

Wind Farms in a Rural Environment  
and  
Potential for Serious Harm  
to Human Health due to Noise

Submission to the Senate Community Affairs Committee  
'Inquiry into the social and economic impacts of rural wind farms'

Submitter: Robert Thorne  
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## **PART I - INTRODUCTION**

The following matter has been referred to the Community Affairs References Committee for inquiry and report by 30 April 2011:

*The social and economic impacts of rural wind farms, and in particular:*

- (a) Any adverse health effects for people living in close proximity to wind farms;*
- (b) Concerns over the excessive noise and vibrations emitted by wind farms, which are in close proximity to people's homes;*
- (c) The impact of rural wind farms on property values, employment opportunities and farm income;*
- (d) The interface between Commonwealth, state and local planning laws as they pertain to wind farms; and*
- (e) Any other relevant matters.*

This submission addresses the issue of adverse health effects and excessive noise. Other relevant matters are brought forward to illustrate or explain the detail of my Submission.

### **Background on which this Submission is based**

As a brief summary of my background and my professional qualifications in this matter I hold a PhD from Massey University New Zealand in health science with the topic 'Assessing intrusive sound and low amplitude sound'. The thesis researched, in part, wind farm noise and human perception of such noise. My work on a day-by-day basis is as the Principal of Noise Measurement Services Pty Ltd. Professionally the work undertaken by Noise Measurement Services Pty Ltd involves specialised acoustical and psychoacoustical investigations for clients. A specific application in development is personalised sound reinforcement for hearing assistive devices. General acoustical work includes environmental noise surveys, social surveys and analysis, health impact assessment and noise impact prediction modelling. I hold post graduate qualifications in acoustics and qualifications in health engineering. My professional experience over more than 40 years' has been involved in both the private and public sectors, in the broad fields of environmental and public health. This work has included a senior position as Director of Planning and Regulatory Services for a New Zealand local government, and as a Principal Environmental Officer for the Department of Environment and Heritage (now the EPA) in Queensland. Academically I hold a position of Environmental Health Research Associate in the Institute of Food, Nutrition and Human Health, Massey University.

There is significant body of peer-reviewed research readily available in the public forum to substantiate the potential for serious to moderate adverse health effects to individuals due to wind farm activity noise while living in their residences and while working on their farms within 2000 metres of large-scale turbines.

This submission is based on personal wind farm research over 5 years in Victoria and New Zealand. The research presented in parts of this Submission has been submitted in part as expert evidence to different wind farm hearings; Turitea (Board of Inquiry, New Zealand); Berrybank, Mortlake, Stockyard Hill and Moorabool (Panel Hearings, Victoria); as well as being part of submissions for other parties in New Zealand, New South Wales and Victoria. At no time has the evidence been significantly challenged or rebutted by the wind farm applicant, their acoustic consultants or the legal practitioners employed by the applicant(s).

Wind has audible and sub-audible character. That is, measurement of wind sound will always present sound levels in the audible, low-frequency and infrasonic frequencies. Adverse health effects are due to extreme psychological stress from environmental noise, particularly low frequency noise with symptoms of-

sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic attack episodes associated with sensations of internal pulsation or quivering when awake or asleep.

Sound in the low frequencies and infrasound frequencies can be heard if the sounds are loud enough. The sounds, however, may be perceptible rather than heard at relatively lower levels of "loudness". My research documented to date indicates "ordinary" wind has a laminar or smooth infrasound and low-frequency flow pattern when analysed over short periods of time. Wind farm activity appears to create a "pulsing" infrasound and low-frequency pattern. These patterns are illustrated in sonograms in this Submission. The hypothesis derived from my research reported here is that wind farm sound has an adverse effect on individuals due to these pressure variations as well as audible noise due to the wind turbines. These effects may be cumulative.

Evidence produced in New Zealand concerning the West Wind and Te Rere Hau wind farms indicate that the adverse effects of wind farm noise are well documented. West Wind has recorded 906 complaints over a 12 month period. Te Rere Hau has recorded 378 complaints over an 11 month period. Waubra has a less well documented complaint history but my observations and the statutory declarations as to effect are sufficient to identify issues. In December 2010 a New Zealand local authority instituted legal action against a wind farm for alleged non-compliance with consent conditions. The declaration presents a

severe critique of both the methods employed in establishing the noise criteria for the wind farm and compliance. The action is important as the New Zealand wind farm standard is referenced in Victoria.

In June 2010 the Australian Government National Health and Medical Research Council released a Paper entitled "*Wind Turbines and Health: A Rapid Review of the Evidence*". In July 2010 the Environment and Heritage Council (EPHC) issued draft *National Wind Farm Guidelines*. My opinion is that, although both documents may make interesting reading, neither explain the known adverse health effects of wind farm noise.

### **Conclusions reached from my research**

It is concluded that, for the reasons given in this Submission, it can not be clearly proven or not proven that individual turbines or cumulative turbines within a wind farm will exceed compliance criteria of a single-value, such as 35 dB(A) measured as the equivalent level LAeq; 40 dB(A) measured as the background level, LA95; or the 'background plus 5dB' sound level, whichever is the greater. This is due to the failure of the approval conditions to provide clear and specific methodologies to measure wind farm sound under compliance testing conditions or under complaint conditions when turbine sound is part of the ambient sound.

It is concluded that wind farms exhibited special audible characteristics that can be described as modulating sound or as a tonal complex. Compliance monitoring must include real-time measurement of special audible characteristics such as modulating sound in order to determine the perceptible effects of audible sound.

It is concluded that meteorological conditions, wind turbine spacing and associated wake and turbulence effects, vortex effects, wind shear, turbine synchronicity, tower height, blade length, and power settings all contribute to sound levels heard or perceived at residences. Current noise prediction models are simplistic, have a high degree of uncertainty, and do not make allowance for these significant variables.

It is concluded that noise numbers and sound character analyses are meaningless if they are not firmly linked to human perception and risk of adverse effects.

In my opinion, based on my training, experience, measurements and observations, serious harm to health occurs when an individual is so beset by the noise in question that he or she suffers recurring sleep disturbance, anxiety and stress. The marker for this sound level is 32 dB(A) LAeq outside the residence and above the individuals threshold of hearing inside the home.

From my observations and measurements at other rural wind farms I expect between 5% and 10% of the exposed households within 2000 metres (or 32 dBA Leq) will have their health seriously harmed by noise causing sleep disturbance, anxiety and stress. My conclusion is that a rural wind farm facility will therefore cause serious harm to health to a significant number of individuals living within 2000 metres of the turbines.

My research indicates “ordinary” wind has a laminar or smooth infrasound and low-frequency flow pattern when analysed over short periods of time. Wind farm activity appears to create a “pulsing” infrasound and low-frequency pattern. These patterns are illustrated in sonograms in this Submission. The hypothesis derived from my research is that wind farm sound has an adverse effect on individuals due to this pulsing nature as well as audible noise due to the wind turbines. These effects may be cumulative.

It is concluded that no large-scale wind turbine should be installed within 2000 metres of any dwelling or noise sensitive place unless with the approval of the landowner.

It is concluded that no large-scale wind turbine should be operated within 3500 metres of any dwelling or noise sensitive place unless the operator of the proposed wind farm energy facility, at its own expense, mitigates any noise within the dwelling or noise sensitive place identified as being from that proposed wind farm energy facility, to a level determined subject to the final approval of the occupier of that dwelling or noise sensitive place.

## **Submissions**

1. It is submitted that there is significant body of peer-reviewed research readily available in the public forum to substantiate the potential for serious to moderate adverse health effects to individuals due to wind farm activity noise while living in their residences and while working on their farms within 2000 metres of large-scale turbines. Adverse health effects are known at distances of 3500 metres with some reports presenting larger distances.

2. It is submitted that funding for research is needed urgently into the potential for adverse health effects from wind farm activities. Noise numbers and sound character analyses are meaningless if they are not firmly linked to human perception and risk of adverse effects. Wind farms can exhibit audible modulating sound or tonal complexes and these characteristics can cause adverse health effects such as sleep disturbance, anxiety, stress and headaches is a health nuisance and is objectionable and unreasonable. The research must include detailed analysis of wind turbine infrasound and audible sound as well as modulation inside and outside residences and in rural workplaces. Such research must

be conducted by an organisation or organisations independent of wind farm operators or their consultants.

3. It is submitted that no large-scale wind turbine should be operated within 2000 metres of any dwelling or noise sensitive place unless the owner and occupier of that residence has given written approval for the turbine location.

4. It is submitted that no large-scale wind turbine should be operated within 3500 metres of any dwelling or noise sensitive place unless the operator of the proposed wind farm energy facility, at its own expense, mitigates any noise within the dwelling or noise sensitive place identified as being from that proposed wind farm energy facility, to a level determined subject to the final approval of the occupier of that dwelling or noise sensitive place.

5. It is submitted that the conditions of approval pertaining to wind farm noise must be written so they can be readily enforced on complaint with turbines being switched off if necessary. There needs to be a regulatory mechanism that is fair and practical to both the wind farm operator and to an individual affected by wind farm noise. This mechanism, if based on sound measurements, must be in the control of an impartial competent body that has the authority, duty of care, obligation and funded ability to act on complaints.

6. It is submitted that the ultimate responsibility for resolving this situation rests with Federal Parliament as it is the Commonwealth's demand for renewable energy that is driving the construction of wind farms. The energy suppliers are legally bound to provide a significant portion of their energy in renewable form (hydro, solar or wind). Therefore, as this a public good issue then the public must compensate the people adversely affected. The energy suppliers operate through the large-scale generation certificate market. A funding process similar to the certificate market can be made available so practical noise mitigation measures can be implemented at any residence, noise sensitive place or farm affected by existing and proposed wind farms.

7. It is submitted that the Inquiry strongly recommend to the Environment Protection and Heritage Council that its draft 'National Wind Farm Development Guidelines' be finalised and peer-reviewed by persons and organisations that are not the same as those persons or organisations responsible for the draft guidelines published in July 2010 and October 2009.



## **PART II - THE PROBLEMS WITH RURAL WIND FARMS**

The problems for wind farm developers and rural residents stem directly from:

- Inappropriate land-use planning;
- lack of understanding of the problems involved with inadequate acoustical and human perception analysis; and
- ineffective compliance approvals.

Residents living near operational rural wind farms report sleep disturbance and adverse health effects. Obtaining a response to complaints appears to be problematic in Victoria and this can be attributed to ineffective complaint mechanisms.

Wind farm developers and operators generally deny any adverse effects from wind farm activity. This response appears to be based on self-selected literature surveys and acoustic standards and guidelines that are based on 'general' noise such as from road traffic. It is very difficult to measure wind farm 'sound' when mixed with 'ordinary' sound. Thus compliance becomes an issue and sounds below 35-40dB(A) can be intrusive and annoying. The character of the sound and its effect on individuals becomes important rather than sound 'volume'

### **Inappropriate Land-use Planning**

The general theme of government guidelines appears to be that if a wind farm is in a rural environment it can do no harm.

Following this logic it is far better that the wind farm be located within the urban area that requires the power. Thus the cost of development is lower, access to a large pool of labour is assured, access to materials and roading is no problem, and there are, based on the guidelines, no adverse environmental effects from wind turbine noise. The Geelong to St Kilda to Mornington Peninsula foreshore and off-shore could, for example, readily assimilate many hundreds of 3MW turbines bringing power to the people who need it. There is no need to go to a rural environment as the standard noise compliance conditions imposed by the Minister through the Victorian Civil and Administrative Tribunal (VCAT) process are clearly satisfactory for both situations. Alternatively, there are no doubt large areas of parkland or industrial reserves within Geelong and Melbourne that can accommodate wind turbines. Issues dealing with zoning are a planning concern and can obviously be addressed by planners. Turbine efficiency is not an issue as the wind farm and turbine choice can be designed for the relevant air and building

environments. Wind farms tend to be developed in areas where rural landowners have agreed to lease a portion of their land for the term of the wind farm, nominally 20 years. Lease arrangements are a normal part of industrial business and would be acceptable in an urban environment.

It is, therefore, a matter of land-use choice and associated planning instruments that brings turbines into rural areas rather than the urban areas where the power is needed. This Submission debates this statement, as well as the potential for adverse health effects from wind turbine noise.

### **The Problems with Wind Farm Noise and Its Perception**

The sound from a wind farm is unique. It is not similar to air conditioning fan noise although it shares some of the low frequency characteristics of fan noise. It is not the same as noise from transportation sources (road, rail, aircraft) although it does share some of the 'movement' characteristics of these sources. The sound is of low amplitude and varies in space (as the blades turn), in location (as the blades turn with the different wind directions), in time (sound levels vary due to turbine activity over time), and in complexity (when the blades interact with disturbed air from other turbines). Turbines are large industrial noise sources. The height from ground to the centre of the hub can often be 80 to 85 metres and the blades themselves can be 46 to 50+ metres in length. The blades move and interact with a huge volume of air to draw energy from the air movement to generate electricity.

Unfortunately, unlike with fan or transportation noise, there are no long established noise exposure models that will give any certainty of prediction as to the effect of wind turbines noise on people. There is an international standard that explains how to measure the sound from a turbine but the standard is very limited in its application. There is an Australian standard for wind farm noise assessment and a number of guidelines referring to the assessment of noise from wind farms. All these standards are limited in application and do not address the core issue of the effect of noise on people.

The sounds from a wind farm are often of low amplitude (volume or loudness) and are constantly shifting in character ("waves on beach", "rumble-thump", "plane never landing"). People who are not exposed to the sounds of a wind farm find it very difficult to understand the problems of people who do live near to wind farms. Some people who live near wind farms are disturbed by the sounds of the farms, others are not. In some cases adverse health effects are reported, in other cases such effects do not appear evident. The sound from a wind farm is intermittent in that it is not constant all day every day at approximately the same level. The sound fluctuates with the wind. It changes as the turbines turn into the wind. Many people living near turbines do not become used to the variations or character of the sound - unlike traffic noise, for example, where people do become used to the relatively consistent

character of the sound. The sound becomes unsustainable and in affected individuals can result in serious adverse health effects.

### **Ineffective Compliance Approvals**

An effective compliance approval is one that applies conditions to specifically avoid adverse environmental outcomes. A partly effective compliance approval is one that mitigates adverse environmental outcomes. An ineffective compliance approval is one that permits or encourages adverse environmental outcomes. My experiences have been with wind farm compliance conditions that fall into this latter category as they have been so drafted that specific conditions cannot be measured with certainty. In particular, this applies to penalties imposed if a sound is tonal or has some special characteristic that must be identified.

There are two situations that involve compliance monitoring: on an audit basis to identify compliance with noise conditions; or, on complaint. The only possible way to prove compliance is to turn the turbines off, measure the ambient levels, turn the turbines on, measure the wind farm and ambient sound levels together, assess the variation and then come to some decision as to compliance. This procedure only applies to an audit process and fails, of course, if noise complaints are being investigated when the wind farm noise and the ambient sound are completely mixed together and the wind farm sound is not clearly dominant. Secondly, and most importantly, the conditions giving rise to the complaint or complaints have gone and cannot be measured or assessed unless recorded.

In practice only the wind farm operator has access to the wind and turbine data necessary to assess compliance. Only the acoustic consultant can determine tonality or special audible character. Thus it is virtually impossible for the “other side” be they regulatory authorities or complainants, to prove non-compliance.

Equally, in my experience, because of the construction of the relevant compliance conditions it is almost impossible for a person to lodge a complaint that will be actioned. Even if the complaint is ‘true’, there is no possible way for the complainant to force the wind farm operator or regulatory authority to undertake any abatement action.

There needs to be a regulatory mechanism that is fair and practical to both the wind farm operator and to an individual affected by wind farm noise. This mechanism, if based on sound measurements, must be in the control of an impartial competent authority that has the authority and obligation to act on complaints.

## **PART III - A CASE STUDY**

### **A Rural Wind Farm**

The issues affecting the development and effects of a rural wind farm can be explained through a case study referencing a residence and persons who are affected by the Waubra wind farm near Ballarat in Victoria. The wind farm received permission to establish and was, as far as I can ascertain, generally welcomed within the rural community as an example of clean green energy. Noise assessment was made and noise compliance conditions imposed. After the wind farm started operating noise complaints and complaints of adverse health effects started to become known. To define the situation status it can be said that the adverse health effects reported by the residents near Waubra did not exist prior to the wind farm commencing operation. The adverse health effects reported by the residents may or may not be due to the operation of the wind farm. Resolving this will take resources, time and a more understanding approach to the resident's complaints. It can be reasonably said that, until the last five years' or so, the potential for adverse health effects from large-scale wind farms was relatively unpublished. That is not the situation now. To date no conclusive explanation for the reported adverse health effects is available but there is little practical difference between cause and effect with this rural wind farm and two others that I have research experience with in rural New Zealand.

There are two significant problems involved in the establishment of a wind farm in a rural environment that are not, I believe, the sole responsibility of a wind farm developer or operator.

The first problem is the way wind farm sound levels are predicted and assessed. There is not a long history of noise exposure and effect with respect to wind farm sound levels and human perception. Thus, 'older' transportation derived assessment guidelines based on fixed numbers that infer some degree of human response cannot be relied upon. Current acoustical standards and guidelines dealing with wind farm noise provide little if any guidance with respect to the potential for harm to individuals.

The second problem is that a rural environment has relatively few individuals who may be seriously affected compared to those who may be moderately affected or not affected at all. This is due, of course, to the relatively few residents in a rural locale compared to say, a city. Rural concerns can be conveniently explained away as affecting a few complainers compared to the large number of persons unaffected in the city. Unanswered is the potential number of persons who may be seriously affected if the wind farm was situated in the city.

To assess the potential number of affected households (rather than individuals) it is a common practice in acoustical wind farm assessments to prepare a noisemap showing the number of residences or noise sensitive places within predicted noise exposure areas. This practice is often seen by regulatory authorities as being clear and precise. It isn't.

### **Prediction of Wind Farm Sound Levels**

Sound level predictions are not “accurate”; they do not present the sound levels that will be heard at any one location at any one time. Rather, a prediction is a mathematical equation referenced to a lot of assumptions and uncertainties. Because of this, the predicted levels are also “uncertain”. The art in prediction is to identify all the assumptions and uncertainties to present a realistic assessment under realistic daily conditions. This is extremely difficult to do and cannot be done with simplistic prediction methods. The reasons for this are given in later in this Submission.

In order to gain an initial understanding of the potential noise levels from a wind farm it is common practice to prepare a noise map of the locality based on the 9 m/s turbine sound power information and residents living in the locale. A common prediction method is International Standard ISO 9613-2 *Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation*. The method is a simple approach to sound prediction and can be considered as the first ‘rough-cut’ or scoping risk assessment.

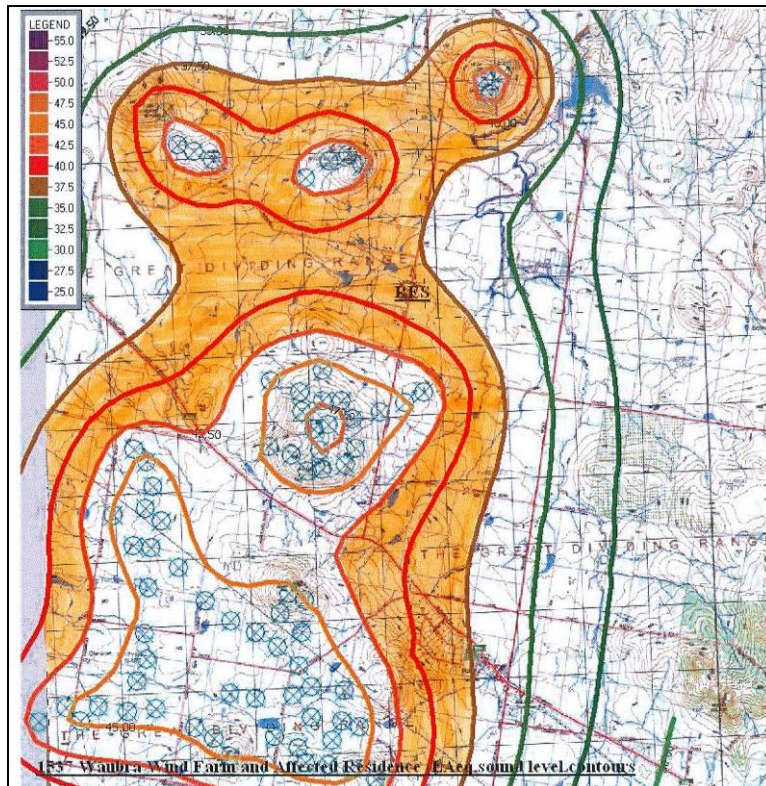
Reasonably accurate noise predictions are complex. Meteorological conditions, wind turbine spacing and associated wake and turbulence effects, vortex effects, turbine synchronicity, tower height, blade length, and power settings all contribute to sound levels heard or perceived at residences. In addition to this the method of prediction has what is known as “uncertainty”. That is, the predicted values are given as a range,  $\pm 3$  dB(A) at distances of between 100 metres and 1000 metres for the ISO 9613-2 prediction method, with the predicted value being the “middle” of the range.

Uncertainty increases with distance and the effect of two or more turbines operating in phase with a light/strong breeze blowing towards a residence. A variation of 6 to 7 dB(A) can be expected under such adverse conditions. This is explained in more detail later in this Submission.

### **Case study with a Waubra residence**

The noise predictions are not a single line or a single number but, in fact, a range of sound levels. The predicted time-average (LAeq) single-value sound level at the residence is 39 dB(A). Turbines are

approximately 2000 – 2200 metres to the north north-west, 3500 metres to the north-west, and 1740 – 2240 metres to the south / south-west of the residence. The uncertainty or potential range in the nominal predicted sound levels due to the prediction method alone is from 36 to 42 dB(A) LAeq at the residence (RES) as shown in **Plate 1**. Assuming a noise criterion or limit of 40 dB(A) the potential affect of the wind farm is not the '40 dB(A)' red line but more than the whole of the area covered by the orange highlighting. This is without the additional effect of any adverse wind effects or weather effects such as inversions, strong directional breezes or turbines acting under enhanced noise propagation (in phase or with wake and turbulence effects).



**Plate 1:** Predicted 40 dB(A) LAeq Zone affecting a residence (RES)

*Note: A blue circle+cross is a wind turbine.*

The view from the residence towards the nearest towers to the south is shown in **Photo 1**. This shows the turbines side-on to the residence. The side-on angle of the blades allows the effect known as vortex-shedding affect the residence. If the blades are full-on, as would be the case with a south-west breeze, the residence can be affected by cumulative sound as well as wake and turbulence effects. The effects are potentially more noticeable on the farm land itself as there is no screening effect from the pressure changes that can occur. The received sound levels can differ significantly from predicted levels.

**Photo 1: wind turbines as seen from a residence**



Noise levels predictions can therefore be considered as only approximations of sound levels and can not be given any weight other than this.

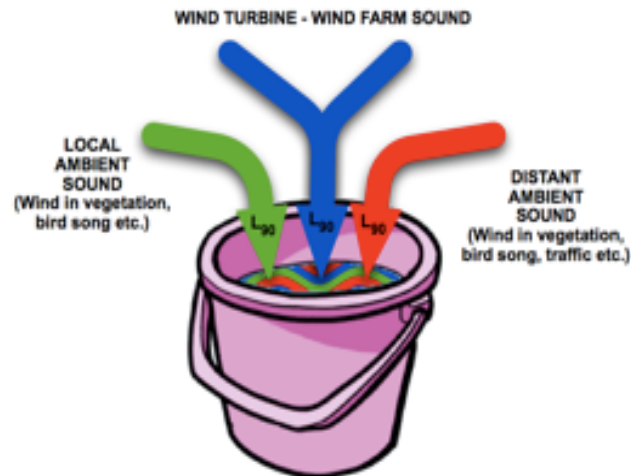
### **Background sound levels**

Various States apply noise criteria referenced to a single sound level value or to what is known as ‘the background sound level’, with and without the wind farm operating. Some states such as Victoria apply both measures so the tests for compliance or non-compliance become extremely complex.

Analysis of ‘single-value’ A-weighted wind farm background levels in the presence of ambient background levels (the real world) is extremely difficult to impossible. This observation is made on the basis of five years’ monitoring wind turbines at different locales under widely different weather conditions. **Figure 1** illustrates the issue: there are 3 separate sets of background influencing sound sources – local ambient, the turbines, and distant sources. It is not possible to separate out the contribution of each source once it is recorded as a single-value background measure (LA90 or LA95) at a specific location, such as a residence.



The same problem occurs when a single-value level, such as 40 dB(A) measured as the time-average or LAeq sound level is given as the compliance level. It is not possible to separate out the contribution of each source once it is recorded as a single-value at a specific location, such as a residence.



**Figure 1:** "Bucket of mixed sound" as LAeq or LA90 level.

By way of example, pour a glass of milk (noise specifically from wind farm activity) into a glass of water (the ambient sound around a residence). Add some extra water for distant sound (wind in trees, distant water pumps, and so on) that affects the background. Now remove the milk.

Difficult? Impossible. The three components are completely intermingled. Unfortunately the example holds true for whatever combination of 'single-value' acoustical descriptors are used to describe wind farm mixed with ambient sound levels. The effect of this is to render compliance monitoring in real-time – using A-weighted sound levels alone – nearly irrelevant. There can be no certainty that the level measured was due to the wind farm. Obviously loud levels of sound from a wind farm in excess of 35 or 40 dB(A) LAeq may be measurable but still very difficult to prove as being the source of sound when mixed into sound from vegetation (wind in trees, for example).

The situation is even more difficult if the noise compliance conditions require the identification of 'special audible characteristics', a New Zealand confection applied in Victoria. Application of this condition requires real-time observations or highly sophisticated recording and monitoring techniques. A practical alternative is to identify a set of sounds that are specific to the wind farm that are not a characteristic of the receiving environment and reference these sounds. Still difficult to do properly, but not impossible.

Conversely, it is easy for people to hear wind farm noise within "ordinary" ambient sound.



## The Effects of Weather

Some residences or noise sensitive places will be more subject to the prevailing breeze than others at different times. Sound propagation varies significantly under different wind conditions, especially:

- a) a prevailing breeze blowing from the wind farm to residences; or
- b) under conditions of cool, clear evenings/nights/mornings when a mist (inversion) covers the ground.

This latter condition (b) is sometimes called the ‘van den Berg effect’. It is a common condition. My own observations at operational wind farms at distances of around 1400 metres show that sound levels are higher under calm or inversion conditions (cold clear night) at the observer than under unstable conditions (e.g. light breeze during the day). Sound levels under inversion conditions are often louder and clearer at observer locations. The effects of temperature inversion in the locale supports inversion (fog) conditions and enhanced and elevated sound levels at the residences are expected. Under stable or inversion conditions sound levels do not decay as quickly compared to unstable conditions.

