Wind Farm Noise and Human Perception

A Review

NOISE MEASUREMENT SERVICES

CONTROL PAGE

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PREAMBLE

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 near large-scale wind farms or large turbines. Adverse health effects can arise from 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 such sensations when awake or asleep.

The hypothesis from this Review is that serious harm to health occurs when a susceptible individual is so beset by the noise in question that he or she suffers recurring sleep disturbance, anxiety and stress. Research for the Review suggests that 5% to 10% of the individuals living in the vicinity of a large wind farm will experience serious harm to their health. The observed markers for serious health effects are

(a) wind farm noise level of LAeq 32 dB or more outside the residence and

(b) wind farm noise is heard or is perceptible (felt) at levels above the individual's threshold of hearing inside the home

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. Wind farms are unique sound sources and exhibit special audible characteristics that can be described as modulating sound or as a tonal complex. Current noise prediction models are simplistic, have a high degree of uncertainty, and do not make allowance for these significant variables. Compliance monitoring must therefore include continuous real-time measurement of characteristics such as modulating sound in order to determine the perceptible effects of audible sound and inaudible infrasound.

The Review contains references to the NMS research, measurements, and observations at different wind farms in New Zealand and Australia. All NMS research including the study methodologies are peer-reviewed. Such work is commercial-in-confdence to NMS and of a confidential nature to the participants. No datasets, apart from those presented in this Review, are disclosed or publicly available.

Keywords: wind farms, health effects, human perception, noise prediction, noise management

CONTENTS

PART I - INTRODUCTION

The design and placement of wind farms cause problems for wind farm developers and residents directly from:

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

Inappropriate Land-use Planning

The general theme 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. 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 no adverse environmental effects from wind turbine noise. Turbine efficiency is not an issue as the wind farm and turbine choice can be designed for the relevant air and building environments. It is, therefore, a matter of land-use choice and associated planning instruments that brings turbines into rural areas rather that the urban areas where the power is needed.

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 air movement to generate electricity.

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. 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 limited in its application to noise assessment near the turbine; not at a distance. The standard does not address the core issue of the effect of such noise on people.

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. Professional 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.

When noise compliance is referenced to wind speed at the wind farm in practice only the wind farm operator has access to the wind and turbine data necessary to assess compliance. Thus it is virtually impossible for the “other side” be they regulatory authorities or complainants to prove non-compliance. There needs, therefore, 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.

All of these issues are addressed further in this Review.

PART II - 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. (A summary of findings from a follow-up study in 2012 is given in Part 6). The wind farm received permission to establish and was, as far as known, 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 or explanations for the reported adverse health effects is available but there is little practical difference between cause and effect between reported complaint histories in Australia, Canada, England, New Zealand and the United States.

There are two significant problems involved in the establishment of a wind farm in a rural environment.

- 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 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, ± 3 dB 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 can be expected under such adverse conditions.

Predictions and assessments – An example with a Waubra residence

Noise predictions are not a single line or a single number but, in fact, a range of sound levels. In this example the predicted time-average (LAeq) single-value sound level at the residence is 39 dB. 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 LAeq at the residence (RES) as shown in **Plate 1.** Assuming a noise criterion or limit of 40 dB the potential affect of the wind farm is not the '40 dB' 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).

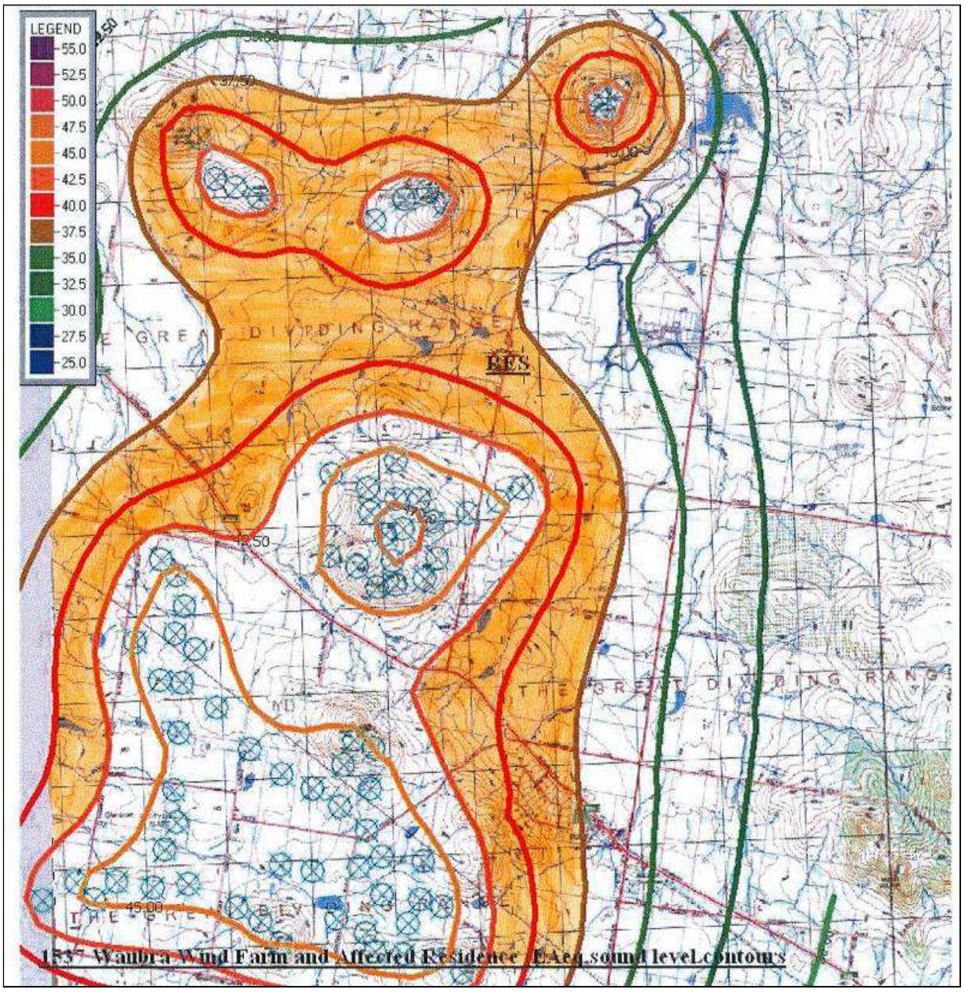


Plate 1: Predicted 40 dB LAeq Zone affecting a residence (RES)

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. The variations in character can be heard when the wind blows from one turbine to the other; the effects are not dependent on the direction of the turbines to the observer. The effect of the turbines at night can be seen in **Photo 2.**

Photo 1: wind turbines as seen from a residence

Photo 2: Warning lights and visual effects, blades emphasised by the lights

Background sound levels

New Zealand and various Australian 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 background levels attributable 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 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.

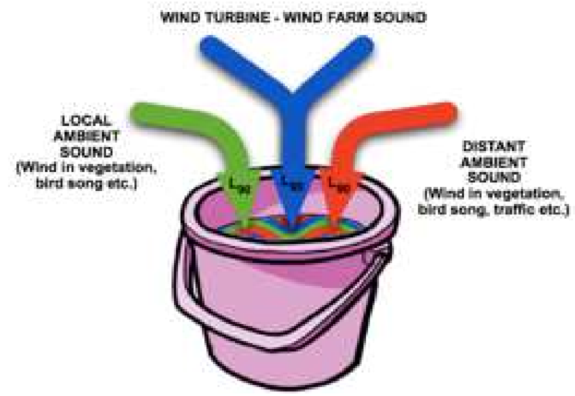


Figure 1: "Bucket of mixed sound" as L_{Aeq} or L_{A90} level.

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 is/was due to the wind farm. Obviously loud levels of sound from a wind farm in excess of LAeq 35 or 40 dB may be measurable but still very difficult to prove as being the sole 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’. Application of this condition requires real-time observations or highly sophisticated recording and monitoring techniques. A practical alternative is to identify sounds that are specific to the wind farm and those that are characteristic of the ‘non-turbine’ ambient environment and correlate these sounds. A range of different measures must be used. 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. Professional 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 example 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 (LAeq) un-weighted sound levels. Un-weighted ('Z' weight sound levels) are referenced for audibility, as explained later.

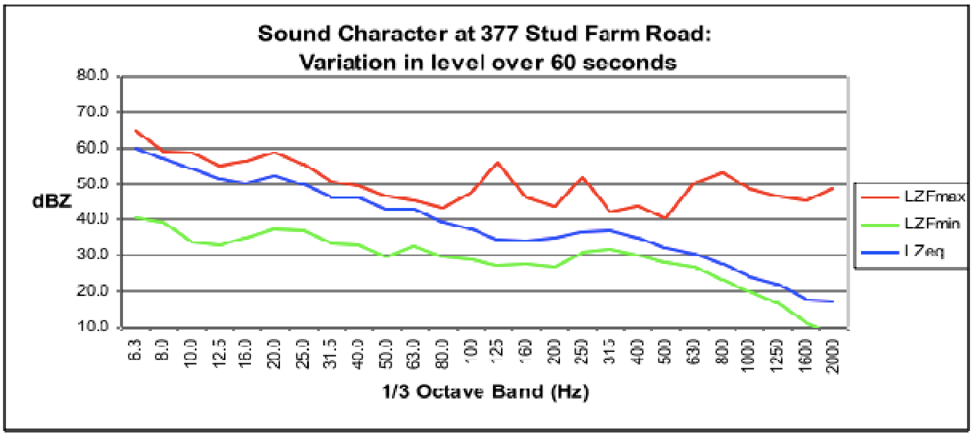


Figure 2: Variation in sound character over 60 seconds

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.

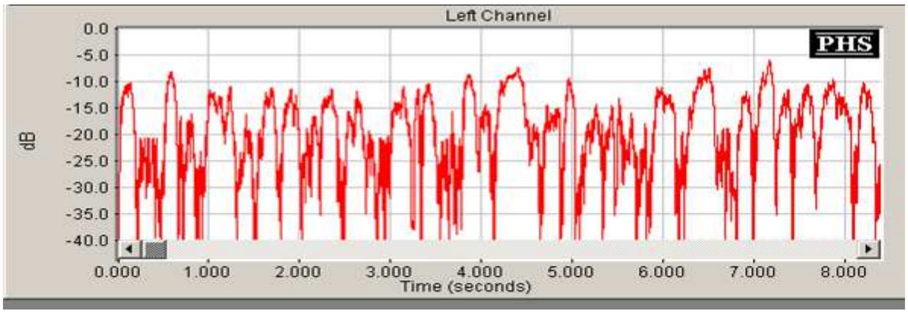


Figure 3: Pulse pattern from an operational wind farm

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.

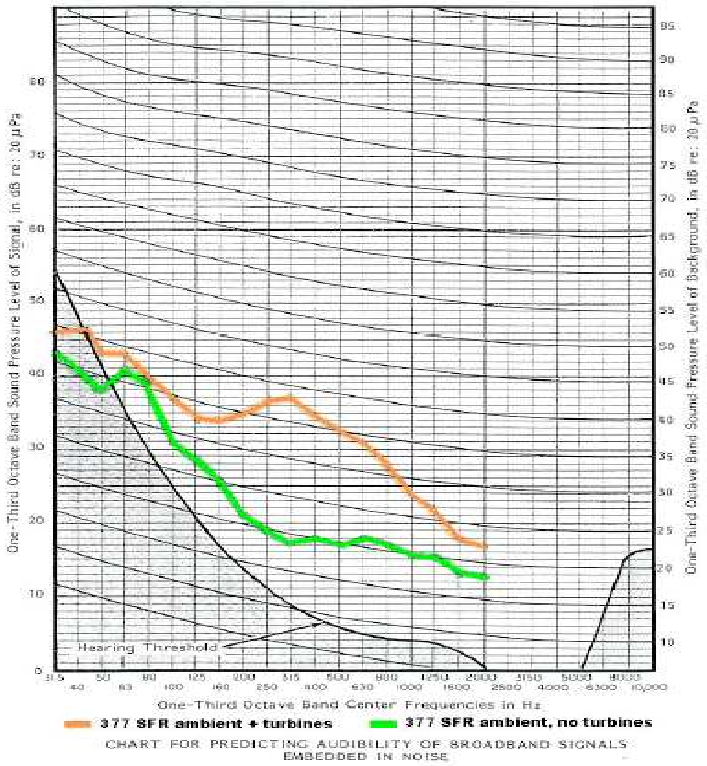


Figure 4: Audibility of wind turbines at Residence

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' sound level, LAeq. The consistency in level is not unusual for inside a home. The LA95 level for the time period is 17.4 dB. The average sound level is LAeq 32.5 dB. At 8pm the wind dropped and the sound levels within the home decreased, with an average sound level of LAeq 18 dB, 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.

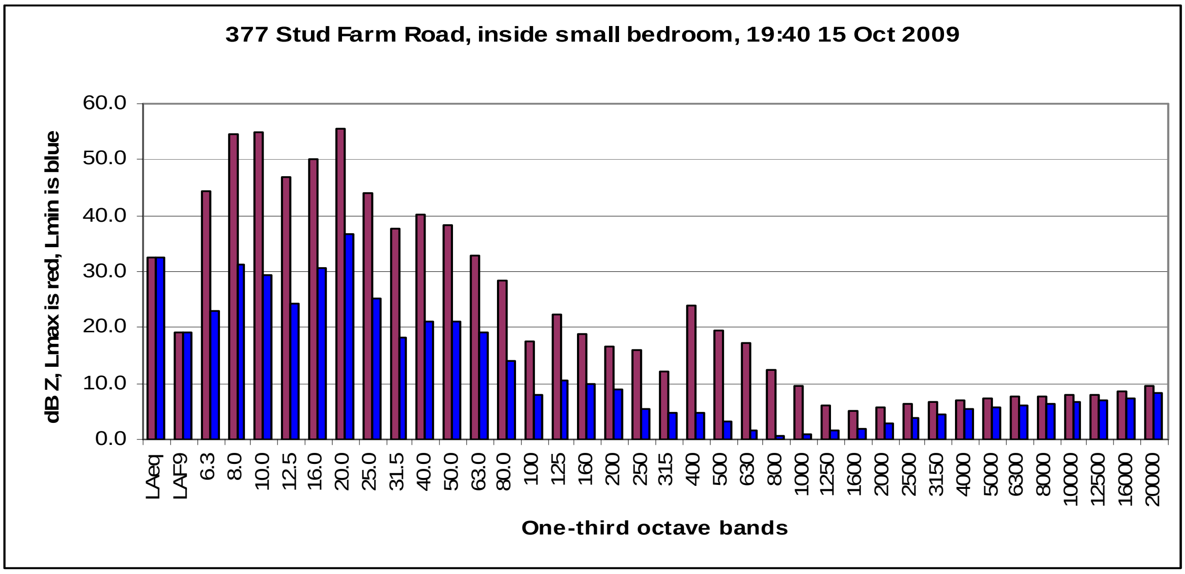


Figure 5: Indoor sound character for the initial survey (LZmax vs LZmin)

The method used to display sound character, modulation, tonality or tonal complexes is through sonograms[1]. These show the 'special audible characteristics' of sound at various frequencies over time as illustrated in **Figures 6 to 11**. 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. These show sound at various frequencies over time as shown in **Plate 1**.

A sonogram can be thought of like a sheet of music or an old pianola roll; the left axis is frequency—musical pitch—while the bottom axis is time. The colour indicates the loudness in unweighted dB (SPL) with the colour bar at the right providing a key to the 'loudness' in decibels associated with each colour. The values (-30 to 20, for example) on the right-hand side of the sonogram are decibel levels. Loud notes appear yellow or while; soft notes would appear purple or black. In the following sonograms much of the colour scale has been made black so that peaks stand out better.

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. The sampling rate for the audible section of the sonogram is the 44.1k that is normally used which is then averaged over 50ms (Leq) to give the sound level in dB. For the infrasound it depends on a number of factors since there are three downsamplings in the process; the first is to improve the Hilbert transform, the second is before running a low pass filter over the transformed data and the third is after the filter. For 44.1kHz the downsamplings give a final sampling rate of 10ms. This then gets averaged (Leq) over 50ms to give the final sound level in dB. Different sampling rates (e.g. 16kHz) have specific downsampling factors. The sonogram frequencies are recorded as 1/24 octave. The frequency bands are log-scaled.

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. At the time of recording it is possible to include reference sound levels in order to assess the sonogram values against measured values.

[1] Various methodologies are available to display sonograms or modulation. The methodology by Dr H. Bakker, Astute Engineering, is preferred.

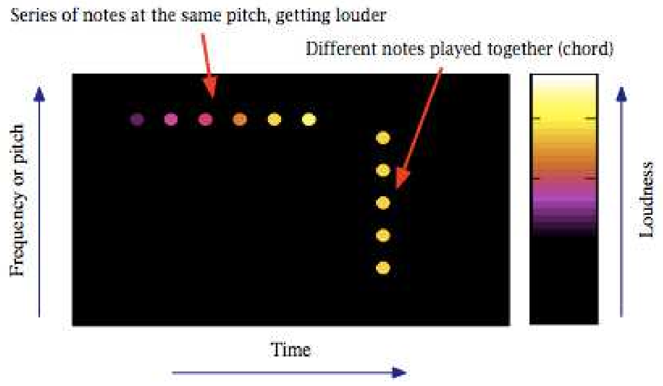


Plate 1: How to interpret a sonogram

There are two types of sonograms shown; one is for audible frequencies (20Hz to 1000Hz), while the other is for low frequencies (0.8Hz to 20Hz), referred to as *infrasound*. The use of sonograms can show the presence of modulation. The rumble/thump of wind turbine modulation has been demonstrated to exist in three, geographically separate wind farms.

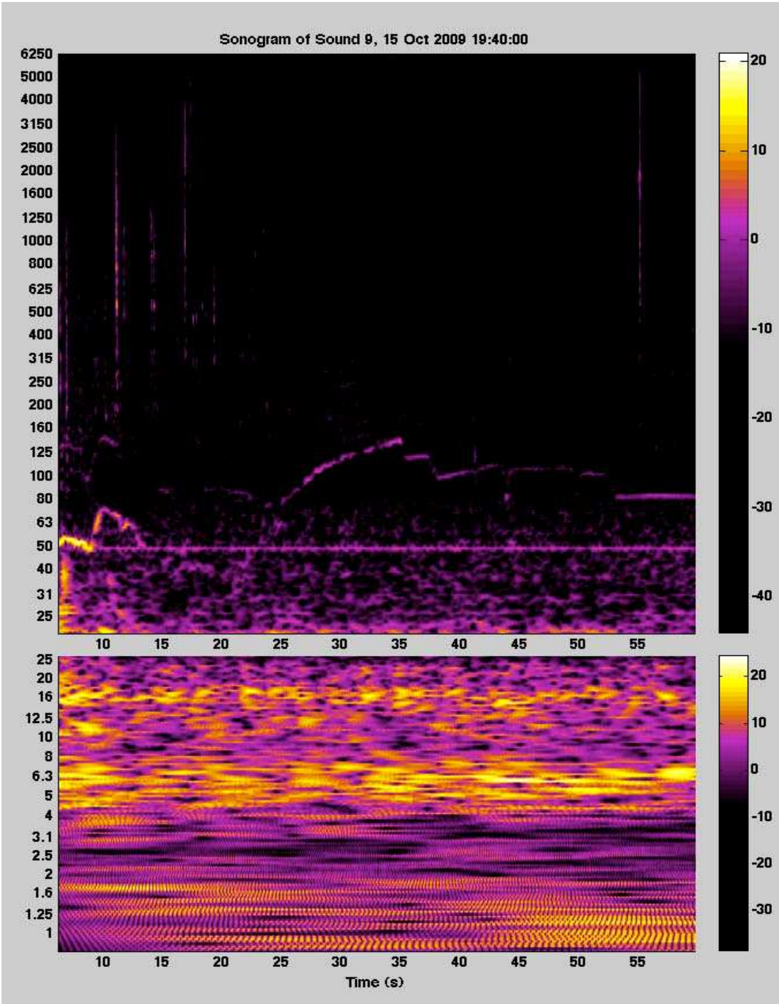
The following sonograms are presented to illustrate specific locations with and without turbine activity. The sonograms illustrate the presence of turbines even though the activity may not be audible. Different time segments are used to illustrate the effects. The important features are:

- 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.

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.



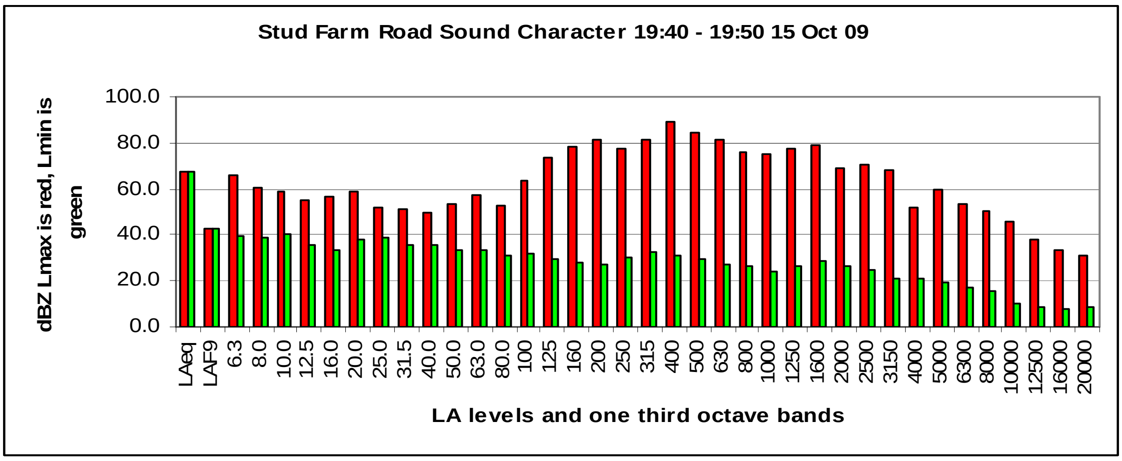
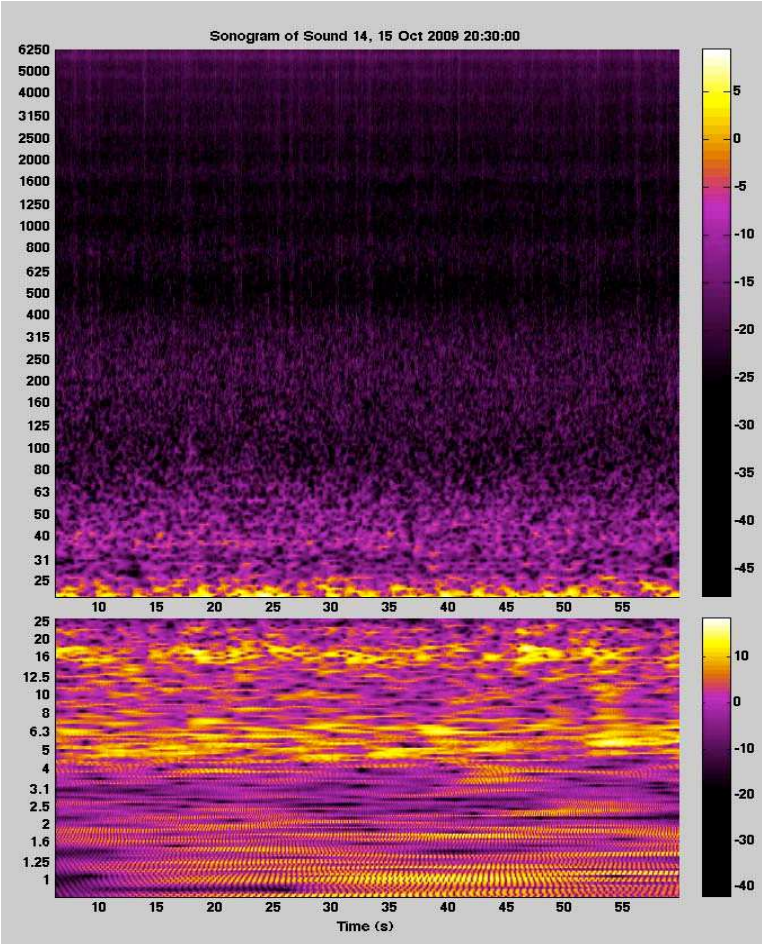


Figure 7: Sound Character at Residence.

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.



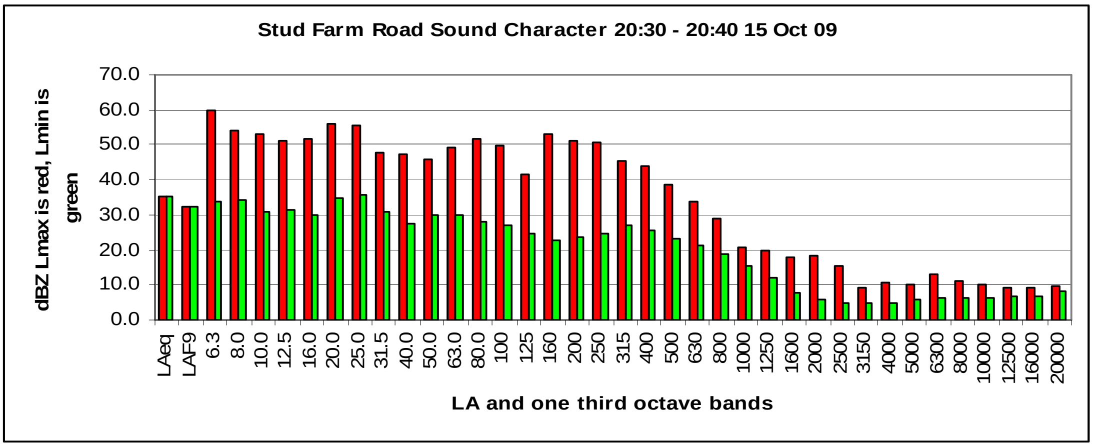
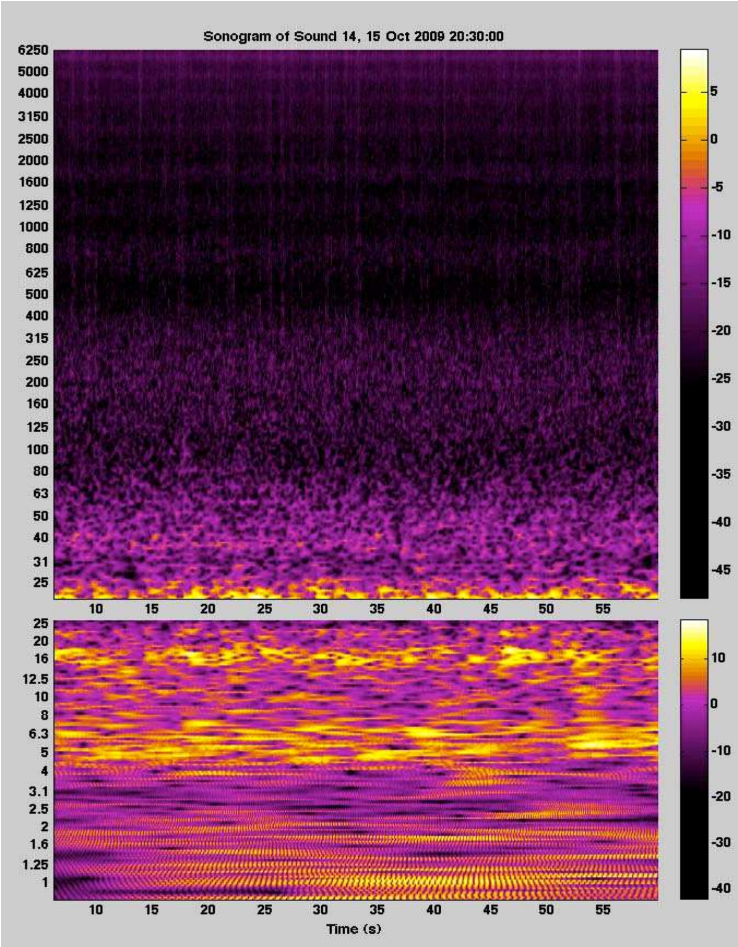


Figure 8: Sound Character at Residence

The audio file identifies 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. Higher frequency content (800-5000 Hz) evident in the third octave band chart is not evident in the sonogram. Low frequency content is evident in both the sonogram and the third octave band chart.



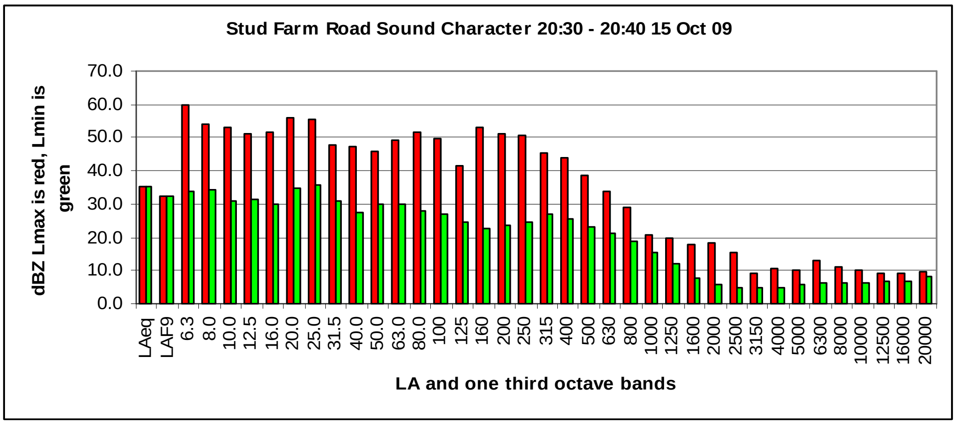
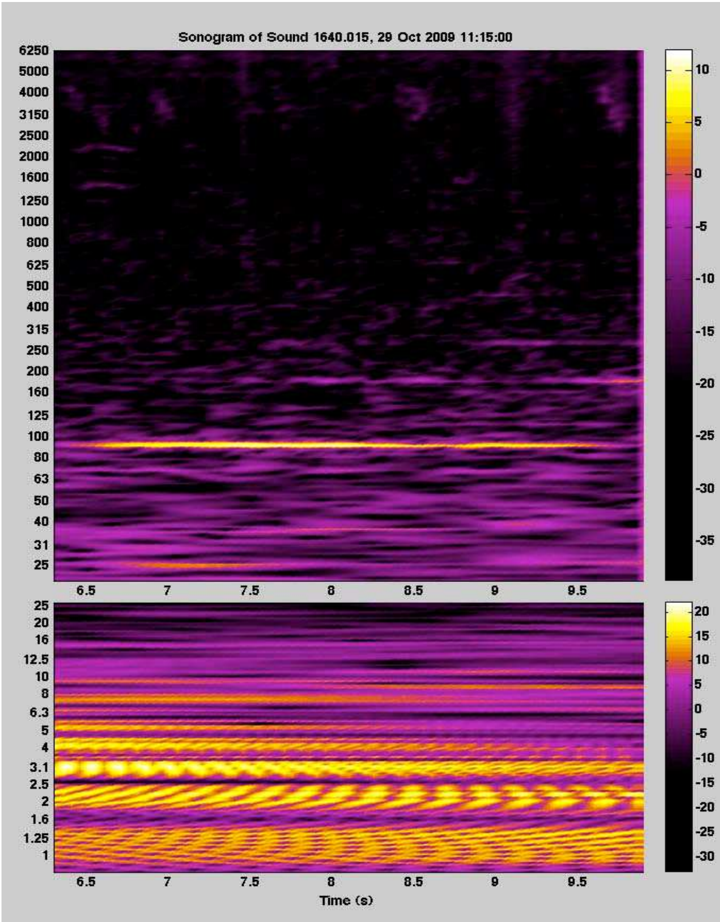


Figure 9: Sound Character at Residence

Wind farm not audible outside residence. The wind pattern is completely different from the previous two sonograms. There is a distinctive 90 Hz tone from an aircraft. Animal and bird noise provide the character. The strong readings at 20 Hz, 16 Hz and 6.3 Hz have gone. The previous regular bands or modulations at around 1 Hz indicate wind turbine blade noise has gone and instead there are smooth bands of sound from "ordinary" wind flow.



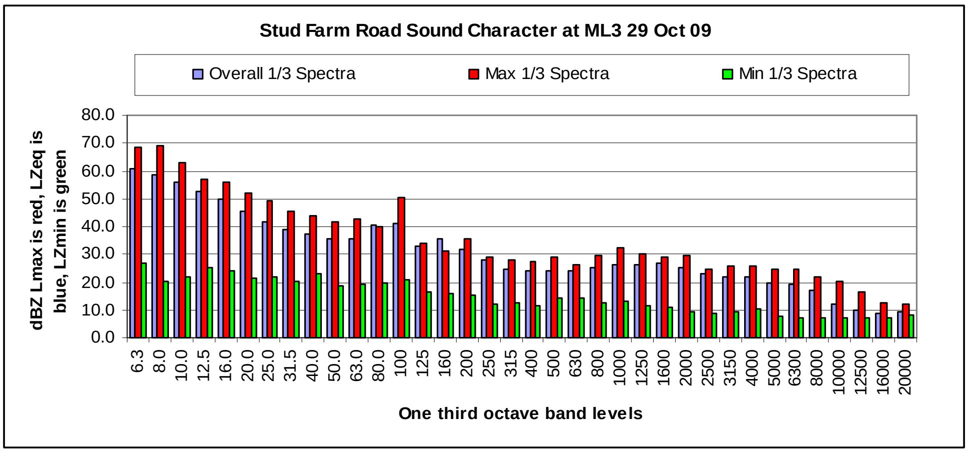
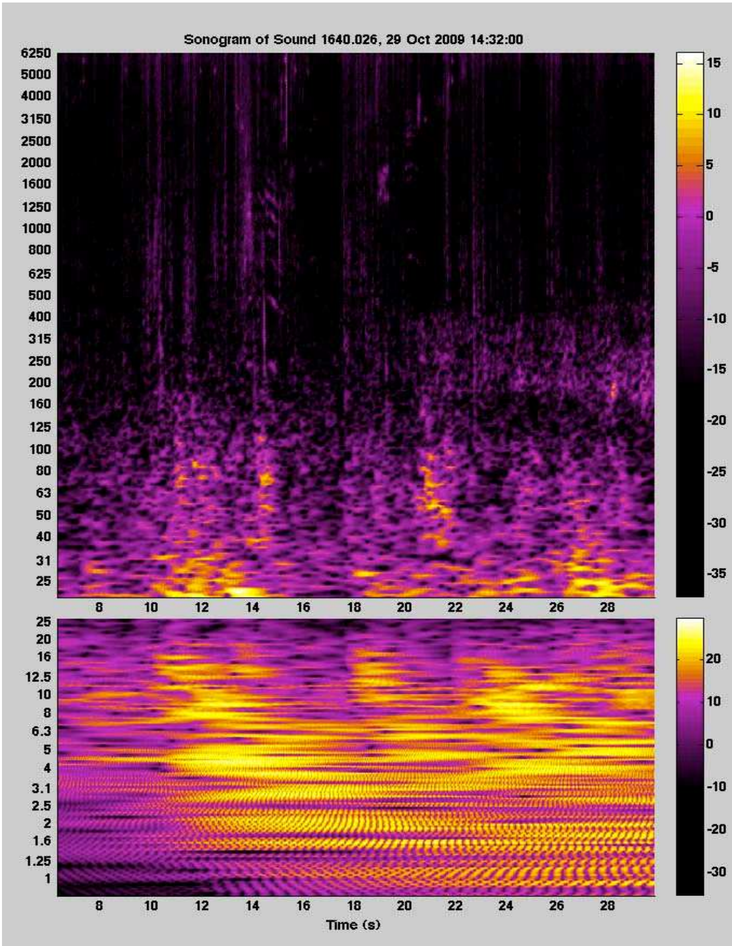


Figure 10: Sound Character between two sets of turbines

The wind farm was audible at the measurement location as a distant rumble and some of the nearest visible turbines approximately 500m to 1500 m distant were moving slowly, as though they were starting up. The sound is similar to an aircraft overhead, although the sound wasn't from a plane. There are strong readings at 20 Hz and below on a regular basis although there was little or no breeze. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass noise.



