Mark Bastasch, Jeroen van Dam, Bo Søndergaard & Anthony Rogers (2006) "Wind Turbine Noise - An Overview"
Canadian Acoustics Vol. 34(2). pp. 7-15



# Wind Turbine Noise – An Overview

**Mark Bastasch[1], Jeroen van Dam[2], Bo Søndergaard[3] and Anthony Rogers[4]**
1 – CH2M HILL, Portland, Oregon, U.S.A.
2 – Windward Engineering, Spanish Forks, Utah, USA
3 – Danish Electronics, Light & Acoustics, Hørsholm, Denmark
4 – Renewable Energy Research Laboratory, University of Massachusetts at Amherst, U.S.A.

## ABSTRACT

This paper presents a general overview of wind turbine noise including sources, measurements standards, psychoacoustics, infrasound, propagation and regulatory perspectives. The authors presented similar material at the National Wind Coordinating Committee's special meeting on "Technical Considerations in Siting Wind Developments" [1] held in Washington D.C. In addition, many relevant papers can be found in the proceedings of the First International Conference on Wind Turbine Noise 2005 [2], some of which are summarized here.

## RÉSUMÉ

Cet article présente un survol général du bruit des éoliennes, incluant les sources, les standards de mesures, la psychoacoustique, les infrasons, la propagation et les perspectives de réglementation. Les auteurs présentent du matériel similaire à la rencontre spéciale du Comité Coordonnateur National du Vent ("National Wind Coordinating Committee's") [1] sur le "Technical Considerations in Siting Wind Developments" tenu à Washington D.C. De plus, plusieurs articles pertinents peuvent être trouvés dans les actes de la Première Conférence Internationale du Bruit des Turbines à Vents en 2005 [2], Quelques un de ces articles sont résumés ici.

## 1. OVERVIEW

Wind turbines have many parts that generate noise but they can be broadly classified as either aerodynamic or mechanical. Mechanical sources of noise include the gearbox, cooling fans, the generator, the power converter, hydraulic pumps, the yaw motor and bearings. Modern turbines incorporate many mechanical noise-reducing features such as nacelle insulation, gearbox isolation, and silenced ventilation. Aerodynamic noise sources are a function of blade geometry (refer to Figure 1). Similar to a fan, the level of aerodynamic noise is highly correlated with the tip speed. Reducing aerodynamic noise is subject of current research [3].

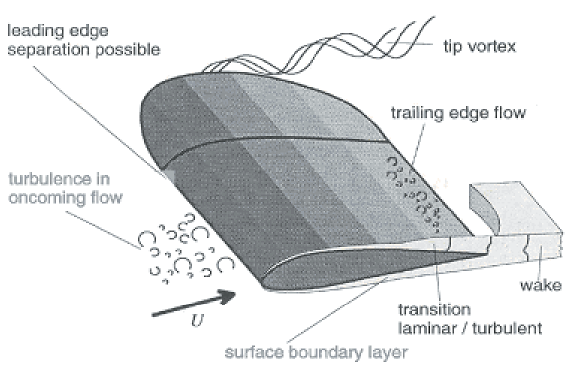


**Figure 1: Schematic of flow around the outer part of rotor blade [4]**

Modern turbines often have the ability to control their noise emissions through a combination of reduced rotor (and tip) speed and blade pitch angle adjustment. This typically comes at the cost of a reduced electrical power output. Typical sound power values for commercial scale wind turbines are in the range of 96-108 dB(A), LWA between cut-in and rated power.

## 2. MEASUREMENT STANDARDS

The International Energy Agency (IEA) has established guidelines for measuring the immisions of wind turbine at receptors, including Part 10, "Measurement of noise immission from wind turbines at noise receptor locations [5]." Because wind turbines do not generate noise, or at least not their normal noise level, under calm or low winds, typical guidelines for measuring noise from industrial or transportation sources are often inappropriate. The fact that background noise increases with wind speed, tending to mask turbine noise, complicates measurement interpretation. Typical background noise sound pressure levels range from 30-45 dB(A). Although the IEA provides recommendations to increase the signal to noise ratio, at more distant receptors it can be difficult to distinguish between turbine and background noise. It is for this reason that measuring noise levels closer to the turbine, where the signal to noise ratio is greater, and then calculating levels at greater distances may be preferred by some.

Most, if not all, turbine manufacturers provide sound power level data determined in accordance with International Electrotechnical Commission's (IEC) International Standard IEC 61400-11, *Wind Turbine Generator Systems – Part 11: Acoustic Noise Measurement Technique (2002)*. This standard defines reproducible measurement techniques that are accepted by the industry and often used in certification, guarantee and permitting applications. The microphone is placed on a reflective plate at ground level to reduce the effects of wind induced noise and to simplify the ground effect to +6 dB at all frequencies. The measurement location is downwind and one hub height plus half the rotor diameter away from the source.

