Wind Farm

Noise Guideline

2011

NOISE MEASUREMENT SERVICES

CONTROL PAGE

NOISE MEASUREMENT SERVICES PTY LTD
18 Lade Street Enoggera Qld 4051
PO Box 2127
Brookside Centre, QLD 4053

Telephone: (7) 3355 9707
Facsimile: (7) 3355 7210
E-mail: info@noisemeasurement.com.au
ABN 70 084 648 023

Revision No	Issue Date	Revision Description	Checked By	Issued By
0-3	2010, 2011	2010Guides superceded January 2011 superceded	MT	BT
March 2011	March 2011	Revised and updated as '2011'	Reviewers	BT

Approved for Release

Bob Thorne

DISCLAIMER

The Guideline presents only the information that Noise Measurement Services Pty Ltd believes, in its professional opinion, is relevant and necessary to describe the issues involved. While the Guideline has been prepared with care, it contains general information and does not profess to offer legal, professional or commercial advice. Noise Measurement Services Pty Ltd accepts no liability for any decisions or actions taken on the basis of this document. Persons should satisfy themselves independently and by consulting their own professional advisors before embarking on any proposed course of action.

The Guideline has been peer-reviewed. Critique from persons having researched conclusions different from the author will be considered when such critique is supported by evidence researched by the person presenting the critique and supported by a statement of qualifications and experience.

PREAMBLE

In the past 10 years more interest has been shown in renewable enrgy and the development of wind farms. Wind farms are now 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 decision highlights the duty of care that decision-makers, developers, acoustical consultants and regulatory authorites have to themselves and potentially affected communities. This Guideline provides impartial information for a wind farm noise risk analysis of reasonable / unreasonable noise and serious adverse effect / serious harm to health and measures to avoid, remedy or mitigate such noise.

CONTENTS

PART I - INTRODUCTION

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.

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

Wind has audible and sub-audible character. That is, measurement of wind sound will always present sound levels in the audible, low-frequency and infrasonic frequencies. Adverse health effects are due to extreme psychological stress from environmental noise, particularly low frequency noise with symptoms of sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic attack episodes associated with sensations of internal pulsation when awake or asleep. Sound in the low frequencies can be heard if the sounds are loud enough. Infrasound, however, is more perceptible rather than heard at relatively lower levels of "loudness". The research documented in this Guideline indicates "ordinary" wind has a laminar or smooth infrasound and low-frequency flow pattern when analysed over short periods of time. Wind farm activity appears to create a "pulsing" infrasound and low-frequency pattern. These patterns are illustrated in sonograms in this Guideline. The hypotheses derived from professional research reported here is that wind farm noise has an adverse effect on susceptible individuals due to these pressure variations as well as audible noise due to the wind turbines. These effects may be cumulative.

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

Conclusions

It is concluded that, based on professional opinion, 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. The markers for this are (a) a sound level of LAeq 32 dB outside the residence and (b) above the individual's threshold of hearing inside the home.

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

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

It is concluded that meteorological conditions, wind turbine spacing and associated wake and turbulence effects, vortex effects, wind shear, turbine synchronicity, tower height, blade length, and power settings all contribute to sound levels heard or perceived at residences. 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.

It is concluded that compliance monitoring must be independent of the wind farm operator and must include continuous real-time measurement of special audible characteristics such as modulating sound in order to determine the perceptible effects of audible sound and inaudible infrasound.

Recommendations

It is recommended that no large-scale wind farm or large turbine should be installed within 2000 metres of any dwelling or noise sensitive place unless with the approval of the landowner. Further, it is recommended that no large-scale wind turbine should be operated within 3500 metres of any dwelling or noise sensitive place unless the operator of the proposed wind farm energy facility, at its own expense, mitigates any noise within the dwelling or noise sensitive place identified as being from that proposed wind farm energy facility, to a level determined subject to the final approval of the occupier of that dwelling or noise sensitive place.

PART II - THE PROBLEMS WITH RURAL WIND FARMS

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

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

Residents living near operational rural wind farms report sleep disturbance and adverse health effects.

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

Inappropriate Land-use Planning

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

Following this logic it is far better that the wind farm be located within the urban area that requires the power. Thus the cost of development is lower, access to a large pool of labour is assured, access to materials and roading is no problem, and there are, based on the guidelines, no adverse environmental effects from wind turbine noise. Turbine efficiency is not an issue as the wind farm and turbine choice can be designed for the relevant air and building environments. Wind farms tend to be developed in areas where rural landowners have agreed to lease a portion of their land for the term of the wind farm, nominally 20 years. Lease arrangements are a normal part of industrial business and would be acceptable in an urban environment.

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

The Problems with Wind Farm Noise and Its Perception

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

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

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

Ineffective Compliance Approvals

An effective compliance approval is one that applies conditions to specifically avoid adverse environmental outcomes. A partly effective compliance approval is one that mitigates adverse environmental outcomes. An ineffective compliance approval is one that permits or encourages adverse environmental outcomes. 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.

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

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

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

PART III - A CASE STUDY

A Rural Wind Farm

The issues affecting the development and effects of a rural wind farm can be explained through a case study referencing a residence and persons who are affected by the Waubra wind farm near Ballarat in Victoria. The wind farm received permission to establish and was, as far as 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 this Guide.

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. This is explained in more detail later in this Guide.

Case study with a Waubra residence

The noise predictions are not a single line or a single number but, in fact, a range of sound levels. In this case study 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).

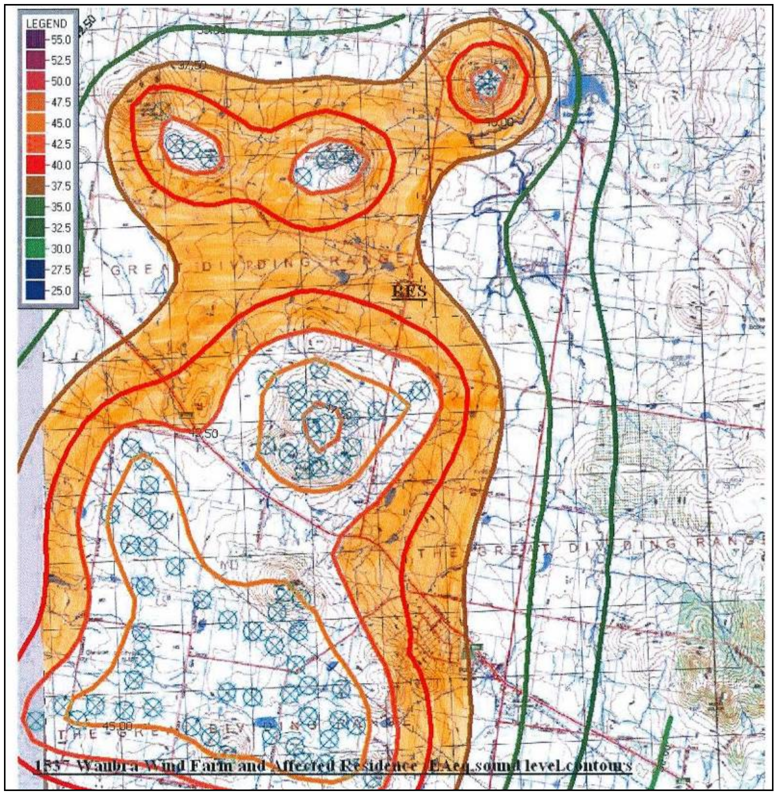


Plate 1: Predicted 40 dB LAeq Zone affecting a residence (RES)

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 wake effects 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 wind farm background levels in the presence of ambient background levels (the real world) is extremely difficult to impossible. This observation is made on the basis of five years' monitoring wind turbines at different locales under widely different weather conditions. **Figure 1** illustrates the issue: there are 3 separate sets of background influencing sound sources – local ambient, the turbines, and distant sources. It is not possible to separate out the contribution of each source once it is recorded as a single-value background measure (LA90 or LA95) at a specific location, such as a residence. The same problem occurs when a single-value level, such as 40 dB 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.

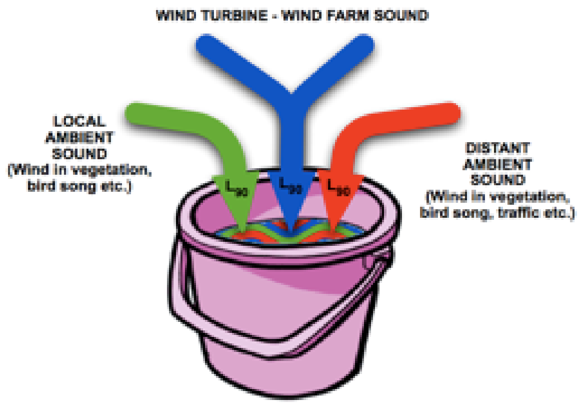


Figure 1: "Bucket of mixed sound" as L_{Aeq} or L_{A90} level.

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

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

The Effects of Weather

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

a) a prevailing breeze blowing from the wind farm to residences; or

b) under conditions of cool, clear evenings/nights/mornings when a mist (inversion) covers the ground.

This latter condition (b) is sometimes called the 'van den Berg effect'. It is a common condition. 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 Case Study the operation of the turbines to the south-west of the residence can be clearly heard at the residence. The sound, with turbines operating, can be described as a steady rumble with a mixture of rumble – thumps. Wind in the trees or vegetation is not intrusive. **Figure 2** presents the variation between maximum, minimum and average (LAeq) un-weighted sound levels. Un-weighted ('Z' weight sound levels) are referenced for audibility, as explained later.

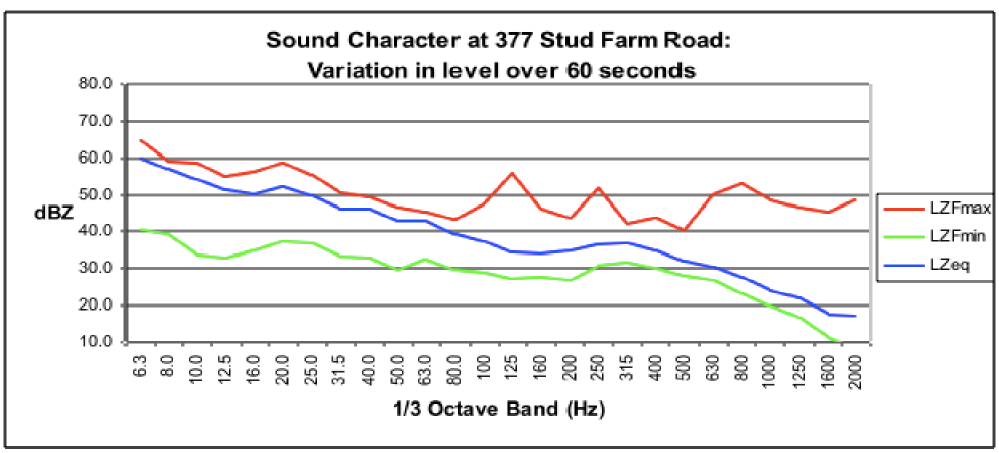


Figure 2: Variation in sound character over 60 seconds

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.

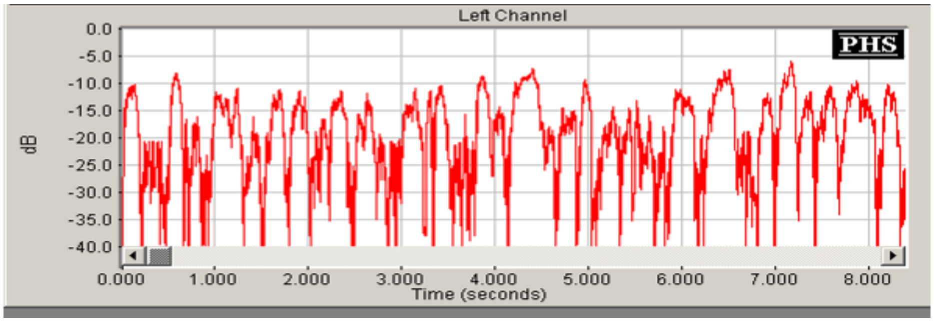


Figure 3: Pulse pattern from an operational wind farm

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.

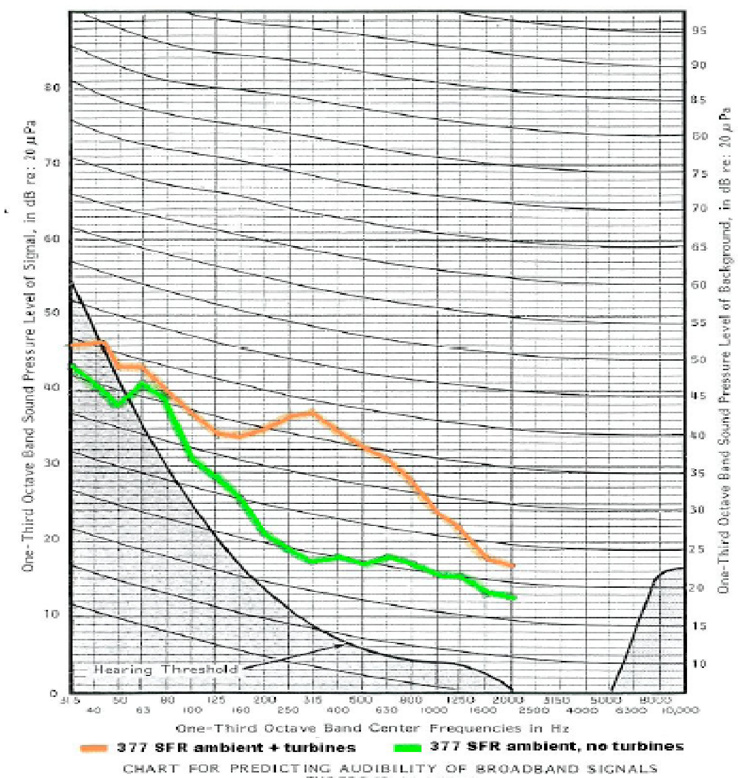


Figure 4: Audibility of wind turbines at Residence

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.

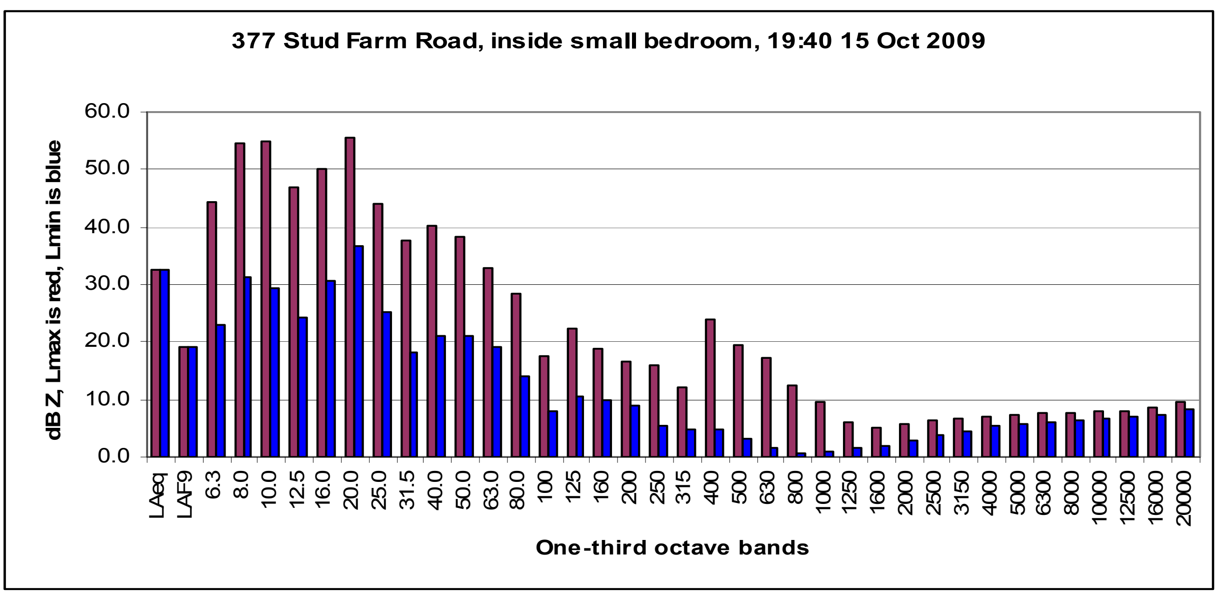


Figure 5: Indoor sound character for the initial survey (LZmax vs LZmin)

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.

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.

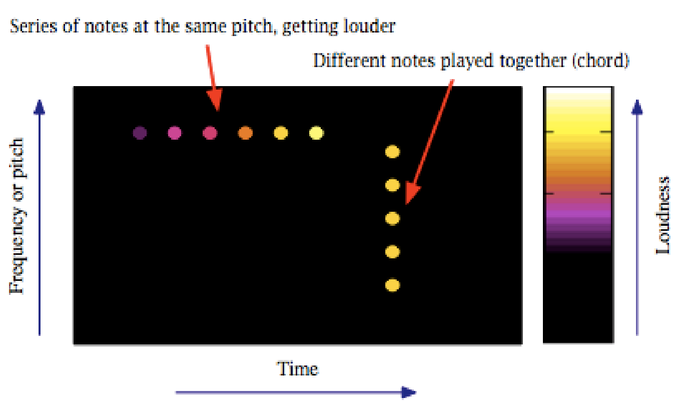


Plate 1: How to interpret a sonogram

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.

---

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

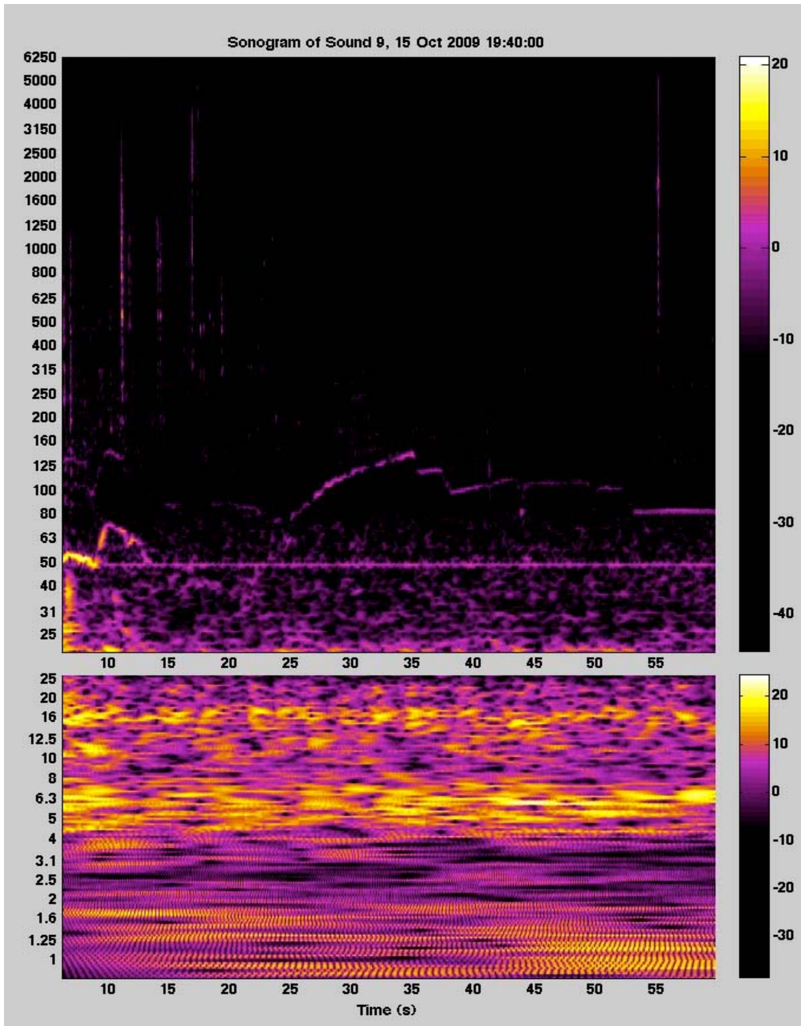
The following sonograms are presented to illustrate specific locations with and without turbine activity. The sonograms illustrate the presence of turbines even though the activity may not be audible. Different time segments are used to illustrate the effects. The important features are:

- 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.



