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Propagation thresholds and measurement of infrasound to establish separation distances from wind farm turbines to residences

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ABSTRACT

Of all the issues surrounding noise emissions from wind farms, the question of the potential for annoyance and adverse effects from low frequency sound is one of the most topical. Anecdotal literature is replete with statements concerning the effects of infrasound and low frequency noise. In this paper we present objective methodologies to measure and assess infrasound and low frequency noise in the context of wind farm emissions. The methodologies are reviewed with respect to three wind farms: one each in New Zealand, Victoria (Australia) and South Australia. The South Australian review incorporates data from a recent South Australian EPA wind farm study. The calculations for recommended stand-off distances from wind turbines to residences are presented. The distances are based on the threshold of annoyance and physiological effects threshold anticipated for different turbines and frequencies.

Keywords: Infrasound, wind turbines, separation, residences
TransmissionI-INCE Classification of Subjects Number(s): 51.4

1. INTRODUCTION

Infrasound. In the words of former United States Secretary of Defense Donald H. Rumsfeld:

> *"... as we know, there are known knowns; there are things that we know that we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns, the ones we don't know we don't know."*

So it is with infrasound. We know that infrasound exists because we can measure it. We know that infrasound has physical properties. We are not too sure if these properties can be consistently measured within a large sound field, such as in a wind farm. We do know that infrasound characteristics are modified by the turbine blades passing the tower. This shows as measurable blade-pass frequency and harmonic peaks inside a building compared to the sound field outside a building. We know that we do not know with certainty that the influence of a wind turbine in the wind field modifies the infrasonic pressure fields to an extent that individuals are affected. We do have known anecdotal information from different individuals in different wind fields affected by wind turbines that suggest there is a known adverse effect, compared to the infrasonic wind field in the absence of the turbines.

To investigate the mechanisms involved requires a complex analysis methodology. The methodology proposed is based on the formulation that adverse health effects are related to a time exposure of sound level and/or vibration level above a given threshold leading to annoyance and health effects. Annoyance effects from wind turbines for the non-infrasonic component have been published. Health effects including nausea, dizziness, and headaches have been reported and assumptions for linking those effects to the infrasonic component are being increasingly suggested. While annoyance curves have been derived from many studies over a relatively long period of time for road, rail and aircraft noise indicators, relatively few studies have been made for annoyance arising from wind farm noise. Health effects associated with noise exposure are well documented for sound pressure levels within the audio range but they are less so for low and infrasonic frequencies. It is postulated that such adverse effects are associated with a level above the detection threshold in a similar way that the temporary threshold shift leads eventually to a permanent threshold shift. This mechanism is very different for a single tone compared to broadband tonality.

2. Determination of thresholds at infrasonic and low frequencies

In recent years there have been claims that infrasound from wind turbines cause nausea, headaches, dizziness, pressure in the ears, and sleep disturbance. At this stage the linkage between these effects and infrasound from wind turbines have not been scientifically established and infrasound thresholds associated with these effects are not determined. The following available data was gathered to assess vibro-acoustic energy for low frequency and infrasound: (a) maximum levels for human exposure, (b) audiology thresholds of detection, (c) annoyance thresholds, (d) thresholds of physiological effect, (e) thresholds of pain, and (f) equaphone curve for very low frequencies.

Figure 1 presents various thresholds of detection of low frequency sound and infrasound available in the literature Fidell et al.[1], Hodgdon et al.[2], Johnson [3], Moller et al. [4], Tokita et al. [5],Watanabe et al. [6], Yeowart et al. [7]. These thresholds of detection have been superimposed with equaphone curves to illustrate the convergence of the curves towards infrasonic frequencies.

There is an observed difference of 20dB or more between the minimum and maximum detection threshold as shown in Figure 1. Using the precautionary principle, the lowest observed effect is selected. The minimum at any frequencies of those detections curves is used for the onset of the detection thresholds of low frequency and infrasonic frequencies. Thresholds for onset of annoyance, oppressive feeling, objectionable feeling, onset physiological effects as well as the detection thresholds for various limits proposed for infrasound and low frequencies limits such as the Danish EPA 20dBA limit and 85dBG limit and the low frequency limit proposed by Sloven [8] for annoyance are recorded.

Johnson[3] explained that infrasound is detectable down to 2Hz , but loses tonal quality at 16Hz. Johnson found that annoyance from infrasound is a definite problem as the threshold of annoyance is very much the same as the threshold of audibility. As can be seen from Figure 1, the presence of sound can produce annoyance before being detected, and further, it can be seen that between the 20Hz to the 50Hz region, the annoyance is very close to the level judged as oppressive by Tokita [5] while at 8 Hz the oppressive level corresponds to a level found by Johnson as a level with biological significance.