The IEC 61400 standard establishes sound power levels for integer wind speeds between 6 and 10 m/s at a reference height of 10 meters. The reference to 10-meter height wind speeds in the IEC 61400-11 method is often misunderstood. The noise standards in the Netherlands [6] and guidance documents in Britain [7] and Australia [8, 9] often refer to wind speed measurements at 10-meters. This should not be confused with the IEC 61400-11 reference to 10 meters as IEC 61400-11 does not require noise measurements to be made when the winds at 10 meter height are at 6, 7, 8, 9 or 10 m/s or that the microphone is located at a height of 10 meters. In fact, the preferred method (which is required for declaration or certification measurements) does not allow wind speed to be measured with a 10 meter met tower (rather the electrical output of the turbine is the basis for determining the wind speed). The reference to 10-meter wind speeds in IEC 61400-11 is simply to ensure that manufacturers are standardizing their data in a similar fashion so that sound power levels of different turbines can be compared on a level playing field.

This is an important topic to understand particularly when assessing compliance with a relative or ambient degradation standard that limits the increase in noise levels. This is increasingly important as technology improves and the height of turbines continues to increase. Today it is not unusual to see wind turbines mounted on 80- or 100-meter towers, while several years ago 50-meter towers were more common. As the height of the towers increases, the correlation between the 10-meter wind speeds and those at hub height would likely decrease. It is for these reasons that the standardized IEC 61400 sound power levels must be adjusted to account for site specific variable such as roughness length and hub height when evaluating the increase in noise levels at specific wind speeds. Figure 2 shows an example where using the standardized values instead of the adjusted site specific values "will result in an underestimation of the noise contribution from the wind turbine at low wind speeds, and an overestimation of the noise contribution at higher wind speeds" [10]. Numerous papers are available to clarify this common misperception [11, 12].

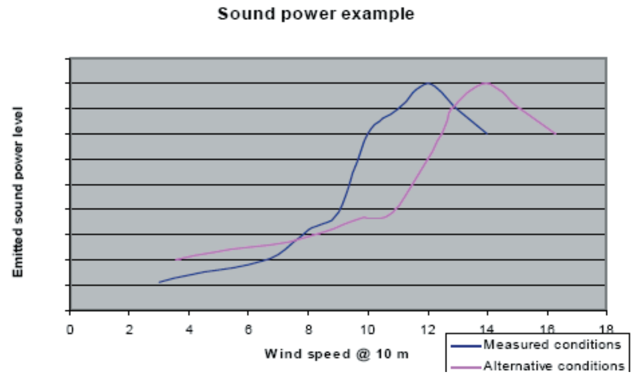


**Figure 2: Sound Power Level Example [10]**

Besides the determination of the sound power level, the IEC 61400-11 also provides a method for determining the severity of potential tones in the wind turbine noise. The same measurements are used as those taken for the calculation of the sound power level, though now the levels of individual frequency bands are determined. For each potential tonal frequency, its level is compared to the level of neighboring frequencies. The neighboring frequencies, or critical band, have the ability to mask the tone, making it less audible to the human ear. If tonal noise is present, local regulations may require a penalty in the form of reduced acceptable overall level, ultimately resulting in larger setback distances.

Within a population of wind turbines of the same make and model there will be variability in the measured sound power level and tonality values. This variation can be the result of different sub components or different suppliers of identical turbine components. IEC 61400-14, "Declaration of sound power level and tonality" provides a method to combine multiple test results from a population into a declared value that is not expected to be exceeded by 95% of the turbines in that population. This value can then be used by the manufacturer to set warranted levels.

IEC 61400 does not quantify other noise characteristics such as amplitude variation, or low frequency noise. Further discussion of those characteristics is given below.

## 3 PSYCHOACOUSTICS

Noise from wind turbines can be a major community concern. Complaints about wind turbine noise are not only a function of the ambient sound pressure levels, but also of the nature of human perception of noise.

It has long been known that annoyance from noise is not related to the noise levels themselves. For example, a meta-analysis of 136 community noise studies (Fields, 1993) [13] found that noise annoyance is only weakly related to noise levels. This analysis found that annoyance is related to:

- Noise sensitivity
- Fear of danger from the noise source

- Attitudes toward noise prevention
- Attitudes about the importance of the noise source
- Annoyance with non-noise aspects of the noise source

Even at low noise levels, a small percentage of people in these studies were highly annoyed.

The same conclusions apply to annoyance from wind turbine noise. A 1993 study by Wolsink et al. [14] looked at 564 people exposed to a sound pressure level (SPL) of 35 dB(A) +/- 5 dB. Only 6% of those surveyed were annoyed, with only a weak relationship between annoyance and A-weighted SPL. Variables related to annoyance included stress related to turbine noise, daily hassles, visual intrusion of wind turbines in the landscape, and the age of the turbine site. (Annoyance decreased the longer the facility was in operation.)

A more recent noise sensitivity study (Pederson and Waye, 2005) [15] looked at 518 people in a rural setting. Respondents were divided into six SPL categories. Annoyance was found to increase with noise level, but factors other than noise levels also were found to strongly affect annoyance. The authors found that the perception of annoyance due to wind turbine noise rises more quickly than with other stationary industrial noise sources at similar sound pressure levels. People with negative attitudes toward wind turbines and their impact on the landscape were more easily annoyed by turbine noise and people with positive or neutral attitudes toward wind turbines and their impact on the landscape were rarely annoyed. Negative attitudes toward wind turbines (and corresponding annoyance in response to turbine noise) was greater when respondents:

- saw the countryside as a place for peace and quiet rather than a place for economic activity and for making one's living;
- felt a lack of control (lack of awareness turbines were going to be built, inability to stop the noise when it annoyed them) or a lack of influence;
- sensed that they were being subjected to an injustice or that others did not understand (the implications of living close to a wind turbine).

