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# WIND TURBINES AND SOUND: REVIEW AND BEST PRACTICE GUIDELINES

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## 1. INTRODUCTION

Howe Gastmeier Chapnik Limited (HGC Engineering) was retained by the Canadian Wind Energy Association (CanWEA) to develop a best practice guide for the development of wind turbine generation facilities in Canada with respect to noise.

Wind power generation has become an accepted industry in Canada, with large scale wind farms involving 20 or more wind turbines now operating in most provinces. Today, Canada has over 1,000 MW of installed wind energy capacity, and the federal government and some provincial governments have programs in place to promote further wind energy projects. Wind is a renewable resource, and with the potential economic and environmental advantages, the prevalence of wind farms in Canada is sure to increase.

The rate of growth of wind farms in Canada brings more people into closer proximity to the wind turbine generators, and it is important that any potential impact from future projects be well assessed. CanWEA has commissioned this study as a review of current practices with regard to noise assessment and to develop a guide for future efforts. The study has been based on a review of relevant literature, discussions with wind farm developers and environmental regulators in different Canadian jurisdictions, and on the experience of HGC Engineering and others pertaining to the assessment of noise associated with wind farms in Canada.

The report begins with a discussion of noise in general, its descriptors and assessment methods, and moves to a discussion of wind turbine generators and the noise they produce. A review of various guidelines and standards used as criteria for assessment of noise in Canada are described, together with a review of international and Canadian experience with the assessment of wind turbine generator noise, based on the results of the surveys and interviews. The report ends with the presentation of the best practice guideline.

## 2. ACOUSTIC PRIMER

Sound is a complex phenomenon with temporal, spatial and psychological dimensions. Noise is simply unwanted sound. Sounds vary in many ways including loudness, character, temporal pattern, and are audible to different extents by different people in different environments. In order to have a meaningful discussion of sound, it is productive to consider some basic terminology.

One of the most basic descriptors of sound is the sound level, or more accurately, the sound pressure level (SPL). The SPL of a sound indicates little about the source of the sound, its character or what it sounds like, but describes only its magnitude. Sound pressure levels are most commonly measured and described in decibels, denoted dB or A-weighted decibels, denoted dBA. A-weighted decibels more closely correlate with the subjective loudness of a sound, as discerned by the human ear.

Another basic descriptor of sound is the Sound Power Level (PWL). This is a basic quantity directly describing the amount of acoustic power radiated by a source. It is the fundamental quantity which produces a sound pressure level (SPL) at a distance. It is used to define the source for assessment purposes, and to calculate the SPL at a receptor. The PWL is also usually described in decibels or A-weighted decibels.

The frequency content (or spectrum) is the property we perceive as pitch, which gives a sound its unique character. A sound can be a purely high frequency sound (a treble note), or a purely low frequency sound (a bass note), or more commonly is made up of a complex mixture of frequencies. A spectral analysis breaks a measured sound into a number of frequency bands of a defined width, like the notes on a musical scale. In acoustics, frequency is most commonly measured in cycles per second, or Hertz, designated Hz.

Human sensitivity to sound can vary considerably between individuals, typically decreasing with age and past exposure to noise. In general, young people are sensitive to sound in the range of

20 to 20,000 Hz. Sounds predominantly outside of this range are difficult to detect except in extreme cases. Also, very quiet sound, measurable with appropriate instrumentation, can be completely inaudible to people, being below the threshold of hearing.

Ambient sound, or background sound, can strongly affect the audibility of a particular sound in a particular environment. In a very noisy environment, such as a factory floor, one must often shout to be heard. Similarly, on a windy day, a nearby industry can be made inaudible (masked) by the natural sounds produced by the wind in the trees, or other environmental noise such as traffic.

The acceptability of sound from an industrial source by an individual depends on many factors. The sound level is an important factor, but is certainly not the only one. The background sound in an area is also important as it directly affects audibility through masking. As background sound levels typically change from moment to moment, as when vehicles pass nearby, aircraft fly overhead, birds chirp and the wind gusts, the sound is less noticeable , possibly inaudible at times, and may not attract an individual’s attention. The character of a sound (does it buzz, rattle, hum, whine, swoosh or thump) can also significantly affect the audibility and potential annoyance. The activities that an observer is engaged in also impact the relative acceptability; someone playing or walking on a busy afternoon will generally notice or be irritated by a noise much less than someone woken up in the middle of the night.

The list below provides definitions of various acoustic terminology used in this report.

**Octave Band:** A filter with a bandwidth of one octave, or twelve semi-tones on the musical scale representing a doubling of frequency.

**1/3-Octave Band:** A filter with a bandwidth of one-third of an octave representing four semitones, or notes on the musical scale. This relationship is applied to both the width of the band, and the centre frequency of the band.

**A-Weighting:** This is a filter, often applied to a pressure signal or to a *SPL* or *PWL* spectrum, which decreases or amplifies certain frequencies in accordance with international standards to approximate the frequency dependence of average human hearing.

**Amplitude Modulated Sound:** A sound which noticeably fluctuates in loudness over time.

**Audible Frequency Range:** Generally assumed to be the range from about 20 Hz to 20,000 Hz, the range of frequencies which our ears perceive as sound.

**C-Weighting:** This is an international standard filter, which can be applied to a pressure signal or to a *SPL* or *PWL* spectrum, and which is essentially a pass-band filter in the frequency range of approximately 63 to 4000 Hz. This filter provides a more constant, flatter, frequency response, providing significantly less adjustment than the A-scale filter for frequencies less than 1000 Hz.