Fidell et al. [1] reviewed the effect of infrasound and low frequency sounds from 1Hz to 70Hz for detection, pressure fullness in ears, temporary threshold shift, aural pain and maximum tolerable level and from 2Hz to 100Hz for loudness, annoyance, interference with task performance, visceral sensation and blurred vision. The sound pressure level for the effect reported was found to vary as a function of the duration of the exposure by as much as 9dB between one hour exposure to 8 hour exposure. Most of the experiments reported do not mention the duration of the sound exposure for the effect reported. The thresholds proposed in this paper do not take into account the duration of the sound exposure for the onset of the effect. It may be a significant modification of the thresholds of annoyance since a resident may be exposed to long sound exposure duration. Harris [9] has proposed maximum sound pressure levels for low frequency sound exposure for three different sound exposure durations. Figure 1 collates detection thresholds, the annoyance/oppressive thresholds and the pain/physiological effects threshold. The thresholds proposed in Figure 1 can be modified as new evidence is published. Thresholds for the onset of headaches, nausea or dizziness are not included in Figure 1. The responses to infrasound are explained by Salt et al. [10] as:

> *"Responses to infrasound reach the brain through pathways that do not involve conscious hearing but instead may produce sensations of fullness, pressure or tinnitus, or have no sensation. Activation of subconscious pathways by infrasound could disturb sleep. Based on our current knowledge of how the ear works, it is quite possible that low-frequency sounds at the levels generated by wind turbines could affect those living nearby."*

On the basis of the thresholds Figure 1 an estimate is able to be made of the sound pressure level for a given frequency for the onset of both the detection of the sound and the annoyance effect. In order to determine at what distance from the wind farm these effects may occur, the linear sound power level of the wind farm needs to be known and the correct attenuation of low and infrasonic frequencies with distance need to be established. The calculations are different for different turbine types (2 or 3 blade), tower height, blade length and type, wind speed and direction, sound power characteristics and so on.

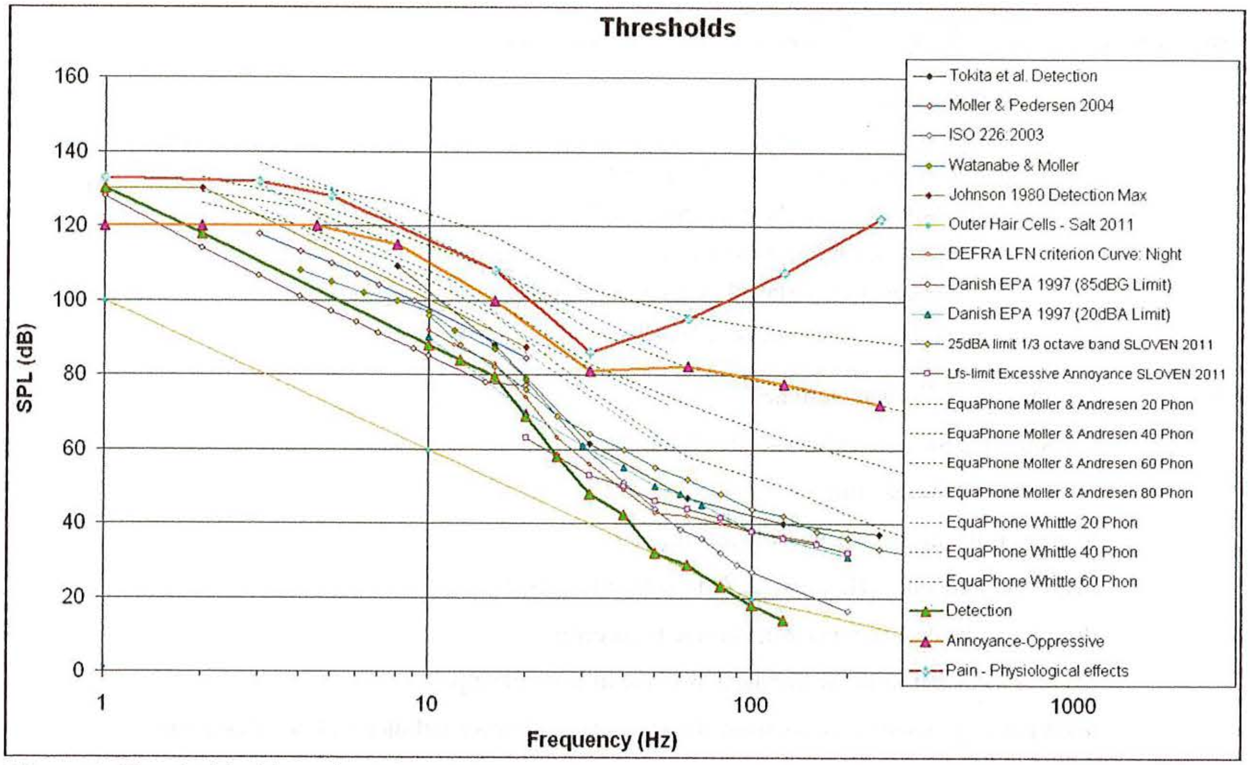

Figure 1. Threshold of detection (Green), Threshold of Annoyance-Oppressive (Orange) and Threshold of Pain-Physiological effects (Red)

3. Propagation of infrasound and low frequencies

The propagation of infrasound and low frequencies has longer decay times compare to mid- and higher frequencies (above 1000 Hz, for example). Wavelength is inversely proportional to frequency and as a result for infrasound the wavelength reaches hundreds of metres, which is significant for the attenuation of sounds. Several effects are combined which are frequency dependent influencing the propagation of sound. The first is the absorption of sound which depends on frequency and humidity, the second is the geometrical spreading which is function of distance and again linked to frequency. The sound source has a directivity which is frequency dependent and the atmospheric effect from the temperature gradient also affects propagation.