Careful work at the planning stages of a project may help to address some of these factors, thus mitigating the surrounding communities' noise concerns.

## 4 INFRASOUND

Infrasound (acoustic energy at frequencies below 20 Hz) is an issue of concern but one that is often misunderstood by wind turbine project opponents.

There are many sources of ambient infrasound, both natural and anthropogenic. Natural sources of infrasound (between .001 Hz and 2 Hz) include ambient air turbulence and waves on the seashore. Man-made sources of infrasound include road vehicles, aircraft, machinery, artillery, air movement machinery, compressors and wind turbines.

Human perception of infrasound is primarily through auditory channels and is experienced as a change of static pressure, the periodic masking of higher frequencies and vibrations of objects excited by the infrasound. The human perception threshold increases as the sound frequency decreases. At frequencies of 20 Hz, the threshold of hearing is typically greater than 80 dB. At 10 Hz the average perception threshold is 100 dB and the standard deviation is about 6 dB. Therefore, at 10 Hz, there will be a very small percentage of people whose threshold is two standard deviations from the mean (less than 88 dB or greater than 112 dB.

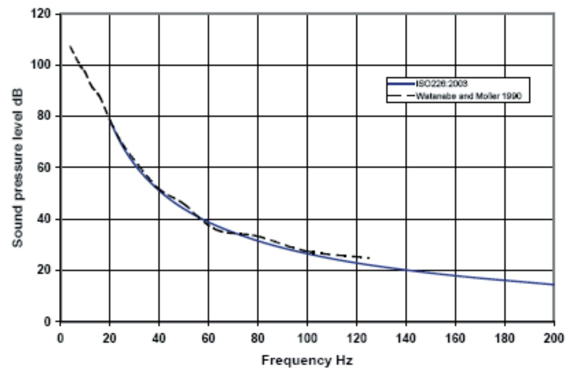


**Figure 3: Low Frequency Thresholds [20]**

At the same time, human sensitivity to increases in sound pressure levels is greater at lower frequencies. For example, a 10 dB increase at 1000 Hz is perceived as a doubling in the loudness, while only a 5 dB increase at 20 Hz is required to be perceived as doubling loudness. Given the variability in human perception levels and increased sensitivity to increases in sound pressure levels at low frequencies, small differences can have a highly variable impact on different people in terms of how annoying the sound is.

Infrasound is not dangerous unless it is very loud. Some humans may experience fatigue, apathy, abdominal symptoms, or hypertension when exposed to infrasound levels at about 115 dB. At 10 Hz, the threshold of pain is about 120 dB. Exposure to infrasound at 120-130 dB for a period of 24 hours causes physiological damage. It is important to reiterate, however, that *there is no evidence of adverse effects below 90 dB*.

The effects of low-frequency noise and infrasound are a topic of several studies and numerous press reports. The Western Morning News article titled "More Attention Must Be Paid to the Harmful Effects [16]" sites the work of Dr. Amanda Harry, a physician in the United Kingdom, who conducted a study that identifies health impacts from wind farms. Some of these impacts have been attributed to low-frequency noise, and similar claims have appeared in numerous anti-wind publications [17]. It appears that many of the effects may not be in whole or in part the result of low-frequency noise: “Another complaint which I encountered when talking to these neighbors of turbines is the effect of the rotating blades in the sunlight—this characteristically causes a strobe effect . . . this effect is not only obtained by direct vision of the blades but also from the shadow flicker caused by the blades in the light. The people questioned stated that this was a cause of headaches, migraines, nausea, vertigo and disorientation in many residents . . .[16]”

Dr. Geoff Leventhall author of "A Review of Published Research on Low Frequency Noise and its Effects" [18] is correctly quoted in the Western Morning News articles that low-frequency noise is a “background stressor which leads to inadequate reserves of coping and may lead to chronic psychological and physiological damage [16]”. However, Dr. Leventhall’s statements have been taken somewhat out of context with respect to low-frequency noise and wind turbines. When Dr. Leventhall was asked specifically about the effects of low-frequency noise from wind turbines, he responded. “There is only a relatively small amount of low-frequency noise from wind farms, where low-frequency noise is taken to mean 10 Hz to about 200 Hz. The noise is mainly mechanical, and gear related. Considering infrasound as below 20 Hz, there is very little from wind turbines. You have to distinguish between what is technically interesting and what is relevant to subjective effects. Available information shows that infrasound levels at approximately 100 meters from a turbine rise to 60 to 70 dB at 10Hz, where the average hearing threshold is nearly 100 dB. I really do not expect infrasound from modern wind turbines to be an issue, but because of the publicity which has been given to low frequency noise, we have to take this on board in order to find out the true facts [19]”.
Dr. Leventhalls recent paper [20] on the matter concluded:

Specialists in noise from wind turbines have work to do in educating the public on infrasound and low frequency noise. Specifically,

- Infrasound is not a problem,
- Low frequency noise may be audible under certain conditions,
- The regular 'swish' is not low frequency noise.

