2) that results were published in a peer-reviewed scientific journal. Over the past seven years the body of peer-reviewed literature has grown significantly. There have been several recent comprehensive reviews of the literature, including McCunney et al. (2014), and Schmidt and Klokke (2014). This current review draws heavily from seven papers published as part of the Health Canada Community Noise and Health Study, covering sleep disturbance, stress related disease, self-reported health outcomes, quality of life, annoyance, sound monitoring, and sound modeling. Given the unprecedented size and rigor of the study, including the use of objective measures of stress, cardiovascular health, and sleep disturbance, and the use of sound measurements to verify sound modeling (Michaud, Keith et al. 2013), this emphasis seems warranted. However, a weakness of discussing each of these papers at length is that it risks overstating the importance of this single study, and invites the possibility that problems or shortcomings in the methods or results of the Health Canada study could have an outsized effect on this review’s conclusions.

3. Stress-related Disease

The Health Canada Community Noise and Health Study used objective measures of stress levels (including hair cortisol, systolic blood pressure, diastolic blood pressure, and heart rate) to assess stress reactions associated with wind turbine noise, in addition to self-reported stress levels (Michaud, Feder et al. 2016b). The analysis did not find an association between wind turbine noise exposure and any of the self-reported or objective measures of stress. Similarly, no association was found between wind turbine noise annoyance and any of the measures of stress. High annoyance related to the blinking aircraft warning lights on the top of wind turbines was significantly associated with slight elevation in diastolic blood pressure (2.90 mmHg 95% Confidence Interval: 0.75 – 5.05 mmHg). Receipt of personal economic benefits (such as partial ownership, employment, rent, lower taxes, or lower utility bills) was associated with a lower (better) resting heart rate (Michaud, Feder et al. 2016b).

4. Sleep Disturbance

While other studies have used questionnaires like the Pittsburgh Sleep Quality Index to capture self-reported episodes of sleep disturbance among those exposed to wind turbine noise, Health Canada's assessment (Michaud, Feder et al. 2015) also included objective measures of sleep quality. Sleeping and waking behaviors were tracked using actigraphy devices worn on the wrist by test subjects. Analysis of the results of self-reported sleep disturbance and physically measured sleep patterns during exposure to wind turbine noise led researchers to conclude that wind turbine noise had no statistically significant effect on self-reported or objectively measured sleep at sound levels up to 46 dBA (the maximum sound level in the study; Michaud, Feder et al. 2015). Participants receiving a personal economic benefit from the wind turbine development reported significantly better sleep quality. Annoyance with blinking aircraft warning lights was significantly associated with higher rates of waking bouts and reduced total sleep time based on objective measures.

Objective physical measurements of sleep disturbance by wind turbine noise were also collected and reported by Jalali et al. (2016) before and after new wind turbines became operational. While physical measurements related to sleep disturbance were not statistically different in the presence or absence of wind turbine noise, a statistically significant number of participants reported in their sleep diaries that their quality of sleep had declined with exposure to wind turbine noise. Bakker *et al.* (2012) surveyed 1,948 people living within 2,500 meters of utility-scale (≥ 500 kW) wind turbines in three environment types in the Netherlands. While self-reported sleep disturbance significantly increased for those exposed to sound pressure levels over 45 dBA, further analysis showed annoyance to be the factor that best predicted self-reported sleep disturbance.

5. Other Health Parameters

The Health Canada Community Noise and Health Study (Michaud, Feder et al. 2016a) surveyed 1,238 randomly selected participants living between 0.25 and 11.22 kilometers from operational wind turbines about health effects (including chronic pain, asthma, arthritis, high blood pressure, bronchitis, emphysema, chronic obstructive pulmonary disease, diabetes, heart disease, migraines/headaches, tinnitus, and dizziness), as well as sleep disturbance, sleep disorders, quality of life, and perceived stress. Other than annoyance, the only self-reported outcome significantly associated with wind turbine noise was sleep medication use. Sleep medication use was significantly associated with wind turbine noise, although rather surprisingly, the highest rates of sleep medication use were found among those people exposed to the lowest levels of wind turbine noise.

The Health Canada Community Noise and Health Study (Feder, Michaud et al. 2015) used the World Health Organization's (WHO) abbreviated (26 question) survey (WHOQOL-BREF) to measure quality of life with respect to physical health, psychological health, social relationships, and the environment. This study found that wind turbine noise levels were not significantly related to any of the measures of quality of life. Wind turbine related variables other than sound levels were found to be significantly associated with quality of life; annoyance with the visual attributes of wind turbines was significantly associated with lower physical health-related and environmental quality of life scores ($p = 0.02$ and $p = 0.01$, respectively). There was also a significant association between 'receiving some personal benefit from having wind turbines in the area' and better physical health scores ($p = 0.04$).