The main mechanism by which sounds attenuate is by the air viscous force which is proportional to velocity or frequency. When sounds travels through a medium, its intensity diminishes with distance. The first effect of the dissipation of sound is due to geometric effect associated with energy being spread over an increasing area and not to any loss of total energy. The weakening of sound wave energy is also due to absorption and scattering. Scattering is the reflection of sound in directions other than its original direction of propagation while absorption is frequency dependent.

The attenuation of noise in dB follows the slope given by *20Log(R)* where R corresponds to the distance between the sound source and the distance corresponding to the attenuation. Shepherd et al. [11] state that the attenuation at very low frequencies would not be 6dB but only 3dB per distance doubling due to atmospheric refraction and channeling of sound in the lower atmosphere.

A relational concept is proposed to integrate the mechanisms of sound propagation, turbine character, and the potential for adverse health effects, Eq.(1). The condition for an adverse health effect (*AHE*) is an exposure for a given duration of a received sound level and/or vibration level that is above the threshold of sensitivity, Eq. (1):

$$AHE = \int_0^t \text{human sensitivity}(\textit{sound pressure level}, \textit{vibration}) \qquad (1)$$

A temporary (raised) threshold shift may occur when sound exposure exceeds the thresholds for a given time. In such a case the threshold is a function of the received sound level over the duration. The received sound pressure level and vibration level are established by Eqs. (2) and (3):

$$\begin{aligned}\text{sound pressure level(dB)} = \sum_{i=1}^{N} \{ & \text{turbine sound power level}_i(B, rpm, spacing, freq) \\ & + \text{spreading law}_i(distance) \\ & + \text{directionality}_i(angle) \\ & + \text{attenuation from air}_i(freq, humidity) \\ & + \text{atmospheric effect}_i(temperature\ gradient) \\ & + \text{attenuation outdoor/indoor}_i(freq) \\ & + \text{vibroacoustic coupling to house}_i(vibration) \\ & + \text{room acoustic resonance}_i(l, w, h) \}\end{aligned} \quad (2)$$

Where N is the number of wind turbines

i denotes that the term applies to the ith turbine

B is the blade size (m)

Spacing is the distance between wind turbines

freq is the frequency (Hz), narrow or broadband in dB(Z)

distance is the distance (m) from turbine to receiver

angle is the angle from the turbine axis to the measurement point

temperature gradient includes wind shear, wind speed, wake turbulence, Pasquill stability

vibration is the transmitted vibration(s) in the ground from turbine to receiver

l, w, h are the room dimensions where the sound pressure level is measured

$$\begin{aligned}\text{vibration(dB)} = \sum_{i=1}^{N} \{ & \text{turbine vibration level}_i(B, rpm, spacing, freq) \\ & + \text{spreading law}_i(dist\ from\ wind\ farm) \\ & + \text{directionality}_i(angle) \\ & + \text{attenuation from soil}_i(freq, humidity, soil) \\ & + \text{vibrational coupling to house}_i(freq, room(l, w, h)) \}\end{aligned} \quad (3)$$

Where N is the number of wind turbines

i denotes that the term applies to the ith turbine

B is the blade size (m)

spacing is the distance between wind turbines

freq is the frequency (Hz), narrow or broadband in dB(Z)

angle is the angle from the turbine axis to the measurement point

l, w, h are the room dimensions where the vibration level is measured

The above equations present a methodology concept to determine noise stand-off distances from a wind farm. The human sensitivity component of the equation in (1) is described in terms of thresholds at infrasonic and low frequencies described in figure 1.

Propagation depends on the component frequencies within the sound emission. Wind turbines are essentially very large propellers. Metzger [12] reviewed the expression of the fundamental frequency for a propeller. Multiple harmonics will stem from the fundamental frequency as the n^{th} multiple of that frequency with decreasing amplitude. As shown in Eq. (2) the fundamental frequency is governed by the rotational speed and therefore is a function of the wind speed. As a function of the RPM for a wind turbine propeller at 20 RPM the fundamental frequency is expected to be 1Hz and the harmonics, 2Hz, 3Hz, 4Hz, 5Hz 6Hz and visible up to 7Hz. Hessler [13], in commenting on the Waterloo EPA study, noted: "*Three bladed modern wind turbines rotate in the 10 to 14 RPM range so the BPF ranges from 0.5 to 0.7 Hz or periods of 2 to 1.4 seconds. At these very low and slow frequencies and periods, any such sound pressure* *would be perceived, if at all, as a series of pulses, not as ordinary noise."* The effect is shown in the preliminary research results from a significant wind farm research program at Cape Bridgewater, Australia, by Pacific Hydro and acoustician Steven Cooper [14] as reported on the Pacific Hydro website.

Propagation and harmonics have been identified and described as 'Heightened Noise Zones' by Bakker et al. [15] in evidence presented at the Turitea, New Zealand, wind farm hearing. The Heightened Noise Zone is the combined effect of directional sound and vibrations (wave trains) from the towers, the phase between turbines' blades, lensing in the air or ground and interference between turbines' noise (audible) and vibration causing very localised zones of heightened noise and/or pressure variations. The wave train travels in time and the heightened peaks and troughs create a Heightened Noise Zone at any affected residence, figure 2. The Heightened Noise Zone is directly affected by the design and operation of the wind farm (location and type of turbines, phase angles between blades) and wind conditions.