Advice to objector groups in this connection could be that, by dissipating their energy on objections to infrasound and low frequency noise, they are losing credibility and, perhaps, not giving sufficient attention to other factors.

In another publicized controversy, the Advertising Standards Authority in the UK adjudicated a complaint regarding an anti-wind pamphlet titled “Facts About Wind Power” [17]. In this case, the Authority ruled that claims, including that “wind turbines still create noise pollution, notably 'infrasound'—inaudible frequencies which nevertheless cause stress-related illness” was misleading.

Concern about infrasound from wind turbines may have originated from the experience of neighbors of early wind turbine designs with downwind rotors (rotors downwind of the tower). The effect of the sudden decrease in wind speed behind the tower on the flow around the blades created objectionable levels of infrasound. In contrast, all modern utility scale wind turbine have upwind rotors that produce significantly lower infrasound emissions. When standing close to a modern wind turbine one may hear a swish-swish sound at the blade passing frequency. This is an amplitude modulation of higher frequency blade tip turbulence and does not contain low frequencies.

Recently Rogers [21] reviewed examples of sound profiles measured at 80 to 118 m from various turbines that showed the range of sound pressure levels at various frequencies, including the infrasound range. For turbines ranging from 450 kW to 2 MW, maximum infrasound sound pressure levels were well below the perceptibility threshold of 90 dB. For example, at 10 m/s wind speed, the infrasound level measured at a distance of 80 m from a 850 kW Vestas turbine peaked at 70 dB, well below perceptible levels. Infrasound levels 118 m from a 2 MW wind turbine also peaked at 70 dB. Levanthal [22] used measurements taken at 100 m from a single turbine to calculate low frequency sound pressure levels at a distance of 400 m from a wind farm with 19 wind turbines. His results showed that at 25 Hz the sound pressure levels would be 25 dB below the sensitivity threshold of the most sensitive 2% of the population. Due to increasing threshold levels and only slightly higher sound pressure levels in the infrasound range, infrasound levels would be even more than 25 dB below the sensitivity threshold of the most sensitive 2% of the population.

Thus, research suggest that modern turbines do emit infrasound, but at levels below the minimum threshold of perception for most of the population, and well below the threshold for any adverse effects.

## 5 PROPAGATION OF NOISE FROM WIND TURBINES

There are multiple noise propagation models commercially available (ISO 9613-2, VDI 2714, Concawe, BS 228, General prediction method (Danish), Danish EPA guidelines, Netherlands guidelines 1999, Swedish methods for land and sea). Most of these were developed for noise from industry, for wind speeds below 5 m/s, and for downwind propagation.

In ISO9613-2 for example, all receiver locations are assumed to be downwind. A receiver on the east and west sides of a turbine are both assumed to be downwind simultaneously. The model assumes wind blows from each turbine to each receiver, every receiver is assumed to be downwind and every source upwind [23].The wind cannot at any time blow in all directions from every wind turbine, so this method results in a worst case analysis [24].

In some situations it may be advantageous to account for the shadow zone in the upwind direction (depicted in Figure 4). The Nord2000 model is one model capable of modeling upwind propagation [25].

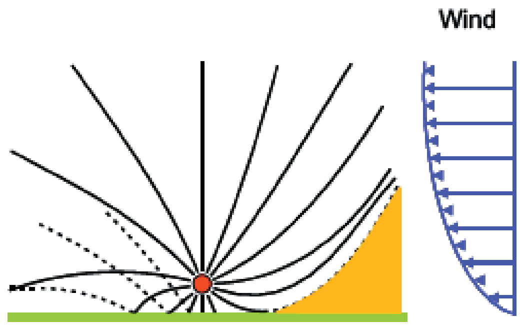


**Figure 4: Illustration of wind influence on sound propagation: Upwind of the source a shadow zone (hatched) occurs. [25]**

The upper part of Figure 5 shows an example of a terrain profile in a mountainous area with grass-covered ground. A wind turbine with 90 m hub height is situated at the left side and a receiver at 1.5 m above the ground to the right. The middle part of Figure 5 shows the terrain profile near the receiver in more detail and reveals a terrain edge screening the sound from the turbine.

The bottom part of Figure 5 shows the calculated effect of ground and screening per one-third octave in the frequency range from 25 Hz to 10 kHz with Nord2000. The solid line shows the result with 8 m/s downwind (wind from turbine to receiver), the dotted line for zero-wind (crosswind) and the dashed line for 8 m/s upwind (wind from receiver to turbine). The attenuation of the noise depends strongly on the weather with much lower noise levels during crosswind and upwind than during downwind. This is due to screening and shadow zone formation.

Figure 6 shows the variation in wind turbine noise source strength as a function of the wind speed in the top of the figure while the bottom of the Figure 6 shows the corresponding overall A-weighted noise levels according to Nord2000 at 1240 m distance at a flat site as a function of the wind speed. This figure includes both source strength variation and weather-induced variation in transmission path attenuation. At all wind speeds Nord2000 gives lower noise levels than ISO 9613-2 for hard ground and higher noise levels for porous ground.

