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The Problems with 'Noise Numbers' For Wind Farm Noise Assessment

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Wind Farms are a Unique Source of 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 such as those proposed are large noise sources relative to dwellings, **Plate 1:**

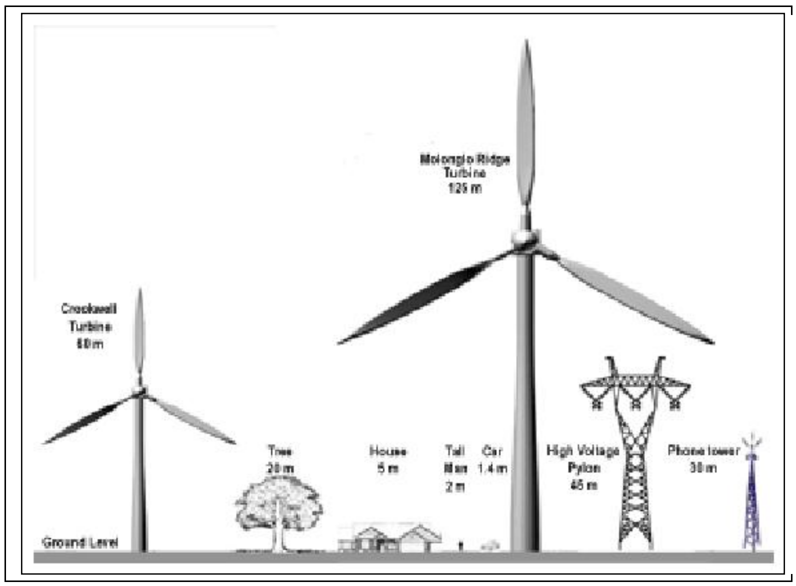


Plate 1: Relative heights of turbines to dwellings
(Source: Molonglo Landscape Guardians, by permission)

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. Sound in the low frequencies and infrasound frequencies can be heard if the sounds are loud enough. The sounds, however, may be perceptible rather than heard at relatively lower levels of "loudness".

Evidence produced in New Zealand concerning the West Wind and Te Rere Hau wind farms indicate that the adverse effects of wind farm noise are well documented. West Wind has recorded 906 complaints over a 12 month period. Te Rere Hau has recorded 378 complaints over an 11 month period. Waubra (Victoria, Australia) has a less well documented complaint history but sufficient to identify issues.

Wind farm sound analysis presents three distinct issues:

- The identification of sound that can be directly attributed to the sound of the wind farm/turbines, measured as a background sound level, compared to the sound of the ambient environment without the presence of the wind turbines;

- The sound of any special audible characteristics of the wind farm/turbines, such as distinct tonal complexes and modulation effects (amplitude and frequency) that may affect human health through sleep disturbance, for example; and
- The presence of any sound characteristics that may affect human health.

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

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

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

Evidence in this Paper allows me to conclude that there is the potential for adverse health effects for individuals due to wind farm activity while living in their residences and while working on their farms within 3500 metres of large-scale turbines. Wind farm activity that causes adverse health effects such as sleep disturbance, anxiety, stress and headaches is a health nuisance, is objectionable and unreasonable.

The research documented to date for this Paper 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 Paper. The hypothesis derived from my research is that wind farm sound has an adverse effect on individuals due to this pulsing nature as well as audible noise due to the wind turbines. These effects may be cumulative.

The Problems with ‘Noise Numbers’ For Wind Farm Noise Assessment

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 5 years’ monitoring wind turbines at different locales under widely different weather conditions. **Figure 1** illustrates the issue: there are 3 separate sets of 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 (e.g. the ‘background or LA95’ sound level or ‘time-average LAeq’ sound level) at a specific location, such as a residence.