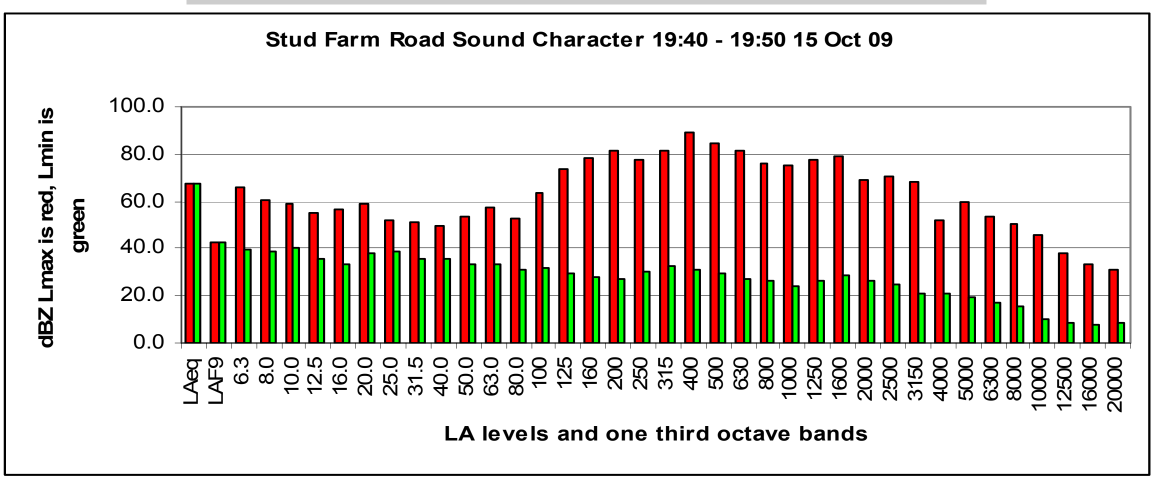
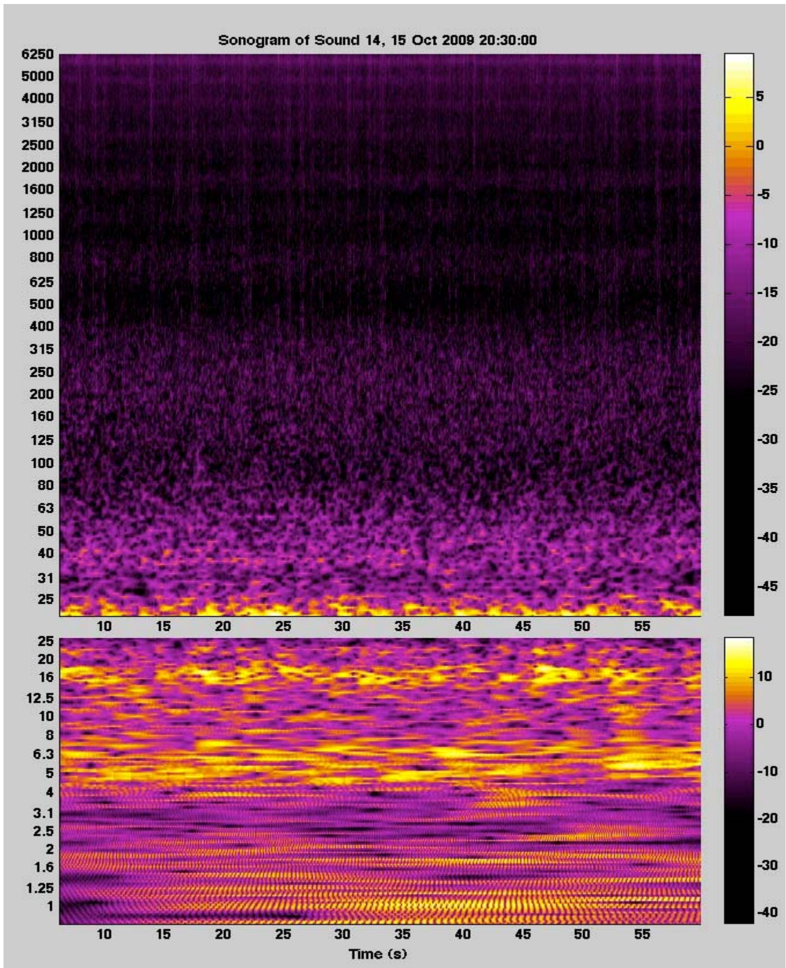


Figure 7: Sound Character at Residence.

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.



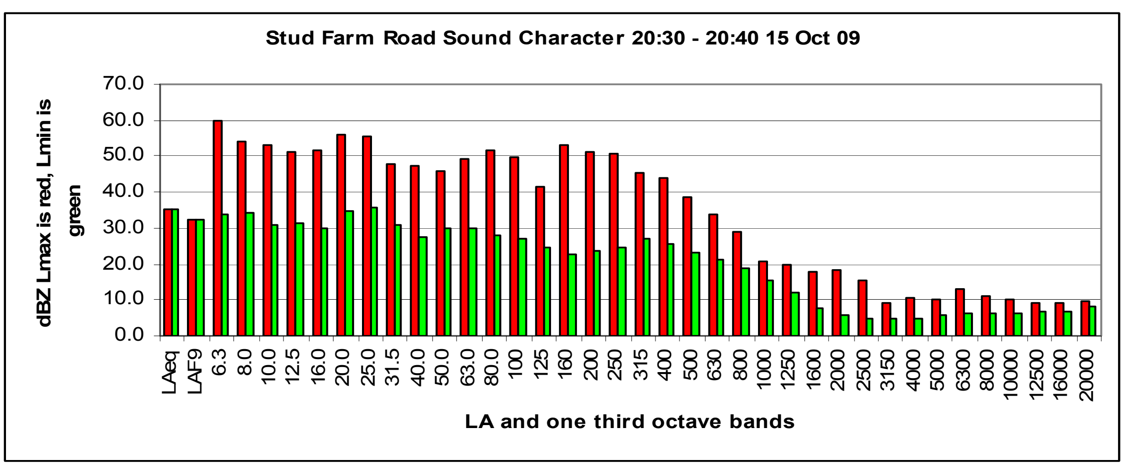
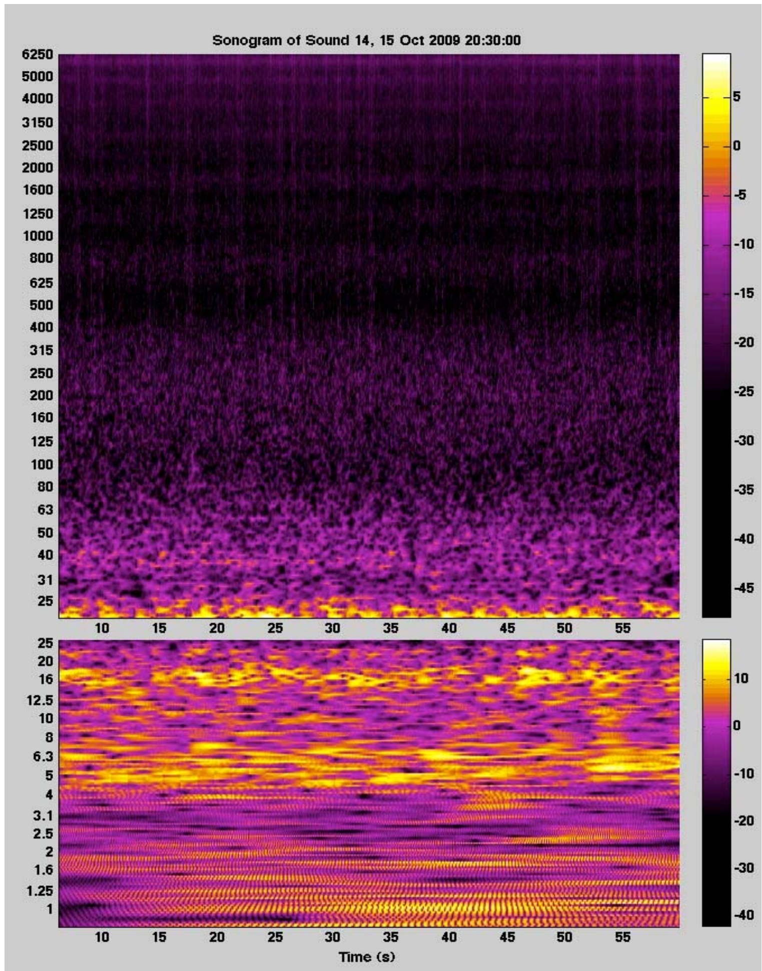


Figure 8: Sound Character at Residence

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.



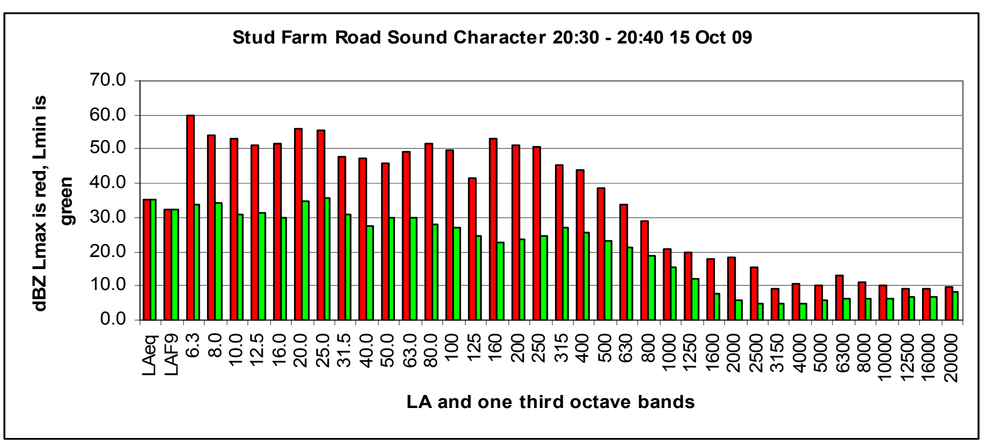
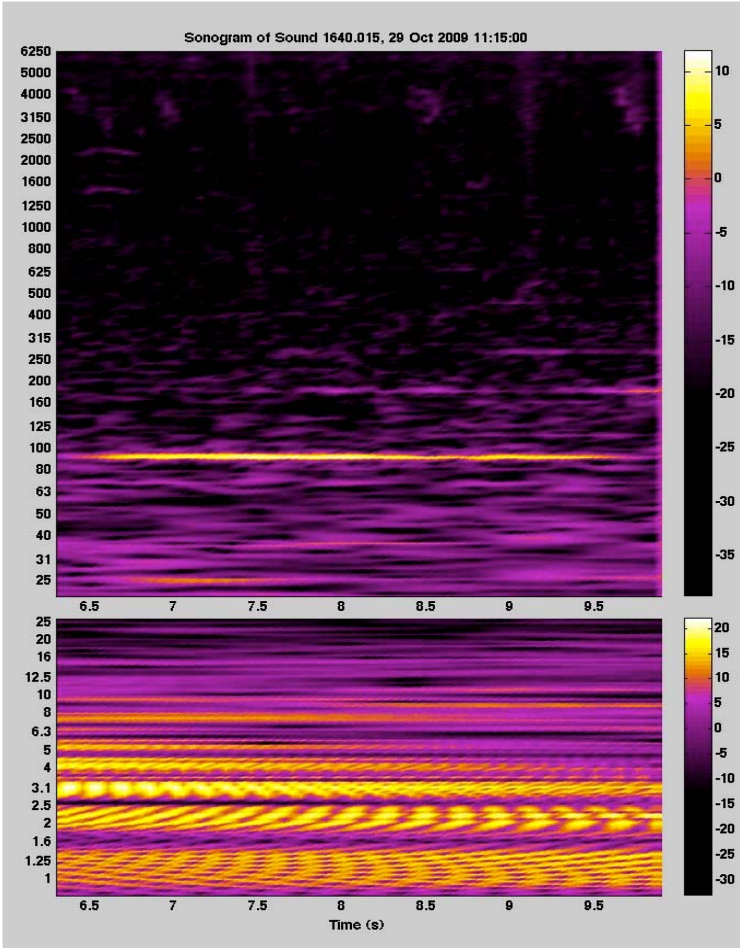


Figure 9: Sound Character at Residence

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.



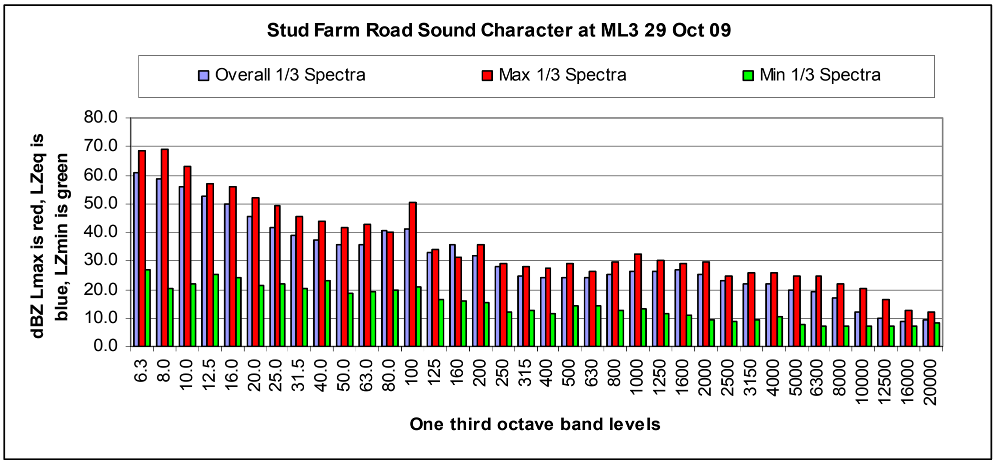
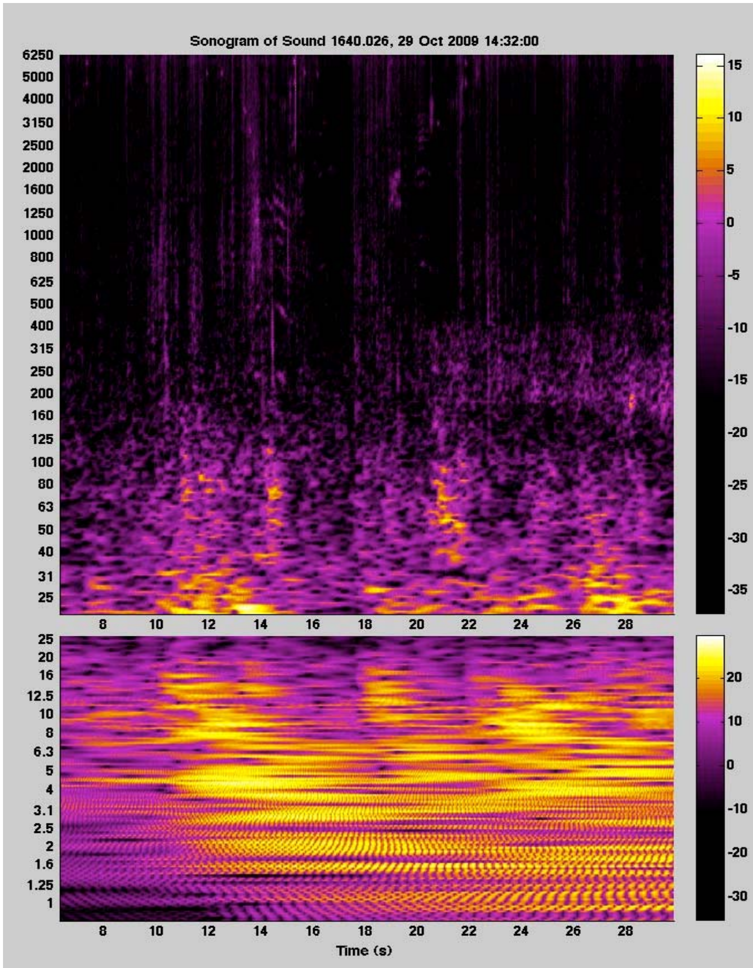


Figure 10: Sound Character between two sets of turbines

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.



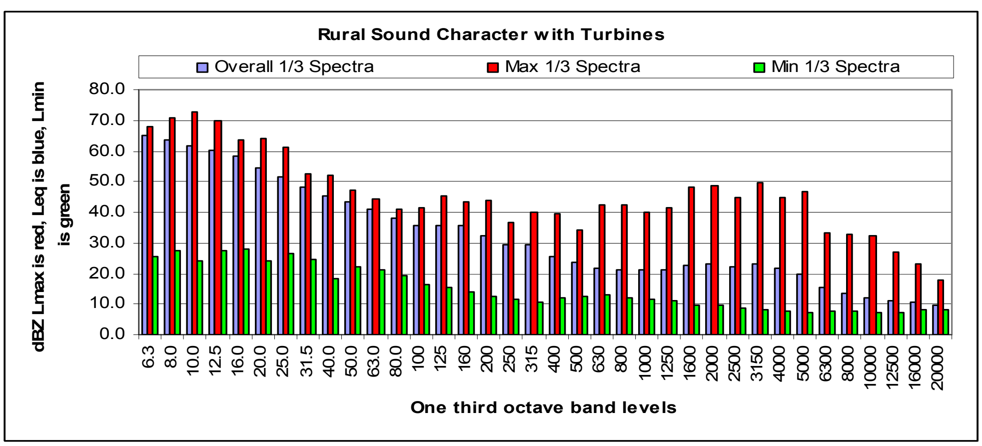
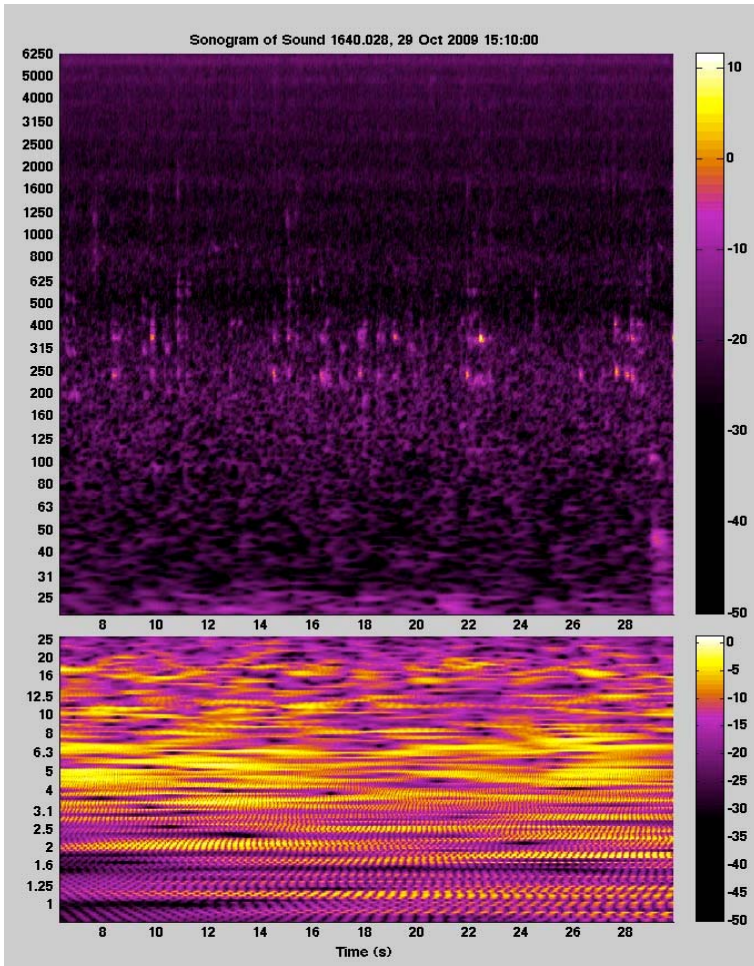
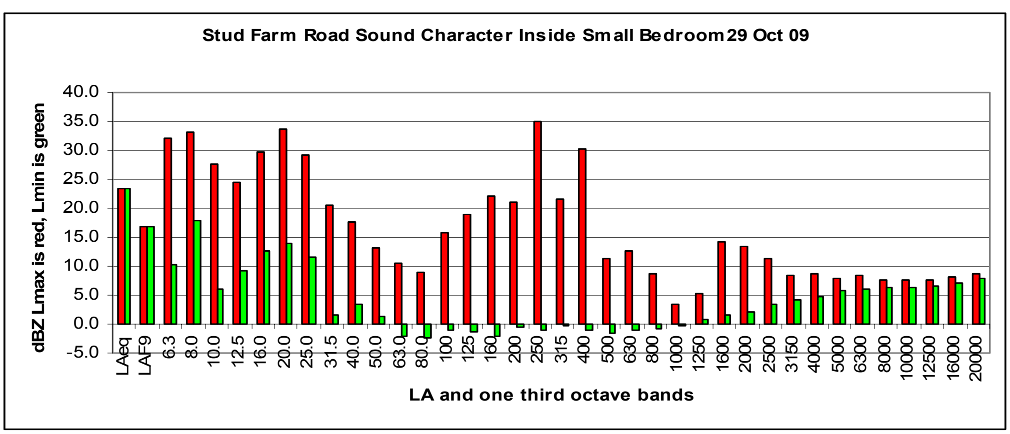


Figure 11: Sound Character Inside Residence

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 although the identification of special audible characteristics is best done through the graphic presentation in a sonogram.
- Individuals can easily hear sound levels of 20 dB LAeq or less when inside the home and trying to get to sleep. The sound of turbines changing their position and turning into the wind can result in audible distinctive sounds that can awaken, annoy and stress a person.