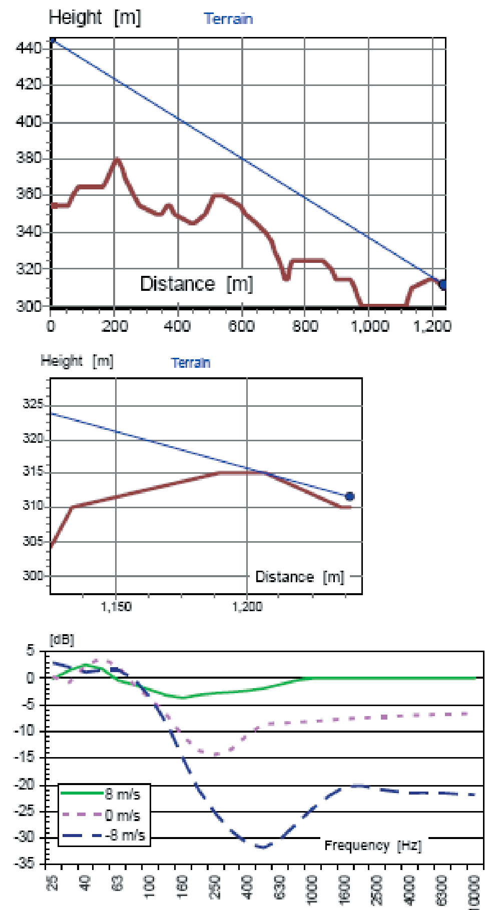


**Figure 5: Vertical section through source and receiver (top), a zoom-in near the receiver (middle), and the combined ground and screening effect [dB] (bottom) calculated for 8 m/s downwind, zero-wind, and 8 m/s upwind, respectively. [25]**

Figure 7 shows the ground effect calculated with Nord2000 on the sound propagating over water from a wind turbine with a hub height of 100 m at distances from 100 to 10,000 m assuming the source spectrum of a modern 2MW wind turbine at a wind speed of 8 m/s at 10 m height. The ground effect has been defined as the difference between the A-weighted sound pressure level and the A-weighted free-field sound pressure level. When calculating the sound pressure levels, the air absorption corresponding to an ISO-atmosphere (15° C and 70% RH) has been used. A flow resistivity of $\sigma$ = 20,000,000 $Nsm^{-4}$ corresponding to a hard surface has been assumed.

Figure 7 shows that the crosswind ground effect does not deviate much from the downwind ground effect. It also shows that the ground effect may be slightly higher (higher noise levels) during crosswind than during downwind at large distances. This is because the path length difference of the direct wave from source to receiver and the wave reflected from the ground is smaller in a homogeneous atmosphere than in a downward refracting atmosphere (meaning that the reflection from the ground is more likely to approach a +6 dB effect in the former case at large distances). The same effect can be seen for upwind at distances just below the distance where the shadow zone occurs. In the upwind direction, large attenuations are observed above a given distance due to a meteorological shadow zone. Below this distance the ground effect corresponds to the situation for the other wind directions.

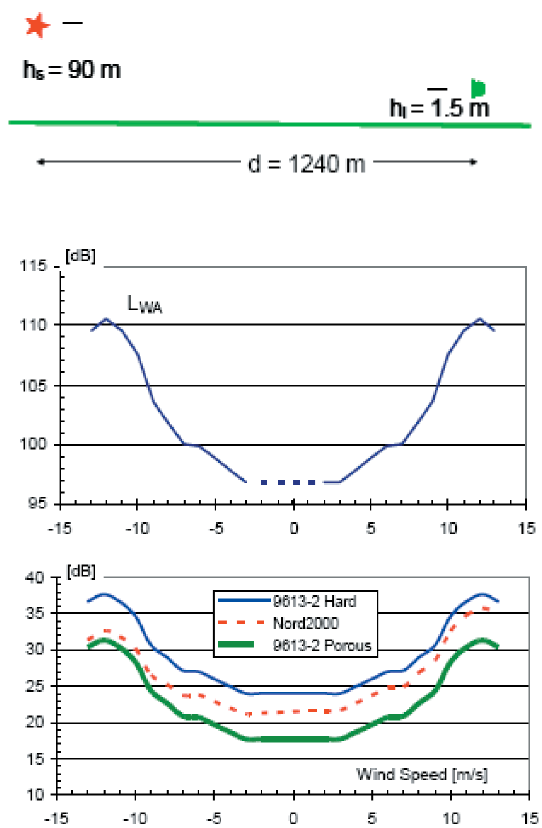


**Figure 6: Source strength LWA (top) and calculated noise level (bottom) from a wind turbine as a function of the wind speed [25]**

# 6 REGULATION OF WIND TURBINE NOISE IN THE UNITED STATES

In the United States, noise is regulated at the federal, state, and local levels. Only a few state or local governments have developed noise regulations specifically for wind turbines.

## 6.1 Federal Noise Regulation

The National Environmental Policy Act (NEPA) provides the regulatory framework for federal regulation of environmental impacts, including noise. However, the federal agencies (e.g., Federal Energy Regulatory Commission (FERC), the Federal Highway Administration, the Federal Aviation Administration, etc.) utilizing this framework have leeway to establish their own standards for what constitutes acceptable noise levels (refer to Table 1 and Figure 8).