**$L_{EQ}$ (Energy Equivalent or Average Sound Level):** A sound level, which if constant over a measurement period, would contain the same acoustic energy as a varying sound level actually measured over the period.

**Frequency:** The rate of oscillation of a sound, measured in units of Hertz (Hz) or kilohertz (kHz). One hundred Hz is a rate of one hundred times per second. The frequency of a sound is the property we perceive as pitch: a low-frequency sound (such as a bass note) oscillates at a relatively slow rate, and a high-frequency sound (such as a treble note) oscillates at a relatively high rate.

**G-Weighting:** A filter used to represent the infrasonic components of a sound spectrum.

**Infrasound:** Sound with a frequency content below the threshold of hearing, generally held to be about 20 Hz. Infrasonic sound with sufficiently large amplitude can be perceived, and is both heard and felt as vibration. While perceptible levels of infrasound can be unsettling and objectionable, there does not appear to be any reliable evidence that adverse impacts on the body occur when amplitudes are below the threshold of hearing. Natural sources of infrasound are waves, thunder and wind.

**Linear Weighting:** This is a term used to indicate that a measurement does not have *A-weighting* or any other frequency weighting applied to it.

**Overall Sound Level:** For the measurements in this report, indicates that the reported level (*SPL*, *SL*, etc.) is the summation of measurements of all audible frequencies (20 Hz to 20 kHz), whether or not A-weighted. Analogous to and alternately implemented as a passband filter from 20 Hz to 20 kHz.

**Sound Power, *w*:** This is the acoustic power output of a sound source, expressed in Watts. It is a function of the source parameters itself and is virtually independent of the environment in which it is located.

**Sound Power Level, *PWL* or $L_W$:** Reported in dB (or dBA if A-weighted), this is 10 times the logarithmic ratio of the acoustic power output of a source to 1 picoWatt. A sound power level is an attribute of a source of noise, virtually independent of both the environment in which it is located and the location of any observer. A sound pressure level meter does not directly measure sound power.

**Sound Pressure, *P*:** Reported in rms Pascals, is the dynamic variation in atmospheric pressure.

**Sound Pressure Level, *SPL*:** A sound pressure level is equivalent to 20 times the logarithmic ratio of the instantaneous sound pressure (in Pascals) of the sound being measured to that at the threshold of hearing, defined as 20 microPascals. Accordingly, the sound pressure level changes from place to place and time to time. The sound pressure level is generally what is meant by the term 'noise level'. Sound pressure levels are expressed in decibels (dB), or A-weighted decibels (dBA).

**Spectrogram:** A chart used to visually illustrate a time-varying sound spectrum. The vertical axis represents frequency, the horizontal axis represents time, and colours used to represent amplitude.

**Spectrum:** Sound Pressure signals may be passed through a parallel series of filters (e.g. *1/3-octave band*) to produce *SPL*s in each filter band. When these are presented in sequential order of filter band, a Sound Pressure Level spectrum is produced. A similar process may be applied to produce Sound Power Level or Sound Intensity Level spectra.

**Time Weighting:** This is an exponential time response function applied to the pressure signal being measured, effectively dampening the signal's response to quickly and highly varying sound pressures.

**Tonal:** A tonal sound is a sound with a significant portion of its energy confined to a narrow frequency band. A highly tonal sound is often described as a buzz, whine, or hum.

**Ultrasound:** Frequencies of sound above the audible range (generally considered to be greater than 20,000 Hz) are not audible or perceptible to humans, but can be perceived by some animals.

## 3. WIND TURBINES, TURBINE SOUND PRODUCTION AND PROPAGATION

A wide variety of wind turbine designs have been developed and constructed in the world and in Canada in recent decades. These have included designs incorporating a vertical axis of rotation, with which the National Research Centre of Canada was involved, and designs incorporating a horizontal axis of rotation which are more common today. Horizontal-axis turbines have been designed in many ways usually using a two or three bladed rotor, but sometimes with rotors using as few as one blade or more than three. Designs have placed the rotor blades both upwind and downwind of the tower. A wide variety of sizes and rated generating capacities have also been developed. Today, most wind turbine generators are horizontal-axis systems with a nacelle housing the gearbox, generator and rotation equipment at the top of the tower connected to the three-bladed rotor, as illustrated in Figure 1. The nacelle rotates to face the wind. These systems have blades with a variable pitch meaning that the blades themselves can rotate around their own radial axis to catch either more or less wind, controlling the speed of the turbine.

Canada today has over 1,000 MW of installed wind turbine generator capacity, and has wind farms dating back to the mid 1990s. The most common turbines installed in the last couple of years appear to be horizontal-axis systems in the 1 to 2 MW range, usually with a nacelle height of about 80 metres, and a blade diameter of about 80 metres. The rotation speed is usually in the range of about 10 to 20 rpm with tip speeds in the subsonic range of 150 to 300 km/hr, with systems allowing for some flexibility in the rotation speed.

Wind turbine generators produce noise through a number of different mechanisms which can be roughly grouped into mechanical and aerodynamic sources. The major mechanical components including the gearbox, generator and yaw motors each produce their own characteristic sounds. Other mechanical systems such as fans and hydraulic motors can also contribute to the overall acoustic emissions. Mechanical noise is radiated by the surfaces of the turbine, and by openings in the nacelle casing. The interaction of air and the turbine blades produces aerodynamic noise through a variety of processes as air passes over and past the blades. Generally, wind turbines radiate more noise as the wind speed increases.