The above conclusions apply to all rural wind farms.

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

PART IV - WIND FARMS AND HEALTH EFFECTS

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

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

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

Dr Eja Pedersen[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:

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

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

In his Paper[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]:

---

[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.

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

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:

[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', pGuideline 2010, available from www.windvigilance.com

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

Dr. Michael M. Nissenbaum, M.D., has conducted a study[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 and health risks

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:

[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

• There is ample scientific evidence to conclude that wind turbines cause serious health problems for some people living nearby. Some of the most compelling evidence in support of this has been somewhat overlooked in previous analyses, including that the existing evidence fits what is known as the case-crossover study design, one of the most useful studies in epidemiology, and the revealed preference (observed behavior) data of people leaving their homes, etc., which provides objective measures of what would otherwise be subjective phenomena. In general, this is an exposure-disease combination where causation can be inferred from a smaller number of less formal observations than is possible for cases such as chemical exposure and cancer risk.

• The reported health effects, including insomnia, loss of concentration, anxiety, and general psychological distress are as real as physical ailments, and are part of accepted modern definitions of individual and public health. While such ailments are sometimes more difficult to study, they probably account for more of the total burden of morbidity in Western countries than do strictly physical diseases. It is true that there is no bright line between these diseases and less intense similar problems that would not usually be called a disease, this is a case for taking the less intense versions of the problems more seriously in making policy decisions, not to ignore the serious diseases.

• Existing evidence is not sufficient to make several important quantifications, including what portion of the population is susceptible to the health effects from particular exposures, how much total health impact wind turbines have, and the magnitude of exposure needed to cause substantial risk of important health effects. However, these are questions that could be answered if some resources were devoted to finding the answer. It is not necessary to proceed with siting so that more data can accumulate, since there is enough data now if it were gathered and analyzed.

• The reports that claim that there is no evidence of health effects are based on a very simplistic understanding of epidemiology and self-serving definitions of what does not count as evidence. Though those reports probably seem convincing prima facie, they do not represent proper scientific reasoning, and in some cases the conclusions of those reports do not even match their own analysis.

In December 2009 the American and Canadian Wind Energy Associations (ACWEA) published a literature Guideline entitled *Wind turbine sound and health effects – An expert panel Guideline*. This Guideline 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 Guideline 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 Guideline 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 Guideline are not supported by its own contents nor does it have convergent validity with relevant literature.*
- *The A/CanWEA Panel Guideline 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 Guideline fails to offer any science based guidelines that would mitigate these health risks.*
- *The A/CanWEA Panel Guideline can only be viewed for what it is. It is an industry association convened and sponsored attempt to deny the adverse health effects being reported.*

In June 2010 the Australian Government National Health and Medical Research Council released a Paper entitled *"Wind Turbines and Health: A Rapid Guideline of the Evidence".* The NHMRC paper does not identify its author(s) and is not stated as being peer-reviewed, a significant omission in a Paper that is widely referenced. An independent critique of the NHMRC report by the Society for Wind Vigilance (in part) states:

- *NHMRC asserts it "… only uses the best available evidence, in the form of peer-reviewed scientific literature, to formulate its recommendations." The contents of the "Rapid Guideline" reveals a different reality. The list of reference omissions is immense.*
- *The "Rapid Guideline" places an inappropriate level of credence in wind energy industry produced and or sponsored material to support its assertions. To compound this bias the "Rapid Guideline" selectively cites references which favour the wind energy industry while inexplicitly omitting relevant citations which do not.*
- *For example, the "Rapid Guideline" repetitively cites a wind energy association sponsored literature Guideline but neglects to disclose this reference states wind turbine noise, including low*

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

frequency noise, may cause annoyance, stress and sleep disturbance. Acknowledged symptoms include distraction, dizziness, eye strain, fatigue, feeling vibration, headache, insomnia, muscle spasm, nausea, noise bleeds, palpitations, pressure in the ears or head, skin burns, stress, tinnitus and tension.

- *The Society for Wind Vigilance does concur with the “Rapid Guideline” on one point – the title of the report. The sub-standard quality of research confirms the Guideline is rushed and hence the title “Rapid Guideline” is undeniably appropriate. The “Rapid Guideline” confirms the adage that haste makes waste.*

In July 2010 the Environment Protection and Heritage Council published its draft *National Wind Farm Development Guidelines.* This is a significant compendium of information and is in draft for 12 months. Read this document in association with the public consultation draft (October 2009) and the original *Report on Impediments to Environmentally and Socially Responsible Wind Farm Development,* November 2008. These two earlier documents are together more informative than the 2010 release. The latest draft when dealing with health impact refers only to the NHMRC paper, above.

Not withstanding the criticisms of dose-response relationships the WHO (Europe) have attempted to categorise different bands of noise levels in relation to health impact, specifically sleep disturbance. They set out to establish a No Observed Effect Level (NOEL) and a Lowest Observed Adverse Effect level (LOAEL) for noise and various measures of health. The WHO’s Night Noise Guidelines for Europe’ (2009: Table 5.4) description of the relationship between noise level ($L_{night,\ outside}$) and health are repeated in Table 2. The 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. The night-time sound level is derived from the measured LAeq sound level <u>plus a penalty of 10 dB</u>:

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

The penalty of 10 dB is similar to that of the day-night level Ldn applied in the United States. For example, if a sound is of a continuous nature, a measured level of 20 LAeq is calculated as 30 $L_{night,outside}$

Table 2: 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.

There are a number of important points to be read from these figures, which are expanded on in the guidelines. First, the WHO recognizes the existence of vulnerable groups and acknowledges the existence of individual differences in noise sensitivity. Second, health begins to be degraded between 30 and 40 dB. Third, 30 dB is the level that can be considered "safe". Lastly, 40 dB and above can be considered "unsafe".

Conclusion

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

PART V - 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 Guide. 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.

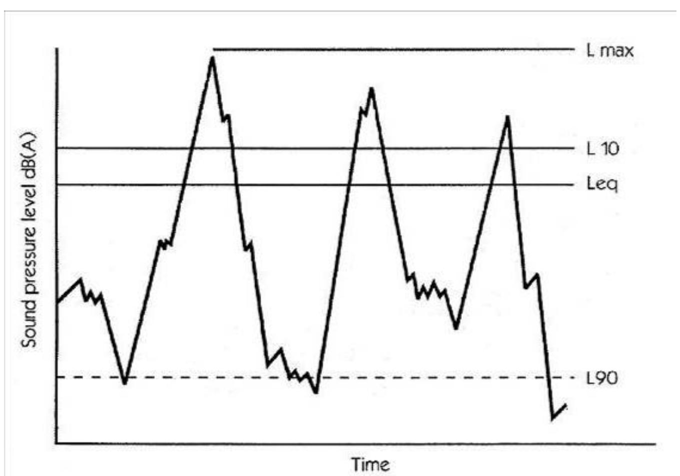


Figure 1: Chart showing different noise descriptors

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.

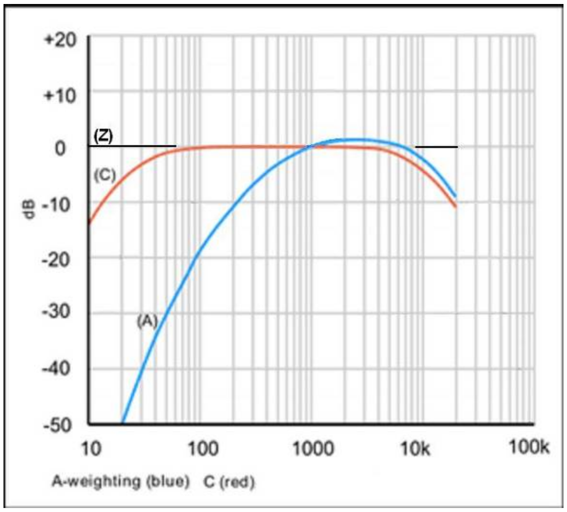


Figure 2: Sound weighting responses

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:

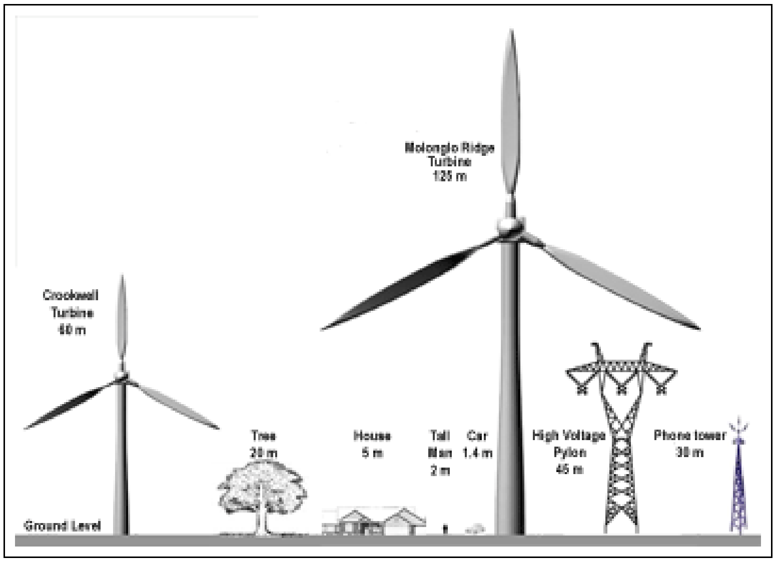


Figure 3: Relative heights of turbines to dwellings
(Source: Molonglo Landscape Guardians, by permission)

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[11]:

> *“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.

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

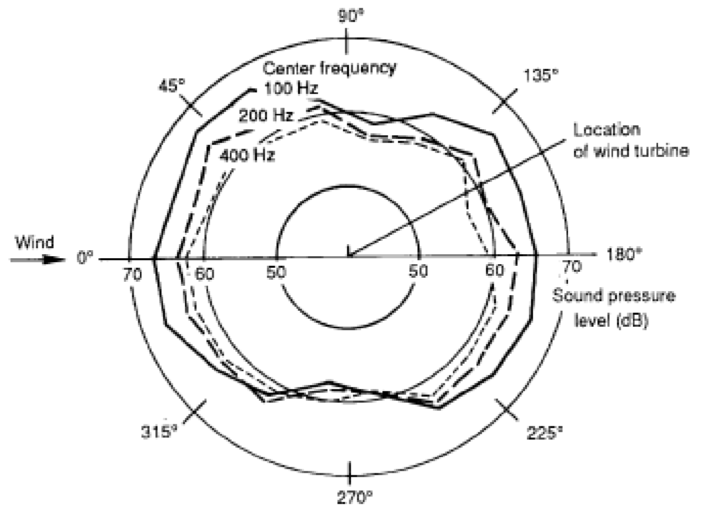


Figure 7-7. Example radiation patterns for broadband noise 200 m from a large-scale HAWT (one-third-octave bands, wind speed = 12.1 m/s, power = 2050 kW) [Shepherd, Willshire, and Hubbard 1988]

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[12] 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:

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

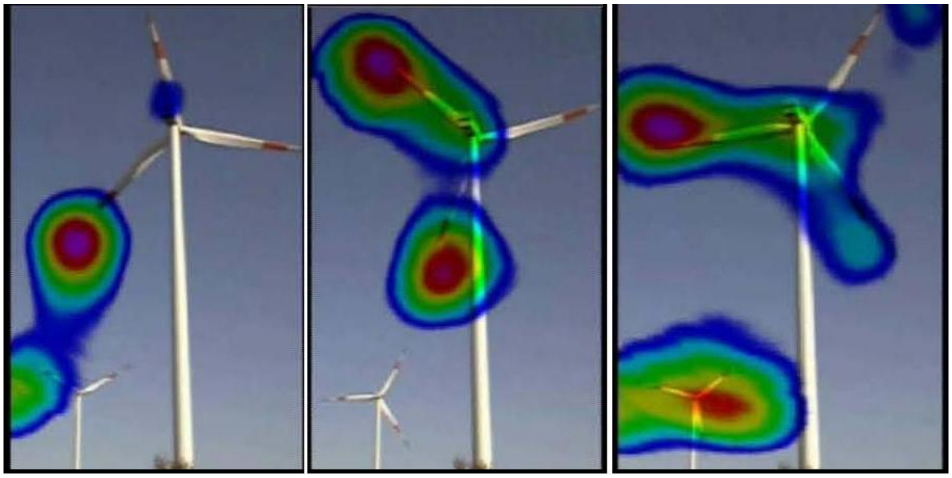


Figure 5: Acoustic photograph of sound sources from two turbines.
Source: Acoustic Camera, 'Multiple sources wind turbines 300Hz – 7kHz.avi" by permission from HW Technologies, Sydney)

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.

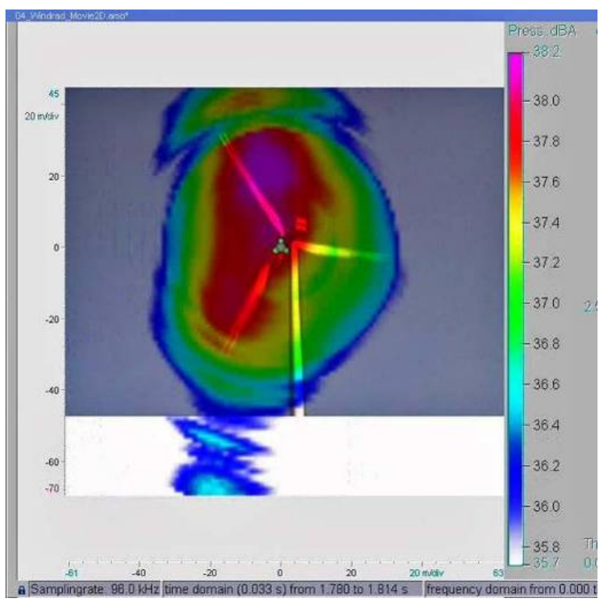
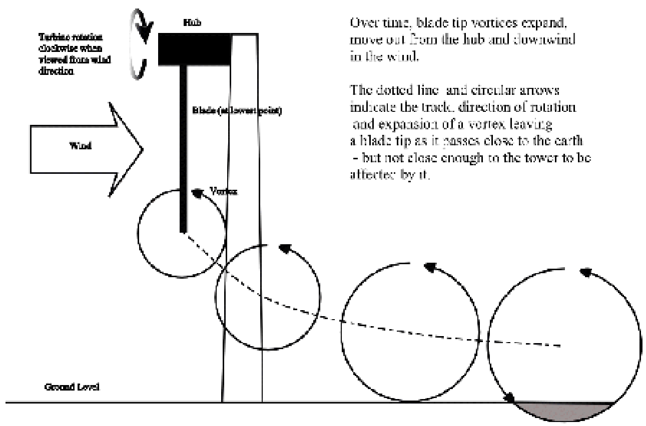


Figure 6: Acoustic photograph of sound sources from a turbine.
Source: Acoustic Camera, by permission from HW Technologies, Sydney)

Shephard[13] reports that 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

[13] Personal communication from Shephard, Ian. 2010. Wake induced turbine noise (v3). Drawing 1 by permission.

speed air. A major wind turbine manufacturer (Vesta) recommends a distance of at least 5 rotor diameters between the wind turbines. Wake effects with pockets of lower speed air are present within 3 rotor diameters downwind and mostly dissipated at a distance of 10 rotor diameters. If a second turbine is situated within 10 rotor diameters of the first turbine the blades of the second turbine can suddenly enter into a pocket of slower air in the wake caused by the first turbine. Increased sound levels will occur and the propagation distance in metres to a defined 'criterion' or sound level can be calculated.



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

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

Figure 7: Vortex eddies (Shephard, by permission)

Another potential source of noise from a wind turbine is boundary layer air breaking away from the trailing edge of the blade. When the wind reaches a blade, part goes over and part goes under the blade. The part of the airflow with momentum great enough to break away forms trailing 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 guide 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-guidelines-for-siting-wind-turbines-to-prevent-health-risks/

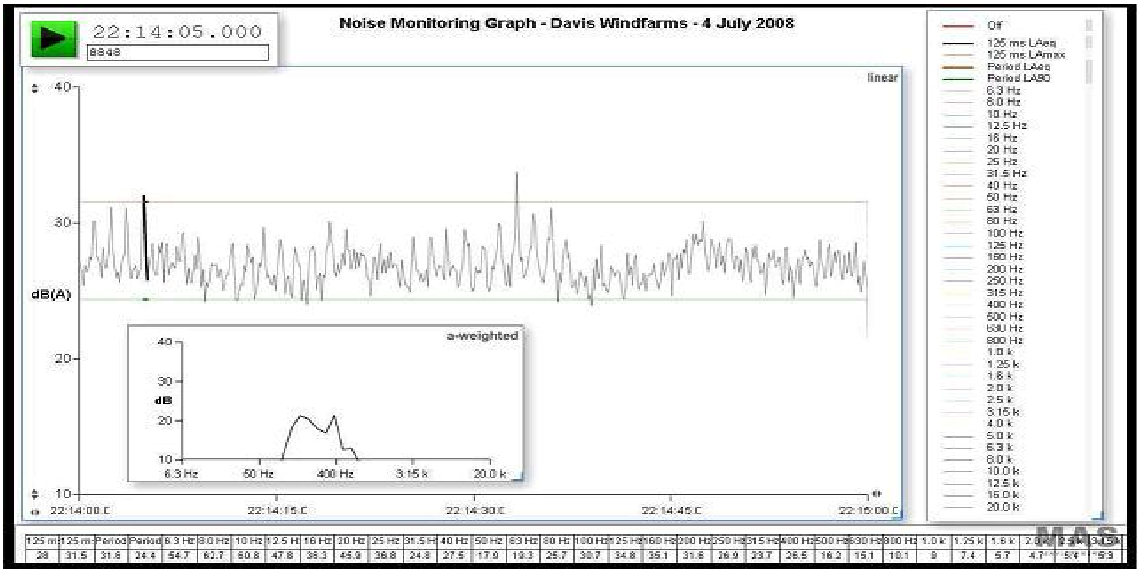


Figure 8: sound of wind turbines at 930 metres, inside residence

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.

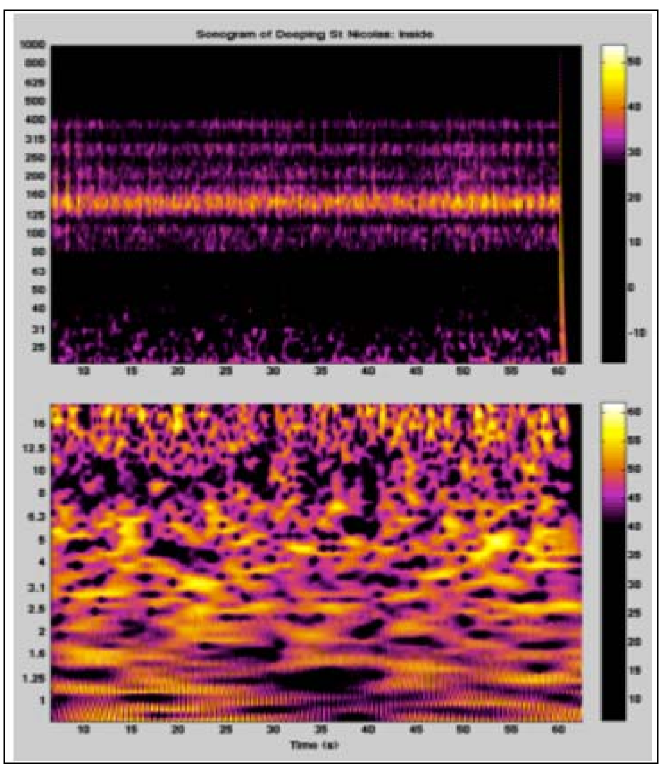


Figure 9: sound of wind turbines at 930 metres, inside residence

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).