## Audible sound character

In this Case Study the operation of the turbines to the south-west of the residence can be clearly heard at the residence. The sound, with turbines operating, can be described as a steady rumble with a mixture of rumble – thumps. Wind in the trees or vegetation is not intrusive. **Figure 2** presents the variation between maximum, minimum and average (Leq) un-weighted sound levels. Un-weighted (‘Z’ weight sound levels) are referenced for audibility, as explained later.

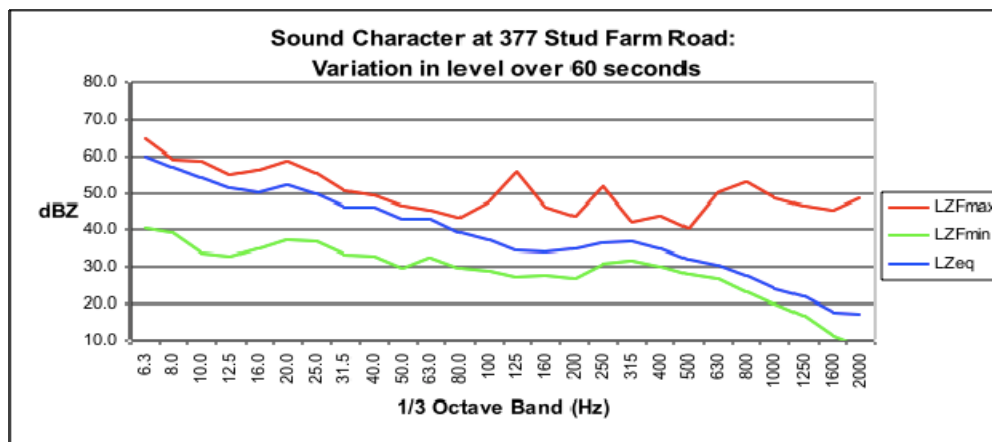
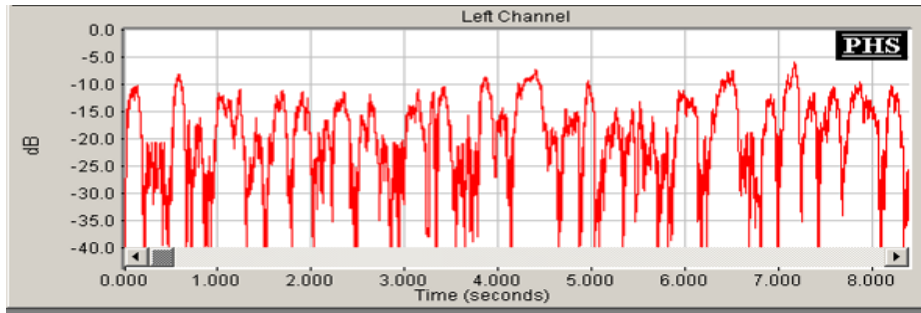


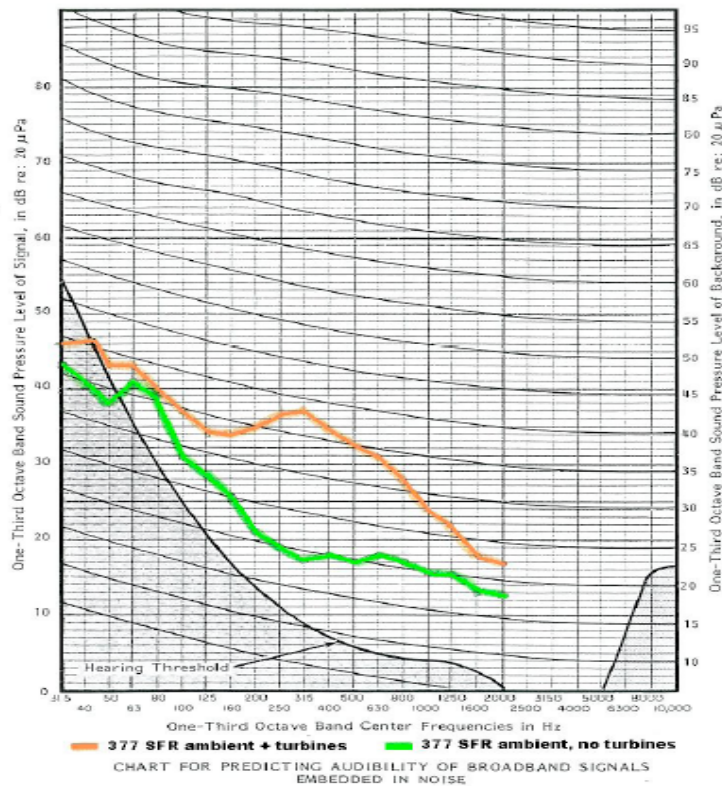
Figure 2: Variation in sound character over 60 seconds

In 60 seconds the sound character varies regularly by more than 20 dB; this level of variation will be audible. The generally accepted variation for a clear sense of audibility is 3 dB. Far finer detail is available by analysing the sound into amplitude variation over the 60 seconds, **Figure 3**. The figure shows the regular pulsing or modulation that is typical of blade passing the tower.



**Figure 3: Pulse pattern from an operational wind farm**

In order to confirm that a sound is audible to a person of 'normal' hearing an analysis of broadband sound – such as the sounds recorded in **figure 2** can be further analysed for audibility. The higher the orange line is above the green line in **Figure 4** the more clearly the signal can be heard. As a guide, a 3 dB shift can be readily heard. The sound is also compared against the hearing threshold level for a 'normal' person.



**Figure 4: Audibility of wind turbines at Residence**

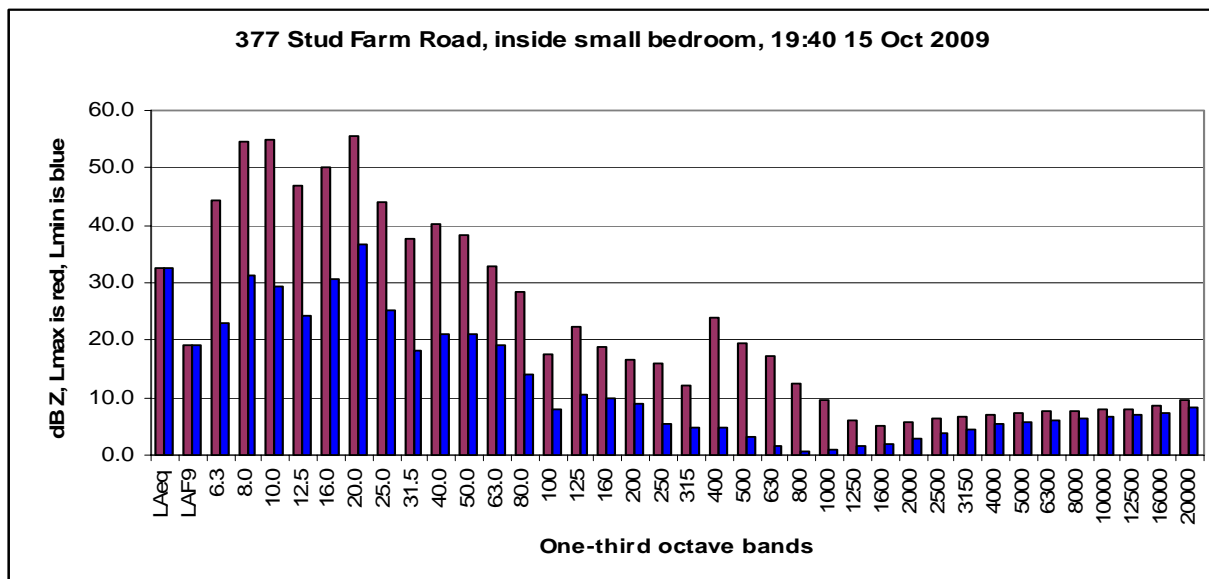
## Sound character at residence and near locale

It is concluded that wind turbine sound at the residence is perceptible and can be analysed and assessed in a meaningful way. The sound character of the wind farm is clearly different from the locale and indicates the presence of special audible characteristics (modulation) as described in various standards.

**Figure 5** represents a time-slice for the beginning of survey when the sound of the turbines was audible outside. The inside sound levels background (LA95) sound levels compared to the 'time-averaged' level, LAeq. The consistency in level is not unusual for inside a home. The LA95 level for the time period is 17.4 dB(A). The average (LAeq) level is 32.5 dB(A). At 8pm the wind dropped and the sound levels within the home decreased, with an average (LAeq) sound level of 18 dB(A), just above the background level.

The caution here is that sound levels vary significantly over very short (10 minutes, for example) periods of time. An assessment based on an 'overall' sound level (**Figure 2**) may not truly represent the effect of varying sound character (**Figure 5**). This shows the need for the test for audibility, **Figure 4**.

The observation from **Figure 5** is that the overall sound character shows substantial variation between the un-weighted minimum level, LZmin and the maximum levels LZmax in each third octave band. The variation is significant above 20 Hz because this is when the difference in sound levels becomes audible. The levels show the failure of A-weighted statistical levels in presenting the true sound character.



**Figure 5: Indoor sound character for the initial survey (LZmax vs LZmin)**

The method used to display sound character, modulation, tonality or tonal complexes is through sonograms<sup>1</sup>. These show the 'special audible characteristics' of sound at various frequencies over time as illustrated in **Figures 6 and 7**. Amplitude and frequency modulation can be identified in the sonograms by distinctive regular patterning at 1 second (or longer or shorter) intervals. Tonality and tonal complexes can also be identified using sonograms. Generally the sonograms are not calibrated against measured sound level but present a comparison between peak and trough (maximum and minimum) levels in a short period of time. The sonograms and third octave band charts following are provided to illustrate the character of the sound. The sonograms and third octave band charts following are provided to illustrate the character of the sound.

The following sonograms are presented to illustrate specific locations with and without turbine activity. The sonograms illustrate the presence of turbines even though the activity may not be audible. Different time segments are used to illustrate the effects. The important features are:

- The significant amount of sound energy in the low frequency and infrasonic ranges
- The variation of 20 decibels between high and low values in the sonograms between the yellow bands and the purple bands. This variation is audible under observed conditions.

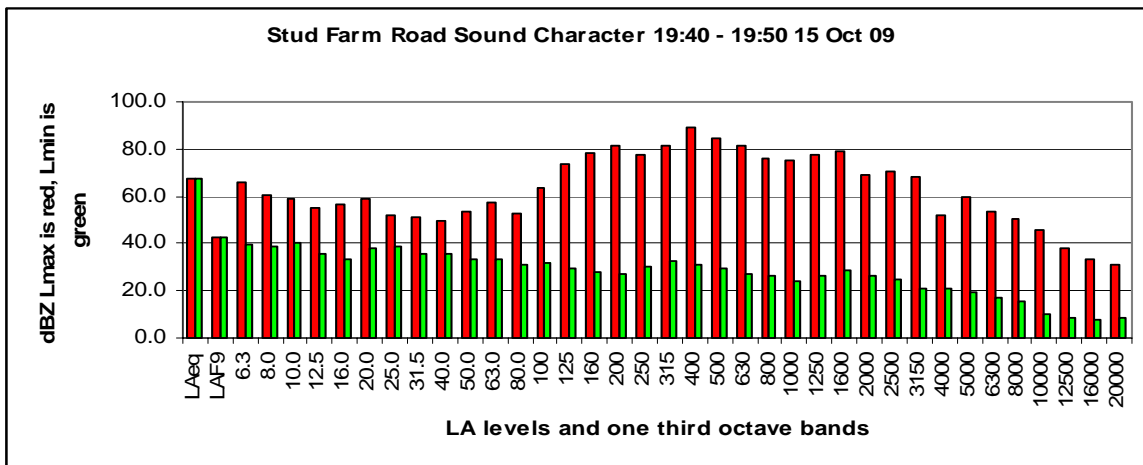
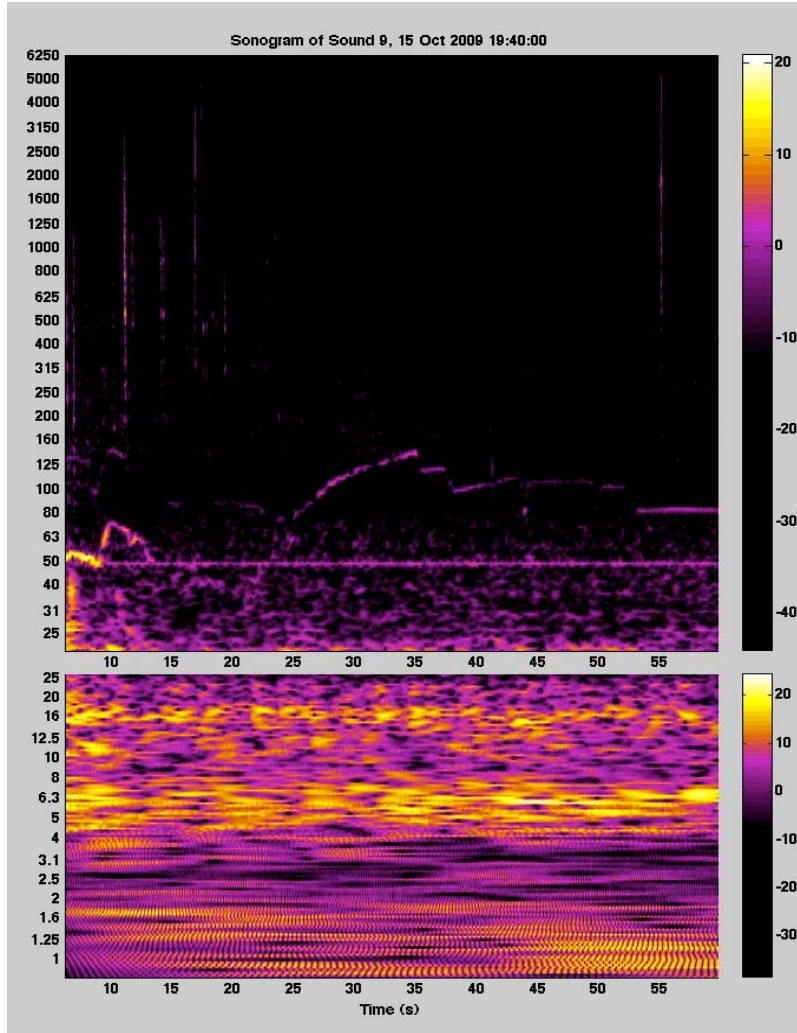
The overall levels in one-third octave band charts are provided to illustrate the difference between maximum and minimum sound levels in the measurement time period. These correspond to the peak and trough values and give a "first-cut" assessment of whether or not audible modulation, audible tonality, perceptible modulation or perceptible tonality may exist. The charts are provided as examples of the sound character. The sonograms are taken from the recorded audio files which are 60 second or 30 seconds in length. Hence the displayed sonogram charts can differ from the one third octave band charts which are calculated over a full 10 minutes.

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<sup>1</sup> Various methodologies are available to display sonograms or modulation. For this Report the methodology by Dr H. Bakker, Astute Engineering, is preferred.

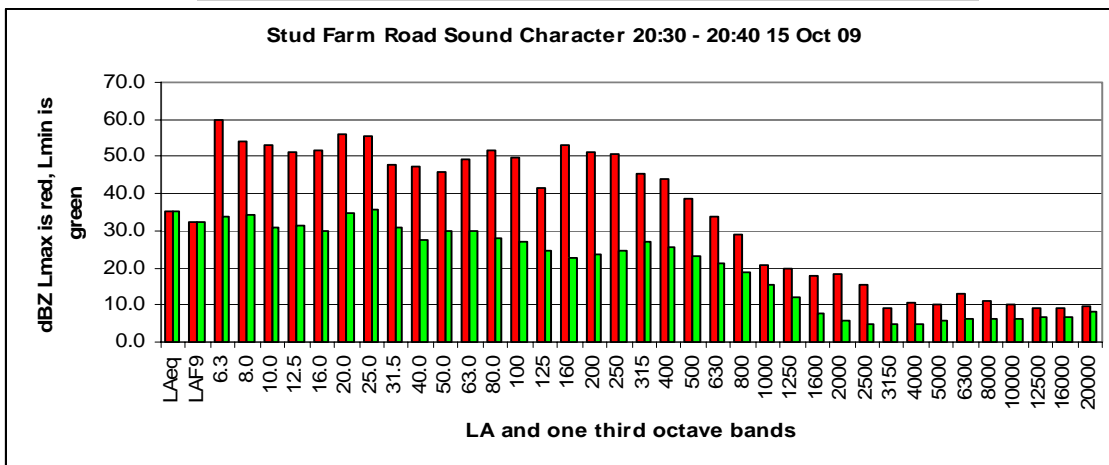
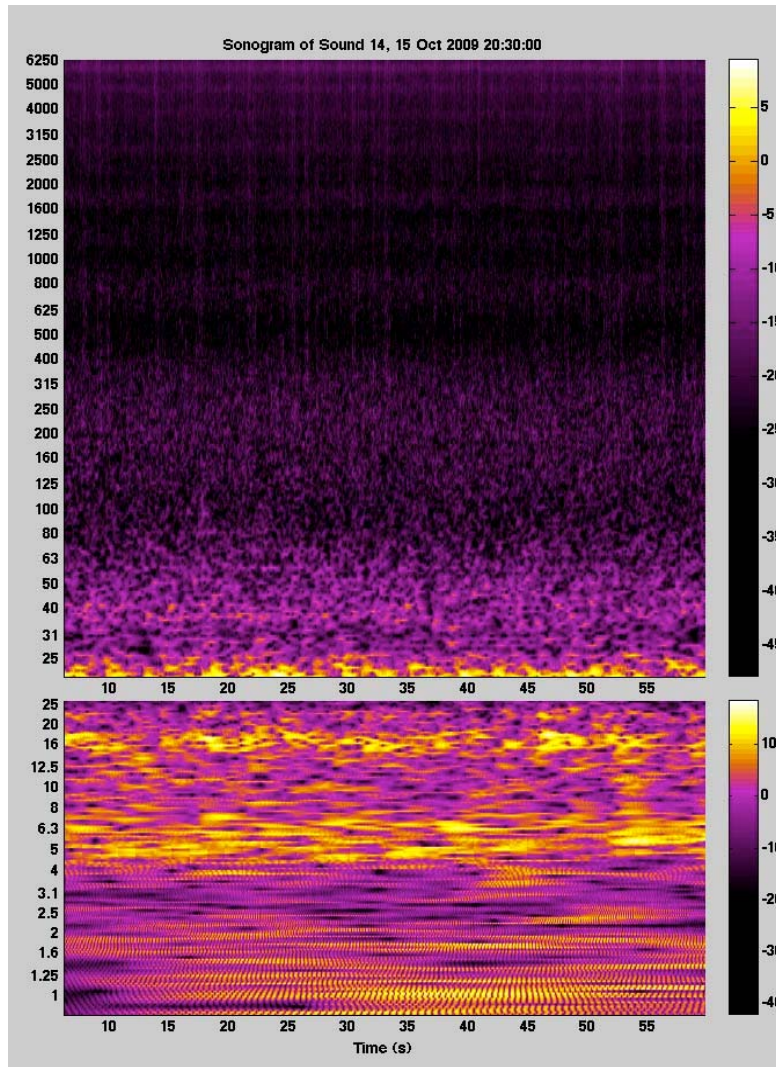
**Figure 6: Sound Character at Residence.**

Sound of wind farm audible at 7:40pm outside residence, as well as wind in trees, voices, setting-up activity and a distant vehicle. The sonogram shows a distinctive 50 Hz tone from a nearby electrical source, as well as strong readings at 20 Hz, 16 Hz and 6.3 Hz. These are indicator frequencies for potential adverse health response. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass frequency.



**Figure 7: Sound Character at Residence.**

The soundfile was recorded with no-one present. The audio file has wind and wind farm sounds. There are strong readings at 20 Hz, 16 Hz and 6.3 Hz. These are indicator frequencies for potential adverse health response. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass frequency.





## **Glossary of Terms**

### ***Event maximum sound pressure level (LA%,adj,T), LA01***

The L01 level is calculated as the sound level equalled and exceeded for 1% of the measurement time, for example 6 seconds in any 10 minute interval. LA01 is an appropriate level to characterise single events, such as from impulsive or distinctive pass-by noise. The level can be adjusted for tonality or impulsiveness.

### ***Average maximum sound pressure level (LA%,adj, T), LA10***

The "L10" level is an indicator of "steady-state" noise or intrusive noise conditions from traffic, music and other relatively non-impulsive sound sources. The LA10 level is calculated as the sound level equalled and exceeded for 10% the measurement time, for example 60 seconds in any 10 minute interval.

### ***Background sound pressure level (LA90,T), LA90 or LA95***

Commonly called the "L95" or "background" level and is an indicator of the quietest times of day, evening or night. The LA95 level is calculated as the sound level equalled and exceeded for 95% the measurement time. The level is recorded in the absence of any noise under investigation and is not adjusted for tonality or impulsiveness.

### ***Equivalent Continuous or time average sound pressure level (LAeq,T), LAeq***

Commonly called the "Leq" level it is the logarithmic average sound level from all sources far and near. The measure is often used as an indicator of sound exposure and is influenced by brief events of high volume sound, such as impact noise from a closing door. The level can be adjusted for tonality.

### ***Façade-adjusted and Free-Field levels***

The façade-adjusted sound level is that measured at a distance of 1.0 metre from a wall or facade. The level is nominally 2.5 dB higher than the free-field level. In comparison, the free-field sound level is measured at a distance of more than 3.5 metres from a wall or facade.

### ***A-weighted or Z-weighted***

The A-weighted sound level is commonly used as a measure of sound but the 'weighting' discriminates against sounds below 500 Hz and above 7500 Hz. The 'Z' weighting, also called 'Lin' or 'Flat', does not discriminate against low or high frequency sounds across the measurement range. The measures are defined in acoustical standards.

The expression 'LAF95', for example, means the A-weighted sound level, fast response, exceeded for 95% of the measurement time. 'Fast' response is a standard method of measuring sound levels.

### ***Third Octave Band***

Sound can be 'divided' into bands for detailed acoustical analysis. Third octave bands are defined within acoustical standards.

### ***Conclusions from Waubra Case Study***

Waubra is neither unique nor outstanding in the problems reported with respect to rural wind farm noise and adverse health effects affecting nearby residents. The question is: *what is different about the sound emissions, audible and / or inaudible, that give rise to the adverse health effects reported by residents?*

The primary conclusions that can be brought out from my initial acoustical study at Waubra are that the environment has changed. The operation of the wind turbines has changed the character of the acoustic environment in observable and measurable ways.

Wind farm sound levels at or below 35 dB(A) LAeq outside the surveyed residence can be heard by occupants. The sound levels can be analysed but at these levels the influence of 'ordinary' ambient sound interferes with the sound of the turbines.

The presence of the turbines can be identified using sonograms but sonograms are not used in formal compliance processes in Victoria although the identification of special audible characteristics is best done through the graphic presentation in a sonogram.

Individuals can easily hear sound levels of 20 dB(A) LAeq or less when inside the home and trying to get to sleep. The sound of turbines changing their position and turning into the wind can result in audible distinctive sounds that can awaken, annoy and stress a person.

The above conclusions apply to all rural wind farms.

The above conclusions will also apply to urban wind farms and the sound character will be different due to the urban soundscape and the presence of buildings modifying wind patterns.



## PART IV - WIND FARMS AND HEALTH EFFECTS

There is an extensive world-wide debate between acousticians, health professionals and the community (primarily affected persons) concerning potential adverse health effects due to the influence of wind farms. Sound and noise from wind farms is becoming more intensely debated and the last few years has seen a substantial increase in peer-reviewed acoustical and health-impact related reports and professional evidence to regulatory authorities hearing applications for wind farm planning permissions.

The following is a very brief introduction to a small sample of experts who have published evidence concerning the extremely interesting topic of wind farm activity and its potential effect on human health. As may be expected there is considerable divergent opinion. At the end of the day, however, the question is simple:

*'If there were no ill effects before the wind farm started operating, and there are a lot of complaints about adverse health effects now that it is operating, what has changed?'*

Dr Eja Pedersen<sup>2</sup> in "Human Response to Wind Turbine Noise: Perception, annoyance and moderating factors" presents an understanding of how people who live in the vicinity of wind turbines are affected by wind turbine noise and how individual, situational and visual factors, as well as sound properties, moderate the response.

Dr Nina Pierpont MD, PhD, has written a peer-reviewed text "Wind Turbine Syndrome" that, in its electronic draft form (March 2009) has been extensively debated by people who agree or disagree with her research concerning wind turbine activity and adverse health effects. The revised work is now available as a printed text. Dr Pierpont states the following symptoms:

*"... sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic attack episodes associated with sensations of internal pulsation or quivering when awake or asleep."*

In his Paper<sup>3</sup> "Wind Turbine Syndrome – An appraisal" Dr Leventhall critiques the work of Dr Nina Pierpont but does agree with Dr Pierpont concerning the identified stress symptoms:

*"I am happy to accept these symptoms, as they have been known to me for many years as the symptoms of extreme psychological stress from environmental noise, particularly low frequency noise. The symptoms have been published before (references given)." (p.9)*

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<sup>2</sup> Pedersen E., 2007, Human response to wind turbine noise: Perception, annoyance and moderating factors, PhD thesis

<sup>3</sup> Leventhall, G., 2009, Wind Turbine Syndrome – An appraisal"

*“The so called “wind turbine syndrome” cannot be distinguished from the stress effects from a persistent and unwanted sound. These are experienced by a small proportion of the population and have been well known for some time.” (p.11)*

In later correspondence<sup>4</sup> Dr Leventhall confirms his belief that there is no such thing as wind turbine syndrome.

Dr Daniel Shepherd specialises in public health and psychoacoustical studies. Before considering any possible impact of wind turbine noise on health a precise definition of health must be adopted. The WHO (1948) defines health as:

*A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.*

Thus health refers not only to physiology functioning, but also well-being, quality of life, and amenity. Quality of life, as defined by WHO (1997), is a multifaceted concept:

*An individual’s perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns. It is a broad ranging concept affected in a complex way by the person’s physical health, psychological state, personal beliefs, social relationships and their relationship to salient features of their environment.*

Primary health embraces the concept of health in all policies (e.g. labour, environment, education), and so includes not only the treatment of disease, but also its prevention. At the community level good health can be facilitated not only by the pursuit of healthy lifestyles (e.g., exercise and diet), but also the provision of restful and restorative living environments. A prominent factor determining the restfulness of a living space is the level of privacy and intrusion by community pollutants, including smell, air quality, and noise. He finds that<sup>5</sup>:

*There exists compelling evidence attesting to the impact that community noise can have on health. A number of interacting factors combine to determine an individual’s response to noise. As such, noise level should not be used as the sole metric with which to judge the potential health effects of noise. Annoyance can lead to degraded health, quality of life and impaired sleep, while disrupted sleep can lead directly to severe health deficits. Noise sensitive individuals are more susceptible to the negative effects of community noise. Turbine noise is a type of community noise and likewise has the potential to impact health and wellbeing. Evidence to this effect now exists in the peer-reviewed literature.*

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<sup>4</sup> Personal correspondence from Dr Leventhall to C. Delaire, Marshall Day Acoustics, provided in response to a query for the Stockyard Hill Wind Farm application, Victoria, May 2010.