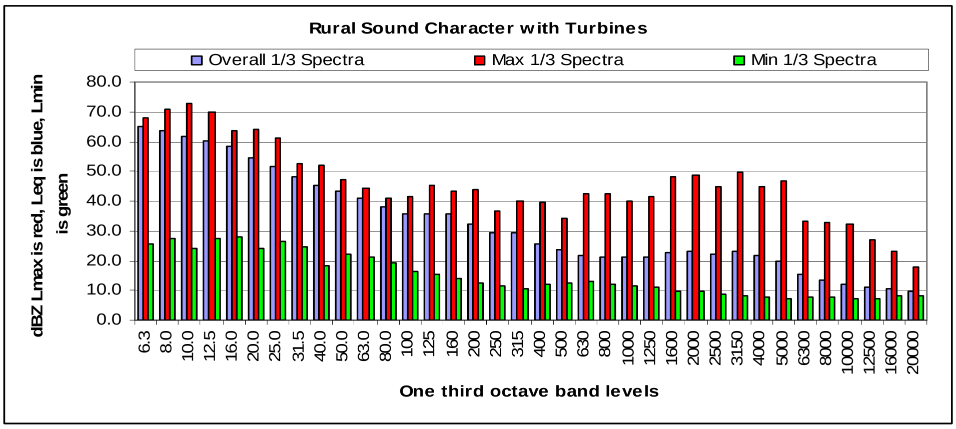
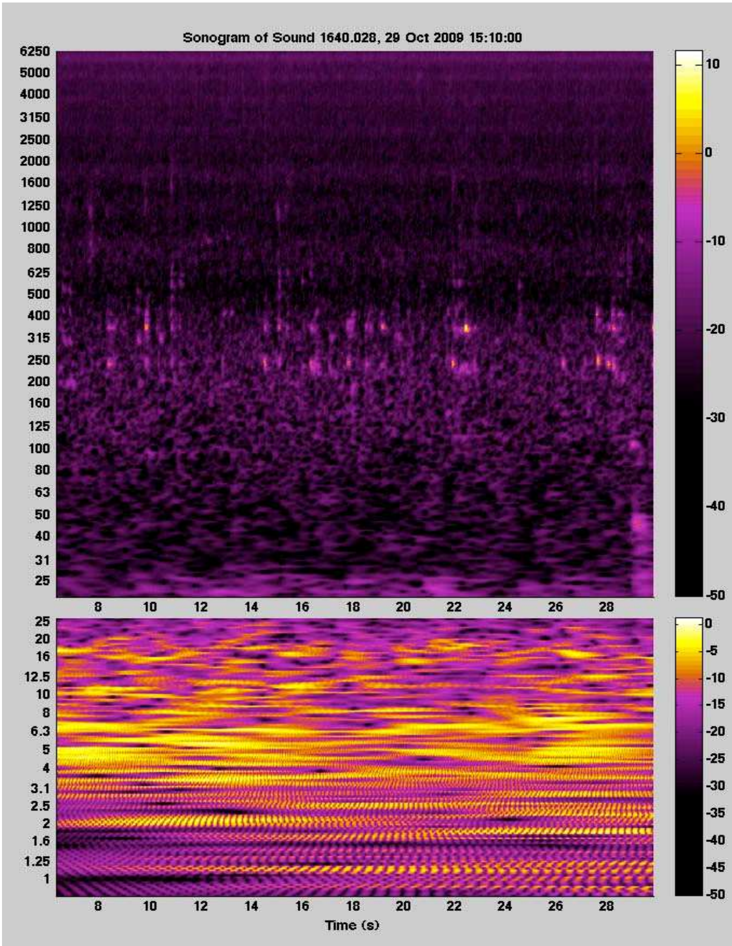
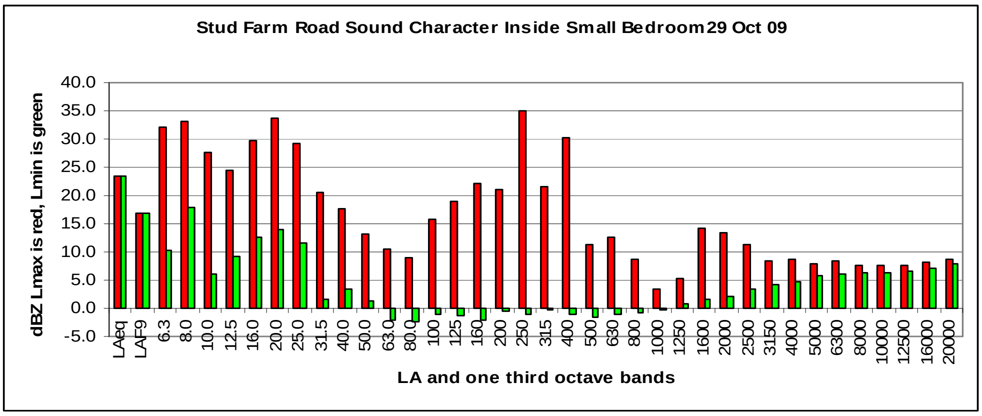


Figure 11: Sound Character Inside Residence

Sound levels measured inside a small bedroom. The audible sound character (200-400Hz) is from distant voices within the house. Wind farm not audible outside residence; turbines to the north turning slowly, turbines to the south not turning. There are strong readings at 20 Hz and below on a regular basis. There was no ground level breeze outside during the recording. There is evidence of normally non-percetible infrasound and audible mid-range frequencies within the bedroom.





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 "LAeq" level it is the energy 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

Internationally the “sound level” is generally taken to be the A-frequency weighted sound pressure level used as a measure of sound. The ‘weighting’ discriminates against sounds below 500 Hz and above 7500 Hz. The ‘Z’ weighting, also called ‘Lin’ or ‘Flat’, is defined by the manufacturer but is generally taken to be ‘flat’ over the frequency range of 20Hz to 20,000 Hz. 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 the 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 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 indentified using sonograms but sonograms are not used in formal compliance processes in Victoria.
- Individuals can easily hear sound levels of 20 dB 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 III - 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[2] 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. A previous study by Pedersen and K. Persson Waye 'Perception and annoyance due to wind turbine noise-a dose-response relationship' (JASA, 116(6) December 2004) presented a comparative sound exposure relationship for wind turbine noise and transportation noise v percent highly annoyed. A later paper by Pedersen, van den Berg, Bakker and Bouma (JASA, 126(2) August 2009) presents a highly detailed report on the response to noise from modern wind farms in The Netherlands. The collected works by Pedersen, Person Waye, van den Berg, Bakker and Bouma present a comprehensive overview and understanding of annoyance and exposure to wind farm noise.

Dr Nina Pierpont MD, PhD, presents a significant body of work relating health effects of wind farm activity. Her work, like Pedersen et al, presents an important body of knowledge that has been extensively peer-reviewed. Dr Pierpont 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."*

---

[2] Pedersen E., 2007, Human response to wind turbine noise: Perception, annoyance and moderating factors, PhD thesis

In his Paper[3] "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)*
>
> *"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[4] 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. He states that 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[5]:

> *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*

[3] Leventhall, G., 2009, Wind Turbine Syndrome – An appraisal"
[4] 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.
[5] Shepherd, D., 2010: 'Wind turbine noise and health in the New Zealand context' available on request from info@noisemeasurement.com.au.

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.

The description of "feeling" rather than hearing the sound is an indication that low frequencies are present. Lower frequencies correspond to the resonating frequencies of our body organs, and in their presence encourage them to vibrate. For example, the head resonates at 20 – 30 Hertz and the abdomen 4 – 8 Hertz. A study examining the chronic effects of low frequency vibration and subsequent psychological and physiological consequence are reported in Table 1 (Rasmussen: Cited in Harry, 2007)[6].

Table 1: psychological and physiological sequelae resulting from low frequency vibration.

Frequency of vibration	Symptoms
4 – 9 Hz	Feelings of discomfort
5 – 7 Hz	Chest pains
10- 18 Hz	Urge to urinate
13- 20 Hz	Head Aches

Dr Shepherd has proposed a simple model demonstrating that, in the rural context, feasible mechanisms exist by which wind turbine exposure can degrade health and wellbeing:

In this scheme turbine noise can lead directly to annoyance and sleep disturbance (i.e. primary health effects), or can induce annoyance by degrading amenity. Additionally, the trait of noise sensitivity constitutes a major risk factor, with annoyance and sleep disturbance the likely mediators between noise sensitivity and health. In relation to secondary health effects, it would be expected that quality of life will be affected immediately, while stress-related disease emerges from chronic annoyance and sleep disturbance over time.

Dr. Hanning founded and ran the Leicester Sleep Disorders Service, one of the longest standing and largest services in the UK until retirement. The University Hospitals of Leicester NHS Trust named the Sleep Laboratory after him as a mark of its esteem. Dr. Hanning[7] 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.

[6] Harry, A. (2007), Wind Turbines, Noise and Health. Retrieved from: http://www.flat-group.co.uk/pdf/wtnoise_health_2007_a_barry.pdf

[7] Hanning 'Wind turbine noise sleep and health', 2010, available from www.windvigilance.com

Dr. Michael M. Nissenbaum, M.D., has conducted a study[8] 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. …*

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[9] 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 summaries 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*

[8] Reported at http://www.wind-watch.org/documents/affidavit-of-dr-michael-m-nissenbaum-m-d/

[9] 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

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

"Wind turbine sound and health effects – An expert panel review".

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.* The 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 Review refutes in total these three conclusions. Peer reviewed evidence is available in the published literature (see the Recommended Reading list) of adverse health effects, identified ground-borne vibration as a possible sound pathway and that the sound from turbines is, in fact, unique. The ACWEA Review has been thoroughly critiqued[10] 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 review 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.*

"Wind Turbines and Health: A Rapid Review of the Evidence".

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 organised in June 2011 a Forum to discuss wind farm issues. The NHMRC report is quoted by people to 'prove' that there are no adverse health effects from wind farms. The review is essentially a literature review of a very small number of reports concerning wind farm noise and the effects on people. The NHMRC states, however, that-

> You have commented on an apparent contradiction between the two NHMRC publications in relation to wind turbines and adverse health outcomes.
>
> As background it may be helpful to provide an explanation on how and why the two products were developed. Initially NHMRC Council wanted to determine whether there was any evidence to support the statement from *Wind Turbines and Health - A Rapid Review of the Scientific Evidence,* that indicated *'There are no direct pathological effects from wind farms and that any potential impact on humans can be minimised by following existing planning reviews'.*
>
> To reach a determination, Council initiated a rapid review of current published scientific evidence on the potential health impacts of infrasound, noise, electromagnetic interference, shadow flicker and blade glint produced by wind turbines. The review concluded that the current available

[10] Wind Energy Industry Acknowledgement of Adverse Health Effects: An analysis of the American/Canadian Wind Energy Association sponsored review. Available at www.windvigilance.com

scientific evidence did support the statement that *'There are no direct pathological effects from wind farms and that any potential impact on humans can be minimised by following existing planning reviews. The findings generated the paper Wind Turbines and Health - A Rapid Review of the Scientific Evidence'.*

However, in acknowledgment of the small body of available evidence, NHMRC developed a Public Statement to provide balance to the initial rapid review outcome. The NHMRC Public Statement clearly notes that because there is not enough robust scientific evidence available:

1. a precautionary approach should be taken
2. research outcomes should continue to be monitored;
3. wind turbine design standards should be complied with;
4. site evaluation should occur to minimise potential impacts; and
5. people who believe they are experiencing health problems should consult their Doctor promptly.

NHMRC does not see the paragraph you have mentioned from Wind Turbines and Health - A Rapid Review of the Evidence as contradictory to the above public statement.

Wind energy is relatively new and therefore very little scientific evidence exists from which to draw a definite conclusion on potential health effects related to wind turbines. The evidence may change as time and experience contribute to the body of knowledge, but based on the literature available at the time NHMRC stands by the findings outlined in both documents.

With regard to your query about planning guidelines, you would need to contact the environmental sector for this material as it is outside the scope of NHMRC activities.

Following this reply independent medical advice was sought and this advice suggests that 'pathological' in the context of wind farm noise has the general meaning of 'indicative or in connection with a disease or disease process'.

IEC wind turbine standard

The identification of audible and perceptible characteristics – and very low frequency noise – is addressed by the standard relating to the certification of wind turbines. 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_{90} or LA_{95}) levels. Emission levels are to be reported as A-weighted LAeq sound levels in one-third octave bands and audibility. Audibility under the wind turbine standard is given as a tone. Annex A, an informative annex to IEC 61400-11, states that:

> *In addition to those characteristics of wind turbine noise described in the main text of this standard, the noise 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.*

World Health Organization Report 2011

The WHO Report 'Burden of disease from environmental noise – Quantification of healthy life years lost in Europe', 2011, is a review of the scientific evidence supporting exposure-response relationships and case studies in calculating burden of disease. The Report has been peer reviewed. The report concludes that:

> There is sufficient evidence from large scale epidemiological studies linking the population's exposure to environmental noise with adverse health effects. Therefore, environmental noise should be considered not only as a cause for nuisance but also a concern for public health and environmental health.

The Report is concerned with the effects of environmental noise in all its facets and does not specifically address potential for noise from wind turbines.

The severity of the relationship between environmental noise, annoyance, sleep disturbance, adverse health effects and disease and number of people affected is summarised in Table 2 derived from Figure 7.1 of the Report:

Table 2: Severity of health effects of noise and number of people affected

Mortality
Disease (sleep disturbance, cardiovascular)
Risk Factors (blood pressure, cholesterol, blood clotting, glucose)
Stress Indicators (autonomous response, stress hormones)
Feelings of Discomfort (annoyance, disturbance)
Number of people affected

The Report considers sleep disturbance and its potential for adverse health effects:

> In 2009, WHO published the *Night Noise Guidelines for Europe*. This publication presented new evidence of the health damage of night-time noise exposure and recommended threshold values that, if breached at night, would threaten health. An annual average night exposure not exceeding 40 dB outdoors is recommended in the Guidelines.

The WHO Europe (2009) 'Night Noise Guidelines for Europe' identifies (Table 3) the effects of outdoor noise on sleep.

- The WHO recognizes the existence of vulnerable groups and acknowledges the existence of individual differences in noise sensitivity.
- Health begins to be degraded between 30 and 40 dB.
- A $L_{night,outside}$ level of 30 dB is the level that can be considered "safe".
- A $L_{night,outside}$ level of 40 dB and above can be considered as the marker for "unsafe".
- The Guidelines are based on a 21 dB noise reduction from outside to inside the residence; a level of 40 dB outside is 19 dB inside
- Supplementary noise indicators (LAmax, sound exposure, etc) may be needed to describe and assess noise for night period protection.

Table 3: WHO Europe (2009) 'Night Noise Guidelines for Europe'.

Average night noise level over a year, $L_{night,outside}$

30 dB $L_{night,outside}$	Although individual sensitivities and circumstances may differ, it appears that up to this level no substantial biological effects are observed.
30–40 dB $L_{night,outside}$	A number of effects on sleep are observed from this range: body movements, awakening, self-reported sleep disturbance, arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (for example children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest. $L_{night,outside}$ of 40 dB is equivalent to the lowest observed adverse effect level (LOAEL) for night noise.
40–55 dB $L_{night,outside}$	Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
>55 dB $L_{night,outside}$	The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed. There is evidence that the risk of cardiovascular disease increases.

The WHO's Night Noise Guidelines noise metric used, ($L_{night,\ outside}$), is referenced to the European Environmental Noise Directive (2002/49/EC) with a target of 40 dB ($L_{night,\ outside}$) to protect the public, including the most vulnerable groups such as children, the chronically ill and the elderly. 'Lnight' is the A-weighted long-term average sound level determined over all nights of the year. Night is defined as 23.00 to 0700 hours. Unlike the Lden assessment, following, there is no 'penalty' added for noise at night.

Annoyance criteria, as distinct from the 'sleep' criteria of Table 3, has a different night-time sound level derived from the measured LAeq sound level <u>plus a penalty of 10 dB in the Lden equation</u>:

$$L_{den} = 10\lg\frac{1}{24}\left(12*10^{\frac{L_{day}}{10}} + 4*10^{\frac{L_{evening}+5}{10}} + 8*10^{\frac{L_{night}+10}{10}}\right)$$

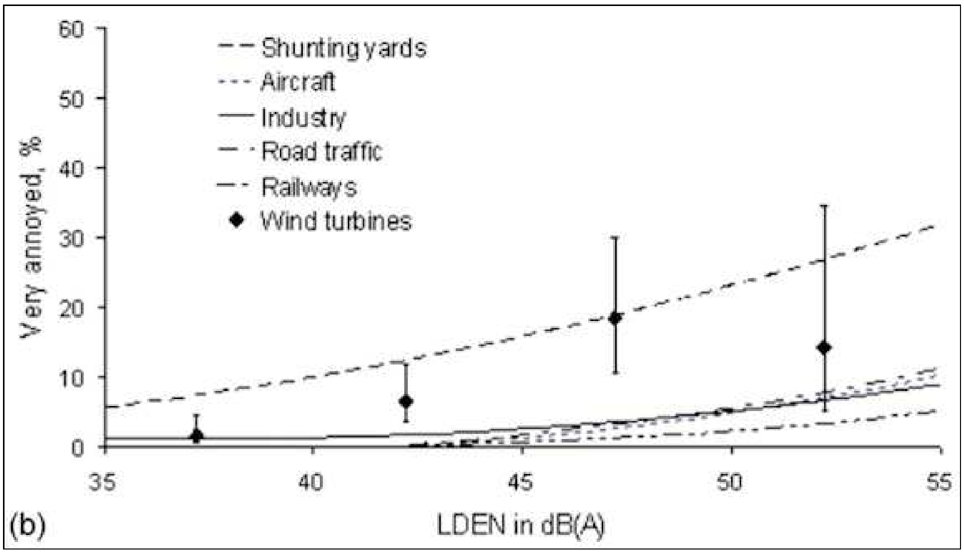
Calculating Lden values from LAeq (24hr)

A night-time level of 40 dB(A) is a measured level of 30 dB(A) plus a penalty of 10 dB.

(a) a constant LAeq 'level' of 35 dB(A) over 24 hours is a Lden value of 41.4 dB(A).

(b) a constant LAeq 'level' of 40 dB(A) over 24 hours is a Lden value of 46.4 dB(A).

The potential for annoyance is additional to the potential for sleep disturbance and is described in the paper 'Response to noise from modern wind farms in The Netherlands' by Pedersen et al.[11] The levels of 41 and 46 Lden have an indicative 'very annoyed' rating of approximately 10-11% and 16-18% respectively, a significant effect that is more than minor.



The relationship between transportation noise annoyance and wind turbine noise annoyance are still being developed. The use of the various reltionships must, therefore, be treated with caution.

Conclusions

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

Considerable research is needed, however, to test the various hypotheses and assessment methods outlined in this Review.

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[11] Pedersen, E, van den Berg, F, Bakker, R, and Bouma J. 2009. Response to noise from modern wind farms in the Netherlands. J. Acoust. Soc. Am. 126 (2) August 2009. pp 634-643

PART IV - WIND TURBINE SOUND

Basic Measures

Sound can be measured in many different ways. The most commonly used measure of environmental sound 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 Review. 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. If extraneous noise is included in the wind turbine measurement its contribution to the overall level must be determined.

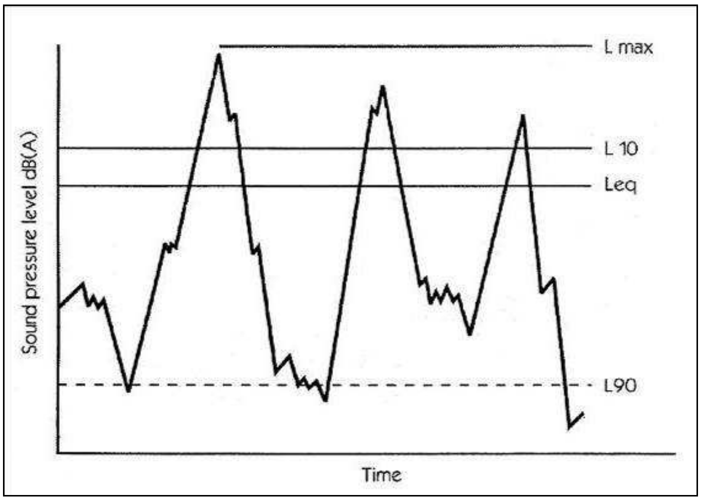

Figure 1: Chart showing different noise descriptors

The A-frequency weighted sound pressure level or "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.

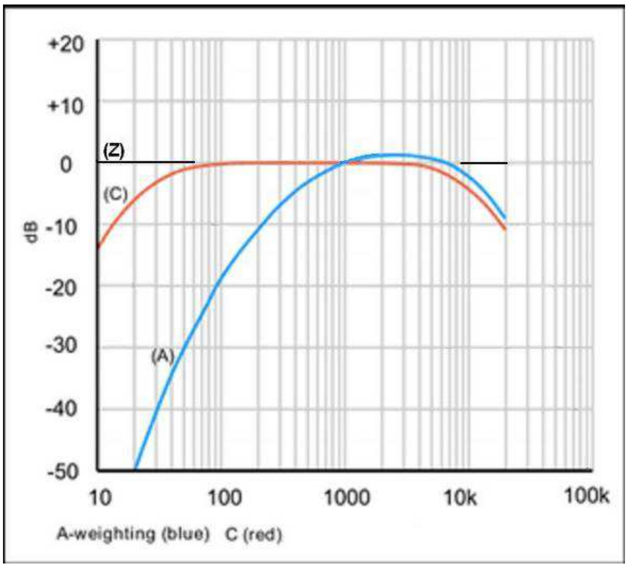

Figure 2: Sound weighting responses

Sound emissions from modern wind turbines are primarily due to turbulent flow and trailing edge sound, blade characteristics, blade/tower interaction, mechanical sound and variations in infrasound (air pressure variations). The sound can be characterised as being audible and inaudible (infrasonic), of an impulsive or broadband nature, with tonality or complex tones and modulation:

- · Infrasound below 20 Hz (perceptible, normally inaudible)
- · 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.

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:

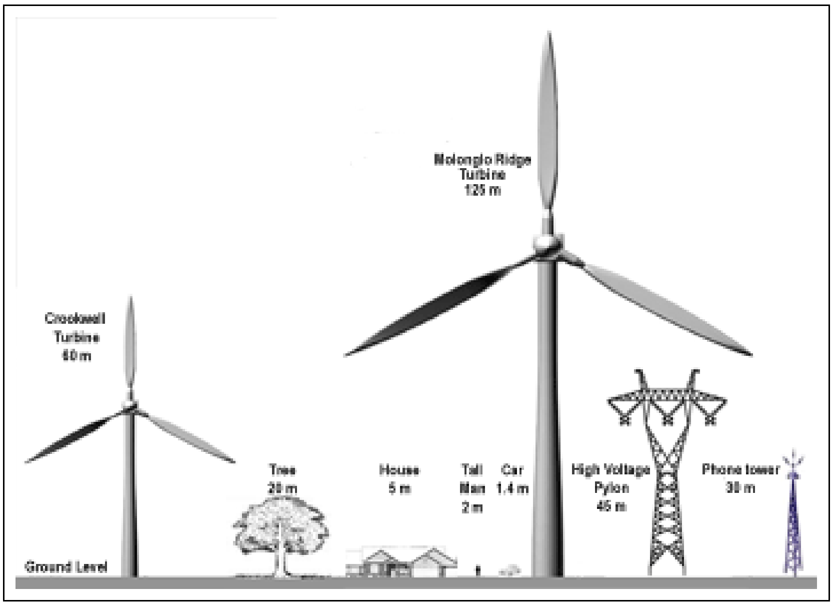

Figure 3: Relative heights of turbines to dwellings
(Source: Molonglo Landscape Guardians, by permission)

Technically, most newly installed 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[12]:

> *“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.

[12] Hubbard H. H., Shepherd K. P., (1990), Wind Turbine Acoustics, NASA Technical Paper 3057 DOE/NASA/20320-77, p19

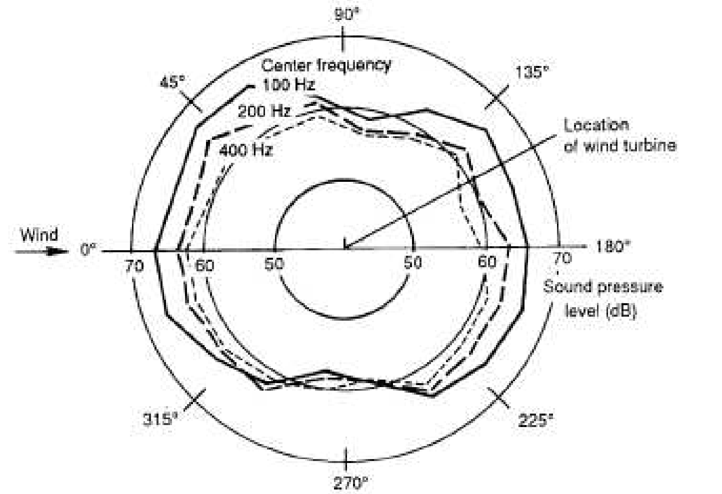

Figure 7-7. Example radiation patterns for broadband noise 200 m from a large-scale HAWT (one-third-octave bands, wind speed = 12.1 m/s, power = 2050 kW) [Shepherd, Willshire, and Hubbard 1988]

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[13] 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:

[13] Shepherd, K. P., and Hubbard, H. H., (1986). Prediction of Far Field Noise from Wind Energy Farms. NASA Contractor Report 177956.

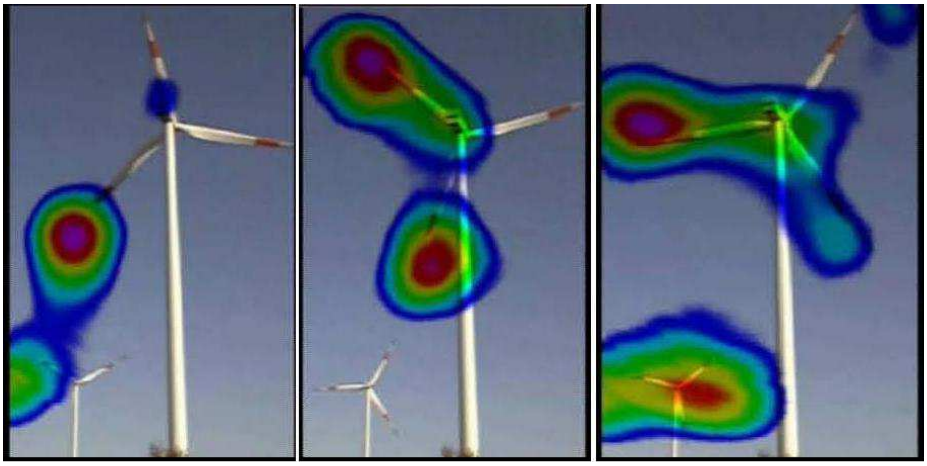

Figure 5: Acoustic photograph of sound sources from two turbines.
Source: Acoustic Camera, 'Multiple sources wind turbines 300Hz – 7kHz.avi" by permission from HW Technologies, Sydney)

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. The measurements are taken at approximately 150 metres behind the turbine. Frequencies below 300Hz can also be measured.

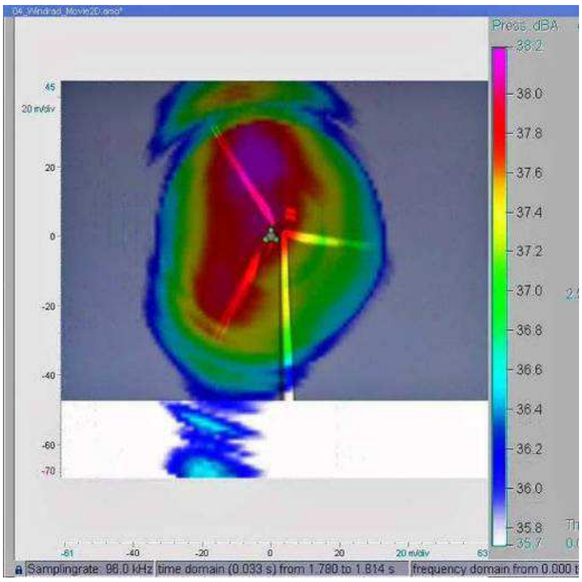

Figure 6: Acoustic photograph of sound sources from a turbine.
Source: Acoustic Camera, by permission from HW Technologies, Sydney)

Wake and turbulence effects have a considerable influence on sound propagation. The effects are created (figure 7) 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.

Figure 7: **Horns Rev 1 Offshore Wind Farm**
'Aeolus' turbulence behind the Horns Rev1 wind farm under very humid conditions, 12 February 2008 at 1300hrs. Photographer Christian Steiness

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 vortexes 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 vortexes and the greater the interaction between the vortexes shed by adjacent wind turbines.

An effect that enhances potential noise is observed by van den Berg[14] 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

[14] 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

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 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"[15] 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."*

[15] DTI (UK), 2006, The measurement of low frequency noise at three UK wind farms.

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

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 using A-weighted measures.
- 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.

The technical nature of a wind turbine in a wind field is very clearly presented on the Danish Wind Industry Association website[16]. Much of the content has not been updated since 2003, however, and does not address current health issues. A practical current acoustical – noise management guidelines to wind farm design to prevent health risks is presented by Kamperman and James[17].

Low frequency sound and Infrasound

The issue of low frequency sound and infrasound has been a controversial topic for many years. Figures 8 and 9 illustrate audible sound as well as both low frequency and infrasound as heard inside a bedroom approximately 930 metres from a set of wind turbines. The modulating character of the sound is clearly defined in the first 5 seconds as a pattern of 3 spikes. The chart shows that low levels of sound are clearly audible inside a dwelling.

[16] http://www.windpower.org/en/knowledge/guided_tour.html
[17] http://www.wind-watch.org/documents/simple-guideliness-for-siting-wind-turbines-to-prevent-health-risks/

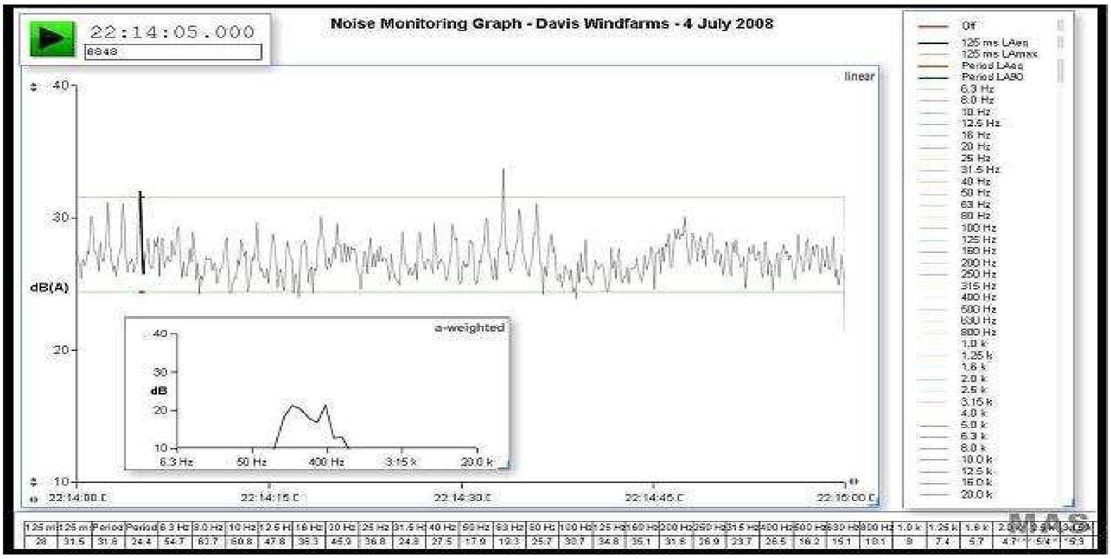

Figure 8: sound of wind turbines at 930 metres, inside residence

Figure 9 illustrates sound character inside the bedroom. The interior level for the 60 seconds is LAeq 31.6 dB. There are clear and distinctive audible, low frequency and infrasound levels.

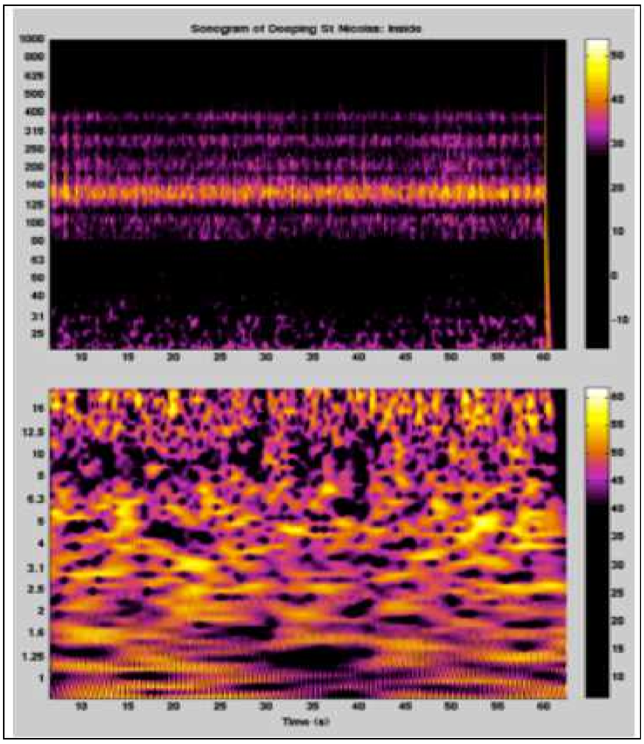

Figure 9: sound of wind turbines at 930 metres, inside residence

The sound character at 2200 metres from a wind farm with large 2MW to 3MW turbines is shown in figure 10. The turbines are not audible in sonogram (figure 11).

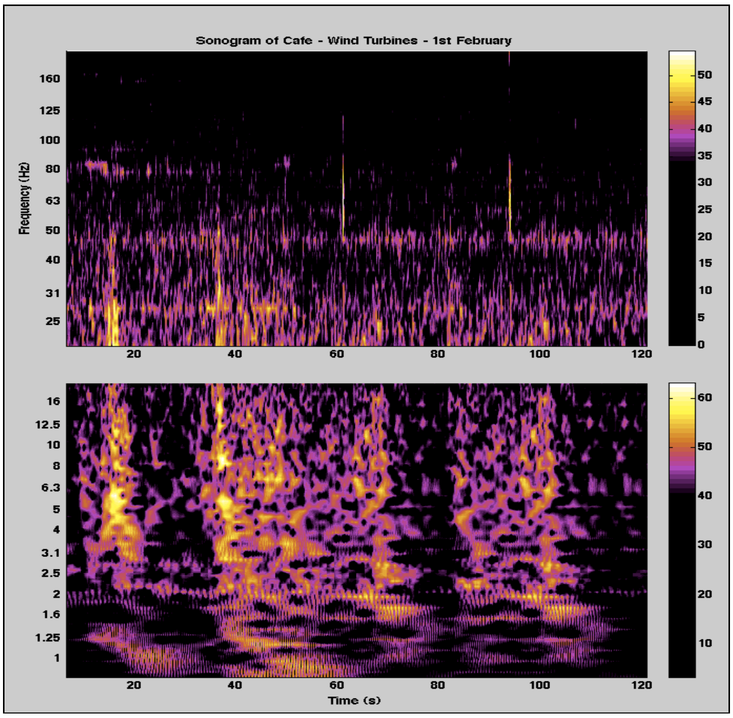

Figure 10: Audible sound of wind farm at 2200 metres over grassland and trees

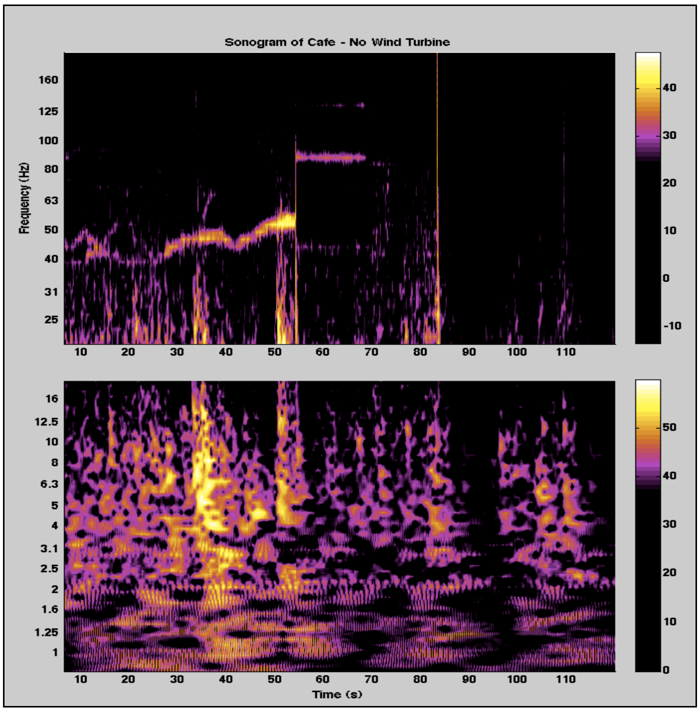

Figure 11: Same location as figure 4 but wind farm not audible

The sound levels for the rural area (figure 5) were LAeq 40 dB and a background level (LA90) of 32 dB. Without the turbine sounds (figure 6) the levels had increased to LAeq 49 dB and a background level (LA90) of 33 dB 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.

