Date:	October 07, 2014
Re:	State of Vermont Docket No. 8167 Sound Limits Related to Wind Turbines
To:	Geoff Commons Director for Public Advocacy Vermont Public Service Dept. 112 State St. Montpelier, VT 05620-2601
Prepared by:	Intrinsik Environmental Sciences and Aercoustics Engineering Limited

Dear Mr. Commons,

The purpose of this memo is to provide you with information about existing sound limits for wind turbines in response to State of Vermont Docket No. 8167. Thank you for the opportunity to work with you on this issue. If you have any questions, please contact the undersigned at your convenience.

Sincerely,

INTRINSIK ENVIRONMENTAL SCIENCES

and

AERCOUSTICS ENGINEERING LIMITED

Loren Knopper, B.Sc., M.Sc., Ph.D.
Senior Scientist
Intrinsik Environmental Sciences Inc.
6605 Hurontario Street, Suite 500
Mississauga, ON L5T 0A3
Phone: 905-364-7800 ext 210
email: lknopper@intrinsik.com

Christopher Ollson, PhD
Vice President, Strategic Development
Intrinsik Environmental Sciences Inc.
6605 Hurontario Street, Suite 500
Mississauga, ON L5T 0A3
Phone: 905-364-7800 ext 232
email: collson@intrinsik.com

Payam Ashtiani, B.A.Sc., P.Eng.
Aercoustics Engineering Ltd.
50 Ronson Dr., Suite 165,
Toronto, ON M9W 1B3
Phone: 416-249-3361 ext 234
Email:PayamA@aercoustics.com

Introduction

Exposure to excessive levels of audible noise, regardless of the source, can cause annoyance, sleep disturbance, cognitive impairment and other serious health effects. According to the World Health Organization (WHO), night time exposure to noise levels above 55 dB(A), averaged over the year, is considered increasingly dangerous for public health and a sizeable proportion of the population will be highly annoyed and sleep-disturbed [1]. It is well known that wind turbines used for the generation of electricity produce audible noise during their normal operation. As a means of protecting the public from potential noise-related health effects from wind turbines, jurisdictions across the globe have developed noise regulations specific to wind turbine projects (Table 1). Though some variability exists among jurisdictions, the majority of the guidelines center around an outdoor limit between 40 and 45 dB(A). This limit coincides with the WHO Europe night time noise guideline of 40 dB(A) outdoors, a health-based value derived to *"protect the public, including the most vulnerable groups such as children, the chronically ill and the elderly, from the adverse health effects of night noise"* [1].

Table 1. Wind turbine noise limits per jurisdiction

Country/Region	Noise Limits	Reference
Australia/New South Wales	"For a new wind farm development, the predicted equivalent noise level (L eq, 10 minute), adjusted for any excessive levels of tonality, amplitude modulation or low frequency, but including all other normal wind farm characteristics, should not exceed 35dB(A) or the background noise (L 90) by more than 5dB(A), whichever is the greater, at all relevant receivers not associated with the wind farm, for wind speed from cut-in to rated power of the WTG and each integer wind speed in between. The noise criteria must be established on the basis of separate daytime (7am to 10pm) and night-time (10pm to 7am) periods"…"criteria have been set to restrict noise generated by wind turbines to 5dB(A) below the lowest acceptable noise criteria for a suburban or rural amenity area (which is 40dB(A) at night)".	[2]
Australia/South	Background noise is to be measured at the wind farm at various wind speeds at which the turbines operate to determine masking effects of wind generated noise at relevant receiver locations. Noise level predictions are to be identified at all relevant receiver locations. Wind farm noise levels, that may be adjusted for tonality, should not exceed "35 dB(A) at relevant receivers in localities which are primarily intended for rural living, or 40dB(A) at relevant receivers in localities in other zones, or the background noise (L Aeq, 10) by more than 5 dB(A), whichever is greater". Wind turbine setback distances are then based on these criteria.	[3]
Australia/Western	Sound generated from wind farms should not exceed 5 dB(A) above the background sound level or 35 dB(A) using a 10-minute L Aeq, whichever is greater. Measurements are to be taken at noise-sensitive premises. Setback limits are based on data obtained from sound studies with a one kilometer guideline.	[4,5]
Australia/Victoria	Noise level limits are set in accordance with the New Zealand Standard NZS 6808:2010 where "the level of sound from a wind farm should not exceed the background sound level by more than 5 decibels (dB), or a level of 40 dB L A90 (10 min), whichever is the greater"… "despite any other condition of this permit, no plans will be endorsed by the responsible authority, and no variation to the endorsed plans will be approved by the responsible authority, which allow a turbine to be located with 2 kms of an existing dwelling…unless evidence has been provided to the satisfaction of the responsible authority that the owner of the dwelling has consented in writing to the location of the turbine".	[6,7]