A smaller study (197 total participants) that measured quality of life using the same WHOQOL-BREF questionnaire (Shepherd D 2011) found that respondents living closer than 2 kilometers from ridgeline wind turbines had significantly poorer scores for their physical health-related quality of life and for their perceived sleep quality than those living more than 8 kilometers away from the turbines. They also

perceived their environment to be significantly less healthy. A third study used a different questionnaire, the Short Form 36 General Health Questionnaire (SF-36; from Quality Metric Inc.), to examine the quality of life of 1,277 participants living at various distances from the nearest wind turbine in Poland (Mroczek, Kurpas et al. 2012). This study found that reported quality of life for residents living closer to the wind turbines (less than 1.5 kilometers) did not differ from reported quality of life for residents living farther away (more than 1.5 kilometers). Neither Shepherd (2011) nor Mroczek et al. (Mroczek, Kurpas et al. 2012) used noise levels to define their exposure groups. They used distance which can be problematic, especially in rough or hilly terrain. Neither of these studies considered whether participants received an economic benefit from the wind turbine development.

6. Annoyance

The most widely studied effect of environmental noise is annoyance. The use of the term *annoyance* should not be confused with our everyday use of the term to indicate a “minor nuisance” or “something that causes a slight irritation.” In their review, McCunney *et al.* (2014) described *noise-related annoyance* as a subjective psychological condition that may result in anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation, or exhaustion. *Community noise annoyance* is defined as the prevalence (percentage) of people in the community who report being very or extremely (together termed *highly*) annoyed. The term *noise annoyance* can be misleading. Noise annoyance is measured by asking people to rank how annoyed they are by a given noise source. However, there can be various factors that are related to the reported level of “noise annoyance” other than the level of noise to which they are exposed. Some of these factors may have a stronger relationship with “noise annoyance” than the noise levels. Therefore, a more accurate description of this type of annoyance would be *annoyance attributed to noise exposure by the respondent* or, for the sake of brevity, *annoyance attributed to noise*. These terms are used in place of *noise annoyance* in the discussion below.

The largest study of annoyance attributed to wind turbine noise by respondents was completed as part of Health Canada’s Wind Turbine Noise and Health Study (Michaud, Keith et al. 2016). Similar to earlier studies (Pedersen and Persson Waye 2004; Pedersen and Waye 2007; Pedersen, van den Berg et al. 2009), this study finds that as noise levels increase, the percentage of people who report being highly annoyed also increases (from 2.1% or less below 30 dBA to 13.7% in the 40 - 46 dBA range). Notably, the prevalence of high annoyance increases by a factor of 10 between the 30 - 35 dBA range (1.0% highly annoyed) and the 35 - 40 dBA range (10% highly annoyed), suggesting an important threshold at or near 35 dBA. However, wind turbine noise levels explained only 9% of the variation seen in annoyance attributed to noise by respondents. The strength of the association improved markedly when other non-noise wind turbine related variables were included in the analysis, for example visual annoyance to wind turbines, annoyance with blinking aircraft warning lights on the wind turbine, perception of vibrations during wind turbine operation, concern about physical safety resulting from having wind turbines in the area, sensitivity to noise, and whether the participant received a personal benefit from the wind turbine development. The authors state that while their understanding of the mechanism by which annoyance attributed to noise affects health is incomplete, their findings would support efforts to minimize such annoyance. Such efforts will be most effective if they focus not only on wind turbine noise levels but also on reducing visual annoyance from blinking aircraft warning lights, addressing concerns about physical safety, and providing personal economic benefits to those most likely to be affected by the noise.

Studies have found an association between annoyance attributed to noise and health outcomes such as migraines and cardiovascular symptoms including high blood pressure (Niemann, Bonnefoy et al. 2006),

sleep disturbance and psychological distress (Pedersen, van den Berg et al. 2009), and mental health status (Pawlaczyk-Łuszczynska, Dudarewicz et al. 2014). While the Health Canada study (Michaud, Keith et al. 2016) did not find a significant association between wind turbine noise and numerous objectively and subjectively measured health outcomes, there was a weak (explaining less than 7% of the variability) but significant association between annoyance attributed to wind turbine noise and many of these outcomes such as migraines, dizziness, tinnitus, chronic pain, hair cortisol concentrations (an indicator of stress), blood pressure, and self-reported sleep quality. These associations do not demonstrate causality between annoyance and these health conditions, and if a mechanism of causality exists, it is not clear whether it is annoyance that increases the risk of the health condition or the health condition that increases the risk of annoyance.