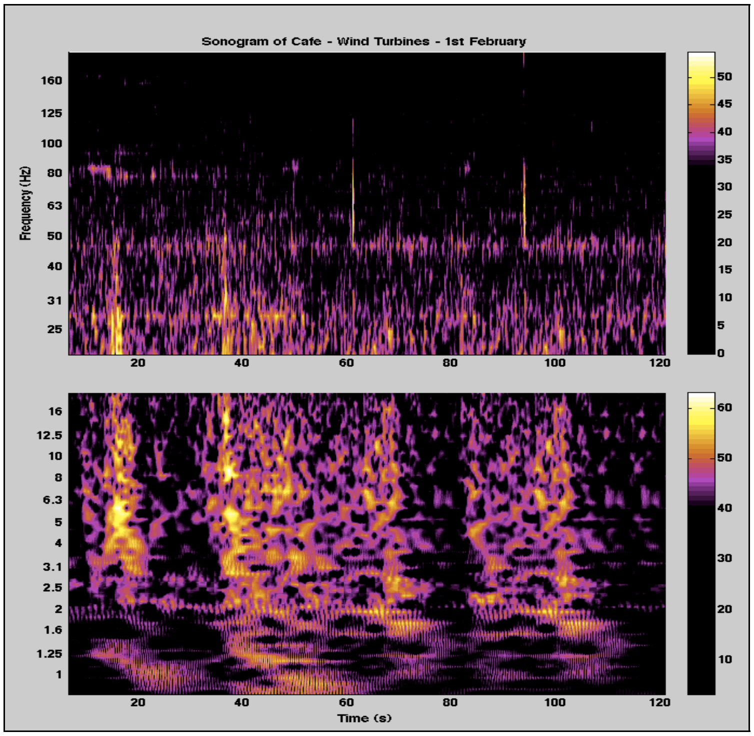


Figure 10: Audible sound of wind farm at 2200 metres over grassland and trees

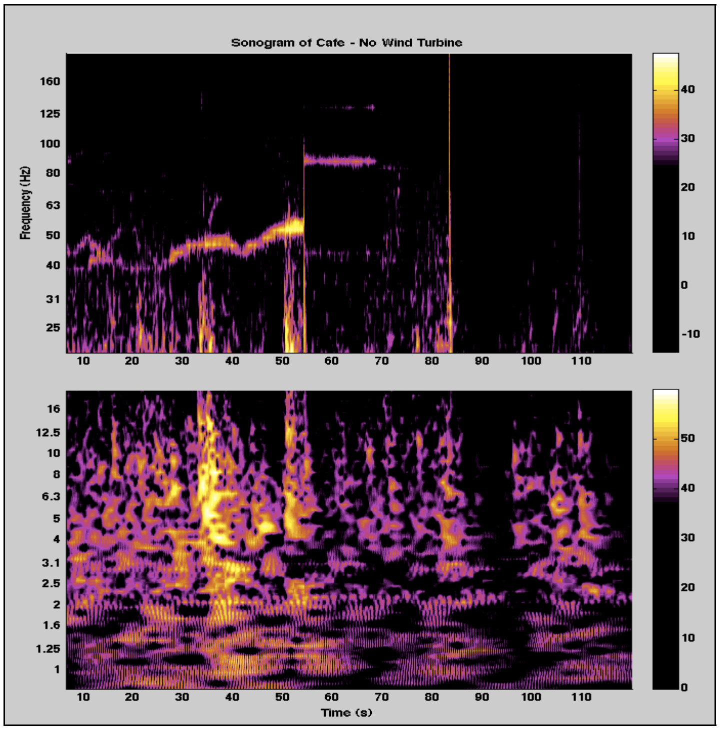


Figure 11: Same location as figure 4 but wind farm not audible

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.

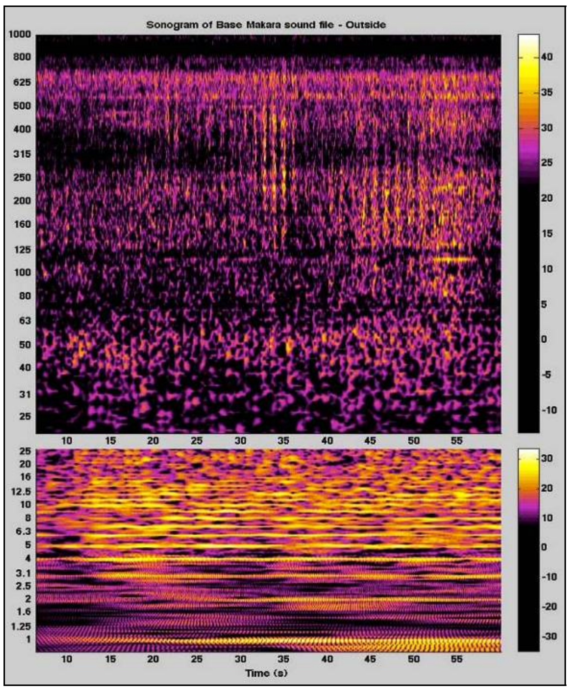


Figure 12: sound of wind turbines at 1200 - 1300 metres, outside residence

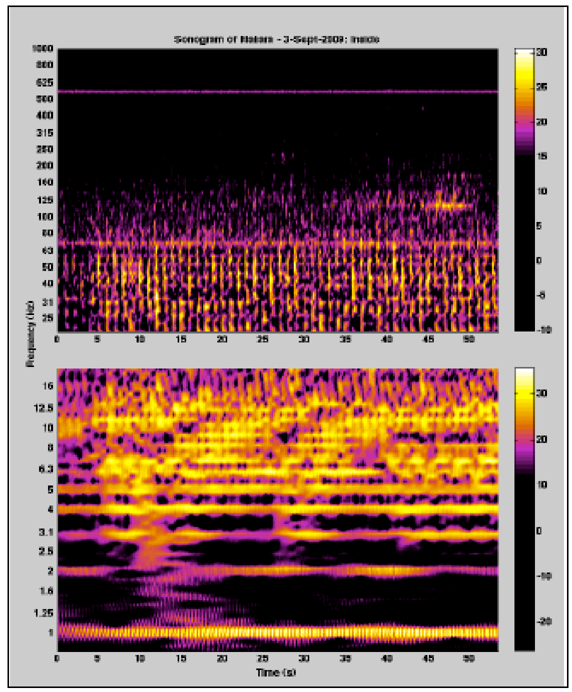


Figure 13: sound of wind turbines at 1200 -1300 metres, inside residence

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.

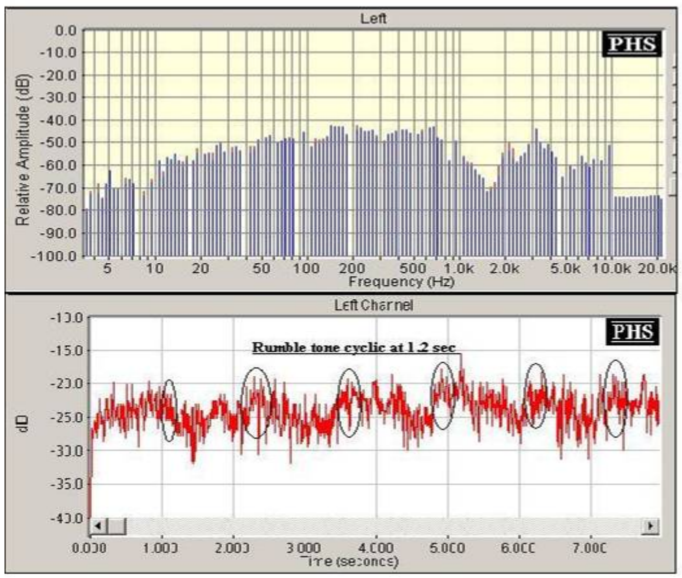


Figure 14: Turbine rumble

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.

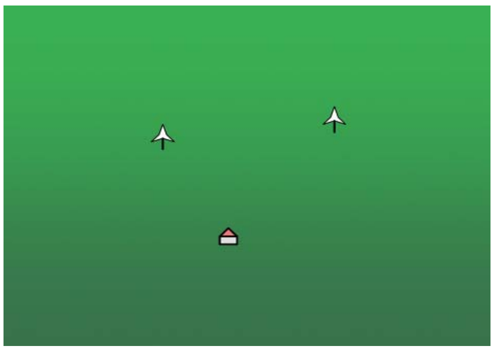


Figure 15: A residence potentially affected by 2 turbines

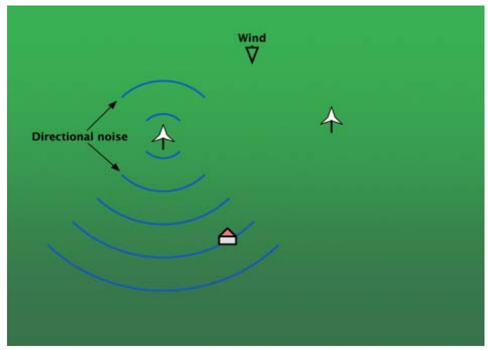


Figure 16: Noise from one turbine

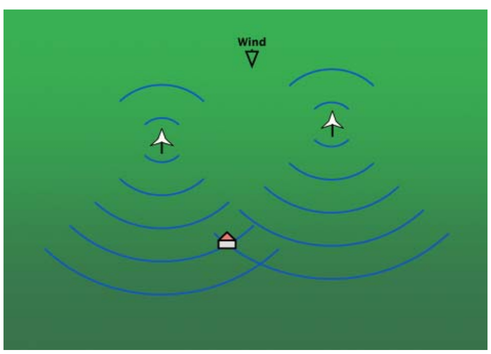


Figure 17: Noise from 2 turbines

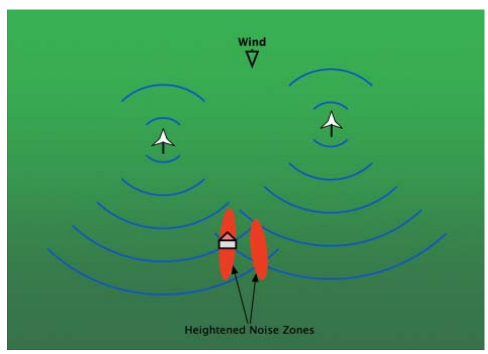


Figure 18: Noise from 2 turbines creating Heightened Noise Zones

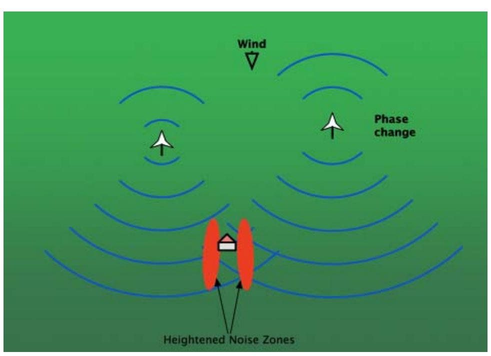


Figure 19: Noise from 2 turbines under slightly different conditions moving Heightened Noise Zones

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.

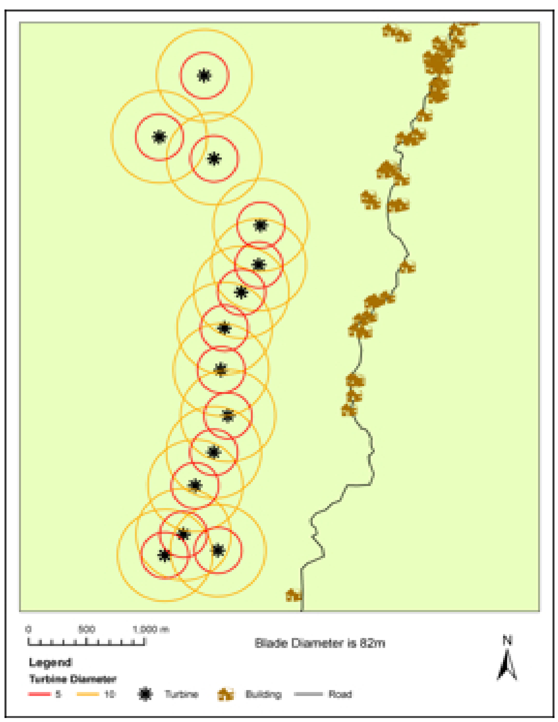


Figure 20: Wind turbines at Makara showing their spacing with regard to 5 and10 blade-diameter circles. *Source: Research graphics by S. R. Summers.*

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 New South Wales Wind Energy Handbook 2002[19] confirms the importance of separation distances by stating (p. 53):

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

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

[19] Sustainable Energy Development Authority (SEDA) New South Wales Wind Energy Handbook 2002

PART VI - 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[20]. Note 24 to ISO 9613-2 provides-

[20] 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.

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[21] and the CSIRO Wind Energy Research Unit[22] .

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

[21] http://www.windpower.org/en/knowledge/guided_tour.html
[22] Coppin, P.A., Ayotte, K.A., Steggel, N. 2003. Wind Resource Assessment in Australia – A Planners Guide. CSIRO Wind Energy Research Unit.

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).

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 Guide.

New Zealand Standard, NZS 6808:1998 *Acoustics-The assessment and measurement of sound from wind turbine generators* is referenced in Victoria as part of the nominal consent conditions. NZS 6808:1998 and its replacement *NZS 6808:2010 Acoustics – Wind farm noise* both lack a methodology to separate background sound levels created by the wind turbines (whether for compliance testing purposes or for complaint assessment) from background sound levels existing at a specific time and place due to wind movement, vegetation movements, bird song and so on. NZS 6808:2010 is different from the 1998 edition by recognising a 35 dB background level for evening and night-time. The lower limit is introduced by way of recognising locales of 'high amenity', clause 5.3.1: '…a more stringent noise limit may be justified to afford a greater degree of protection of amenity during evening and night-time'. No definition of 'high amenity' is provided.

Prediction of Sound Variation at a Receiver

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.

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 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 VII - RESPONSES OF RESIDENTS NEAR WIND FARMS

Community and Individual Noise Exposure

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

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

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

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

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

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

The Effects on People near the Waubra Wind Farm, Victoria

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

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

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

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

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

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

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

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

and

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

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

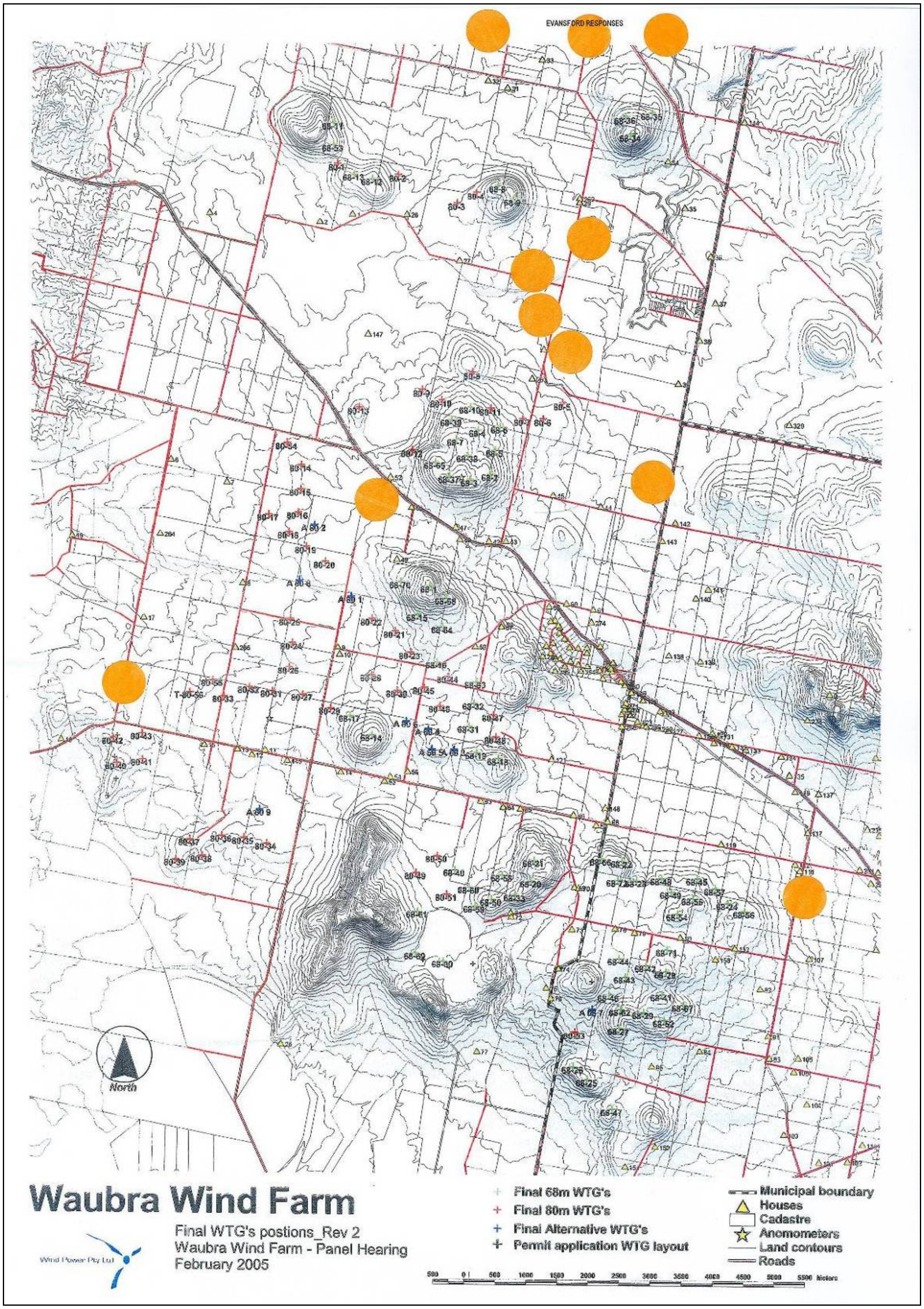
Statutory declarations (June 2010) concerning noise issues have been declared by residents affected by the Waubra wind farm. Noise from the turbines is being experienced by residents within approximately 1000 metres of the nearest turbines and at distances of approximately 3000 to 4000 metres distant from the nearest turbines. The locales where the residents experience noise are shown in Plate W1. The noise and health effects experienced by residents are presented in Table W1. Professional observations at Waubra include sound level measurements of audible sound and infrasound. Further more detailed acoustical, human perception and health effects studies are planned for 2011.

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

Conclusion

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

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



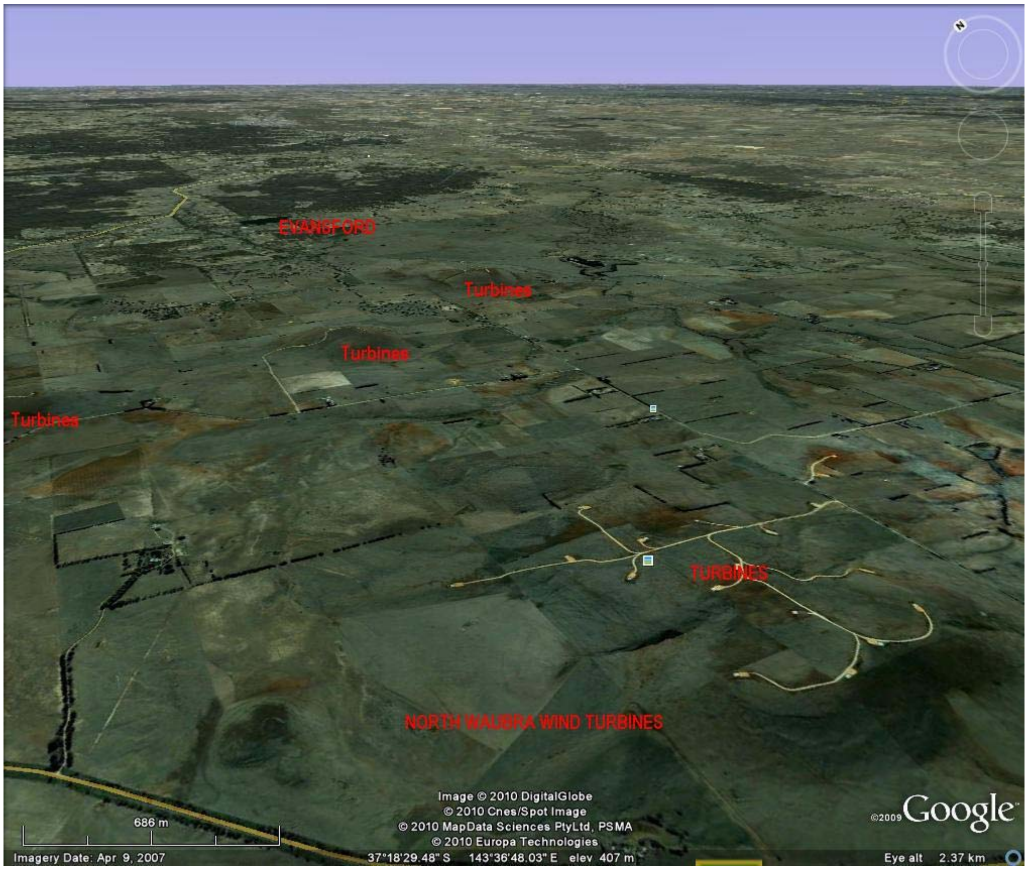
Note: the locales affected by wind farm noise are identified by the orange circles.