The Heightened Noise Zones can be small in extent – even for low frequencies – leading to turbine sounds 'disappearing' and 'appearing' in areas spaced only a few metres apart. It can readily be observed in some situations where the turbines can be clearly heard at one position, but walking one or more paces can cause the sound to disappear and reappear. The concept of Heightened Noise Zone goes a long way to explaining the problem of wind farm noise and its variability on residents. The other factor is the variability of the background sound levels as affected within the Heightened Noise Zones. The turbine sound levels have the effect of lifting the background (when in phase or acting together). The background drops when in the trough between the crest of the Heightened Noise Zone levels. This effect can change quite quickly depending on wind direction, temperature conditions and turbine activity.

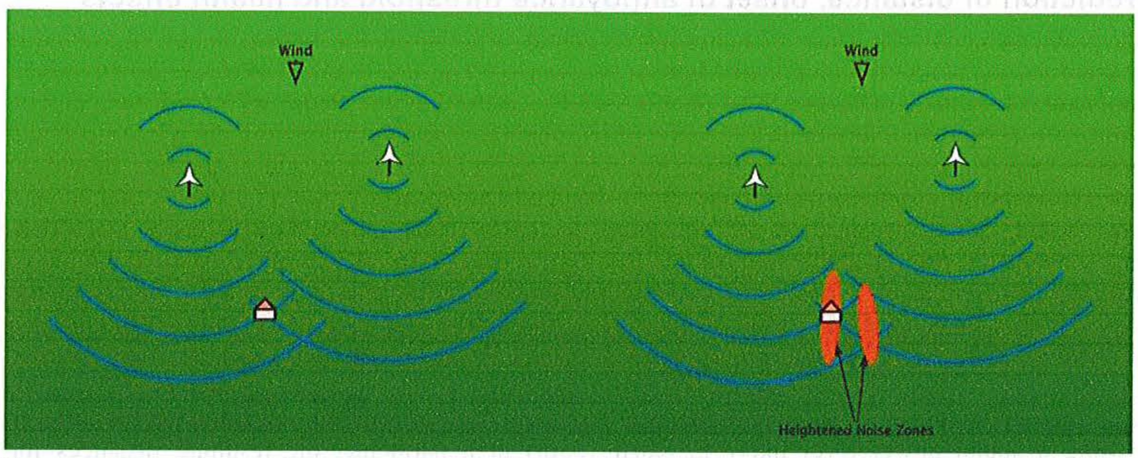

Figure 2: Sound field without and with a Heightened Noise Zone Effect

Doolan [16] reviewed the directivity curve of each contributing element of the wind turbine sound generation mechanism and concluded that the trailing edge generation mechanism was the main noise generation for the wind turbine and exhibited similar directional characteristics to aircraft propeller noise. Doolan found that the blade tower interaction generated a supplementary noise source as a very low frequency pulse.

Style et al. [17] investigated the seismic propagation of vibration produced by wind turbines to check the interference that wind farms may have on a seismic monitoring station located in Eskdalemuir. The harmonic signals are related to overtones of the blade-passing frequency of the turbine and that the vibration in the 0.5 to 5Hz band could be detected beyond 10km from the wind turbine. Styles found that a wind farm composed of a number of turbines produces a noise proportional to the square root of the number of turbines because they are not all working in phase and they are not operating at the same frequency because of the small variations in rotation speed and wind conditions across the wind farm and the vibration from the different turbines interacted between each other. In air, a similar interaction is expected [15].

The mode of vibration below 1Hz is the strongest. This is highly relevant since the measurement of very low frequencies requires specialised instrumentation and wind-screening. Frequencies below 1Hz are those that are related to motion sickness (Griffin [18]) and the effects of motion sickness have been reported in, for example, Nissembaum [19] and Davidsen [20]). Evans [21] reported for sound pressure level between 100dB and 125dB for frequencies ranging from 2Hz to 5Hz movement of the eardrum in response to the pressure change of pressure build-up in the middle ear and resulted in headaches and for 125dB to 137dB for 2 Hz to 5Hz, Evans reported lethargy and drowsiness, post exposure headaches and fatigue.

The vibration propagation is important since when those vibrations arrive into a residence, the residence becomes the resonant chamber in the same way a violin is the resonant chamber from the string vibration. In other words, the resulting sound field within the residence is the interaction between the potential modes of resonance of the residence and the source of vibration. The vibration may also resonate within a residence with a vibration mode which is a multiple of its fundamental frequency. The vibration mode within the residence may further be enhanced by the propagated acoustic pressure wave tuned to the same harmonics. The coupling may significantly enhance the sound within a residence, as the airborne wave coupled with the vibration wave may interact in a complex manner and be further combined with a standing wave resonance within a room.

The blade tower interaction expressed in Doolan [16] gives rise to a further low frequency pulse. Hubbard and Shepherd [11] investigated the amplification due to interaction of the multiple wind turbines and gave an equation to quantify this amplification according to the number of wind turbines. They found the sound pressure level can be calculated for a given harmonic at a given distance. Using this equation, Ceranna [22] found that for the 2Hz harmonic of a 600KW turbine at 1km the sound pressure level should be 58.5 dB and the same 2Hz harmonic generated by an array of 11 wind turbine would generate 68dB at 1km.