In summary, at comparable sound levels, communities are less tolerant of (more highly annoyed by) wind turbine noise than other common sources of community noise (Michaud, Keith et al. 2016). People who complained of being highly annoyed by wind turbine noise were also more likely to have various objectively measured (Michaud, Keith et al. 2016) and subjectively measured adverse health outcomes (Pedersen, van den Berg et al. 2009; Pawlaczyk-Łuszczynska, Dudarewicz et al. 2014; Michaud, Keith et al. 2016). However, the cross-sectional study design does not allow us to infer the directionality of these relationships (i.e. whether sleep disturbance leads to annoyance, or whether annoyance leads to sleep disturbance). Annoyance associated with wind turbine noise is more likely to occur after one year of residing near a wind turbine development (Michaud, Keith et al. 2016), and more likely to occur where background noise levels are low (Bakker, Pedersen et al. 2012). Finally, wind turbine noise is only one factor among many that influence annoyance levels (Pedersen, van den Berg et al. 2009; Michaud, Keith et al. 2016), and therefore efforts to minimize community annoyance should address issues related to visual impacts, concerns about safety, and economic benefits in addition to addressing concerns about noise.

7. Guidelines for Protecting Human Health

The Vermont Department of Health recommended in its 2010 review that in order to prevent sleep disturbance (and secondary health effects associated with sleep disturbance), “nighttime sound levels from wind turbines be limited to 40 decibels or less, as measured at the exterior façade of the dwelling and averaged over 12 months of exposure.” This recommendation was consistent with the World Health Organization’s *Guidelines for Community Noise* (WHO 1999) which recommended limiting nighttime noise in the bedroom to 30dBA averaged over 8 hours and 2009 *Night Noise Guidelines for Europe* (WHO 2009) which recommended an annual limit of 40 dBA as measured at the façade of the dwelling.

Annually averaged noise limits may be useful for planning and development siting purposes, but are impractical for compliance monitoring purposes because the long averaging time does not permit a timely response. In recent years, the Public Service Board has applied a sound level limit of 45 dBA (averaged over an hour) to large scale industrial wind turbine projects. In the response of the Department of Public Service to questions raised by the Public Service Board’s August 26, 2016 notice, the Department of Public Service recommended that not-to-exceed sound levels use an averaging time interval of one minute. The epidemiological literature specific to wind turbine noise is not instructive as to an appropriate one-minute sound limit to prevent sleep disturbance. However, the 1999 WHO report states that, “For a good night’s sleep, [...] individual noise events exceeding 45 dBA should be avoided.”

The same report (WHO 1999) also states that, “[s]pecial attention should also be given to: noise sources in an environment with low background sound levels; combinations of noise and vibrations; and to noise sources with low-frequency components.” Sound associated with wind turbines meets all of these

criteria. For such sounds, Berglund and Job (1996) suggest that standards should not focus solely on sound pressure levels, but should also consider impulsiveness and the predominance of sound energy in the low frequency range. More recent laboratory studies of wind turbine noise that quantify the effect of amplitude modulation (Hafke-Dys, Preis et al. 2016; Ioannidou, Santurette et al. 2016) on annoyance support this contention. There may be value in incorporating limits on impulsiveness, amplitude modulation, or predominance of low frequency noise into noise standards. For example Maine's proposed Wind Energy Standards rule (Maine Department of Environmental Protection 2016) incorporates limits on short duration repetitive sounds.

8. Conclusions

The 2010 Vermont Department of Health review found that, if improperly sited, noise from wind turbines could potentially pose a risk of sleep disturbance, and recommended an annual nighttime noise limit of 40 dBA at the façade of the building to prevent sleep disturbance.

The current literature review does not find any new evidence of direct effects of wind turbine noise on health. Wind turbine noise has been found to be associated with increased levels of annoyance attributed to noise. Independent of noise levels, the Health Canada Study found weak, but significant associations between reported annoyance attributed to noise and several health endpoints.