Table 1. Wind turbine noise limits per jurisdiction

Country/Region	Noise Limits	Reference
Canada/Alberta	The minimum basic sound level used to calculate the permissible sound level is 40 dB(A) L eq nighttime with adjustments made for proximity to transportation and population density. The night noise limits should remain between 40 and 56 dB(A) LA eq, based on the number of other residences and existing infrastructure noise sources. For most wind energy locations, the night noise limits will probably fall between 40 and 46 dB(A) LA eq. The day noise limits are 10 dB(A) above night limits.	[8]
Canada/British Columbia	Outdoor sound levels measured at an existing residence are to not exceed a maximum of 40 dB(A) based on wind speed 8-11 m/s. More specifically, "where ambient conditions are 35 dB(A) or less: night-time criterion: L eq, 9hr of 40 dB(A) between 10:00 pm and 7:00 am; Day-time criterion: L eq, 15 hr of 40 dBA between 7:00 am and 10:00 pm; Ambient conditions are to be assumed at 35 dB(A) for calculation purposes. Where ambient conditions are shown to be greater than 35 dB(A) during either the day or night (except where another wind power project is present), a 5 dB(A) increment may be applied to a measured background sound level to determine the day or night criterion, to a maximum of 50 dB(A)".	[9]
Canada/Manitoba	Sound limits are based on the levels recommended by CanWEA where a sliding scale based on wind speed is used. These levels start at 40 dB(A) at a wind speed of 4 m/s and rise to 53 dB(A) at 11 m/s. For setback limits, sound modeling-based assessments have been used to determine that 500-550 m from a receptor (an occupied dwelling) is sufficient to ensure that the sound criteria can be met.	[10]
Canada/New Brunswick	At a wind speed of 7m/s the overall noise limit is 40 dB(A), this value increases with increasing wind speeds to 53 dB(A) at speeds equal to or greater than 10 m/s. Proposed wind farms must demonstrate compliancy with these guidelines for all sensitive receptors, including homes and recreational areas within 1 km of the turbine. These values are used to determined setback distances.	[5,11]
Canada/Ontario	“If the wind turbine(s) are audible in a recording (does not include extraneous noise sources) then additional analysis is required for the subject recording: determine the value of the 10 minute L eq via software or obtain it directly from the recording device; determine if the wind turbine noise is tonal; obtain the average wind speed at the microphone height (1.5 or 4.5 metres) over the 10 minute recording session”... “Results of the10 minute L eq (including tonal penalty if applicable) are to be compared against the applicable sound level limits contained in the 2008 Noise Guidelines” where at standardized wind speeds at 10 m Height from below 5 m/s to 10 m/s the sound level limit ranges from 40 dB(A) to 51 dB(A).	[12]
Canada/Quebec	Based on a review by the Minnesota Department of Commerce, municipalities determine setbacks in the Province of Quebec, with 500 m being the most commonly used setback distance. No noise guidelines were reported. However, it does appear the Province of Quebec has a nighttime rural noise limit (zone 1) of 40 dBA that is not wind turbine specific	[13, 14]
Denmark	“The total noise impact from wind turbines may not exceed the following limit values: 1) At the most noise-exposed point in outdoor living area no more than 15 meters from dwellings in open countryside: (a) 44 dB(A) at a wind speed of 8 m/s. (b) 42 dB(A) at a wind speed of 6 m/s. 2) At the most noise-exposed point in areas with noise-sensitive land use: (a) 39 dB(A) at a wind speed of 8 m/s. (b) 37 dB(A) at a wind speed of 6 m/s.”	[15]
Germany	"For immission points outside buildings, the binding immission values for the rating level are: a) in industrial areas 70 dB(A); b) in commercial zones during the day 65 dB(A) at night 50 dB(A) c) in core areas, village areas and mixed-use zones during the day 60 dB(A) at night 45 dB(A); d) in general residential areas and small residential estate areas during the day 55 dB(A) at night 40 dB(A); e) in purely residential areas during the day 50 dB(A) at night 35 dB(A); f) in spa areas, for hospitals and nursing homes during the day 45 dB(A) at night 35 dB(A)."	[16]