<sup>5</sup> Personal communication from Dr Shepherd forwarding his paper ‘Wind turbine noise and health in the New Zealand context, 2010’ for preview.

Dr. Hanning founded and ran the Leicester Sleep Disorders Service, one of the longest standing and largest services in the country, until retirement. The University Hospitals of Leicester NHS Trust named the Sleep Laboratory after him as a mark of its esteem. Dr. Hanning<sup>6</sup> reports that:

*Inadequate sleep has been associated not just with fatigue, sleepiness and cognitive impairment but also with an increased risk of obesity, impaired glucose tolerance (risk of diabetes), high blood pressure, heart disease, cancer and depression. Sleepy people have an increased risk of road traffic accidents.*

Dr. Michael M. Nissenbaum, M.D., has conducted a study<sup>7</sup> of the health effects of persons living within 1100 meters of the Mars Hill Wind Turbine Project in Aroostook County, Maine, which consists of 28 wind turbines. He has produced significant evidence before tribunals. He states:

*It is my professional opinion that there is a high probability of significant adverse health effects for those whose residence is located within 1100 meters of a 1.5 MW turbine installation based upon the experiences of the subject group of individuals living in Mars Hill, Maine. It is my professional opinion, based on the basic medical principle of having the exposure to a substance proven noxious at a given dose before risking an additional exposure, that significant risk of adverse health effects are likely to occur in a significant subset of people out to at least 2000 meters away from an industrial wind turbine installation. These health concerns include:*

- a. Sleep disturbances/sleep deprivation and the multiple illnesses that cascade from chronic sleep disturbance. These include cardiovascular diseases mediated by chronically increased levels of stress hormones, weight changed, and metabolic disturbances including the continuum of impaired glucose tolerance up to diabetes.*
- b. Psychological stresses which can result in additional effects including cardiovascular disease, chronic depression, anger, and other psychiatric symptomatology.*
- c. Increased headaches.*
- d. Unintentional adverse changes in weight.*
- e. Auditory and vestibular system disturbances.*
- f. Increased requirement for and use of prescription medication. ...*

There are many excellent researched Papers dealing with wind farm noise and health effects, for example, those included in the recommended reading to this Submission.

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<sup>6</sup> Personal communication from Dr Hanning forwarding his paper 'Wind turbine noise sleep and health', preview 2010

<sup>7</sup> Reported at <http://www.wind-watch.org/documents/affidavit-of-dr-michael-m-nissenbaum-m-d/>

## Epidemiology and health risks

In counterpoint to the acousticians who seem to believe that wind farm noise is only the consideration of a set of numbers, there are epidemiologists who are deeply involved in the consideration of health effects. Epidemiology is the study of actual health outcomes on people and is the only science that can directly inform about actual health risks from real-world exposures. In his evidence<sup>8</sup> before the Public services Commission of Wisconsin Dr Phillips states that *real world exposures and the human body and mind are so complex that we cannot effectively predict and measure health effects except by studying people and their exposures directly*. Based on his knowledge of epidemiology and scientific methods and his reading of the available studies and reports he summarizes that:

- *There is ample scientific evidence to conclude that wind turbines cause serious health problems for some people living nearby. Some of the most compelling evidence in support of this has been somewhat overlooked in previous analyses, including that the existing evidence fits what is known as the case-crossover study design, one of the most useful studies in epidemiology, and the revealed preference (observed behavior) data of people leaving their homes, etc., which provides objective measures of what would otherwise be subjective phenomena. In general, this is an exposure-disease combination where causation can be inferred from a smaller number of less formal observations than is possible for cases such as chemical exposure and cancer risk.*
- *The reported health effects, including insomnia, loss of concentration, anxiety, and general psychological distress are as real as physical ailments, and are part of accepted modern definitions of individual and public health. While such ailments are sometimes more difficult to study, they probably account for more of the total burden of morbidity in Western countries than do strictly physical diseases. It is true that there is no bright line between these diseases and less intense similar problems that would not usually be called a disease, this is a case for taking the less intense versions of the problems more seriously in making policy decisions, not to ignore the serious diseases.*
- *Existing evidence is not sufficient to make several important quantifications, including what portion of the population is susceptible to the health effects from particular exposures, how much total health impact wind turbines have, and the magnitude of exposure needed to cause substantial risk of important health effects. However, these are questions that could be answered if some resources were devoted to finding the answer. It is not necessary to proceed with siting so that more data can accumulate, since there is enough data now if it were gathered and analyzed.*
- *The reports that claim that there is no evidence of health effects are based on a very simplistic understanding of epidemiology and self-serving definitions of what does not count as evidence. Though those reports probably seem convincing prima facie, they do not represent proper*

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<sup>8</sup> Phillips, C.V., (2010). An analysis of the epidemiology and related evidence on the health effects of wind turbines on local residents. Evidence before the Public Service Commission of Wisconsin. PSC Ref#: 134274. Retrieved from: <http://www.windaction.org/documents/28175>. Dr Phillips can be contacted at: cvphilo@gmail.com

*scientific reasoning, and in some cases the conclusions of those reports do not even match their own analysis.*

In December 2009 the American and Canadian Wind Energy Associations (ACWEA) published a literature review entitled *Wind turbine sound and health effects – An expert panel review*. This review reached consensus on the following conclusions:

- *There is no evidence that the audible or sub-audible sounds emitted by wind turbines have any direct adverse physiological effects.*
- *The ground-borne vibrations from wind turbines are too weak to be detected by, or to affect, humans.*
- *The sounds emitted by wind turbines are not unique. There is no reason to believe, based on the levels and frequencies of the sounds and the panel's experience with sound exposure in occupational settings, that the sounds from wind turbines could plausibly have direct adverse health consequences.*

The research summarised in this Submission refutes in total these three conclusions. We have found evidence of adverse health effects, we have identified ground-borne vibration as a possible sound pathway, and we confirm that the sound from turbines is, in fact, unique.

The ACWEA review has been thoroughly critiqued<sup>9</sup> by the Society for Wind Vigilance. The Executive Summary of the critique states (in part) that:

- *The conclusions of the A/CanWEA Panel Review are not supported by its own contents nor does it have convergent validity with relevant literature.*
- *The A/CanWEA Panel Review acknowledges that wind turbine noise may cause annoyance, stress and sleep disturbance and that as a result people may experience adverse physiological and psychological symptoms. It then ignores the serious consequences.*
- *Despite the acknowledgement that wind turbine noise may cause annoyance, stress and sleep disturbance the A/CanWEA Panel Review fails to offer any science based guidelines that would mitigate these health risks.*
- *The A/CanWEA Panel Review can only be viewed for what it is. It is an industry association convened and sponsored attempt to deny the adverse health effects being reported.*

In June 2010 the Australian Government National Health and Medical Research Council released a Paper entitled "*Wind Turbines and Health: A Rapid Review of the Evidence*". The NHMRC paper does not identify its author(s) and is not stated as being peer-reviewed, a significant omission in a Paper that is

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<sup>9</sup> Wind Energy Industry Acknowledgement of Adverse Health Effects: An analysis of the American/Canadian Wind Energy Association sponsored review. Available at [www.windvigilance.com](http://www.windvigilance.com)

widely referenced. In my view the NHMRC paper has no standing. An independent critique of the NHMRC report by the Society for Wind Vigilance (in part) states:

- *NHMRC asserts it "... only uses the best available evidence, in the form of peer-reviewed scientific literature, to formulate its recommendations." The contents of the "Rapid Review" reveals a different reality. The list of reference omissions is immense.*
- *The "Rapid Review" places an inappropriate level of credence in wind energy industry produced and or sponsored material to support its assertions. To compound this bias the "Rapid Review" selectively cites references which favour the wind energy industry while inexplicitly omitting relevant citations which do not.*
- *For example, the "Rapid Review" repetitively cites a wind energy association sponsored literature review but neglects to disclose this reference states wind turbine noise, including low frequency noise, may cause annoyance, stress and sleep disturbance. Acknowledged symptoms include distraction, dizziness, eye strain, fatigue, feeling vibration, headache, insomnia, muscle spasm, nausea, noise bleeds, palpitations, pressure in the ears or head, skin burns, stress, tinnitus and tension.*
- *The Society for Wind Vigilance does concur with the "Rapid Review" on one point – the title of the report. The sub-standard quality of research confirms the review is rushed and hence the title "Rapid Review" is undeniably appropriate. The "Rapid Review" confirms the adage that haste makes waste.*

In July 2010 the Environment Protection and Heritage Council published its draft *National Wind Farm Development Guidelines*. This is a significant compendium of information and is in draft for 12 months. My preference is to read this document in association with the public consultation draft (October 2010) and the original *Report on Impediments to Environmentally and Socially Responsible Wind Farm Development*, November 2008. These two earlier documents are, in my view, more informative than the 2010 release. The latest draft when dealing with health impact refers only to the NHMRC paper, above. In my opinion, it is strange that such an important Guideline refers to this sole report amongst the many available. Therefore, it is submitted that the Inquiry strongly recommend to the Environment Protection and Heritage Council that its draft 'National Wind Farm Development Guidelines' be finalised and peer-reviewed by persons and organisations that are not the same as those persons or organisations responsible for the draft guidelines published in July 2010 and October 2009.

Neither the NHMRC nor the Guideline documents state the names of the authors or their qualifications and neither of the documents appear to have been independently peer-reviewed.

## **Amenity and costs imposed by rural wind farms**

Amenity values are based upon how people feel about an area, its pleasantness or some other value that makes it a desirable place to live. The valuation of quiet or noise as commodities is not an unusual concept. They are commodities that can be bought and sold like any other commodity. As there is not an accepted system for the definition of cost, mechanisms need to be defined for the distribution of value. Conceptually, peace, tranquillity and quiet have value while noise has cost. Noise affects individuals and the community by modifying the extrinsic and intrinsic nature of the environment that attracts and holds people to the locality. The noise may have a positive value or, more likely given its nature, a negative value. Unregulated noise emissions – immissions, for example, impose a cost on to the receiver of that noise, without compensation or redistribution of cost back to its creator. There is a cost in producing the noise, a cost in receiving the noise and a cost in reducing or mitigating such noise. Typically, noise can be quantified by sound exposure levels or audibility and qualified in terms of unwantedness, annoyance and loss of amenity. Different models have been proposed to value noise and changing values in environmental quality, with the most common being Hedonic Pricing. Hedonic Pricing has been primarily applied to transportation noise because of the relative ease in defining the noise source, the affected parties, and the use of property valuations as an assessment tool. As caution is needed to assess clearly defined noise sources, the concepts are highly problematical for rural sources due to the extrinsic and intrinsic nature of the receiving environment. The costs in amenity and diminished health are not currently compensated although the wind farm is nominally in the public good to achieve the Commonwealth goal of 20% renewable energy by 2020. There is, therefore, a need for a more balanced approach to the development of wind farms in rural communities. Clearly, if there are no proven adverse effects to amenity or health then the wind farms can be readily sited in urban environments

## **Conclusion – Serious harm to health**

In my opinion, based on my training, experience, measurements and observations, serious harm to health occurs when an individual is so beset by the noise in question that he or she suffers recurring sleep disturbance, anxiety and stress. The marker for this sound level is 32 dB(A) LAeq outside the residence and above the individuals threshold of hearing inside the home.

From my observations and measurements at other rural wind farms I expect between 5% and 10% of the exposed households within 2000 metres (or 32 dBA Leq) will have their health seriously harmed by noise causing sleep disturbance, anxiety and stress. My conclusion is that a rural wind farm facility will therefore cause serious harm to health to a significant number of individuals living within 2000 metres of the turbines.

My research indicates “ordinary” wind has a laminar or smooth infrasound and low-frequency flow pattern when analysed over short periods of time. Wind farm activity appears to create a “pulsing” infrasound and low-frequency pattern. These patterns are illustrated in sonograms in this Submission. The hypothesis derived from my research is that wind farm sound has an adverse effect on individuals due to this pulsing nature as well as audible noise due to the wind turbines. These effects may be cumulative.

## **Conclusions**

In my opinion there is considerable agreement between the parties – residents, clinicians and acousticians – as to observable health effects from noise.

Conclusively, in my opinion, there are clear and definable markers for adverse health effects before and after the establishment of a wind farm and clear and agreed health effects due to stress after a wind farm has started operation.

There is, in my opinion, clear evidence that the operation of a rural (or urban) wind farm will affect some individuals so severely that there is a known risk of serious harm to health. It is the mechanism of the physical or mental process from one to the other that is not yet defined.

A rural wind farm imposes costs on the people affected living nearby. The costs in amenity and diminished health are not currently compensated although a rural wind farm development is nominally in the public good to achieve the Commonwealth target of 20% renewable energy by 2020.



## PART V - AUDIBLE SOUND AND NOISE

### Basic Measures

Noise can be measured in many different ways. The most commonly used measure of environmental noise is the A-weighted sound pressure level.

The most commonly used noise compliance assessment methods for wind farms are the 'time-average' sound level  $L_{Aeq}$  or the background sound level,  $L_{A90}$ . These levels are quite different as the time-average level includes all noise from far and near whereas the background level supposedly is not affected noise by discrete sources, such as the wind turbines. This is not strictly true and is the cause of significant compliance issues, as explained later in this Submission. The difference between the levels, and other common levels, is illustrated in Figure 1. The chart shows that sound levels change over time and that any derived sound level is a 'snapshot' of the levels in that time period. If the time period is relatively short, 10 minutes, then unique noise events such as bangs or thuds from turbines shifting in the wind may be captured. If the time period is relatively long, 1 hour, then the sound levels from the events are averaged away.

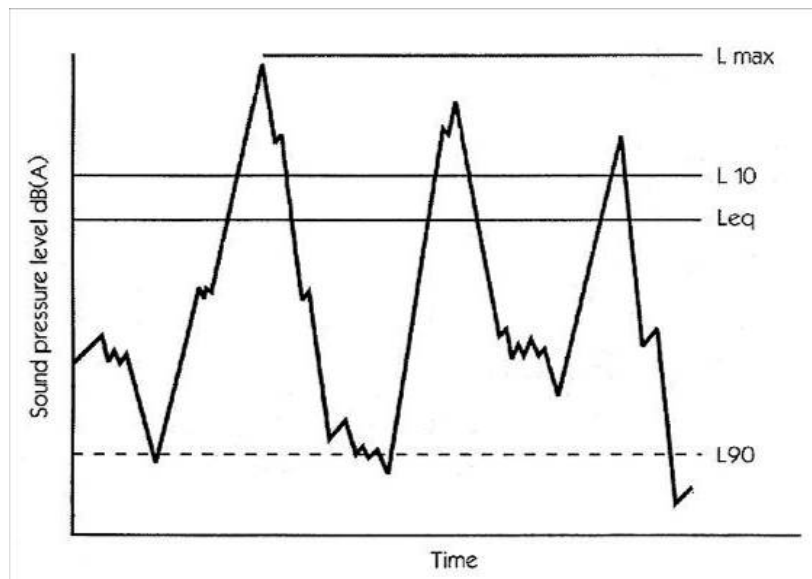


Figure 1: Chart showing different noise descriptors

Noise contributing to noise levels from the place under investigation must exclude extraneous noise unless the noise cannot practicably be avoided at the time of measurement. If extraneous noise is included in the measurement its contribution to the overall level must be determined.

The A-weighted sound level is the most common sound descriptor and is reputedly analogous to our hearing at medium sound levels. This is not strictly true and the A-weighting has a significant restriction in that it does not permit measurement or assessment of low frequency sound.

For more complex situations where dominant tonal components are significant, a procedure for determining tonal adjustment requiring one-third octave band frequency analysis is needed. The assessment procedure utilises what is known as the 'C' weighting or the un-weighted (also known as 'Z') response to measure low frequency sound. Both these weightings are essential for the assessment of audibility and human perception (psychoacoustic) response. The weighting responses are compared in Figure 2 and it can be seen that the C-weighting is able to analyse low frequency sounds such as the rumble and thump from wind turbines. The Z response is more suitable for infrasound measurements.

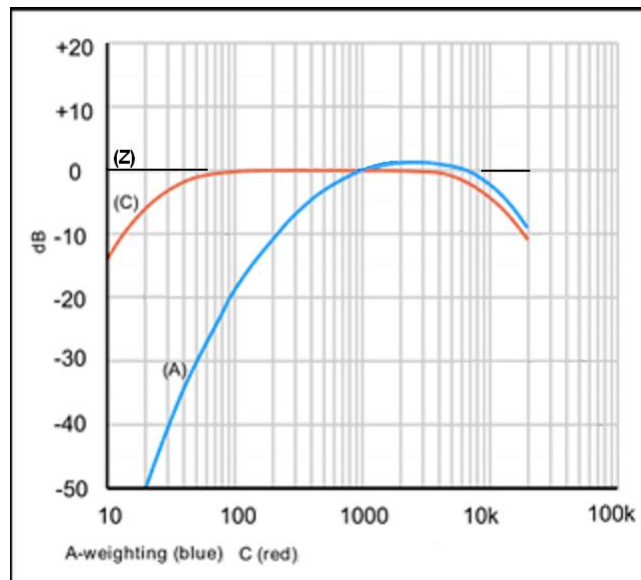


Figure 2: Sound weighting responses

## Wind Farm Noise

Wind farms and wind turbines are a unique source of sound and noise. The noise generation from a wind farm is like no other noise source or set of noise sources. The sounds are often of low amplitude (volume or loudness) and are constantly shifting in character (“waves on beach”, “rumble-thump”, “plane never landing”, etc). People who are not exposed to the sounds of a wind farm find it very difficult to understand the problems of people who do live near to wind farms. Some people who live near wind farms are disturbed by the sounds of the farms, others are not. In some cases adverse health effects are reported, in other cases such effects do not appear evident. Thus wind farm noise is not like, for example, traffic

noise or the continuous hum from plant and machinery. Wind turbines are large noise sources relative to dwellings, Figure 3:

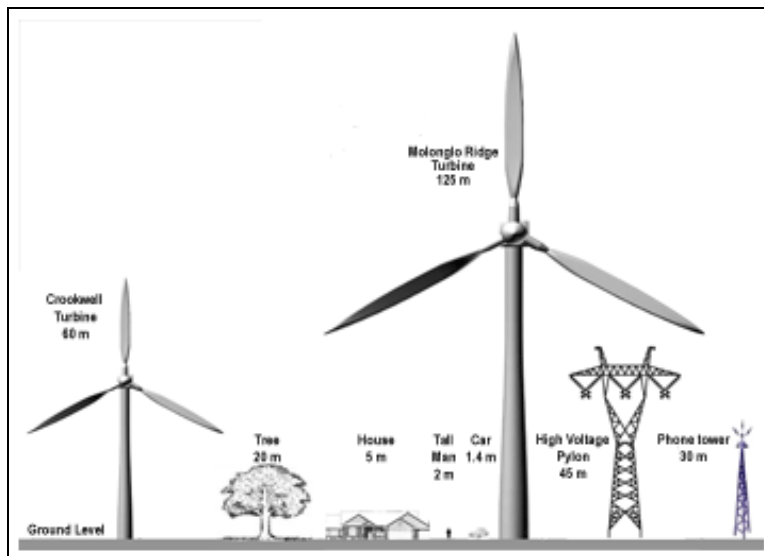


Figure 3: Relative heights of turbines to dwellings  
(Source: *Molonglo Landscape Guardians*, by permission)

Audible noise from modern wind turbines is primarily due to infrasound, turbulent flow and trailing edge sound. Sound character relates to blade characteristics and blade/tower interaction and can be grouped into 4 main bands. The sound can be characterised as being impulsive and broadband, audible and inaudible (infrasonic):

- Infrasound below 20 Hz
- Low frequencies 20 Hz to 250 Hz
- Mid Frequency 250 to 2000 Hz (broadly, although the higher level could be 4000 Hz)
- High frequency 2000 Hz to 20,000 Hz

Not all these frequencies can be heard by a person with “normal” hearing as hearing response is unique to an individual and is age-dependent as well as work and living environment-dependent. It is important to note that infrasound can be “audible” to people with sensitive hearing.

Technically, the proposed wind turbines can be classed as “upwind turbines” where the blades are upwind of the tower. As explained by Hubbard and Shepherd, the noise is created by the blade’s interaction with the aerodynamic wake of the tower<sup>10</sup>:

<sup>10</sup> Hubbard H. H., Shepherd K. P., (1990), *Wind Turbine Acoustics*, NASA Technical Paper 3057 DOE/NASA/20320-77, p19

*“As each blade traverses the tower wake, it experiences short-duration load fluctuations caused by the velocity deficiency in the wake. The acoustic pulses are of short duration and vary in amplitude as a function of time.”*

Upwind turbines show a lesser amplitude modulated time history and do not have the sharp pressure peak that characterises the downwind turbine. Hubbard and Shepherd (figure 4 taken from their figure 7-7) illustrate the nature of noise radiation patterns for broadband noise. The pattern for low frequency noise (8 Hz is given as the example) is broadly similar but with a more ‘pinched’ waist.

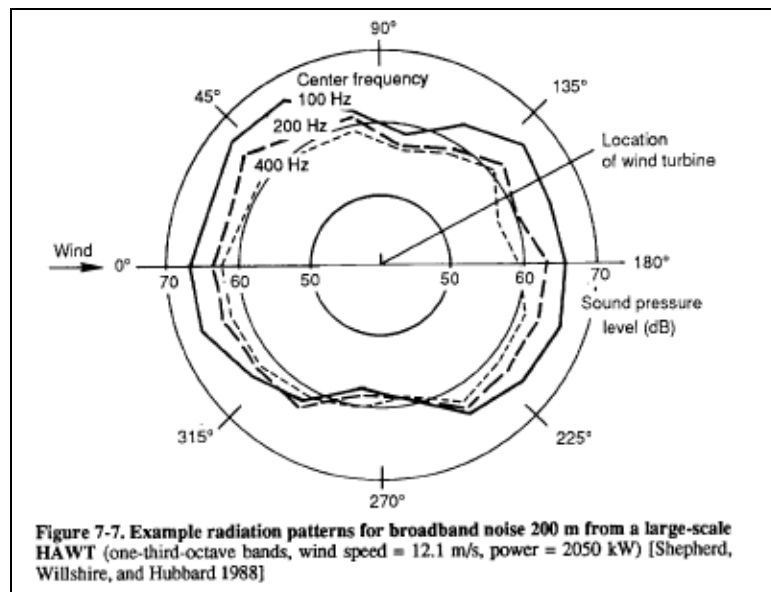


Figure 4: wind turbine sound pattern

Hubbard and Shepherd state, with respect to distance effects:

*“When there is a non-directional point source as well as closely grouped, multiple point sources, spherical spreading may be assumed in the far radiation field. Circular wave fronts propagate in all directions from a point source, and the sound pressure levels decay at the rate of -6 dB per distance in the absence of atmospheric effects. (Atmospheric effects illustrated in the text). For an infinitely long line source, the decay rate is only -3 dB per doubling of distance... Some arrays of multiple wind turbines in wind power stations may also acoustically behave like line sources.”*

Shepherd and Hubbard<sup>11</sup> suggest that multiple turbines “shift” from a point source decay rate of -6dB per doubling of distance to a line source with only -3dB decay per doubling of distance. The distance at which this occurs depends on the turbine types and spacings between turbines. The shift is frequency dependent with lower frequencies having the reduced decay rate. The report indicates a distance of approximately 900 metres from the front row of turbines, but this does relate to the referenced turbines.

Thus a wind farm can be considered as a discrete line source consisting of multiple sources that can be identified by distance and spacing (blade swish, blade past tower, wake and turbulence interference effects and vortex shedding). These sources are identifiable, figures 5 and 6:

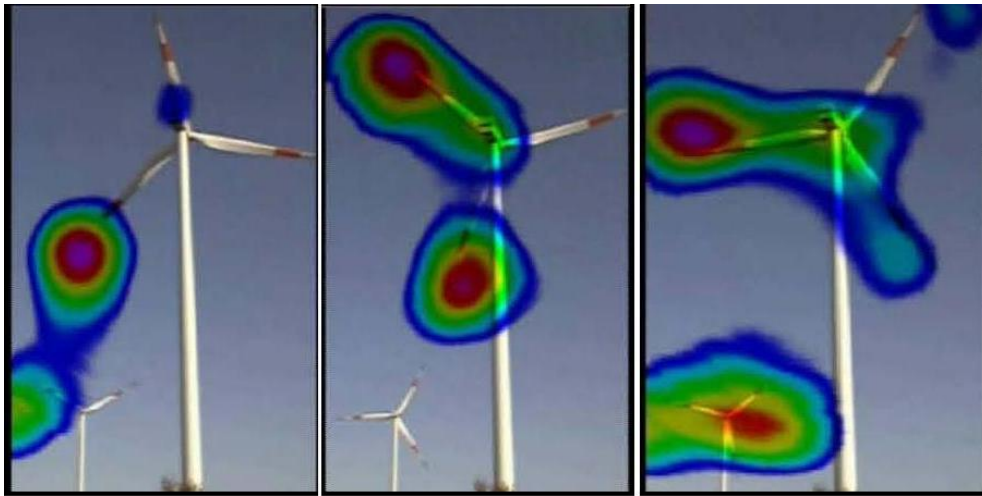


Figure 5: Acoustic photograph of sound sources from two turbines.  
Source: Acoustic Camera, 'Multiple sources wind turbines 300Hz – 7kHz.avi' by permission from HW Technologies, Sydney )

The pattern in Figure 6 shows clearly the vortex shedding from the blade on the downstroke. The dominant source of sound is from the blades with an overall sound variation in the order of 2 dB(A). The measurements are taken at approximately 150 metres behind the turbine. Frequencies below 300Hz can also be measured.

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<sup>11</sup> Shepherd, K. P., and Hubbard, H. H., (1986). Prediction of Far Field Noise from Wind Energy Farms. NASA Contractor Report 177956.