In order to minimize annoyance attributed to noise, an annual limit of 35 dBA outside the home could be considered (Pedersen and Persson Waye 2004; Michaud, Keith et al. 2016) coupled with community engagement. The aim of such a noise limit would be to minimize changes in attitude (annoyance) rather than preventing sleep disturbance (Schomer and Fidell 2016). In addition, the Health Canada study results (Michaud, Keith et al. 2016) suggest that efforts to minimize annoyance should address both sound emissions and other non-noise related factors found to be associated with annoyance, including visual annoyance (blinking aircraft warning lights), prior attitudes toward wind turbine development, concerns for physical safety, and whether or not the person received personal economic benefits.

Therefore, to minimize long-term community annoyance, addressing noise alone is not enough. In a 2013 memorandum to the Governor's Energy Generation Siting Policy Committee (Vermont Department of Health 2013), the Health Department recommended that applicants to the Public Service Board be required to conduct a project-specific public health impact assessment in the affected community or communities. A public health impact assessment is a comprehensive evaluation of potential health impacts from a proposed development or policy change that engages all stakeholders to help ensure that a broad spectrum of concerns and exposures are considered for analysis. The health impact assessment would, for example, characterize the people likely to be affected, identify vulnerable populations, assess the potential for health benefits and adverse effects, and suggest mitigation strategies.

More broadly, sustained community engagement that listens to and considers community members' input, reports on changes and progress throughout the application and development process, and enables community members to have greater influence and control in making decisions about factors that affect their lives may help to reduce anxiety, stress, and negative attitudes toward wind turbine development projects (Pedersen, Hallberg et al. 2007).

At the noise levels studied in the papers reviewed above, there was no evidence of a direct health effect from sound associated with wind turbines. An annually-averaged limit of 35 dBA (measured at the façade of the dwelling) paired with sustained community engagement including a project-specific public

health impact assessment may help to reduce the levels of annoyance attributed to noise among members of the community.

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Appendix



Potential Impact on the Public's Health from Sound Associated with Wind Turbine Facilities

October 15, 2010

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Potential Impact on the Public's Health from Sound Associated with Wind Turbine Facilities

October 15, 2010

Summary

The Vermont Department of Health conducted a literature review of the potential human health effects from exposure to sound and vibration from wind-powered electrical generating facilities, as requested by the Vermont Department of Public Service.

To do this, we convened a panel of public health scientists who are experienced in reviewing the quality of the scientific literature on health protection, and in assessing the adequacy of the evidence that an exposure can cause, or contribute to, an adverse health outcome. The Health Department panel drew primarily upon the most recent and most comprehensive literature reviews conducted by other expert panels. These included citations for hundreds of primary research studies on the health effects of exposure to sound generally, and to wind turbine sound specifically.

From this extensive review, the Vermont Department of Health concludes that there is no direct health effect from sound associated with wind turbine facilities. However, there is sufficient evidence of a secondary health effect from sleep disturbance due to excessive sound at night. The potential adverse health effects that can result from sleep disturbance include increased heart rate, sleep state changes and awakening, increased use of medications to aid sleep, increased body movements, insomnia, fatigue, accidents, reduced performance, cardiovascular illness and depression and other mental illness (WHO 1999). The 1999 WHO report also concludes that limiting sound exposure at night to reduce the probability of sleep disturbance can minimize these effects in the exposed population.

To protect public health, the Vermont Department of Health recommends that nighttime sound levels from wind turbines be limited 40 decibels or less, as measured at the exterior facade of the dwelling and averaged over 12 months of exposure. This is consistent with the most recent recommendations of the World Health Organization (WHO 2009).

This review and conclusions are general in nature. No specific wind turbine facility has been assessed.

Discussion

Sound from Wind Turbine Facilities

The frequency range of human hearing is between 20 and 20,000 hertz or Hz. Sounds from wind turbines may exist throughout that range, but are predominantly experienced at frequencies less than 1,000 Hz (Roberts and Roberts 2009). In addition to frequency, the intensity of the sound at specific frequencies is important to human sensation. Sound intensity, or more exactly, sound pressure level, is measured in decibels (dB). The term dBA is used for sound pressure levels weighted to the range of human hearing.

The sound pressure level as measured in decibels (dB) for a whisper is 30 dB, and for the sound of rustling leaves or soft music is 45 dB. Very loud sounds above 90 dB may be experienced as painful. A gunshot or police siren 100 feet away could reach 140 dB. (Colby *et al* 2009, Roberts and Roberts 2009, WHO 1999, WHO 2009). For frequencies predominant at wind turbine facilities, the hearing threshold is about 25 dB (Roberts and Roberts 2009, Colby *et al* 2009, Minnesota Department of Health 2009).