This relationship shows that the turbines can be regarded as uncorrelated. The propagation of infrasound given by Hubbard and Shepherd [11] appears to follow closely the cylindrical propagation with an attenuation function of *10Log(R)*.

4. Prediction of distance, onset of annoyance threshold and health effects

In the previous section, the 'onset of annoyance threshold' is proposed, the propagation of infrasound is reviewed and the sound spectrum for a wind turbine is reviewed. The sound power levels are usually given by manufacturer's in dBA, although this is not a useful measure for low frequency or infrasound. The sound power level of a wind turbine is a function of its rotational speed and therefore the wind speed and its diameter. In order to establish the distance for which physiological effect and annoyance should be anticipated from the infrasonic harmonics, the narrow band measurements of a wind turbine or from a wind farm are needed. Sound propagation for infrasound increases under temperature inversion condition. Spherical propagation from a single point source has -6dB reduction in relative intensity per doubling of distance. However from a single point source to multiple sound sources, as is the case for a wind farm, the propagation slope may be modified toward cylindrical or line source propagation with only -3dB reduction per doubling of distance. The argument presented in this paper is based on 'single point source' propagation.

The corresponding threshold at 10 Hz for annoyance and physiological effects are extracted from Figure 1 and using a sound power level likely to reach 155dB at a harmonic, the resulting distances for physiological effects range from 280m to 780m for temperature inversion condition. Using a similar procedure, for annoyance, the resulting distance ranges from 1400m to 4400m. Since the thresholds are changing rapidly between the 10Hz and 30Hz the next derivation is to express the distance relating to 20Hz to 30Hz band. Assuming the sound power level for a modern wind turbine to be about 117dB in the range between 20Hz to 30Hz and taking the assumption of a 3dB increase from the wind turbine to a wind farm the resulting sound power level is assumed to be 120dB. In Figures 3 and 4, the distances (termed the 'stand-off distance) associated with the onset of expected annoyance and corresponding onset of expected physiological effects are shown for a wind turbine with a sound power level of 120dB. The sharp harmonics generated by the blades of the wind turbine are assumed to generate a sound power level about 120dB. Low frequency absorption also results in sound being strongly affected by temperature gradient and weather effects. This result in the sound propagation being for the frequency range to follow a slope for sound propagation ranging from 14.3 *Log(R)* for a day time sound propagation to 12.4 *LogR* when a temperature inversion occurs. The bounding of those expected minimum and maximum slopes are only valid for those frequencies and for reference the commonly used 20 *Log(R)* for normal audio frequencies together with the 10 *Log(R)* for the line source are also added for comparison. In Figure 1 the threshold for oppressive feeling – annoyance is reported at 80dB and the threshold for physiological effect and pain is reported at 90dB. By taking the precautionary approach it would be expected the onset of such effects to be lower for a percentage of population.

Figures 3 and 4 therefore show the onset of the effect 5dB below the reported data until those thresholds are reassessed and confirmed on a larger population sample. Figure 4 shows that the onset of annoyance for the frequency range from 20Hz to 30 Hz is expected to be about 75 dB and that for the given sound power level of 120 dB at the corresponding frequency range and the corresponding propagation slopes, the 75 dB received level at those frequencies are expected between 1300m to 4400m. Using a similar approach the received sound pressure level of 85 dB linear at frequencies ranging from 20Hz to 30 Hz would intersect the propagation slopes for those frequencies at distances ranging from 280m to 750m. The distances of 280m to 750m would correspond to the expected onset of physiological effects.