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

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

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

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



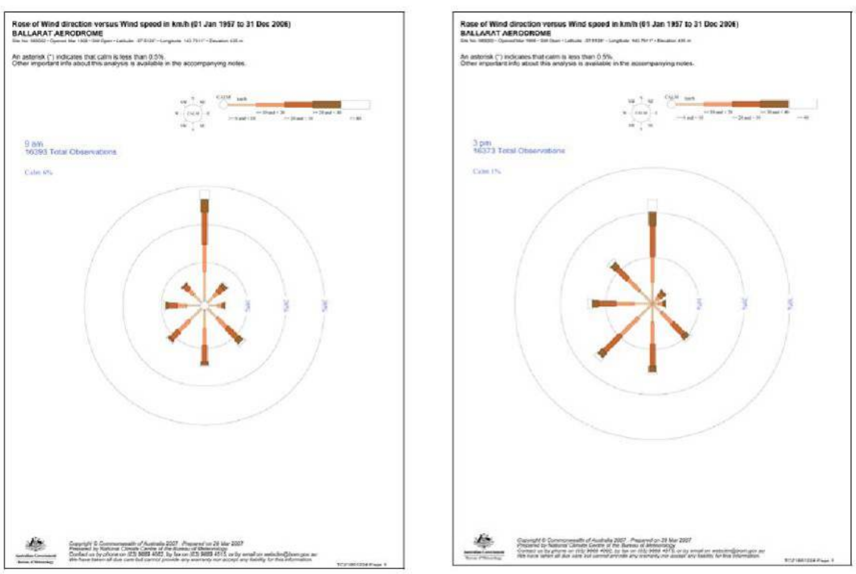


Figure W1: wind rose, Ballarat Aerodrome, mid-morning and mid-afternoon

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

The Westwind wind farm commenced operation in May 2009. From 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.

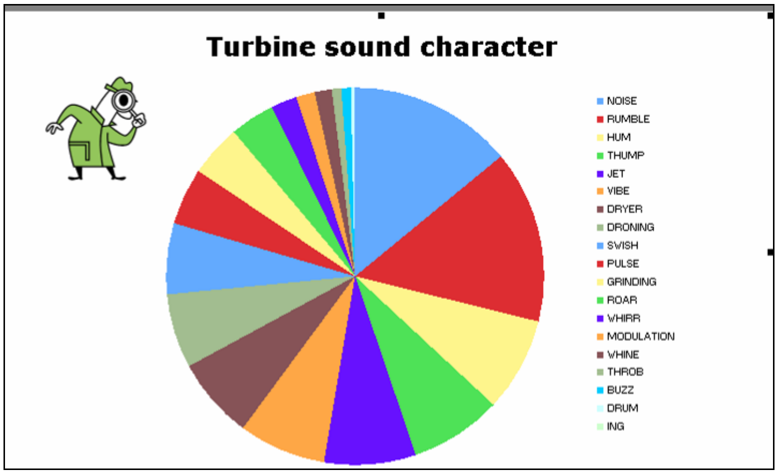


Figure WW1: Westwind complaints by turbine character

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.

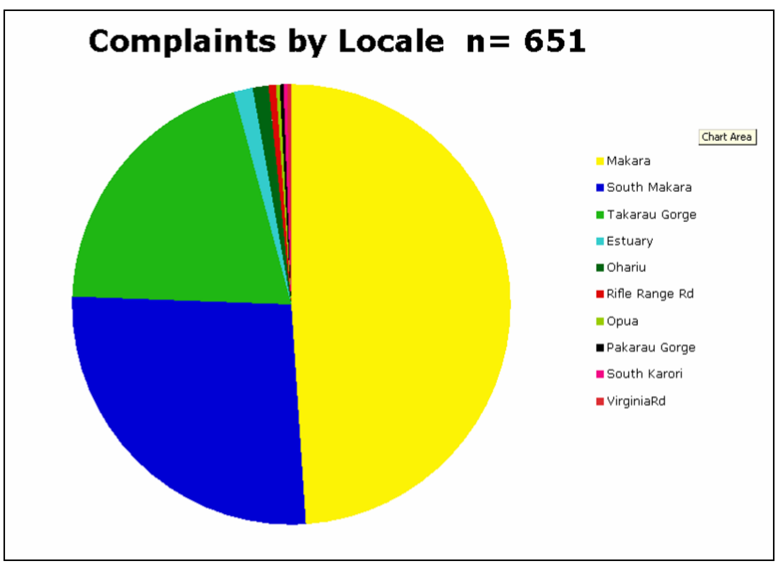


Figure WW2: Westwind complaints by locale

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

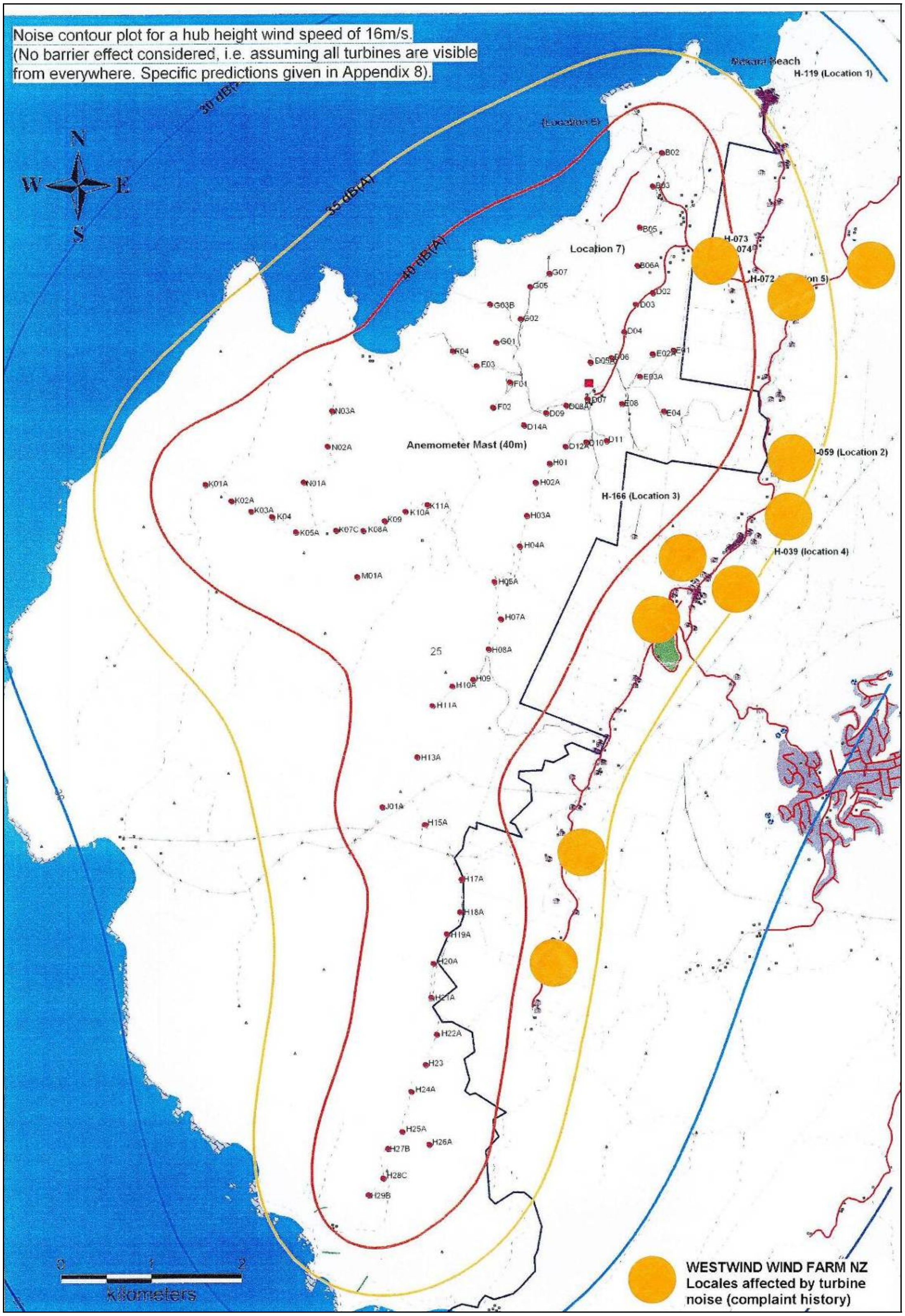
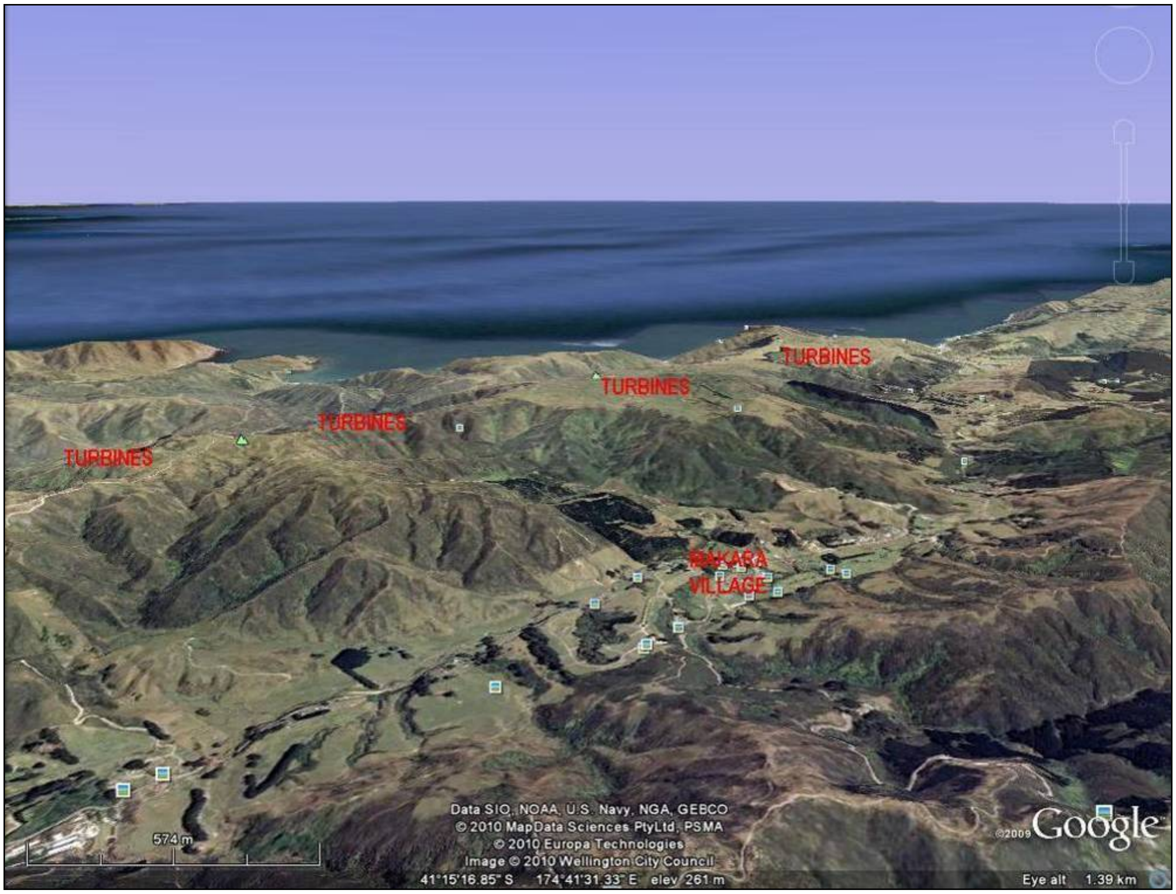


Table WW1: Westwind affects, perception and complaint analysis to November 2009

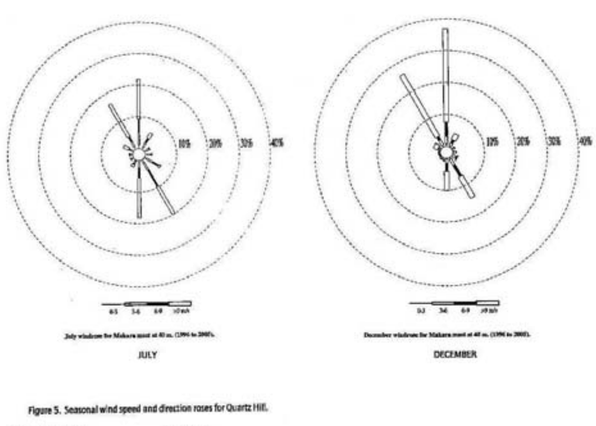
Locale	Distance	Noise affect
1	1200-1300	Kept awake with turbine noise pulsing in bedroom. Sleep disturbance. Sounds not masked by wind in trees or stream
2	1200-1300	Possible to hear and feel the turbines (20 of them) over usual household noises during the day and evenings. At night disturbs sleep patterns 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

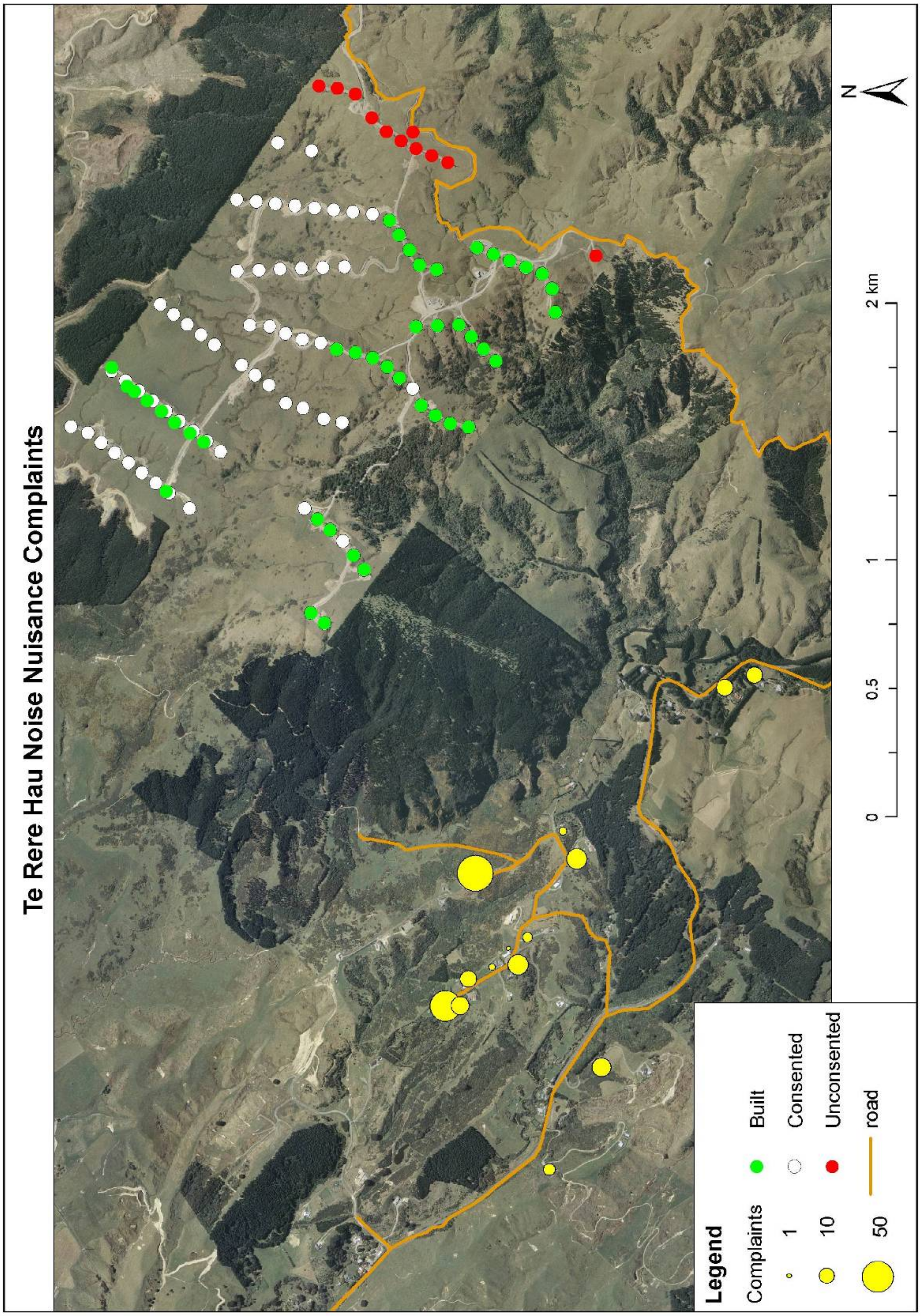


Table TRH 1: Te Rere Hau noise complaints, August 2009 to February 2010, single residence

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

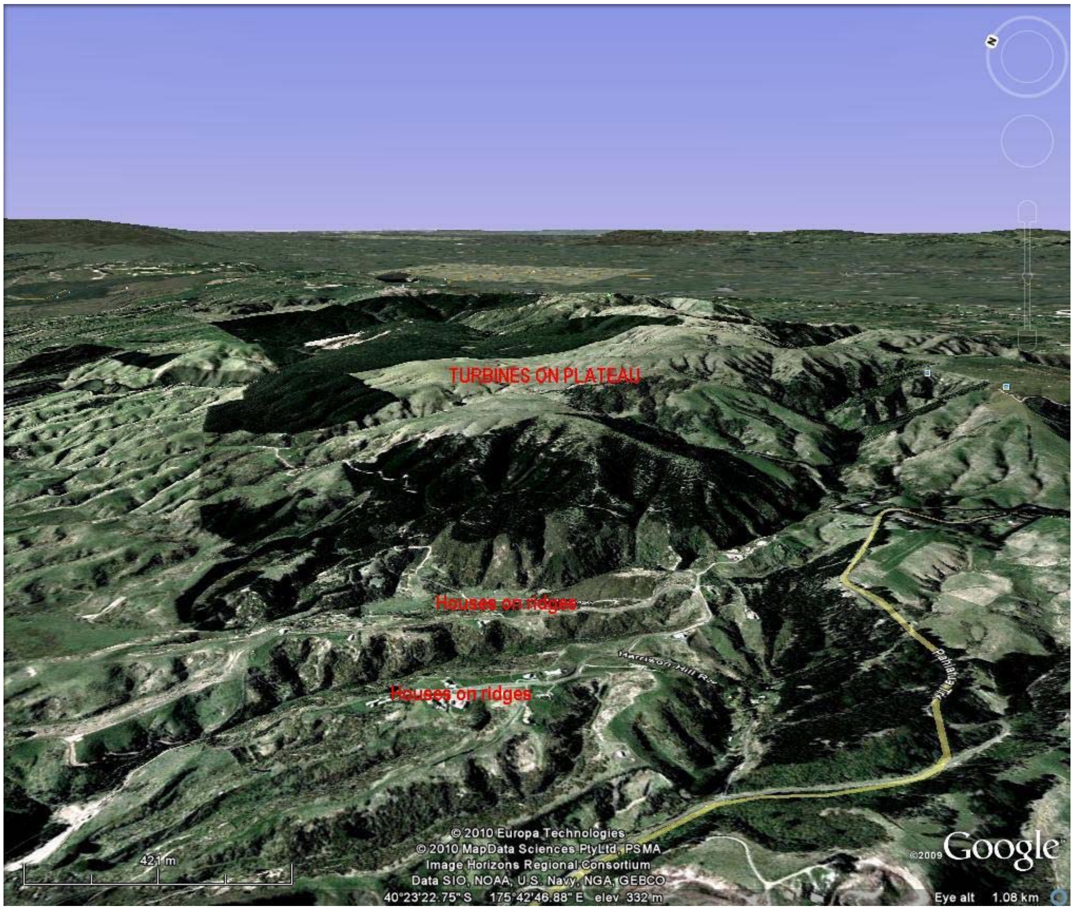
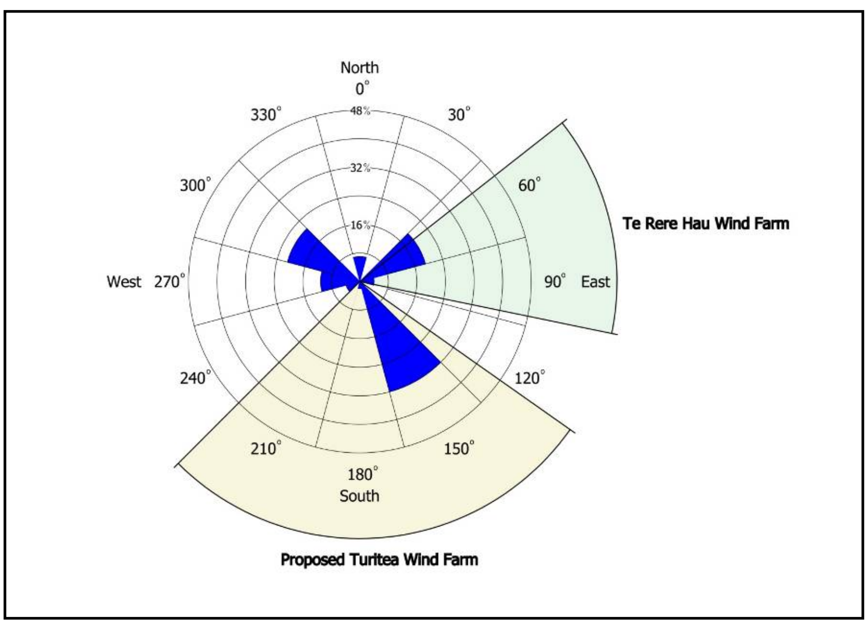


Figure TRH 1: Wind Rose for May to September 2009 illustrating existing wind farm effect (Te Rere Hau) and effect from a proposed wind farm (Turitea) to the south



Real-world noise compliance problem at a wind farm

The Te Rere Hau wind farm in New Zealand is presently the subject of a legal Guideline[23] of 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.