“Infrasound” is sound below the normal frequency range of hearing unless experienced at high levels (Colby *et al* 2009). Infrasound and other low frequency sound below 100 Hz travel farther than higher frequencies, penetrate physical barriers such as walls and windows with little attenuation, and are associated most often with sound-induced vibrations (Roberts and Roberts 2009, Colby *et al* 2009, Minnesota Department of Health 2009).

Sounds emitted from wind turbines are generally classified as mechanical (from the movements of the physical components) and aerodynamic. Aerodynamic sound from the movement of air by the turbine rotors is the dominant source of sound from wind turbines, and is in the lower frequency range of audible sound at 500 to 1,000 Hz (Roberts and Roberts 2009). An inaudible spectrum of frequencies, or infrasound, is also generated. Mechanical sound is unlikely to exceed aerodynamic sound, except when the turbine is not functioning properly (Minnesota Department of Health 2009).

Possible Health Effects of Sound from Wind Turbine Facilities

Given that the dominant source of sound from wind turbine facilities is low frequency, this review focused especially on the literature relating to health effects of low frequency sound and infrasound.

In a report for the Wisconsin Public Service Commission, Roberts and Roberts (2009) conducted a thorough review of this literature that included 156 articles. Of these, 99 dealt with low frequency sound and health effects, 16 with infrasound and health effects, 21 with wind turbines or wind power and sound, and 20 with wind turbines alone. They concluded that:

The effects of low frequency noise and vibration have not been well characterized,[sic] objective body vibration results only from very high levels of low frequency noise, greater than those produced by wind turbines. Sleeplessness and insomnia have been associated with low frequency noise, but this finding has been poorly correlated and lacking in consistency. However the level of annoyance with low frequency noise was found to be correlated with insomnia.

In a review prepared for the American and Canadian Wind Energy Associations, Colby *et al* (2009) documented how low frequency sound and infrasound can only be heard at higher decibels compared to higher frequency and audible sound waves. They reviewed several studies that indicate wind turbine sound at typical distances of exposure are unlikely to be audible below 50 Hz. This review concluded that “the body of accumulated knowledge provides no evidence that the audible or subaudible sounds emitted by wind turbines have any direct adverse physiological effects.”

Colby *et al* rejected “annoyance” as a direct adverse physiological effect, but recognized that annoyance could undermine coping and progress in some individuals to result in stress-related effects. They noted that a predominant stress-related effect is sleep disturbance, and that this may lead to other health consequences. The authors wrote that audible low frequency sound is unlikely to disturb sleep until it is 10 to 15 dB greater

than the hearing threshold. For low frequencies, predominant in wind turbine facility exposures, the hearing threshold starts in the 25 dB range (Roberts and Roberts 2009, Colby *et al* 2009, Minnesota Department of Health 2009). Therefore, sleep disturbance may occur at sound levels from wind turbine facilities as low as 35 to 40 dB.

The Minnesota Department of Health (2009) described studies that supported a sound limit outside the home. These studies describe the results from survey questionnaires indicating higher numbers of complaints or self-reported symptoms of exposure for populations in Sweden and the Netherlands. In the two Swedish studies, reported annoyance doubled when exposures were calculated to be greater than 40 dBA, compared to 30 to 40 dBA. In the Dutch study, annoyance rose from 2 percent of the respondents who were exposed to 30 dBA or less to 25 percent for those with calculated exposures greater than 45 dBA.

Guidelines for the Protection of Human Health

The World Health Organization (WHO) published two reports, in 1999 and in 2009, on the protection of human health from all sources of sound exposure, but not specifically sound from wind turbines. These reports included comprehensive reviews of hundreds of scientific papers and set health protection guidelines.

In their 1999 report, *Guidelines for Community Noise*, an international expert panel established consensus guidelines for preventing interference with speech, hearing impairment, annoyance and sleep disturbance due to community noise. Their recommendations were also applied to various environments, including homes and schools both urban and rural. The report set guidelines for preventing sleep disturbance during the nighttime at 30 dBA in the bedroom averaged over eight hours, with a maximum of 45 dB (WHO 1999).

In 2009, the WHO published *Night Noise Guidelines for Europe* as an extension of its 1999 report. In this document, the expert panel identified 40 dB as the lowest observed

level for adverse health effects. This recommended limit is for an average exposure for a 12 month period, where the sound is measured or modeled at the outside facade of a dwelling where a person lives and sleeps. As with the earlier WHO guidelines, this recommended limit is for the prevention of adverse effects due to sleep disturbance. In the 2009 report, the WHO stated that there was a causal relationship between nighttime noise-generated disturbance of sleep and adverse health effects. In the WHO 1999 report, these associations were described only as weak. Epidemiological findings collected after the 1999 report (see below) provided the WHO stronger evidence of causality.