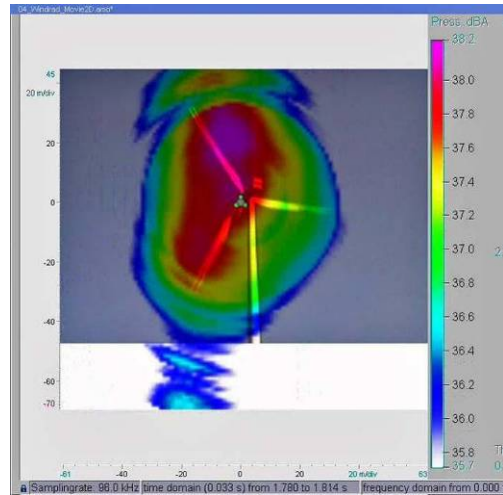
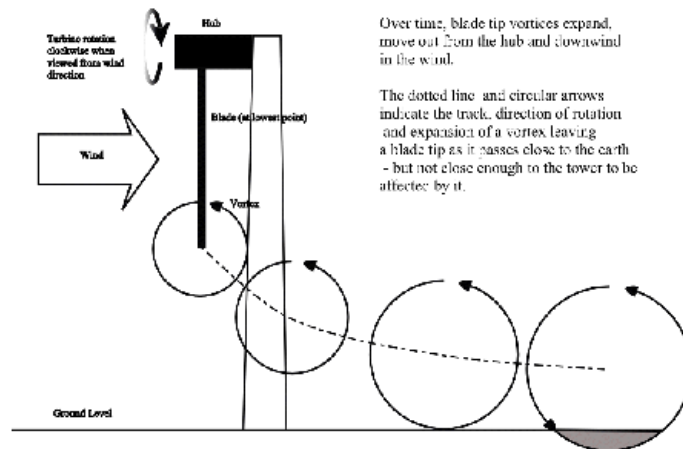


Figure 6: Acoustic photograph of sound sources from a turbine.  
 Source: Acoustic Camera, by permission from HW Technologies, Sydney )

Shephard<sup>12</sup> reports that wake and turbulence effects have a considerable influence on sound propagation. The effects are created (figure 5) as highly turbulent air leaving a turbine interacts with lower speed air. A major wind turbine manufacturer (Vesta) recommends a distance of at least 5 rotor diameters between the wind turbines. Wake effects with pockets of lower speed air are present within 3 rotor diameters downwind and mostly dissipated at a distance of 10 rotor diameters. If a second turbine is situated within 10 rotor diameters of the first turbine the blades of the second turbine can suddenly enter into a pocket of slower air in the wake caused by the first turbine. Increased sound levels will occur and the propagation distance in metres to a defined ‘criterion’ or sound level can be calculated.



Drawing 1: Vortex creation from a single wind turbine blade at the lowest point of travel (most interference has been ignored)

Drawing 1 illustrates the relative motions of wind, blade and vortices as the blade passes close to the earth leading to significant turbulence as the vortex reaches the earth's surface.

<sup>12</sup> Personal communication from Shephard, Ian. 2010. Wake induced turbine noise (v3). Drawing 1 by permission.

Another potential source of noise from a wind turbine is boundary layer air breaking away from the trailing edge of the blade. When the wind reaches a blade, part goes over and part goes under the blade. The part of the airflow with momentum great enough to break away forms trailing vortices and turbulence behind the blade, producing a set of sound sources. The power of each sound source depends on the strength of the turbulence, which in turn depends on the speed of airflow, the compressibility and viscosity of the air, the design and surface texture (roughness) of the blade, the wind speed, and the velocity of the blade at that point. The faster the blade is allowed to turn, the earlier the break-up in the bound vortices and the greater the interaction between the vortices shed by adjacent wind turbines.

An effect that enhances potential noise is observed by van den Berg<sup>13</sup> is when two or more turbines are or nearly synchronous, when the blade passing pulses coincide then go out of phase again. With exact synchronicity there is a fixed interference pattern, with near synchronicity synchronous arrival of pulses will change over time and place. Dr Van den Berg notes that of the relatively high annoyance level and characterisation of wind turbine sound such as swishing or beating may be explained by the increased fluctuation of the sound. In a stable atmosphere van den Berg measured fluctuation levels of 4 to 6 dB for a single turbine. Individuals are also highly sensitive to changes in frequency modulation variations of approximately 4 Hz. Such variations can be expected in wind farm designs such as this development.

Stable atmospheric conditions that give rise to noise propagation at ground level are prevalent over the year, however. The presence of stable conditions is critical for noise analysis, as noted by van den Berg. He observes that:

- a turbine operating at high speed into a stable atmosphere can give rise to fluctuation increases in turbine sound power level of approximately 5 dB;
- fluctuations from 2 or more turbines may arrive simultaneously for a period of time and increase the sound power level by approximately 9 dB.
- In-phase beats caused by the interaction of several turbines increases the pulse height by 3 to 5 dB.

Van den Berg observes that wind turbines in a stable atmosphere generate more sound than in a neutral atmosphere, while at the same time the wind velocity near the ground is so low that the natural ambient sound due to rustling vegetation is weaker. As a result the contrast between wind turbine sound and natural ambient sound is more pronounced in stable than neutral conditions. This situation enhances the ability to hear the trailing edge sound from the turbine blades. The differences in wind speed lead to

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<sup>13</sup> van den Berg, G. P., (2006). The Sounds of High Winds: the effect of atmospheric stability on wind turbine sound and microphone noise. Science Shop, Netherlands

variations in the sound radiated by blade tips that reach their highest values when the tip passes the mast. Van den Berg calculates the variation as approximately 5 dB at night and 2 dB in daytime.

As fluctuations, beats and trailing edge sound are characteristics of wind turbines, and as such are special audible characteristics of a wind farm, a penalty of 5 dB must be added to the noise from the wind farm.

The mechanisms of annoyance are significantly influenced to sound modulation ('rumble/thump') and the cessation /commencement of sound ('when will that noise start again?'). In "The measurement of low frequency noise at three UK wind farms"<sup>14</sup> the issue of modulation from wind turbines is discussed as 'blade swish', aerodynamic modulation and risk of modulation. The report comments on sleep disturbance at one residence with recorded interior sound levels of 22–25 dB  $L_{Aeq}$  with windows closed and states:

*"This indicates that internal noise associated with the wind farms is below the sleep disturbance threshold proposed within the WHO guidelines."*

and:

*"However, wind turbine noise may result in internal noise levels which are just above the threshold of audibility, as defined within ISO 226. For a low frequency sensitive person, this may mean that low frequency noise is audible within a dwelling."*

The character of the "ground-level" atmosphere in the vicinity of the residences within approximately 5000 metres of the wind farm therefore becomes critical in understanding the potential for noise from the wind farm. Under downwind conditions the sound generated by the turbines is affected by downwind refraction.

The effects of low amplitude sound from wind farms on individuals can be summarised as:

- Wind farms have significant potential for annoyance due to sound modulation effects even though these effects are of a low amplitude
- The potential adverse effects of low-amplitude sound and vibration that can induce adverse levels of low frequency sound are not well documented
- The interactions between background levels, ambient levels, modulation and tonal character of a wind farm overlaid within a soundscape are complex and difficult to measure and assess in terms of individual amenity
- Sound level predictions for complex noise sources of this nature are only partially relevant to this type of environmental risk assessment

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<sup>14</sup> DTI (UK), 2006, The measurement of low frequency noise at three UK wind farms.



Two significant situations not clearly identified by existing environmental sound assessment methodologies are:

- Sound that is clearly audible but below the generally accepted assessment criteria or which has an identifiable character that is difficult to measure and assess.
- Sound that just intrudes into a person's consciousness. Such sound may be distinctly audible, or have a definable character, or it may be almost inaudible to others.

## **Conclusions**

From my observations, interviews and measurements I conclude that residents in a rural environment will be affected by wind farm noise, although not all residents will be adversely affected.

- Wind farm noise can be intrusive in the home and is identified as low amplitude modulated sound (modulated in amplitude and frequency)
- Under 'adverse' wind conditions the sound of wind turbines are clearly audible at distances to approximately 5000 metres turbines-to-receiver to the extent that the sound can be recorded inside and outside a residence at these distances
- The sound of the turbines is not masked by wind or by wind through vegetation or leaf rustle in trees
- The ambient sound character in the absence of wind farm noise, and in the greenfield localities, is smooth wind in vegetation and animal (most often bird song) with no modulation effects



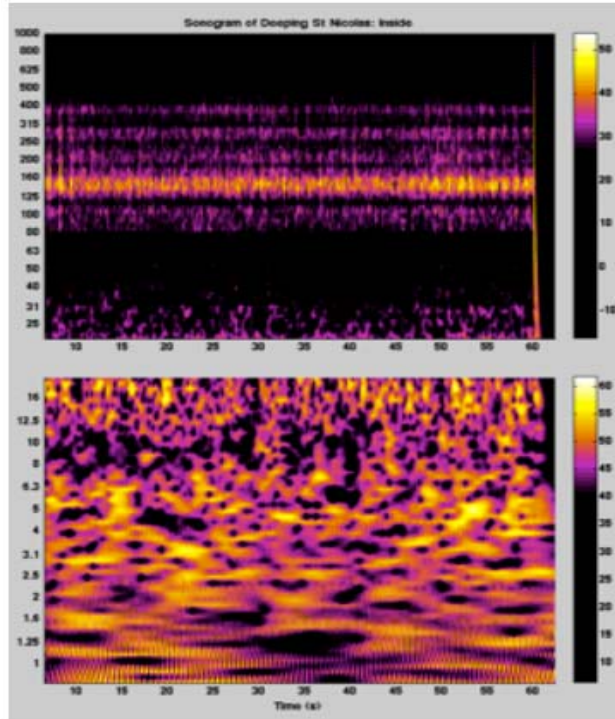


Figure 2: sound of wind turbines at 930 metres, inside residence

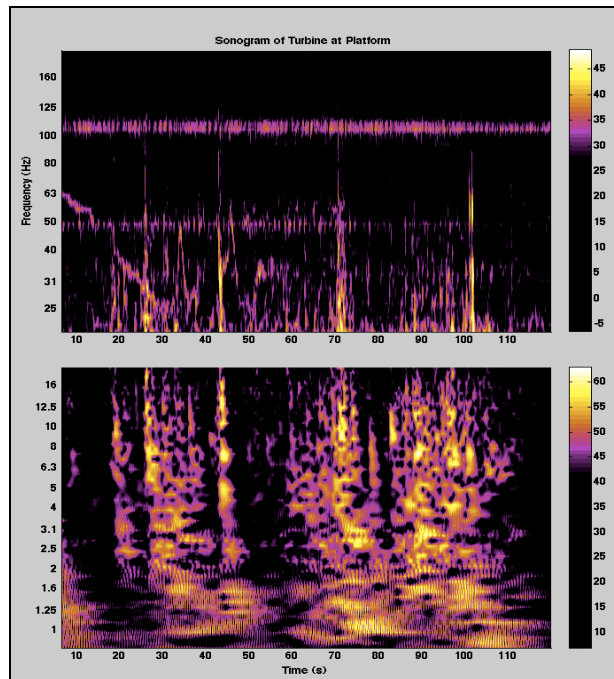


Figure 3: sound of a wind turbine at the turbine platform

Figure 3 shows a distinctive tonal complex at around 48 Hz. The sound levels at the wind turbine (Figure 3) were LAeq 52 dB(A) and a background level (LA90) of 32 dB(A).

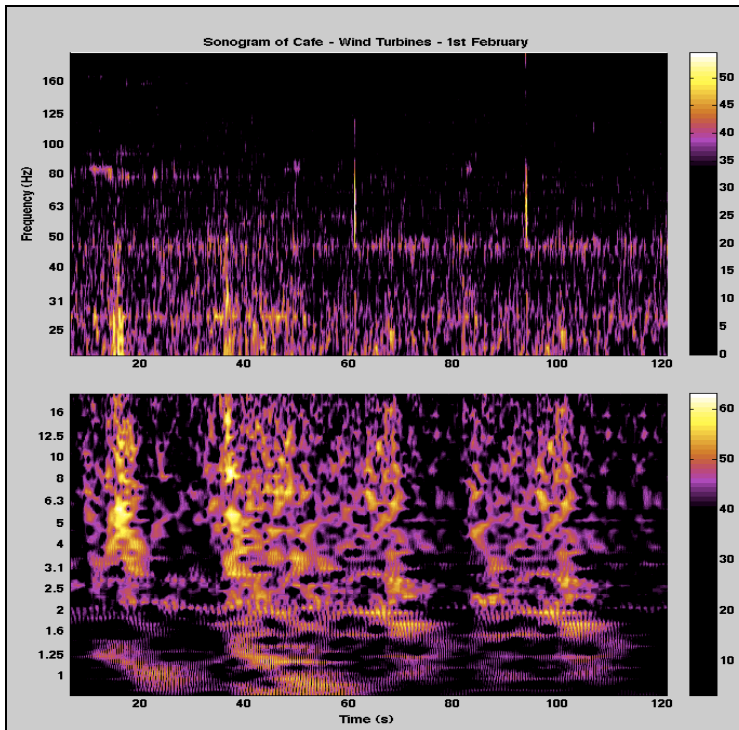


Figure 4: Audible sound of wind farm at 2200 metres over grassland and trees

The sound character from the wind farm with this type of Vestas turbine is shown at 2200 metres (figure 4). The turbines are not audible in sonogram (figure 5).

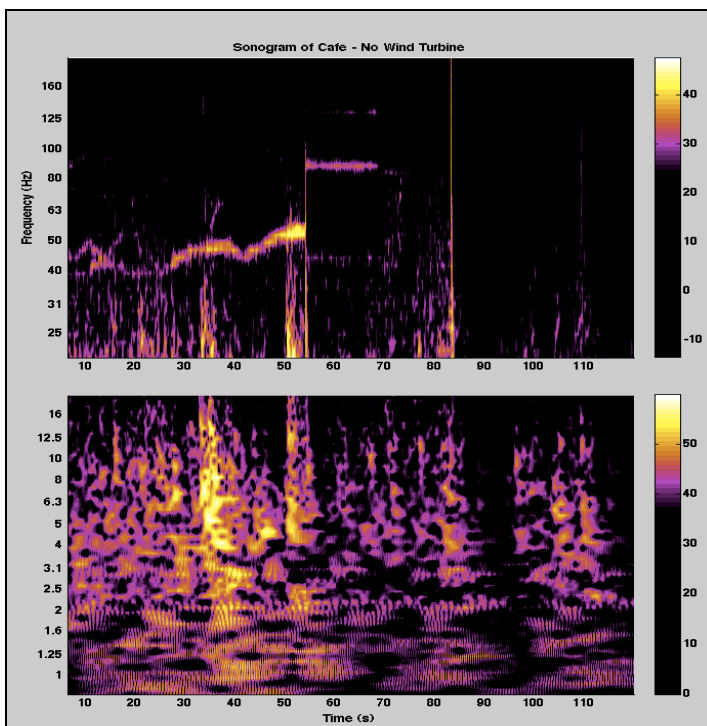


Figure 5: Same location as figure 4 but wind farm not audible

The sound levels for the rural area (figure 4) were LAeq 40 dB(A) and a background level (LA90) of 32 dB(A). Without the turbine sounds (figure 5) the levels had increased to LAeq 49 dB(A) and a background level (LA90) of 33 dB(A) due to bird song and a light breeze in the trees that was blowing towards the wind farm.

Thus ambient conditions play a significant part in recording sound levels. The exterior ambient levels for the residence (Figures 6 and 7) was 30 dB(A) LAeq and 29 dB(A) L90. The interior level was 18 dB(A) LAeq with the rumble-thump of the turbines clearly audible. The background level had dropped to the noise floor of the class 1 instrument, at 12 dB(A). In figures 6 and 7 the difference in character between outside and inside levels are clearly shown. The variation is due to building construction and room resonance.

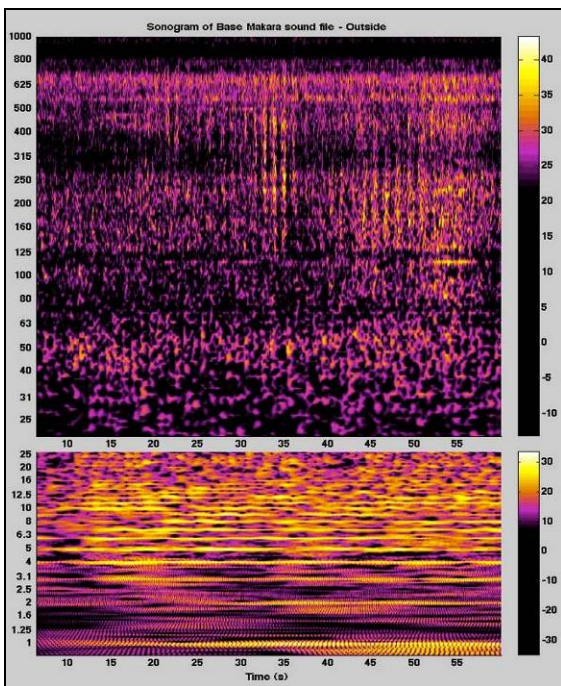


Figure 6: sound of wind turbines at 1200 - 1300 metres, outside residence

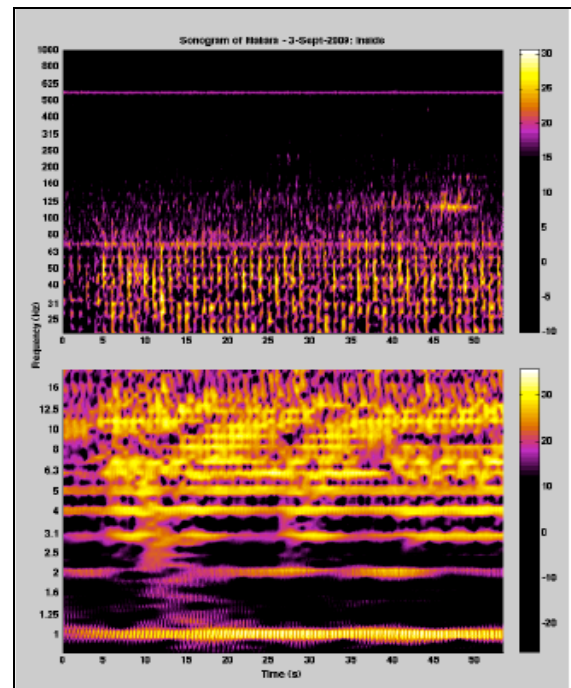


Figure 7: sound of wind turbines at 1200 -1300 metres, inside residence

## Conclusions

Based on interviews with affected persons and some years of measurements and assessments, it is my opinion that, on balance, there is potential for low frequency noise and wind turbine modified infrasound to affect residents. This must be qualified by emphasising that not all people are affected, nor does the problem appear to occur all the time that the wind farm is operating.

## **PART VII - CHARACTERISTICS OF MULTIPLE AND SINGLE WIND TURBINES**

The concept of Heightened Noise Zones created when multiple wind turbines are in operation is presented. The concept is presented to illustrate the complexity of sound from a wind farm. The sound character of a single turbine is presented in comparison.

This summary refers to two wind farms in New Zealand: “Manawatu” which includes three distinct wind farms, and Makara near Wellington. Both the Manawatu and Makara wind farms are spread over a large land area within their respective locales. Analysis of the turbine layout in both locales indicates wind turbines installed in straight and vee-formations. The potential effect of these formations at affected residences is to enhance sound emissions and propagation due to the additive effects of turbines operating more or less together. The effect is significant under adverse weather conditions (e.g. a south-east wind in the case of some homes in the Manawatu) and not significant under different non-adverse weather conditions.

Multiple turbines present a cumulative effect and complex propagation effect that is observed in practice at both Manawatu and Makara. The typical beating or modulating sound of turbines is heard as they synchronise or “phase in” and “phase out”.

Figure 1 illustrates the situation at Makara where at least one turbine is causing a low rumbling sound that is clearly audible during the day within the ordinary sounds in the environment including bird song. The sound is heard as a “rumble-thump” and occurs every 1.2 seconds (approximately). A lot of the sound is coming from the 10 Hz – 50 Hz end with a peak at about 35 Hz and another peak at 118 Hz and harmonics with fundamental frequencies in the 300 Hz – 400 Hz range.



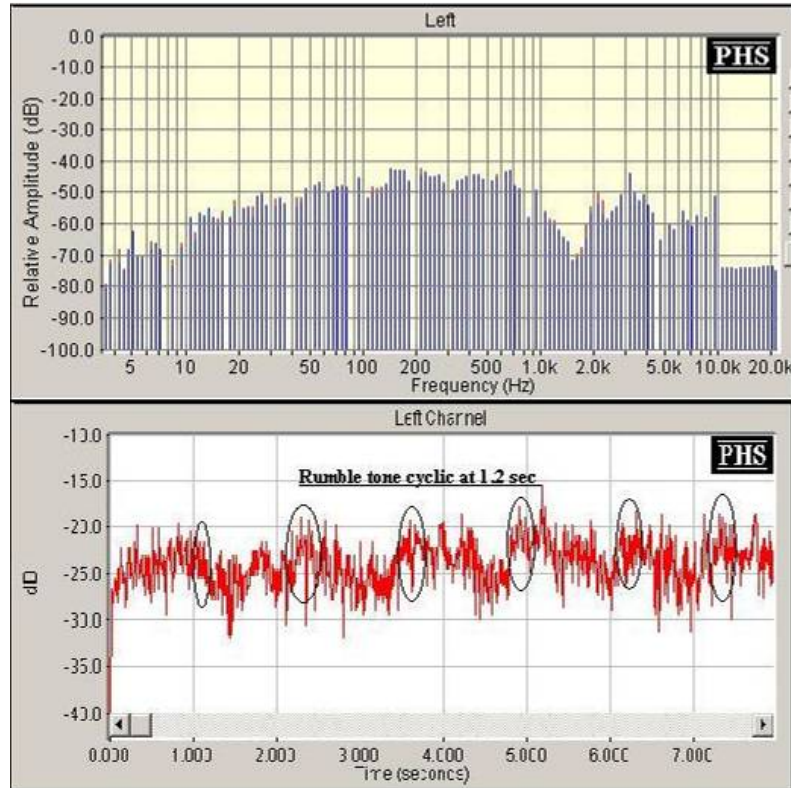


Figure 1: Turbine rumble

This effect is compounded at night when ambient sound levels are low or when more than one turbine are “in line” in such a way as to increase audible or inaudible noise at affected residences. Figures 2 to 6 illustrate the mechanism of sound transfer from a complex wind farm.

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 patches 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. 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. 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. However, this effect can change quite quickly depending on wind direction, temperature conditions and turbine activity.



Figure 2: A residence potentially affected by 2 turbines

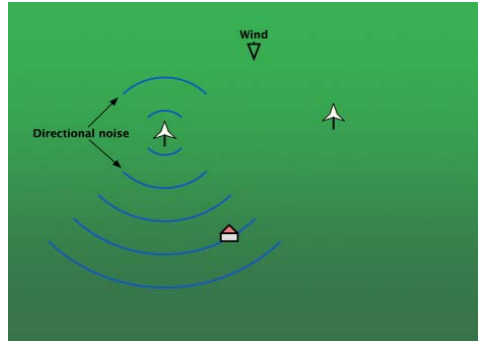


Figure 3: Noise from one turbine

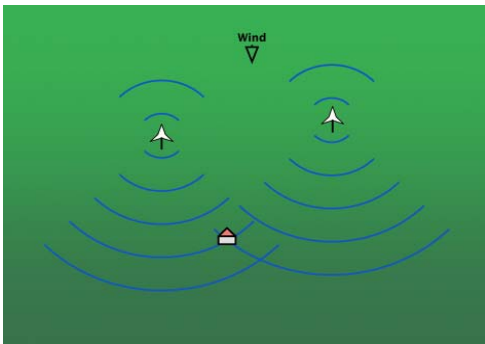


Figure 4: Noise from 2 turbines

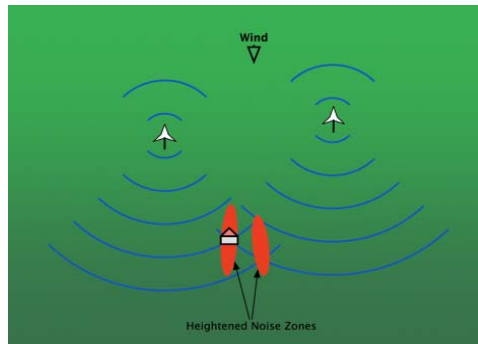


Figure 5: Noise from 2 turbines creating Heightened Noise Zones

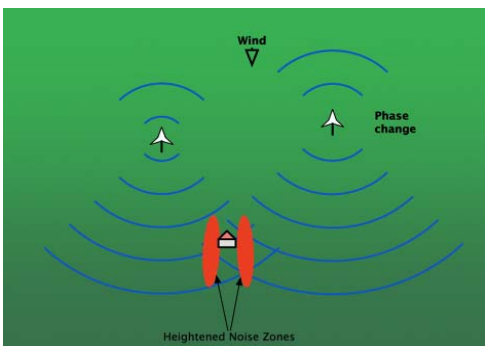


Figure 6: Noise from 2 turbines under slightly different conditions moving Heightened Noise Zones

For the simple, two-turbine situation shown in Figures 5 and 6, the circle-crossings are seen to occur in straight lines diverging away from the turbines. Between them are the nodal points where a circle meets a



space. The former are called *anti-nodal lines* and the latter are called *nodal lines*. The Heightened Noise Zones can be seen to lie on the anti-nodal lines.

These attributes of Heightened Noise Zones – small size and dependence on time-related factors like wind direction – explain much of the problem of wind farm noise and its variability as heard by residents and the potential where some people may be adversely affected while others are not affected.

Modulation is a basic characteristic of a wind turbine as the sound levels increase and decrease as the blades pass the tower and ‘pulsing’ due to wake and turbulence interference. The effect can be enhanced when a number of turbines are in synchrony or near synchrony and when wind directivity enhances propagation. Modulation affects both audible and inaudible sound and is a characteristic in wake and turbulence effects. As presented previously, wake and turbulence effects modify sound propagation from turbines. Figure 7 shows the spacings at Makara, New Zealand, where the red circle is at 5 rotor diameters and the gradual non-disturbance zone at 10 rotor diameters. If a second turbine is situated within 10 rotor diameters of the first turbine the blades of the second turbine can suddenly enter into a pocket of slower air in the wake caused by the first turbine. In the situation where a wind gust occurs behind each turbine there is a wake, essentially in two parts:

- An inner, smooth (laminar) wake where the wind continues to move as a body together although at reduced speed and,
- An outer, turbulent wake where the air moves in rolling eddies.

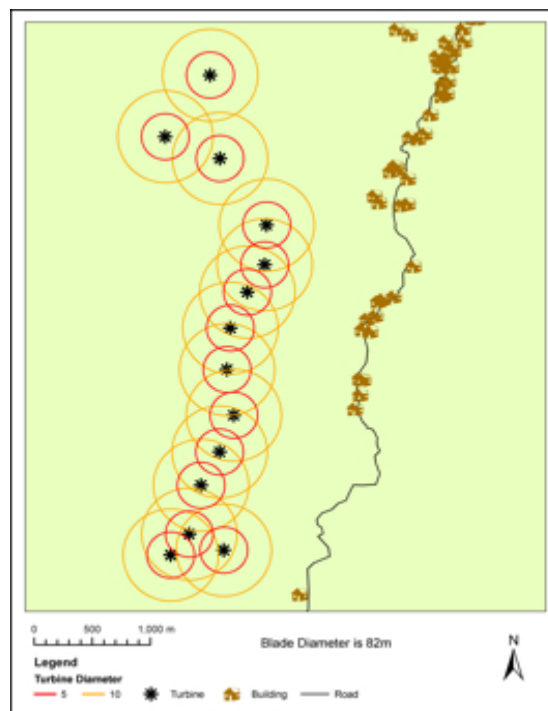


Figure 7: Wind turbines at Makara showing their spacing with regard to 5 and 10 blade-diameter circles. *Source: Research graphics by S. R. Summers.*

The smooth inner wake eventually breaks down into turbulence that soon mixes the air with that surrounding it and is restored to the bulk wind speed. A turbine downstream at this point will see air more-or-less unaffected by the upstream turbine. When the wind speed increases, such as due to a wind gust, the length of the smooth wake is extended. Should the smooth wake extend to the downwind turbine, it will interact with the turbine blades to cause increased sound until the wind gust dies and the smooth wakes retracts.