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

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.

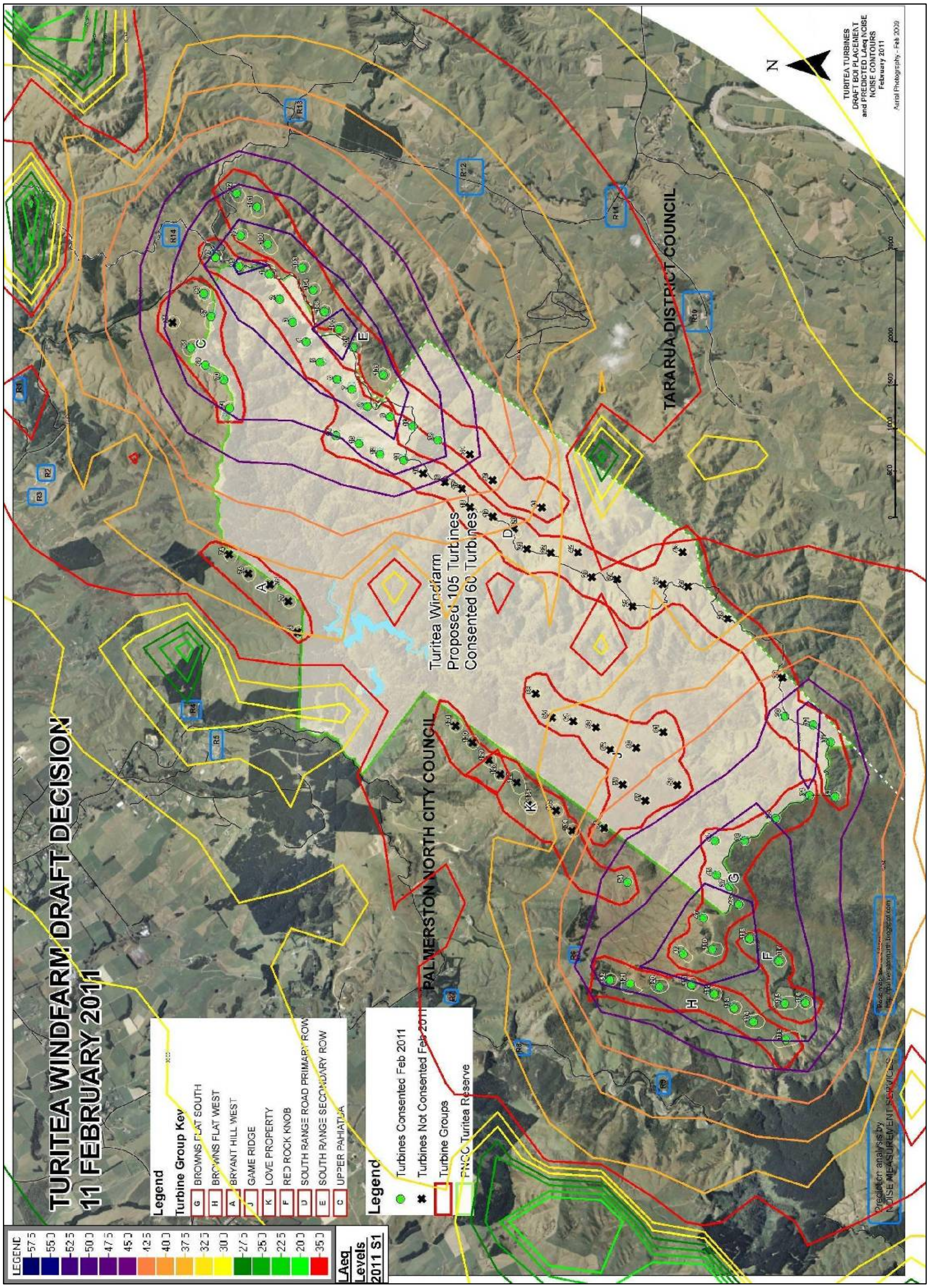
Table T1: Turitea predicted sound levels at receivers (residences, locales)

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 VIII - 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.

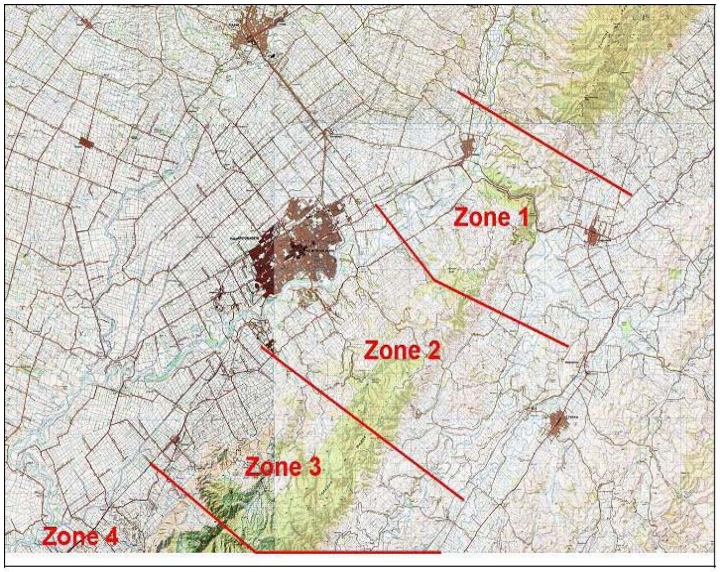


Figure 1: Manawatu Study Zones

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.

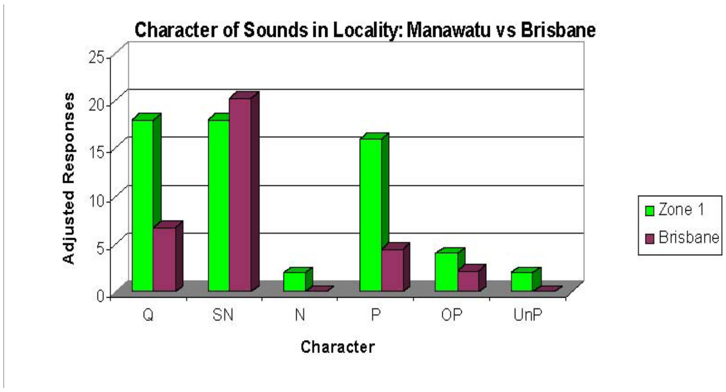


Figure 2: Character of the environment – Manawatu vs Brisbane.

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

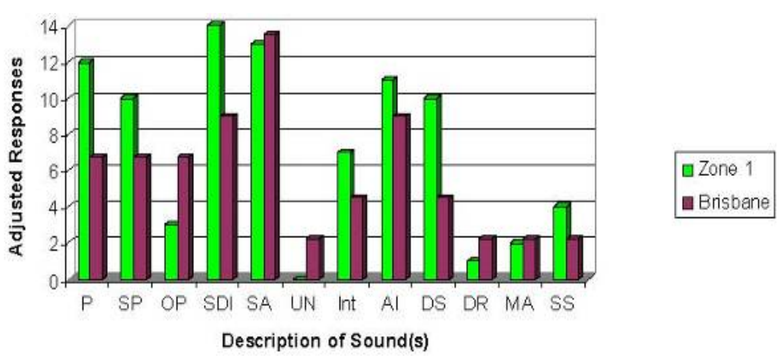


Figure 3: Description of sound(s) in the environment - Manawatu vs Brisbane.

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.

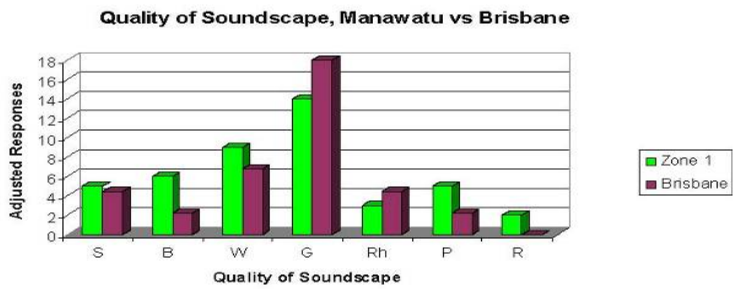


Figure 4: Qualities of Soundscape - Manawatu vs Brisbane.

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”.

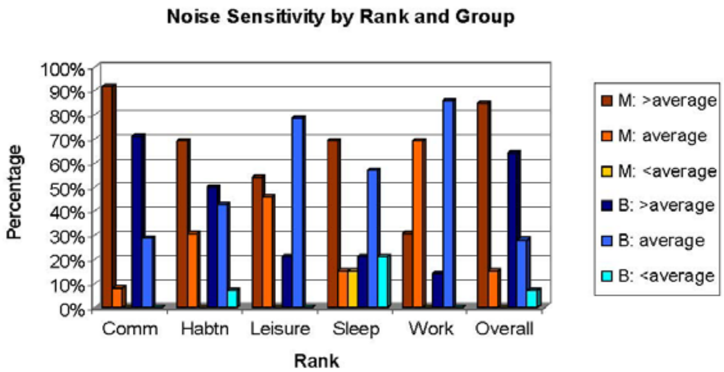


Figure 5: NoiSeQ Noise Sensitivity by rank and group as a percentage.

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.

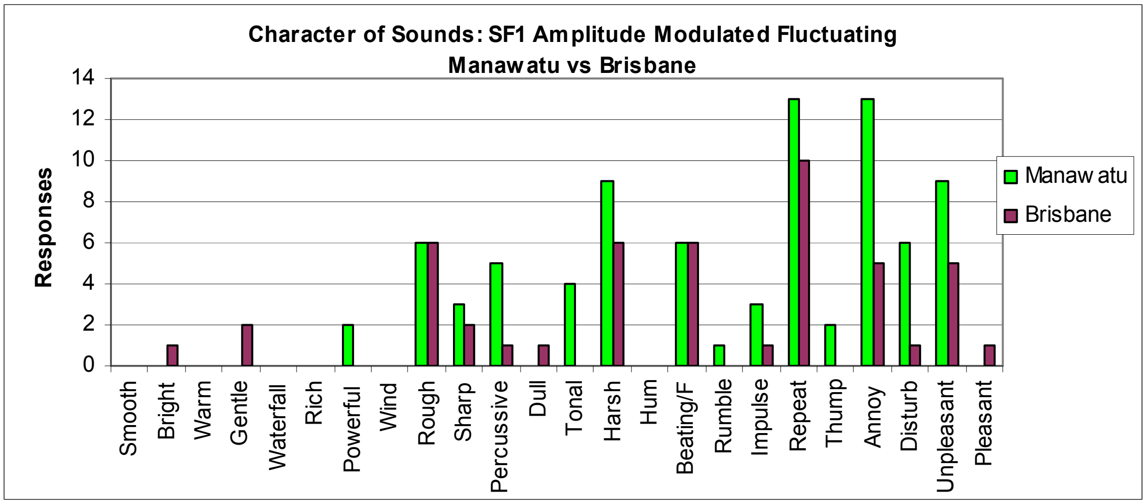


Figure 6: Responses to the character of SF1.

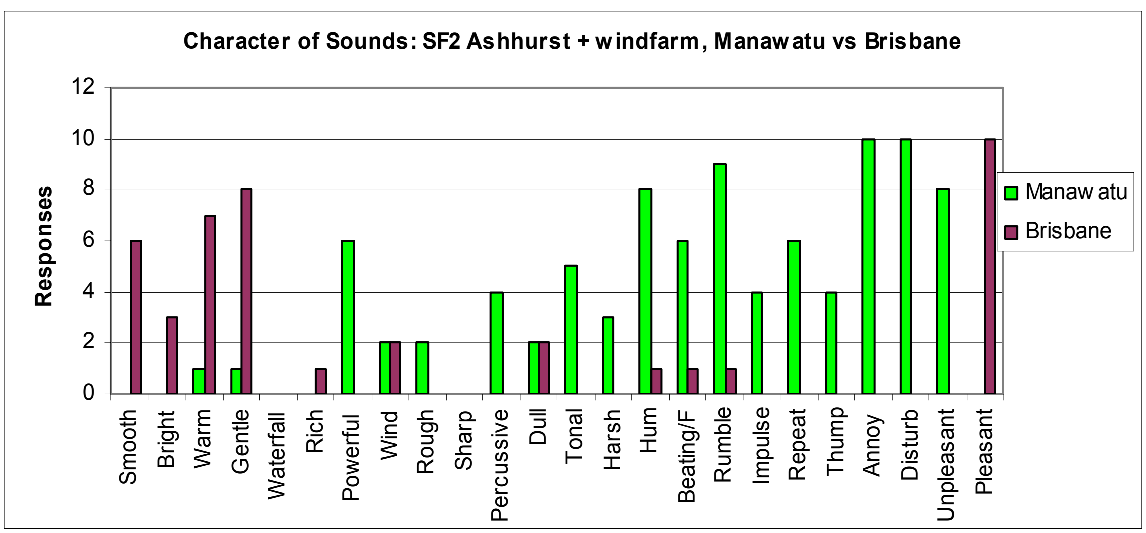


Figure 7: Responses to the character of SF2

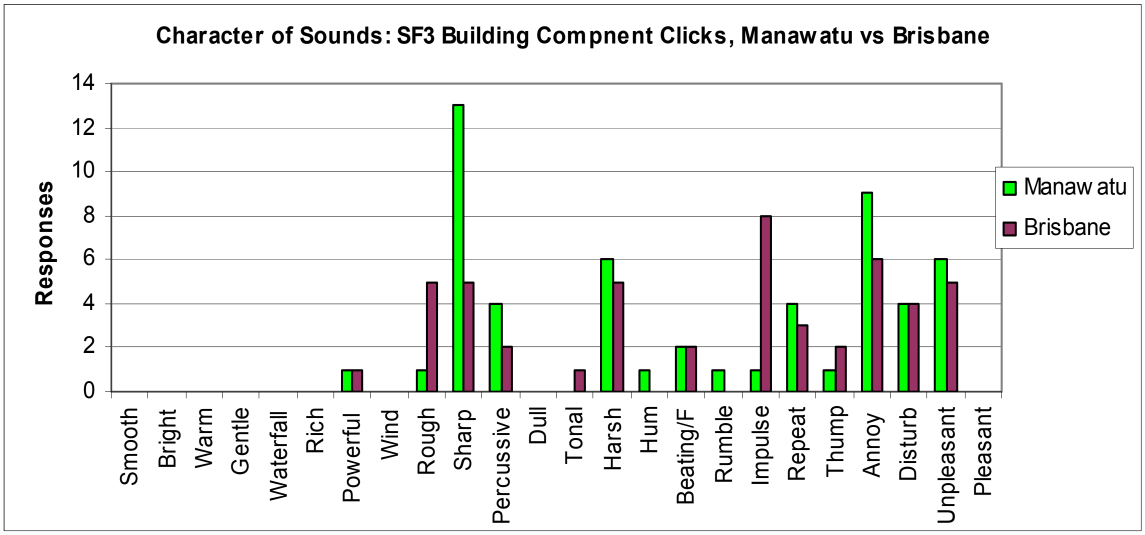


Figure 8: Responses to the character of SF3.

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 IX - 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.

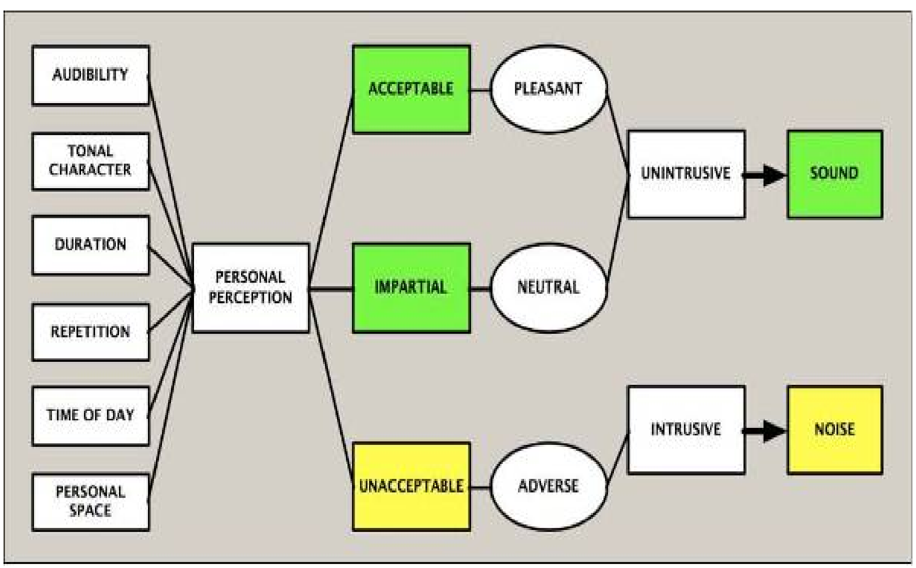


Figure 1: Subjective decision processes to differentiate between sound and noise.

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 Guideline 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.

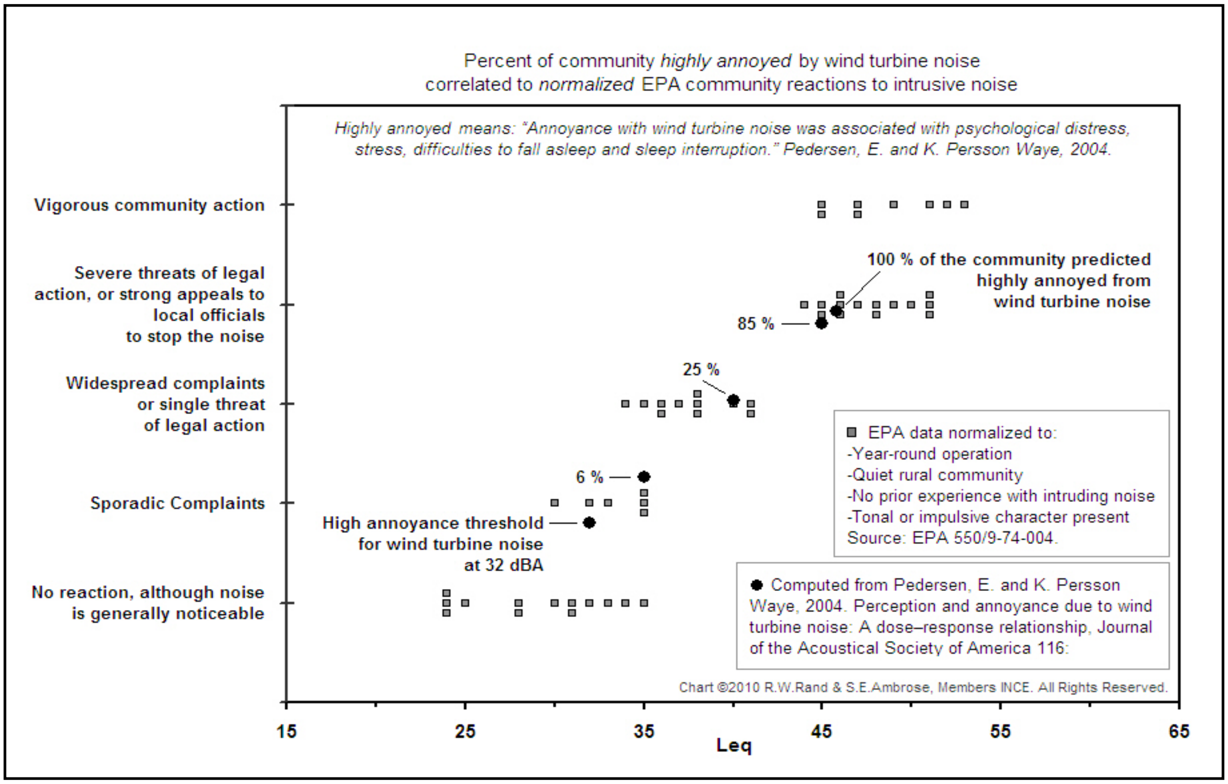


Figure 2: Predictable community reactions – annoyance, intrusive noise and complaints
Source: Ambrose, S and Rand, R. 2010, with permission

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.