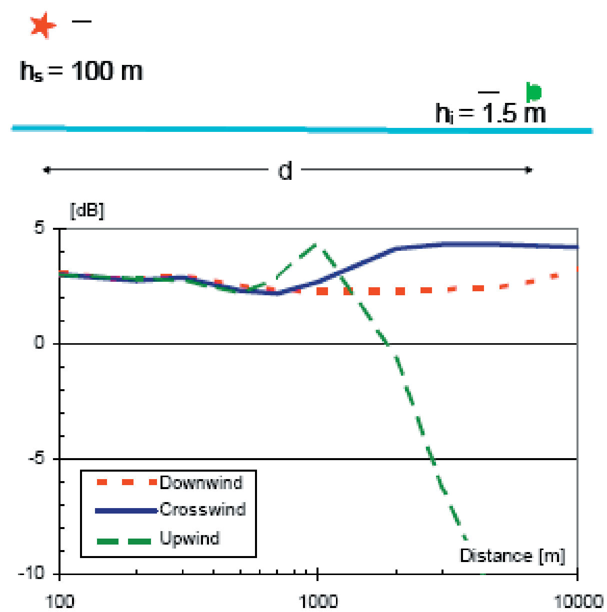


**Figure 7 – Calculated ground effect on sound propagating over water from a wind turbine with a hub height of 100 m at distances from 100 to 10,000 m [25]**

**Table 1: Summary of Federal Guidelines/Regulations for Exterior Noise (dBA)**

| Agency | $L_{eq}$ | DNL |
|---|---|---|
| Federal Energy Regulatory Commission (FERC) | [49] | 55 |
| Federal Highway Administration (FHWA) | 67 | [67] |
| Federal Aviation Administration (FAA) | [59] | 65 |
| U.S. Department of Transportation—Federal Rail and Transit Authorities (FRA & FTA) [26, 27] | Sliding scale, refer to Figure 8 | Sliding scale, refer to Figure 8 |
| U.S. Environmental Protection Agency (EPA) [28] | [49] | 55 |
| U.S. Department of Housing and Urban Development (HUD) [29] | [59] | 65 |

Note: Brackets [59] indicate calculated equivalent standard. Because FHWA regulates peak noise level, the DNL is assumed equivalent to the peak noise hour.

The U.S. Department of the Interior (DOI), Bureau of Land Management (BLM) is the federal agency charged with managing federal public lands and is responsible for the development of wind energy resources on BLM-administered lands. The BLM recently prepared a programmatic EIS in accordance with the requirements of NEPA to establish a "Wind Energy Development Program" [30].

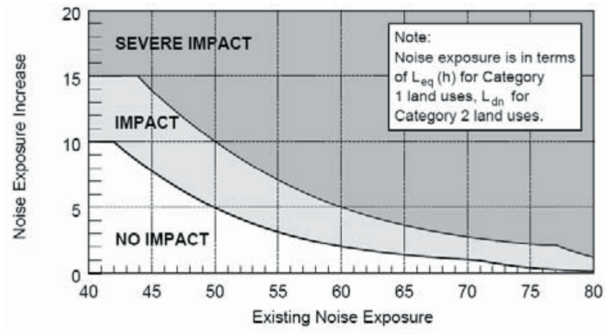


**Figure 8: FRA & FTA Allowable Increase in Cumulative Noise Level. (Note: Residential uses are included in Category 2) [26, 27]**

Several key findings/statements relevant to assessing noise impacts of a wind project are quoted below:

- At many wind energy project sites on BLM-administered lands, large fluctuations in broadband noise are common, and even a 10-dB increase would be unlikely to cause an adverse community response.
- For a typical rural environment, background noise is expected to be approximately 40 dB(A) during the day and 30 dB(A) at night, or about 35 dB(A) as DNL.
- The EPA guideline recommends a day-night sound level ($L_{dn}$) of 55 dB(A) to protect the public from the effect of broadband environmental noise in typically quiet outdoor and residential areas (EPA 1974). This level is not a regulatory goal but is "intentionally conservative to protect the most sensitive portion of the American population" with "an additional margin of safety."
- Geometric spreading alone results in a sound pressure level of 58 to 62 dB(A) at a distance of 50 meters (164 feet) from the turbine, which is about the same level as conversational speech at a 1-meter (3-foot) distance. At a receptor approximately 2,000 feet (600 meters) away, the equivalent sound pressure level would be 36 to 40 dB(A) when the wind is blowing from the turbine toward the receptor. This level is typical of background levels of a rural environment.
- To estimate combined noise levels from multiple turbines, the sound pressure level from each turbine should be estimated and summed. Different arrangements of multiple wind turbines (e.g., in a line along a ridge versus in clusters) would result in different noise levels; however, the resultant noise levels would not vary by more than 10 dB.
- Proponents of a wind energy development project should take measurements to assess the existing background noise levels at a given site and compare them with the anticipated noise levels associated with the proposed project.
- Noise generated by turbines, substations, transmission lines, and maintenance activities during the operational phase would approach typical background levels for rural areas at distances of 2,000 feet (600 meters) or less and, therefore, would not be expected to result in cumulative impacts to local residents.

While the above are not regulations, they provide detail on how BLM will assess the "significance" of noise impacts on individual projects and provide guidelines on how individual projects will need to address noise.