This can also explain the phenomenon where the rumble/thump is heard in just before or after the wind gusts; the gust can hit the turbines and the home within seconds of each other depending on the wind direction.

Another significant source of noise from a wind turbine is the generation of the turbulent wake as the boundary layer air breaks away from the trailing edge of the blade. When the wind reaches a blade, part goes over and part goes under the blade. The part of the airflow with momentum great enough to break away forms trailing eddies (vortices) and turbulence behind the blade, producing a set of sound sources. The power of each of these sound source depends on the strength of the turbulence.

A vortex travels downwind as a helix, rotating about its axis. As each new vortex is created it replaces the previous one at approximately 1 second intervals—sometimes more, sometimes less depending on the speed of rotation and number of blades. When two or more turbines are rotating at a similar speed they will shed these vortices at nearly the same rate. As the rates of shedding change with respect to each other the sounds can create a 'beating' similar two, slightly different notes of music.

The New South Wales Wind Energy Handbook 2002<sup>15</sup> confirms the importance of separation distances by stating (p. 53):

*A wind-farm layout must take into account that turbines have substantial 'wakes', which interfere with each other and spacing. The general rule of thumb for spacing (the '5r-8r rule') is five times rotor diameter abreast and eight times rotor diameter downwind. On very directional sites the 'abreast spacing' can be decreased by around 15 per cent, but the down-wind spacing is not as variable.*

It is therefore concluded that reliable wind data and the effects of turbine spacings are critical in the prediction and assessment of wind farm noise on residences.

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<sup>15</sup> Sustainable Energy Development Authority (SEDA) New South Wales Wind Energy Handbook 2002

## **PART VIII - PREDICTION OF SOUND LEVELS – APPROACHES AND LIMITATIONS**

### **Limits to Accuracy of Prediction**

All prediction models have limits to their accuracy of prediction. This is due to the inherent nature of the calculation algorithms that go into the design of the models, the assumptions made in the implementation of the model, and the availability of good source sound power data. Various researchers have suggested that an uncalibrated model has an accuracy of  $\pm 5$  dB while a calibrated model has an accuracy of  $\pm 2$  dB.

ISO 9613-2 *Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation* a common propagation model states that the average propagation equation of the standard holds under well developed moderate ground based temperature inversion. This is not necessarily correct. Note 24 to the standard provides-

*The estimates of accuracy in Table 5 are for downwind conditions averaged over independent situations (as specified in clause 5). They should not necessarily be expected to agree with the variation in measurements made at a given site on a given day. The latter can be expected to be considerably larger than the values in Table 5.*

ISO 9613-2 has an estimated accuracy for broadband noise of  $\pm 3$  dB at between 100 and 1000 metres. Calibration means that the model has been established with reference to measured sound levels at a receiver, known source levels and tightly defined propagation variables (wind speed and direction, for example).

Verification of predictions confirm the importance of meteorological conditions on sound propagation and potential for increased sound levels under night-time conditions when moderate temperature inversions occur. Sound prediction calculations are most often made to present sound levels at some defined location or in broad “sweeps” or contours. The prediction noise contours are calculated on “grids” over the whole of the locality. The contour levels (30, 35, 40, for example) are calculated by linear interpolation between the levels at adjacent grid points. The sound levels calculated are the equivalent energy / time average  $L_{eq}$  levels in dB(A).

Under downwind conditions the sound generated by the turbines is affected by downwind refraction. There can be considerable variation in sound levels due to atmospheric conditions and the presence of stable conditions are critical for noise prediction and analysis because, as established by van den Berg:

- a turbine operating at high speed into a stable atmosphere can give rise to fluctuation increases in turbine sound power level of approximately 5 dB
- fluctuations from 2 or more turbines may arrive simultaneously for a period of time and increase the sound power level by approximately 9 dB
- In-phase beats caused by the interaction of several turbines increases the pulse height by 3 to 5dB
- The enhanced levels are not consistent and will change as the wind changes

Sound levels at a residence more than 1000 metres from a broadband sound source (the wind farm in this case) can therefore vary by:

- $\pm 3$ dB due to propagation variations inherent in the model being used (e.g. ISO9613)
- +4dB to +7dB due to special audible characteristics, turbine phasing, site characteristics and site specific meteorological effects including wind shear and turbulence

This presents a possible variation of -3dB to +10dB over the “nominal calculated level” for sound level predictions at 1000 metres. Best practice would suggest that the consideration of these uncertainties with the ‘predicted’ level recorded and a variation of  $\pm 5$  dB(A) is a more conservative (i.e. cautious) approach to wind farm noise prediction.

### **Consideration of Variable Weather Conditions**

The primary concern is with wind and weather data. My experience is that almost without exception wind farm applicant's fail to present any useful data concerning the wind and weather conditions affecting their proposed wind farm. This failure is all the more strange because it is essential to consider wind and weather data when preparing noise assessments. Accurate weather data is needed to allow good for reliable sound level predictions. This issue has been clearly raised by Clark, G., in his evidence to the Taralga Wind Farm Modification Application, reference number ‘NSW Land & Environment Court Proc 11216 of 2007.’ Weather (wind direction, wind speed and the presence of temperature inversions) will all change the levels of received sound at residences. Weather data needs to be recorded or predicted from the wind towers (at 10 metre, hub and blade tip heights) and at residences (a minimum 3m above ground or at 10 metres) for reliable sound level predictions.

The received noise levels at residences will vary subject to varying meteorological conditions in the locality (wind speed and direction, wind shear, temperature, humidity, inversions). Data at residences will be quite variable and potential noise from the turbines will be affected by this. These potential noise effects are predicted to occur during cool, stable conditions particularly in early morning and evenings. As a starting point for assessment, it is reasonable to assume that a certain percentage of the weather

experienced in the locality at residential level will support or promote adverse noise propagation from the wind farm. This prediction is for a potentially frequent event with high probability of adverse effect.

A wind rose at the wind measurement towers (at a point 80m above ground) is the most useful but this data is rarely presented in an applicant's documentation. Alternative sources of data from nearby met stations or residential sources are often necessary but provides only a cursory overview of wind direction near ground level.

Extended measurements at a Canadian wind farm over approximately 4 months' indicate time-average  $L_{Aeq}$  and background  $L_{A90}$  sound levels have a strong correlation to electrical output from wind turbines at the same time. Conversely, there is a much weaker correlation between observed sound levels and the wind speeds at 10 metres above ground. Wind levels at 80 metres (nominal hub height) or 10 metres at the turbines are not observed to have a strong correlation to wind speed and sound level at a distant receiver. It is concluded that the electrical output is a major driver of increased sound levels.

### **Wind Farm Noise` Standards**

*Australian Standard AS 4959-2010 Acoustics – Measurement, prediction and assessment of noise from wind turbine generators states that:*

*In order to determine the acceptability of predicted wind farm noise levels at relevant receivers, it is necessary to consider the unique noise characteristics of both the wind farm and the noise environment around the actual or proposed wind farm.*

*Therefore, when setting criteria, the Relevant Regulatory Authority should consider the existing ambient noise environment at receivers around the proposed wind farm and the characteristics of wind farm noise, so as to provide a satisfactory level of protection of amenity.*

The Standard recommends the Relevant Regulatory Authority allow, at a nominal wind speed, the higher of a minimum noise level limit ( $L_{Aeq}$ ) or 'background ( $L_{A90}$ ) noise levels plus a specified amount', as well as a penalty for special audible characteristics. The standard assumes that modulation will be accounted for in the noise level criteria. The Standard is in many ways similar to, and as complex as the New Zealand standard applied in Victoria and will, therefore, be subject to the same problems experienced in noise measurement, prediction, and compliance related elsewhere in this Submission.

New Zealand Standard, NZS 6808:1998 *Acoustics-The assessment and measurement of sound from wind turbine generators* is referenced in Victoria as part of the nominal consent conditions. NZS 6808:1998 and its replacement *NZS 6808:2010 Acoustics – Wind farm noise* both lack a methodology to separate background sound levels created by the wind turbines (whether for compliance testing purposes

or for complaint assessment) from background sound levels existing at a specific time and place due to wind movement, vegetation movements, bird song and so on.

NZS 6808:2010 is different from the 1998 edition by recognising a 35 dB(A) background level for evening and night-time. The lower limit is introduced by way of recognising locales of 'high amenity', clause 5.3.1: '...a more stringent noise limit may be justified to afford a greater degree of protection of amenity during evening and night-time'. No definition of 'high amenity' is provided as each area is established according to the New Zealand District Plans.

In order to assist possible interpretation of the sound of the wind farm as a nuisance condition or injurious to personal comfort the general rule is, as I understand it, that the occupier of land is obliged to adopt the best practicable option to ensure the emission of noise from that land does not exceed a reasonable level. "Best practicable option" means the best method for preventing or minimising the adverse effects on the environment having regard, among other things, to—

- (a) The nature of the discharge or emission and the sensitivity of the receiving environment to adverse effects; and
- (b) The financial implications, and the effects on the environment, of that option when compared with other options; and
- (c) The current state of technical knowledge and the likelihood that the option can be successfully applied.

Certification of wind turbine noise is undertaken in accordance with the International Standard *IEC 61400-11:2002 'Wind Turbine Generators Part 11, Acoustic noise measurement techniques'*, Wind turbine sound levels are presented in their test certificates as LAeq levels, not background (LA<sub>90</sub> or LA<sub>95</sub>) levels. Emission levels are to be reported as A-weighted Leq sound levels in one-third octave bands and audibility. Audibility under the wind turbine standard is given as a tone. Chapter A, an informative Chapter to IEC 61400-11, states that:

*In addition to those characteristics of wind turbine noise described in the main text of this emission may also possess some, or all of the following:*

- *Infrasound;*
- *Low frequency noise;*
- *Impulsivity;*
- *Low-frequency modulation of broad band or tonal noise;*
- *Other, such as a whine, hiss, screech, or hum, etc., distinct pulses in the noise, such as bangs, clatters, clicks or thumps, etc.*

## **Prediction of Sound Variation at a Receiver**

In summary, the prediction of sound variation at a receiver depends on measures of uncertainty, for example:

- the true sound power level of the turbine(s) at the specified wind speed
- individual turbine and overall wind farm power output related at a specific time to sound levels
- the reduction in sound level due to ground effects
- the increase or reduction in sound level due to atmospheric (meteorological) variations, wind shear and wind direction
- the variation due to modulation effects from wind velocity gradient
- increase and reduction in sound levels due to wake and turbulence modulation effects due to turbine placement and wind direction
- increased sound levels due to synchronicity effects of turbines in phase due to turbine placement and wind direction
- building resonance effects for residents inside a dwelling

## **Conclusions**

It is concluded that the prediction results from ISO 9613-2 or similar calculation method must be treated with caution as non-compliance can be a significant problem for the wind farm with subsequent review of the consent conditions.

It is concluded that measurement for non-compliance requires specific procedures and that special audible characteristics (modulation, tonality or impulsiveness) are significant factors that must be considered.

It is concluded that the Victorian wind farm noise compliance conditions are similar in drafting style to New Zealand conditions and the problems evidenced at Te Rere Hau apply to all existing Victorian consents.

## **PART IX - RESPONSES OF RESIDENTS NEAR WIND FARMS**

### **Community and Individual Noise Exposure**

Community noise exposure is commonly measured in terms of a noise exposure measure. Noise exposure is the varying pattern of sound levels at a location over a defined time period. The time period is most often one day (short-term) or over weeks, months or a year (long-term).

The practical difficulty in locale measurements is that many of them are needed to describe a neighbourhood. It is customary, therefore, to use a suitable single-number evaluation for community neighbourhood noise exposure.

Individuals, however, are different in their tolerance to specific sounds: there is a distinct duration – intensity relationship that varies depending on the character of the sound.

There is no defined relationship that can predict when a noise is reasonable or unreasonable; for this to happen, the noise must be audible or perceptible to cause an adverse response in the person affected.

Previous wind farm investigations in Victoria and New Zealand rural wind farms indicate that residences within 3500 metres of a wind farm are potentially affected by audible noise and vibration from large turbines, such as those proposed. Residences within 1000 metres to 2000 metres are affected on a regular basis by audible noise disturbing sleep.

In this part the adverse effects of wind farms on three communities is described. The complaint histories are brief anecdotes to establish what the noise is and when it occurs. In the main concurrent acoustic surveys were not taken at the same time. The complaints, however, present a disturbing trend over time. In each case the complaints are over 12 months. Detailed complaint histories have been recorded as statutory declarations or affidavits, depending on the hearing in question. The disturbing recurring issue is the sense of helplessness experienced by the individuals affected as their complaints are ignored by both the regulatory authorities and by the wind farm operators. Only in one case (Te Rere Hau) is a regulatory authority undertaking compliance proceedings.



## The Effects on People near the Waubra Wind Farm, Victoria

The Waubra wind farm commenced operation in March 2009 in the Ballarat section and May 2009 in the northern Waubra section. Within a short time nearby residents were becoming concerned about noise. By August 2009 adverse health effects were being reported. In September-October I interviewed 5 different families near the northern section of the wind farm, all of whom report some adverse reaction since the commissioning of a nearby wind farm earlier in the year. The families are all within approximately 1000 – 2000 metres of turbines and had at least two sets of turbines near to them. Under these circumstances the residences are affected by wind farm activity over a range of wind directions. The interviews were preliminary in nature and standard psych and noise sensitivity tests were not conducted, nor were detailed health notes recorded.

Family A reports headaches (scalp and around the head pressure), memory problems and nausea when the turbines are operating. Symptoms include an inability to get to sleep and sleep disturbance, anxiety and stress, pressure at top and around head, memory problems, sore eyes and blurred vision, chest pressure. When the turbines are stopped the symptoms do not occur. A difference in severity is recorded with different wind directions. A personal comment made states:

*"I am having problems living and working indoors and outdoors on our property ... problems include headaches, nausea, pain in and around the eyes, sleep disturbance, pain in back of head; we feel this is coming from generation of wind from wind farm as it is OK when turbines are stopped."*

Family B reports tinnitus, dizziness and headaches since the turbines have started operating. Sleep disturbance at night with the sound of the turbines interrupting sleep pattern. Vibration in chest at times. Tiredness and trouble concentrating during the day. Does not have problems sleeping when not at Waubra overnight.

Family C reports the noise coming from the turbines at night disturbs sleep. During the day there is noise which causes bad headaches, sore eyes causing impaired vision earache and irritability.

Family D reports suffering from sleep disturbance, headaches, nausea and tachychardia (rapid heart rate) since the turbines started operating.

Family E reports that when the turbines are operating symptoms include feeling unwell, dull pains in the head (acute to almost migraine), nausea and feeling of motion sickness. At night when the turbines are in motion sleep disturbance from noise and vibration (unable to get any meaningful deep sleep), sleep deprivation leading to coping problems. The problems are reported as:

*“Some days when the wind is in the north-east my eyes feel swollen and are being pushed out of the sockets. I have a buzzing in my ears. On these days I feel it very difficult to summon memory and difficult to concentrate.”*

and

*“The sound of the turbines when functioning is on most days so intrusive that it affects my concentration and thought processes when performing complex tasks. I suffer from sleep interruption as a direct result of the noise which then affects my ability to function at 100% the following day. One is aware of a throbbing in the head and palpitations that are in synchrony with the beat of the turbines and to a degree the flashing of the red lights. Because of this impact on my everyday life it causes me great stress and in turn great irritability.*

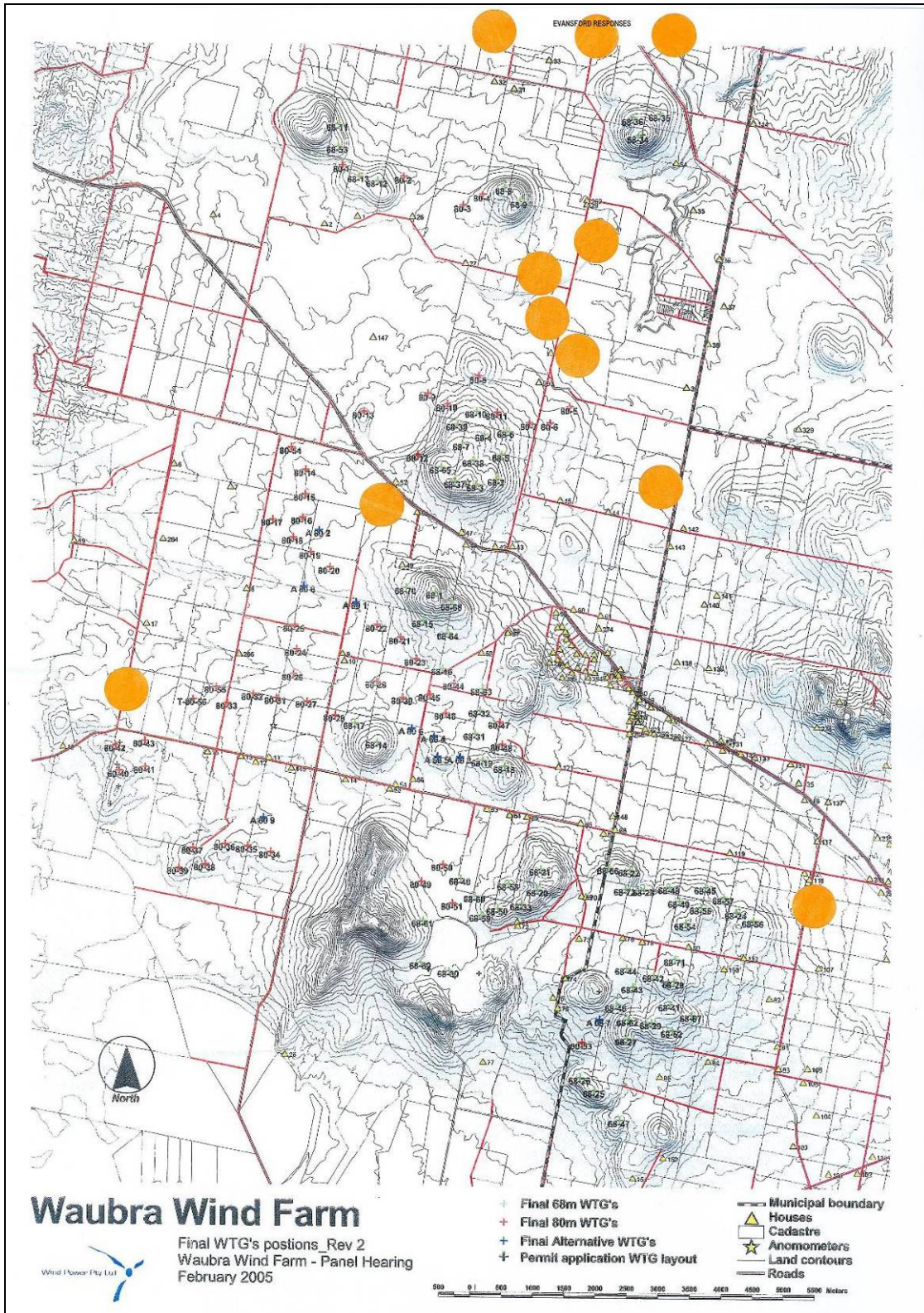
Two families identified blade glint / flicker and the red warning lights on the top of each tower as an additional source of annoyance.

Statutory declarations (June 2010) concerning noise issues have been declared by residents affected by the Waubra wind farm. Noise from the turbines is being experienced by residents within approximately 1000 metres of the nearest turbines and at distances of approximately 3000 to 4000 metres distant from the nearest turbines. The locales where the residents experience noise are shown in Plate W1. The noise and health effects experienced by residents are presented in Table W1.

The Waubra north and Ballarat locales are rural in nature with relatively low hills and rolling countryside. The northern section of the wind farm is illustrated in Plate W2 following. The locale is affected by south-west winds at turbine level but can be relatively calm at residences. The prevailing winds at Ballarat airport are shown in Figure W1, following. The measured wind directions are given to illustrate the importance of accurate wind data in predicting or assessing complaints.

My observations at Waubra include sound level measurements of audible sound and infrasound. Further more detailed acoustical, human perception and health effects studies are planned for 2011.

Plate W1: Locales in Waubra affected by Waubra wind farm turbine noise



Note: the locales affected by wind farm noise are identified by the orange circles.

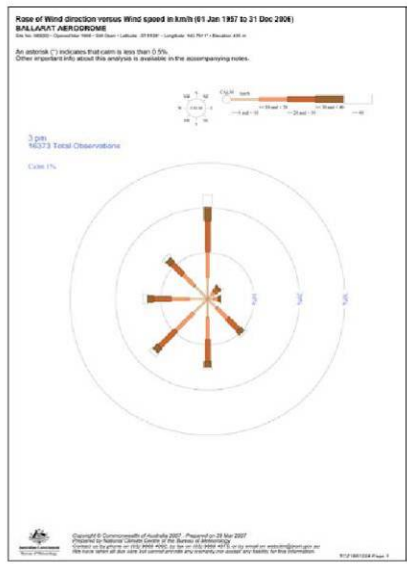
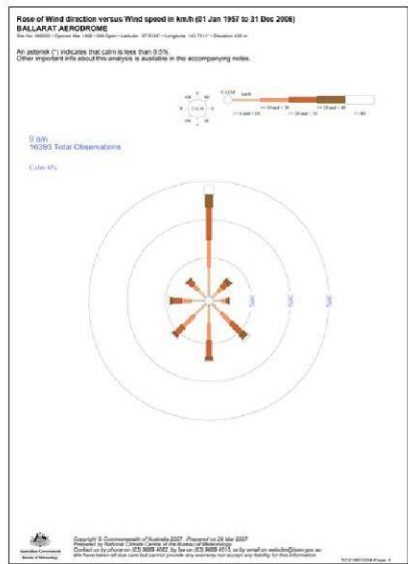
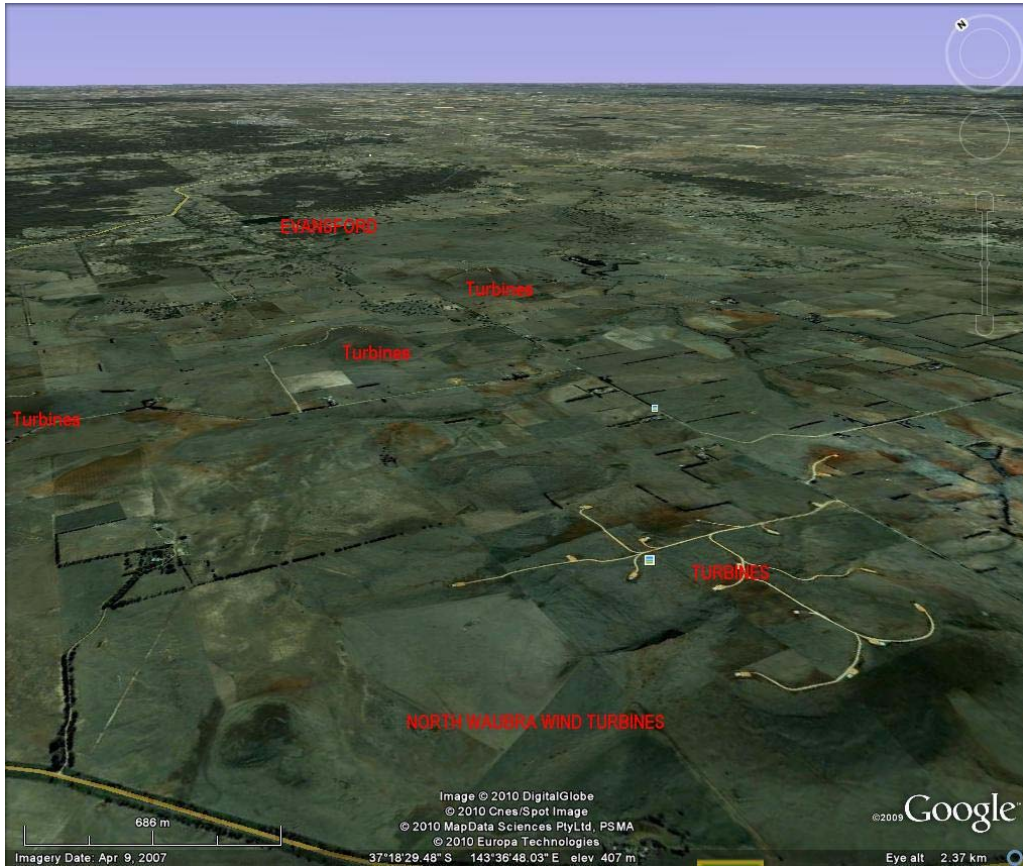
**Table W1: Waubra wind farm affects, perception and complaint analysis**

Locale	Distance	Noise affect
1	1500-2500	Sleep disturbance, headaches, affects eyes and back of head, tinnitus. Worst affect is while working the farm. Heart pressure changes
2	1000	Sleep disturbance, headaches, high blood pressure
3	1000-1300	Sore eyes and headaches when the turbines are operating
4	1250-3000	Sleep disturbance. Affects people working on the farm. Headaches, earaches, blood pressure changes and poor eye sight.
5	1300-2200	Insomnia, headaches, sore eyes, dizziness, tinnitus and heart palpitations. Deteriorating health due to lack of sleep and stress levels. Unable to sleep through the night. Affects while working outside on the farm.
6	2000-2300	Headaches and pressure in ears when working on the farm.
7	550-1400	Sleep disturbance, windows vibrate. Affects while working on the farm. Headaches, lack of sleep, major problem with flicker. Excessive noise under a strong southwest wind
8	1000-3500	Headaches when working farm within 1500 metres of turbines. Dizziness when 2 turbines inline and in sync, effect went when approx 300m out of alignment. Sleep awakenings and disturbed by pulsating swish. Heart palpitations, vibrating sensation in chest and body. Headaches while at home. Stress and depression.
9	3500-4300	Frequently suffer from headaches, tinnitus, irritability, sleepless nights, lack of concentration, heart palpitations. Turbines exhibit a loud droning noise and pulsating whoosh.
10	3400-3800	Headaches, ringing in ears when turbines are operating. Pressure in ears, heart palpitations and anxiety attacks. Awaken at night, sleep disturbance.
11	3000-4600	Elevated blood pressure, heart palpitations, ear pressure and earache, disrupted sleep, increasing frequent headaches, head pressure, vibration in body, mood swings, problems with concentration and memory. Awaken at night, sleep disturbance.
12	1000-1200	Headaches, sickness, frequent sleep disturbance, very stressed. Affects personal life. Lights on turbines cause extreme distress. Ear pressure and loss of balance while working on the farm. Enormous pressure and stress on home and work.