Modern wind turbine generators are considerably quieter than earlier versions, with some investigators showing a reduction in recent years of about 10 dB over earlier versions. Different models and different manufacturer's systems have their own acoustic characteristics, although various investigations indicate that the radiated sound power levels form a fairly consistent band as shown in Figure 2. Sound power levels of 105 dBA re $10^{-12}$ W are typical for modern turbines in the 1 to 2 MW range at moderate wind speeds.

The noise produced by a wind turbine generator can include tonal components produced by the gearbox and generator. The noise produced by air interacting with the turbine blades tends to be broadband noise, but is amplitude modulated as the blades pass the tower, resulting in a characteristic 'swoosh'. The spectrograph attached as Figure 3 illustrates the swoosh measured near a typical wind turbine generator, showing an amplitude modulation of about 0.8 Hz, most audible in the 250 to 1000 Hz range.

There appears to be some confusion between this low speed temporal modulation of sound and low-frequency or low-pitched sounds. To avoid misunderstanding, it should be realized that any sound, with predominantly low, middle, or high-pitched frequency content, can be modulated in time, without changing the pitch of the sound. Low frequency modulation of audible sound does not imply the presence of infrasound.

Some older turbines, with blades arranged downwind of the tower, resulted in infrasonic noise being generated through changes in the airflow pressure near the tower. In modern turbines with upwind blades, this issue has been minimized. While a great deal of discussion about infrasound in connection with wind turbine generators exists in the media there is no verifiable evidence for infrasound production by modern turbines.

Because modern horizontal axis turbines can vary rotor speed and blade pitch, there is some ability to control the aerodynamic noise of the turbines, and this creates some variability in the sound of a wind turbine generator.

There has been discussion about the appropriate weighting network for the assessment of a wind turbine noise. While there are a variety of weighting networks in use for various technical purposes, an A-weighted spectrum provides a better indicator of the spectral makeup of a sound as perceived by the human ear than any other frequency weighting network commonly in use today. For this reason, it is used worldwide in the assessment of the impact of environmental noise on people, and has been widely adopted in assessment guidelines and criteria. While the use of another weighting network, such as the C-weighting network would generate a higher single-number sound level descriptor than the equivalent A-weighting level, it is unclear what it would represent in terms of human perception, and it is equally unclear what the appropriate criterion for a C-weighted sound level would be. There does not appear to be any technical justification for the use of the C-weighting network in the assessment of the acceptability of noise from wind turbine generators on people.

Mechanical issues such as yaw motor supports or power train design can result in anomalous sounds such as periodic booming or tonal noises. Experience in Canada suggests that often these matters can generally be corrected through maintenance.

Sound radiating from a sound source to a receptor location is attenuated through a number of mechanisms in addition to the simple geometric spreading with distance. These include viscous losses in the air, interaction with the ground and any intervening structures, topography or vegetation. Sound from a wind turbine generator is no different. Various calculation methodologies are used to predict sound levels at a specified point. One such model which currently sees wide application in Canada is ISO standard 9613-2, *Acoustics – Attenuation of sound during propagation outdoors*. This model uses as input the total acoustic energy radiated by the operating wind turbine generator (the sound power level), and predicts the sound pressure level at any given point, taking into account the natural propagation mechanisms discussed above.

Atmospheric conditions play a large role determining the sound level due to a wind turbine generator at any given location at any given time. Different prediction models consider atmospheric effects in different ways. ISO 9613-2 considers propagation conditions equivalent to a moderate downwind condition in all directions simultaneously (ie, the model favors the propagation of sound from a source to any receptor to some degree). However, it does not purport to consider the absolute worst case environmental situation, and consequently, there may be times when the actual impact exceeds that predicted, due to infrequent or extreme environmental conditions. While ISO 9613-2 has this and other limitations, it remains a widely applied and recognized assessment methodology.

The subjective audibility of a wind turbine generator is also highly dependant on the background sound level. The sound from a wind turbine generator generally increases with wind speed, but so too does the background sound. Interestingly, both the experience of HGC Engineering and published articles suggest that the greatest apparent intrusion of sound of a modern wind turbine over the background sound typically occurs at relatively low wind speeds. At high wind speeds, the wind tends to generate significant background sound by moving trees, grasses, etc. in most environments, masking the sound of a wind turbine.

## 4. ASSESSMENT CRITERIA

The assessment of the acceptability of a sound is complex. In Canada, a number of assessment guidelines, methodologies and criteria are currently in use. The standards generally recognise that different acceptability criteria should apply in different circumstances, often offering different criteria during different times of the day, and for different acoustical environments (such as urban settings, as well as rural or natural settings). Many standards are explicitly based on background sound levels, often qualified with minimum levels for use in very quiet areas. Audibility is generally not an assessment criterion for industrial noise under the provincial documents; it is not expected that a receptor should be entirely free of industrial noise.