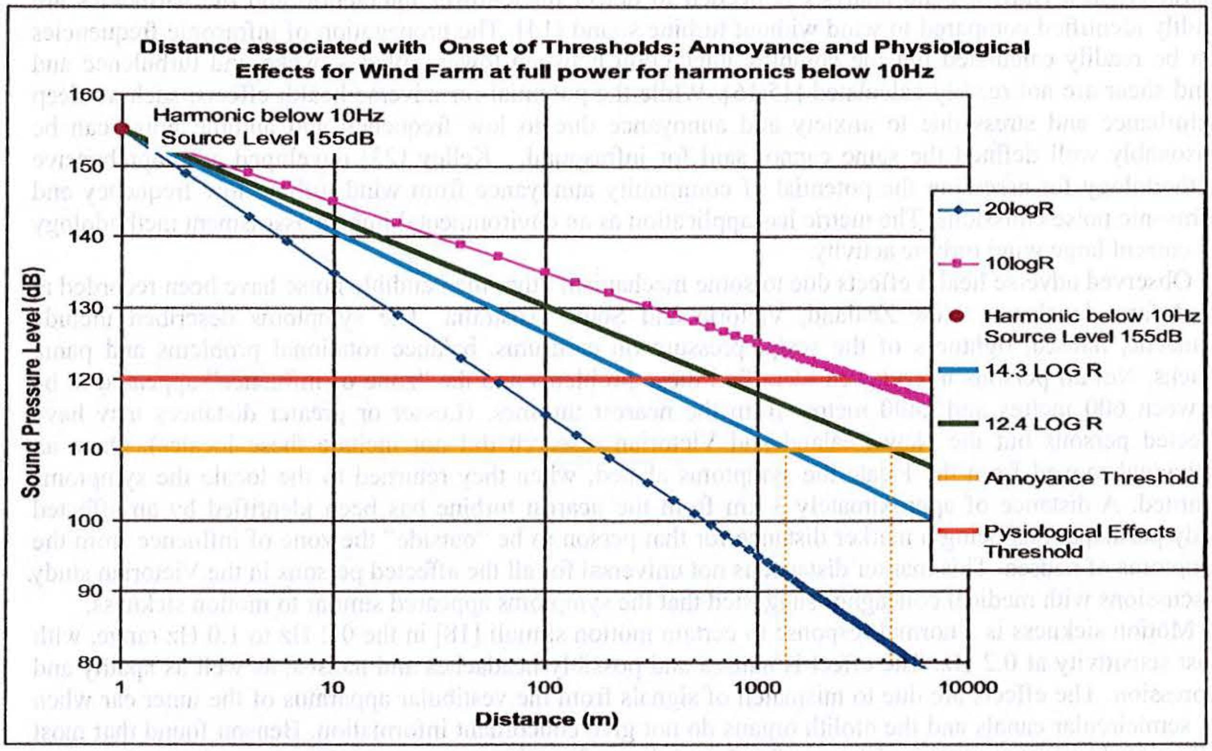

Figure 3. Distance for which the threshold of annoyance and physiological effects threshold are anticipated for one wind turbine generating a source level of 120dB in the frequencies below 10Hz.

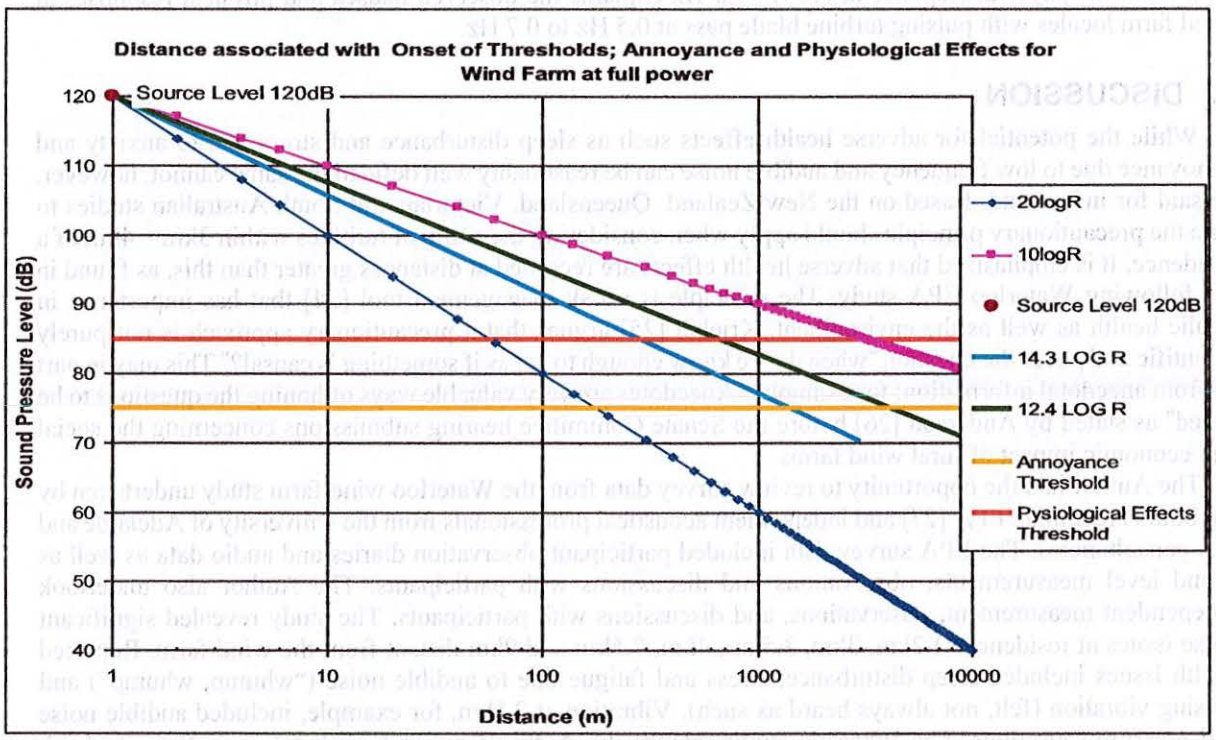

Figure 4. Distance for which the threshold of annoyance and physiological effects threshold are anticipated for one wind turbine generating a source level of 120dB in the frequencies 20Hz to 30Hz.