**Notes:** 'Distance' is the distance in metres between the locale and the nearest turbines. The distances vary where turbines are in different directions surrounding the locale. Each locale contains one or more affected families. A common observation is that the adverse health effects noted did not exist before the wind farm commenced operation or diminish / disappear when not in the district affected by turbines.



**Plate W2: North Waubra locale, residents and the Waubra wind farm**



**Figure W1: wind rose, Ballarat Aerodrome, mid-morning and mid-afternoon**

## **The Effects on People near the “West Wind’ wind farm, New Zealand**

The Westwind wind farm commenced operation in May 2009. From my observations at Makara New Zealand at a residence situated approximately 1200 - 1300 metres from 5 turbines and within 3500 metres of 14 turbines there is known probability that the wind farm will exhibit adverse “special audible characteristics” on a regular basis resulting in sleep disturbance, annoyance and stress.

The observations and measurements being recorded at Makara involve the residents taking notes of the noise heard when they are awakened. At the same time a fully automated monitoring system records exterior audio as well as exterior and interior sound level data in summary levels and third-octave band levels. This allows the generation of tracking data and sonograms for compliance and unreasonable noise assessment. The complaint data is retained by the City Council. Statistical data is retained by the wind farm operator and summarized for the Council. Audio data for real-time analysis of special audible characteristics is not recorded by either Council or the wind farm operator. Audio data is recorded, however, by at one affected resident.

In the period April 2009 to 31 March 2010 a total of 906 complaints have been made to the Wellington City Council New Zealand concerning noise from the wind farm at Makara. These complaints have been made by residents living near to and affected by the wind farm. The turbines are Siemens 2.3MW machines situated approximately 1200 metres to 2200 metres from residences.

In personal interviews at Makara some residents have identified nausea as a problem. In the most severely affected case known the residents have bought another property and moved away from their farm.

Low frequency sound and infrasound are normal characteristics of a wind farm as they are the normal characteristics of wind, as such. The difference is that “normal” wind is laminar or smooth in effect whereas wind farm sound is non-laminar and presents a pulsing nature. This effect is evident even inside a dwelling and the characteristics are modified due to the construction of the building and room dimensions.

An analysis of the complaint history has been made from 64 households in a population of approximately 140 occupied residences. Of these households 57% of the complaints are from 10 households and 79% are from 20 households. The character of 650 complaints has been sorted by type, figure WW1. Rumble, with 252 mentions, is the most common characteristic. Hum and thump are the next most common annoying sounds. In comparing complaints of noise outside to inside, of 650 complaints, only 23 specifically mention the noise as being outside. This, from my measurements, would be outdoor

background levels of much less than 40 dB(A), around 28 to 30 dB(A) L95. Of the indoor complaints, 4.5% specifically mention sleep disturbance. Further analysis of specific complaints is presented in **Table WW1**, following. The number of turbines affecting a locale is noted, when identified by a resident.

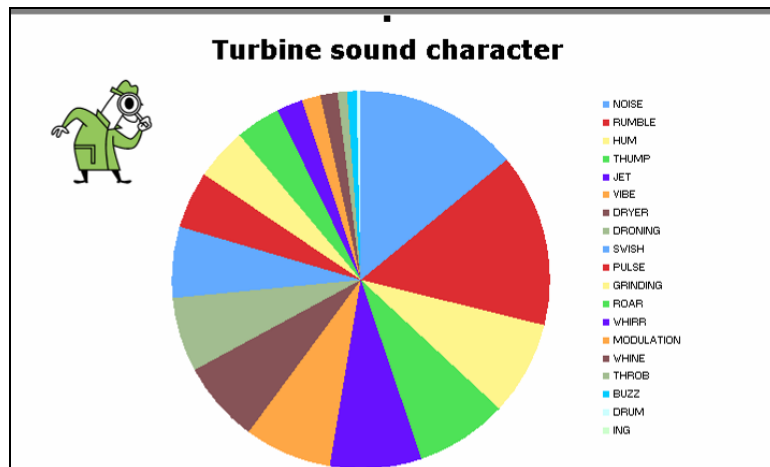


Figure WW1: Westwind complaints by turbine character

The Makara complaints are not limited to a small locale, Figure WW2. Complaints are over the whole of the district that is a distance of approximately 12 km, Plate WW1 following. The turbines are situated in both clusters and rows. The locale 'Makara' is a small village and school affected by a cluster of approximately 14 turbines within 2000 metres; the locale 'South Makara' is a line of residences facing a line of 25 turbines within 2000 metres over approximately 5 km. The issue is that turbine noise is known, it can be defined by character and distance, and it does have significant impact on a large number of people.

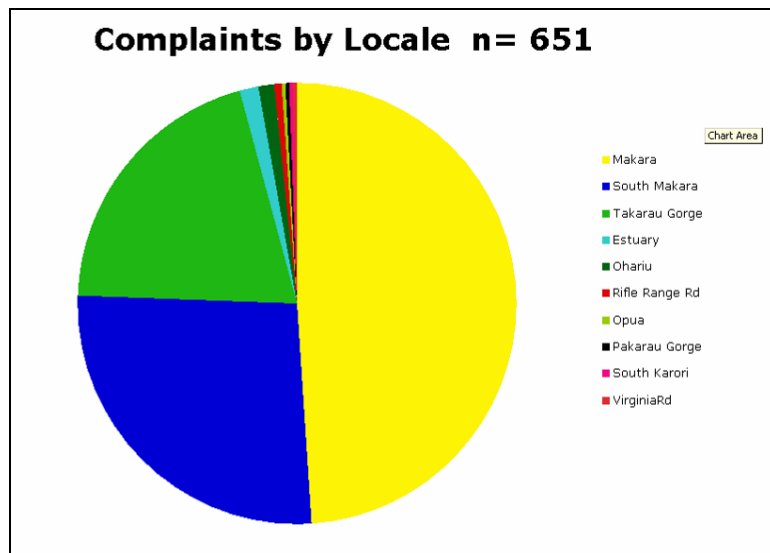


Figure WW2: Westwind complaints by locale

Nausea and sleep disturbance was reported by one visitor to a residence 2200 metres from the nearest turbine. The residents also complained about the visual nuisance caused by blade glint and flicker, as well as the red glow from the warning lights on top of each tower. A recent complaint (March 2010) about the operation of the wind farm is expressed as follows:

*We have had a persistent level of disturbance noise now for several hours throughout the evening that is now preventing us sleeping since 11:15 pm. The predominant noise is a continuous loud booming rumble that is even more noticeable after a gust at ground level. When the wind noise drops, the background noise from the turbine continues and is also felt as a vibration being transmitted through the ground. Even with wind noise the vibrations in the house continue. The varying wind speed also causes a beating noise from the blades that occurs in cycles creating yet another form of noise disturbance.*

A second resident says:

*We are 2k away to the east and the thumping also penetrates our double glazing. The reverberation is somehow worse inside the house.*

And a third resident says

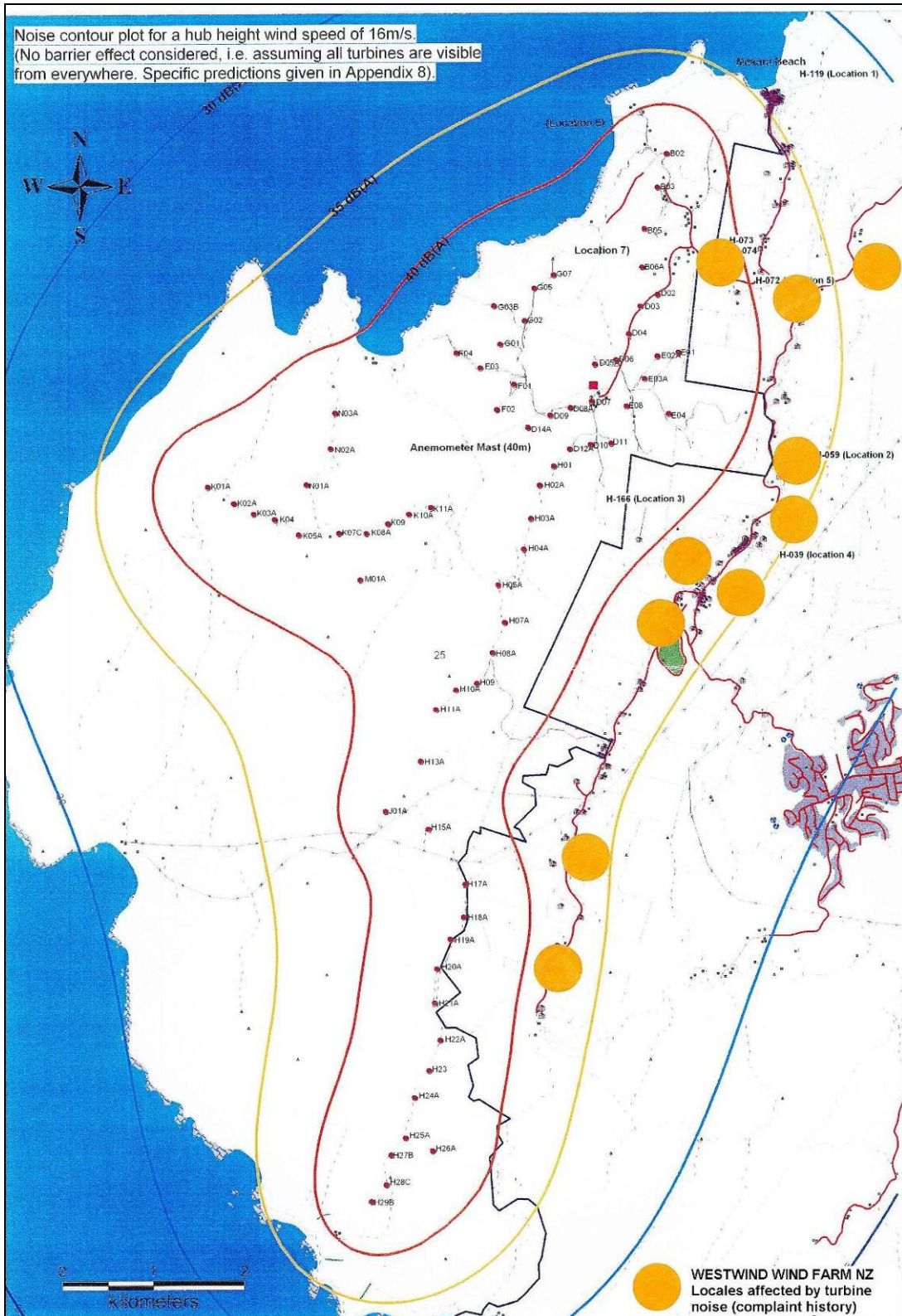
*We ... get the low frequency thump/whump inside the house, is very similar to a truck driving past or boy racers sub woofer 100 meters away...we have no line of sight turbines and the closest one in 1.35km away. There are however 27 turbines within 2.5km (which would apply for the whole village). The sound is extremely 'penetrating' and while we have a new house with insulation and double glazing, the low frequency modulation is still very evident in the dead of night. It is actually less obvious outside as the ambient noise screens out the sound.*

The valley is affected by strong winds at turbine level but can be relatively calm at residences. The prevailing wind at the turbines' mast at 40 metres above ground is shown in Figure WW3, following. The measured wind directions are given to illustrate the importance of accurate wind data in predicting or assessing complaints.

**Note:** 'Distance' is the distance in metres between the locale and the nearest turbines. Each locale contains one or more affected families.



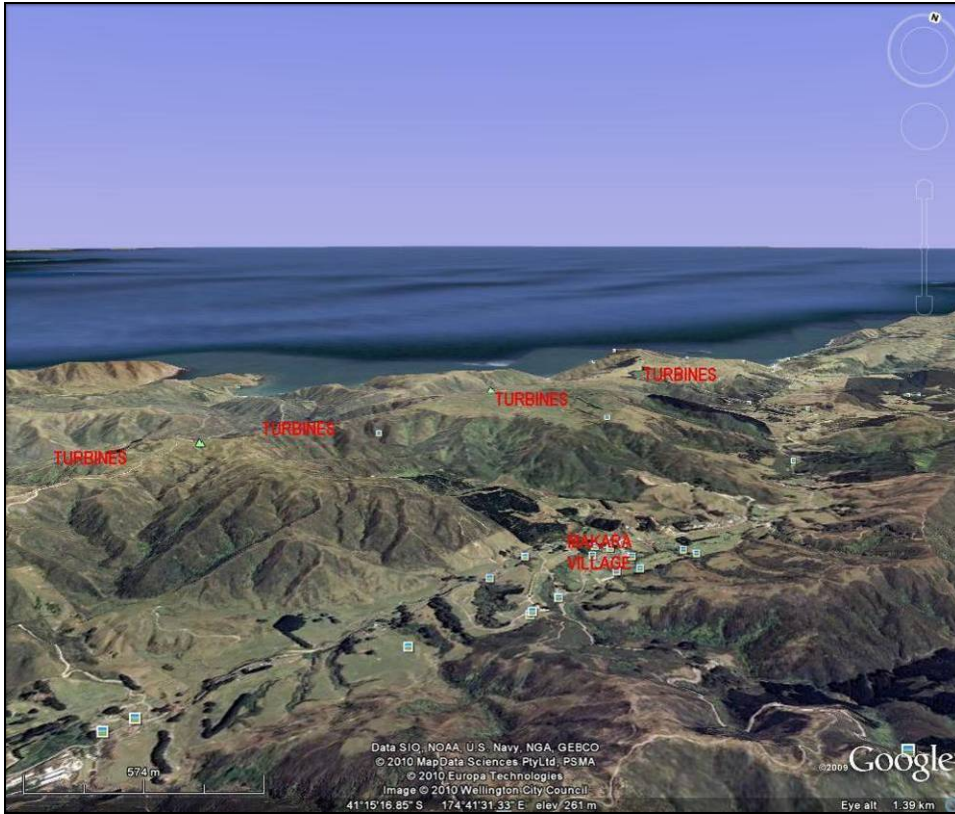
**Plate WW1: Locales in Makara affected by West Wind wind farm turbine noise**



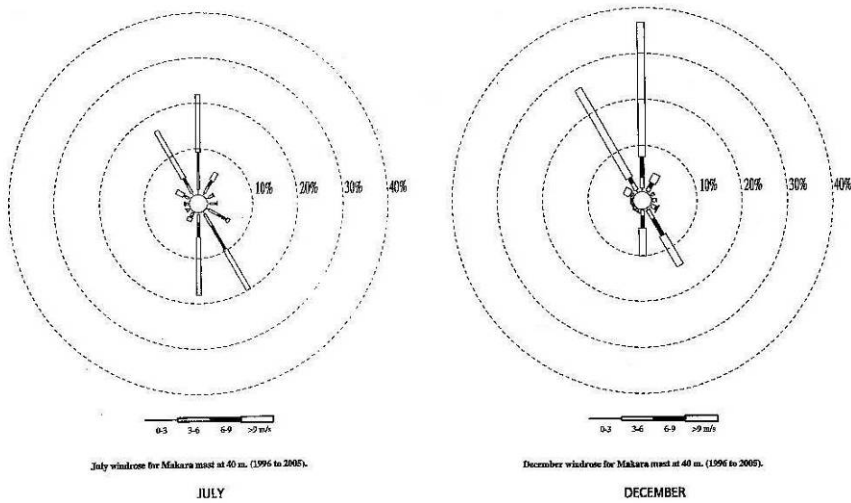
**Table WW1: Westwind affects, perception and complaint analysis to November 2009**

<b>Locale</b>	<b>Distance</b>	<b>Noise affect</b>
1	1200-1300	Kept awake with turbine noise pulsing in bedroom. Sleep disturbance. Sounds not masked by wind in trees or stream
2	1200-1300	Possible to hear and feel the turbines (20 of them) over usual household noises during the day and evenings. At night disturbs sleep patterns and affects health and well-being. Can hear the noise through the bed pillow. Sounds like a tumble dryer.
2	1200-1300	Can hear the turbines inside and outside the house during the day and at night. Disturbs sleep and affects health (tiredness). Family is stressed.
3	1700	Sound is a rhythmic humming heard inside and outside the house during the day and at night. Northwest wind brings noise, southerly does not. Noise is highest when it is calm at the house but windy at the turbines. Turbines audible inside the home with TV on. Noise is a low hum
4	1750	When the wind is from the north to north-west the noise penetrates into the home. Persistent deep rumbling around 1 second interval and lasts for 10-20 seconds then abates. Awakens and disturbs sleep. Generates annoyance and irritability.
4	1700	Disturbs sleep. Turbines are heard when it is calm at the house and windy at the turbines. Annoyance, nausea, earaches and stress.
5	2100	Turbines audible in bedroom. Awaken and disturbs sleep. Creates pressure in head and headache. Feeling tired and distressed.
6	2000	Northwest wind brings noise and disturbs sleep.
7	1250	Northwest sound is constant thumping, pulsing. Cannot stand being in the house or around the property, sick feeling, headaches, tight chest. Can be heard at night cannot sleep, get agitated and wound-up. Has ruined peace and tranquillity.
7	1250	Northwest wind, mild to wild, sound is constant thrumming. Noise is intensified in the house and more noticeable at night. Feeling of nausea precludes sleep. Disturbed and sleepless nights.
8	1500-2000	Turbine noise heard within the home. Severe sleep deprivation from interrupted sleep and lack of sleep. Fear of causing an accident on the farm due to lack of sleep. Noise at night is a southerly with a grinding rumbling sound. Noise from the northwest grinding a 'plane takeoff' noise. Lot of ringing in ears. Easily heard above the background noise. Depression due to noise at night and lack of sleep.
9	750	Noise from the southerly winds rumbling, grinding all day and night. Trouble sleeping.
10	2200	Regular sleep disturbance, sound like a plane. Louder inside the home than outside. Northwest wind thumping or rumbling sound, noise and vibration in the home (double glazed). Headaches. Low frequency humming. Awakenings and sleep deprivation.

**Plate WW2: Makara Valley residents and the West Wind wind farm**



**Figure WW3: Prevailing winds for Makara at the wind farm mast (40m)**



**Figure 5. Seasonal wind speed and direction roses for Quartz Hill.**

## **The Effects on People near the 'Te Rere Hau' Wind Farm, New Zealand**

In the period May 2009 to 31 March 2010 a total of 378 complaints about noise were made to Palmerston North City Council New Zealand concerning the Te Rere Hau wind farm. The complaints have been made by persons within approximately 2300 metres south, 3100 metres south-west and 2100 to the north of the centre of the '97' turbine wind farm. Complaints concern both the loudness and character (grinding, swishing) of the sound from the turbines. The turbines are of a smaller 500kW design.

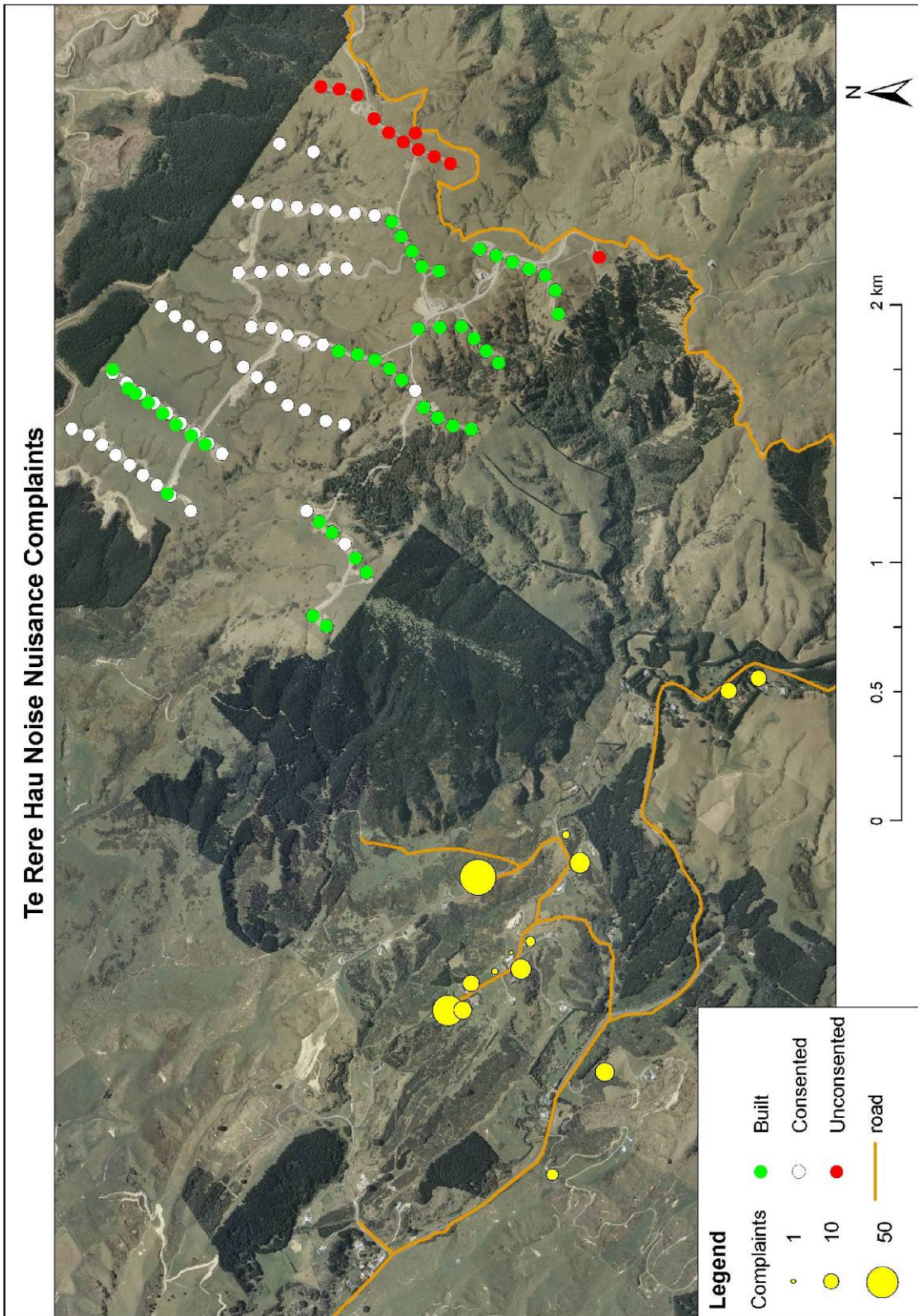
The Te Rere Hau wind farm complaints are important as they reflect the concerns of a rural community with relatively few people living within 3500 metres of the centre of the wind farm. Te Rere Hau is a densely packed design with wind turbines arranged in a grid pattern. In the 10 months for which records have been seen, 21 different residents complained about noise, with 2 residents logging more than 40 complaints each and a further 8 logging more than 10 complaints each. There is an estimated 46 residences within a radius of 3500 metres of the wind farm.

The original noise predictions calculated a sound level of 34.9 to 40.8 dB(A) at the monitoring location in wind speeds of 8 m/s. The actual sound levels are significantly higher, by up to 12.8 dB(A) higher under certain wind speeds and directions. The measured levels are said to be consistently over 40 dB(A) at the monitored residences. This level is measured as the A-weighted background sound level, LA95, and did not include the penalty for modulation and tonality as is required by the compliance conditions. The penalty is 5 dB(A). The documentation specifically states the problems involved with measuring wind turbine sound within ambient sound.

The following Plate, TRH Plate 1, presents the impact of the wind farm on nearby residences. The number of complaints lodged by the residents is indicated on the Figure. The Table TRH 1 following the plate, for a single residence, illustrates the common thread of the noise problems found and the relationship to weather conditions. The residence is approximately 1200 metres from the nearest row of wind turbines. The position of the wind farm on a plateau above the residences is illustrated in Plate TRH 2. The measured wind directions are given in TRH Plate 3 to illustrate the importance of accurate wind data in predicting or assessing complaints. In order to mitigate the noise complaints the sound emissions from the wind farm are currently subject to legal action by the regulatory authority before the Environment Court. Eighteen sworn affidavits from 14 households were tendered by residents in the course of preparation of the action.