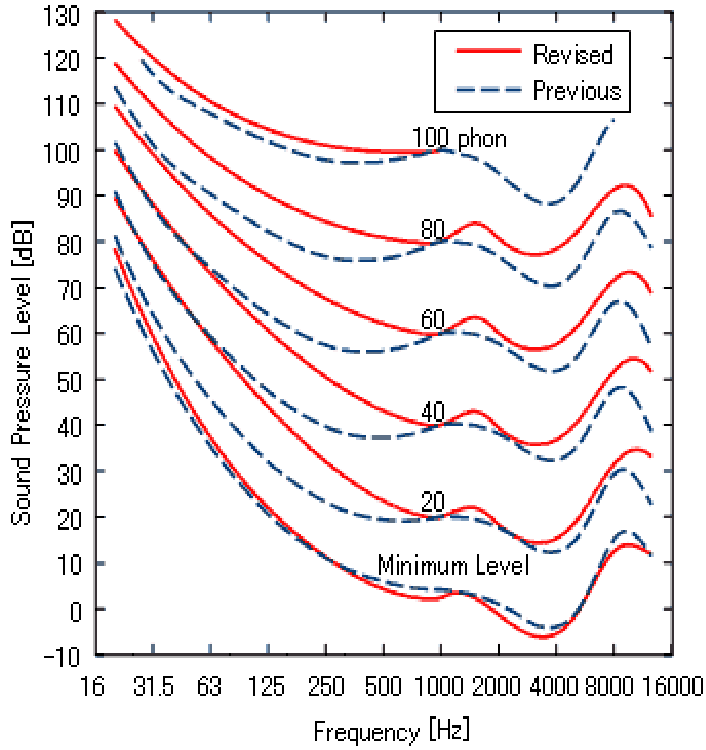


Figure 3: Equal loudness level contours vs sound pressure levels
(from: http://www.aist.go.jp/aist_e/latest_research/2003/20031114/20031114.html)

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.*

[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

This compression can be seen in the equal-loudness-level contours, and it implies that a slight increase in level can change the perceived loudness from barely audible to loud. Combined with the natural spread in thresholds, it may have the effect that a sound, which is inaudible to some people, may be loud to others. Some investigations give evidence of persons with an extraordinary sensitivity in the low and infrasonic frequency range, but further research is needed in order to confirm and explain this phenomenon.

The complexity of our hearing processes illustrates the reason why there can be significant variation in interpretation of sound from one person to another. Not only can a sound be interpreted differently between people but one person may not be able to hear a sound while a second person is seriously affected by the 'noise'. Moller and Pedersen observe that especially sensitive persons, however, may have extraordinary high hearing sensitivity at low frequencies, figure 4. Infrasound may, therefore, be perceptible to sensitive persons at levels far lower than that nominally accepted as being the thresholds for persons with normal hearing. At 8 Hz, for example, levels of 78 dB to 88 dB may be perceptible.

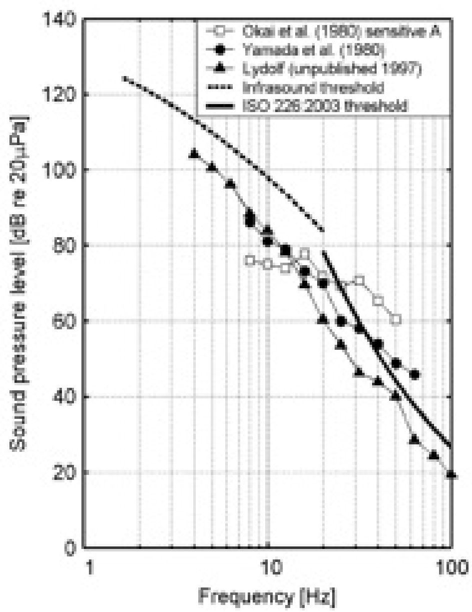


Figure 4: Hearing thresholds of three especially sensitive persons
(from Moller and Pedersen Figure 12)

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."

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

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

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.

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

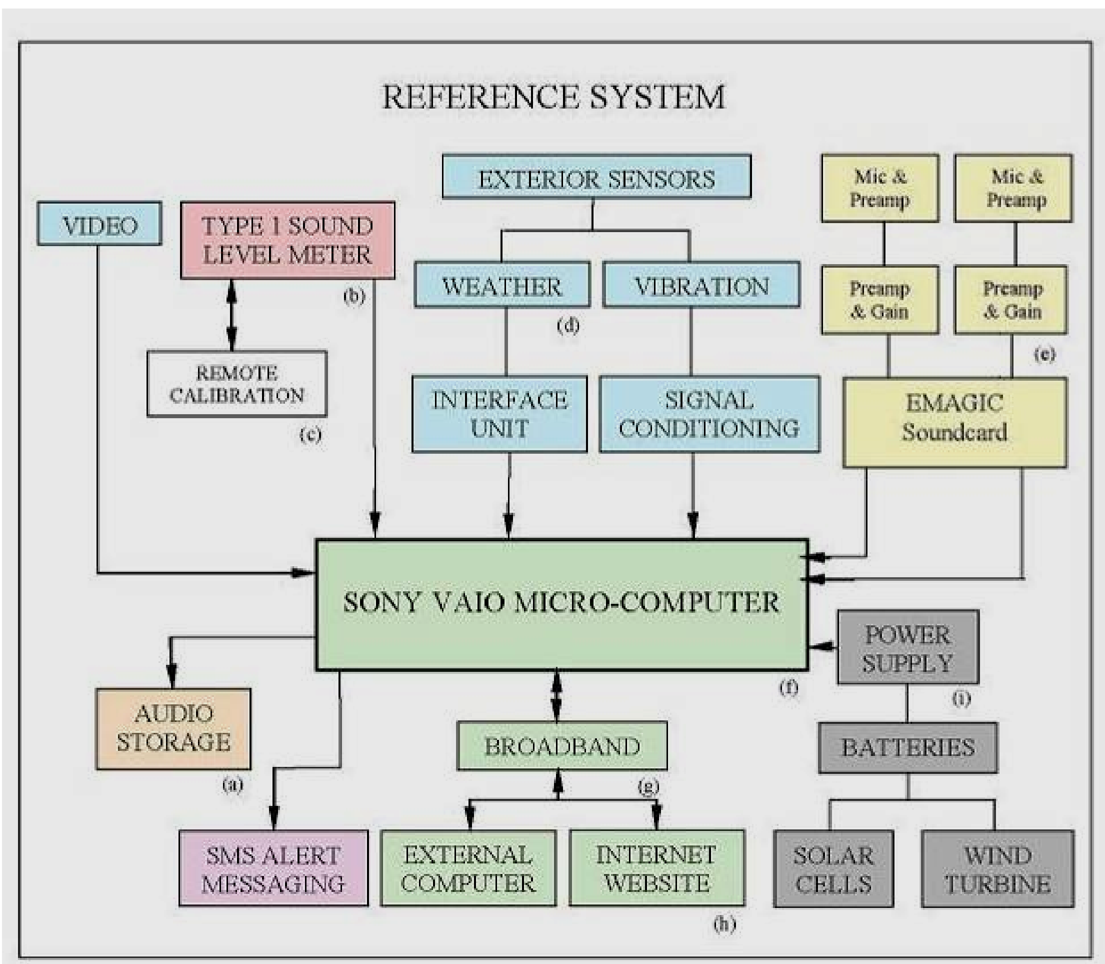


Figure 1: Reference sound recording system

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, including sealed lead-acid batteries, solar panels or small 'hobbyist' wind turbine power generator

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 decisions 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. In cases where this analysis does not result in a tonal component being defined although the sound is perceived as being tonal it will be necessary to undertake a narrow band analysis in order to determine if a sound is tonal using International Standard ISO 1996-2 second edition, *Acoustics - description, assessment and measurement of environmental noise - part 2: Determination of environmental noise levels*.

A standard test for modulation is if the measured A-weighted peak to trough levels exceeds 5 dB on a regularly varying basis, of if the measured one-third octave band peak to trough levels exceeds 6 dB on a regular basis in respect of the blade pass frequency. Alternatives for spectral analysis for a test of 'reasonableness' are:

(a) if the measured narrow-band (unweighted) peak to trough amplitude of the complex under investigation measured at a sampling rate of 50 milliseconds or 125 milliseconds, for example, exceeds 3 dB on a regularly varying basis, or

(b) 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.

The character, salience, or dissonance of the sound can be measured with standard descriptors for loudness, sharpness, fluctuation and unbiased annoyance.

Zwicker's unbiased annoyance (UBA) is modified 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 $d = 1 + (N10/5)^{0.5}$.

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

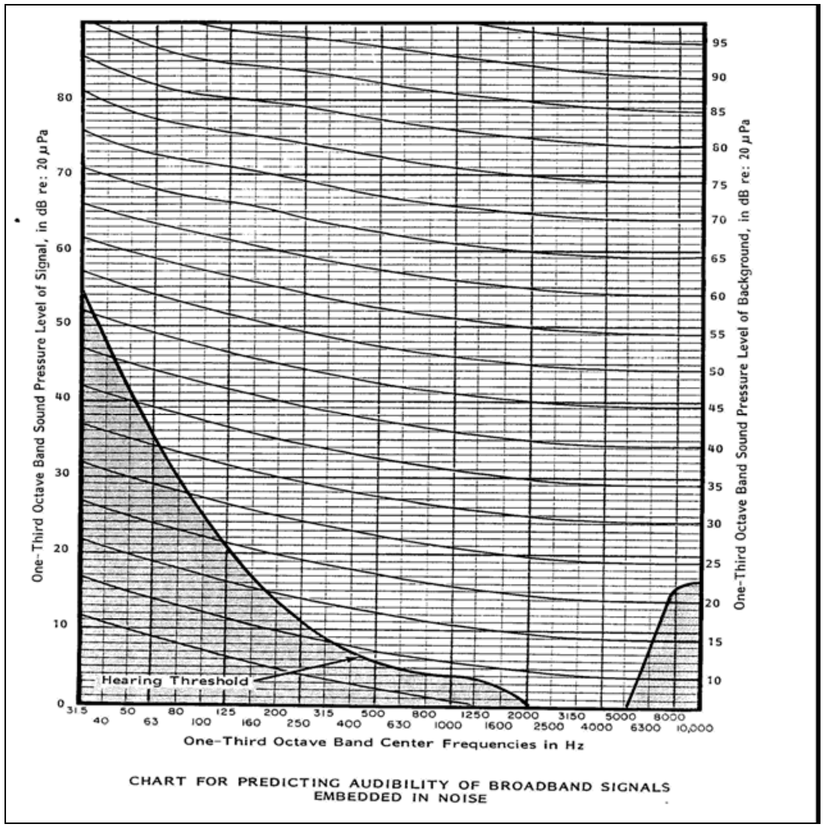


Figure 2: Audibility of a sound

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[32]. Sound and weather monitoring systems are available from Kenelec Scientific. 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[33]. The designs of the hardware and software systems are described in more detail in *Assessing intrusive noise and low amplitude sound* by Thorne, recommended reading reference 3.

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.

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

PART XI - 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	Cautiously moderate or 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 nighttime 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, then this should be noted too.
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

PART XII - RECOMMENDED READING

In addition to the references in the Guideline 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.

Thorne, R., (2007). Assessing intrusive noise and low amplitude sound. Doctoral thesis and analysis software, Massey University, Palmerston North, New Zealand. Access from university library:

http://kea.massey.ac.nz/search~S1?/aThorne+Robert/athorne+robert/1%2C2%2C2%2CB/frameset&FF=athorne+robert&1%2C1%2C

1. Alain, C., Arnott, S. R., Hevenor, Graham, S., and Grady, C. L., (2001). 'What' and 'where' in the human auditory system. PNAS, 19(21), pp12301–12306.
2. Alves-Pereira, M., and Castelo Branco, N. A. A., (2007). In-home wind turbine noise is conducive to vibroacoustic disease. Second International Meeting on Wind Turbine Noise, Lyon, France.
3. Alves-Pereira, M., and Castelo Branco, N. A. A., (2007). Public Health and noise exposure: the importance of low frequency noise. Proceedings the InterNoise Conference, Istanbul, Turkey, pp3–20.
4. American National Standard, (1973). ANSI S3.20, Psychoacoustical Terminology. Standards Secretariat Acoustical Society of America, New York.
5. Assessing vibration: a technical guideline, (2006). Department of Environment and Conservation, New South Wales, Australia.
6. Australian Standard AS/NZS 2107:2000, Acoustics-Recommended design sound levels and reverberation times for building interiors, Sydney: Standards Australia International Ltd.
7. Bakker, H. & Rapley, B. editors. (2010) Sound, noise, flicker and the human perception of wind farm activity. Turitea wind farm proposal evidential text available from www.atkinsonrapley.co.nz
8. Bakker, H. H. C., Bennett, D. J., Rapley, B. and Thorne R., (2009). Seismic Effect on Residents from 3 MW Wind Turbines, Third International Meeting on Wind Turbine Noise, Aalborg, Denmark.
9. Barregard, L., Bonde, E., and Ohrstrom, E., (2009). Risk of hypertension from exposure to road traffic noise in a population based sample. Occup. Environ. Med. 66, pp410-415.
10. Basner, M., (2008). Nocturnal aircraft noise exposure increases objectively assessed daytime sleepiness. Somnologie 12(2), pp110-117.
11. Basner, M., Glatz, C., Griefahn, B., Penzel, T., Samel, A., (2008). Aircraft noise: Effects on macro- and microstructure of sleep. Sleep Medicine, 9 (4), pp382-387.
12. Belojevic, G., et al. (2008). Urban road traffic noise and blood pressure and heart rate in preschool children. Environment International. 34, pp226-231.
13. Belojevic, G., Jakovljevic, B., Aleksic, O., (1997). Subjective reactions to traffic noise with regard to some personality traits. Environ Int 23 (2), pp221–226.
14. Beranek, L. L., (1988). Acoustical Measurements. Acoustical Society of America. Massachusetts.
15. Berglund, B. and Lindvall, T., (Eds) (1995). Community Noise. Archives of the Center for Sensory Research. 2(1), pp1-195. ISBN 91-887-8402-9.
16. Berglund, B., and Lindvall, T., (1990). Public health implications of environmental noise. Environment International, 16(46), p,313-601.
17. Berglund, B., and Nilsson, M. E., (1997). Intrusiveness and dominant source identification for combined community noises. Proceedings of the thirteenth annual meeting of the international society for psychophysics, Poznan, Poland.
18. Berglund, B., Lindval, T., and Schwela, D., (Eds) (2000). Guidelines for community noise. World Health Organization, Geneva, Switzerland.
19. Bergman, A., (1990). Auditory Scene Analysis. MIT Press, Cambridge MA.

20. Berry, B. F. and and Flindell, I. H., (1998). Noise effects research: The importance of estimating noise exposure properly. Proceedings of Noise Effects '98, November 22-26, Sydney, pp627–630.
21. Bolin, K., (2009). Wind Turbine Noise and Natural Sounds: Masking, Propagation and Modeling. Doctoral dissertation, Kungliga Tekniska Hogskolan, Stockholm.
22. Bolt, Beranek and Newman (1982) Graphic Method for Predicting Audibility of Noise Sources, US Flight Dynamics Laboratory Air Force Systems Command, publication AFWAL–TR–82–3086
23. Bowdler, D., (2008). Amplitude modulation of Wind Turbine Noise. A Review of the Evidence. Acoustics Bulletin, 33(4).
24. British Standard BS6472:1992, (1992). Guide to Evaluation of Human Exposure to Vibration in Buildings (1Hz to 80Hz). British Standards Institution.
25. Bruck, D., Thomas, I., and Rouillard, V., (2009). How does the pitch and pattern of a signal affect auditory arousal thresholds? Journal of Sleep Research, 18 (2). pp196–203. ISSN 0962-1105
26. Butré J-L. (2005). French St. Crepin windplant noise survey results (2005), cited as a personal communication from J-L Butre, Ventducobage, 11-5-05 in Pierpont N. 2006[13].
27. Carter, S., Williams, S., Paterson, J., and Lusitini, L., (2009). Do perceptions of neighbourhood problems contribute to maternal health?: Findings from the Pacific Islands Families study. Health and Place. 15, pp622–630.
28. Casella, S., (2001). Low Frequency Noise Update. DEFRA Noise Programme, Department of the Environment, Northern Ireland, Scottish Executive, National Assembly for Wales, pp1–11.
29. Castelo Branco, N. A. A., (1999). The clinical stages of vibroacoustic disease. Aviation Space Environmental Medicine, 70 (3, Suppl), pA329.
30. Castelo Branco, N. A. A., Alves-Pereira, M., (2004). Vibroacoustic disease. Noise & Health, 6(23), 320.
31. Clark, G. H., (2007). Meteorological aspects of noise propagation in the atmosphere – application to the Taralga wind-farm. Evidence to the Taralga wind farm modification hearing, reference NSW Land & Environment Court Proc 11216 of 2007.
32. Colby, W.D., et al. (2009) Wind turbine sound and health effects; an expert panel review. Prepared for the American Wind Energy Association and Canadian Wind Energy Association.
33. Critique of the NHMRC Paper Wind Turbines and Health: A Rapid Review of the Evidence by the Society for Wind Vigilance June 2010
34. Cui, B., Wu, M., & She, X. (2009). Effects of Chronic Noise on Spatial Learning and memory of rats. Journal of Occupational Health. 51, pp152-158.
35. Davis, J., (2007). Noise Pollution from Wind Turbines. Presented at the Second International meeting on wind turbine noise, Lyon, France.
36. Devlin, E., (2005). Factors Effecting Public Acceptance of Wind Turbines in Sweden. Wind Engineering. 29(6), p503-511.
37. Dratva, J., (2010). Impact of road traffic noise annoyance on health-related quality of life: results from a population-based study. Quality of Life Research. 19, pp37–46.
38. DZ6808:2009 Review, (2009), 283 pages; released under the NZ Official Information Act.
39. EnHealth Council, (2004). The health effects of environmental noise – other than hearing loss. ISBN 0-642-823049, The Australian Government Department of Health and Aging, Australia.
40. Environment Court Decision W031/2007 Meridian Energy (et al.) vs Wellington City Council (et al.)
41. Environment Court Decision W59/2007 Meridian Energy West Wind decision
42. ETSU, (1996). The Assessment & Rating of Noise from Wind Farms. Final Report, ETSU R97 for the UK Department of Trade and Industry, UK.
43. European Union. (2000). The Noise Policy of the European Union – Year 2. Luxembourg.
44. Fidell, S., (2003). The Schultz curve 25 years later: a research perspective. Journal of the Acoustical Society of America, 114(6), pp3007-3015.
45. Fields, J. M., (1993). Effect of Personal and Situational Variables on Noise Annoyance in Residential Areas. Journal of the Acoustical Society of America. 93, pp2753–2763.
46. Fletcher, H., (1940). Auditory Patterns. Reviews of Modern Physics, 12, pp47–65.
47. Flindell, I. H., and Stallen, P. J., (1999). Nonacoustical factors in environmental noise. Noise and Health, 3, p11–16.