A simultaneous survey of exterior and interior ambient levels for a residence at Makara is given in figures 12 and 13. The exterior sound level was 30 dB LAeq and 29 dB L90. The interior level was 18 dB 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. In figures 12 and 13 the difference in character between outside and inside levels are clearly shown. The variation is due to building construction and room resonance.

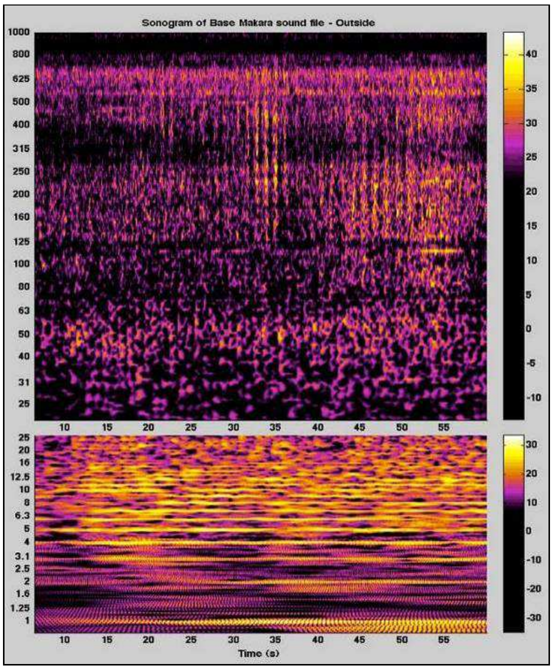

Figure 12: sound of wind turbines at 1200 - 1300 metres, outside residence

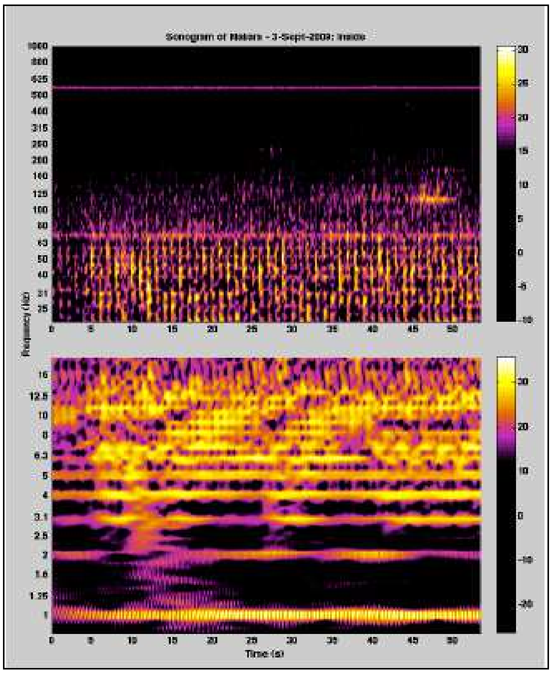

Figure 13: sound of wind turbines at 1200 -1300 metres, inside residence

Heightened Noise Zones

The concept of Heightened Noise Zones[18] created when multiple wind turbines are in operation is presented. The concept is presented to illustrate the complexity of sound from a known wind farm at Makara near Wellington New Zealand. Analysis of the turbine layout indicates wind turbines installed in straight and vee-formations. The potential effect of these formations at affected residences is to enhance

[18] From research by Astute Engineering, Palmerston North, New Zealand, by permission

sound emissions and propagation due to the additive effects of turbines operating more or less together. The effect is significant under adverse weather conditions and not significant under different non-adverse weather conditions. Multiple turbines present a cumulative effect and complex propagation effect that is observed in practice as a typical beating or modulating sound. Figure 14 illustrates the situation at Makara where at least one turbine is causing a low rumbling sound that is clearly audible outside the affected residence during the day and at night 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.

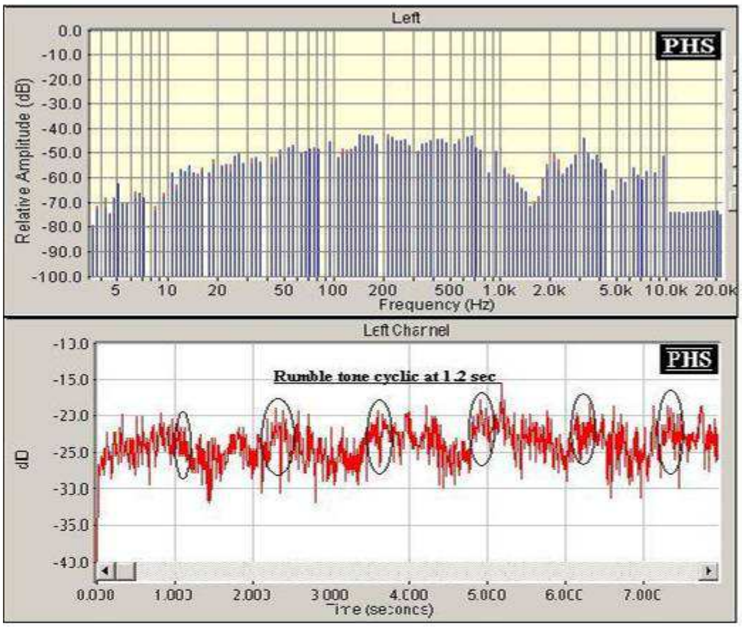

Figure 14: Turbine rumble

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 15 to 19 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.

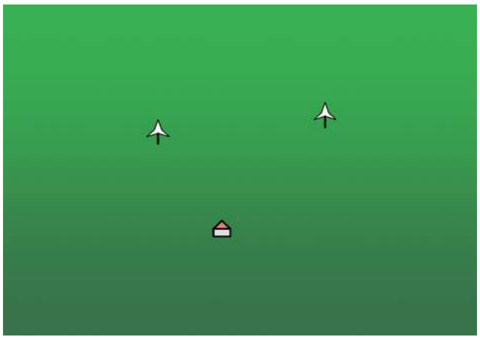

Figure 15: A residence potentially affected by 2 turbines

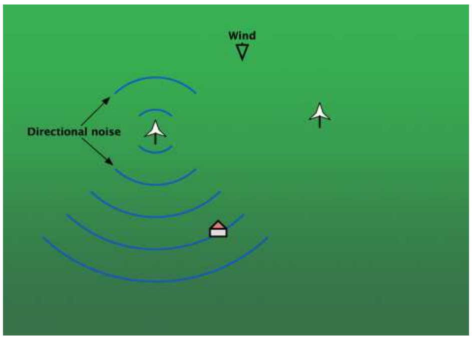

Figure 16: Noise from one turbine

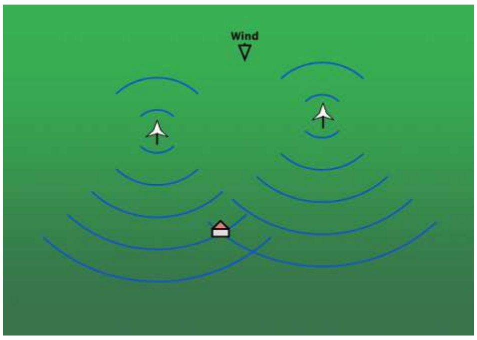

Figure 17: Noise from 2 turbines

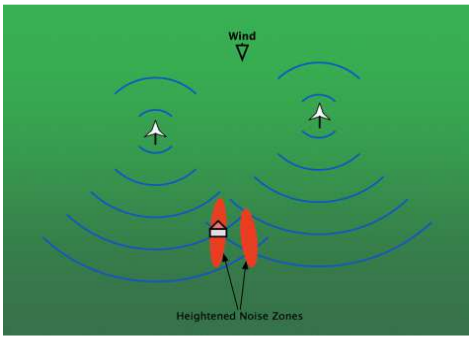

Figure 18: Noise from 2 turbines creating Heightened Noise Zones

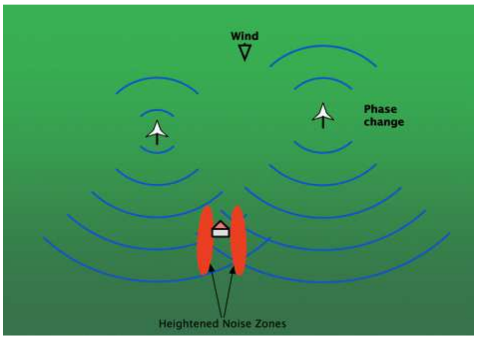

Figure 19: Noise from 2 turbines under slightly different conditions moving Heightened Noise Zones

The attributes of Heightened Noise Zones – small size and dependence on time-related factors like wind direction – help to explain the variability of wind farm noise 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 20 shows the spacings at Makara, New Zealand, from which the Heightened Noise Zone concept was derived. 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.

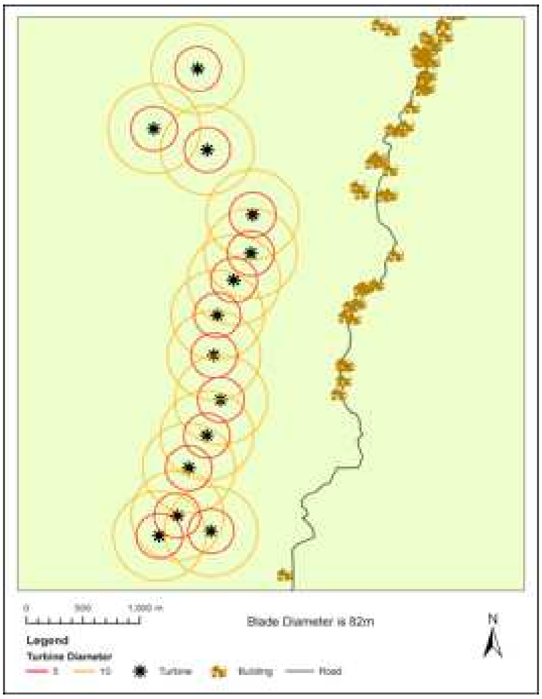

Figure 20: Wind turbines at Makara showing their spacing with regard to 5 and10 blade-diameter circles. *Source: Research graphics by S. R. Summers.*

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 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.

A simulation is presented in Figures 21 to 23 to envisage the sound amplitudes and sound propagation - dispersion patterns from the turbines at Makara. This is a very simple simulation and must be taken as being illustrative only of potential effects). A single turbine is shown in Figure 21. The peaks and troughs from the inter-action of the blades and tower are shown as clean, radiating waves. Figure 22 illustrates the highly complex propagation pattern at a residence with five turbines in a line (vee formation in Figure 23) operating approximately 1200 -1300 metres distant. The node/antinode (read quiet/loud) points vary but can be about 4 metres apart. The maximum levels reach about more than 4 times the level of one turbine. Figures 21 to 23 present a simple simulation and would be much more complex if geography etc. was included. The simulations were created to test the effects of low frequency sound using 20 Hz, 48 Hz and 66 Hz bands.

Figures 24 and 25 present the effect of one turbine and 5 turbines to illustrate the difference between a single source and the cumulative effect of multiple sources.

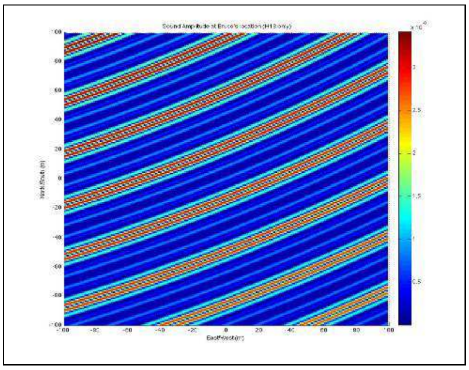

Figure 21: Propagation pattern from a single turbine

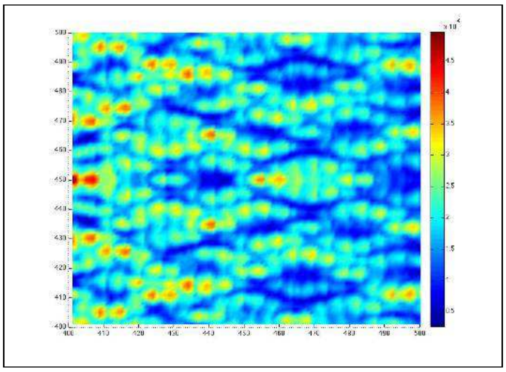

Figure 22: Propagation pattern from 5 turbines in a line formation

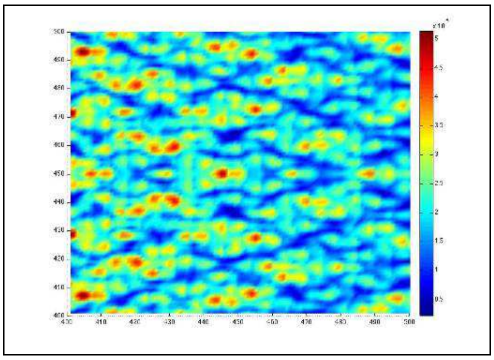

Figure 23: Propagation pattern from 5 turbines in a vee formation

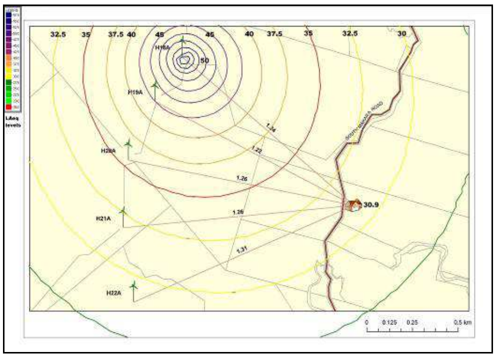

Figure 24: one turbine operating, sound level contours and predicted sound level at a residence

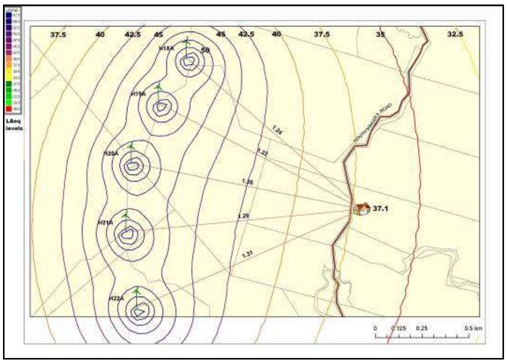

Figure 25: five turbines operating, sound level contours and predicted sound level at a residence

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.

PART V - PREDICTION OF SOUND LEVELS – APPROACHES AND LIMITATIONS

The prediction of wind farm sound levels is most often referenced to national or international standards that have been based on ISO 9613-2 *Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation.* The propagation method is calculated with the receivers being downwind from the noise source(s). The long-term average A-weighted sound level L_{fT}(DW) at the receiver is calculated from:

$$L_{fT}(DW) = L_W + D_C - A \qquad \text{(eqn 1)}$$

Where L_W is the octave band sound power level (LAeq)
D_C is the directivity correction
A is octave band attenuation, source to receiver

Attenuation is given in the standard as $A = A_{div} + A_{atm} + A_{gr} + A_{bar} + A_{misc.}$ The first four terms, attenuation due to geometrical divergence, atmospheric absorption, ground effect and barriers are detailed in the standard. The method is referenced to spherical spreading in a free field. Guidance is given for the final 'miscellaneous' term for propagation through housing, foliage and industrial sites.

All prediction models have uncertainty 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 ±5 dB while a calibrated model has an accuracy of ±2 dB. 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).

The method holds for wind speeds of between approximately 1 m/s and 5 m/s, measured at a height of 3 m to 11 m above the ground. Wind turbines are sound sources that operate at higher wind speeds than allowed for under the standard. ISO 9613-2 states that the average propagation equation of the standard holds for downwind propagation or under well developed moderate ground based temperature inversion such as commonly occurs on a calm, clear night. The standard refers to the calculation conditions under ISO 1996-2: 1987. The relevant conditions, however, are quite different as detailed in ISO 1996-2:2007[19]. Note 24 to ISO 9613-2 provides-

[19] ISO 1996-2:2007 Acoustics-Description, measurement and assessment of environmental noise-Part 2: Determination of environmental noise levels, 2nd edition

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 Table 5 has an estimated accuracy for broadband noise of ±3 dB at between 100 and 1000 metres.

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:

- ±3dB 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 ±5 dB is a more conservative (i.e. cautious) approach to wind farm noise prediction.

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 (30, 35, 40, for example) are calculated on “grids” over the whole of the locality. The sound levels calculated are the A-weighted equivalent energy / time average sound levels. Thus it is possible to graphically present the potential average long-term predicted sound level as well as short-term potential variations due to variable weather conditions and turbine placement. This approach allows detailed assessment of the potentially affected residential community living near the turbines.

The potential sound levels from 3 different combinations of turbines is presented in **Plate 1.** The sound levels from the turbines are predicted using ISO 9613-2 at distances of 1000m, 2000m and 3000m.

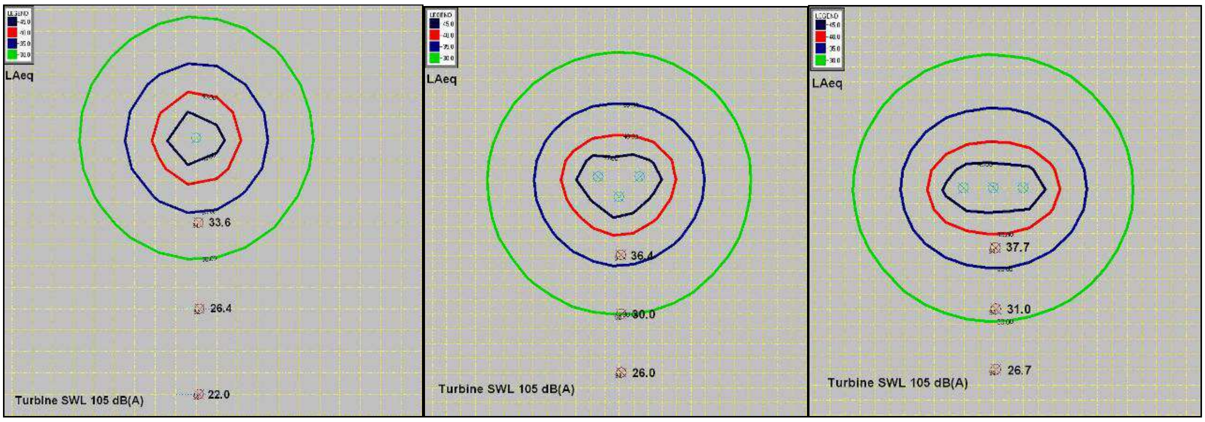

Plate 1: predicted LAeq sound levels at distances of 1000m, 2000m and 3000m.

How a wind turbine interacts with its environment and the factors that influence sound propagation may be found on the Danish Wind Industry website[20] and the large wind turbine research publications on the DELTA[21] website.

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.

Consideration of Variable Wind Conditions

This section is to provide a very brief overview of how a wind turbine interacts with its environment and the factors that influence sound propagation. Far more information may be found on the Danish Wind Industry website and the CSIRO Wind Energy Research Unit[22] .

[20] http://www.windpower.org/en/knowledge/guided_tour.html
[21] http://www.madebydelta.com and then search 'large wind turbines'
[22] Coppin, P.A., Ayotte, K.A., Steggel, N. 2003. Wind Resource Assessment in Australia – A Planners Guide. CSIRO Wind Energy Research Unit.

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) and at potentially affected residences 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, a much weaker correlation between observed sound levels and the wind speeds at 10 metres above ground was observed. 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.

A common way of siting wind turbines is to place them on hills or ridges overlooking the surrounding landscape. It is always an advantage to have as wide a view as possible in the prevailing wind direction in the area. On hills wind speeds are higher than in the surrounding area. This is due to the fact that the wind becomes compressed on the windy side of the hill, and once the air reaches the ridge it can expand again as its moves down into the low pressure area on the lee side of the hill. If the hill is steep or has an uneven surface, the turbine may be affected by significant amounts of turbulence which may negate the advantage of higher wind speeds.

The purpose of a wind turbine is to extract energy from the force of the wind and convert this wind energy into electrical energy. Speaking generally, turbines start operating when the wind speed measured at hub height is around 4 m/s and shuts down at some higher wind speed, say 15 m/s. A turbine power curve will give the turbine power output vs wind speed. The curves will often present the A-weighted sound power level at the different wind speeds. Different turbines have different cut-in and stop wind speeds. The kinetic energy in the wind thus depends on the density of the air; the "heavier" the air, the more energy is received by the turbine. Air is more dense when it is cold than when it is warm. The wind speed is extremely important for the amount of energy a wind turbine can convert to electricity: the energy content of the wind varies with the cube (the third power) of the average wind speed, e.g. if the wind speed is twice as high it contains 8 times as much energy.

A wind turbine will deflect the wind before the wind reaches the rotor plane (blades). It is not possible to capture all of the energy in the wind using a wind turbine. The wind turbine rotor must obviously slow down the wind as it captures its kinetic energy and converts it into rotational energy. The wind will be moving more slowly after leaving the rotor than before reaching the rotor. Since the amount of air entering through the swept rotor area (every second) must be the same as the amount of air leaving the rotor area, the air will have to occupy a larger cross section (diameter) behind the rotor plane. The wind will not be slowed down to its final speed immediately behind the rotor plane. The slowdown will happen gradually behind the rotor, until the speed becomes almost constant. Moving farther downstream the turbulence in the wind will cause the slow wind behind the rotor to mix with the faster moving wind from the surrounding area. There will be a wake behind the turbine, i.e. a long trail of wind which is quite turbulent slowed down, when compared to the wind arriving in front of the turbine. Wind turbines in wind farms are usually spaced in order to avoid too much turbulence around the turbines downstream. As a rule of thumb, turbines in wind parks are usually spaced somewhere between 5 and 8 rotor diameters apart (front-to-rear) in the prevailing wind direction, and between 3 and 5 diameters apart (side-by-side) in the direction perpendicular to the prevailing winds.

In general, the more pronounced the roughness of the earth's surface, the more the wind will be slowed down. Forests and large cities obviously slow the wind down considerably, while concrete runways in airports will only slow the wind down a little. Water surfaces are even smoother than concrete runways, and will have even less influence on the wind, while long grass and shrubs and bushes will slow the wind down considerably. A sea surface is in roughness class 0. Flat, open landscape which has been grazed by sheep has a roughness class 0.5. A high roughness class of 3 to 4 refers to landscapes with many trees and buildings. The roughness may also be expressed as a distance. A roughness length of 0.055 metres has a roughness class of 1.5 and is referenced to “Agricultural land with some houses and 8 metre tall sheltering hedgerows with a distance of approx. 1250 metres”. This is a common value for rural wind farms.

Obstacles will decrease the wind speed downstream from the obstacle. The decrease in wind speed depends on the porosity of the obstacle, i.e. how "open" the obstacle is. (Porosity is defined as the open area divided by the total area of the object facing the wind). A building is obviously solid, and has no porosity, whereas a fairly open tree in winter (with no leaves) may let more than half of the wind through. In summer, however, the foliage may be very dense, so as to make the porosity less than, say one third. The slowdown effect on the wind from an obstacle increases with the height and length of the obstacle. The effect is obviously more pronounced close to the obstacle, and close to the ground.

Wind moving across the ground surface is slowed by trees, buildings, grass, rocks, and other obstructions in its path. The result is a wind velocity that varies with height above the surface – a phenomena known as wind shear. For most situations, wind shear is positive (wind speed increases with height), but situations in which the wind shear is negative or inverse are not unusual. The increase in wind speed with height only holds true for the height above the effective ground level. Wind shear, sometimes referred to as wind gradient is a difference in wind speed and direction over a relatively short distance in the atmosphere. A wind shear graph shows how wind speeds vary at different heights based on the roughness class of the environment surrounding the wind turbine. The wind profile is twisted towards a lower speed closer to ground level. This is important for large wind turbines as there are different wind speeds affecting the rotor. For example, a wind turbine with a hub height of 40 metres and a rotor diameter of 40 metres with a wind blowing at 9.3 m/s when the tip of the blade is in its uppermost position has only 7.7 m/s when the tip is in the bottom position. This means that the forces acting on the rotor blade when it is in its top position are far larger than when it is in its bottom position. It also means that the wind moving past the rotor and tower have different wind speeds and so develop wake turbulence.

Associated with wind shear is trailing edge sound emission and modulation. The calculation method is based on the thesis by Fritz van den Berg (2006) using data for the Vestas V90 turbine. It assumes the most sensitive atmospheric condition of a very stable atmosphere and nominal windspeed (15m/s). The calculation is for sound from trailing edge (TE) created sound or “swish”. The level of aerodynamic wind turbine noise depends on the angle of attack: the angle between the blade and the incoming air flow. Of the three factors (wind velocity gradient, wind direction gradient and reduced large scale turbulence) influencing blade swish, the largest effect comes from the wind speed gradient. That is, the changes in wind speed. For a 80 metre hub height and a wind speed of 12 m/s the difference in swish level is 2 dB between a 46m blade and a 51m blade (the longer blade has more swish).

Consideration of ‘Stand-Off distances between Turbines and Residents’.

The following approach (Thorne & David, Conference Paper 2013) to establish / predict stand-off distances between turbines and residents’ is based on the formulation that adverse health effects are related to a time exposure of sound level and/or vibration level above a given threshold leading to annoyance and health effects. It is postulated that such adverse effects are associated with a level above the detection threshold in a similar way that the temporary threshold shift leads eventually to a permanent threshold shift. This mechanism is very different for a single tone compared to broadband tonality. The condition for an adverse health effect (*AHE*) is an exposure for a given duration of a received sound level and/or vibration level that is above the threshold of sensitivity, Eq. (1):

$$AHE = \int_0^t \text{humansensitivity}\left(sound\ pressure\ level, vibration\right) \qquad (1)$$

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

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

Where *N* is the number of wind turbines

i denotes that the term applies to the *i*th turbine

B is the blade size (m)

Spacing is the distance between wind turbines

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

distance is the distance (m) from turbine to receiver

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

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

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

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

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

Where *N* is the number of wind turbines

i denotes that the term applies to the *i*th turbine

B is the blade size (m)

spacing is the distance between wind turbines

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

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

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

The above equations present the methodology proposed to determine noise stand-off distances from a wind farm. The human sensitivity component of the equation in (1) is described in terms of thresholds at infrasonic and low frequencies. The linkage between adverse health effects and infrasound from wind turbines have not been scientifically established and infrasound thresholds associated with these effects are not determined, consequently the prediction method proposed is for discussion purposes.

Taking into account anecdotal information and field studies the following available data was gathered to assess vibro-acoustic energy for low frequency and infrasound: (a) maximum levels for human exposure, (b) audiology thresholds of detection, (c) annoyance thresholds, (d) thresholds of physiological effect, (e) thresholds of pain, and (f) equaphone curve for very low frequencies. With this information, thresholds for detection of low frequency and infrasound, annoyance and physiological effects are proposed by means of "stand-off distances"; that is, the prediction of minimum distances between turbines and people. The interactions of several wind turbines will result in complex sound fields given the different effects involved such as harmonics generations, directivity of the sound field, difference in rotational speed between wind turbine, interference, beating effects and modulation may result. The diurnal effect temperature inversion, variability in wind speed, will add to the complexity in the assessment of the impact of low frequency and infrasound. Modulation of low-and infrasonic frequencies is influenced by the interaction of several wind turbines.

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

Plates 2 and 3 show the onset of the effect 5dB below the reported data until those thresholds are reassessed and confirmed on a larger population sample. Figure 3 shows that the onset of annoyance for the frequency range from 20Hz to 30 Hz is expected to be about 75 dB and that for the given sound power level of 120 dB at the corresponding frequency range and the corresponding propagation slopes, the 75 dB received level at those frequencies are expected between 1300m to 4400m. Using a similar approach the received sound pressure level of 85 dB linear at frequencies ranging from 20Hz to 30 Hz would intersect the propagation slopes for those frequencies at distances ranging from 280m to 750m. The distances of 280m to 750m would correspond to the expected onset of physiological effects.

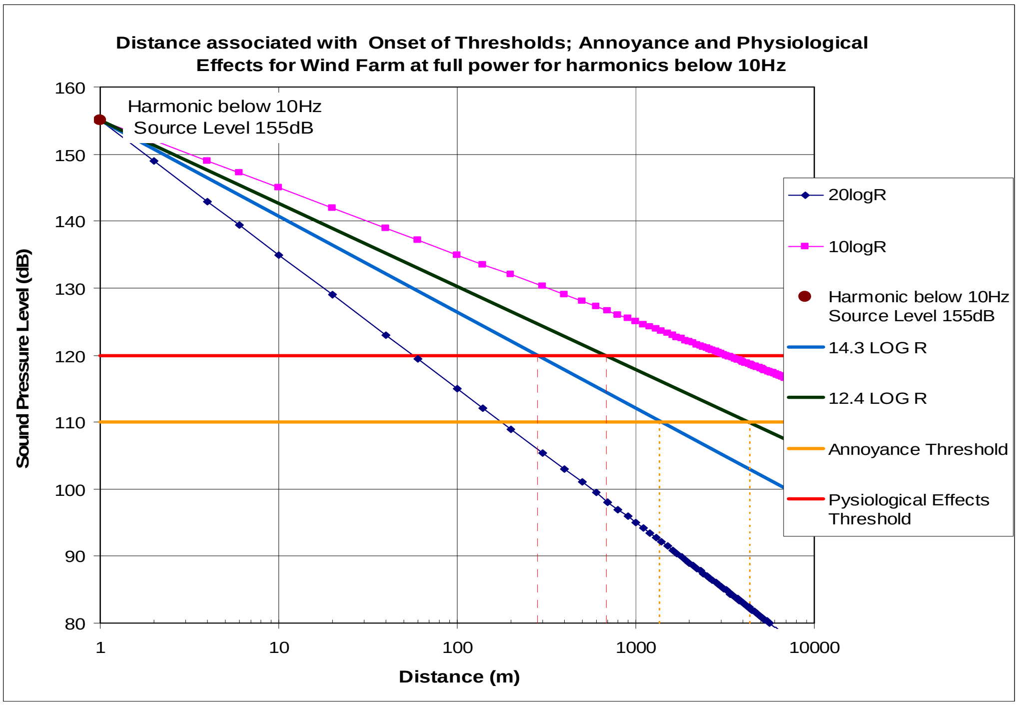

Plate 2. Distance for which the threshold of annoyance and physiological effects threshold are anticipated for one wind turbine generating a source level of 120dB in the frequencies below 10Hz.

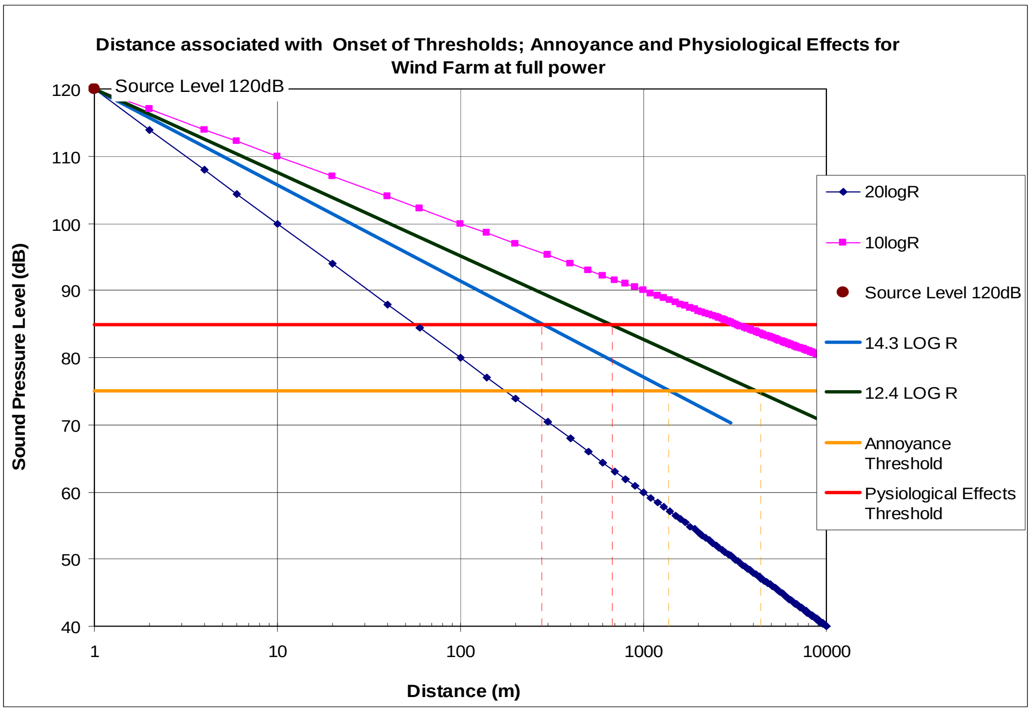

Plate 3. Distance for which the threshold of annoyance and physiological effects threshold are anticipated for one wind turbine generating a source level of 120dB in the frequencies 20Hz to 30Hz.

Wind Farm Noise` Standards

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_{90} or LA_{95}) levels. Emission levels are to be reported as A-weighted LAeq 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.*

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 Review.

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 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.

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 speed, 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

Conclusion

It is concluded that the prediction results from ISO 9613-2 or similar calculation method must be treated with caution as the method does not factor in known wind farm noise effects and prediction uncertainty.

PART VI - 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

1. Wind farm noise – A unique source of noise

The noise from wind farms is often compared to noise from traffic and industrial sources. Environmental noise impact studies and human perception studies of noise personally undertaken by the author confirms that wind farm noise is unique in terms of environmental noise perception because of the observed adverse effects of low amplitude sound. This study presents an analysis of wind farm noise as it affects two small rural populations and is a follow-up study to an initial case study at Waubra.

2. Study Design and Instruments

2.1 Introduction

A purpose-specific study was undertaken in January – June 2012 of noise levels and human perception of the Waubra and Cape Bridgewater wind farms. The study team consisted of persons qualified in acoustics, psychoacoustics, psychology, medicine (general practice), statistics and philosophy. Reviewers hold similar qualifications. The study design wais exploratory and observational, establishing the research required for the development of a hypothesis or hypotheses. It is a scientific-method-driven determination of health-related, perceptual and environmental variables, i.e. health-related quality of life and noise exposure in a sample of adults exposed to wind farm-generated noise. It is not within the scope of the study to determine if a causal relationship exists between variables.

2.2 Study Design Elements

The study design consisted of the following elements:

1. Investigation of the relationship between variables such as annoyance and adverse health effects. The survey records the perceived intrusiveness of noise, annoyance towards the noise, sleep interference due to the noise exposure and general health [1], [2], [3], [4]. Claims of adverse health effects are described. Of necessity, the investigation was applied to residents who claim they are adversely affected. The research is survey-based and is largely exploratory in nature; that is, hypothesis generating.
2. Spatial sampling was applied to obtain sound levels from wind farm locales and non-affected locales. A minimum of 5 sites were measured for statistical sound levels over a period of 2 weeks. One site at an affected locale and one site at an unaffected locale were identified as permanent monitoring stations. Measurements were recorded in real-time data-streaming mode with audio recording. Selected sites had full monitoring for low frequency sound and infrasound. The population sampled were residents within 5 kilometres of two wind farms and a quiet ‘greenfields’ locale that is unaffected by wind farm noise. The survey included self-report assessments on exposure to community noise and perceived intrusiveness of noise; annoyance

and sleep interference due to noise exposure; and relational questionnaires to the health effects surveys [3].

2.3 Participants in the study

The participants were 23 adults residing in rural locales nominally within 1000 to 3500 metres of clusters of 3 or more wind turbines. Two participants were chosen from a locale that does not currently have wind turbine activity. Participants were selected on the basis of health concerns evidenced through statutory declarations, submissions to hearings or through the research program interview process. The demographic profile of the sample is in Table 2.3.1.

Table 2.3.1. Demographic characteristics of participants (*n*=25).

Variable	Category	Number	Percent
Sex	Male	13	52
	Female	12	48
Age	25 - 34	1	4
	35 - 44	2	8
	45 - 54	10	40
	55 - 64	8	32
	65 - 74	0	0
	75 and over	4	16
Total		25	100

2.4 Instruments – WHOQOL BREF

In addition to items requesting demographic information, the survey contained three self-report assessments, providing measures of Health Related Quality of Life (HRQOL), noise annoyance, and noise sensitivity. Participants were asked to make their ratings with respect to the previous two weeks. Health-related quality of life was assessed using the World Health Organization Quality of Life (short-form) scale, the WHOQOL-BREF [2]. The respondents are asked to respond to these items, keeping the last two weeks in mind. Lower domain scores indicate more negative perceptions of Health-related Quality of Life, while higher scores indicate higher and more positive evaluations.