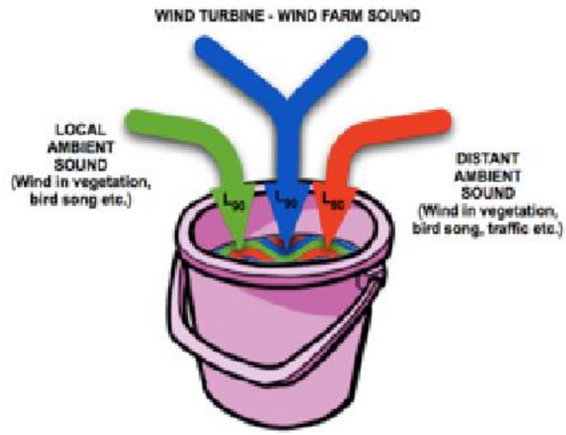


Figure 1: "Bucket of mixed sound" from different sources.

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. 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. The levels are recorded as, for example, Z-unweighted sound levels in third-octave or 1/12 octave bands. Still difficult, but not impossible.

Obviously loud levels of sound from a wind farm in excess of 35 dB(A) Leq may be measurable but still very difficult to prove as being the source of sound when mixed into sound from vegetation (wind in trees, for example).

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

It is on this fundamental issue that any standard or condition requiring a wind farm to comply with a specific compliance level will fail. The only possible way 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.

The problems with understanding the potential effects of the wind farm start with the sound level predictions often used to assess compliance against some form of guideline or legislation.

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 certainty using simple prediction methods such as ISO 9613-2:1996 *Acoustics-Attenuation of sound during propagation outdoors; Part 2 General method of calculation*. Conversely, the prediction method can be used to provide an indication of expected sound levels over a long-term of 12 months, for example.

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. Noise predictions do not tell the whole story, however. 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(A) at 1000 metres for the most common prediction method with the predicted value being the “middle” of the range. The uncertainty increases with distance and the effect of two or more turbines operating in phase with a light/strong breeze blowing towards a residence. A variation of 6 to 7 dB(A) can be expected under such adverse conditions. Thus on any given day the wind farm background LA95 or ‘source’ time-average (LAeq) sound levels – assuming the wind farm is operating – could vary significantly in comparison with the predicted sound level. This is without the additional effect of any adverse wind effects or weather effects such as inversions.

A typical view from a residence towards the nearest towers approximately 1800 metres to 2200 metres 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 is affected by cumulative sound as well as wake and turbulence effects. The effects are potentially more noticeable on the land as there is no screening effect from the pressure changes that can occur. The wake effects are observable 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, a local wind farm

Shepherd and Hubbard [1] suggest that turbines "shift" from line source to point source decay characteristics at a separation distance of approximately 900 metres. 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, **Photos 3 and 4.** The imaging in **Photo 3** shows the different sound levels from the blades of the two turbines.

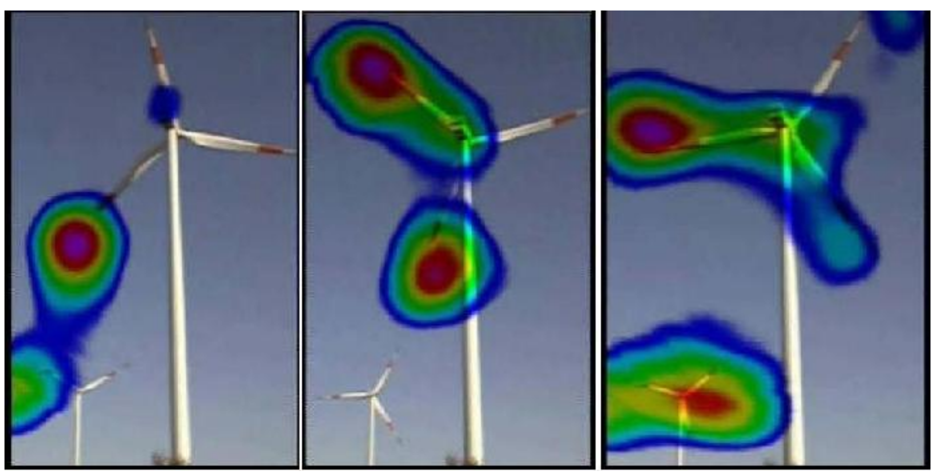


Photo 3: Acoustic photograph of sound sources from two turbines.
Source: Acoustic Camera, 'Multiple sources wind turbines 300Hz – 7kHz.avi" by permission from HW Technologies, Sydney)