Several provincial jurisdictions do not have specific sound level guideline policies for environmental noise published by the provincial ministries of the environment. Included in this group are the Maritime Provinces, Saskatchewan and British Columbia. Other provinces have guidelines governing the assessment of industrial sound developed to various degrees. At present, Ontario is the only provincial jurisdiction with a noise assessment guideline specifically intended for wind turbine generators, recognising that the maximum sound power output generally corresponds with high background sound levels. The provincial noise guidelines are briefly discussed below:

Manitoba

The Manitoba Department of Environment has published *Guidelines for Sound Pollution Prepared by Environmental Management Division*". That document provides separate limits for residential areas, commercial areas and industrial areas. For a residential area, the Maximum Acceptable sound levels are 60 dBA and 50 dBA during daytime (07:00 to 22:00) and nighttime (22:00 to 07:00) hours respectively. The Maximum Desirable sound levels are 55 and 45 dBA for daytime and nighttime hours respectively. The Maximum Acceptable levels are to be reduced by 5 dBA if the sound source under assessment contains predominant discrete tones or impulsive character. Definitions of tonal and impulsive character are provided in the guideline. There is no guideline or document specific to wind turbine generator noise.

Quebec

Instruction note 98-01, published by *Ministère du Développement durable, de l'Environnement et des Parcs* provides criteria and a methodology for assessing noise from industrial sound sources, including power related facilities. The standard provides different sound level criteria for different areas, and for nighttime and daytime hours. For a residential area with a light density, the limits are 40 dBA and 45 dBA during the nighttime and daytime respectively, and for denser areas the limits increase by 5 dBA.

Alberta

The Alberta Energy & Utility Board publishes noise guidelines for energy related industrial installations. The noise guidelines are contained in Directive ID99-08. The limits depend on the background sound at the point of reception, as well as several other factors including the dwelling density per quarter section. In areas where the background sound and dwelling density are low, the Permissible Sound Level (PSL) is 40 dBA at night and 50 dBA during the day. (Daytime is 07:00 to 22:00 and night is 22:00 to 07:00). In some cases of very low sound level, the limits could be slightly lower than these, but are typically somewhat greater. The PSL applies to the combined level of the background sound and the source under assessment. There is no specific technical guideline for assessing the acoustic impact of wind turbine generators, although such a document is currently under discussion.

Ontario

The Ontario Ministry of Environment (MOE) publishes a fairly comprehensive series of guideline documents for assessing industrial noise. Two of the MOE guideline documents, NPC-205 *Sound Level Limits for Stationary Sources in Class 1 and 2 Areas (Urban)*, and NPC-232 *Sound Level Limits for Stationary Sources in Class 3 Areas (Rural)* provide general assessment guidelines for industrial noise impacting a sensitive land use such as a residence or residential area. An acoustically urban area is defined as one with man-made sounds such as traffic dominating the acoustic environment. Rural areas have sound levels generally dominated by natural sounds, other than the industrial noise source under consideration.

Both NPC-205 and NPC-232 indicate that in general, the applicable sound level limit for a stationary source of sound is the background sound level. However, where background sound levels are low, exclusionary minimum criteria apply, with an exclusionary limit of 40 dBA specified for quiet nighttime periods in rural areas, and 45 dBA specified for quiet daytime periods in rural areas. In urban areas, these limits are 45 dBA and 50 dBA for nighttime and daytime periods.

Because wind turbines generate more sound as the wind speeds increase, and because increasing wind speeds tend to cause greater background sound levels, wind turbine generators have been identified by the MOE as a unique case, and they have provided supplementary guidance for the assessment of wind turbine generator noise in publication *Interpretation for Applying MOE NPC Technical Publications to Wind Turbine Generators* (hereafter, *Interpretation*). This publication, while consistent with NPC-232 at low wind speeds, provides criteria for the combined impact of all wind turbine generators in an area as a function of wind speed, thus adjusting to some degree the criteria of NPC-232. The criteria are presented in A-weighted decibels, as follows.

**Table 1. MOE Criteria for Wind Turbines.**

| **Wind Speed [m/s]** | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|
| **Wind Turbine Noise Criteria [dBA]** | 40 | 40 | 40 | 43 | 45 | 49 | 51 | 53 |

This guideline publication specifies an analytical method of assessment; the manufacturers sound power data is used as input to a model which predicts the acoustic impact at a point of reception over a full range of wind speeds. The publication further specifies that the calculation methodology of ISO 9613-2, *Acoustics-Attenuation of sound during propagation outdoors* be used. Consequently, the MOE guidelines share the limitations of ISO 9613-2, and yield a receptor sound level under a single assumed propagation condition that does not reflect a realistic meteorological situation, but is generally favourable to the propagation of sound from a source to a receptor (essentially a moderate downwind condition in all directions). Consequently, there may be times when the actual impact exceeds that predicted.

It is important to note that the MOE guidelines do not require inaudibility of a sound source. In fact, even if the sound levels from a source are less than the criteria, the spectral and temporal characteristics of a sound often result in audibility.

<u>Federal Government</u>

Health Canada, Natural Resources Canada, the Canadian Environmental Assessment Agency all have experience and capability in the assessment of noise from wind turbine generators, and are actively involved with their assessment. However, for the most part, these Ministries and agencies rely on provincial regulations where they apply.

## 5. REVIEW OF CANADIAN EXPERIENCE

During the preparation of this survey, environmental assessments for several wind farm projects were reviewed. Eight different wind farm developers were contacted to discuss their experiences with noise assessment and other acoustic issues in different jurisdictions in Canada. Altogether, developers of wind farms in Nova Scotia, Quebec, Ontario, Saskatchewan and Alberta were interviewed. British Columbia does not yet have an operating wind farm, but some are under consideration at present.