2.5 Instruments – SF36v2

The SF36v2 Questionnaire [5] was applied as an adjunct to the WHOQOL-BREF. The SF36v2 Questionnaire is a multi-purpose, short-form health survey. Two standardised summary scores are calculated from the SF-36; the physical component summary (PCS) and the mental health component summary (MCS). The weightings of the questionnaire are reviewed with the US norm applied to support or clarify clinical impressions for individuals, rather than as a population study [6].

2.6 Instruments – NoiSeQ

Noise sensitivity was estimated using the Noise Sensitivity Questionnaire (NoiSeQ) scale [7] which measures global noise sensitivity as well as sensitivity for different domains of everyday life: leisure, work, sleep, communication, and habitation. The subjective experience of annoyance represents the most frequent human reaction to noise. According to the results of psycho-acoustic studies, noise sensitivity has no relation to auditory acuity but reflects a judgmental, evaluative predisposition towards the perception of sounds.

2.7 Instruments – Sleep Disturbance

Sleep disturbance was assessed through application of the Pittsburgh Sleep Quality Index (PSQI) [8], the Epworth Sleepiness Scale (ESS) [9] and the Nissenbaum [4] sleep quality – health effects questionnaire.

The Pittsburgh Sleep Quality Index is scored on the basis of 7 components: Subjective sleep quality; Sleep latency; Sleep duration; Habitual sleep efficiency; Sleep disturbances; Use of sleeping medication; and daytime dysfunction. Sleep problems commonly co-occur with anxiety, mood (especially depression and dysthymia), impulse-control, and substance abuse disorders. For example, persons with generalized anxiety disorder (GAD) are approximately three times (3x) more likely to report difficulty initiating sleep, problems maintaining sleep, and early morning awakening, and are indicated as being six times (6x) more likely to experience non-restorative sleep. All scores are combined according to the scoring criteria included with the form to produce a Global PSQI Score. Scores above 5 indicate clinically meaningfully disturbed or poor sleep.

The Epworth Sleepiness Scale is used to assess the level of daytime sleepiness. A score of 10 or more is considered sleepy. A score of 18 or more is very sleepy. The Nissenbaum sleep quality – health effects questionnaire provides supplemental questions relating to headaches and satisfaction ratings before and after the turbines went online.

2.8 Instruments - Annoyance

Susceptibility to noise annoyance was assessed using a questionnaire developed by Thorne [8] and assessed annoyance due to other sources of neighbourhood noise. Annoyance due to wind turbines and other sources is discussed in the 'Genlyd' noise annoyance model [10].

2.9 Instruments - Sound Perception

An outcome of the observations and interviews of the previous studies 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 'soundfiles' to be judged by the respondents. Each sound has a unique character or characteristics and these are correlated to significant acoustical and perception measures. The measures for loudness, sharpness, roughness, modulation and unbiased annoyance are calculated with dBSONIC v4.5, a sound quality analysis program [11].

2.10 Instruments - Sound Measurement

The surveys were monitored with Larson Davis 831 Class 1 sound level meters and PRM831 preamplifiers. Recording time was 50ms for events, 1 second for continuous time logging and 10 minutes for global data. Standard A-weighted and data was recorded. The frequency responses of the GRAS 40AZ microphone is ±1dB 1Hz – 10kHz and ±2dB 10 kHz – 20 kHz; the Larson Davis type 377B02 microphone is ±1dB 5Hz – 10kHz and ±2dB 3.15Hz – 20 kHz with a lower limiting frequency -3dB at 1.0 to 2Hz. The Larson Davis type 831 with PRM831 preamplifier typical Z-weighted frequency response with a lower limiting frequency -3dB at 2Hz to 3Hz. Each meter microphone was 1.3m above ground level and fitted with a standard 90mm windscreen.

Audio recordings were taken simultaneously with the Larson Davis 831 audio recording function with a sampling rate of 16,000 samples/second and analysed for sound character (as required) with specialized audio analysis software.

Sound levels were also recorded with Rion NL21 Class 2 sound level meters at 1.3 metres above ground and fitted with a standard 90 mm windscreen. The Rion has a calibrated low noise floor of 12 dB(A). Measurements were recorded as blocks of data every 10 minutes.

Each sound level meter was calibrated with a Class 1 calibrator immediately before and immediately after each measurement session.

The weather conditions during the study were fine and cool to mild. Generally the conditions were calm to a light breeze of 2.2 to 3.7 m/s (depending on time of day and location) from the south to south-west blowing towards the different monitoring locations. Cloud cover during the study varied from half-cover to $7/8^{th}$ cover (nearly all cloud and little clear sky). Temperature was recorded as 12°C to 24°C (depending on time of day and location) and 50%-60% relative humidity. Measurements were taken with a Jaycar weather station at 10 metres above ground at the greenfields location and a handheld weather station at monitoring locations.

Infrasound measurements are recorded with the caveat that only levels taken under calm conditions or inside a dwelling are reliable. Levels below 10Hz taken under mild wind conditions below 2m/s are recorded but levels at wind speeds above 2m/s are disregarded. A purpose designed in-ground verified infrasound measurement system is required to complement indoor measurements.

The predicted sound level is necessary for the assessment of potential effects. The method under ISO9613-2:1996 *Acoustics-Attenuation of sound during propagation outdoors-Part 2 General method of calculation* is applied in this study.

2.11 Instruments – World Health Organization Health and Noise criteria

The study refers to the World Health Organization as the appropriate 'starting-point' as 'Health' is defined by the World Health Organization [1] as

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

Consequently 'Health' refers not only to physiology functioning, but also well-being, quality of life, and amenity. Quality of life, as defined by the World Health Organization [2] 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"*

'Noise' is most often defined as 'unwanted sound'. The study presents the instruments necessary to establish the human perception of 'unwanted' and the acoustical measures for 'sound'. When these measures are combined, measures for the concepts of 'excessive noise' and 'serious harm to health' are defined.

The WHO Report 'Burden of disease from environmental noise – Quantification of healthy life years lost in Europe', 2011, is a review of the scientific evidence supporting exposure-response relationships and case studies in calculating burden of disease. The Report concludes that:

> *There is sufficient evidence from large scale epidemiological studies linking the population's exposure to environmental noise with adverse health effects. Therefore, environmental noise should be considered not only as a cause for nuisance but also a concern for public health and environmental health.*

In 2009, WHO published the *Night Noise Guidelines for Europe*. This publication presented new evidence of the health damage of night-time noise exposure and recommended threshold values that, if breached at night, would threaten health. Health effects are identified in relation to nominated sound levels referenced as "instruments" for the study:

- A $L_{night,outside}$ level of 30 – 40 dB: a number of sleep effects are observed; 40 dB is equivalent to the lowest observed adverse effect level (LOAEL).
- A $L_{night,outside}$ level of 40 – 55 dB: adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
- The outdoor levels are applied with an insulation value of 21 dB from outside to inside the home; a level of 40 dB outside is 19 dB inside

The WHO recognizes the existence of vulnerable groups (such as children, the elderly, people with ill health) and acknowledges the existence of individual differences in noise sensitivity.

3. Results and Discussion – Quality of Life and Health Effects

Except where stated, all the results summarized in this section are from the respondents living within the locale of operational wind farms.

3.1 Health Related Quality of Life

The WHOQoL instruments have been shown to have excellent reliability and validity, and its use has been reported in thousands of studies. Furthermore, the WHOQoL-BREF has also been tested for its validity for different cultural groups and results demonstrate that the WHOQoL-BREF is a valid instrument to use across different cultural groups. Analyses [12] of Quality of Life data is given in Table 3.1.1

Table 3.1.1: Means, standard deviations (SD) and the Cronbach's alpha (α_c) of the summated scales for the WHOQOL-BREF

	N	No of items	*M*	*SD*	α_c
Physical	25	7	18.8	5.97	.880
Psychological	25	6	17.68	5.15	.887
Social	25	3	10.16	3.14	.695
Environment	25	8	25.15	6.74	.841

Table 3.1.1 displays, for the turbine noise exposure group, mean scores for the four health-related quality of life domains measured by the WHOQOL-BREF. Estimates of Cronbach's alpha are above, or sufficiently close to, α_c=0.7, indicating that the data can be considered statistically reliable. The mean domain scores were then transformed [12] (see table below) to afford comparisons with Australian normative data, and Australian clinical data (the LIDO study). The Longitudinal Investigation of Depression Outcomes (LIDO) Study aimed to explore the relationship between major depressive disorders in primary care patients and their quality of life. The data presented in Table 3.1.2 suggests that the sample of individuals exposed to turbine noise have, on average, substantially lower health-related quality of life compared to the community and clinical samples.

Table 3.1.2: WHOQOL-BREF transformed scores calculated for the turbine samples compared to Australian normative data (Hawthorne, Herrman, & Murphy, 2005) and LIDO (inpatient/outpatient) clinical data.

	Physical	*Psychological*	*Social*	*Environmental*
Turbine Sample	42.43	48.67	59.67	53.63
Community Norms	73.5	70.6	71.5	75.1
Outpatient Norms (LIDO)	61.47	65.37	62.89	67.93
Inpatient Norms (LIDO)	51.55	64.04	63.36	66.99

Based on the results of the study it can be argued that, when exposed to wind farm noise and wind turbine generated air pressure variations, some will more likely than not be so affected that there is serious harm (also termed 'significant adverse effect') to health.

3.2 Results - SF36v2

The mean (rounded) values for the combined male and female profiles in the 1995 Australian Bureau of Statistics 1995 National Health Survey (SF36 Norms) are: PCS ages 18-44 = 53; MCS ages 18-44 = 49; PCS ages 45-54 = 50; PCS ages 55-64 = 47; PCS ages 65-74 = 43 and PCS ages 75 and over = 39. The MCS values are more consistent with ages 45 and above at 51. Assuming a mean of 50 and a standard deviation of 10 points the SF36v2 scores indicates that for most participants their physical (PCS) and mental health (MCS) is average or below average. The US demonstration scoring system as applied in this study, however, has a different point separation for assessments between below average (40-45), about average (45-49), average (50), about average (51-54), above average (55-). A score of less than 39 is recorded as being "very much below average". This is clearly a significant issue based on the MCS and PCS scores of many of the participants, figures 3.2.1 and 3.2.2. Only 4 participants were above average: the two 'greenfields' respondents and two local residents aged 75 and over.

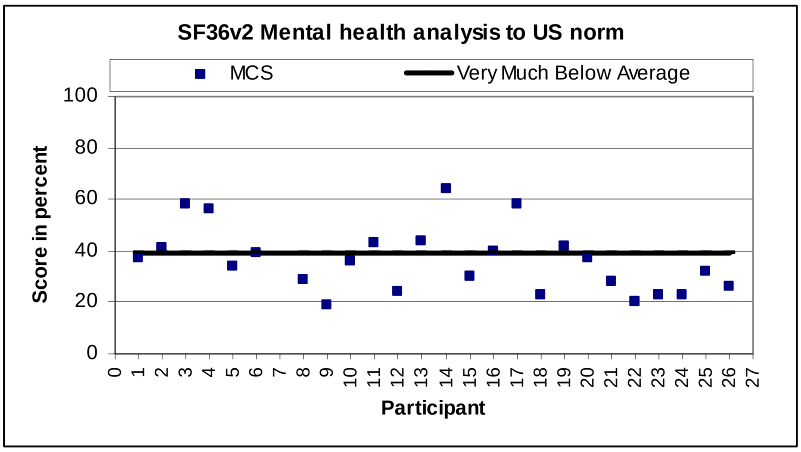

Figure 3.2.1: SF36v2 US norm analysis for mental (MCS) health

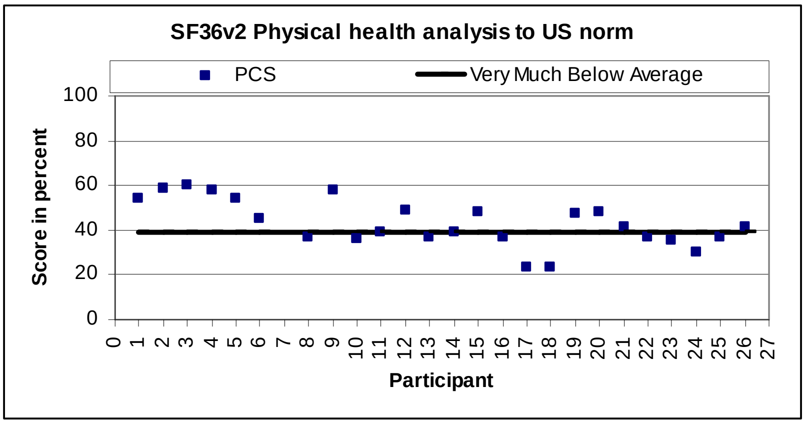

Figure 3.2.2: SF36v2 US norm analysis for physical (PCS) health

3.3 Results - Noise Sensitivity (NoiSeQ)

A detailed noise sensitivity analysis was performed in addition to the WHO Quality of Life analysis. The NoiSeQ analysis allows comparison with an earlier study of a rural locale affected by wind farms (Manawatu, New Zealand) and a totally urban locale (Brisbane city). The respondents are generally either self-employed or professional persons. The sensitivity of the respondents can vary depending on the subscale being measured. Higher values indicate higher noise sensitivity. Noise sensitivity influence annoyance and noise sensitivity also has an effect on the sound level-related changes of annoyance. Both rural locales in Manawatu and Victoria exhibit higher percentages of respondents with above average noise sensitivity for 'Global' and 'Sleep' compared to the urban respondents.

The responses for Global Noise Sensitivity are: Above average - Manawatu 85%; Victoria 82%; Brisbane 71%. Average responses are Manawatu 15%; Victoria 18%; Brisbane 29%. The responses for Sleep Noise Sensitivity are: Above average - Manawatu 70%; Victoria 60%; Brisbane 21%. Average responses are Manawatu 15%; Victoria 40%; Brisbane 58%. The below-average values are Manawatu 15%, Victoria 0%, Brisbane is 21%.

3.4 Results - Noise Annoyance

In response to the question "Select the best description descriptions for sounds heard in your local environment – I find the sounds are…" the responses were: pleasant (43%); sometimes pleasant (22%); often pleasant (13%); *and* sometimes disturbing/irritating (86%); sometimes annoying (60%). The observations indicate that the rural environment soundscape is considered pleasant but there is a defined disturbing and annoying intrusion.

Of the respondents with an opinion, 60% found the sound of turbines intrusive with the sound sometimes noisy (73%), unpleasant (64%), with no respondent saying that the sound(s) could be ignored. The effect of the noise was well defined: 82% of the respondents stated that the noise was disturbing sleep, 56% disturbing rest or relaxation, and 64% stated that the noise was making that person anxious.

In response 48% stated that ‘I’m sensitized to a particular sound’. The respondents who reported being sensitized to a particular sound identified wind turbine noise as being the cause. Wind turbine noise was referred to as the sound most often affecting the respondents.

In response to the question ‘Do the turbines annoy you inside the home’ 91% of the respondents stated ‘yes’ and 9% stated ‘no’. For turbine noise heard outside the home 95% of the respondents stated ‘yes’ and 5% stated ‘no’.

When asked “Do you find noise in your environment (including your home environment) a problem” 56% replied ‘Yes’, 39% replied ‘Sometimes’ and one person (5%) said ‘No’. This cross-check question related to all types of noise and not just from one or more specific sources.

All report that wind turbines affect sleep and the ability to work is dramatically affected. Nausea and vertigo are constants for some, occasional for others, as well as feelings of anxiety, anger and helplessness; and irritation with the turbine noise. Stress, anger and hopelessness are constants; not all day every day but recorded as frequent each week.

Families have moved away to sleep, must still work the land, will not sell. Two families report farm property is devalued; they have heritage homes and cannot rebuild. All of these factors compound the general feeling of annoyance with the placement and operation of the wind farm(s).

Building construction generally is inadequate to reduce or mitigate sound levels and, hence, annoyance. The observed homes are generally of light timber frame construction with metal roofing. Glazing is lightweight and thermal or acoustic glazing is not installed in any home.

3.5 Results - Pittsburgh Sleep Quality Index (PSQI), ESS.

Of the 25 participants, 92% have noted a change in sleeping patterns since the turbines went online. The 8% who have not experienced sleep changes are living in a greenfields locale. The changed sleep patterns are described as being entirely new by 80% of the respondents, with 8% of the non-affected persons being in the greenfields locale. For 24 % of the participants the sleep problems described (with the exception of getting up to use the bathroom) existed before but are now worsened since the turbines went online. With the exception of the greenfields participants, 80% of the respondents agreed that sleep improves when away from home (that is, home near the turbines). Critically, however, even those residents who sleep away from the influence of the wind turbines also record high PSQI scores indicating that living away does not alleviate working in a turbine-affected locale. The Global PSQI scores are recorded in Figure 3.5.1.

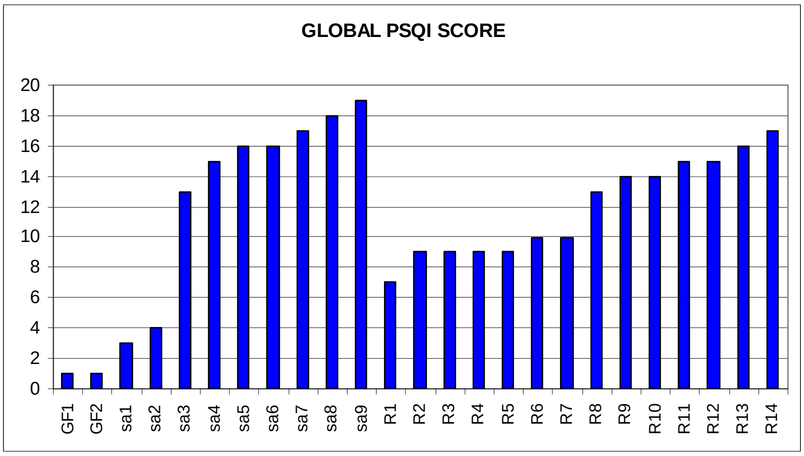

Figure 3.5.1 Global PSQI Score

(Key: GF=Greenfield, no turbines; sa= sleep away from wind farm; R=resident and sleep within wind farm influence)

One limitation with the study is the lack of a matched control group. In the event only 2 completely turbine-free (greenfield) residents are reported. The case study is important, however, as the PSQI scores of residents who are residing and work in the locale are recorded against the scores of residents who have left their homes to reside away from the wind farm. These persons must still work their farms within the influence of the wind farm.

Having said that, the very high PSQI scores are worthy of comment: 80% >5 is exceptional, typical community values are 25-35% depending upon age and gender (higher in females and with age). A later table locates the respondents by distance and predicted sound levels from turbine clusters.

The Epworth Sleepiness Scale (ESS) recorded 90% of the respondents scoring 10 or less.

3.6 Results - Headaches and associated health effects

In order to more fully assess the potential for adverse health effects experienced by the respondents a series of general health questions were presented. In response to general questions that asked 'What health effects such as headaches have you experienced since the turbines went online that did not exist previously" 24% responded with daily or constant headaches, 56% experienced headaches 2-4 times per week, 64% experienced a tight scalp or band-effect around the head, 52% experienced blurred vision, 40% stated dizziness was experienced, 4% experienced chest pains, 52% experienced nausea, 76% stated ear-ringing was experienced, 12% experienced pressure in the ears, and 60% experience vertigo/balance problems.

Of the persons who responded citing headaches as a problem 80% observe that headaches occur only when the turbines are operating.

Most of the respondents noted that these effects are not experienced all the time but often enough to be debilitating. The responses relating to nausea and the time before symptoms were experienced were probed further. In response to the question 'How long did it take after the turbines started before you felt unwell' 36% of the respondents said fairly quickly (a month or less) and 56% said 6-8 months. Of the people who responded 'fairly quickly' there were some who became unwell almost immediately. These respondents now find it very difficult to return to the locale to work when the turbines are operating as they suffer from headaches and/or nausea almost immediately. In 56% of the responses the symptoms improve/abate fairly quickly when the person leaves the locality.

3.7 Results – Infrasound, low frequency sound and health effects

This study and substantive reports [e.g. 13] have raised the question as to the reasons for the adverse health effects experienced by people affected by low frequency sound. Annoyance and sleep disturbance, with associated adverse health effects, are described in this paper. These effects, however, usually take some time before they become significant as stressors. The reported immediate health effects of nausea and headaches do not correspond to the readily perceived audible sound issues. One respondent observed that nausea experienced at 1000 metres is not experienced at 4200 metres downwind from the turbines.

The observation from this and earlier studies is that there is a physical effect affecting sensitive individuals. The premise for this is based on the fact that the individuals did not experience adverse health effects before the wind farm started operation but do so now when the turbines are operating. Some researchers suggest that this is an "infrasound" effect but this is not quite the observed effect.

The descriptor 'infrasound effect' is too broad in definition as individuals are always exposed to "infrasound" as this is a natural component of our wind environment. Wind has a very long wave length compared to (say) bird song and wind has a characteristic measurement in the 1 Hz to 20 Hz range of sound levels. The significant observation of the study is that there is a fundamental difference between an environment without a wind farm (no health effects) and a wind farm (health effects). The "effect" is recorded as being the physical action of the turbines. The turbine blades turn and extract energy from the wind and create audible and perceptible turbulence effects. The effect of the influence of the wind turbine(s) is to change the character of the wind from a relatively smooth laminar flow to a disturbed air flow with readily measured air pressure variations.

Not all individuals in the study appear to have these adverse health effects recorded, however, and this is a confounder relating to the physical properties of wind farms. The general effect can be termed as "land-sickness', similar to sea-sickness or car-sickness as the described symptoms are very similar. The mechanisms involved in adverse reactions to wind turbines are not well understood but anxiety is a common response by individuals. It is clear that responses due to "acoustical" mechanisms are only a part of the response paradigm. Information applicable to normal physiological responses is critical. Balaban [14], for example, has investigated the neurological bases between balance control and avoidance conditioning, anxiety and conditioned fear responses.

In this study, of the 13 individuals who experience nausea, 6 are susceptible to sea-sickness or car-sickness. Two individuals who are significantly adversely affected by nausea are not susceptible to sea-sickness or car-sickness, however. Instead of noise as such the effect may be better described as being due to vibration. Thus the adverse health effects on persons living near the turbines may be due to a unique combination of presently undefined acoustical, psychological and physiological responses. This is a significant area of new research.

4. Results and Discussion - Turbines and sound levels

Turbine noise criteria are often referenced to a single A-weighted sound level value. Analysis of 'single-value' A-weighted wind farm sound levels in the presence of all the sounds in the environment (the real world) is extremely difficult to do as at any one time there are at least 3 separate 'sources of sound' influencing sound levels – local sounds (e.g. insects), 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 measure (e.g. LA90 or LAeq) at a specific location, such as a residence. It is possible, however, to identify individual sound characteristics of, for example, insect vs. turbine sound. ***Conversely, it is easy for people to hear wind farm noise within "ordinary" ambient sound.*** The following study results and observations quantify and qualify the above statements.

4.1 Audible sound and noise exposure

Wind turbine sound has a unique nature that is variable over time and is highly dependent on wind speed and directions, as well as locale. Objective measurement of such sound is not easy yet can be achieved using suitable measurement methods. Some standards refer to "audible characteristics" such as amplitude modulation, tonality, impulsiveness and so on. Observations at the different locations near the wind farms under different weather conditions and measurement distances indicate the sound of turbines are individually observable (swish, rumbles, clunks, whines) at distances of 200 – 500 metres. At around 900 metres only clearly distinctive turbines are identifiable (swish, rumbles) and by 2000-3000 metres the sound of turbines is cumulative and is heard as a general source of noise. At each wind farm turbines could be clearly heard at dwellings approximately 2000 metres from the nearest turbines. The sound of turbines can be heard 2000 metres both upwind and 2000 metres downwind, as well at an angle to the turbines. The sound, with turbines operating, can be described as a steady rumble with a mixture of rumble – thumps. Turbine sound character varies regularly both in "loudness" and "tonality". The general character over a long time period of an hour or so is of a steady rumble. This, however, depends considerably on wind speed and direction. The sound of turbines is also evident and sometimes more pronounced inside a dwelling, windows open.

It is observed that wind turbine sound at residences around 2000 metres or so is perceptible outside or inside a dwelling. The sound of turbines is often clearer inside a dwelling as higher frequencies are reduced through the building fabric. The question then becomes “Can the sound be analysed and assessed in a meaningful way?” This is an important question as sound character of the wind farm is clearly different within locales.

The general character of a long time period of an hour or so is of a steady rumble. This, however, depends considerably on wind speed and direction. Masking of turbine sound by tree rustles, wind noise or insects was not observed as being significant at the time of the study. The general wind speed at ground level was 2-3m/s with the breeze blowing from the turbines to the observer. Sound measurements at wind speeds above 3m/s recorded unacceptable levels of wind-induced noise within the recording. Insect noise and bird-calls affect the measurements at all the different sound levels (LAeq, Ldn, Lden, LA95) and at specific times of the day and night – most commonly towards dawn.

4.2 Sound assessment of wind farms

Prediction of the potential sound levels at residences from turbines within a wind farm is a necessary first step in establishing potential effects. The calculation methodology of ISO 9613-2 [15] is employed. 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”. ISO 9613-2 has an uncertainty of ±3dB(A) at 1000 metres. However, in an operational wind farm sound levels are not just from the turbines immediately upwind (that is, sending sound ‘down’ to residences) but also from turbines downwind. Observations indicate turbines at a distance of about 2000 metres upwind and downwind are audible and affect the received levels at a central residence. The scatter in figure 4.2.1 and the ‘840 metre’ data in table 4.2.1 (for example) illustrate the effect of multiple turbines. Table 4.2.1 presents the distances of the respondents’ homes from turbines and the predicted sound levels at each residence. The measured sound levels at sampled residences are included.

Table 4.2.1: Measured and predicted sound levels at participant's homes from wind farms.

3+ turbines	Predicted Sound Levels		Outdoor measured sound levels (24hr)					Turbine sound causes	
Distance (m)	LAeq	LA95	LAeq	Ldn	Lden	LA95	LA95 night	Distress	Annoyance
800	42	40						yes	yes
800	42	40						yes	yes
840*	44	42						yes	yes
840*	44	42	48	56	56	31	38 - 45	yes	yes
1000	41	39						yes	yes
1000	41	39						yes	yes
1100	40	38						yes	yes
1100	40	38	50	54	54	41	28 - 51	yes	yes
1190	40	38						yes	yes
1575	36	34	61	65	65	41	36 - 43	yes	no
1575	36	34						yes	yes
1435	38	36						yes	yes
1435	38	36						yes	yes
1525	37	35						yes	yes
1400	34	32						no	no
1740	38	36	43	46	47	33	25 - 35	no	yes
1915	38	36	49	54	54	38	39	yes	yes
1915	38	36						yes	yes
2245	30	28						yes	yes
2245	30	28						yes	yes
3400	<28	<26						yes	yes
3400	<28	<26						yes	yes
3500	<28	<26						yes	no
Note * this location is affected by more than 6 turbines within 1500-2000 metres in a 270 degree arc around the residence									

Figure 4.2.1 identifies the relationship between distance from a wind turbine (or group of turbines) and an affected residence. The distance is the shortest distance to a residence from the midpoint of the 3 nearest turbines. Spearman's Rho = -.9, $p<0.001$ indicates that there is a strong correlation that as distance increases, predicted sound level decreases.

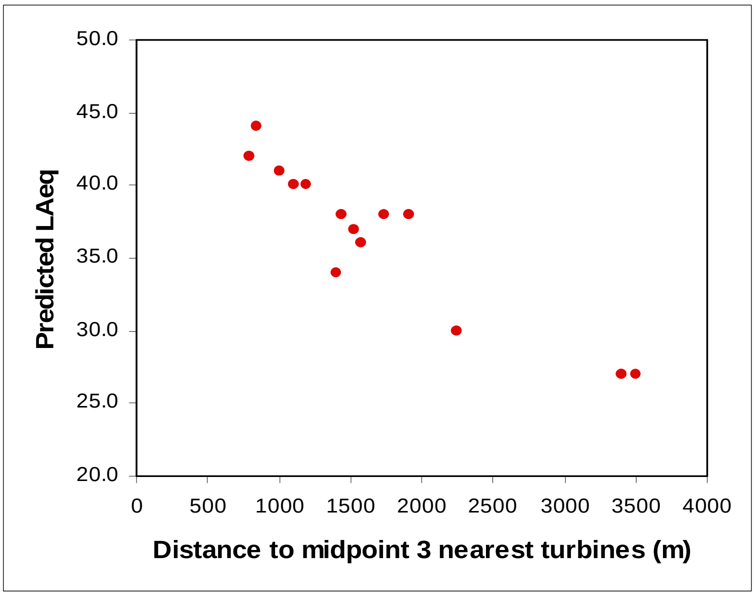

Figure 4.2.1: Correlation of distance to predicted sound levels (LAeq).

4.3 Audible Sound Character

When asked to 'describe any one sound that is clearly noticeable when you are here at home', respondents who live and sleep within the locale of the wind farms described the sound of the turbines as being "a distinctive hum or drone (63%)", "repetitive (77%)", "fluctuating, undulating or beating (77%)". Of the residents offering an opinion, 32% found the sound percussive and 36% found the sound tonal in nature.

A sound audible to one person may be inaudible to another and, therefore, a method is needed to define, measure and assess "audible sound" [16]. A sound is said to be audible if it can be heard within the ambient sound (soundscape, [21]) 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.

In order to confirm that 'audible characteristics' exist and can be measured, measures of sound character are applied in Table 4.3.1 to describe the character of the sound of the turbines. The observations were made throughout the survey and the sample time in the Table reflects the observed time when people in a rural environment tend to be easily awakened. The outdoor measurements were taken 9 metres from the most affected façade; the indoor measurements were taken at head level, on the bed, by the pillow. The measures for loudness, sharpness, roughness, and modulation are calculated with dBSONIC v4.5, a sound quality analysis program.

Table 4.3.1: Example: Measures of sound character vs. outdoor sound level.

Sound Character Psychoacoustic Measures	Inside bedroom		Outside bedroom	
	Windows closed 4:00am	Windows open 4:40am	Windows closed 4:00am	Windows open 4:40am
Loudness N sone	2.5	3.0	2.9	8.5
Sharpness S acum	1.7	1.1	1.7	1.5
Fluctuation F vacil	0.10	0.03	0.07	0.08
Roughness R asper	0.17	0.02	0.12	0.36
Modulation vs band	5Hz, 85% at 400Hz band	5Hz, 40% at 25/31.5/40Hz	5Hz, 40% at 25/31.5/40Hz	5Hz, 40% at 25/31.5/40Hz
LAeq dB 60sec	19	24	33	32

The measured levels as shown in Table 4.3.1 are due to observed turbine sound alone. The values change depending on wind speed and direction and are measured in the absence of other confounding sound, such as bird or insect song and tree-leaf rustle. It is the audible and inaudible sound character of the turbines that is the critical and overlooked factor in turbine noise assessment. People do not hear "dBA". People hear sound and hear instantaneous variations in pitch ("swish"), thump, and loudness.

Observations at a residence approximately 430 – 750 metres from the nearest 5 turbines confirmed it is possible to hear distinct differences in sound character (whine, whoosh, thump) from individual turbines on a minute by minute basis. The resident affected made the observation that he records the turbines as being 'none', 'quiet', 'noisy' and 'roaring'. It is very noticeable when the turbines stop as only 'ordinary' ambient sounds remain. The observed and recorded difference between 'quiet' and 'noisy' is the character of the thump/whoosh noise as well as the overall LAeq sound level. A 'noisy' level is recorded outdoors at 42 LAeq dB. A 'quiet' level is recorded outdoors at 40 LAeq dB. The difference was in the character or loudness of the turbine noise.

The characteristics of 'whoosh', 'thump' etc. are often grouped into a generic term called "amplitude modulation". Modulation can be a variation in the dBA sound level; for example, a variation in the tonal nature of the individual turbine, or a combination of both. At levels about 40 dB Fastl and Zwicker [17], [22] state that a degree of amplitude modulation of 6% becomes noticeable. In a simple analysis 'modulation vs. band' is recorded, Table 4.3.1, where modulation may be more pronounced in specific third octave sound level bands (typically the 25Hz, 31.5Hz, 40Hz and 400Hz bands). Legarth [23] has defined the perceptive attributes of wind turbine sound as being loudness, swishing sound, tonality and pace.

The lowest values in Table 4.3.1 are of – as far as could be recorded over 60 seconds – sounds predominantly due to audible wind turbine noise free of vegetation and or insect / animal / other noise. Higher values will be influenced by extraneous noise. This indicates that there is not yet a good objective measure for the character of audible turbine sound; from observation this appears to be a function of wind speed and direction and whether 2 or more turbines influence the sound.

Sound character changes over distance and the effect is critical in noise assessment for human perception. Measurements and observations show that as sound moves away from the turbines it changes its character with a rapid loss of higher frequencies leaving the lower frequencies audible. Changes in wind speed and direction also modify this change in character and low frequencies can be enhanced (increased) downwind. Upwind the lower frequencies are still audible even when there is a ground level breeze of 2m/s - 3m/s blowing against the turbines. It is also observed that as the temperature drops to around 10°C and a shifting breeze of 2m/s - 3m/s it becomes harder to physically distinguish sound because of the wind chill on the ears. Sound level meters may detect the variation in sound character but cannot identify the source. This must be done by observation.

Sound level decay rates by distance are shown following for a nominal wind turbine that has a sound power level of 104 dB(A) at a wind speed of 8 m/s. The overall A-weighted sound level for a single turbine decreases from 37 dB(A) at 500 metres to 12 dB(A) at 4500 metres, Figure 4.3.1. Figure 4.3.2 illustrates the difference between the A-weighted reduction in sound level and the true reduction in sound level referenced to the Z-weighting. The frequency bands that characterize observed modulated sound are presented. At low sound levels the Z-weighted values relate to audibility and a person's threshold of hearing. The A-weighted sound levels do not do this. The figures clearly show that the 'modulated' 25Hz, 31.5Hz and 40Hz bands are significantly understated in the A-weighted values compared to the Z-weighted values.

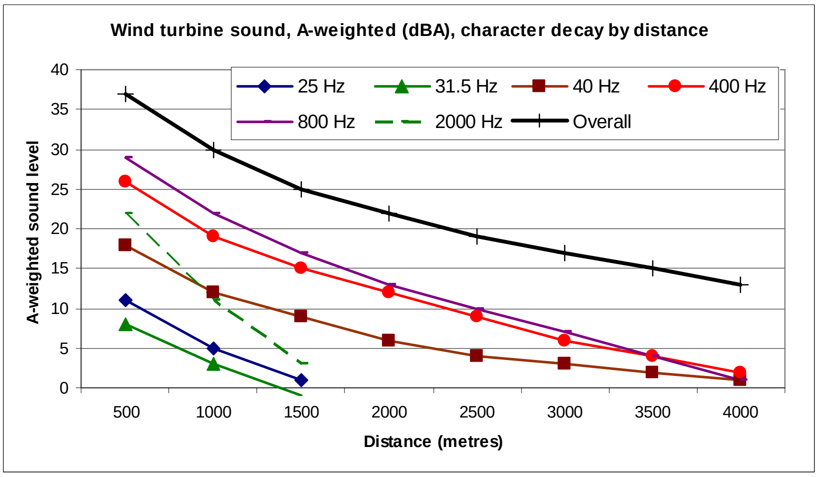

Figure 4.3.1: Sound level decrease by distance for a 104 dB(A) SWL turbine, A-weighted

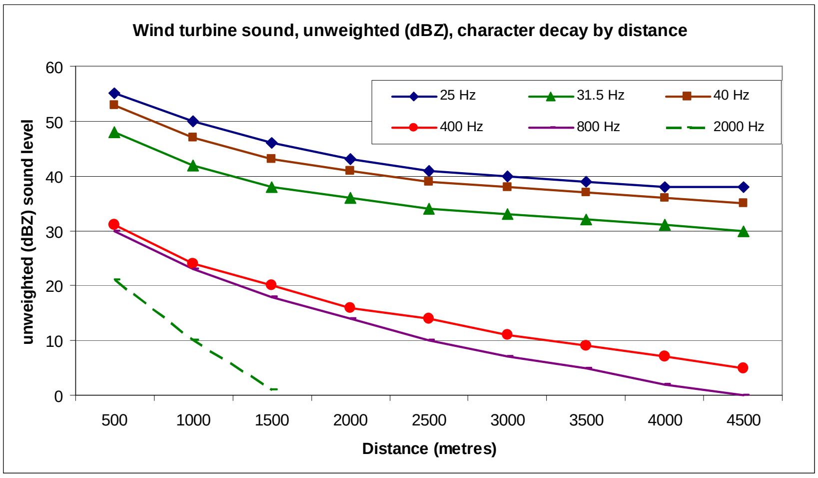

Figure 4.3.2: Sound level decrease by distance for a 104 dB(A) SWL turbine, Z-weighted

The sound levels from four active turbines are illustrated in Figures 4.3.3 – 4.3.5 following. Measurements were made in line with two sets of two turbines. There is a 4.5 dB(A) LA95 noise reduction with a doubling of distance from the measurement location to the turbines (153 metres v 327 metres). This indicates noise reduction per doubling of distance between that for a point source (-6dB) and of a line source (-3dB). This suggests that the 'standard' noise reduction of 6 dB per doubling of distance must be treated with caution when prediction of noise from a group of turbines is being considered in the near field.