The pattern in **Photo 4** shows clearly the vortex shedding from the blade on the downstroke. The dominant source of sound is from the blades with an overall sound variation in the order of 2 dB(A). The measurements are taken at approximately 150 metres behind the turbine. Frequencies below 300Hz can also be measured.

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

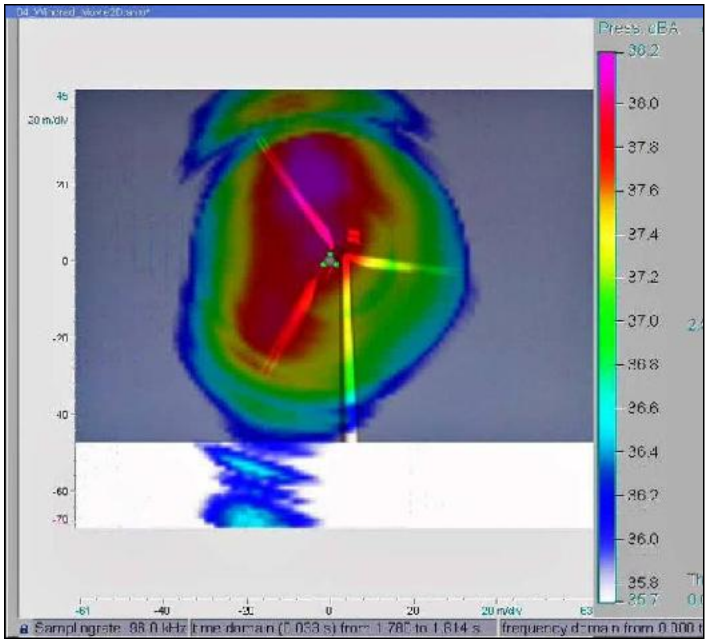


Photo 4: Acoustic photograph of sound sources from a turbine.
Source: Acoustic Camera, by permission from HW Technologies, Sydney)

Wake effects are always created as highly turbulent air leaving a turbine interacts with lower speed air. A major wind turbine manufacturer 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.[2]

The vortexs travel downwind in the form of a helix, rotating about its axis with each vortex replacing the previous one in space at approximately 1 second intervals—sometimes more, sometimes less depending on the speed of rotation and number of blades. The practical effect is to create Heightened Noise Zones.

A Heightened Noise Zone (HNZ) 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 vibration. The wave train travels in time and the heightened peaks and troughs create a Heightened Noise Zone at an affected residence. The effect has been consistently measured at a residence 1400 metres to 2000 metres downwind from a row of turbines. The HNZ is directly affected by the design and operation of the wind farm (location and type of turbines, phase angles between blades) and wind conditions. These variables and the effects of wind shear are confounding factors that must also be taken into account when predicting the potential for noise from a wind farm.

2 Shepherd, Ian. 2010. Wake induced turbine noise (draft), from part pers. comm.

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.

In summary, the prediction of wind farm sound levels at a receiver depends on a whole range of different assumptions and uncertainty, for example:

- the true sound power level of the turbine(s) at the specified wind speed
- the reduction in sound level due to ground effects
- the increase or reduction in sound level due to atmospheric (meteorological) variations 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

Wind farm noise level predictions can therefore be considered as only approximations of sound levels and can not be given any weight other than this. The reasons are due to the highly complex nature of the sound created by each individual turbine and the cumulative effects of a number of turbines. Unfortunately noise predictions are often taken as being 100% true by naïve approving authorities. This sense is often bolstered by consultants claiming their predictions are 'conservative' when in fact they are nothing of the kind. A conservative set of predictions includes all assumptions and uncertainties for different times of day / night, different weather / wind conditions, and the cumulative influence of the whole wind farm.