Each of the wind farms had a substantial number of large wind turbine generators in place and operational. A number of the wind farms are sited such that residences are located between 300 and 400 metres, and this is generally the minimum setback encountered. Often, residences this close or closer are associated with a landowner leasing land to the wind farm and experiences with this situation appear positive. However, particularly where no financial relationship exists, complaints amongst people living this close to a wind turbine generator are not uncommon.

In populated areas, typical sound level impacts from turbines tend to be 40 to 50 dBA at the closest homes, although atmospheric conditions have a significant effect on the actual sound level at any given moment.

Some areas of Canada with very light population densities have seen wind farm projects. In such areas, plans placing no wind turbine generator closer to a residence than about 1000 metres have been feasible. Not surprisingly, complaints at this distance are very rare.

A realistic expectation of the acoustic impact of the potential audibility of a proposed wind farm appears to be critical. Public consultation and dialog is of course important at all stages of a project, but without an accurate understanding of wind turbine noise such consultation can be counterproductive. One developer discussed a site which had a pilot turbine installed early on in the development process. This allowed local residents to see and hear the turbine, creating a realistic expectation to the eventual impact of the completed farm. A similar effect occurs in areas with pre-existing wind farms. Conversely, where the expectation of inaudibility was suggested, the ensuing audible wind turbine noise was deemed unacceptable by affected residences.

Mechanical problems with wind turbine generators tend to produce identifiable sounds, increasing the potential for annoyance and complaints among nearby residents. For example, mechanical issues such as yaw motor supports or power train designs can result in anomalous sound producing periodic booming or tonal noises. Developer's experience suggested that such problems can be correctable.

Neither a review of published technical literature, nor the experience of HGC Engineering indicates that infrasound in connection with wind turbine generators is a problem in Canada.

## 6. CONCLUSIONS AND BEST PRACTICE GUIDELINES

With its potential for environmental and economic advantages, wind power generation has quickly become an accepted industry in Canada with over 1,000 MW of installed wind energy capacity. Large scale wind farms with 20 or more wind turbines are now operating in most of the provinces, and their prevalence is sure to increase. However, when wind farms come close to residences, consideration must be given to ensuring a compatible co-existence. The residences should not be adversely affected and yet, at the same time the wind farms need to reach an optimal scale in terms of layout and number of units.

Wind turbines produce sound, primarily due to mechanical operations and aerodynamics effects at the blades. Modern wind turbine manufacturers have virtually eliminated the noise impact caused by mechanical sources, and instituted measures to reduce the aerodynamic effects. But, as with many activities in society, the wind turbines emit sound power at a level that does impact areas at some distance away. When residences are nearby, care must be taken to ensure that the operations at the wind farm do not unduly cause annoyance or otherwise interfere with the quality of life of the residents. This is not to suggest that the sound should be inaudible under all circumstances – this is an unrealistic expectation that is not required or expected from any other agricultural, commercial, industrial or transportation related noise source – but rather that the sound due to the wind turbines should be at a reasonable level in relation to the ambient sound levels.

Discussions with a variety of wind farm operators and regulators across the country leave no doubt that the above goal can be achieved, and very often is. There have been some situations where issues related to sound have arisen. Lessons can and should be learned from these situations and assimilated by the wind farm developers in future endeavours. With this in mind, the following are suggested as best practices for future wind farm developments, presented somewhat in order of implementation.

1. At the initial stage of planning for a potential wind farm site, it is important to identify all potentially critical receptors for noise. These include residences, but could also include institutional uses such as hospitals, schools or places of worship, or First Nations sacred sites. In addition, the zoning and official plans for the jurisdictions should be considered to determine if future receptors are currently allowed. Needless to say, the wind farms have to make themselves aware of and comply with any local, provincial and federal approvals processes.

2. Good public relations are essential, and at the early stage this principally consists of educating the public with respect to the sound generated by wind turbines. The information presented to the public should be factual and should not set unrealistic expectations. It is counterproductive to suggest that the wind turbines will be inaudible, or to use vague terms like "quiet". Modern wind turbines produce a sound due to the aerodynamic interaction of the wind with the turbine blades, audible as a "swoosh", which can be heard at some distance from the turbines. The magnitude of the sound will depend on a multitude of variables and will vary from day to day and from place to place with environmental and operational conditions. Audibility is distinct from the sound level, since it depends on the relationship between the sound level from the wind turbines and the ambient background sound level. As wind farms are becoming common across the country, arranging visits to existing operations or using pilot installations is an excellent means of allowing community members to hear and judge the situation for themselves.

3. Community involvement needs to continue throughout the project. Annoyance is a complicated psychological phenomenon; as with many industrial operations, expressed annoyance with sound can reflect an overall annoyance with the project, rather than a rational reaction to the sound itself. Wind projects offer a benefit to the environment and the energy supply for the greater population, and offer economic benefits to the land owners leasing installation sites to the wind farm. A positive community attitude

throughout the greater area should be fostered, particularly with those residents near the wind farm, to ensure they do not feel taken advantage of.

4. While dealing with the public in a straightforward and honest fashion, it is important for the wind farm proponents to dispel inaccurate concerns and rumours that sometimes arise. For example, infrasound is often cited as a concern despite the fact that numerous studies, along with HGC Engineering's own research, show that it is not an issue for modern wind turbines.