In both the 1999 and 2009 reports, the WHO identified populations that are more vulnerable to adverse health effects from noise, and should be considered when developing regulations or recommendations. In its Large Analysis and Review of European housing and health Status final report (*WHO LARES Final Report Noise Effects and Morbidity 2004*), the WHO presents data about the actual health experiences relative to noise for vulnerable populations, particularly children and the elderly. This report provides much of the epidemiological basis of the WHO 2009 conclusion that there is a causal relationship between sleep disturbance and adverse health effects. This relationship was especially the case for adverse effects on the cardiovascular, respiratory and musculoskeletal systems, and for depression.

The U.S. Environment Protection Agency (EPA) guidance published in 1974 is consistent with the more recent WHO 2009 40 dB nighttime yearly average guidelines. The EPA recommended that indoor day to night levels not exceed 45 dBA averaging over a 24-hour period, where 10 dB extra weight is given to nighttime sounds between 10 p.m. and 7 a.m., to minimize sleep disruption (EPA 1974).

Conclusions

The Vermont Department of Health concludes that there is no direct health effect from sound associated with wind turbine facilities. However, as determined in the 1999 WHO report, there is sufficient evidence of a secondary health effect from sleep disturbance due to excessive sound at night. The potential adverse health effects that can result from sleep

disturbance include increased heart rate, sleep state changes and awakening, increased use of medications to aid sleep, increased body movements, insomnia, fatigue, accidents, reduced performance, cardiovascular illness and depression and other mental illness (WHO 1999). The 1999 WHO report also concludes that limiting sound exposure at night to reduce the probability of sleep disturbance can minimize these effects in the exposed population.

To protect public health, the Vermont Department of Health recommends that nighttime sound levels from wind turbines be limited to 40 decibels or less, as measured at the exterior facade of the dwelling and averaged over 12 months of exposure. This is consistent with the most recent recommendations of the World Health Organization (WHO 2009).

This review and conclusions are general in nature. No specific wind turbine facility has been assessed.

Note

The scope of this literature review is limited as described above, and does not review or elaborate on potential health effects from very high level sounds associated with acoustic trauma or hearing loss that is not likely to result from public exposures to wind turbines (Colby *et al* 2009; Minnesota Department of Health 2009; Roberts and Roberts 2009). The intensity of sound generally required for these effects are unlikely, except very near or inside a wind turbine as might be the case for occupational exposures at a wind turbine facility. This review is focused on protecting public health.

Glossary

The following definitions are taken from the 1999 publication of the World Health Organization referenced in this report (1999):

Adverse effect: A change in morphology and physiology of an organism which results in impairment of functional capacity or impairment of capacity to compensate for additional stress or increase in susceptibility to the harmful effects of other environmental influences. This definition includes any temporary or long-term lowering of physical, psychological or social functioning of humans or human organs.

Acoustic trauma: Injury to hearing by noise, especially loud noise.

A-weighting: A frequency dependent correction that is applied to a measured or calculated sound of moderate intensity to mimic the varying sensitivity of the ear to sound for different frequencies.

Annoyance: A feeling of displeasure associated with any agent or condition known or believed by an individual or group to be adversely affecting them.

Cardiovascular: Pertaining to the heart and blood vessels.

Decibel (dB): Unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power.

dBA: A weighted frequency spectrum in dB, see A-weighting.

Frequency: For a function periodic in time, the reciprocal of the period.

Hearing impairment, hearing loss: A decreased ability to perceive sounds as compared with what the individual or examiner would regard as normal.

Hertz: Unit of frequency, the number of times a phenomenon repeats itself in one unit of time; abbreviated to Hz.

Mental health: In noise research, mental health covers a variety of symptoms, ranging from anxiety, emotional stress, nervous complaints, nausea, headaches, instability, argumentativeness, sexual impotency, changes in general mood and anxiety, and social conflicts, to more general psychiatric categories like neurosis, psychosis and hysteria.

Morphological: Pertaining to the science of structure and form of organisms without regard to function.

Noise: Undesired sound.

Stress: The sum of the biological reactions to any adverse stimulus, physical, mental or emotional, internal or external, that tends to disturb homeostasis.

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