1) Turbine Group 1: measured LAeq 45.2, LA95 43.6, nearest turbine at 153 metres

A clean 'whrr' sound, no thumps, turbines running but no audible turbulence noise, wind blowing from turbines to measurement, breeze 2.5m/s – 4.8m/s at ground level

2) Turbine Group 2: measured LAeq 40.6, LA95 39.1, nearest turbine at 327 metres

A clean 'whrr' sound, no thumps, tonal noise, turbines running but no audible turbulence noise, wind blowing from turbines to measurement, 1.6m/s at ground level.

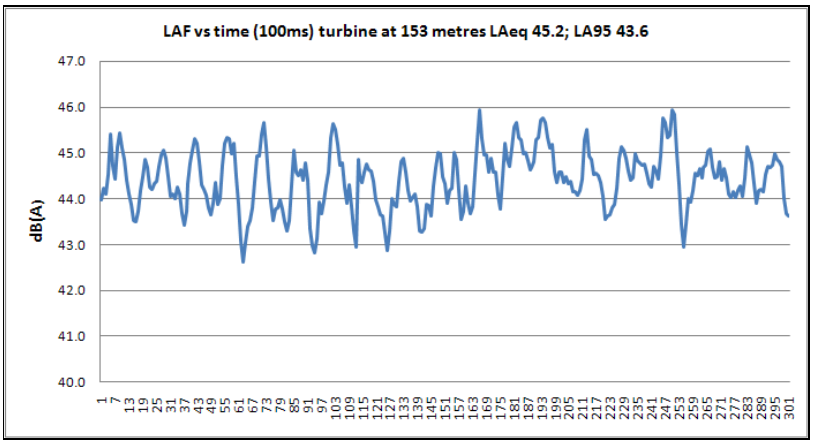

Figure 4.3.3 Turbine sound levels at 153 metres

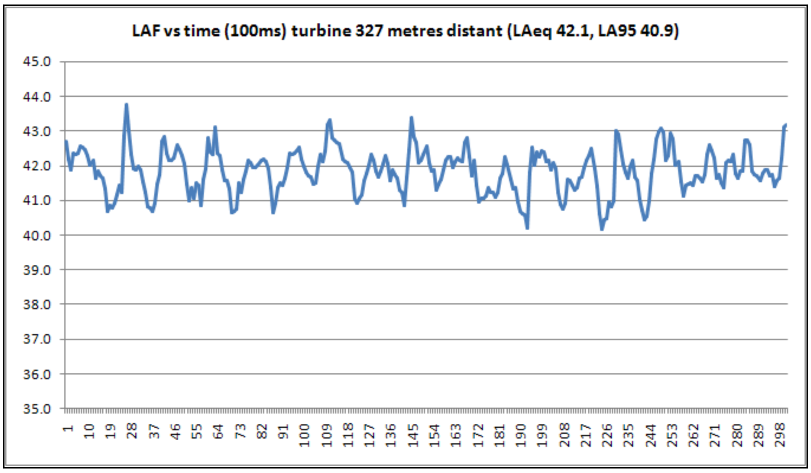

Figure 4.3.4 Turbine sound levels at 327 metres

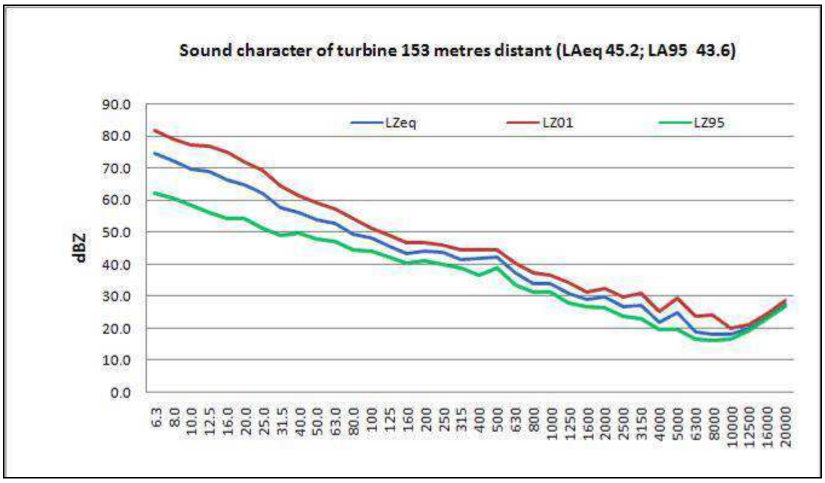

Figure 4.3.5 Turbine sound levels in third octave bands

The observations show a regular beat in the order of 2 dB. This beat is in the overall sound levels and would not normally be audible. The modulation shows, however, that audible sound components can be generated from normally operating turbines. The later figure shows that infrasound levels can be readily measured in the field under conditions of low wind speed when a standard wind shied is acceptable. The 4 turbines to the south appear to have their loudest 'whoosh' on the down stroke, approximately 30 degrees from the horizontal. There are deep 'whoomph' lasting for approximately 3 to 6 blade / tower pass-bys. The whoosh can also be heard on the upstroke, as well as whines and clunks.

However, while the study is concerned with health effects and sound character it is acknowledged that all noise criteria dealing with wind farm noise are based on single values, usually related to the A-weighted background level or equivalent-continuous level. This means that all detail is lost, figure 4.3.6. It is not possible to say what the actual sound levels consisted of without observational detail. In this particular case, the observational detail noted turbine activity and high ambient levels due to wind noise in vegetation. The conclusion is that single-level noise criteria have almost no value or applicability in determining sound levels and effects from wind turbine noise emissions.

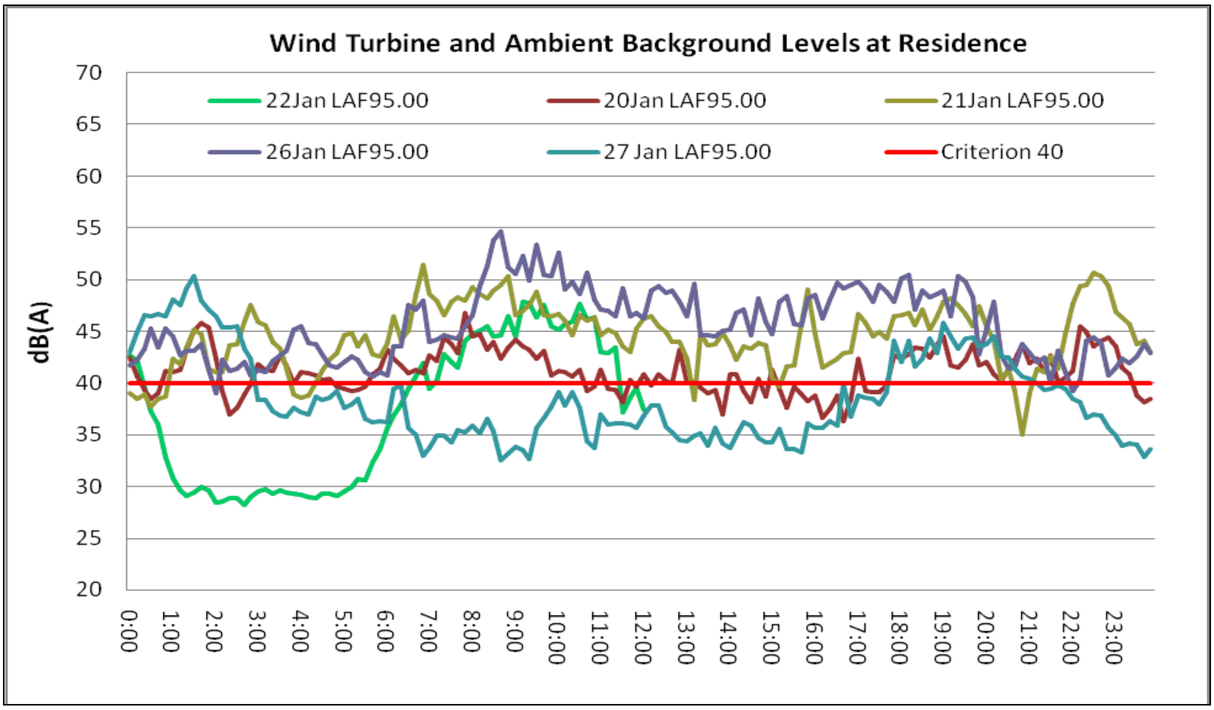

Figure 4.3.6 Turbine and ambient sound levels on different days

Field notes from one of the study days illustrate the type of information that is needed to clearly identify the sound of turbines compared to the sound of the local environment:

> **4:32am** Small bedroom to side of the house. Opened window beside bed and turbines clearly audible as a 'roar' 10min LAeq 24.1dB; LA95 20.9dB; 8Hz-12Hz around 59dB and modulating 53dB-63dB; The rear yard is a lot quieter than the front yard as the eastern turbines are a lot more noticeable
>
> - Turbines to the east clearly audible inside living room with window open
> - Opened windows in main bedroom (above bed, large window to the east).
>
> Shifting character of the turbine noise noticeable inside and outside the home. The sound of the turbines began to fade at first light – weather still calm. At dawn the wind picked up and tree rustle plus infrequent bird song and infrequent dog bark.

4.4 Sound Outside - Inside the Home

The sound of turbines is also evident and sometimes more pronounced inside a dwelling, windows open or closed. Observations confirm that wind turbine sound at residences around 2000 metres or so is perceptible outside or inside a dwelling. The sound of turbines is often clearer inside a dwelling as higher frequencies from wind and insect activity are reduced through the building fabric. Figure 4.4.1 presents measured sound levels inside and outside a home located approximately 900 metres from turbines, windows closed and open, at 4am.

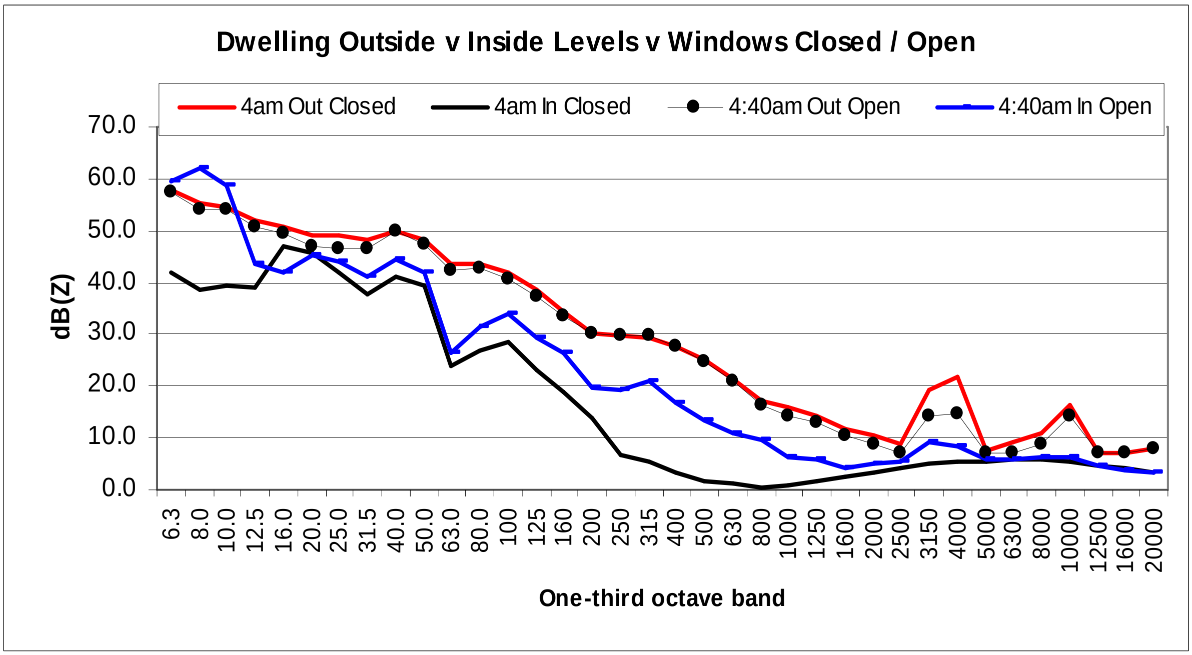

Figure 4.4.1: Measured LZeq sound levels inside and outside a home, windows closed and open.

Table 4.2.3 (see previous section 'Audible Sound Character) analyses the character of the sound at the same times. Figure 4.4.1 shows that insect and bird noise (3150-4000Hz and 10,000Hz) heard outside the bedroom is not significant inside with the windows closed. The sound is audible with the windows open. Critically, however, the infrasound and low frequency sound levels (12.5Hz to 60HZ) are not reduced as much as the higher frequencies. Most importantly the infrasound levels at 6.3Hz – 10Hz actually increase. The infrasound and low frequencies of 1Hz to 80Hz are of most interest in this research with respect to nausea and general wellbeing.

The following figures (4.4.2 to 4.4.4) provide more detail as to the different measures summarised in Table 2. The figures further confirm that audible characteristics such as modulation can be measured with a variety of standard pyschoacoustical – sound character measures.

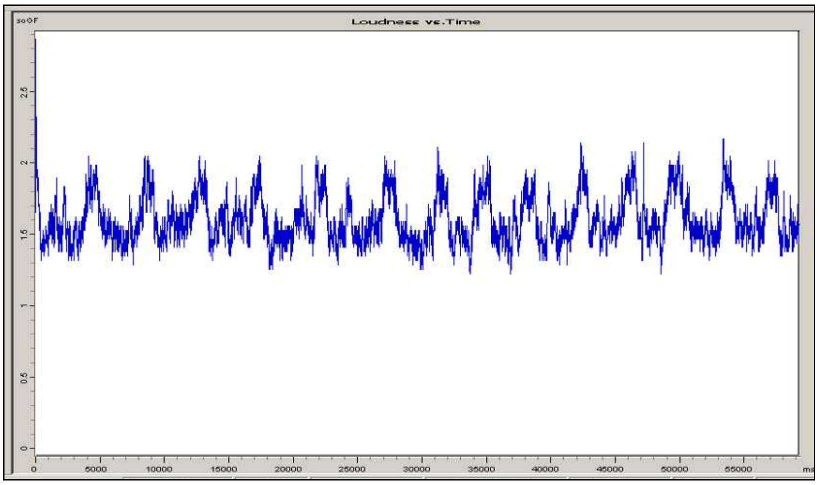

Figure 4.4.2: Time variation of turbine noise, outdoors, turbines 930-1280 metres distant, showing regular amplitude modulation (loudness) at 4am outside the bedroom

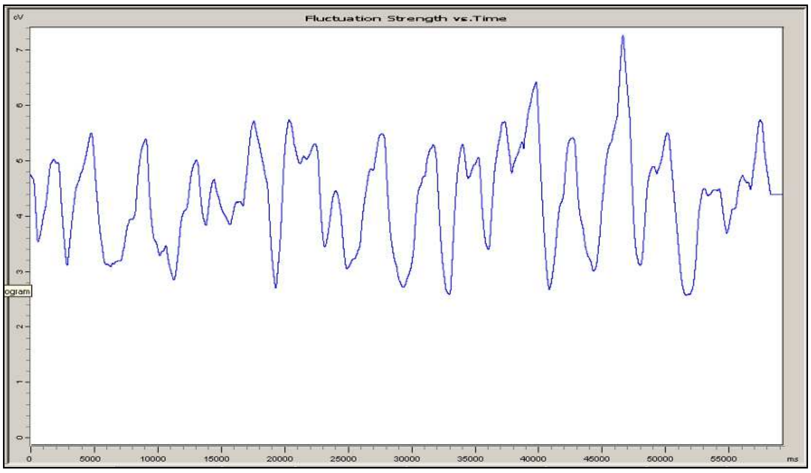

Figure 4.4.3: Same location, showing regular modulation (fluctuation strength) at 4am outside the bedroom

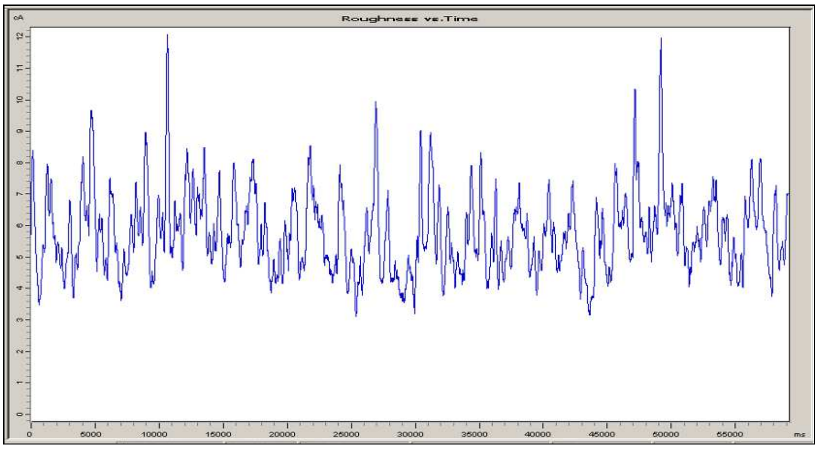

Figure 4.4.4: Same location, showing regular modulation (roughness) at 4am outside the bedroom

The variability of sound by character is illustrated in Figure 4.4.5. The figure shows distinct ‘peaks’ at different frequencies and these peaks can be attributed to different types of noise sources. Broadly, for example, below 1000 Hz belongs to wind turbine sound; 3000-4000 Hz belongs to insects; 6000 Hz belongs to bird-calls, and so on. It is the sound of the insects that dictates the overall A-weighted sound level and this illustrates the extremely difficult task of attributing A-weighted ‘background’ sound levels to any one source. For much of the time the sound levels will be a mixture of short-term sound (such as bird-calls), medium-term sound (such as insect noise) and long-term sound from turbine activity. The turbines – when running – provide a constant source of ‘background’ noise into the environment. This source can be affected by wind in vegetation, which can be identified by reference to spectrum analysis. Standard sound analysis using ‘background’ measures fail to differentiate between different types of sound that make up the total acoustic environment.

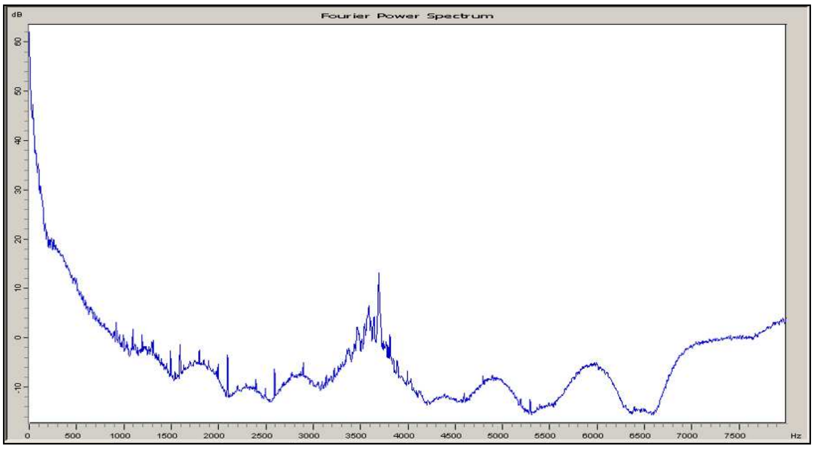

Figure 4.4.5: FFT spectrum of turbine noise, outdoors, turbines 930-1280 metres distant, at 4am outside the bedroom showing the effect of insect/animal/bird noise at 3500Hz and at other frequencies.

Figure 4.4.5 shows that conservatively, the dB(A) value could be reduced by 10 dB or more if this source of noise is removed from the calculation. Audible turbine sound is generally important in the 25 Hz-40 Hz and 160 Hz – 800 Hz third-octave bands and clearly audible as rumble and clunks. Audible or sub-audible sound emissions from turbines will not occur all the time, of course, as turbines are often stopped and operate at different times and under different prevailing wind directions and wind speeds. 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.

Additionally, if the sound has information content that the person does not want to hear that sound is perceived negatively. The evidence, however, is that once a person has become sensitised to the activity of the turbines this sensitivity is not habituated. Personal perception of a sound as “noise” therefore combines a variety of attributes that cannot be measured by simple instrumentation. The perception of audible character by individuals is ‘active all the time’. Practical assessment therefore requires monitoring, measurement and assessment must be in real-time on a continuous ‘24/7’ basis using automated sound quality analysis software.

4.5 Low frequency Noise and Infrasound

Low frequency noise and infrasound are normal characteristics within the environment. Wind itself has measurable low frequency and infrasonic character. Measured levels of infrasound inside and outside a dwelling as described in the previous section give an indication of potential effect. Putting aside the question of audibility the levels in the following Figures 4.5.1 and 4.5.2 are assessed on the basis of their energy variation at an analysis rate of 10 ‘samples’ per second. The pulses are seen as being regular in nature with a confined peak to trough shift of 6 dB to 7dB over a range of approximately 13 dB. Modulating sound with these characteristics outside and inside a home indicates that the sound is not natural but is being generated by an external source. In this case the operation of the wind farm. The people living in the home are affected by wind farm activity outside and inside the home. The potential affect of low frequency infrasound is assessed more as a sound induced vibration, or by rapid variation in perceived air pressure, Table 4.5.1, rather than as audible sound.

Table 4.5.1: psychological and physiological sequelae resulting from low frequency vibration [20].

Frequency of vibration	Symptoms	Frequency of vibration	Symptoms
4–9 Hz	Feelings of discomfort	10–18 Hz	Urge to urinate
5–7 Hz	Chest pains	13–20 Hz	Head Aches

The following figures, 4.5.1 and 4.5.2, illustrate the character of the 12.5 Hz band over 60 seconds inside and outside a dwelling. The sound is from wind turbines (as recorded by observations of the audible sound). The 12.5 Hz band is illustrated as a ‘marker’ for potential adverse health effects due to air pressure variations but the band is not the only marker. The interior figure shows regular peaks and troughs compared to the outside levels recorded at the same time. Turbine sound character within the bedroom is related to building construction and room dimensions. This is most noticeable at 38Hz – 40Hz where the sound is audible.

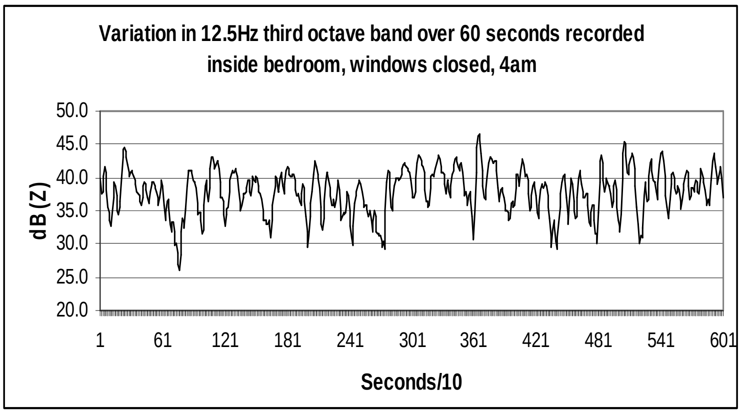

Figure 4.5.1: Variation in infrasound levels, inside bedroom at 4am

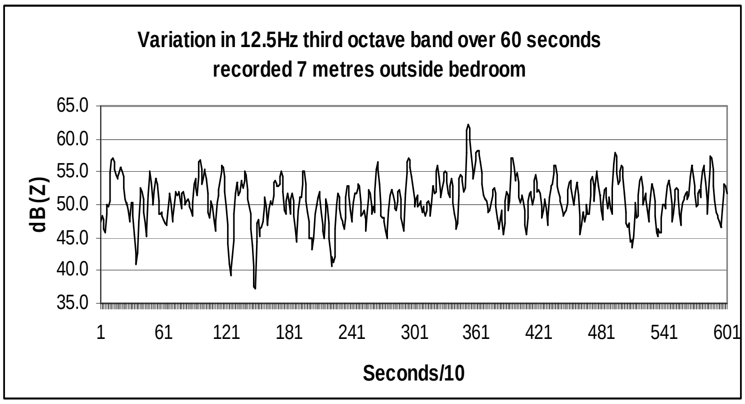

Figure 4.5.2 Variation in infrasound levels, outside bedroom at 4am

In comparison to the relatively consistent (both in sound level and modulation) wind farm affected levels (above) figure 4.5.3 illustrates the natural sound levels in the 12.5 Hz third octave band level recorded in a rural environment without turbines. At a mild breeze of 2m/s the levels vary considerably from 32 dB to 78 dB, with distinctive shifts in 100ms LZeq levels over the 60 seconds.

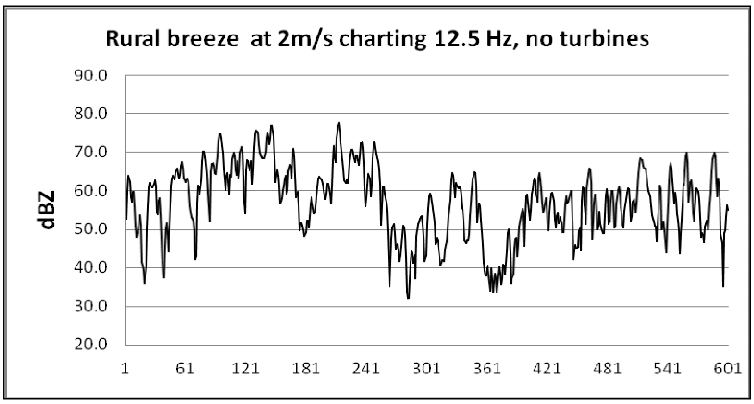

Figure 4.5.3: Outdoor rural natural sound levels in the 12.5Hz LZeq third octave band

Not all wind farms recorded as part of this research appear to have adverse health effects recorded for the infrasound frequencies and this is a confounder relating to the physical properties (wind turbine power rating and design, wind farm layout, topography, wind speeds and wind direction) of specific wind farms.

4.6 Sound Perception

An outcome of the observations and interviews of the previous studies 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 'soundfiles' to be judged by the respondents. Each soundfile was recorded at a sampling rate of 44100 Hz, 16 bit, mono and saved in Microsoft PCM .wav format. The character of the soundfile was not made known to the respondents until after the person had made an initial assessment. The character was then discussed.

The reference soundfiles consisted of: (1) Amplitude modulated fluctuating noise; (2) Outdoor residential neighbourhood and wind farm noise; (3) Outdoor rural environment with sound of wind farm 2200 metres distant, through trees; (4) sound plus tones at 150 Hz, 990 Hz and 4000Hz; (5) sound plus tones at 330 Hz, 400 Hz and 471 Hz; (6) Sound of wind turbines 930 metres distant, inside bedroom, windows closed [19]. Each sound has a unique character or characteristics and these can be identified by acoustical, musical and sound quality measures.

The aim of this part of the study was to observe if respondents can identify wind turbine sound in ambient sound. In response to the question "Choose, from the following list, the words that best describe the quality or character or 'soundscape' of your environment that you hear when you are here at home. The usual character is…," 28% of respondents selected smooth, 16% bright, 4%warm, 44% gentle, 12% rich, 24% powerful, and 44% rough. In this question there was some confusion between different homes, with some referring to homes away from the wind farm locale. The words used by respondents to describe the 'rough' quality of their environment used the words industrial, monotonous, irritating, invasive and beating and these referred to the activity of the wind turbines.

The question 'Choose, from the following list, the words that best describe any one sound that is clearly noticeable when you are here at home. The sound is…' was answered by the respondents to describe the environment, including wind turbine sound as gentle 24%, powerful 32%, rough 16%, sharp or metallic 12%, percussive 32%, dull 16%, tonal 36%, harsh 16%, a distinctive hum or drone 48%, fluctuating or beating 60%, impulsive 36%, and repetitive 60%. Post response interviews with respondents indicated that this question was answered with people providing an impression of the environment when the turbines were not operating (e.g. gentle) and when they are operating (e.g. beating).

The personal (individual) perceptions of the character of soundfile (6), figure 4.5.4, with distinctive wind turbine sound is described by 90% of the respondents as being 'annoying', with 68% saying the sound had a 'thumping' characteristic and 88% saying the sound is repetitive. The dominant characteristics are described by the respondents as being: Fluctuating, undulating, beating (84% of respondents); rumble (72%); a distinctive hum (52%); tonal (32%); percussive (48%); and powerful (40%). Similar characteristics were observed for wind turbine soundfiles 2 and 3.

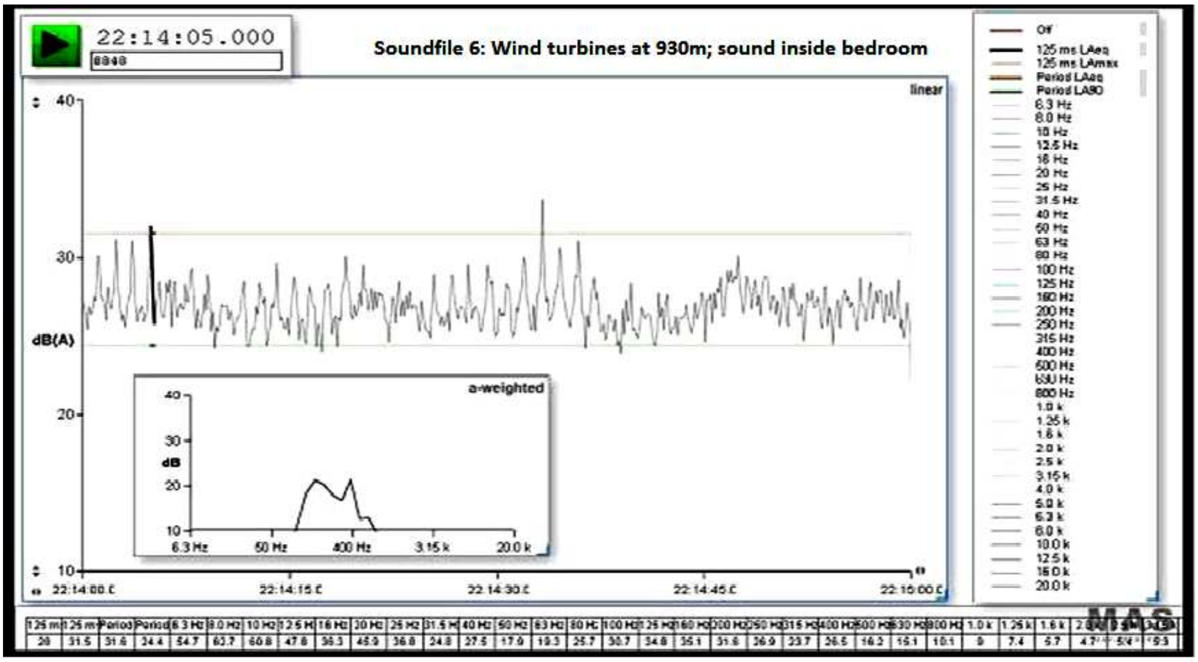

Figure 4.5.4: Soundfile 6 turbine thump

The 'thumps' are shown in the figure as groups of 3 spikes and it is this characteristic that people find intrusive, disturbing and annoying. The three peak-to-trough levels at 3-5 seconds, for example, exceeds 4 dB(A) and is assessed as being unreasonable, tending to excessive. It is therefore reasonable to apply the subjective terms of thump, beating, hum, etc. to the definition of 'audible characteristics' and apply them as objective measures of wind farm noise assessment.

5. Study Limitations

First, the sample size was a major limiting factor in the analysis and interpretation of the data. However, while the findings reported here may be considered somewhat speculative and need to be confirmed with a larger sample, they are congruent with findings reported overseas on health-related quality of life and exposures to noises. Future studies capturing more participants would afford the use of structural equations modelling, a more powerful multivariate technique capable of elucidating and testing causal relationships.

Second, while objective measures of sound levels (A-weighted and Z-weighted values) are applied in this study, such measurements have had very limited success in predicting health outcomes and they are severely lacking in predicting individual responses to noise. Additional objective measures of sound character are presented (loudness, sharpness, roughness, and fluctuation) and this study concludes they have limited application although more descriptive than measures of sound levels alone.

Third, while use of predicted noise contours calculated are applied, the study shows that it is essential to undertake actual real-time outdoor and indoor noise measurements to further elucidate the relationship between noise and health. Additionally, estimating the time that residents are exposed to the measured noise is an important covariate.

Finally, the use of subjective versus objective health measures to detect changes in health due to environmental factors maybe viewed as “soft”. Objective outcome metrics such as blood pressure or chronically elevated cortisol levels are arguably well defined and easily measured, while noise-induced sleep disruption, stress, and similar subjective symptoms are less easily measured and distinguished from the background levels present in the population. However, objective manifestation of health effects associated with noise-related annoyance may emerge after some years since the onset of exposure, whereas subjective appraisals of wellbeing and health suffer no such time lag. Thus for cross-sectional studies as reported here subjective measures are more suitable.

6. Conclusions

The study is the final in a 7-year research program into low amplitude intrusive noise. The people who took part in the study (apart from the greenfields’ respondents) are all adversely affected by wind farm activity and, as recorded in individuals’ case study, there is evidence of serious harm to health. The subjective experience of annoyance is a common reaction to noise. Different individuals can exhibit different annoyance reactions to the same noise, and these individual differences can be ascribed partly to differences in noise sensitivity. The findings suggest that the individuals living near the wind farms of this study have a degraded Health-Related Quality of Life through annoyance and sleep disruption and that their health is significantly and seriously adversely affected (harmed) by noise.

Based on the results of the study it is argued that, when exposed to wind farm noise and wind turbine generated air pressure variations, some individuals will more likely than not be so affected that there is a known risk of serious harm (also termed ‘significant adverse effect’) to health. By ‘serious harm’ it is meant harm that is more than mere annoyance and that can be quantified in terms of reported illness, sleep disturbance or other physical effect. Definitions of ‘serious harm’ are postulated:

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

The outcomes of the study are concerned with the potential for adverse health effects due to *wind farm modified* audible and low frequency sound and infrasound. The study confirms that the logging of sound levels without a detailed knowledge of what the sound levels relate to renders the data uncertain in nature and content. Observations including sound recordings are needed to confirm the character of the sound being measured.

The threshold measures for noise exposure attributable to wind turbine activity identified from the research program as acoustical markers for excessive noise and adverse health effects are:

1. An LAeq sound level of 32 dB(A) or above over any 10 minute interval, outside;
2. An LAeq sound level of 22 dB(A) or above over any 10 minute interval inside a dwelling with windows open or closed.
3. Measured wind turbine sound levels shall not exhibit unreasonable or excessive modulation ('fluctuation'). Tests for modulating wind turbine sound are:
    - An audible wind turbine sound is modulating if continuous 100ms discrete LAeq sound levels exhibit a regular variation of peak-to-trough levels in (a) amplitude or (b) third octave or narrow band characteristics that exceed the following criteria: 2dB exceedance is negligible, 4dB exceedance is unreasonable and 6dB exceedance is excessive.
    - A low frequency or infrasonic wind turbine sound is modulating if continuous 100ms discrete LZeq sound levels exhibit a regular variation of peak-to-trough levels in (a) amplitude or (b) third octave or narrow band characteristics that exceed the following criteria: 2dB exceedance is negligible, 4dB exceedance is unreasonable and 6dB exceedance is excessive.
4. The threshold for unreasonable wind turbine noise is defined as being 5 dB(A) below the sound levels in (1) and (2) above.
5. Definitions [18]: 'LAeq' means the A-weighted equivalent-continuous sound pressure level; "regular variation" is where the wind turbine sound exhibits a consistent 'saw tooth' pattern for 10% or more of a measurement time interval of 10 minutes; Z-weighting has the meaning under AS IEC 61672.1 and a lower limit of 0.5 Hz.