Table 1. Wind turbine noise limits per jurisdiction

Country/Region	Noise Limits	Reference
Ireland	A minimum setback distance of 500 m has been suggested, but is not absolute "because of the lack of correlation between separation distance and wind turbine sound levels, the use of a defined setback of turbines…is not appropriate"… An outdoor limit of 40 dB(A) "attributed to one or more wind turbines, should be applied in order to restrict noise from wind turbines at noise sensitive properties" was defined. Post construction noise levels can be measured at wind farms to confirm if noise regulations are being met.	[17]
New Zealand	"The level of sound from a wind farm should not exceed the background sound level by more than 5 decibels (dB), or a level of 40 dB L A90 (10 min), whichever is the greater. 40 dB is typical of a quiet residential area with only light traffic and natural sounds such as the wind in the trees. In contrast, sound levels along-side an urban road would be around 60 to 70 dB during the day and about 50 to 60 dB at night. There are some locations that are particularly quiet at times and so the recommended limit of 40 dB would be considered to be unreasonable"… "Where a local authority has identified in its district plan the need to provide a higher degree of protection of acoustic amenity. The Standard recommends that when particular conditions are met, the sound from the wind farm during the evening and night time should not exceed the background sound level by more than 5 dB or a level of 35 dB LA90(10 min),whichever is the greater."	[7]
UK/England	For both day and night time, noise is recommended to be limited to 5 dB(A) above background noise. There is a fixed night limit of 43 dB(A) using L A90 (10 min) or 45 dB(A) for properties benefitting financially from wind turbine development. A penalty of up to 5 dB(A) may be added if a distinct tone is distinguishable. England has no minimum setback distance though the noise limits suggest a minimum of 350 meters for a typical wind turbine.	[18]
USA/Oregon	For noise generated by a wind energy facility, the assumed background L50 noise levels if 26 dB(A) or the actual ambient background level. "The noise levels from a wind energy facility may increase the ambient statistical noise levels L10 and L50 by more than 10 dBA… Noise levels at the appropriate measurement point are predicted assuming that all of the proposed wind facility's turbines are operating between cut-in speed and the wind speed corresponding to the maximum sound power level established by IEC 61400-11 (version 2002-12).	[19]
USA/Massachusetts	Massachusetts has draft "Promising Practices for Nighttime Sound Pressure Levels by Land Use Type" for wind turbine noise. These values were provided in a 2012 report (Wind Turbine Health Impact Study). MassDEP convened a technical advisory group to consider potential revisions to its noise regulations and policy. The Promising Practices for Nighttime Sound Pressure Levels are: Industrial areas 70 dBA; Commercial areas 50 dBA; Villages, mixed usage 45 dBA; Sparsely populated areas, 8 m/s wind 44 dBA; Sparsely populated areas, 6 m/s wind 42 dBA; Residential areas, 8 m/s wind 39 dBA; Residential areas, 6 m/s wind 37 dBA. Wind speeds should be measured at 10 m above ground, outside of residence or location of concern	[20]
USA/New Hampshire	No noise limit has been imposed by the State. However the State Site Evaluation Committee (SEC) has accepted a 45 dBA setback on at least one project (e.g., Groton Wind Project; Groton, New Hampshire)	[21]
USA/Maine	The State of Maine has Sound Level Limits for Routine Operation of Wind Energy Developments in Chapter 375 of Rule Chapters for the Department of Environmental Protection. The sound levels resulting from routine operation of a wind energy development shall not exceed (a) 75 dBA at any time of day at any property line of the wind energy development or contiguous property owned or controlled by the wind energy developer, whichever is farther from the proposed wind energy development's regulated sound sources; and (b) 55 dBA between 7:00 a.m. and 7:00 p.m. (the "daytime limit"), and 42 dBA between 7:00 p.m. and 7:00 a.m. (the "nighttime limit") at any protected location.	[22]