Plate TRH 1: Te Rere Hau Wind Farm Complaints by Location

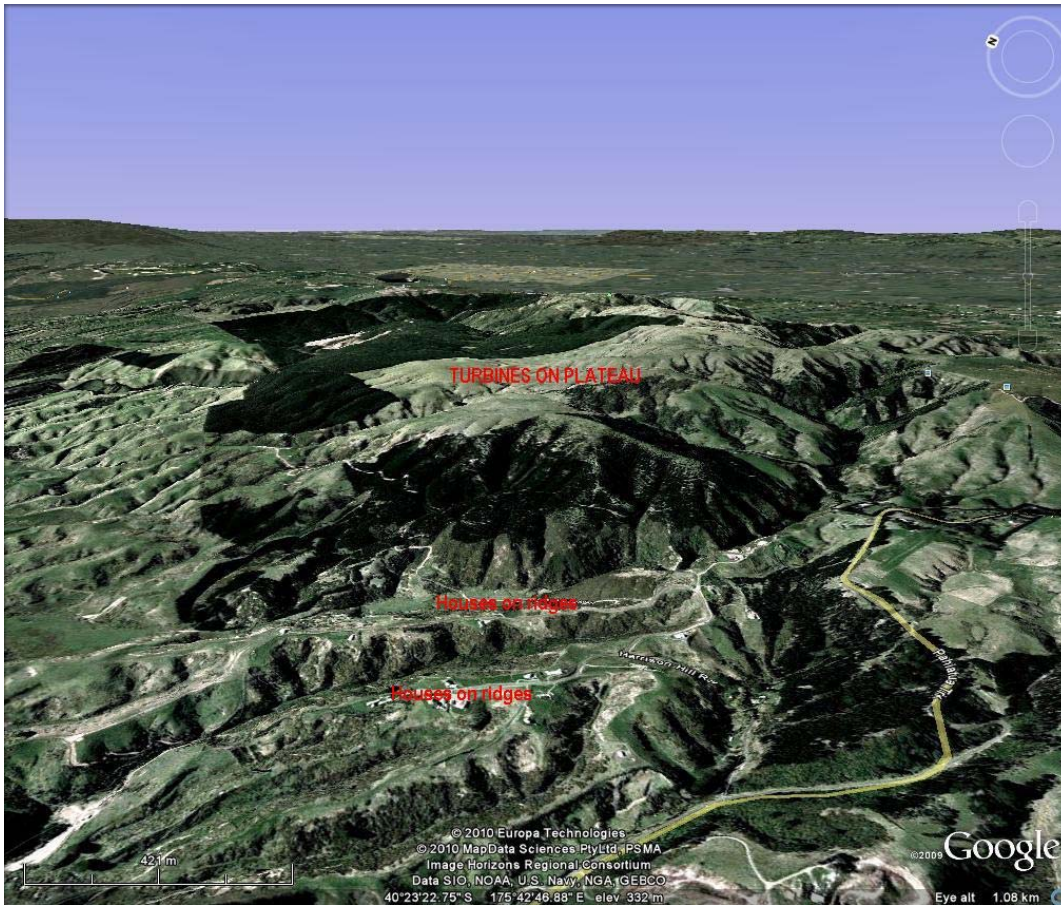


**Table TRH 1: Te Rere Hau noise complaints, August 2009 to February 2010, single residence**

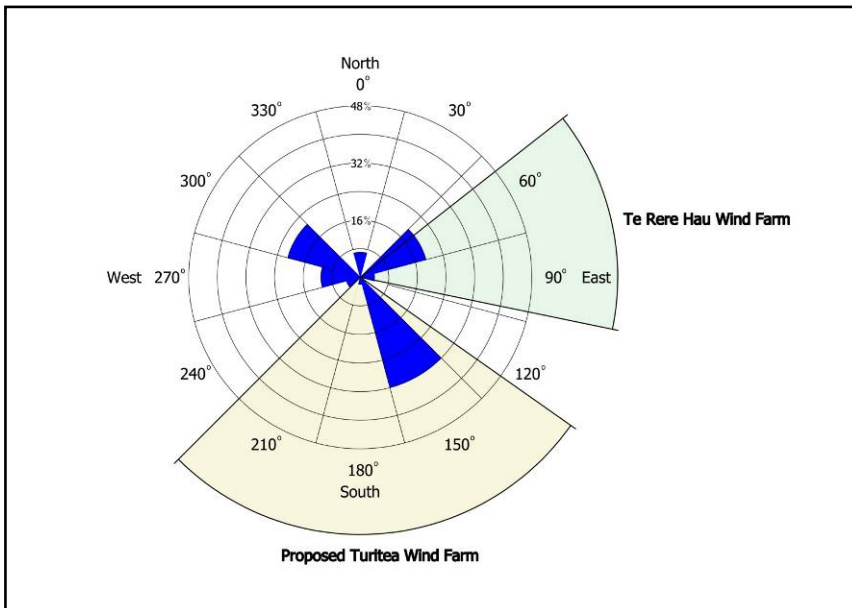
Date / Time	Wind Direction	Complaint
07/08/09 5.45pm		Noise from windfarm
20/08/09 6.55am	S-SE	Windfarm loud this morning
20/08/09 8.45am	S-SE	Loud wind mills at 5.00am
21/08/09 6.32am	E	Windfarm noise
22/08/09 12.51pm	E	Medium strength, swooshing & grinding, only 1/2 on
29/08/09 8.45am	W	Very loud again today
15/09/09 6.31pm	E	Loud noise coming from windfarm
11/10/09 10.48am	W	Light wind, windfarm extremely loud
21/11/09 5.42am	W	WF too loud
05/08/09 7.02am		Noise from te Rere hau this morning
09/08/09 6.02pm		Excessive noise Te Rere hau
11/08/09 1.03pm		Windmills beeping noise every 2 minutes
04/09/09 8.05am	E	Continuous noise last half hour
09/09/09 11.24am	W	Started turbines 103&104, now noisy
11/09/09 6.21am	N	Light Northerly, noisy since he got up
19/09/09 10.49am	S	Very noisy again today
20/09/09 8.13am	E	Loud noise
28/09/09 7.15am	NE	Windfarm noise
07/10/09 5.32pm	W	Light wind, loud noise from wind farm
08/10/09 7.42am	W	Light wind swooshing noise this morning
09/10/09 7.02am	NE	Light wind, windfarm really loud this morning
10/10/09 9.59am	S	Light wind, would like to complain about noise
12/10/09 7.48am	N	Light wind loud noise from windfarm
20/10/09 3.53pm	S	Loud noise at wind farm
08/11/09 9.36am	0	Still, noisy today
16/11/09 7.25am	W	Lots of noise coming from windfarm this morning
17/11/09 6.27pm	W	Light wind, very loud tonight
20/11/09 7.22am	W	Noise complaint
22/11/09 7.16pm	E	Light wind WF very noisy
04/12/09 6.18am	W	Noisy this morning
07/12/09 6.21pm	W	Loud windfarm
09/12/09 6.50am	W	Light wind, droning noise
15/12/09 7.28am	S	Noisy wind turbines
19/12/09 7.04pm	W	Light wind noise from turbines over days whirring
25/12/09 8.59am	W	Light Westerly, very loud today
16/01/10 9.09am		Noise
17/01/10 7.44am	S	Light-medium Southerly wind farm quite loud today
17/01/10 6.58pm	S	Southerly wind wind mill noise
18/01/10 7.26am	SE	Medium wind, wind turbine noise last hour this am
18/01/10 6.45pm	E	Noise very bad
18/01/10 10.54pm	SE	Extremely loud
19/01/10 7.28pm	W	Turbines causing a lot of noise tonight
21/01/10 8.21pm	E	Loud noise from the turbines
25/01/10 4.43pm	E	Wind mill noise
26/01/10 8.12am	E	Medium wind, wind turbines making a lot of noise
28/01/10 7.27pm	E	Light wind, turbines are noisy again this evening
29/01/10 10.21am	E	Loud noise from blades & mechanical noise
29/01/10 6.12pm	E	Med wind same noise as usual coming from turbines
02/02/10 6.51pm	E	Loud noise from win farm
03/02/10 7.19pm	E	Noise from wind farm
04/02/10 7.01am	E	Noise loud this morning
05/02/10 6.22am	E	Light, loud today
05/02/10 5.57pm	E	Light wind, same whirring gearbox noise as usual
07/02/10 12.49pm	NW	Excessive noise
08/02/10 6.58am		Wind farm very loud this morning
08/02/10 8.16pm	E	Light wind
10/02/10 7.11am	N	Te Rere Hau noisy this morning
15/02/10 8.14pm	E	Medium wind
16/02/10 7.50am	E	Turbine noise in east direction at least hour



**Plate TRH 3: Te Rere Hau Wind Farm in Relation to residences**



**Figure TRH 1: Wind Rose for May to September 2009 illustrating existing wind farm effect (Te Rere Hau) and effect from a proposed wind farm (Turitea) to the south**



## Real-world noise compliance problem at a wind farm

The Te Rere Hau wind farm in New Zealand is presently the subject of a legal review<sup>16</sup> of its compliance and the methodologies applied to measure background sound levels and compliance levels.

In brief, specific issues raised are:

- The acoustic information supplied in the AEE was inaccurate;
- The Te Rere Hau wind farm is being operated at levels higher than those predicted in the {wind farm} application;
- The respondent has substantially underestimated the effects of the wind farm noise on the amenity of the area;
- The AEE concluded noise from the wind farm would not exhibit special audible characteristics (i.e. clearly audible tones, impulses or modulation of sound levels). This conclusion is inaccurate {reasons given};
- The actual experience of residents (located up to 2.18 km from the nearest turbines) and the number of complaints made to the Council indicating there are noise effects (which also exhibit special audible characteristics) being experienced at a significant number of local properties;
- The actual results reported in the revised compliance report (April 2010) demonstrate the actual sound levels from the wind farm are significantly higher (up to 12.8 dBA higher) at the monitoring location under certain wind speeds and directions than predicted;
- The AEE noise report predicted the sound level from the wind farm to be 34.9 dBA to 40.8 dBA at the monitoring location in wind speeds of 8 m/s;
- While monitored noise included noise from all sounds in the area (not just wind farm noise), the uncertainty as to the actual wind farm noise levels warrants further investigation. A new noise testing specification is the subject of the memorandum of 21 December 2010.

## Conclusion

Victoria applies the New Zealand wind farm standard NZS6808:1998 *Acoustics – The assessment and measurement of sound from wind turbine generators*. The Te Rere Hau compliance issues stem in part from the application of this standard. Matters touching on the application of this standard therefore are significant for consideration of prediction, assessment and compliance methods for existing and proposed rural wind farms in Victoria.

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<sup>16</sup> PNCC v NZ Windfarms, NZ Environment Court, ENV-2010-WLG-000114, Application for Declaration 11 October 2010 and Memorandum dated 21 December 2010



## **PART X - INDIVIDUALS' PERCEPTION OF WIND FARM SOUNDS**

### **Introduction**

This Part discusses the observed and measured differences between two distinct groups of people: one rural, one urban, and their responses to different sounds. The issues raised have application to wind farm developments in a wider context than Manawatu (rural) and Brisbane (urban) and its primary purpose is to highlight evidenced differences in human perception. The detail is provided in my doctoral thesis, *Assessing intrusive noise and low amplitude sound*, referenced previously.

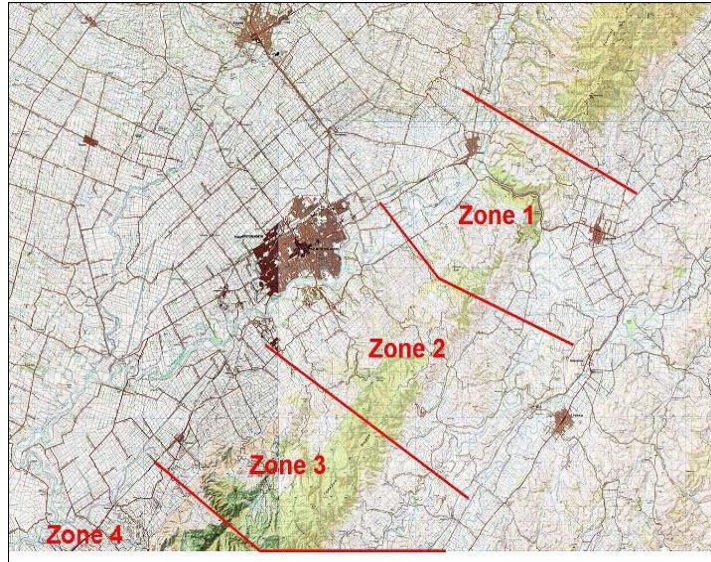
### **The Manawatu – Brisbane Pilot Study**

The Manawatu – Brisbane Pilot Study was undertaken by me over 2007 – 2008 as a peer-reviewed study offered to respondents of an earlier survey investigating wind farm issues. A series of attitudinal and acoustical studies in the Manawatu and Brisbane in order to assess the differences between a rural population and an urban population with respect to a specific set of sounds.

The Manawatu respondent's were determined as being an 'environmentally aware' population. The group was chosen on the basis that this segment of the research required responses from persons who had an interest in their environment and who would be willing to answer a lengthy questionnaire. The occupational status of the Manawatu group was not identified. It was anticipated that the Manawatu group would exhibit a wide range of noise sensitivities as the group was drawn from different 'zones' within the Manawatu: wind-farm affected urban and/or rural locales, and 'green-fields' unaffected by wind farms.

A comparison group was selected in Brisbane City. The Brisbane group was self-selected from invitations to musicians, teachers, lawyers and acoustical professionals. The Brisbane group was defined on the basis of previous investigations that indicated these occupations showed considerable attention to detail and focussed on issues more than 'ordinary' individuals. It was anticipated that this group would be significantly noise-sensitive.

The Zone map for the Manawatu is presented in figure 1. Zones 1 and 2 are potentially affected by wind farm noise; Zone 3 is green-fields but may be affected by wind farm noise to the north. Zone 4 is green-fields and unaffected by wind farm noise. The overall size of the locale in Figure 1 is 27 km by 10 km.



**Figure 1: Manawatu Study Zones**

Personality noise sensitivity questionnaires were administered to respondents in each zone. Brisbane was deemed to be the 'unbiased control' population. The analysis of the results from 69 responses (57 in the Manawatu, 12 in Brisbane) indicates that Zone 3 responses are statistically different from the other zones and the Brisbane group. All respondents to the survey are considered to be noise sensitive. This is an unexpected outcome from the study where a more spread distribution was anticipated. The responses to the noise annoyance questions indicate noise is sometimes a problem in both groups, with the local environment heard as being quiet / very quiet.

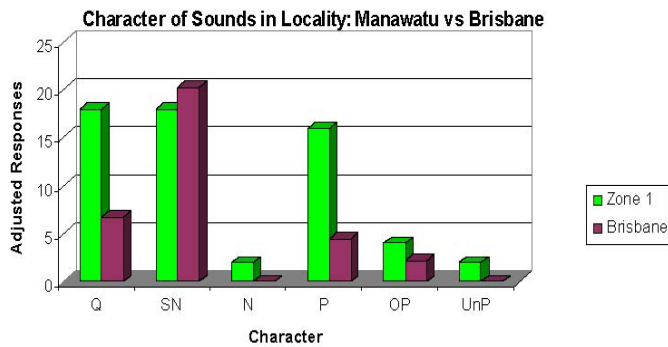
In response to the question "Do you find noise in your environment (including your home environment) a problem?" 65% within Manawatu have some experience of noise being a problem sometimes, 19% did not and 16% did find noise a problem. In the Brisbane group, 50% found noise a problem sometimes and 50% did not.

In response to the question "Thinking about where you live, could you please say how quiet or noisy you think your area is?" in the Manawatu 84% of the respondents recorded their locality as being quiet or very quiet, 13% as moderately noisy, while 3% found their locality noisy or very noisy. For the Brisbane group 67% of the respondents recorded their locality as being quiet or very quiet, 17% as moderately noisy and 17% found their locality noisy or very noisy.

In response to "Are you ever disturbed or annoyed by noise at home (not including from those living in your household?" 71% within Manawatu said 'Yes' while 29% said 'No'. In the Brisbane group, 83% said 'Yes' and 17% said 'No'.

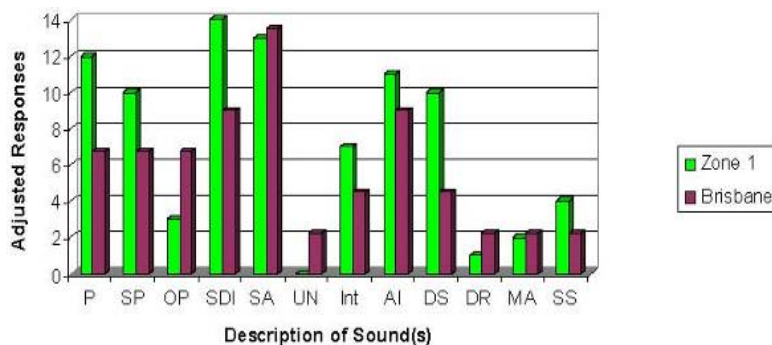
The question “does noise affect you while..?” provided a range of responses. Noise during relaxation and sleeping causes the most effect.

Questions concerning the character of the sounds within the local environment were answered mainly by the Zone 1 respondents (27 of the Manawatu total of 32). This zone is affected by wind turbines and is partly ‘residential’ urban and partly rural. The Brisbane group (12 of 12 responses) are from a completely urban environment. Figures 2 and 3 present the responses of the survey. The Brisbane group responses are adjusted by \*2.25 to allow direct comparison to the Manawatu responses.



**Figure 2: Character of the environment – Manawatu vs Brisbane.**

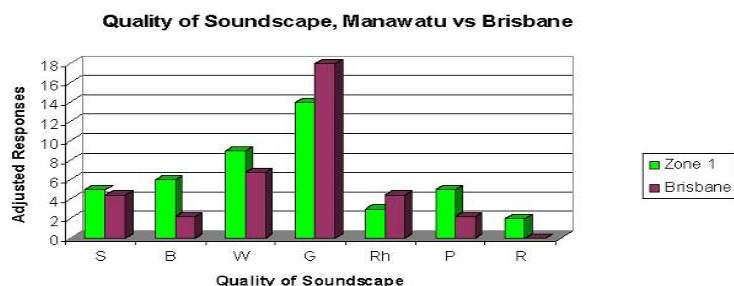
Key: (Q) quiet, (SN) sometimes noisy, (N) noisy, (P) pleasant, (OP) often pleasant, (UnP) unpleasant.



**Figure 3: Description of sound(s) in the environment - Manawatu vs Brisbane.**

Key: (P) pleasant, (SP) sometimes pleasant, (OP) often pleasant, (SDI) sometimes disturbing/irritating, (SA) sometimes annoying, (UN) ugly/negative, (Int) intrusive, AI (able to be ignored), (DS) disturbs sleep, (DR) disturbs rest or conversation, (MA) makes the respondent anxious, (SS) the respondent is sensitised to a particular sound.

In evaluating the qualities of the soundscape as it affected them, the respondents in Zone 1 had different impressions of their environment from the people in Brisbane, Figure 4.



**Figure 4: Qualities of Soundscape - Manawatu vs Brisbane.**

Key: (S) smooth, (B) bright, (W) warm, (G) gentle, (Rh) rich, (P) powerful, (R) rough.

In describing a sound clearly noticeable when at home, 39% of the Zone 1 respondents replied with “repetitive hum”. The source was not identified in all responses but the source mentioned most often was from wind turbines. The turbines were described, overall, as being heard within a pleasant, gentle soundscape; they were sometimes disturbing, irritating or annoying but able to be ignored except for occasions when the sound disturbed sleep.

### **A Study of Noise Sensitivity vs. Specific Sounds**

The responses from the previous study indicated a need for further investigation into individual noise sensitivity, the quality of the environment and individual responses to specific sounds was desirable. A new noise sensitivity questionnaire (NoiSeQ), a slightly revised annoyance questionnaire and set of sound files were presented to individuals in Manawatu and Brisbane.

The Manawatu focus group of 13 persons were self-selected by invitation from the previous Manawatu study. Approximately 50% of the group was from Zone 1 and 50% from Zone 3. The Brisbane group of 14 persons were self-selected by invitation from a group of people interested either in music or in acoustics. Individuals in this group may or may not have an interest in environmental issues. It was concluded that this is an acceptable component within the study design. An “Annoyance” questionnaire was included for consistency in application of the surveys.

The NoiSeQ noise sensitivity questionnaire is divided into an overall scale and sub-scales. The sub-scales are communication, habitation, leisure, sleep and work. The sensitivity of the respondents can vary depending on the sub-scale being measured. Higher values indicate higher noise sensitivity. As there are

two different groups (Manawatu and Brisbane) a test was required to check whether both groups are compatible or equivalent with respect to the noise sensitivity. An equivalence test of the two groups with respect to global noise sensitivity shows the groups are not compatible with respect to this characteristic. Analysis of the data indicates that a statistically significant difference exists between the mean ranks of the Manawatu (M) and Brisbane (B) groups. The differences appear in the noise sensitivity rankings of the groups, Figure 5, as “more than average”, “average” and “less than average”.

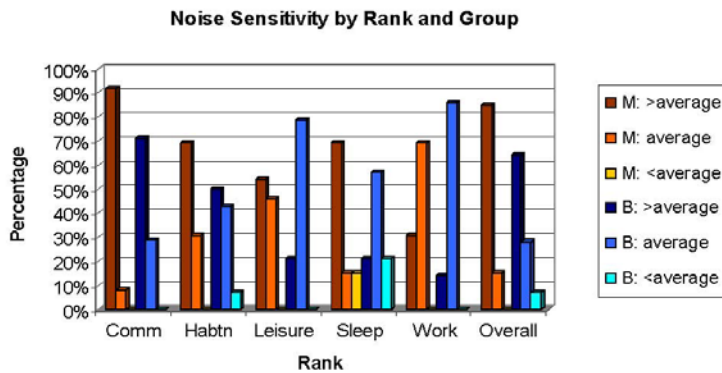


Figure 5: NoiSeQ Noise Sensitivity by rank and group as a percentage.

### Noise Annoyance

In response to the question “Do you find noise in your environment (including your home environment) a problem?” 62% within Manawatu have some experience of noise being a problem sometimes, 15% did not and 23% did find noise a problem. In the Brisbane group, 43% found noise a problem sometimes, 43% did not and 14% did find noise a problem.

The question “does noise affect you while..?” provided a range of responses. Noise during relaxing and sleeping causes the most effect.

An outcome of the observations and interviews of the pilot study indicated a need to establish a baseline reference point with sounds of known characteristics that could be reviewed by any person at any time. The purpose was (and is) to identify the perceptions of the sound as experienced by the person listening to the sound. The study was expanded by presenting a series of environmental sounds or ‘sound files’ to be judged by the respondents. The Manawatu group had the benefit of discussion concerning the sounds but all responses were made independently. The Brisbane group was not made aware of the nature of any of the sound files apart from the sound-file title. The perceptual responses help to characterise the groups of sounds investigated for individual response. A significant outcome is shown in the perception of wind farm noise between the Manawatu and Brisbane groups. The Manawatu group has a negative

outlook to the sounds while the Brisbane group are not negatively inclined towards wind farm noise. It was the character of the sound that was under review, not the 'loudness' of the sound. The character or characteristics of the sounds as perceived by the respondent's are presented in figures 6 to 8. The responses are recorded as percentages.

Sound file 1 is an amplitude modulated fluctuating sound. Sound file 2 is from a residential location in Ashhurst with wind farm sound audible. Sound file 3 is rural location of the eastern side of the ranges with wind farm sound audible.

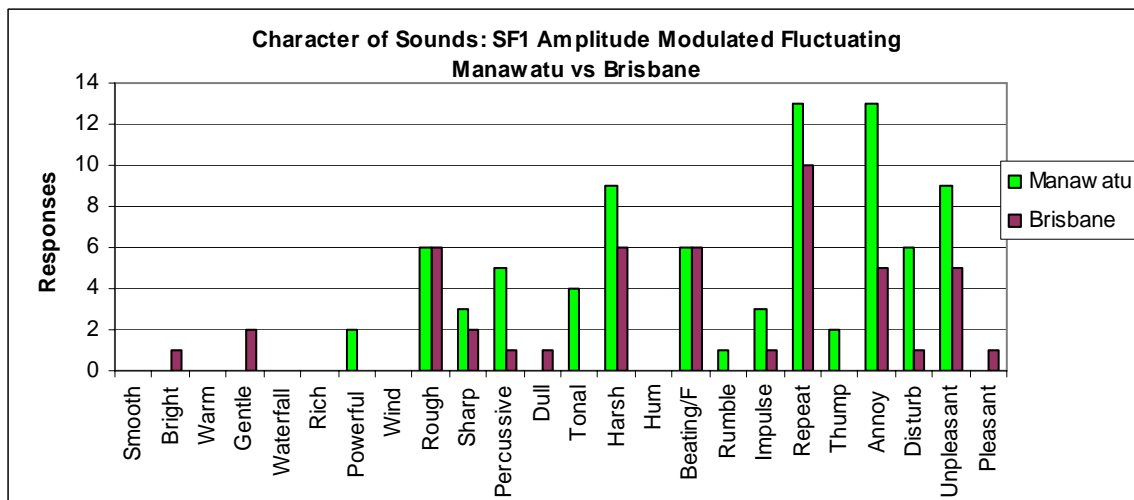


Figure 6: Responses to the character of SF1.

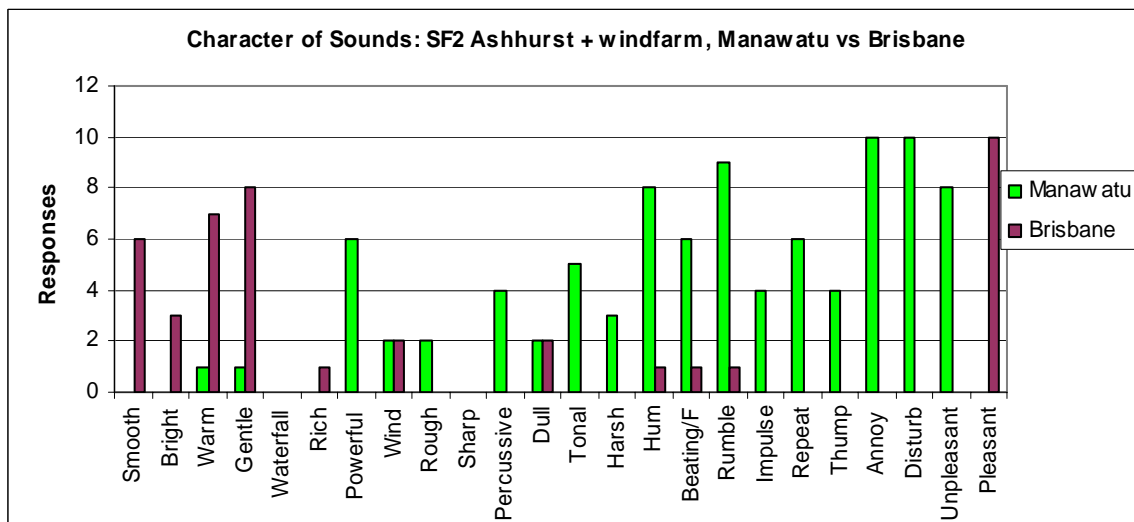


Figure 7: Responses to the character of SF2

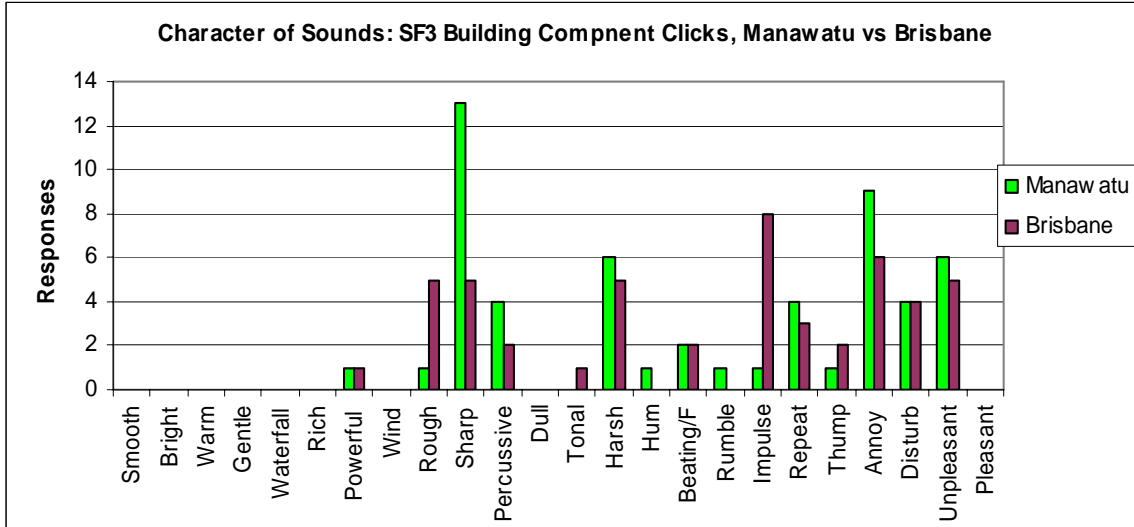


Figure 8: Responses to the character of SF3.