48. French Academy of Medicine. (2006). Repercussions of wind turbine operations on human health. Retrieved from http://ventdubocage.net/documentsoriginaux/sante/eoliennes.pdf
49. Gastaut, H., Tassinari, C. A., (1966). Triggering mechanisms of epilepsy. The electroclinical point of view, 7, pp85-138.
50. Glaze, A. L., Ellis, J. M., (2003). Pilot Study of distracted drivers. Report, Transportation and Safety Training Centre, Centre for Public Policy, Virginia Commonwealth University, Virginia, USA.
51. Graham, J. B., Stephenson, J. R. and Smith I. J., (2008). Public perceptions of wind energy developments: case studies from New Zealand. Report, University of Otago, Dunedin, New Zealand.
52. Griefahn, B., et al., (2008). Autonomic arousals related to traffic noise during sleep. Sleep. 31, pp569-577.
53. Griffiths, R., and Raw, G. J., (1989). Adaptation to changes in traffic noise exposure. Journal of Sound and Vibration. 132(2), pp331-336.
54. Gross, C., (2007). Community perspectives of wind energy in Australia: The application of a justice and community fairness framework to increase social acceptance. Energy Policy. 35, pp2727-2736.
55. Haralabidis, A. S., et al., (2009). Acute effects of night-time noise exposure on blood pressure in populations living near airports. European Heart Journal. March 2008, 29, pp658–664.
56. Harding, G., Harding, P., Wilkins, A., (2008). Wind turbines, flicker, an photosensitive epilepsy: Characterising the flashing that may precipitate seizures and optimising guidelines to prevent them. Epilepsia, 49(6), pp1095-1098
57. Hardoy, M.C., (2005). Exposure to aircraft noise and risk of psychiatric disorders. Social psychiatry and Epidemiology, 40, pp24-26.
58. Harris, C., (1998). Handbook of Acoustical Measurements and Noise Control. American Institute of Physics. Melville, New York. ISBN 1-56396-774-X.
59. Harry, A., (2007). Wind Turbines, Noise and Health. Retrieved from http://www.flatgroup.co.uk/pdf/wtnoise_health_2007_a_barry.pdf
60. Hayes McKenzie Partnership Ltd, (2006). The measurement of low frequency noise at three UK wind farms. Report to DTI, URN number 06/1412. Retrieved from http://www.berr.gov.uk/energy/sources/renewables/explained/wind/onshore-offshore/page31267.html
61. Hayes, M. D., (2007), Affidavit-in-Reply to the Environment Court New Zealand, West Wind Proceedings, Decision W59/2007, Clause 34.
62. Heinonen-Guzejev, M., Heikki, S., Vuorinen, Mussalo-Rauhamaa, H., Heikkilä, K., Koskenvuo, M., and Kaprio, J., (2005). Genetic Component of Noise Sensitivity, Twin Research and Human Genetics. 8, pp245–249.
63. Horner, B. et al. (2010) An analysis of the American/Canadian Wind Energy Association sponsored "Wind turbine sound and health effects An expert panel review, December 2009. Prepared for the Society for Wind Vigilance. Retrieved from www.windvigilence.com
64. Hubbard H. H., Shepherd K. P., (1990), Wind Turbine Acoustics, NASA Technical Paper 3057 DOE/NASA/20320-77.
65. Hubbard, H. H., Shepherd, K. P., (1991). Aeroacoustics of large wind turbines. J Acoust. Soc. Am., 89(6), June 1991.
66. IEC, (2002). IEC61672-1:2002, Electroacoustics – sound level meters – Part 1 Specifications. International Electrotechnical Commission. Geneva, Switzerland.
67. IEHMRC Institute for the Environment and Health, (1997). The non-auditory effects of noise. Report 10, ISBN 1 899110143, Leicester, England.
68. Ingard, U., (1953). A review of the influence of meteorological conditions on sound propagation. JASA. 25 pp405-411.
69. International Electrotechnical Commission, (2002). IEC 61400-11, 2nd edition, Wind turbine generator systems - Part 11: Acoustic noise measurement techniques. International Electrotechnical Commission.
70. International Standard ISO 9613–2 :1996E Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation. (1996) International Organization for Standardization, Genève, Switzerland.
71. International Standards Organization, (2003). ISO 226, Acoustics-Normal equal loudness contours. International Standards Organization.

72. International Standards Organization, (2007). ISO 1996-2 second edition, Acoustics - description, assessment and measurement of environmental noise - part 2: Determination of environmental noise levels. International Standards Organization.

73. Jabben, J., Verheijen, E. and Schreurs, E.. (2009). Impact of wind turbine noise in the Netherlands. Third International Meeting on Wind Turbine Noise. Aalborg, 17-19 June 2009.

74. Job, R. F. S., (1988). Community Response to Noise: A review of factors influencing the relationship between noise exposure and reaction. Journal of the Acoustical Society of America, 83, pp991-1001.

75. Job, R. F. S., Hatfield, J., Peploe, P., Carter, N. L., Taylor, R. and Morrell, S., (1999), Reaction to combined noise sources: The roles of general and specific noise sensitivities. Proceedings of Inter-noise '99, December 6-8, Florida, pp1189-1194.

76. Joberta, A., Laborgneb, P., and Solveig M., (2007). Local acceptance of wind energy: Factors of success identified in French and German case studies. Energy Policy. 35(5), pp2751-2760.

77. Johansson, M., and Laike, T., (2007). Intention to respond to local wind turbines: the role of attitudes and visual perception. Wind Energy. 10, pp543-545

78. Kabes, D. E. and Smith, C., (2001). Lincoln Township Wind Turbine Survey, Agricultural Resource Center, University of Wisconsin Extension/Cooperative Extension, May 16, 2001.

79. Kamperman, G. and James, R. R., (2008). Simple guidelines for siting wind turbines to prevent health risks. INCE NOISE_CON 2008, pp.1122-1128.

80. Kluizenaar, Y., et al., (2009). Long-term road traffic noise exposure is associated with an increase in morning tiredness. Journal of Acoustical Society of America, 126, pp626–633.

81. Kryter, K. D., (1985). The Effects of Noise on Man. Academic Press Inc, London, England, 2nd Edition.

82. Kryter, K. D., (2007). Acoustical, sensory, and psychological research data and procedures for their use in predicting the effects of environmental noises. Journal of the Acoustical Society of America, 122(5), pp2601-2614.

83. Kuwano, S., and Seiichiro, N., (1990). Continuous Judgment of Loudness and Annoyance. Proceedings of the Sixth Annual Meeting of the International Society of Psychophysics, Wurzburg, Germany, pp129–134.

84. Lama, K., Chana, P., Chanb, T., Aua W., and Huia, W., (2009). Annoyance response to mixed transportation noise in Hong Kong. Applied Acoustics, 70(1), pp1-10.

85. Leventhall, G., Pelmear P. & Benton S., (2003). A review of published research on low frequency noise and its effects. Department for Environment, Food and Rural Affairs, Defra Publications, London, England.

86. Leventhall, H. G., (2004). Low frequency noise and annoyance. Noise & Health, 6(23), pp59-72.

87. Leventhall, H. G., (2006). 'Infrasound from Wind Turbines – Fact, Fiction or Deception'. Canadian Acoustics, Special issue, 34(2), pp 29–36.

88. Leventhall, H.G., (2009). Wind Turbine Syndrome - An appraisal. Testimony before the Public Service Commission of Wisconsin, PSC Ref#121877 20 October 2009

89. Maris, E., Stallen, P. J., Vermunt, R., and Steensma, H., (2007). Noise within the social context: annoyance reduction through fair procedures. Journal of the Acoustical Society of America, 121(4), pp2000-2010.

90. Maris, E., Stallen, P.J., Vermunt, R., and Steensma, H., (2007). Evaluating noise in the social context: the effect of procedural unfairness on noise annoyance judgements. Journal of the Acoustical Society of America, 122(4), pp3483–3494.

91. Mathews, R., (2009). The Effects of Community Noise on Health and Wellbeing. AUT University Library, Dissertation.

92. Miedema, H. M. E., and Oudshoorm, C. G. M., (2001). Annoyance from transportation noise: Relationship with exposure metrics DNL and DENL. Environmental Health Perspectives. 109(4), pp409–416.

93. Miedema, H. M., and Vos, H., (1999). Demographic and attitudinal factors that modify annoyance from transportation noise. Journal of Acoustical Society of America, 105(6), pp3336-3344.

94. Miedema, H. M., and Vos, H., (2003). Noise sensitivity and reactions to noise and other environmental conditions. Journal of the Acoustical Society of America. 113(3), pp1492–1504.

95. Miller, J. D., (1974). Effects of noise on people. Journal of the Acoustical Society of America. 56(3), pp729-764.

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

97. Mosley, K., (2007). Evidence to the Inquiry under the RMA into the proposed Motorimu wind farm. Heard before the Joint Commissioners 8th–16th March 2007, Palmerston North.

98. National Wind farm Guidelines Draft July 2010, Environment Protection and Heritage Council, Australia

99. Navrud, S 2002, The state-of-the-art on economic valuation of noise, Report to European Commission DG Environment, Norway: Agricultural University.

100. Nelson, D. A. (2007). Perceived loudness of wind turbine noise in the presence of ambient sound. Presented at the Second International Meeting on Wind Turbine Noise, September 20 –21, Lyon, France.

101. Niemann, H., and Maschke, C., (2004). WHO Lares: Report on noise effects and morbidity. World Health Organisation, Geneva.

102. Nord2000. Comprehensive Outdoor Sound Propagation Model. Part 2. Propagation in an atmosphere with refraction. AV1851/00

103. Nosulenko, V. N., (1990). Problems of Ecological Psychoacoustics. Proceedings of the Sixth annual meeting of the international society of psychophysics, Wurzburg, Germany, pp135–138.

104. Origin Energy (2006). Driving investment in renewable energy in Victoria: Options for a Victorian market-based measure. Guide by Origin Energy in response to the Issues paper released by the Department of Infrastructure and Department of Sustainability and Environment, December 2005.

105. Osbourne, B., (2007). Impact on Wind Farms on Public Health. Taken from Kansas Legislative Research Department; retrieved from www.kslegislature.org/kird

106. Oteri, F., (2008). An Overview of Existing Wind Farm Ordinances. Technical Report NREL/TP-500-44439, for the U.S. Department of Energy, USA.

107. Pedersen, E., (2007). Human response to wind turbine noise; perception, annoyance and moderating factors., Thesis, Göteborgs Universitet, Germany.

108. Pedersen, E., and Nielsen, K. S., (1994). Annoyance due to noise from wind turbines. Delta Acoustic and Vibration Ltd. Report 150, Copenhagen, Denmark.

109. Pedersen, E., and Persson Waye, K., (2004). Perception and annoyance due to wind turbine noise: a dose response relationship. Journal of the Acoustical Society of America, 116(6), pp3460-3470.

110. Pedersen, E., and Persson Waye, K., (2007). Wind turbine noise, annoyance and self-reported health and wellbeing in different living conditions. Occupational Environmental Medicine, 64, pp480-486.

111. Pedersen, E., and Waye, K. P. (2008). Wind Turbines – low level noise sources interfering with restoration? Environmental Research Letters, 3, 1-5.

112. Pedersen, E., Hallberg, L.R.M., and Persson Waye, K. P. (2007). Living in the Vicinity of Wind Turbines - A Grounded Theory Study. Qualitative Research in Psychology, 4: 1, 49 – 63.

113. Pedersen, E., van den Berg, F., Bakker, R., and Bouma, J. (2009). Response to noise from modern wind farms in The Netherlands. Journal of the Acoustical Society of America. 126:634-643.

114. Pederson, E. W., (2005). Human Response to Wind turbine Noise – Annoyance and moderating factors. Wind Turbine Noise: Perspectives for control, Berlin, INCE/European Conference.

115. Persson, W., Bengtsson, J., Rylander, R., Hucklebridge, F., Evans, P., and Chow, A., (2002). Low frequency noise enhances cortisol among noise sensitive subjects. Life Sciences, 70, pp745-758.

116. 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

117. Phipps, R. A, Amati, M., McCoard, S., Fisher R.M., (2007). Visual and Noise Effects Reported by Residents Living Close to Manawatu Wind Farms: Preliminary Survey Results. New Zealand Planners Institute Conference, Palmerston North, 27-30 March 2007

118. Pierpont, N., (2006). Wind Turbine System. Testimony before the New York State Legislature Energy Committee. Retrieved from http://www.ninapierpont.com/?s=wind

119. Pierpont, N., (2009), Wind turbine syndrome: A Report on a natural experiment, ISBN 978-0-9841827-0-1, K-Selected Books, Santa Fe, New Mexico, USA.

120. Pirrera, S., De Valck, E., and Cluydts, R., (2009). Nocturnal road traffic noise and sleep quality: Habituation effects assessed in a test-retest field situation. Sleep. 32, pA422.

121. Pripfl, J., Robinson, S., Leodolter, U., Moser, E., and Bauer, H. (2006). EEG reveals the effect of fMRI scanner noise on noise-sensitive subjects. NeuroImage 31, 332 – 341.

122. Project West Wind Condition 18 Compliance Report, Draft Report 1610-R3, Hayes McKenzie Partnership and Delta Test Report Measurement of Noise Emission from a Siemens 2.3 MW VS Wind Turbine Situated at Braderup, Germany. Draft 23 August 2007

123. Rhudy, J. L., & Meagher, M. W., (2001). Noise-induced changes in radiant heat pain thresholds: Divergent effects in men and women. Journal of Pain. 2, pp57–64.

124. Risto, T. (2008). Comparison of electricity generation costs. Research report EN A-56, Kivistö Aija Lappeenranta University of Technology.

125. Salt, A.C & Hullar, T.E., (2010) Response of the ear to low frequency sounds, infrasound and wind turbines. Access from Hearing Research pub. Vol 268, Issues 1-2, p12-21, Sept 2010 and see extra information at http://oto.wustl.edu/cochlea/

126. Sandrock, S., Schutte, M., and Griefahn, B., (2009). Impaired effects of noise in high and low noise sensitive persons working on different mental tasks. International Archive of Occupational and Environmental Health. 81, pp179–191.

127. Schick, A., (1990). Proceedings of the Sixth Annual Meeting of the International Society of Psychophysics, Wurzburg, Germany.

128. Schomer, P., (2001). A White Paper: Assessment of noise annoyance. Schomer and Associates Inc, Champaign, Illinois.

129. Schultz, T. J., (1982). Community noise rating. 2nd edition. ISBN 0-85334-137-0 Applied Science Publishers. Barking Essex UK.

130. Schütte, M., Markes, A., Wenning, E. & Griefahn, B., (2007). The development of the noise sensitivity questionnaire. Noise & Health. Jan-Mar 2007, 9, pp15–24.

131. Selye, H., (1975). Stress Without Distress. Lippincott, New York, USA.

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

133. Standfeld, S. A., (1992). Noise, noise sensitivity, and psychiatric disorders: epidemiological and psychophysiological studies. Psychological Medicine, 22, pp1–44.

134. Stephens, D. G., Shepherd, K. P., Hubbard, H. H., and Grosveld, F. W., (1982). Guide to the evaluation of human exposure to noise from large wind turbines. NASA Technical Memorandum 83288, Langley Research Centre.

135. Stigwood, M., (2008). Evidence to the Public Enquiry into the proposed North Dover Wind Park. PINS Ref: APP/X2220/A/08/2071880/NWF.

136. Styles, P., Stimpson, I., Toon, S., England, R. and Wright, M., (2005), Microseismic and Infrasound Monitoring of Low Frequency noise and Vibration from Wind Farms: Recommendations on the Siting of Wind Farms in the Vicinity of Eskdalemuir, Scotland. Report, Keele University, Keele, UK.

137. Styles, P., Toon, S., (2005). Wind Farm Noise, Article, British Wind Energy Association. Retrieved from http://www.bwea.com/ref/lfn_keele.html

138. Suter, A., (1991). Noise and Its Effects. Prepared for the Consideration of the Administrative Conference of the United States. Retrieved from www.nonoise.org/library/suter/suter.htm

139. Tatarski, V. I., (1967). Wave propagation in a turbulent medium. Dover publications, New York.

140. The Noise Association, (2009). Location, Location, Location - An investigation into wind farms and noise by The Noise Association. The UK Noise Association, Chatham. Retrieved from http://windconcernsontario.files.wordpress.com/2009/07/ukna-windfarmreport.pdf

141. Thorne, R., (2007). Assessing intrusive noise and low amplitude sound. Doctoral thesis and analysis software, Massey University, Palmerston North, New Zealand. Access from university library *http://kea.massey.ac.nz/search~S1?/aThorne+Robert/athorne+robert/1%2C2%2C2%2CB/frameset&FF=athorne+robert&1%2C1%2C*

142. Tickell C. E., Ellis J. T. & Bastasch M., (2004). Wind turbine generator noise prediction – comparison of computer models. Proceedings of ACOUSTICS 2004, Australian Acoustical Society, Gold Coast Australia, pp45–50.

143. Vainio, M & Paque G (eds.) 2002. Highlights of the workshop on the 'State-of-the-art in noise valuation', Final Report. European Commission-DG Environment, Brussels.

144. van den Berg, F., Pedersen, E., Bouma, J., and Bakker, R. (2008). Visual and Acoustic impact of wind turbine farms on residents. FP6-2005-Science and Society-20, Project no. 044628. A report financed by the European Union.

145. van den Berg, G. P., (2004). Do wind turbines produce significant low frequency sound levels? Eleventh Meeting on Low Frequency Noise and Vibration and its Control. August 30–September 1, Maastricht, Holland.
146. 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 for Physics, Netherlands.
147. Van Gerven, P. W. M., Vos, H., Boxtel, M. P. J., Janssen, S. A., and Miedema, H. M. E., (2009). Annoyance from environmental noise across the lifespan. Journal of the Acoustical Society of America, 126(1), pp187–194.
148. van den Berg, G. P., (2005). The beat is getting stronger: The effect of atmospheric stability on low frequency modulated sound by wind turbines. Journal of Low Frequency Noise, Vibration and Active Control. 24(1), pp1–24.
149. Vassilakis, P. N., (2001). Perceptual and physical properties of amplitude fluctuation and their musical significance. PhD thesis, University of California
150. Vasudevan, R. N., and Gordon, C. G., (1977). Experimental study of annoyance due to low frequency environmental noise. Applied Acoustics 10, pp57–69.
151. Vestas. (2008). V90 - 3.0MW An efficient way to more power. Product Brochure, Vestas Wind Systems A/S, Randers, Denmark
152. Westman, J. C., and Walters, J. R., (1981). Noise and stress: A comprehensive approach. Environmental Health Perspectives, 41, pp291–309.
153. Wild T., (2008). Attitudes to Wind Farms: the Dynamics of Submitters Opinions. Masters Thesis, University of Otago, Dunedin, New Zealand.
154. Williams H. L., (1970). Auditory stimulation, sleep loss and the EEG stages of sleep. Physiological Effects of Noise, Welch B L & Welch S W. (Eds) Plenum Press.
155. Wind Turbines and Health: A Rapid Review of the Evidence, National Health and Medical Research Council, Paper, June 2010
156. Critique of (157) the NHMRC Paper Wind Turbines and Health: A Rapid Review of the Evidence by the Society for Wind Vigilance June 2010
157. World Health Organisation (1997). WHOQOL. Measuring quality of life. Geneva: WHO.
158. World Health Organisation, (2007). Report on the first planning meeting on night noise guidelines. World Health Organization. Geneva.
159. World Health Organisation, (2008). World health report 2008 - Primary Health Care: Now more than ever. World Health Organization. Geneva. Retrieved from: http://www.who.int/whr/2008/whr08_en.pdf
160. World Health Organisation. (2009). Night noise guidelines for Europe. Copenhagen.
161. World Health Organization, (2003). Investing in Mental Health. World Health Organization. Geneva. Retrieved from http://www.who.int/mental_health/en/investing_in_mnh_final.pdf
162. Wußow, S., Sitzki, L., Hahm, T., (2007). 3D-simulation of the Turbulent Wake Behind a Wind Turbine. Journal of Physics: Conference Series 75 012033, pp1–8.
163. Yost, W. A., (2000). Fundamentals of Hearing, 4th ed. Academic Press. California.
164. Zimmer, K and Ellermeier, W. (1999). Psychometric Properties of four measures of noise sensitivity. Journal of Environmental Psychology, 19(3), pp295–302.
165. Zwicker, E., & Fastl, H., (1999). Psycho-acoustics facts and models, 2nd ed. Springer-Verlag Berlin Heidelberg, Berlin.