Table 1. Wind turbine noise limits per jurisdiction

Country/Region	Noise Limits	Reference
USA/New York	It appears that no noise limits are prescribed by New York State; rather assessments are based on likelihood of perception of noise above ambient	[23]

Infrasound and Low Frequency Noise

Wind turbines produce noise that is broadband in nature, meaning generated noise includes infrasound (IS; 0.01-20 Hz) and low frequency noise (LFN; 10-200 Hz) spectrums. Only two jurisdictions were found that have developed clear guidelines for IS, but neither is specific to wind turbine noise (Table 2).

1. The Queensland Department of Environment and Resource Management's Draft *ECOACCESS Guideline- Assessment of Low Frequency Noise* proposed an interior IS limit of 85 dB(G) [24]. Unlike the audible noise limits from the previous section that are presented in dB(A), limits for IS are often provided in dB(G). The dB(G) weighting highlights the lower frequency range from 1 to 20 Hz. This value was derived based on a 10 dB protection level from the average 95 dB(G) hearing threshold [25] and previous Danish recommendations for IS limits [26].

2. The Japanese Handbook on Low Frequency Noise provides an IS reference value of 92 dB(G) at 10 Hz and 1/3 octave bands up to 80 Hz [27]. These values were derived from investigations that monitored complaints of mental and physical discomfort from healthy adults exposed to low frequency sounds in a room [27].

Table 2. Infrasound noise limits per jurisdiction (not wind turbine specific)

Country/Region	Noise Limits	Reference
Australia/Queensland	G-weighting function used to determine annoyance due to infrasound within the frequency range from 1 Hz to 20 Hz. The recommended limit value for infrasound inside dwellings during the day, evening and night is 85 dB(G). Noise is measured over a 10-minute period and a 5 dB penalty is added for impulsive noise. Approximate determination of sound pressure level may be made by analysis of the signal using one-third octave bands and application of the provided weighting values.	[24]
Japan	The reference value for complaints of mental and physical discomfort include the G-weighted sound pressure level of 92 dB(G) as measured at 10 Hz.	[28]

Similarly, only a small number of jurisdictions have outdoor LFN noise limits and again, these are not specific to wind turbine noise (Table 3). Several of these guidelines determine the difference between C- and A-weighted sound measurements [3,8,28]. This calculation can provide an indication of an unbalanced spectrum; a difference greater than 20 dB between two weightings may warrant further investigation based on those regulations [29, 30].

Table 3. Outdoor LFN Noise Limits per Jurisdiction (not wind turbine specific)