**Makara and Waubra studies into adverse health effects**

Further perception studies have been conducted at Makara (existing windfarm, Wellington, New Zealand) and Waubra (existing windfarm, Victoria, Australia) locales. The results of personal interviews with 5 groups at Makara, 5 groups at Waubra and 2 groups at proposed windfarm locales in Victoria present considerable response variation compared to the Manawatu and Brisbane groups. The Makara and Waubra groups have only recently experienced (mid-2009) the operation of the wind farm in their locality, compared to “long-term” experience in the Manawatu. The experiences of the “new” vs “long-term” groups are starkly different. The new groups experience audible noise at distances of around 2000 metres, as well as reported adverse health effects of sleep disturbance, headaches, nausea, stress and anxiety. These adverse health effects have been reported independently; that is, no one group or respondents in any one group were aware of the comments made by the other people.

The Makara and Waubra effects do not appear to be due to ground-borne vibration, a potential effect in the Manawatu. The physical acoustical levels are below the normally accepted levels for effect from low frequency or infrasound. The data from these studies is still being analysed at the time of writing.

## **Community perception and acceptance of wind farms**

The Turitea wind farm hearing heard professional opinion concerning community perception and acceptance of wind farms. The Palmerston North City Council commissioned a social impact assessment and the developer also commissioned a public perception survey. Previous to this a social impact assessment for a neighbouring wind farm had been undertaken by a community group. The overall impression given by the submitted Turitea evidence is that the community generally accepts wind farm development subject to checks and balances. What the Board of Inquiry thinks of these surveys will not be known until 2011.

## **Conclusions**

(1) It is concluded that there are significant differences between the Manawatu and Brisbane groups, not only in noise sensitivity but also in perception and responses to similar situations. This has two possible explanations: the Manawatu group has an unbiased negative response due to pre-knowledge and environmental awareness. Or, the group has a biased negative response due to pre-knowledge and environmental awareness.

(2) It is concluded that any attitudinal study that asks questions concerning environmental modification (whether wind farm, waste dump or any other similar industrial activity) will be significantly biased if the respondents have no first-hand experience of the activity. The decision process developed from this work recognises this 'enviro-cultural' influence.

(3) It is concluded that the unbiased annoyance approach to wind farm assessment is a viable alternative to existing objective measures. The calculated unbiased annoyance values for green-fields unaffected by wind turbines are 36-40 points (night). The residential and rural wind farm affected unbiased annoyance values are 109 to 419 points (night).

(4) There are observed adverse health responses from residents living within the locality of operating wind farms. These effects are, in my opinion, sufficient for investigations to be made for assessment of adverse health effects due to unreasonable noise or objectionable noise from wind farms.

(5) The process of understanding the risk options from no adverse health effects to unreasonable noise or objectionable noise and to significant / excessive or serious harm is not fully understood and may well be the influence of audible and infrasound or pressure variations affecting individuals. This is considered further in this statement.



## **PART XI - ANNOYANCE, AUDIBILITY, LOW AND INFRASOUND PERCEPTION**

The sound from a wind farm is essentially of an intrusive nature and is of low amplitude. That is, it is not very loud and it has varying character depending on wind speed and direction. This part outlines the process of an individual's response to noise.

A wind farm development creates a complex nature of adverse wind farm noise effects on people requiring an analysis of effect as well as the simple sound level calculations. The sounds of wind farms, in both audible and inaudible character, have a potential effect on individuals. Some people are affected, others are not. The effect, however, can be described in the context of intrusive noise.

The relationship between individual amenity and the adverse effects of noise is fundamental in the description of intrusive noise. For a sound to become noise, it must be unwanted by the recipient. Noise intrudes upon the amenity of a person and due to its unpleasantness causes annoyance and distress. The mechanism for this transformation of sound to noise varies widely from person to person.

Amenity has the general meaning of:

*Those natural or physical qualities and characteristics of an area that contributes to people's appreciation of its pleasantness, aesthetic coherence, and cultural and recreational attributes.*

An individual may react differently to noise from a combination of sources than to noise from a single source at the same level. Significantly, other persons in the vicinity may not hear or be disturbed by the noise. Individuals possess, however, a stable personality trait for noise sensitivity that provides a foundation for the assessment of individual acceptability of a particular sound under general and specific conditions. Individual amenity is a complex mix of personal noise sensitivity, personal and cultural attitudes to noise in the environment, and habituation effects.

The assessment of "intrusive" noise, or "nuisance" noise, is subject to individual sensitivity to the noise in question (that is, why is the sound noise?). Audibility and intrusive noise can therefore be defined in terms of effect, referenced to before, during and after some identified noise event. The reaction modifiers for individuals include:

- Attitude to noise source
- Attitude to information content in the noise
- Perceived control over the noise

- Sensitivity to noise (in general and specific)
- Sensitivity to specific character of the noise

Based on my research:

- Noise is a sound that is perceptible to an individual and has definable characteristics that modify the individual's emotional and informational responses to that sound from pleasurable or neutral to adverse.
- Intrusive noise, to an individual, is a sound whose variance in character (such as audibility, dissonance, duration, loudness, tonality, pitch or timbre) is perceived adversely compared to the character of the environment in the absence of that sound.
- Amenity is the pleasantness or a useful feature of a place. Quiet and tranquility are common attributes sought by an individual. Amenity values are based upon how people feel about an area, its pleasantness or some other value that makes it a desirable place to live.

Amenity in a rural locale affects the way individuals and the community feel about their environment and how these "amenity" values form part of the economic values placed on the environment by the community as a whole. The adverse intrusion of a sound into the well-being or amenity of an individual is a significant precursor to annoyance. The amenity of an individual can, therefore, be defined in terms of the effects of annoyance and character of sound in the environment:

- Significant serious or excessive adverse effect. The noise creates adverse health reactions including annoyance, stress, anxiety, sleep disturbance not acceptable to the individual and can lead to serious harm to health;
- Significant nuisance adverse effect causing anger, annoyance, or adverse health reactions including annoyance, stress, anxiety, sleep disturbance not acceptable to the individual;
- Adverse effects more than minor with intermittent nuisance that is ultimately accepted by the individual;
- An adverse effect, but no more than minor (minor irritation) normally accepted by the individual;
- No adverse effect, pleasurable sounds or peace and tranquillity.

Based on the foregoing, it is practical to define "excessive noise" as the first dot point, "unreasonable noise" as the second dot point; the transition stage between unreasonable and reasonable noise as the third dot point "adverse effects more than minor", and "reasonable noise" as being the fourth dot point. The fifth dot point infers no noise whatsoever.

In terms of noise, therefore, a person has cause for complaint about noise and is acting in a not unreasonable manner if he or she is:

- Awoken or suffering from disturbed sleep due to noise
- Disturbed by noise while relaxing within his or her home
- Annoyed by noise inside or outside the home
- Reacting to the sound because the individual finds that the sound contains perceptually negative information

In summary, a reasonable level of sound is a level that:

- does not annoy any person while inside their home.
- does not disturb the sleep or relaxation or wellbeing of any person while inside their home.
- is not intrusive outside the home in any area where a person may relax.
- does not cause annoyance, anxiety, stress, or a loss of personal wellbeing whether inside or outside a home.

An individual's comfort within an environment and sensitivity to noise are affected by that individual's exposure and habituation to different types of sounds. The subjective component of the methodology outlined in figure 1 presents the various indicators a person may subconsciously perceive and apply when listening to a sound. The criterion 'personal space' includes an individual's emotional state and sensitivity to a particular sound.

Having heard a sound and made an instantaneous value of that sound, an individual immediately characterises the sound as pleasant or unpleasant, acceptable or unacceptable, a sound that can be accommodated or intrusive noise. Figure 1 presents the relationships in a format to describe why the same sound does not always provoke the same intensity of disturbance or annoyance at different times in the same individual.

The processes presented in figure 1 are common features in how an individual responds to a sound and makes perceptive choice that the sound is "good", "annoying but can be lived with" or "intrusive – get rid of it".

A person can change his or her perception about a sound but tends towards a stable response with a set "value" for the sound. That is, ultimately, the sound is either accepted or rejected as a nuisance.

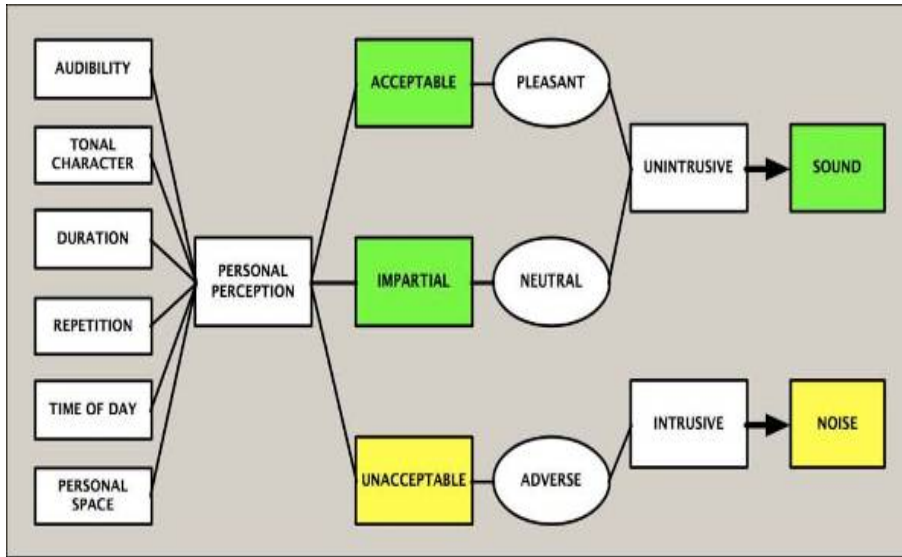


Figure 1: Subjective decision processes to differentiate between sound and noise.

The audibility of a sound is its most common feature – a sound must be audible to be heard by a person. This is the essential problem with all sound – noise assessment systems: a person is an individual and his or her responses cannot be mimicked by a machine. Equally, one individual cannot tell another individual what he or she hears and how he or she should respond to that sound. Audibility is aided by the character of the sound: if the sound is similar to the locale then, even if the sound is audible, it is more likely to be accepted.

If the character of the sound is foreign to the existing environment then it has less chance of being accepted. To an individual, the time of the day the sound is heard is important with unusual sounds in the early morning being less acceptable than if they are heard during the day. If a sound affects the personal space of a person while at home, inside or outside, that sound has a high degree of probability as being a disturbance. Additionally, if the sound has information content that the person does not want to hear that sound is perceived negatively. Personal perception therefore combines a variety of attributes that cannot be measured by instrumentation.

The sound emissions from the turbines will not occur all the time, of course, as the turbines operate at different times and under different prevailing wind directions and wind speeds. The evidence, however, is that once a person has become sensitised to the activity of the turbines this sensitivity is not habituated. That is, the person does not ‘learn to live with it’. Thus the adverse effect can be considered as being ‘active all the time’.

My hypothesis, based on my research and assessments of rural wind farms is that an operating wind farm with no breeze or a light breeze at ground level blowing towards the residences, and with at least 3 two-

MW to three-MW turbines visible at distances of between 1200 metres and 2600 metres from a potentially affected population, will have:

- an overall night-time residential outdoor sound level of 32dB(A) to 35 dB(A) LAeq;
- a significant serious adverse effect on approximately 5% to 10% of the exposed population expressed as households; and
- a significant nuisance adverse effect on approximately 20% of the exposed population expressed as households; and
- a 'more than minor' effect on 50% of the exposed population expressed as households.

Waubra, however, appears to have a far higher proportion of significant serious adverse effect reactions and claims of serious harm to health. The values are based on audible sound and do not take into account adverse health effects due to or possibly due to pressure variations or infrasound. The values will change, of course, for households closer to or further away from the wind farm.

The process of understanding the risk options from no adverse health effects to unreasonable noise or objectionable noise and to significant / excessive or serious harm is not fully understood and may well be the influence of audible and infrasound or pressure variations affecting individuals.

## **Annoyance**

The World Health Organization<sup>17</sup> states that the perception of sounds in day to day life is of major importance for human wellbeing. The WHO defines annoyance as

*"a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them".*

Used as a general term to cover negative reactions to noise, annoyance may include anger, dissatisfaction, helplessness, depression, anxiety, distraction, agitation or exhaustion.

In terms of noise management the WHO is clear: the goal of noise management is to maintain low noise exposures such that human health and wellbeing are protected. The environmental management principles to achieve this are three-fold:

- The precautionary principle: In all cases, noise should be reduced to the lowest level achievable in a particular situation. Where there is a reasonable possibility that public health will be damaged, action should be taken to protect public health without awaiting full scientific proof;
- The polluter pays principle;
- The prevention principle.

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<sup>17</sup> "Guidelines for Community Noise, World Health Organization, 2000

To understand these principles requires a shift in thinking away from the usual ‘noise from transportation’ noise exposure mindset. There has been considerable research into noise annoyance from turbines, such as that reported by Pedersen and Persson Waye,<sup>18</sup> identifying the relationship between noise from turbines and transportation. Figure 2 presents the relationship derived by Pedersen and Persson Waye showing the effect of “percent people highly annoyed” by noise from transportation and from wind turbines. Annoyance from wind turbine noise occurs at noise levels far lower than for traffic noise.

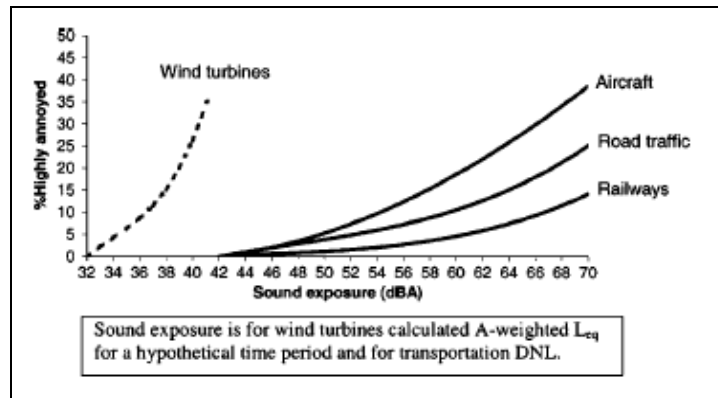


Figure 2: Wind turbine noise levels and persons highly annoyed by the noise  
 Source: Pedersen and Persson Waye

The research by Pedersen and Persson Waye indicates that, for example, 10 percent of the exposed population is highly annoyed with traffic noise at 60 dBA DNL (day-night noise level) whereas this same degree of annoyance occurs at 36 dBA Leq for a population exposed to wind turbine noise. Twenty percent of the population is highly annoyed with traffic noise at 68 dBA DNL whereas this same degree of annoyance occurs at 39 dBA Leq for a population exposed to wind turbine noise.

The potential effects of wind farm noise on people are annoyance, anxiety, changing patterns of behaviour, and possibly sleep disturbance. The response of a person to noise from wind turbines is likely to depend on the following-

- the variation in wind speed and strength;
- the amount of time the receptor is exposed to the noise levels;
- the nature of the noise output from the wind turbine including tonal content, modulation (blade swish) and or low frequency effects;
- background noise levels at the receptor location;
- wind and non-wind related effects;
- non-acoustic factors, such as the sensitivity of the listener and attitude to the source.

<sup>18</sup> ‘Perception and annoyance due to wind turbine noise-a dose-response relationship, Pedersen E and Persson Waye K, J Acoust. Soc. Am 116 (6) December 2004

The importance of noise sensitivity assessment, as a measure of human response, is the strong association between noise sensitivity and annoyance. Noise sensitivity has a strong influence on annoyance and is independent of the noise exposure. Job et al<sup>19</sup> has found that-

*Only a small percentage (typically less than 20%) of the variation in individual reaction is accounted for by noise exposure. ...*

*Variables, such as attitude to the noise source and sensitivity to noise, account for more variation in reaction than does noise exposure.*

Noise affects individuals and the community by modifying the nature of the environment that attracts and holds people to the locality. Acoustical amenity, therefore, can be described as the enjoyment of a place without unreasonable exposure to unwanted sound that is a by-product from some activity. Individual amenity is evaluated with respect to personal noise sensitivity, personal and cultural expectations and attitudes to noise in the environment and habituation effects. Noise intrusion, as a personality variable, is dependent on noise sensitivity.

### **Audibility – Low frequency - Infrasound**

My field work observations indicate that low-amplitude intrusive noise is often significantly more audible at night and can be highly audible at considerable distances, especially on cold or cool nights and if there is a slight breeze blowing from noise source to the person. This is due not only to the increase in noise over the background level but also the distinct difference in the character of the noise, or its audibility, in comparison to the environment without the noise.

People are unique in their individual hearing response. A sound audible to one person may be inaudible to another and, therefore, a method is needed to define, measure and assess “audible sound”. A sound is said to be audible if it can be heard within the ambient sound (soundscape) of the locality. That is, the sound is not masked by the soundscape. This is a signal-to-noise phenomenon and can be defined in terms of sound detectability.

Audibility can be considered as a psychophysical quantitative relationship between physical and psychological events:

- the physical relationship is considered as being the role of signal detection
- the psychological or behavioural and perceptive reactions of an individual are considered as psychoacoustical or sound quality relationships

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<sup>19</sup> Job, RFS, 1988, Community response to noise: A review of factors influencing the relationship between noise exposure and reaction, J.Acoust.Soc.Am. 83(3), 991-1001

A method for the prediction of the audibility of noise sources is detailed in a report<sup>20</sup> providing technical rationale and relationships between signal-to-noise ratio and frequency that govern detectability of acoustic signals by human observers and provides methods to:

- Predict the frequency region of a spectrum that is most detectable in any given sound environment
- Quantify the degree of detectability of the signal in question
- Estimate reduction in signal-to-noise ratio necessary to render the signal undetectable

The report states that detectability is the product of three terms:

- the observer's efficiency relative to an ideal energy detector
- masking bandwidth
- signal-to-noise ratio at the output of a hypothetical auditory filter

Just-noticeable differences (jnd) are the smallest difference in a sensory input that is perceivable by a person. Just-noticeable changes in amplitude, frequency and phase are an important feature for the assessment of low amplitude sound in a quiet background, where slight changes in frequency or amplitude can be readily noticed as a change in ambience. The characteristic of the sound is its absence; that is, the sound is not noticed until it has gone. It is the absence of the sound that defines its degree of intrusion and potential annoyance.

The other kind of change is a just-noticeable difference where the one sound is compared to another sound; that is, increment detection vs. difference discrimination. The just-noticeable degree of modulation threshold factor is approximately 1 dB, with smaller sensitivity at high sound levels. Our hearing is most sensitive for sinusoidal frequency modulations at frequencies of modulation of approximately 4 Hz. At 50 Hz the just noticeable change corresponds to a semi-tone in music.

Human sound perception can be described in terms of equal loudness contours. Strictly speaking these are not measures of audibility but they do provide a useful starting point for comparison between sound levels by frequency (tone). An equal loudness contour is a measure of sound pressure, over the frequency spectrum with pure continuous tones, for which a listener perceives an equal loudness. Loudness level contours are defined in International Standard ISO 226:2003 *Acoustics-Normal equal loudness contours*, figure 3. The revised ISO 2003 contours are in red, the 1961 contours are in blue. The 40 phon equal loudness contour is the contour referenced in the derivation of the decibel A-weighted scale (dBA).

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<sup>20</sup> *Graphic Method for Predicting Audibility of Noise Sources* (1982) by Bolt, Beranek and Newman for the US Flight Dynamics Laboratory (publication AFWAL-TR-82-3086).



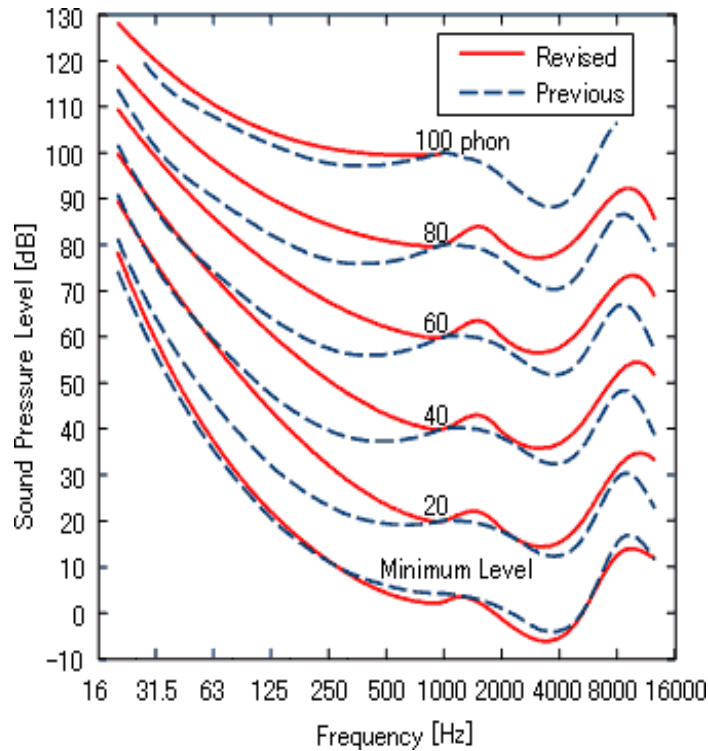


Figure 3: Equal loudness level contours vs sound pressure levels

(reference source: [http://www.aist.go.jp/aist\\_e/latest\\_research/2003/20031114/20031114.html](http://www.aist.go.jp/aist_e/latest_research/2003/20031114/20031114.html))

The research by Moller and Pedersen<sup>21</sup> into hearing at low and infrasonic frequencies extends our ability to assess the potential for audible sound from a wind farm. They say:

*The human perception of sound at frequencies below 200 Hz is reviewed. Knowledge about our perception of this frequency range is important, since much of the sound we are exposed to in our everyday environment contains significant energy in this range. Sound at 20–200 Hz is called low-frequency sound, while for sound below 20 Hz the term infrasound is used. The hearing becomes gradually less sensitive for decreasing frequency, but despite the general understanding that infrasound is inaudible, humans can perceive infrasound, if the level is sufficiently high. The ear is the primary organ for sensing infrasound, but at levels somewhat above the hearing threshold it is possible to feel vibrations in various parts of the body. The threshold of hearing is standardized for frequencies down to 20 Hz, but there is a reasonably good agreement between investigations below this frequency. It is not only the sensitivity but also the perceived character of a sound that changes with decreasing frequency. Pure tones become gradually less continuous the tonal sensation ceases around 20 Hz, and below 10 Hz it*

<sup>21</sup> Moller H., Pedersen C. S., (2004). Hearing at low and infrasonic frequencies. Noise Health, 6, pp37-57. <http://www.noiseandhealth.org/text.asp?2004/6/23/37/31664>

*is possible to perceive the single cycles of the sound. A sensation of pressure at the eardrums also occurs. The dynamic range of the auditory system decreases with decreasing frequency. This compression can be seen in the equal-loudness-level contours, and it implies that a slight increase in level can change the perceived loudness from barely audible to loud. Combined with the natural spread in thresholds, it may have the effect that a sound, which is inaudible to some people, may be loud to others. Some investigations give evidence of persons with an extraordinary sensitivity in the low and infrasonic frequency range, but further research is needed in order to confirm and explain this phenomenon.*

The complexity of our hearing processes illustrates the reason why there can be significant variation in interpretation of sound from one person to another. Not only can a sound be interpreted differently between people but one person may not be able to hear a sound while a second person is seriously affected by the 'noise'.

Moller and Pedersen observe that especially sensitive persons, however, may have extraordinary high hearing sensitivity at low frequencies, figure 4. Infrasound may, therefore, be perceptible to sensitive persons at levels far lower than that nominally accepted as being the thresholds for persons with normal hearing. At 8 Hz, for example, levels of 78 dB to 88 dB may be perceptible.

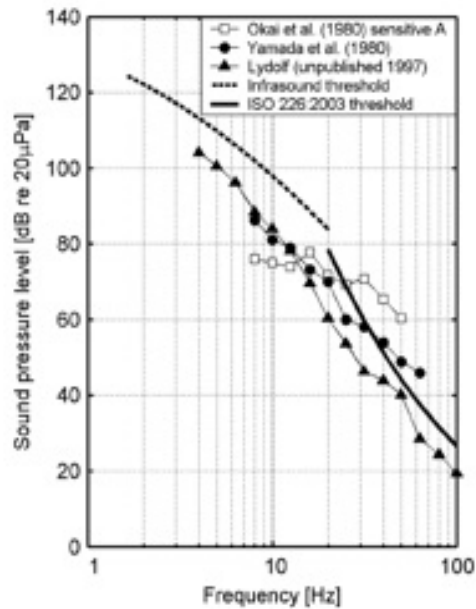


Figure 4: Hearing thresholds of three especially sensitive persons (Moller and Pedersen Figure 12)

Significant research is being conducted into the effects of infrasound on perception and the vestibular system. This research is starting to fill in knowledge-gaps with respect to human response and adverse health effects.

In 'Response of the ear to low frequency sounds, infrasound and wind turbines', Salt and Hullar conclude:

*"... low frequency sounds that you cannot hear DO affect the inner ear. The commonly held belief that "if you can't hear it, it can't affect you" is incorrect. The paper shows how the outer hair cells of the cochlea are stimulated by very low frequency sounds at up to 40 dB below the level that is heard. It shows that there are many possible ways that low frequency sounds may influence the ear at levels that are totally unrelated to hearing sensitivity. As some structures of the ear respond to low frequency sound at levels below those that are heard, the practice of A-weighting sound measurements grossly underestimates the possible influence of these sounds on the ear. Studies that focus on measurements in the "audio frequency range" (i.e. excluding infrasound) will not provide a valid representation of how wind turbine noise affects the ear. The high infrasound component of wind turbine noise may account for high annoyance ratings, sleep disturbance and reduced quality of life for those living near wind turbines."*

*"According to the British Wind Energy Association, the A-weighted sound level (in which the high infrasound component has been taken out) generated by wind turbines is 35-45 dB SPL. ... This characterization of wind turbine noise totally ignores the high infrasound component of the noise. A-weighting or G-weighting sound measurements are perfectly valid if hearing the sound is the important factor. But, as sensory cells in the ear are stimulated at levels substantially below those that are heard, A-weighted measurements do not adequately reflect the true effect of the sound on the ear."*

Their paper shows there are many possible ways that infrasound may influence the ear at levels that are totally unrelated to hearing sensitivity. They state that:

*It cannot yet be concluded that this type of stimulation causes specific symptoms in people. More research needs to be performed in this area. It does, however, suggest that the infrasound component of wind turbine noise should be studied further as a possible cause of people's symptoms, rather than being dismissed as an impossible cause.*

## **Conclusions**

It is concluded that wind turbine noise is a complex relationship between audible sound, infrasound, individual sensitivity, individual perception, sound exposure by time of day and audibility, wind speed and direction, wind farm design, turbine design and design of residence.

It is concluded that there have been more than sufficient credible observations, measurements and peer reviewed research papers and articles indicating that for 5% to 10% of the individuals living in the vicinity of a large rural wind farm its operation will cause serious harm to their health.

## PART XII - RECOMMENDED READING

In addition to the references in the Report and in no particular order, the following are recommended reading to the issues of sound, noise, human perception, adverse health effects and wind farm activity. These documents are not part of my Submission and are included to assist any person wishing to source an overview of some of the literature currently available.

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