5. In certain jurisdictions and situations there is pressure to introduce guidelines that require a certain minimum distance between the placement of turbines and any residential receptors. In fact, distances of up to 1,000 m have been proposed in an attempt to eliminate complaints. While this would likely achieve that goal, it is not well founded and would unduly hamper the wind power industry. It is far more appropriate to deal with each application on its own merits, taking into account the topography in the area, the number and placement of the wind turbine, the sound power produced by the particular model of wind turbine, and the ambient sound levels at the receptors. For example, based on a review of operating wind farms in rural areas with 10 or more turbines rated in the range of 1 to 2 MW, acceptable separation distances for sound are generally found to be in the neighbourhood of 300 to 600 m, depending on the particulars for the site. For residences near single low noise models of turbines, separation distances of less than 250 m may achieve acceptable sound levels. Strict enforcement of a large separation distance would also not make sense for installations in high density urban areas or near busy highways, or in instances where the resident has ownership in the turbine and prefers a lower separation distance.

6. A technical assessment of the sound impact of a wind farm project should be undertaken if there are any potentially sensitive receptors within a kilometre or so, even if one is not specifically required during the approval process. The assessment should be completed

by an engineer qualified in the area of acoustics, following accepted engineering practices, and be based on reliable data.

7. Ambient sound levels should be monitored at the receptors to assist in defining criteria and to provide a benchmark for any sound measurements following start-up of the operations. It is important to note that, particularly in quiet rural areas, the ambient sound levels are influenced by wind – as the wind speed increases the ambient sound levels increase. Therefore, it is appropriate to correlate ambient sound levels to wind speed.

8. Accurate sound power data for the wind turbines is necessary for the predictions, and is readily available from leading manufacturers. The sound power data should be based on measurements conducted in accordance with IEC 61400-11, *Wind turbine generator systems – Part 11: Acoustic noise measurement techniques,* and be provided as a function of wind speed.

9. Predictions of the sound levels should be made using an accepted methodology that takes into account the layout of the wind farm and the topography of the surrounding area. ISO 9613-2, *Acoustics-Attenuation of sound during propagation outdoors* is the internationally recognized standard recommended by the Ontario Ministry of the Environment under their assessment protocol, is implemented in most of the leading environmental acoustical modelling packages, and is currently under review by the Canadian Standards Association (CSA) for adoption in Canada. It is important to recognize that ISO 9613-2 is only one of several possible prediction standards, and that while it is considered conservative in that it relies on an assumed atmospheric condition that favours the propagation of sound to the receptor, it does not necessarily predict the absolute worst case. Thus, it must be anticipated that some degree of statistical variability will occur in practice.

10. The specific numeric criteria for the sound pressure level produced by wind turbines vary from jurisdiction to jurisdiction. Many provinces do not currently provide numeric sound level criteria. Some, such as Alberta and Quebec provide applicable environment sound level limits from industrial sources, but these have not necessarily been specifically developed for wind turbines. The Ontario Ministry of the Environment provides the most comprehensive guidance relevant to wind turbines in their publications NPC-232 *Sound Level Limits for Stationary Sources in Class 3 Areas (Rural)* and PIBS 4709 *Interpretation of Applying MOE NPC Technical Publications to Wind Turbine Generators*. *Interpretation* is an analytical, prediction-based standard that relies on sound powers from IEC 61400-11 using the propagation model of ISO 9631-2. It is well suited for wind turbines because it starts with criteria similar to Alberta and Quebec, 40 dBA at night in quiet rural areas, but adjusts the limit for acceptability as a function of wind speed, reflecting the fact that the ambient sound levels increase with wind speed. The criteria are presented in A-weighted decibels, as follows.

**Table 1. Recommended Sound Criteria for Wind Turbines.**

| **Wind Speed [m/s]** | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|
| **Wind Turbine Noise Criteria [dBA]** | 40 | 40 | 40 | 43 | 45 | 49 | 51 | 53 |

In all likelihood, given the relatively early stage of large scale wind energy production in Canada, guidelines and criteria will develop further in the various jurisdictions. In the meantime, and in the absence of locally applicable assessment criteria, it is suggested that an approach similar to that put forward in the Ontario Ministry of the Environment guidelines be used. Even still, it should be appreciated by all parties that adhering to these guidelines does not necessarily ensure that there will be no complaints from area residents. Under selected circumstances, further investigation may be in order. For instance, it may be appropriate to give special consideration to residences in quiet valleys that are affected by wind to a lesser degree than nearby wind turbines.

Good public relations during the construction and following start-up can be just as important as during the planning stages. The wind farm should maintain a commitment to the community and respond to concerns in an expedient fashion. Sporadic and legitimate noise complaints could develop. For example, sudden and sharp increases in sound levels could result from mechanical malfunctions or perforations or slits in the blades. Problems of this nature can be corrected quickly, and it is in the wind farm developer's interest to do so.

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Figure 1: A Typical Modern Horizontal-Axis, Upwind Turbine in Use Throughout Canada Today.