Assessment of perception, health effects and the complex nature of wind turbine noise require the more detailed measures of sound and soundscape character such as audibility, low frequency and infrasound, loudness, fluctuation strength, dissonance, tonality and unbiased annoyance. Perceptive measures for noise exposure relevant to wind turbine activity are described in Thorne [3], Pedersen [10], Leventhall et al. [13], Fidell & Horonjeff [16], Fastl & Zwicker [17], Lenchine [22] and Legarth [23]. The application of these measures requires specialized analysis software unlike the relatively simple acoustical measures presented above. Further research is needed to establish threshold markers for noise perception measures that describe excessive noise and adverse health effects.

The working hypothesis from the study is “Adverse health effects are experienced by sensitive individuals due to modulating air pressure variations broadly measured in the 1Hz to 80Hz and 160Hz third octave bands.” Not all wind farms in this study appear to have these adverse health effects recorded, however, and this is a confounder relating to the physical properties of wind farms.

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8. The Study Design

The following is the full study proposed in 2011 to the Minister of Health, State of Victoria. Modifications have been made to accommodate the 2012 study presented above.

A. To investigate the relationship between psychological factors

Aims and Objectives

To investigate the relationship between psychological factors (e.g., personality and noise sensitivity) and annoyance; to investigate the relationship between social and cultural factors (e.g., attitudes and locality) and annoyance, and; to investigate the relationship between annoyance and health. The survey will estimate the perceived intrusiveness of noise, annoyance towards the noise, sleep interference due to the noise exposure, and general health as measured by the WHO. These measurements will afford an examination of the correlation between annoyance and health, and differences between groups in wind turbine areas vs. quiet areas in quality of life, noise sensitivity, and general health.

The study will investigate the claims of adverse health effects and bring them into context with the overall study design. Of necessity, investigation will need to be with residents who claim they are adversely affected and who are willing to undertake intensive medical testing for sleep disturbance and other health-related effects. This component of the Study is to be refined subject to various approvals and epidemiological study design. The study design will be reviewed by an independent group of experts before the final design is implemented.

HYPOTHESES

The study will be exploratory in nature; though will still yield a number of testable hypotheses. It should be noted that it is not within the scope of the study to determine if a causal relationship exists between variables. Hypotheses:

I) There will be a relationship between poor health and annoyance.

II) More negative attitudes towards noise generators will lead to great annoyance responses.

III) There will be a small but significant positive correlation between annoyance and noise exposure for those individuals residing close to the wind farms.

IV) Psychological variables such as personality will predict annoyance scores.

V) There will be differences in quality of life domains and general health between noisy and quiet areas.

VI) There will be a correlation between annoyance and physical distance from wind farm.

i) Design

The research is survey-based, and is largely exploratory in nature, that is, hypothesis generating. It will involve convenience samples from four areas proximal to wind farms and one SES-matched quiet area. There will be multiple comparisons conducted between and within the groups. The study design will be reviewed by an independent group of experts before the final design is implemented.

ii) Methods

The study will use convenience sampling to obtain completed questionnaires. It is hoped that 1000 completed questionnaires will be obtained from those living around wind farms and a SES-matched quiet locale that will be used as a comparison group. The purpose of the survey is to describe the study population from the information received from the sample. The probability level can be either 90% or 95%. For a sample size of 1000 completed surveys we would expect a range of ±3.09% for a confidence of 95% and ±2.60% for a confidence of 90%. We have recommended 1000 completed questionnaires to insure a maximum range of ±3.09% at the 95% level. For example, if 40% of the sample replied that there were no annoying noise problems, then we could estimate that the population value is with a confidence of 40 ±3.09%, i.e. 38% to 43% with a probability of 95%. The population to be sampled from is all residents within 5 kilometres of the Waubra wind farm and a quiet area that is unaffected by wind farm noise. Exclusions will include people normally residing outside the region (e.g., tourists).

MATERIALS

A social attitudinal survey designed to compliment future research involving physical noise measurements will be developed. The survey will include self-report assessments on exposure to community noise and perceived intrusiveness of noise; annoyance and sleep interference due to noise exposure; psychological wellbeing, quality of life, and general health; noise sensitivity and personality traits; attitudes to noise sources; and demographic information. Questions will be guided by pre-existing studies in the literature or by the use of pre-existing and validated inventories, including:

Construct	**Measure**
Psychological Wellbeing	The Depression, Anxiety, and Stress Scale (DASS-42)
Quality of Life and general health	The World Health Organisation Quality of Life Scale (WHOQOL-BREF)
Annoyance	Four questions taken from Kroesen et al., 2008.
Personality	The NEO PI-R
Noise sensitivity	Noise Sensitivity Questionnaire (NoiSeQ)
Attitude	Eight questions taken from Katsuya (2002)

Specific questionnaires relating to adverse health effects include:

Construct	**Measure**
Health survey	SF-36v2
Sleep disturbance	Epworth Sleepiness Scale, Pittsburgh Sleep Quality Index
Turbines and health	Questions taken from Nissenbaum (2010)

ANALYSIS

Returned questionnaires will be entered into a computer-based spreadsheet (Microsoft Excel) and from here exported to appropriate data analytical software packages (e.g., SPSS, LISREAL). Analysis will progress in distinct steps:

1) Data will be assessed for suitability of inclusion (i.e., a missing value analysis / outlier analysis).

2) Where appropriate items will be reverse-coded.

3) The psychometric properties of the scales will be assessed using reliability analyses (e.g., Cronbach's alpha), descriptive statistics for floor and ceiling effects (e.g., means / standard deviations), and validated for dimensionality using data ordination techniques (e.g., item-total correlations / Factor Analysis).

4) Contingent on 3) composite variables will be computed and, if necessary, normalised.

5) Inferential tests will be carried out (e.g., zero-order correlations, multiple linear regression, one-way analysis of variances, *t*-tests) to address research hypotheses.

6) If afforded by the data, structural Equation Modelling will be performed using two pre-existing models

7) Two pre-existing models of attitude formation, the deficit model and the dual process model, will be applied to the attitudinal data.

As part of the Quality of Life Study a separate question will be asked of respondents whether they would be prepared to be involved in a more detailed study of adverse health effects. The adverse health effects study presents more detailed questionnaires on a person-to-person basis. The respondent will be invited to participate in a physical study involving sleep disturbance analysis and other health measures. Respondents accepted for this part of the study will include susceptible individuals and non-susceptible individuals, as recorded by their initial survey responses. Strict confidentiality will be maintained. Each study site will have intensive acoustical studies undertaken for low frequency noise and vibration.

HYPOTHESES

The study will be exploratory and essentially a Pilot study in nature; though will still yield a number of testable hypotheses. It should be noted that it is not within the scope of this Pilot study to determine if a causal relationship exists between variables. Hypotheses:

I) There will be a relationship between adverse health effects and annoyance with respect to susceptible and non-susceptible individuals.

II) There will be a relationship between adverse health effects and perceived noise with respect to susceptible and non-susceptible individuals.

ANALYSIS

An analysis protocol will be developed as part of the Peer Review process as it is considered that this will be the most controversial, yet vital, part of the study.

B. Acoustic and Psychoacoustic factors affecting health

(i) Aims and Objectives

To investigate the relationship between acoustical and psychological factors (e.g, sound levels in the environment, noise perception and noise sensitivity) and annoyance. The survey will estimate the perceived intrusiveness of noise, unbiased annoyance due to sound and noise, and sleep interference due to the noise exposure. These measurements will afford an examination of the correlation between sound, perceived noise, annoyance and health, and differences between groups in wind turbine areas vs. quiet areas in quality of life, noise sensitivity, and general health.

HYPOTHESES

The study will be exploratory in nature; though will still yield a number of testable hypotheses.

I) There will be a relationship between measured sound levels outside a residence and annoyance.

II) There will be a relationship between measured sound levels inside a residence (windows open; windows closed) and annoyance.

III) There will be measurable low frequency sound and noise inside and outside a residence;

IV) There will be a measurable variation between the noise character of the wind affected by, and unaffected by, the operation of wind turbines;

V) There will be a small but significant positive correlation between annoyance and noise exposure for those individuals residing close to the wind farms.

VI) Psychological variables such as personality will affect noise sensitivity scores.

VII) There will be differences in quality of life domains and general health between noisy and quiet areas.

VIII) There will be a correlation between annoyance and physical distance from wind farm.

IX) There will be a correlation between sound character, annoyance and physical distance from the wind farm.

(ii) Design

The research is survey-based, and is largely exploratory in nature, that is, hypothesis generating. It will involve convenience samples from four areas proximal to wind farms and one SES-matched quiet area. There will be multiple comparisons conducted between and within the groups. The study design will be reviewed by an independent group of experts before the final design is implemented.

iii) Methods

The study will use spatial sampling to obtain sound levels from wind farm locales and non-affected locales. A minimum of 20 sites will be measured for statistical sound levels over a period of 4 weeks and at least 4 sites will be measured for 3 months. One master site at an affected locale and at an unaffected locale will be established as permanent monitoring stations. Each study locale will have a weather station. At selected sites measurements will be maintained in real-time data-streaming mode. Selected sites will have full monitoring for low frequency sound and infrasound. The population to be sampled from is all residents within 5 kilometres of the Waubra wind farm and a quiet area that is unaffected by wind farm noise.

<u>*MATERIALS*</u>

An acoustical and psychoacoustical survey designed to compliment future research involving physical noise measurements will be developed. The survey will include self-report assessments on exposure to community noise and perceived intrusiveness of noise; annoyance and sleep interference due to noise exposure; relational questionnaires to the health effects surveys. Questions will be guided by pre-existing studies in the literature or by the use of pre-existing and validated inventories, including:

Construct	Measure
VCAT compliance	Statistical measures to AS1055 and NZS6808
Noise Exposure	USEPA. Lden, Sleep Disturbance Index
Special audible characteristics	Amplitude modulation, tonality, impulsiveness to ISO 1996-2 and UK High Court decision
Special audible characteristics	Loudness to DIN 45631 and ANSI S3.4
Unbiased annoyance	Zwicker, Thorne

ANALYSIS

Returned questionnaires and sound level datasets will be entered into a computer-based spreadsheet (Microsoft Excel) and from here exported to appropriate data analytical software packages (e.g., SPSS). Analysis will progress in distinct steps:

1) Data will be assessed for suitability of inclusion (i.e., a missing value analysis / outlier analysis).

2) Where appropriate items datasets relating weather and sound levels will be integrated.

3) The psychometric properties of the scales will be assessed using reliability analyses, descriptive statistics for floor and ceiling effects (e.g., means / standard deviations), and validated for dimensionality using data ordination techniques (e.g., item-total correlations / Factor Analysis).

4) Contingent on 3) composite variables will be computed and, if necessary, normalised.

5) Inferential tests will be carried out (e.g., zero-order correlations, multiple linear regression, one-way analysis of variances, *t*-tests) to address research hypotheses.

6) Sound quality analysis will be determined with methods of analysis for amplitude modulation, dissonance, impulsiveness, loudness, roughness, sharpness, salience and tonality.

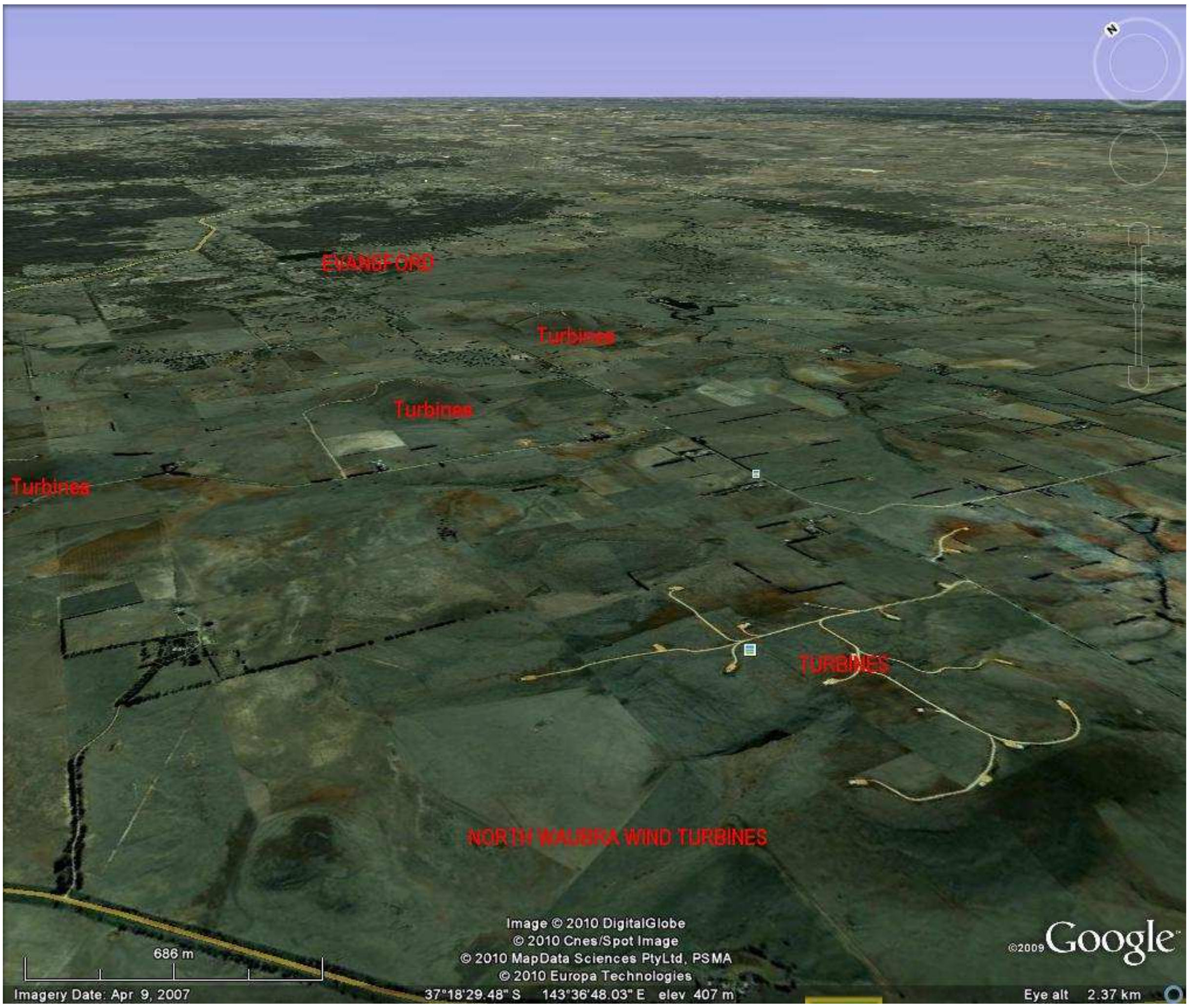
7) The Unbiased Annoyance models of attitude formation will be applied to the psychoacoustical data.

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



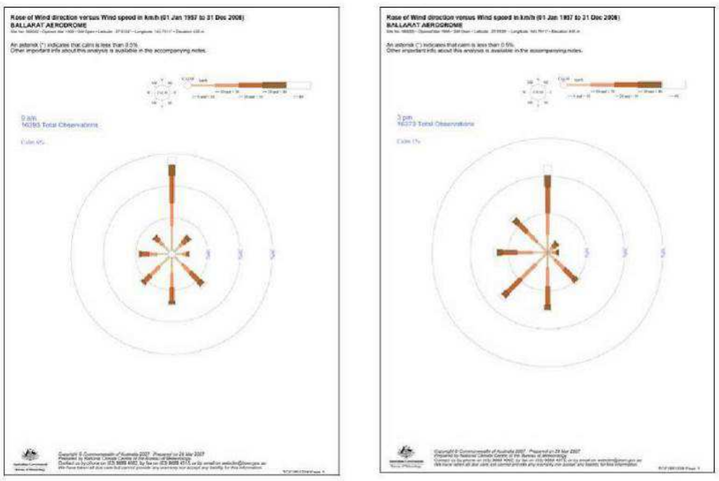
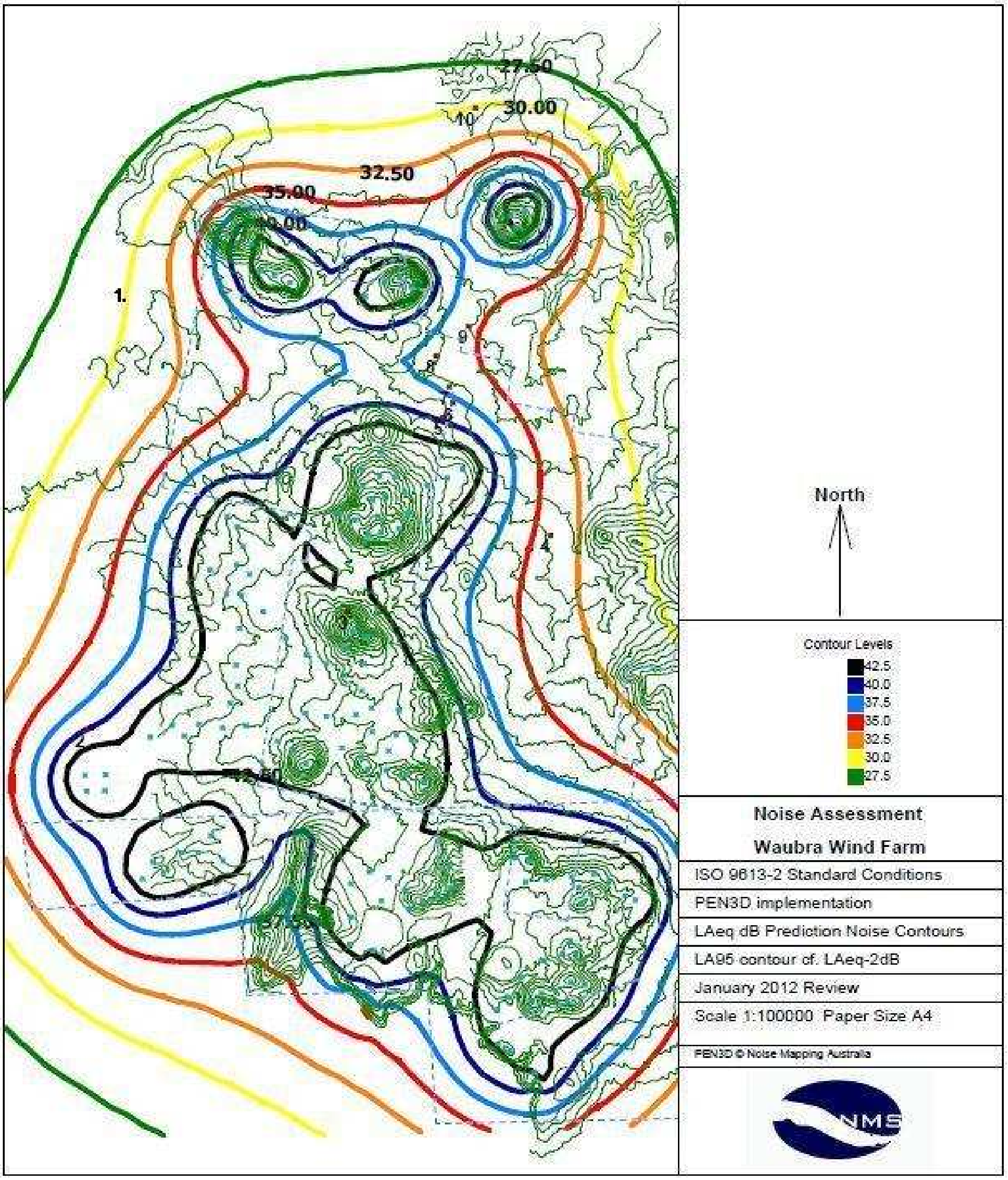


Figure W1: wind rose, Ballarat Aerodrome, mid-morning and mid-afternoon

Plate W3: Waubra locale, residents and the Waubra wind farm

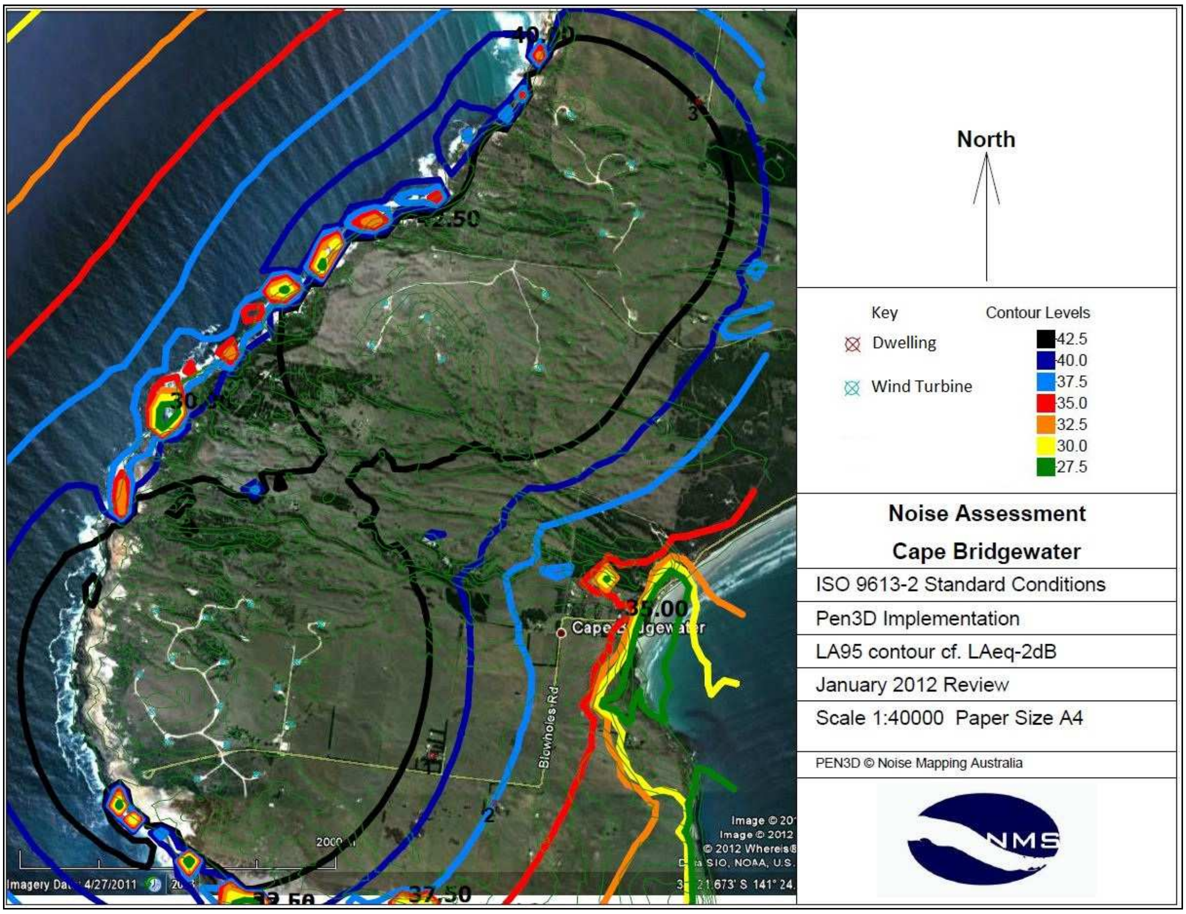


Note: turbines are shown as 'blue dots' on the map

Receiver	LAeq	LA95	Receiver	LAeq	LA95
1	30	28	**6**	38	36
2	40	38	**7**	37	35
3	44	42	**8**	37	35
4	34	32	**9**	36	34
5	40	38	**10**	30	28

Predicted sound levels at 8m/s

Plate W4: Cape Bridgewater locale, residents and wind farm



Receiver	LAeq	LA95	Receiver	LAeq	LA95
1	41	39	**2**	38	36
3	42	40			

Predicted sound levels at 8m/s

The Effects on People near the "West Wind' wind farm, New Zealand

The Westwind wind farm commenced operation in May 2009. From professional 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 by the acoustical consultant for the wind farm operator. The complaint histories from 64 households in a population of approximately 140 occupied residences were analysed. 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 professional measurements, would be outdoor background levels of much less than 40 dB, around 28 to 30 dB 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.

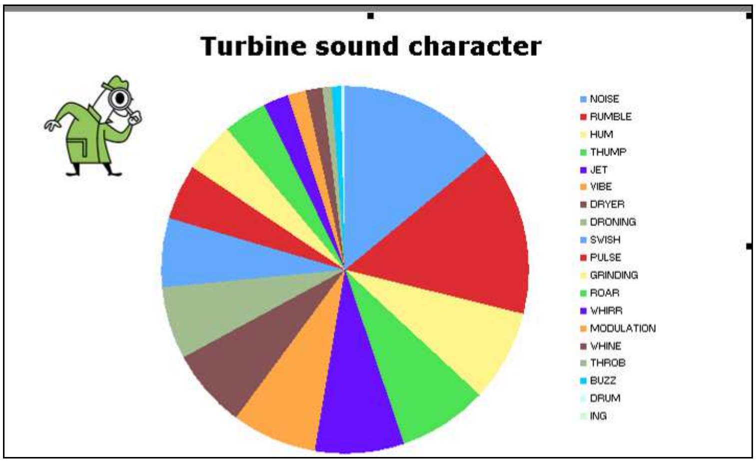


Figure WW1: Westwind complaints by turbine character

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.

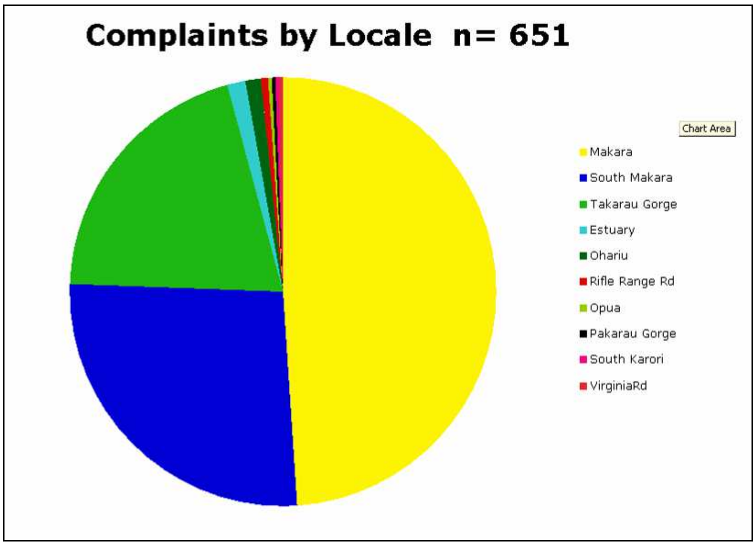


Figure WW2: Westwind complaints by locale

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.*

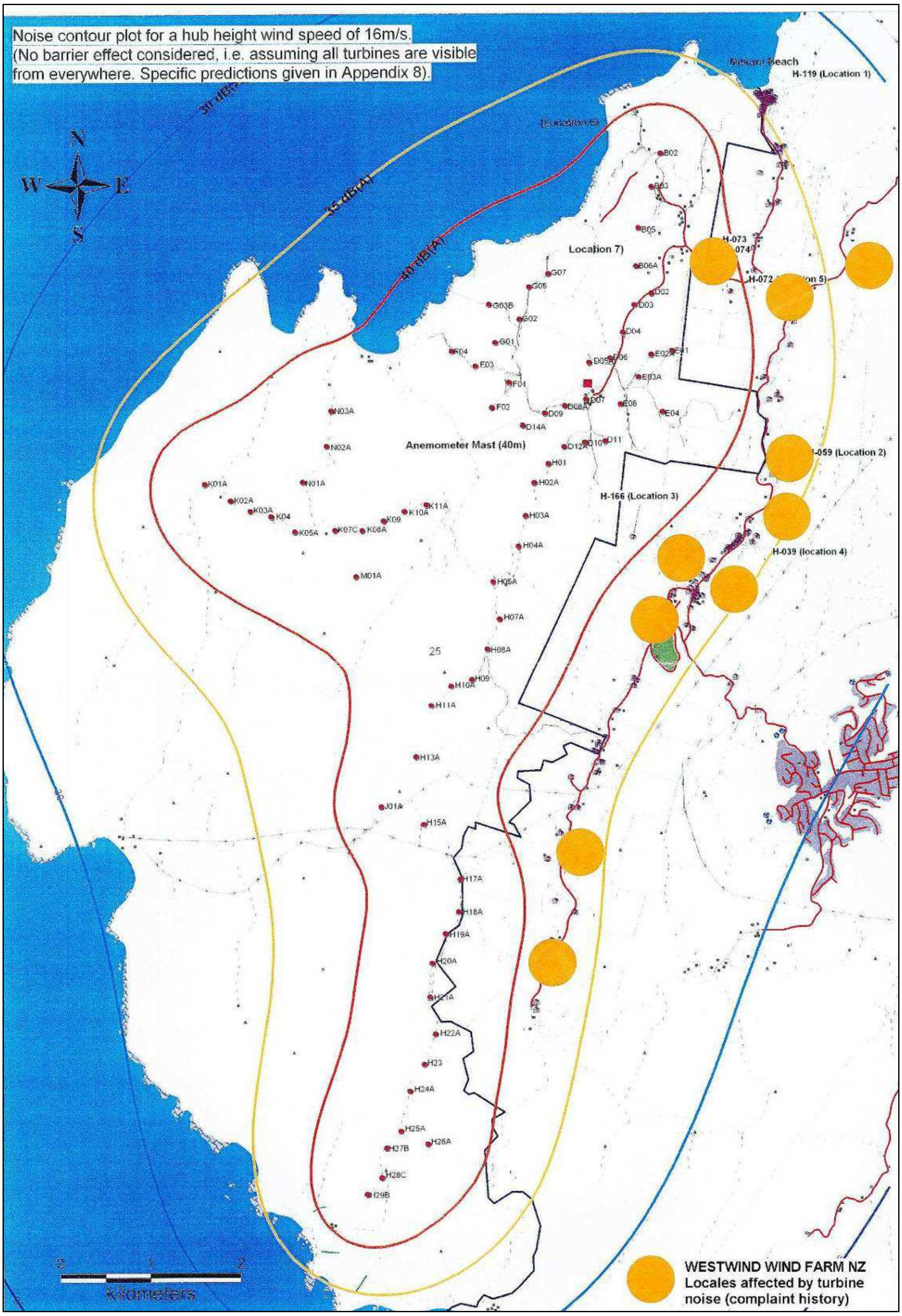
And a third resident says

> *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



Approximate noise contours generated by the developer on the basis of Vestas V90 turbines

Plate WW1(a): Locales in Makara affected by West Wind wind farm turbine noise

Noise contours generated by the developer on the basis of Siemens 2.3MW VS turbines (as installed)

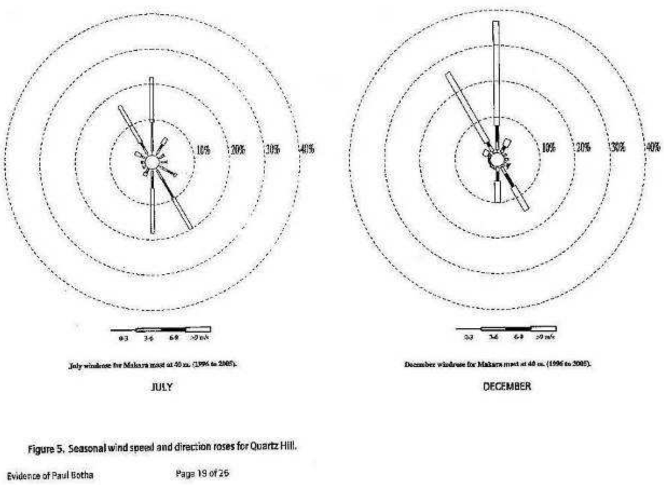
Table WW1: Westwind affects, perception and complaint analysis to November 2009

Locale	Distance	Noise affect
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

Note: the turbines (red letters) are on the top of the ridges, the residences (blue boxes) are in the valley. The prevailing winds blow from the turbines to the residences.

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



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 at the monitoring location in wind speeds of 8 m/s. The actual sound levels are significantly higher, by up to 12.8 dB higher under certain wind speeds and directions. The measured levels are said to be consistently over 40 dB 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. 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

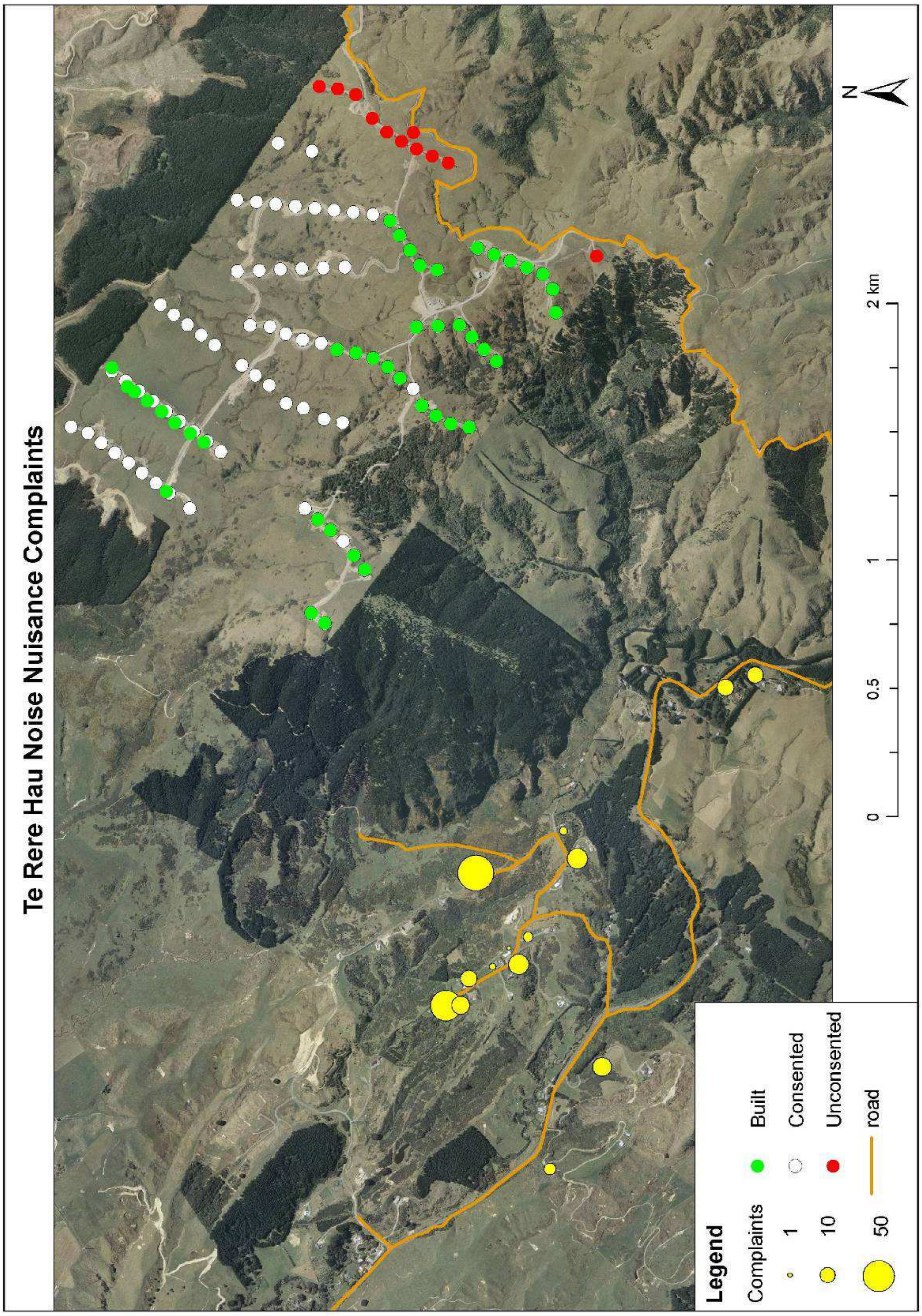


Table TRH 1: Te Rere Hau noise complaints, August 2009 to February 2010, single residence

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

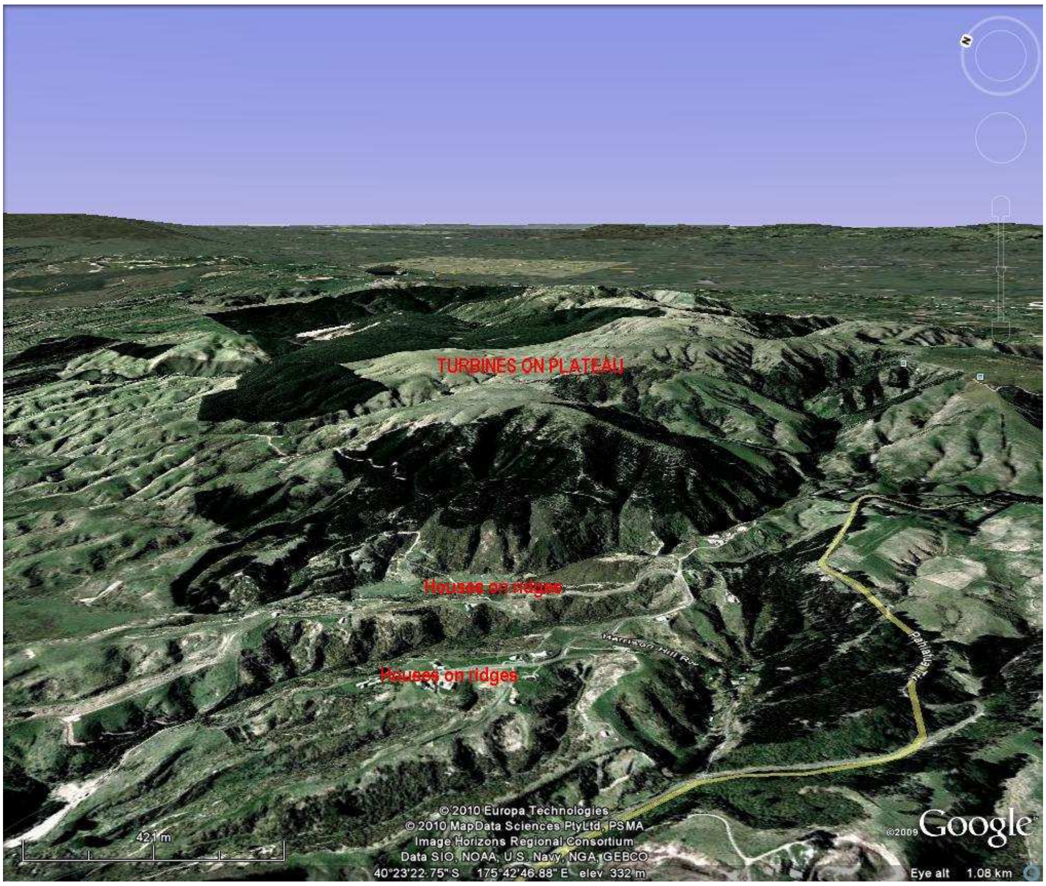
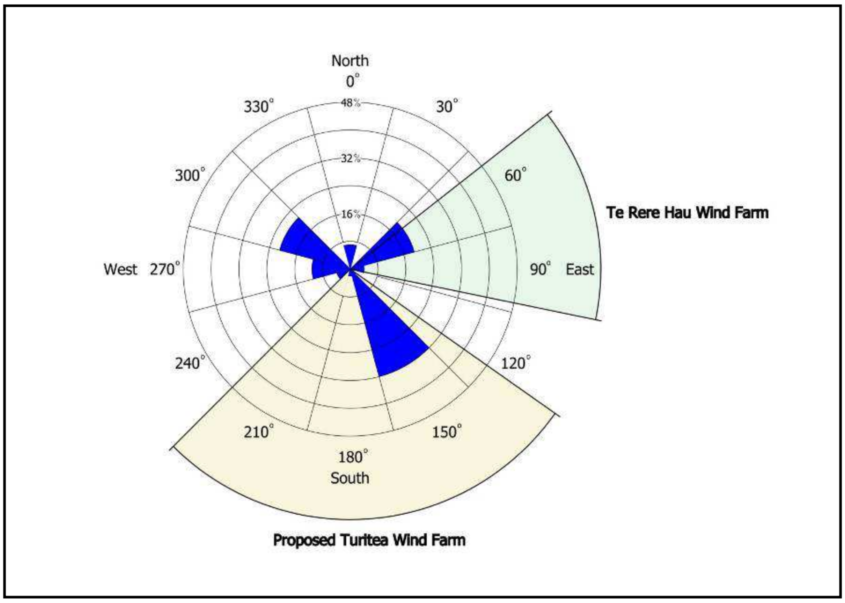


Figure TRH 1: Wind Rose for May to September 2009 illustrating existing wind farm effect (Te Rere Hau) and effect from a proposed wind farm (Turitea) to the south



Real-world noise compliance problem at a wind farm

The Te Rere Hau wind farm in New Zealand is presently the subject of an Environment Court action[23] with respect to its compliance and the methodologies applied to measure background sound levels and compliance levels.