The measurement of infrasound and calculation of propagation distances for wind turbine enhanced infrasound is complicated by the fact that wind is, by its very nature, found in the 'low' infrasonic range of nominally 1Hz to 10Hz [14,15,16]. Wind generated infrasound can be measured with one-third octave band analysis and is shown to be a relatively smooth curve, higher at 1Hz and lower at 10 Hz. Wind turbine enhanced infrasound is sound generated from the blade-tower pass-by and has different measurable characteristics. Narrow-band analysis is needed to detect blade-tower interaction and the harmonics are readily identified compared to wind without turbine sound [14]. The propagation of infrasonic frequencies can be readily calculated but the complex interaction between towers, blades, wake and turbulence and wind shear are not readily calculated [15,16]. While the potential for adverse health effects, such as sleep disturbance and stress due to anxiety and annoyance due to low frequency and audible noise can be reasonably well defined the same cannot said for infrasound. Kelley [23] developed a comprehensive methodology for assessing the potential of community annoyance from wind turbine low frequency and infrasonic noise emissions. The metric has application as an environmental impact assessment methodology for current large wind turbine activity.

Observed adverse health effects due to some mechanism other than audible noise have been recorded at wind farm locales in New Zealand, Victoria and South Australia. The symptoms described include headache, nausea, tightness of the scalp, pressure on eardrums, balance rotational problems and panic attacks. Not all persons interviewed identified these problems and the "zone of influence" appeared to be between 600 metres and 2400 metres from the nearest turbines. (Lesser or greater distances may have affected persons but the New Zealand and Victorian research did not include these locales). Once an individual moved from the locale the symptoms abated; when they returned to the locale the symptoms returned. A distance of approximately 3 km from the nearest turbine has been identified by an affected study participant as being a marker distance for that person to be "outside" the zone of influence from the symptoms of nausea. This marker distance is not universal for all the affected persons in the Victorian study. Discussions with medical colleagues suggested that the symptoms appeared similar to motion sickness.

Motion sickness is a normal response to certain motion stimuli [18] in the 0.2 Hz to 1.0 Hz range, with most sensitivity at 0.2 Hz. The effect is nausea and possibly headaches and nausea, as well as apathy and depression. The effects are due to mismatch of signals from the vestibular apparatus of the inner ear when the semicircular canals and the otolith organs do not give concordant information. Benson found that most suffers could adapt to motion sickness after 3 or 4 days of continuous exposure in a particular environment (e.g. while at sea). Adaption is different for different individuals and a small proportion of the population (around 5%) do not adapt, or adapt very slowly. Research is needed to establish whether motion sickness with a known physical response at 0.2 Hz-1.0 Hz explains the observed nausea and physical responses at wind farm locales with pulsing turbine blade pass at 0.5 Hz to 0.7 Hz.

5. DISCUSSION

While the potential for adverse health effects such as sleep disturbance and stress due to anxiety and annoyance due to low frequency and audible noise can be reasonably well defined the same cannot, however, be said for infrasound. Based on the New Zealand, Queensland, Victorian and South Australian studies to date the precautionary principle should apply when considering the siting of turbines within 3km – 4km of a residence. It is emphasized that adverse health effects are recorded at distances greater than this, as found in the following Waterloo EPA study. The principle is a risk management tool [24] that has importance in public health as well as the environment. Kriebel [25] argues that a precautionary approach is not purely scientific and poses the question "when do we know enough to act as if something is causal?" This may in part be from anecdotal information; for example, "Anecdotes are very valuable ways of honing the questions to be asked" as stated by Anderson [26] before the Senate Committee hearing submissions concerning the social and economic impact of rural wind farms.

The Author had the opportunity to review survey data from the Waterloo wind farm study undertaken by the South Australian EPA [27] and independent acoustical professionals from the University of Adelaide and two consultancies. The EPA survey data included participant observation diaries and audio data as well as sound level measurements, observations and discussions with participants. The Author also undertook independent measurement, observations, and discussions with participants. The study revealed significant noise issues at residences 1.2km, 3km, 3.5km, 4km, 7.5km and 9km distant from the wind farm. Reported health issues included sleep disturbance, stress and fatigue due to audible noise ("whump, whump") and pulsing vibration (felt, not always heard as such). Vibration at 2.5km, for example, included audible noise and pressure sensations. The Waterloo study extends the Author's research undertaken in New Zealand, Queensland and Victoria, Australia. The conclusion from the Waterloo study, as well as the main study research, is that wind farm assessment to current standards and guidelines will not provide a satisfactory guide to potential degradation of the environment with respect to wind farm modified audible noise, low frequency noise, or infrasound.

Based on anecdotal observations it is argued that, when exposed to wind farm noise and wind turbine generated air pressure variations, some individuals will more likely than not be so affected that there is a known risk of serious harm (also termed 'significant adverse effect') to health. By 'serious harm' it is meant harm that is more than annoyance alone and that can be quantified in terms of reported illness, sleep disturbance or other physical effect such as "land-sickness" nausea created by pulsing (modulating) infrasonic pressure waves. A definition of 'serious harm' proposed is: nausea created by pulsing (modulating) infrasonic pressure waves. A measure of 'serious harm' proposed is:

1) If the exposed individual is adversely affected to the extent that he or she is obliged to remove himself or herself from the exposure in order to mitigate the harm; and / or
2) If three or more serious adverse health effects are recorded for an individual. Three serious adverse health effects are established from this study as being:
    a) sleep disturbance with a global PSQI greater than 5,
    b) a state of constant anxiety, anger and helplessness,
    c) an SF36v2 mental health value of less than 40.

The collection of sound levels without a detailed knowledge of what the sound levels relate to renders the data uncertain in nature and content. Observation is needed to confirm the character of the sound being recorded. Sound recordings and spectral analysis with valid instrumentation are needed to confirm the character of the sound being recorded.