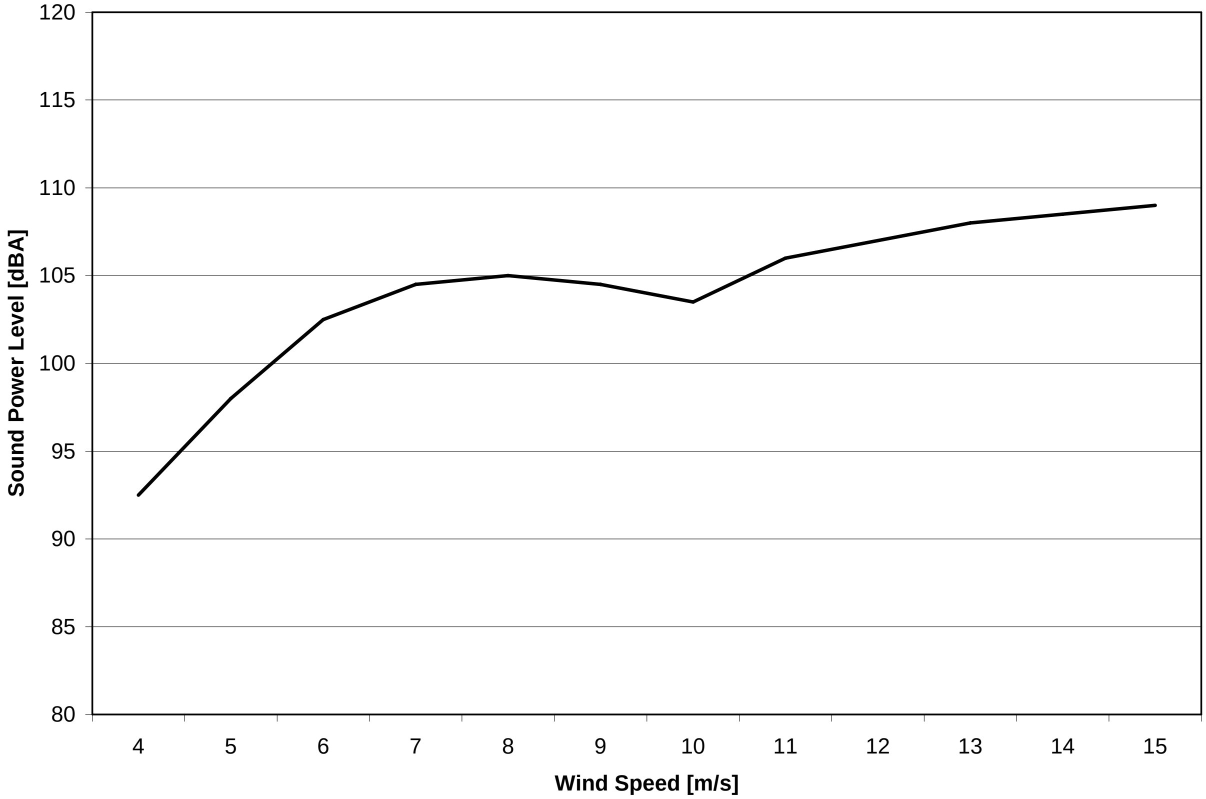


Figure 2: Typical Sound Power Levels of Modern 2 MW Wind Turbine

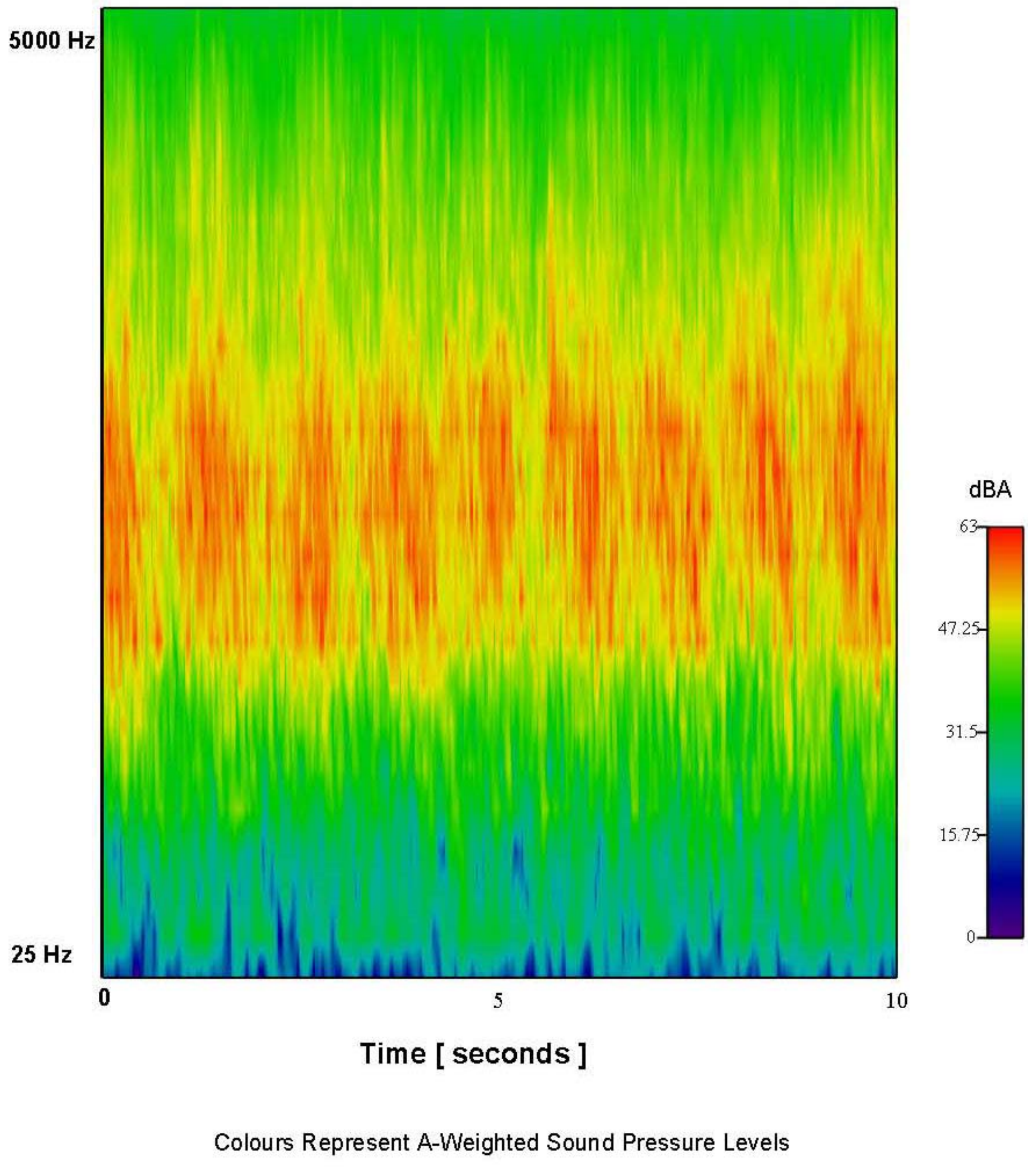


Figure 3: Spectrogram of Sound Pressure Level Measured