## 6.2 State and Local Regulations

According to a 1997 survey, only 13 states had state-level noise regulations [31]. Five of those states had regulations "on the books," but did not enforce them, although state permitting processes may require compliance. Some states, such as New York and California, do not have noise regulations, but do have guidance or model ordinances. For the most part, noise in the United States is regulated at the local level. Note that at both the state and local levels, noise regulations tend not to be written by acoustic professionals and are ambiguous. Regulations are discussed more thoroughly in Reference [32], below is a summary.

*Colorado.* Colorado's noise regulations stipulate that noise shall "not be objectionable due to intermittence, beat frequency, or shrillness," and impose a 5 dBA penalty for "periodic, impulsive, or shrill noises." However, none of these terms are defined in the regulations, and there are over 340 local jurisdictions which may impose additional standards.

*California.* Wind turbines are not regulated by the California Energy Commission (CEC), but the California Environmental Quality Act (CEQA) requires assessment of project-related noise increases. Local ordinances vary with some specifically addressing wind turbines and others not.

Riverside County establishes two thresholds for noise, one for permitting and another for operational compliance. An acoustical study is not required by the county when permitting a project where a 2,000-foot setback is maintained on projects consisting of 10 turbines or less or 3,000 feet when there are more than 10 turbines. When these setbacks are not maintained, an acoustical study must document wind project noise to be less than or equal to 55 dBA. Unless a more restrictive limit is established, operational noise (compliance measurements) is limited to 60 dBA.

In a recent permit for a wind project, PPM Energy's Shiloh project, Solano County limited a wind projects noise to 50 dBA CNEL or 44 dBA $L_{eq}$. It appeared to presume that level would be met if a 2,000-foot setback was maintained, but the county maintained the 50 dBA CNEL or 44 dBA $L_{eq}$ level as enforceable upon receipt of a complaint.

The Kern County General Plan requires proposed commercial and industrial uses or operations to be designed or arranged so that they will not subject residential or other noise sensitive land uses to exterior noise levels in excess of 65 dB $L_{dn}$ and interior noise levels in excess of 45 dB $L_{dn}$. For wind projects, Chapter 19.64 WIND ENERGY (WE) COMBINING DISTRICT of the Kern County Code establishes a not-to-exceed level of 50 dBA and an $L_{8.3}$ of 45 dBA. It also establishes for a waiver provided that the affected property owners consent and a permanent noise easement is recorded with the county.

For wind projects Chapter 88-3 WIND ENERGY CONVERSION SYSTEMS of the Contra Costa County Code establishes a maximum noise limit of 65 dBA at the property line. The noise element of the general plan states that noise levels up to 60 dBA $L_{dn}$ are normally acceptable at residential receptors.

*Oregon.* The State of Oregon has a new wind turbine noise (WTN) standard that [33]:

- establishes minimum existing ambient noise levels (26 dBA) – resulting in a 36 dBA maximum project level (if landowners choose not to waive it),
- requires maximum sound power level to be used in predictions ("worst case" analysis);
- allows wind developers to negotiate with landowners; with an upper limit of 50 dBA

## 7 EUROPEAN PERSPECTIVES ON NOISE CONTROL

Noise standards vary from one country to another. Denmark has one perspective, but Germany has a different one, Spain yet another, and so on. In Denmark and the northern part of Europe, noise limits are based on outdoor sound pressure levels, whereas further south, they are based on indoor sound pressure levels. This affects whether or not and how you take into account background noise. Distance requirements likewise vary from one place to another. In Denmark, the required minimum setback is four times the total turbine height from the nearest residence.

The 42nd IEA Topical Expert meeting, "Acceptability in implementation of wind turbines in social landscapes" was held in 2003 in Stockholm. One of the conclusions of this meeting was the importance of collaborative rather than "hierarchical" planning.

## 8 CONCLUSIONS

This paper presented a general overview of wind turbine noise including sources, measurements standards, psychoacoustics, infrasound, propagation and regulatory perspectives. Findings include:

Turbine noise level strongly correlates with tip speed.

The IEC 61400 standard governs the measurement (Part 11) and declaration (Part 14) of turbine sound power level.

It is important to understand the meaning of 10 meter high reference wind speed and site specific factors that influence correlation with hub height wind speeds.

Wind turbine noise can be perceived as annoying, particularly when negative attitudes toward wind turbines already exist.

Wind turbines do emit infrasound, but not at levels that should be cause for concern.

Propagation of wind turbines under various meteorological conditions can be evaluated with Nord2000.

Wind turbine noise regulations vary widely. Some allow for louder levels at "project participants".

## 9 REFERENCES


1 http://www.nationalwind.org/events/siting/default.htm

2 http://windturbinenoise2005.org/

3 Schepers, J.G. et al. "SIROCCO: Silent Rotors by aCoustic Optimalisation", Proceedings of Wind Turbine Noise 2005, Berlin, October 2005. www.windturbinenoise2005.org

4 Blake, W.K. Mechanics of Flow-Induced Sound and Vibration. Vol II: Complex Flow Structure Interactions. Academic Press Inc. Harcourt Brace Jovanaovich, 1986.