Consequently, it is timely to investigate the above proposals or "known unknowns": that adverse health effects experienced by some individuals with respect to wind farm activity are a response to pressure variations similar in cause and effect to motion sickness.

6. CONCLUSIONS

This paper proposes a methodology to assess the effect of wind turbine low frequencies and infrasonic frequencies on nearby human receptors. The method includes objective calculations and subjective responses. Thresholds for detection of low frequency and infrasound, annoyance and physiological effects are proposed. The interactions of several wind turbines will result in complex sound fields given the different effects involved such as harmonics generations, directivity of the sound field, difference in rotational speed between wind turbine, interference, beating effects and modulation may result. The diurnal effect temperature inversion, variability in wind speed, will add to the complexity in the assessment of the impact of low frequency and infrasound.

Modulation of low-and infrasonic frequencies is influenced by the interaction of several wind turbines. Frequency analysis measured in the presence of wind turbines has three separate components: (a) the basic blade rate infrasound, (b) a secondary unsteady component of blade lift induced noise, and (c) the broadband ambient from turbine and wind-flow noise. The propagation of sound for low frequency and infrasonic frequency has been reviewed and the slope for the attenuation of sound below 100Hz is proposed to range from $14.3Log(R)$ to $12.4Log(R)$ when a temperature inversion takes place.

A proposal to investigate for "known unknowns" is presented: *that adverse health effects experienced by some individuals with respect to wind turbine activity are a response to pressure variations similar in cause and effect to motion sickness.*

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Sherman Fuerniss

Basin Electric Rates Increase

Impact to CME Members to be Determined

Russell Gall
General Manager

Nobody likes to be the bearer of unwelcome news. So, when I got word that Basin Electric's Board of Directors had authorized a rate increase starting August 1st, I knew it was only a matter of time before I'd be writing this article to let our members know what, when and why they, too, would be seeing an electricity price change.

Based in Bismarck, ND, Basin Electric is a cooperative owned by cooperatives, including Charles Mix Electric. Basin is our main supplier of electricity, mostly generated from coal, but also from natural gas, heat recovery, wind, and even a small amount of nuclear power. They are darn good at what they do, and have always demonstrated they have the best interests of the member cooperatives in mind.

In early June, the Basin Electric Board decided that an immediate increase of .7¢ per kWh was needed to make up the financial shortfall which began back in October, 2015. As a member cooperative of Basin, the woes of this financial quagmire will impact Charles Mix Electric, and ultimately, its end-use consumers.

Paul Sukut, Basin Electric CEO and general manager, summed it up like this: "Basin Electric has essentially encountered the perfect storm, and it happened suddenly and rapidly in early October. The cooperative is taking several steps to mitigate the impact, but ultimately, we need the membership's help."

Here are the main reasons given for Basin's request for help:

- ***Lower than anticipated member sales.*** The wet summer and mild winter of 2015-16 significantly decreased electricity sales that Basin would normally make to its members. Less sales means less revenue.

- ***Reduced revenue from non-member sales (surplus sales).*** Again, the mild weather resulted in decreased sales to customers outside of the Basin Electric family.

- ***Added costs to operate generation facilities.*** Expenses from wind power cost Basin Electric more to produce electricity.

- ***Generation and transmission investments.*** Installation of new gas-fired generators and the construction of new lines in North Dakota have added expenses to Basin's bottom line.

- ***Reduced revenue support from non-electric or subsidiary businesses, specifically Dakota Gasification Company (DGC).*** This is the biggie. Due to the drop in all the commodity prices, including natural gas and oil prices, the DGC plant, owned by Basin Electric, is presently losing money, especially since it is heavily dependent on sale of natural gas.

Since the reduced revenue from DGS is the biggest issue, I'll cover that a bit more. Revenue from DGC has typically contributed financial support to Basin Electric. In fact, it is estimated that DGC typically has a benefit of $78 million per year to Basin Electric and its membership. This includes fuel supply, power supply, shared facilities and other miscellaneous benefits. That means that DGC profits have benefited every member of Charles Mix Electric in the past. However, with depressed commodity prices, DGC was unable to provide this same level of support in 2016. This is where Basin needs help from its members. As markets rebound over the next year or so, those benefits will return to the members to help keep future rate increases at bay.

How this will affect you has yet to be determined. A rate adjustment is expected for CME members beginning Jan 1st, 2017.

On the bright side, there is expected to be a slight decrease in the cost of power received from Western Area Power Administration (WAPA) starting in 2017. This will provide some relief, but since the amount of power received from the dams is only 27% of our total power supply, it cannot eclipse the overall increase from Basin.

The increase from Basin resulted in a 13% power cost increase to East River Electric starting August 1st. Fortunately, the frugal efforts of East River Electric's and CME's directors have delayed the impact of the increase until January of 2017.

How this rate change will affect you, the end consumers of Charles Mix Electric, is yet to be determined. CME's employees and Board of Directors are studying costs to the co-op to determine the magnitude of the price change to our members. It should be expected that a rate adjustment will be in put in place starting January 1st 2017.

As always, we like to keep our members informed of issues that will affect them, and will continue to do so over the next few months.

Wind Power does not lower rates!