at 70 metres from a Modern 1.5 MW Wind Turbine Generator

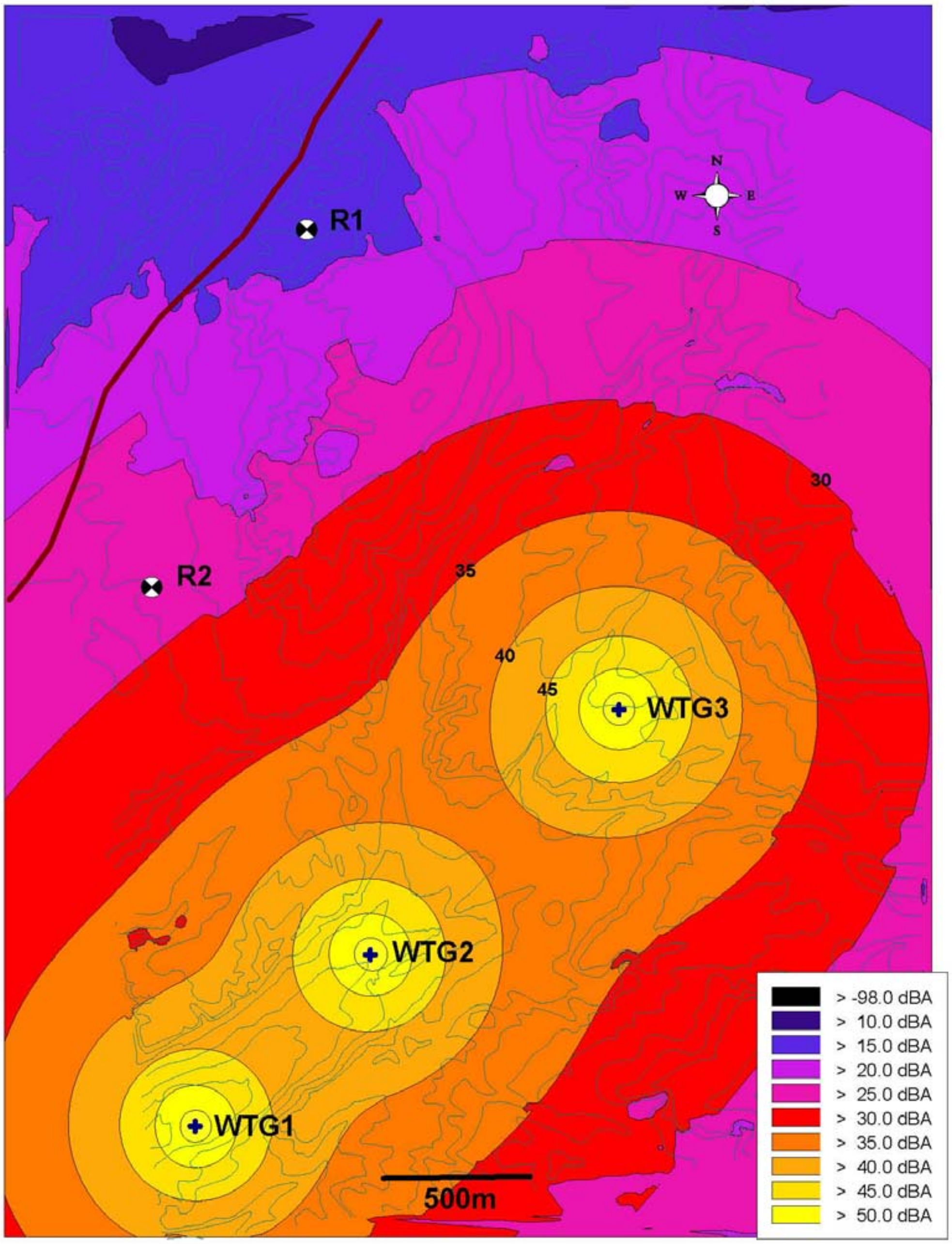


Figure 4: Representative Acoustic Model showing the Propagation of Sound from Typical Wind Turbine Generators