5 "Measurement of noise immission from wind turbines at noise receptor locations" IEA International Energy Agency (IEA), Part 10.

6 G.P. van den Berg, "Effects of the wind profile at night on wind turbine sound", J. Sound Vibr., Article In Press, (accepted September 2003)

7 Acoustics-Measurement, prediction and assessment of noise and wind turbine generators. Draft for public comment. (Standards Australia. March 31, 2004).

8 Environmental Noise Guidelines: Wind Farms. Environmental Protection Authority of South Australia. (February 2003)

9 Noise Working Group. The Assessment & Rating of Noise from Wind Farms. ETSU-R-7. (September 1996).

10 Sloth, E. "Modeling of noise from wind farms and evaluation of the noise annoyance." Proceedings of Wind Turbine Noise 2005, Berlin, October 2005.

11 Søndergaard, B. "Noise measurements according to IEC 61400-11. How to use the results." Proceedings of Wind Turbine Noise 2005, Berlin, October 2005.

12 Klug, H. "A Review of Wind Turbine Noise" Proceedings of Wind Turbine Noise 2005, Berlin, October 2005.

13 Fields, J. M., Effect of personal and situational variables on noise annoyance in residential area, Journal of Acoustical Society of America, 93, (5), 2753-2763, 1993.

14 Wolinski, M., Sprengers, M., Keuper, A., Pedersen, T. H., Westra, C. A., "Annoyance from wind turbine noise on sixteen sites in three countries, Proc. European community wind energy conference, March 8-12, 1993, Lübeck, pp. 273-276.

15 Pedersen, E., Waye, K. P., "Human response to wind turbine noise – annoyance and moderating factors", Proceedings of the First international Meeting on Wind Turbine Noise: Perspectives for Control, Berlin, October 17-18, 2005.

16 Western Morning News. "More Attention Must Be Paid to the Harmful Effects." Evidence received for renewable energy in Scotland inquiry. Submitted by John B. P. Hodgson to the Enterprise and Culture Committee of the Scottish Parliament. February 10, 2004. Viewed online April 15, 2004, at http://www.scottish.parliament.uk/enterprise/inquiries/rei/ec04-reis-hodgson,johnbp.htm.

17 Advertising Standards Authority. Complaint and adjudication relating to Ochils Environmental Protection Group t/a OEPG. March 31, 2004. Viewed online April 15, 2004, at http://www.asa.org.uk/adjudications/show_adjudication.asp?adjudication_id=37697&from_index=issues&issue_id=2

18 Geoff Leventhall, Peter Pelmear, and Stephen Benton. "A Review of Published Research on Low Frequency Noise and its Effects." Produced for the UK Department for Environment, Food, and Rural Affairs. May 2003. Viewed online April 15, 2004, at http://www.defra.gov.uk/environment/noise/lowfrequency/index.htm

19 Geoff Leventhall. Consultant in Noise Vibration and Acoustics. Personal communication (e-mail). (April 13-16, 2004).

20 Leventhall, G., "How the "mythology" of infrasound and low frequency noise related to wind turbines might have developed", Proceedings of the First international Meeting on Wind Turbine Noise: Perspectives for Control, Berlin, October 17-18, 2005.

21 "Infrasound and Psychoacoustics", Anthony L. Rogers, Ph.D. National Wind Coordinating Committee meeting on Wind Turbine Siting Issues, Washington, DC, December 2, 2005.

22 Leventhall, G., Low Frequency Noise from Wind Turbines with special reference to the Genesis Power Ltd Proposal, near Wailuku NZ,. Geoff Leventhall, Surry UK, June 2004

23 Brittan, Frank. Proceedings of INCE NoiseCON04, Baltimore, MD.

24 Sloth, E. "Modeling of noise from wind farms and evaluation of the noise annoyance." Proceedings of Wind Turbine Noise 2005, Berlin, October 2005.

25 "Prediction of Wind Turbine Noise Propagation over Complex Terrain in all kinds of Weather with Nord2000" Kragh, J. et al, Proceedings of Wind Turbine Noise 2005.w

26 *High-Speed Ground Transportation Noise and Vibration Impact Assessment.* U. S. Department of Transportation, Federal Railroad Administration (December 1998). Available online at http://www.fra.dot.gov/downloads/RRDev/nvman1_75.pdf

27 *Transit Noise and Vibration Impact Assessment*. U. S. Department of Transportation, Federal Transit Administration (April 1995). Available online at http://ntl.bts.gov/data/rail05/rail05.html

28 *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety,* EPA-550/9-74-004, EPA. U.S. Environmental Protection Agency (March 1974)

29 United States Code of Federal Regulations Title 24 Part 51B.

30 *Final Programmatic Environmental Impact Statement on Wind Energy Development on BLM-Administered Lands in the Western United States*. U.S. Department of Interior, Bureau of Land Management (June 2005). Available online at http://windeis.anl.gov/eis/index.cfm

31 www.Nonoise.org

32 Bastasch, M. "Regulation of Wind Turbine Noise in the Western United States." Proceedings of Wind Turbine Noise 2005, Berlin, October 2005.

33 Bastasch, M. "Revising Oregon's Noise Regulations for Wind Turbines." Proceedings of INCE NoiseCON04, Baltimore, MD.