In brief it is understood that the 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.

The Environment Court, in its Decision of 4 July 2012 states at [132]:

> *That the acoustic information supplied in the AEE by the Respondent and the evidence of the Respondent was inaccurate to such an extent that Palmerston North City Council may rely on s128(1)(c) RMA to conduct a review of the noise consent conditions applicable to the Te Rere Hau wind farm.*

Thus the most critical of all matters within a consent condition, certainty of application, has failed completely at Te Rere Hau.

[23] PNCC v NZ Windfarms, NZ Environment Court, ENV-2010-WLG-000114, Application for Declaration 11 October 2010 and Memorandum dated 21 December 2010; Decision No [2012] NZEnvC 133 4 July 2012

The Effects on People near the proposed Turitea Wind Farm, New Zealand

The Manawatu wind farms are causing concerns regarding noise, especially from those residents immediately near to the turbines. In this regard, the Board of Inquiry into the proposed Turitea (New Zealand) wind farm is important as it is the outcome of nearly two years' deliberations. The Board, in its draft decision of February 2011, says:

> *Creating an environment where wind farm noise will be clearly noticeable at times of quiet background sound levels is not an option the Board condones, especially where large numbers of residents are affected. It is the Board's view that energy operations in New Zealand will have to learn not to place wind farms so close to residential communities if they are not prepared to accept constraints on noise limits under such conditions.*

The Board decided in the draft decision that:

> *Where the wind farm wind speed is 6m/sec or lower, a secondary noise limit shall apply under which the turbines shall be designed, constructed, operated and maintained so that wind farm sound levels (La90(10min)) shall not exceed the background sound level by more than 5dB, or a level of 35dBA (La90(10min)), whichever is the greater;*

Plate T1 following illustrates the sound levels from the wind farm. The red LAeq 35 dB contour is the marker for night-time levels. (Unfortunately, there is also a red line around the turbine clusters. This line is not the predicted LAeq contour). Broadly, the LAeq 35 dB contour is at 2000 metres from the nearest turbine. Representative receiver and residential locations are given in the blue boxes. The LA90 residential levels for the 61 turbines, adjusted by -2dB for the difference between LAeq and LA90, are given in Table T1.

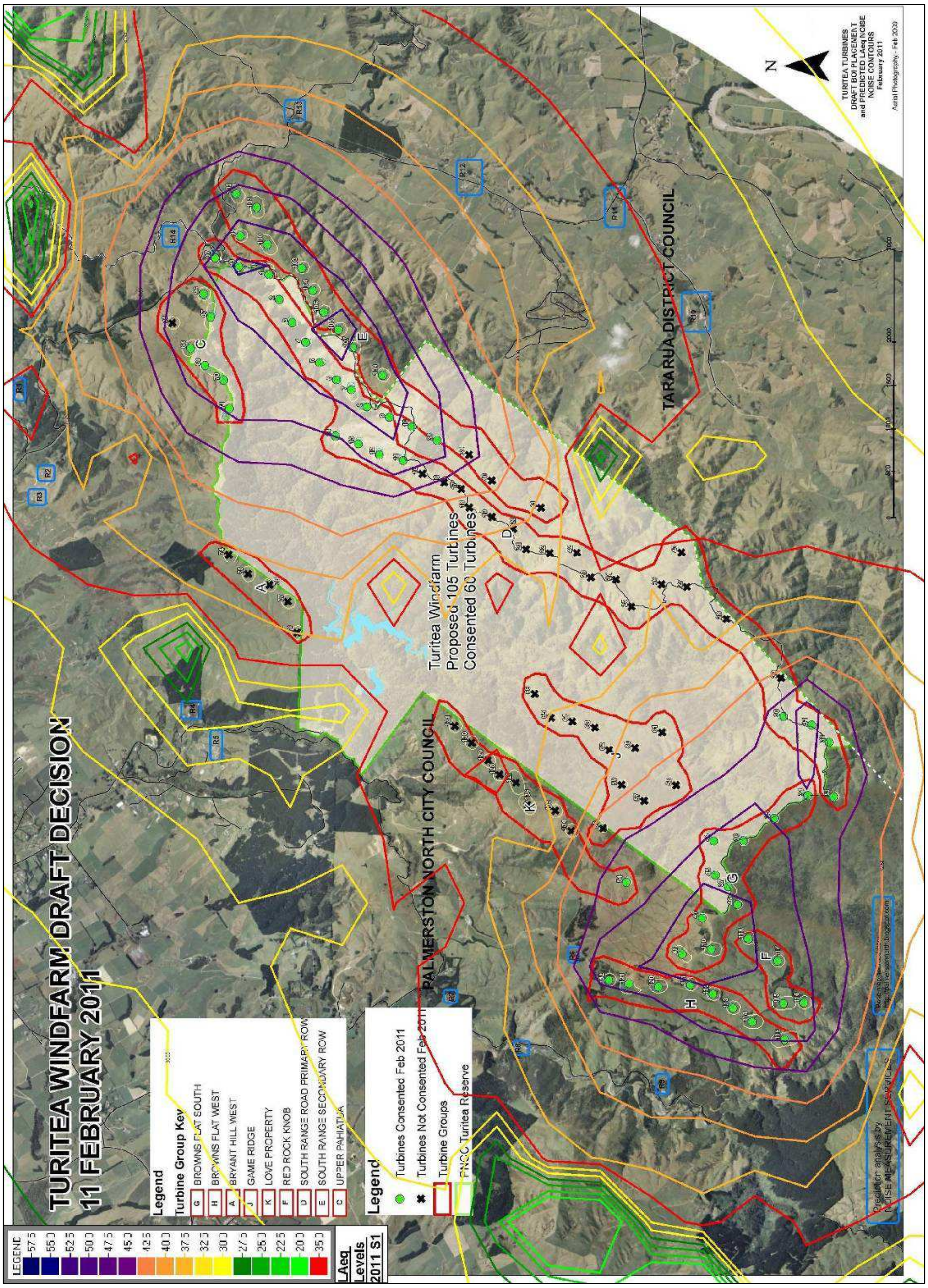
Table T1: Turitea predicted sound levels at receivers (residences, locales)

Receiver	LA90 dB	Turbine-Receiver Distance (metres)	Receiver	LA90 dB	Turbine-Receiver Distance (metres)
R1	33	1950	R8	36	1250
R2	35	2150	R9	40	1100
R3	34	2250	R10	33	3200
R4	29	3400	R11	34	3300
R5	30	3700	R12	38	2100
R6	34	1750	R13	40	1150
R7	44	450	R14	45	500

The predictions, made under ISO 9613-2 as required by NZS6808:2010 will have significant variation under soth-east wind conditions. Increases in sound level of 3dB to 6dB as well as modulating audible characteristics are predicted. Some residences are significantly affected and will be above the criteria established by the Board. The penalty of 5dB for special audible characteristics must also be considered.

This is of particular import to the residences to the north and north-west of the wind farm as this locale is impacted by the previously described noise problems from the Te Rere Hau wind farm.

Plate T1: Proposed Turitea Wind Farm Noise Levels in Relation to residences and other receivers



PART VII - 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 Manawatu – Brisbane Pilot Study

The Manawatu – Brisbane Pilot Study was undertaken by Thorne 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.

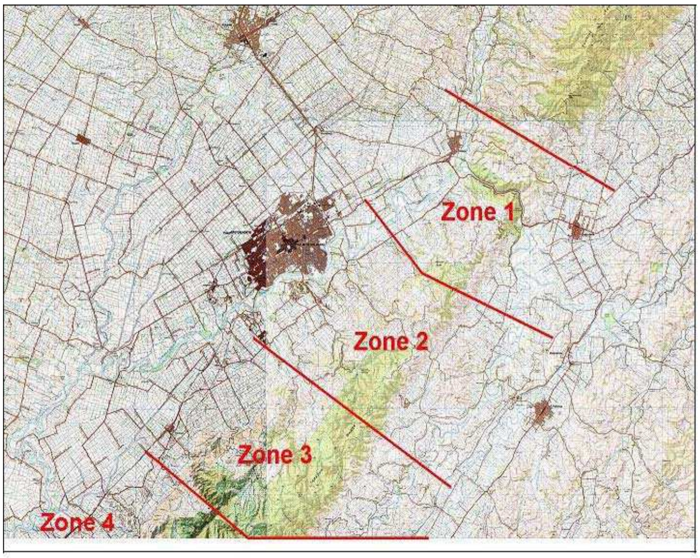


Figure 1: Manawatu Study Zones

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.

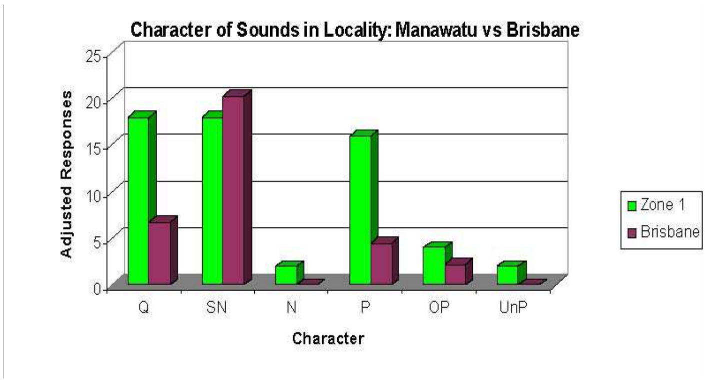


Figure 2: Character of the environment – Manawatu vs Brisbane.

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

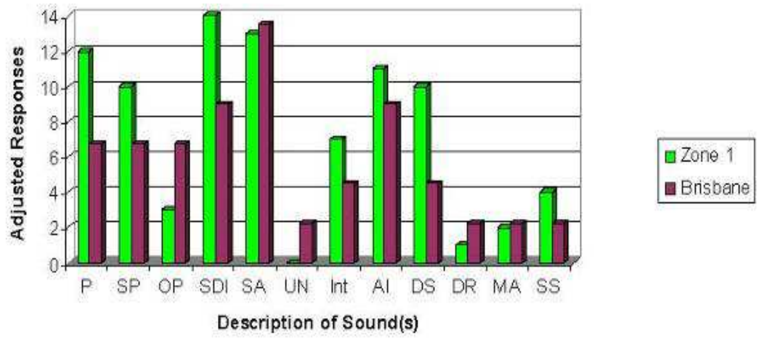


Figure 3: Description of sound(s) in the environment - Manawatu vs Brisbane.

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.

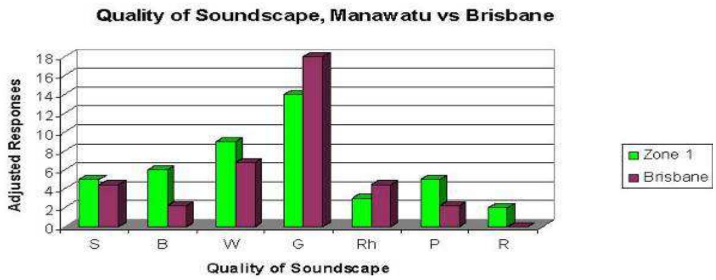


Figure 4: Qualities of Soundscape - Manawatu vs Brisbane.

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".

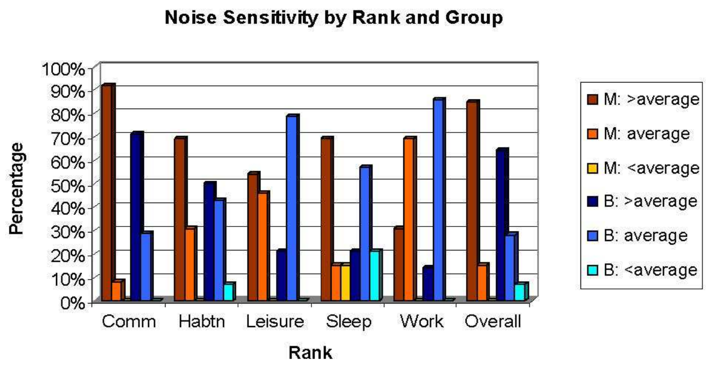


Figure 5: NoiSeQ Noise Sensitivity by rank and group as a percentage.

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.

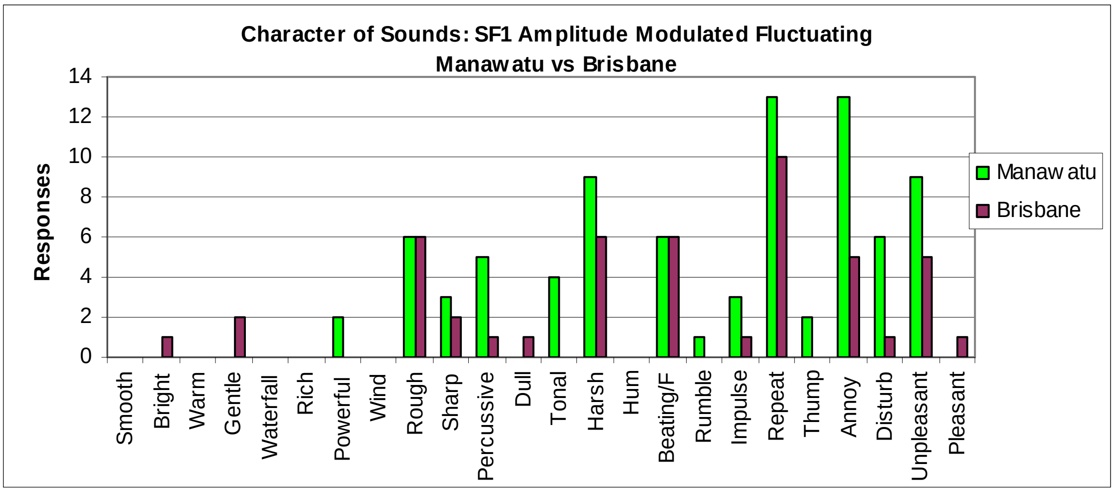


Figure 6: Responses to the character of SF1.

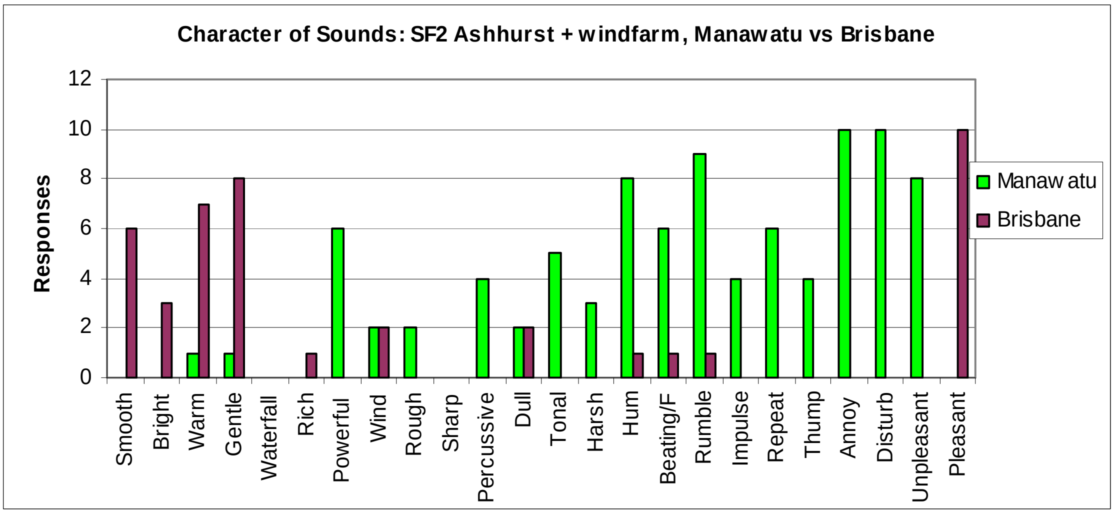


Figure 7: Responses to the character of SF2

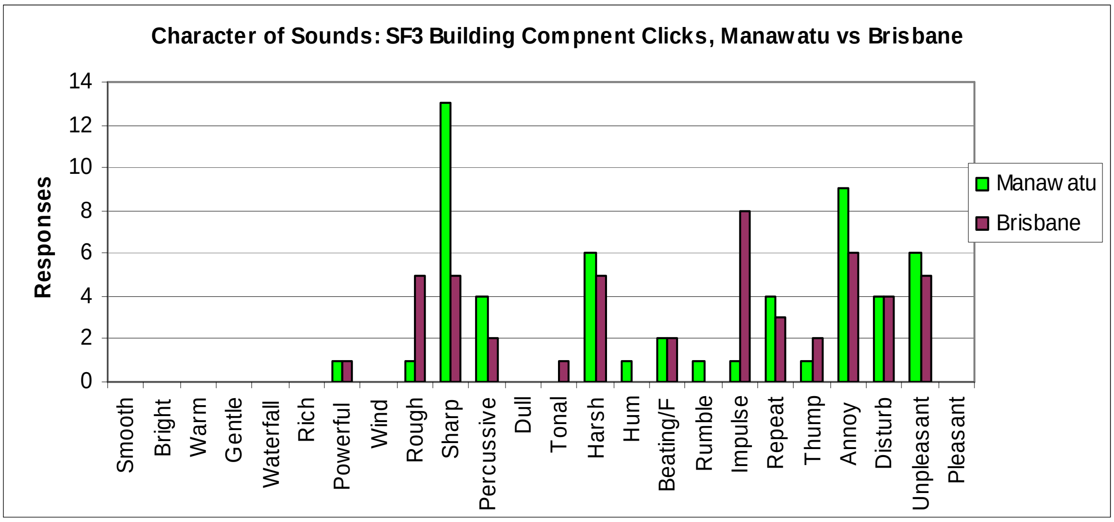


Figure 8: Responses to the character of SF3.

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.

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 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 VIII - 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

Therefore:

- 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.

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. 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.

Sound Perception

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. Acoustical analysis has little meaning to a person unless it is has a real relationship with an individual's responses to intrusive sound and can be described or explained in a way that the individual understands. Individuals understand intuitively what "noise" is to them personally, and this distinction may change day-by-day even to the same sound. Individual amenity is assessed as an *intrinsic* value reflecting personal noise sensitivity, personal and cultural attitudes to sound in the environment, the environment itself, and habituation effects. The *extrinsic* values that affect individual amenity are presented as community values that may have potential effect on the individual.

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. 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.

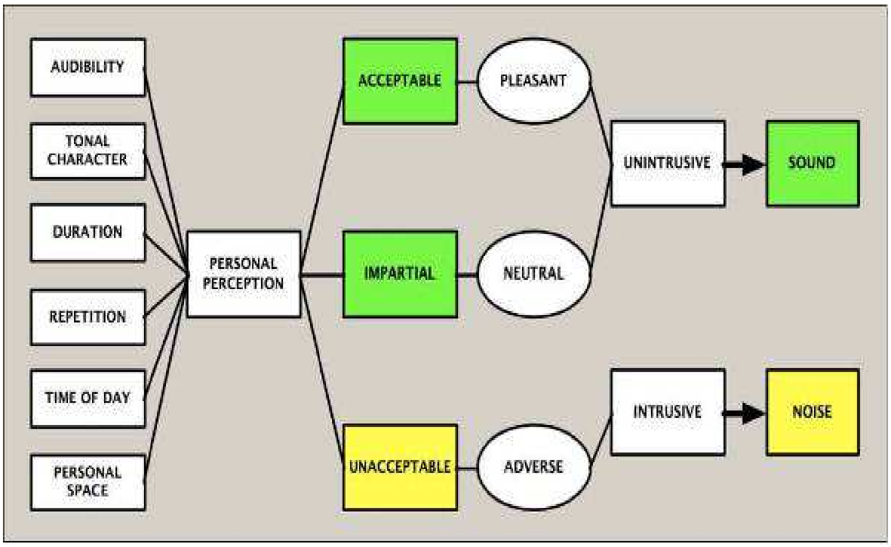


Figure 1: Subjective decision processes to differentiate between sound and noise.

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'.

The hypothesis, based on 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 to 35 dB 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[24] 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.

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.

[24] "Guidelines for Community Noise, World Health Organization, 2000

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[25] 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.

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,[26] identifying the relationship between noise from turbines and transportation. Pedersen and Persson Waye illustrate 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.

In 2009 Pedersen et al[27] published further research into the response to noise from modern wind farms in The Netherlands. The comparison of outdoor wind farm noise with other noise from transportation and industry, referenced to Lden sound levels, shows between 0% to 4% very annoyed at 37 dB and between 2% to 12% very annoyed at 42 dB. The medians are 1% and 5% respectively. The sound levels were calculated at the residences using the standard model ISO 9613-2. The 2009 data has a quite different wind turbine response curve to the 2004 paper. At an outdoor LAeq sound level of 35-40 dB, for example, the 2009 study presents approximately 6% very annoyed and 20% annoyed. At an outdoor level of 30-35dB approximately 2 to 3% of the respondents were highly annoyed. For both outdoors and indoors at 30-35 dB a high proportion (82-86%) of respondents either did not notice the turbines or were not annoyed by them. Noise from wind turbines was found to be more annoying than noise from several other sources at comparable Lden levels. The authors conclude, in part:

[25] 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

[26] '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

[27] Pedersen E, van den Berg F, Bakker R, & Bouma J, 2009, Response to noise from modern wind farms in The Netherlands, J. Acoust. Soc. Am. 126(2), 634-643

This study enlarges the basis for calculating a generalized dose-response curve for wind turbine noise usable for assessing wind turbine noise in terms of its environmental health impact, the number of people influenced by it, and, by extension, its role from a public health perspective. The syudy confirms that wind turbine sound is easily perceived and, compared with sound from other community sources, relatively annoying. Annoyance with wind turbine noise is related to a negative attitude toward the source and to noise sensitivity: in that respect it is similar to reactions to noise from other sources. This may be enhanced by the high visibility of the noise source, the swishing quality of the sound, its unpredictable occurrence, and the continuation of the sound at night. …

Further work has been published by Ambrose and Rand[28] to illustrate the relationship of wind farm noise exposure to transportation noise. They state that:

community noise studies have shown that public annoyance increases substantially when there is a noise source with unpredictable variability and unusual sounds. The Environmental Protection Agency's 1974 "Information On Levels Of Environmental Noise Requisite To Protect Public Health And Welfare With An Adequate Margin Of Safety, 550/9-74-004" presents a community reaction prediction methodology, which includes annoyance correction factors for seasonal operation, background sound level, previous experience to the noise and tone. Community reaction to wind turbine noise can be predicted using the EPA methodology and is normalized for quiet areas and the {1-hour} use of LAeq. Correction factors include 0 dB for year round operation, 10 dB for being located in a quiet area, 5 dB for no prior experience and, 5 dB for having a tonal or impulsive sound character. The graph showing normalized EPA community reactions is shown in Figure 3. This graph includes the results of 2004 independent wind turbine annoyance research, "Perception and annoyance due to wind turbine noise: A dose - response relationship," by E. Pedersen and K. Persson Waye, in the Journal of the Acoustical Society of America[29]. Figure 2 clearly shows that there is a predictable adverse community response for wind turbine noise levels above 32 dBA. Wind turbine noise levels below 35 dBA may be audible, but will result in the community reactions ranging from "no reaction, although noise is generally noticeable" to "sporadic complaints". Whereas from 35 to 45 dBA, there is a predicted adverse community response ranging from "widespread complaints or single threat of legal action" to "severe threats of legal action or strong appeals to local officials to stop the noise". Similarly, the 2004 data predict 6 to 85 percent of the community will be highly annoyed, with the associated adverse health effects of "psychological distress, stress, difficulties to fall asleep and sleep interruption."

[28] *October 30, 2010 by Stephen Ambrose and Robert Rand in Herald Gazette*
http://www.windaction.org/news/29706

[29] NMS Caution to readers: the Pedersen and Persson Waye findings have changed after 2004 with the publication of the 2009 paper. The changes will be reflected in a future revision of Figure 2.

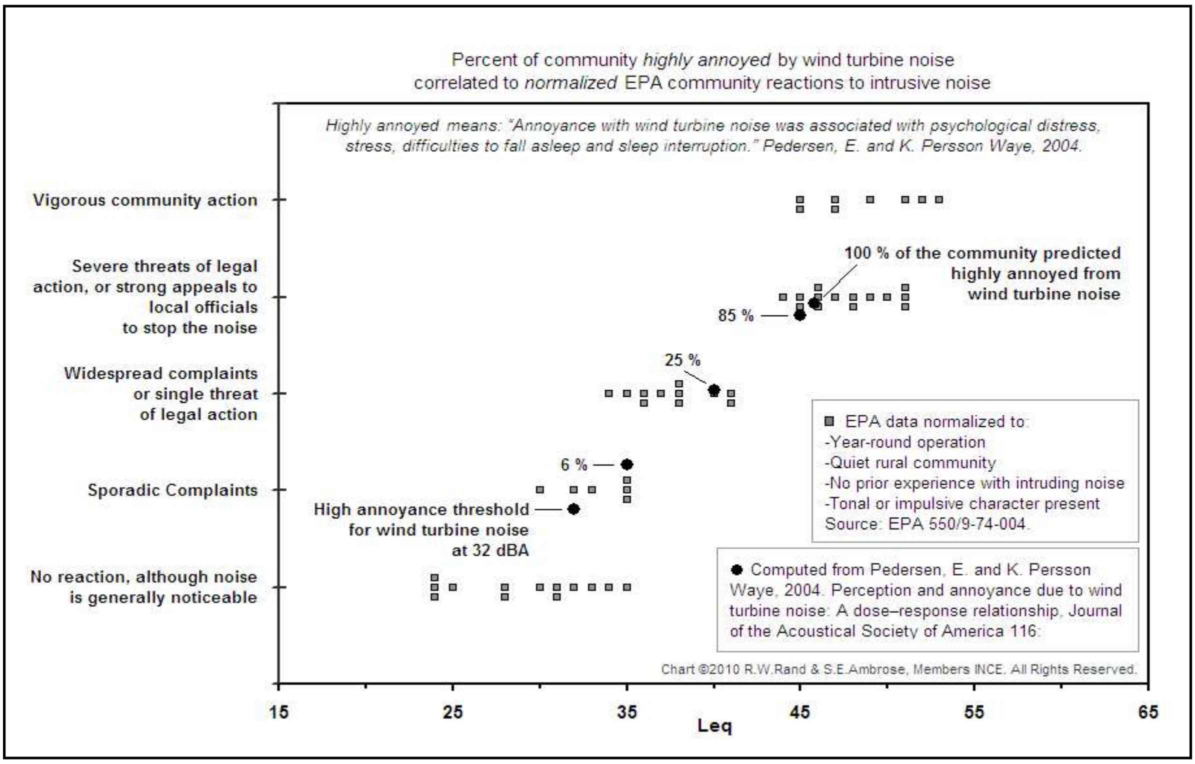


Figure 2: Predictable community reactions – annoyance, intrusive noise and complaints
Source: Ambrose, S and Rand, R. 2010, with permission

Audibility – Low frequency - Infrasound

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

A method for the prediction of the audibility of noise sources is detailed in a report[30] 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

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).

[30] *Graphic Method for Predicting Audbility of Noise Sources* (1982) by Bolt, Beranek and Newman for the US Flight Dynamics Laboratory (publication AFWAL-TR-82-3086.

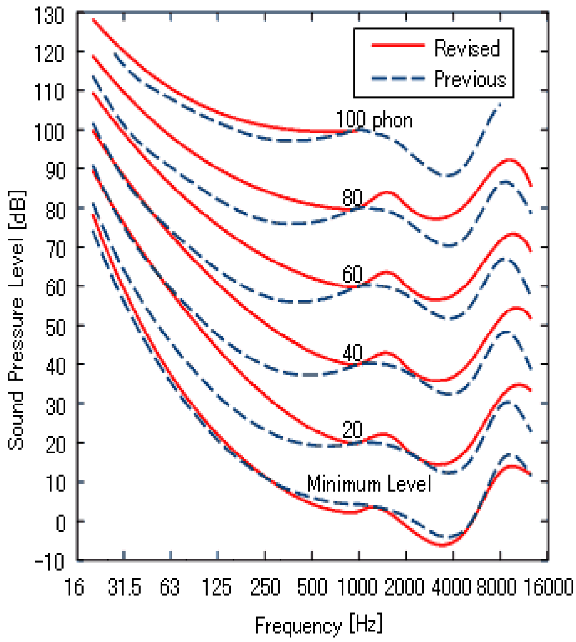


Figure 3: Equal loudness level contours vs sound pressure levels
(from: http://www.aist.go.jp/aist_e/latest_research/2003/20031114/20031114.html)

The research by Moller and Pedersen[31] 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 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

[31] 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

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.

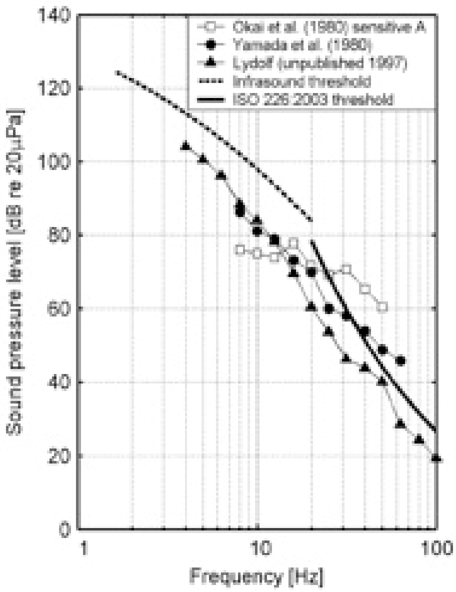


Figure 4: Hearing thresholds of three especially sensitive persons
(from Moller and Pedersen Figure 12)

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."

Salt and Hullar show 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.

A later paper by Salt and Kaltenbach[32] concludes that

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

Conclusion

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.

[32] Salt A.N. & Kaltenbach J.A. 2011. Infrasound from wind turbines could affect humans. (Not currently published)

PART IX - LOW FREQUENCY NOISE AND ITS EFFECTS

A Review of Published Research on Low Frequency Noise and its Effects

A Report for Defra by Dr Geoff Leventhall, Assisted by Dr Peter Pelmear and Dr Stephen Benton May 2003

10. Low frequency noise and stress

Stresses may be grouped into three broad types: cataclysmic stress, personal stress and background stress. Cataclysmic stress includes widespread and devastating physical events. Personal stress includes bereavements and similar personal tragedies. Cataclysmic and personal stresses are evident occurrences, which are met with sympathy and support, whilst their impacts normally reduce with time. Background stresses are persistent events, which may become routine elements of our life. Constant low frequency noise has been classified as a background stressor (Benton, 1997b; Benton and Leventhall, 1994). Whilst it is acceptable, under the effects of cataclysmic and personal stress, to withdraw from coping with normal daily demands, this is not permitted for low level background stresses. Inadequate reserves of coping ability then leads to the development of stress symptoms. In this way, chronic psychophysiological damage may result from long-term exposure to low-level low frequency noise.

Changes in behaviour also follow from long-term exposure to low frequency noise. Those exposed may adopt protective strategies, such as sleeping in their garage if the noise is less disturbing there. Or they may sleep elsewhere, returning to their own homes only during the day. Others tense into the noise and, over time, may undergo character changes, particularly in relation to social orientation, consistent with their failure to recruit support and consent that they do have a genuine noise problem. Their families and the investigating EHO may also become part of their problem. The claim that their "lives have been ruined" by the noise is not an exaggeration, although their reaction to the noise might have been modifiable at an earlier stage.

10.1 Low frequency noise and cortisol secretion. It is difficult to measure stress directly, but cortisol secretion has been used as a stress indicator (Ising and Ising, 2002; Persson-Waye et al., 2002; Persson-Waye et al., 2003). Under normal circumstances, cortisol levels follow a distinct circadian pattern in which the diurnal variation of cortisol is to drop to very low levels during the early morning sleep period, rising towards the awakening time. The rise continues until about 30 minutes after awakening, followed by a fall until midday and further fluctuations. Stress disrupts the normal cortisol pattern.