Country/Region	Noise Limits	Reference
Australia/New South Wales	Considered it unnecessary to establish the full spectral signature of all wind turbines based on the findings that wind turbines have very similar spectral signatures and do not generate excessive levels of low frequency noise. Recommended using dB(C) measurements at intermediate locations to identify any anomalies such as a mechanical problem or a need for any further investigation. "Trigger levels of 65/60 dB(C) as suggested by Broner (2011) were adopted."... "5dB(A) penalty should be applied to the predicted or measured noise level from the wind farm for the periods and meteorological conditions under which the low frequency noise has been identified". *New South Wales Industrial Noise Policy (1999)* suggests that a difference of 15 dB or greater between dB(A) and dB(C) weightings can establish the presence of a low frequency noise can be established and addressed.	[28]
Australia/South Australia	Follow the suggestions made by the New South Wales Industrial Noise Policy, but do not provide any specific limit or required actions.	[3]
Canada/Alberta	A LFN issue exists both when "A) the time weighted dBC-dBA value for the measured daytime or nighttime period is equal to or greater than 20 dB and B) A clear tonal component exists at a frequency between 20 to 250 Hz." When a LFN issue has been identified, measurements of C- and A-weighted scales are to be made concurrently. The presence of a LFN issue is confirmed when both "A) The isolated time-weighted average dBC - dBA value for the measured daytime or nighttime period is equal to or greater than 20 dB. For the 1/3 octave frequency bands between 20 to 250 Hz and below: a) the linear sound level of one band must be at least 10 dB or more above one of the adjacent bands within two one-third octave bandwidths b) there must be at least a five dB drop in level within two bandwidths on the opposite side of the frequency band exhibiting the high sound levels". If these conditions exist, "five dBA must be added to the measured comprehensive sound level. If this value exceeds the permissible sound level, the licensee must identify the source of the LFN and implement noise attenuation measures to address the issue in a timely way."	[8]
Japan	Reference values for outdoor measurements of low frequency noise to provide guidance in how to address complaints of rattling windows and doors are provided for 1/3-octave bands from 5 Hz up to 50 Hz as reported in L eq. The values were based on rattling thresholds observed in two studies. At 5 Hz the maximum value is 70 dB L eq and increases up to 99 dB L eq at 50 Hz.	[27]

In 2014, Knopper et al. [31] published a review of the scientific literature conducted on wind turbines and human health. Based on the available evidence, these authors suggested the following best practices for wind turbine development in the context of human health. These limits are meant to be consistent with WHO time measurements (yearly average) and the practical application of these to post-construction monitoring will need to be considered by regulatory bodies.

1. Setbacks should be sound-based rather than distance-based alone.
2. Preference should be given to sound emissions of ≤40 dB(A) for non-participating residents (people who are not economically benefiting from a project), measured outside, at a dwelling, and not including ambient noise. This value is the same as the WHO (Europe) night noise guideline [1] and has been demonstrated to result in levels of wind turbine community annoyance similar to, or lower than, known background levels of noise-related annoyance from other common noise sources.

3. Post construction monitoring should be commonplace to ensure modelled sound levels are within required noise limits.
4. If sound emissions from wind projects is in the 40-45 dB(A) range for non-participating residents, we suggest community consultation and community support. For example, developers could hold public open houses or town hall meetings with local communities, and hold workshops with elected community representatives, to promote open dialogue about the project. Developers can hold site visits so interested people can see the area where the project is proposed, and continue visits after the project is operational. Community advisory groups could also be struck in order to maintain a communication link between community and the project team.
5. Setbacks that permit sound levels >45 dB(A) (wind turbine noise only; not including ambient noise) for non-participating residents directly outside a dwelling are not supported due to possible direct effects from audibility and possible levels of annoyance above background.
6. When ambient noise is taken into account, wind turbine noise can be >45 dB(A), but a combined wind turbine-ambient noise should not exceed >55 dB(A) for non-participating and participating residents. Our suggested upper limit is based on WHO conclusions [1] that noise above 55 dB(A) is "*considered increasingly dangerous for public health*", is when "*adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed*" and "*cardiovascular effects become the major public health concern, which are likely to be less dependent on the nature of the noise*".

There are roughly 60 studies that have been conducted worldwide on the issue of wind turbines and human health [31]. Based on the findings and scientific merit of the research conducted to date, the weight of evidence suggests that when sited properly, wind turbines are not related to adverse health effects. Collectively, the evidence has shown that while noise from wind turbines is not loud enough to cause hearing impairment and is not causally related to adverse effects, wind turbine noise can be a source of annoyance for some people and that annoyance may be associated with certain reported health effects (e.g., sleep disturbance), especially at sound pressure levels greater than 40 dB(A). There is also a growing body of research that suggests that nocebo effects (where the etiology of the self-reported effect is in beliefs and expectations rather than a physiologically harmful entity) may play a role in a number of self-reported health impacts related to the presence of wind turbines. Negative attitudes and worries of individuals about perceived environmental risks have been shown to be associated with adverse health-related symptoms such as headache, nausea, dizziness, agitation and depression, even in the

absence of an identifiable cause. Therefore, it is possible that a segment of the population may remain annoyed (or report other health impacts) even when noise limits are enforced.

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