Ising and Ising (2002) discuss how noise, perceived as a threat, stimulates release of cortisol. This also occurs during sleep, thus increasing the level of night cortisol, which may interrupt recreative and other qualities of sleep. Measurements were made of the effect on children who, because of traffic changes, had become exposed to a high level of night lorry noise. There were two groups of subjects, exposed to high and low noise levels. The indoor noise spectrum for high levels typically peaked at around 60Hz, at 65dB, with a difference of maximum LC and LA of 26dB. The difference of average levels was 25dB, thus indicating a low frequency noise problem. Children exposed to the higher noise levels in the sample had significantly more problems with concentration, memory and sleep and also had higher cortisol secretions.

Conclusions of the work were that the A-weighting is inadequate and that safer limits are needed for low frequency noise at night.

Perrson Waye et al (2003), studied the effect on sleep quality and wakening of traffic noise (35dB LAeq, 50dBLAmax) and low frequency noise (40dBLAeq). The low frequency noise peaked at 50Hz with a level of 70dB. In addition to cortisol determinations from saliva samples, the subjects completed questionnaires on their quality of sleep, relaxation and social inclinations. The main findings of the study were that levels of the cortisol awakening response were depressed after exposure to low frequency noise and that this was associated with tiredness and a negative mood.

In a laboratory study of noise sensitive subjects performing work tasks, it was found that enhanced salivary cortisol levels were produced by exposure to low frequency noise (Persson-Waye et al., 2002). A finding was that subjects who were sensitive to low frequency noise generally maintained higher cortisol levels and also had impaired performance. A hypothesis from the study is that changes in cortisol levels, such as produced by low frequency noise, may have a negative influence on health, heightened by chronic noise exposure.

The three studies reviewed above show how low frequency noise disturbs the normal cortisol pattern during night, awakening and daytime exposure. The disturbances are associated with stress related effects.

EEG recording has been used to study sleep disturbance by low frequency noise (Inaba and Okada, 1988). Subjects in a sleep laboratory were exposed to levels up to 105dB at 10Hz and 20Hz, up to 100dB at 40Hz and up to 90dB at 63Hz. The effects were assessed by the "sleep efficiency index", which is the ratio of total sleep time to time in bed. Sleep times were determined from continuous EEG recordings. There was little effect for sound levels under 85dB, but reactions for the highest sound levels were significantly greater at 40Hz and 63Hz than for 10Hz and 20Hz.

PART X - MEASUREMENT SYSTEMS

The measurement of wind turbine sound presents practical problems with respect to the choice and application of sound measurement instrumentation. In most instances of noise measurement the sound is measured outside the dwelling, whereas the sound being complained about is heard inside the dwelling.

Most importantly, a sound level meter is a single channel (mono) electronically defined non-interpretative recorder compared to humans who are dual channel (stereo-ears) variable complex interpretative sound analysers. Dual channel recording is useful, therefore, in providing outside / inside sound level comparisons. Sound levels are recorded to test for compliance against standards or approval conditions and to assess human perception.

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_{90} or LA_{95}) levels. Emission levels are to be reported as A-weighted LAeq 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.*

Assessment of sound levels for human perception is more complex and is defined in amplitude (sound level) and in salience or dissonance (sound character). Both these concepts are standard measures in the world of music and known but not practiced in acoustics. It is this gulf of understanding – which people perceive sound as being pleasant or unpleasant, smooth or rough, dissonant or consonant – that appears to cause engineering acousticians so much trouble in comprehension. Whereas, to persons trained in music or psychoacoustics the measures are well understood. In acoustics the measures have become part of the 'sound quality' measurement methodologies.

A measurement system consists of a Class 1 microphone and preamplifier combination working through a purpose-designed low noise preamplifier and power supply. The system needs to be purpose designed as low amplitude sounds to around 15 dB and low frequency sounds to 1 Hz or less need to be accurately recorded. Inexpensive microphone and sound measurement systems tend to be 'noisy' and not record low amplitude or low frequency sounds. A sound recording system for measuring and assessing low amplitude intrusive sound is illustrated in Figure 1 and consists of:

- Hardware consisting of a microphone; preamplifier modules; a balanced cable to connect the preamplifier to a soundcard; a computer sound card; a power supply for the preamplifier; a calibration system
- Recoding and analysis software programs to record the sound into digital format; calibrate the soundcard and analysis program; simulate a Class 1 sound level meter; analyse the recorded sound; and display the results of the analyses made
- A Class 1 sound level meter to provide the reference – verification module
- Weather monitoring and vibration sensors

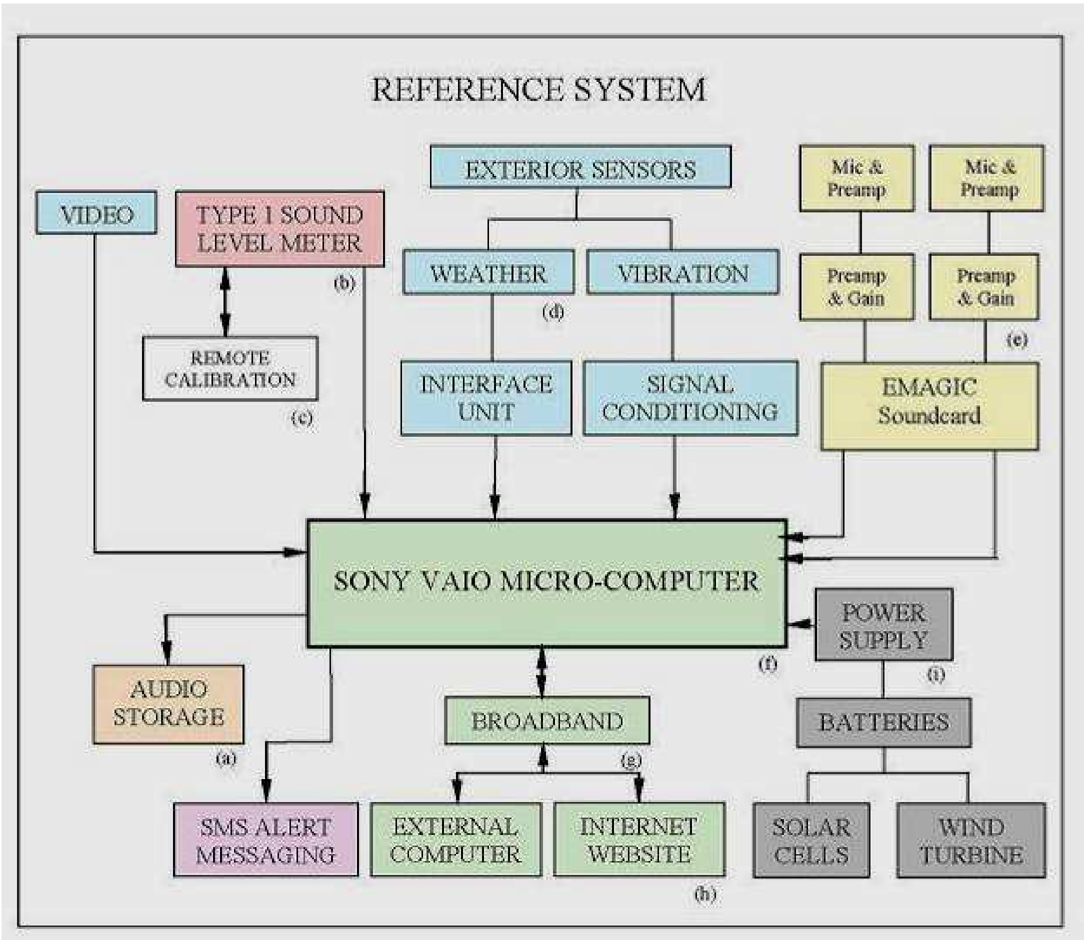


Figure 1: Reference sound recording system

Notes to figure:

(a) Audio storage – recorded at 44100 samples /sec, 16 bit, wav format

(b) Class1 sound level meter to independently record one-third octave and overall sound levels, and for recording output

(c) Remote calibration unit (used with a Larson Davis 831 Class 1 sound level meter)

(d) External sensors for weather at 3m and 10m above ground (wind speed and direction, rain, temperature and humidity); vibration; and video provided by standard commercial modules

(e) Microphone and preamplifier system Class 1, low noise, low frequency

(f) Sony Vaio computer or similar for remote access and control of complete system

(g) Broad-band access to upload sound files

(h) Data download to website for interested parties to access summary data

(i) Un-interruptible power supply

Standard sound levels are recorded in A-weighting as these are the most common values called up by approval or consent conditions. A-weighted levels, however, do not give the detail required in order to assess the operation of a turbine, the wind farm, or human perception. Making a decision about a sound requires listening to its audible characteristics but as the perception of these sounds vary from person to person other methods need to be made to communicate meaning or awareness. In the previous sections tables and line charts of summary values have been presented but these are often meaningless by themselves. Often it is the character of the sound that must be determined; whether for example, it has distinctive modulation or some special audible or perceptible characteristic.

Character of sound

Sound character is often called ‘sound quality’. Sound quality algorithms combine the psychoacoustical, physical, and cognitive aspects of sound in order to provide new analysis metrics. The character, salience, or dissonance of the sound can be measured with standard descriptors for audibility, loudness, sharpness, fluctuation, modulation, and unbiased annoyance.

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

A method for the prediction of the audibility of noise sources is detailed in the report "Graphic Method for Predicting Audibility of Noise Sources" (1982) by Bolt, Beranek and Newman for the US Flight Dynamics Laboratory Air Force Systems Command, publication AFWAL – TR – 82 – 3086. The report provides 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

Stationary loudness

Stationary loudness is an algorithm for steady-state noises, or signals that do not vary with time. This algorithm measures the 1/3 octave spectrum, combines the fractional-octave bands into critical bands, and then applies spectral masking. Stationary loudness is also known as ISO 532B loudness or Zwicker loudness and is in compliance with ISO 532B and DIN 45631.

Time-varying loudness

Time-varying loudness is an algorithm for calculating the loudness of non-steady-state noises, or signals that vary with time in compliance with DIN 45631/A or Glasberg & Moore.

Roughness

Roughness correlates to how noticeable or annoying a sound is as heard by the human ear. More specifically, roughness is a hearing sensation related to loudness modulations at frequencies too high to discern separately, such as modulation frequencies greater than 30 Hz.

Sharpness

Sharpness is a hearing sensation related to frequency and independent of loudness. Sharpness corresponds to the sensation of high-frequency sound and higher frequency components in the signal generally result in higher sharpness measurements.

Tonality

Tonality is used to determine whether a sound consists mainly of tonal components or broadband noise. The algorithm measures the relative strength of the tones in a signal compared to the overall signal. A standard method for tonal analysis is found in International Standard ISO 1996-2 second edition, *Acoustics - description, assessment and measurement of environmental noise - part 2: Determination of* *environmental noise levels*. The method is implemented in NoiseLab software and in some sound level meters.

Fluctuation

Fluctuation strength is a hearing sensation related to loudness modulations at low frequencies that are discernable individually. Fluctuation strength uses a similar method to "roughness versus time" analysis except that it focuses specifically on signal variations with very low modulation frequencies. The algorithm examines modulations between 0 to 30 Hz, with special emphasis on those near 4 Hz.

Modulation of Sound

Alternatives for spectral analysis for 'modulation' include the following measues:

(1) if the measured narrow-band (unweighted) peak to trough amplitude of the complex under investigation measured at a sampling rate of 50 milliseconds or 100 milliseconds, for example, exceeds 3 dB on a regularly varying basis, or

(2) if modulated unweighted spectral characteristics of the complex under investigation exhibit an audible frequency variation of 1 Hz to 4 Hz, for example, on a regularly varying basis, or a combination of both, or

(3) if the peak sound level (unweighted) peak to trough amplitude of the complex under investigation measured at a sampling rate of 50 milliseconds or 100 milliseconds, for example, exceeds 8 dB on a regularly varying basis.

Conditions relating to excessive amplitude modulated sound (blade swish) and the amenity of local residents including sleep disturbance are established in the United Kingdom Court of Appeal (Civil Division). The Approved Judgment is Case No: C1/2010/2166/QBACE of 26 May 2011 (available at www.bailii.org/ew/cases/EWCA/Civ/2011/638.html). The Approved Judgment canvasses a range of matters including compliance with conditions but the detail relating to modulation is-

> 20. "… to assess whether noise immissions at the complainant's dwelling are characterised by greater than expected amplitude modulation. Amplitude modulation is the modulation of the level of broadband noise emitted by a turbine at blade passing frequency. These will be deemed greater than expected if the following characteristics apply:
>
> a) A change in the measured LAeq, 125ms turbine noise level of more than 3 dB (represented as a rise and fall in sound energy levels each of more than 3 dB) occurring within a 2 second period.
>
> b) The change identified in (a) above shall not occur less than 5 times in any one minute period provided the LAeq, 1 minute turbine sound energy for that minute is not below 28dB.
>
> c) The changes identified in (a) and (b) above shall not occur for fewer than 6 minutes in any hour.

Noise immissions at the complainant's dwelling shall be measured not further than 35m from the relevant building, and not closer than within 3.5m of any reflective building or surface, or within 1.2m of the ground".

Unbiased Annoyance

Zwicker's unbiased annoyance (UBA) is modified by Thorne [2007] as a primary measure for noise assessment. The modified unbiased annoyance UBA*m* measure applies loudness (N10 in sones), Aures sharpness (in acums) and a new approach to fluctuation by implementing Sethare's Tonal Dissonance, *TD(S)* in *sets*, to account for frequency as well as amplitude fluctuation. The UBA*m* measure has an effect on soundfile measured values by emphasising the contribution of dissonance and tonalness. The calculation is given in 'intrusion units, *iu*':

$$UBAm = d(N10)^{1.3} \cdot \left\{1 + 0.25(S-1) \cdot \lg(N10+10) + 0.3TD(S) \cdot \frac{1+N10}{0.3+N10}\right\} \quad \text{iu} \qquad \text{eqn 1}$$

Loudness (N10) is the loudness in sones which is exceeded for 10% of the time. (The exponent in the first expression is 1.3). UBA*m* is modified for night-time. The value of '*d*' in equation 1 for the day is 1, for night-time the value of $d = 1 + (N10/5)^{0.5}$.

Hardware systems

Hardware systems to meet the measurement requirements are available from Larson Davis (Class 1, 831 sound level meter with audio recording, weather data and logging functions). Sound quality software systems are available from Head Acoustics[33]. An extremely versatile sound recording and analysis system, including hardware and software, is available for the iPhone™ from StudioSixDigital. Additional sound analysis software for the iPhone is available from FaberAcoustical. Purpose designed hardware and software is available from Atkinson&Rapley[34].

Conclusion

It is concluded that a combination of the methods is necessary to describe the character of the overall sound and the prominence of the sounds in relation to each other in order that people may easily gain knowledge of the character of the soundscape and the effects of wind turbines within that soundscape.

[33] The Australian agents for Larson Davis and Head Acoustics are at www.thermofisher.com.au
[34] Spectro Audio Meter, www.atkinsonrapley.co.nz

PART XI - NOISE MANAGEMENT

The measurement of wind turbine sound presents practical problems with respect to the choice and application of sound measurement instrumentation. In most instances of noise measurement the sound is measured outside the dwelling, whereas the sound being complained about is heard inside the dwelling. Noise management can be way of noise numbers, such as those in Part A, or setback distances, Part B.

Part A is a set of conditions that includes objective measurement. Noise numbers are given as a guide only to what may be acceptable in a particular location.

Part B is a précis of the distances established by the Wind Turbines (Minimum Distances from Residential Premises) Bill currently before the United Kingdom House of Lords. Setback distances are simple to establish and relate primarily to mitigating the effects of audible sound on non-sensitive individuals. The setback distances in the Bill are ineffective in mitigating noise for sensitive individuals or mitigating low frequency and infrasound effects.

Best practice will apply a combination of both Part A and Part B noise management methods.

In this regard, the Board of Inquiry into the proposed Turitea (New Zealand) wind farm is important as it is the outcome of nearly two years' deliberations. The Board, in its draft decision of February 2011, says:

> *Creating an environment where wind farm noise will be clearly noticeable at times of quiet background sound levels is not an option the Board condones, especially where large numbers of residents are affected. It is the Board's view that energy operations in New Zealand will have to learn not to place wind farms so close to residential communities if they are not prepared to accept constraints on noise limits under such conditions.*

The decision highlights the duty of care that decision-makers, developers, acoustical consultants and regulatory authorites have to themselves and potentially affected communities.

Part A: Noise Management by Noise Numbers

a) Except for times when the wind farm wind speed and background sound levels are such as to trigger a secondary noise limit, the turbines shall be designed, located, operated and maintained so that the wind farm sound levels measured by (LAeq, adj, 10 min) outdoors at any residence or noise sensitive place during the operational lifetime of the wind farm shall not exceed the background sound level of the existing acoustic environment by more than 5dB(A).

b) Where the outdoor wind speed at any residence or noise sensitive place is 6m/s or lower, a secondary wind farm noise limit shall apply under which the turbines shall be designed. located, operated and maintained so that the wind farm sound levels measured by (LA90, 10 min) outdoors at any residence or noise sensitive place during the operational lifetime of the wind farm shall not exceed the background sound level of the existing acoustic environment by more than 5dB(A), or a level of 35 dB(A) (LA90,10 min) whichever is the greater.

c) The secondary noise limit shall apply only between the hours of 10:00pm to 7:00am the next day.

d) The noise from wind farm activity, as measured inside any habitable room of a residence or noise sensitive place with windows open to represent typical 'worst case' conditions, shall not exceed:

i) during night-time (10:00pm to 7:00am the next day), a noise level of 30 dB LAeq,adj,10 min. and;

ii) at any other time the sound level shall not exceed 35 dB LAeq,adj,10 min.

In addition, perceptible or audible noise from wind farm activity shall not affect human health or wellbeing, including sleep or relaxation.

e) When noise from the wind farm has perceptible or audible characteristics that are perceived by the complainant as being cause for complaint, the measured sound level of the source shall have a 5 dB penalty added. Audible characteristics include tonal character measured as amplitude or frequency modulation (or both); and tonality (where the tonal character/tonality of noise is described as noise with perceptible and definite pitch or tone).

f) Before the use commences, an effective noise monitoring, evaluation and response process that addresses the noise compliance conditions must be submitted to, and approved by, Council’s delegated officer. The response measures will include the control, turning off, and/or decommissioning of turbines to alleviate noise breaches, and will be documented in a Wind Farm Noise Operations Manual.

g) Monitoring must be in accordance with International Standard ISO 1996-1:2003 Acoustics-Description, measurement and assessment of environmental noise - Part 1: Basic quantities and assessment procedures; International Standard ISO 1996-2:2007 Acoustics-Description, measurement and assessment of environmental noise - Part 2: Determination of environmental noise levels. The monitoring shall include all the sound levels as required by these noise conditions and shall include monitoring for the characteristics described in Annex A of International Standard IEC 61400-11 Wind turbine generator systems – Part 11: Acoustic noise measurement techniques. Wind speed and wind direction shall be measured at the same location as the noise monitoring location.

h) Thereafter, alleged noise breaches by the wind farm must be addressed in accordance with the approved noise monitoring, evaluation and response process as documented in the Wind Farm Noise Operations Manual to the satisfaction of the Council's delegated officer.

i) A post-construction noise monitoring program must be undertaken by the proponent that commences no later than 2 months after the commissioning of the first turbine and which continues for a minimum of 12 months after the commissioning of the last turbine, to the satisfaction of Council's delegated officer. That monitoring will be undertaken at all existing residences or noise sensitive places and the results will be provided to Council at six monthly intervals commencing from the date of commissioning of the first turbine.

j) An independent specialist noise consultant (other than the company who prepared the predictive acoustical report) will be appointed by the Council and will monitor and verify wind farm noise levels that are the subject of complaint about either environmental nuisance or environmental harm due to noise. For the purposes of these conditions, a specialist noise consultant is taken to be a person qualified in acoustics and experienced in real-time measurement and post-processing assessment of audible and perceptible characteristics of wind farm noise.

k) The proponent will lodge a cash bond of $ 40,000 for any costs associated with that monitoring and verification.

l) The wind farm complaint process must provide for an immediate, 24-hour, 7-day response by the wind farm operator to a complaint, and the specified responses will include noise monitoring and noise mitigation. The wind farm operator must notify Council within 24 hours of the receipt of a complaint and the operator must state what action has been taken, or is proposed, to bring the wind farm into compliance. The complaint process will also provide for complaints received by Council.

m) If the post-construction noise monitoring at any existing residence or noise sensitive place identifies wind farm noise that exceeds the noise limit criteria specified in these conditions, or if a valid complaint lodged under the process established under these conditions is received by Council or the operator, the approval holder shall take immediate action to mitigate such noise.

n) Where reasonable and feasible, the applicant/operator may, subject to the owner's agreement and consent, provide that noise mitigation in the form of physical building modifications to an existing residence, or to a new residence built on any vacant parcel of land. The noise mitigation measures are to achieve a night-time noise level (10:00pm to 7:00am the next day), of 30 dB LAeq, adj, 10 min and daytime and evening noise level of 35 dB LAeq, adj, 10 min inside a habitable room of the residence with windows open. The sound inside the habitable room shall have no perceptible or audible noise from wind farm activity.

Definitions: a 'noise sensitive place' includes a school, hostel, hotel or accommodation premises.

Part B: Noise Management by Setback Distances

(1) The "minimum distance requirement" means the necessary minimum distance between the wind turbine generator and residential premises as set out in subsection (4).

(2) "Residential premises" means any premises the main purpose of which is to provide residential accommodation, including farmhouses.

(3) If a number of wind turbine generators are being built as part of the same project the minimum distance requirement applies to each wind turbine generator individually.

(4) If the height of the wind turbine generator is—

(a) greater than 25m, but does not exceed 50m, the minimum distance requirement is 1000m;

(b) greater than 50m, but does not exceed 100m, the minimum distance requirement is 1500m;

(c) greater than 100m, but does not exceed 150m, the minimum distance requirement is 2000m;

(d) greater than 150m, the minimum distance requirement is 3000m.

(5) The height of the wind turbine generator is measured from the ground to the end of the blade tip at its highest point.

(6) There is no minimum distance requirement if the height of the wind turbine generator does not exceed 25m.

(7) If planning permission is granted on the condition that the proposed wind turbine generator meets the minimum distance requirement under subsection (5) the actual height of the wind turbine generator must not exceed the maximum height in relation to that minimum distance.

PART XII - GLOSSARY

Term	Definition
Acoustic environment	The part of the environment of a place or locality characterised by the noise that may be experienced there (*cf. soundscape*)
A-weighting	A-frequency weighting is the weighted sound pressure over the frequencies between 10 Hz and 20,000 Hz.
Algorithm	A well-defined procedure to solve a problem
Ambience	Our physical surroundings and personal perception of those surroundings; sense of place
Amenity	Pleasantness or a useful feature of a place
Amenity values	Means 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.
Amplitude	The equivalence of "loudness" and "volume" to intensity in decibels *(colloquial)*
Annoyance	A feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them
Attribute	Property, e.g., the pitch, loudness or timbre of a sound sensation
Audible	Capable of being heard
Audible level	Level of a pure tone (component) above masked threshold
Audibility	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
Aural texture	The perception by a person of the interaction of the characteristics of all the sounds in a particular environment at a particular time
Bark	Unit of critical band rate equal to one critical bandwidth
Beats	Periodic variations that result from the superposition of two simple harmonic quantities of different frequencies f_1 and f_2. They involve the periodic increase and decrease of amplitude at the beat frequency ($f_1 - f_2$)
Calibration	A standard test method for an instrument to check its performance against a standard measure
Cent	1/100 of an equal temperament semitone
Character	Distinctive features
Chroma (1)	Pitch class without the specification of octave register, eg "C" instead of "C_4"
Chroma (2)	Interval in semitones between a pitch category and the nearest "C" below
Chroma salience	Measure of the perceptual importance of a particular chroma in a musical sound or sequence, as perceived by an average or "ideal" listener
Complex sound	Sound whose pressure waveform is not sinusoidal, and whose spectrum therefore contains more than one pure tone component
Complex tonalness	Measure of tonalness; the audibility of the most audible complex tone sensation of a sound
Conservative	Opposed to great change, avoiding extremes; (of an estimate) purposefully low

Consonance	How well the tones of a simultaneity or sounds in a sequence sound together, depending on roughness, tonalness, pitch commonality, pitch distance, context, familiarity and cultural conditioning (*cf. sensory consonance*)
Costs and benefits	Includes costs and benefits of any kind, whether monetary or non-monetary, and valuation of amenity
Critical band	Maximum range of frequencies over which the ear is like a single band-pass acoustic filter (so loudness is independent of bandwidth); at wider ranges, it is like a bank of band-pass filters (so loudness increases with increasing bandwidth)
Critical bandwidth	Width of a critical band (in semitones or Hz), equal to about 3 semitones above 500 Hz, and 50 - 100 Hz below 500 Hz; contains a constant number of pitch difference thresholds
Day-Night Level	Day-night average sound level; the cumulative 24-hour level is calculated by the hour or second and sound exposure levels at night (10pm to 7am) are weighted by +10dB
dB	decibel; one-tenth of a bel
dB	decibel, where the sound pressure is A-frequency weighted
Decision support systems	computer based information systems that combine models and data in an attempt to solve non-structured problems with extensive user involvement
Disease (Humans)	An abnormal condition affecting the body; often used more broadly to refer to any condition that causes pain, distress, social problems or death.
Dissonance	Roughness, unpleasant *(cf sensory dissonance)*
DNL	See Day-Night Level
Environment	Ecosystems and their constituent parts, including people, their communities, and their amenity values and the social, economic, aesthetic, and cultural conditions which affect them.
Environmental value (personal)	The qualities of the acoustic environment that are conducive to the well-being of an individual, including the individual's opportunity to have sleep, relaxation and conversation without unreasonable interference from intrusive noise.
Environmental value (community)	The qualities of the acoustic environment that are conducive to the well-being of the community, or part of the community, including its social and economic amenity
Epidemiology	is the study of factors affecting the health and illness of populations
Equal temperament	Term for the 12-tone tuning system of 12-TET that divides the octave into 12 equal parts
Equivalent frequency	Measure of pitch; frequency of a standard reference tone whose pitch is the same as that of a particular tone sensation
Erb	Equivalent rectangular bandwidth. The Erb of a given auditory filter using Patterson's method are typically between 11% and 17% of the centre frequency.
Excessive noise	Any noise that is under human control and of such a nature as to unreasonably interfere with the peace, comfort, and convenience of any person.
Expert system	A computer based system that applies reasoning methodologies on knowledge in a specific domain in order to render advice or recommendations, much like a human expert.
Extrinsic	Not inherent or essential to an individual; community values that may have potential effect on the individual
FFT	Fast Fourier Transform. A mathematical algorithm to compute the discrete Fourier transform (frequency domain) from a digital (time domain) signal or soundfile
Forward masking	The condition in which the masking sound appears before the masked sound
Fundamental	First harmonic; lowest pure tone component of a full complex tone

Harmonic	Whole multiple of a specified number; pure tone component whose frequency is (close to) n times the waveform (fundamental) frequency of a complex tone
Harmony	General term embracing consonance
Health (1)	A state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity
Health (2)	Includes physical, mental, emotional, social and spiritual wellbeing. *(for NZ health impact assessment)*
Hearing threshold level	The hearing level at which a tone of specified frequency is heard by an ear in a specified fraction of trials
Heuristics	Decision rules regarding how a problem should be solved
High amplitude sound	Sound levels above 80 dB
Holistic	The treating of the whole person including mental and social factors rather than just the symptoms of a disease *(cf. wholistic)*
Hz	Hertz; frequency in cycles per second
Intensity	Of a sound: amount of energy transmitted per unit time, per unit area perpendicular to the direction of propagation
Intrinsic	inherent, essential, belonging naturally; reflecting personal noise sensitivity, personal and cultural attitudes to sound in the environment, the environment itself, and habituation effects
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
Intrusive sound	A sound that, by its characteristics, is audible and intrudes upon the well-being or amenity of an individual
ISO	International Organization for Standardization
Just noticeable difference (1)	The differential threshold, or difference limen, is the change in stimulus that can be correctly judged as different from a reference stimulus in a specified fraction of trials
Just noticeable difference (2)	Under careful testing, the just noticeable difference can be 2 to 3 cents
Knowledge base	A collection of facts, rules, and procedures organized into schemas. The assembly of all information and knowledge of a specific field of interest
L10, L90, L95	The time-weighted and frequency-weighted sound pressure level that is exceeded for 10%, 90% or 95% of the time interval considered, in decibels
LAeq	See Time-average sound level
Lden	Day-evening-night noise exposure; the long term time-average level to which penalties of 5dB for evening and 10 dB for nightime hours are added
Loudness	Attribute of auditory sensation by which different sensations may be ordered on a scale extending from “soft” to “loud”
Loudness Level	Value in phons that has the same numerical value as the sound pressure level in decibels of a reference sound, consisting of a frontally incident, sinusoidal plane progressive wave at a frequency of 1000 Hz, which is judged as loud as the given sound
Loudness Level (2)	Normal equal-loudness-level contour
Low amplitude	Sound levels below 50 dB to nominal threshold of hearing
Masked threshold	Threshold of audibility in the presence of maskers
Masker	A sound that masks other sounds

Masking	Complete or partial “drowning-out” of one tone by another
MIDI	Musical Instrument Digital Interface – a protocol for electronic musical devices
Moderate amplitude sound	Sound levels ranging between 50 dB to 80 dB
Modulation (1)	Periodic change in the amplitude or frequency of a sound (beating)
Modulation (2)	‘Amplitude modulation’ is a spectral modification process that produces discrete upper and lower sidebands determined by the modulation frequency and the modulation depth *m*.
Modulation (3)	‘Amplitude modulation depth’ is a measure of the spectral energy spread of an amplitude modulated signal.
Modulation (4)	Modulation, by amplitude, is defined as a peak to trough variation that exceeds 3dB on a regular basis (3dB is taken as negligible, 6dB as unreasonable and 9dB taken as excessive); by frequency, modulation is defined as a variation that exceeds one semi-tone on a regular basis.
Modulation frequency	The difference between the frequencies of two beating pure tone components
ms	milli-second (1/1000 of a second)
Negligence	A failure to exercise duty of care in a professional situation
Noise	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.
Noise annoyance	An emotional and attitudinal reaction from a person exposed to noise in a given context.
Noise sensitivity	A person’ condition enhancing their reactivity to noise
Normal equal-loudness-level contour	Equal-loudness-level-contour that represents the average judgment of otologically normal persons within the age limits from 18 years to 25 years inclusive
Octave	Distance between two tones or frequencies corresponding to a frequency ratio of 2:1; a frequency level difference of 12 semitones
Peer Review	Professional or scholarly. An impartial critique of someone else’s work to determine if it is sound and robust. The review is based on the reviewer’s own research / experience and knowledge of the current literature in the field. The role of the reviewer is not to bring in new information, but rather to say whether or not, in the reviewer’s expert opinion, that the person’s work being reviewed is sound. If there are errors or critical omissions, these need to be highlighted with appropriate justification. If the information / data is considered accurate, this should be noted.
Perceive	To understand; to apprehend
Phon	The loudness level of a given sound or noise
Pitch (1)	Attribute of a tone sensation by which it may be ordered on a scale from “low” to “high”
Pitch (2)	An auditory attribute in terms of which sine tones can be ordered on the low-high dimension *(cf. spectral pitch and virtual pitch)*
Pitch (3)	Perceived fundamental frequency of a sound
Pitch difference thresholds	Just noticeable difference in pitch, smallest perceptible physical change in a stimulus
Pitch prominence	Audibility, salience of a pure tone
Precautionary Principle	Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation
Prediction methods	Methods to calculate sound levels emitted from a source(s) to a distant receiver(s);

	an estimate defined by the model's calculation assumptions and uncertainties
Psychoacoustics (1)	The science that deals with the psychological correlates of the physical parameters of acoustics
Psychoacoustics (2)	Human perception of sound and noise
Psychophysics	The science that deals with the qualitative relationships between physical and psychological events
Pulsing	A rhythmic beat or vibration; as in a pulsating sphere
Pure tone	Tone whose pressure waveform is sinusoidal
QEPA	Environmental Protection Agency, Queensland, Australia
Qld EPP (Noise)	Environmental Protection (Noise) Policy 1997 (2008), Queensland, Australia
Root mean square (RMS)	Average value of a waveform calculated by taking the square root of the mean of the square of the function
Roughness	Sensation associated with beating at frequencies in the range 20 – 300 Hz
Rule	A formal way of specifying a recommendation, directive or strategy, expressed as IF premise, AND statement(s), THEN conclusion
Salience	Perceptual importance or prominence of a stimulus; probability of being noticed or sensation being experienced
Semitone	Unit of frequency level; twelfth part of an octave; equal to 100 cents (equal temperament)
Sensation	The consciousness of perceiving or seeming to perceive some state or condition of one's body or its parts or senses or of one's mind or its emotions
Sensory consonance	The absence of dissonant beats
Sharpness	Sharpness is a measure of the high frequency content of a sound, the greater the proportion of high frequencies the 'sharper' the sound.
Significant	(in statistics) most unlikely to have occurred by chance (e.g., $p<0.05$ means that the probability of a given result occurring by chance is less than 5%.
Socio-acoustic	Social attitudinal study combined with an acoustical survey within the same community
Sone	Loudness. The numerical definition of the strength of a sound which is proportional to its subjective magnitude as estimated by normal observers. One sone is the loudness of a sound whose loudness level is 40 phons.
Sound exposure	The total sound energy produced from a sound source over a specified time or event
Soundfile	Sound recording (often) in Microsoft PCM .wav format
Sound quality	The character of sound as perceived by a person
Soundscape	The part of the environment of a place or locality characterised by the sounds that may be experienced there (*cf. acoustic environment*)
Special audible characteristics	Sound that has distinct features such as impulsiveness, modulation or tonality that makes the sound stand out from other sounds in the same soundscape
Spectral pitch	An elementary auditory object that immediately represents a spectral singularity, e.g., a sine tone *(cf virtual pitch)*
Subharmonic	Whole multiple of a particular number (e.g., 2.5 is the 4^{th} subharmonic of 10)
Threshold of audibility	Threshold sound pressure (defined for an average "ideal" listener) below which a pure tone is inaudible, expressed as a function of its frequency *(cf Hearing threshold level)*
Threshold of hearing	Level of a sound at which, under specified conditions, a person gives 50% of correct

	detection responses on repeated trials
Threshold of pitch	Lowest (20 Hz, E_0) or highest (16 kHz, C_{10}) audible pitch
Timbre	Timbre or tone quality or tone colour is a function in time of the frequency content or spectrum of a sound, including its transients and pitch, loudness, duration and manner of articulation. Timbre allows a person to distinguish between different sounds, instruments and voices.
Time-average sound level	Time-average sound level or equivalent continuous sound level, no frequency weighting stated but normally A-weighted
Tonal	Evoking pitch or tone sensation(s)
Tonality (1)	Pitch structure in music in which some pitches are more important (salient, stable) than others
Tonality (2)	A sound sensation having unambiguous pitch; other attributes include loudness or salience, timbre, and apparent duration *Cf. tone sensation*
Tonalness	The extent to which a sound evokes (pure or complex) pitch or audible tone sensations
Tone (1)	Sound which evokes a tone sensation; approximately or exactly periodic sound in the audible range of frequencies; sound whose various possible pitches belong mostly to a single chroma
Tone (2)	A sound sensation having pitch
Tone sensation	Auditory sensation having one, unambiguous pitch; other attributes include loudness or salience, timbre, and apparent duration
Unbiased Annoyance	The response of subjects annoyed exclusively by sound under describable acoustical circumstances in laboratory conditions without relation to the nature of the source
Unreasonable noise	Unreasonable noise is a sound or vibration that is: - annoying to a reasonable person; or - injurious to personal comfort or health, including sleep disturbance; or - a disturbance to the quiet enjoyment of land including the grazing of stock or keeping of animals; or - observed to have a detrimental affect on wildlife or the environment
USEPA	United States Environmental Protection Agency
Virtual Pitch	An attribute of auditory sensation with the fundamental pitch ‘extracted’ by the auditory system from a range of the Fourier spectrum that extends above the fundamental
.wav	Microsoft uncompressed PCM audio file format for storing audio in digital format in a computer
WHO	World Health Organization
Wholistic	Whole, complete, comprising or involving all parts
Z-weighting	Z- weighting (very similar to the previous ‘Lin’ or ‘Flat’ response) gives the unweighted sound pressure level with lower and upper cut-off as specified by the manufacturer; generally 20 Hz to 20,000 Hz

RECOMMENDED READING

In addition to the references in the body of the Review the following are recommended reading to the issues of sound, noise, human perception, adverse health effects and wind farm activity. These documents are included to assist any person wishing to source an overview of some of the literature currently available.

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