The situation becomes worse when the predicted levels are referenced to background sound levels as is the case with many wind farm guidelines, standards and compliance requirements. These conditions are often called 'background-plus' criteria where the compliance levels are determined against measured of predicted background sound levels.

Background Sound Levels

Background sound levels are the corner-stone of many acoustical standards dealing with wind farm noise. But what are background levels and how are they measured? Are they constant? Can anyone say with certainty that a background level measured at one location will be the same as in another nearby location? Does the wind affect the levels of background sound? How can wind turbine sound be identified in background sound?

This paper refers to a case study ('the Dean report') taken at two different times in 2009 under different weather conditions. Although the residence is affected by wind turbine noise a series of ambient and background sound levels were recorded in order to gain an indication of the levels within the locale. Ambient recordings were taken over the period 15-30 October 2009.

Ambient A-weighted sound levels were measured generally in accordance with Australian Standard AS1055.1:1997 - 'Acoustics-Description and measurement of environmental noise - Part 1: General procedures'. The ambient sound levels were recorded at 10 minute intervals over a 10 day period, **Table 1.** Weather data (wind speed and direction, temperature and humidity) was recorded for the same time period. Night-time is recorded as from 10pm the previous day to 7am on the nominal day.

Table 1: Average LA95 background sound levels recorded at Residence (levels rounded)

Date	LA95 Day 7am to 6pm	LA95 Evening 6pm to 10pm	LA95 Night 10pm to 7am
15 October	-	35	-
16	37	40	32
17	34	32	36
18	29	26	27
19	29	29	25
20	34	31	29
21	34	29	31
22	30	31	33
23	32	25	36
24	33	35	26
25	38	-	-

Table 1 shows the wide range in sound levels at the residence. The levels, at approximately 2000 metres from the turbines, show the impossibility of determining when or if the wind farm is exceeding a background level of 35 dB(A) or 40 dB(A). It can be inferred that for some of the time the wind farm is in compliance but at other times it might not. The situation becomes more difficult if there is sufficient breeze to cause a significant lift in background levels.

Finally, if compliance depends on the presence – or not – of audible tones or modulation, then determination becomes near impossible without people to describe the character of the sound. Due to the nature of an operational turbine modulation is a continuous feature of the wind farm under normal operational conditions – but the sound may not always be audible. In this case the residence is not occupied and the character of the sound – audible modulation in particular – can not be determined "all the time" on the basis of personal physical observation. The background sound levels are often adjusted for special audible characteristics such as modulation or tonality. Modulation can, however, be determined from sound recordings from a calibrated sound level meter at a relevant time and place investigating the sounds of the wind farm.

The important compliance issue is: how can special audible characteristics be measured in real-time. The answer is: with difficulty. Either of these two criteria requires full-time real-time monitoring in order for compliance to be proven or not-proven at any affected residence.

Sound propagation varies significantly under different wind conditions and influences both the background levels and the character of the sound, especially:

- when there is a strong breeze at the turbines but no or little breeze at the residence;
- when the prevailing breeze is blowing from the wind farm to the residence; or
- under conditions of cool, clear evenings/nights/mornings when a mist (inversion) covers the ground.

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

Thus the real sound levels from the wind farm may vary considerably within any 24-hour period, due to weather conditions. As with special audible characteristics, measurement of wind farm noise for compliance requires full-time real-time monitoring in order for compliance to be proven or not-proven at any affected residence. This applies to both audible and inaudible sound.

Audible Sound Character

The operation of the turbines to the south-west of the residence can be clearly heard at the residence. The sound on Thursday evening at 9:40 pm, 15 October 2009, can be described as a steady rumble with a mixture of rumble – thumps. Wind in the trees or vegetation is not intrusive. **Figure 2** presents the variation between maximum, minimum and average (Leq) un-weighted sound levels. Un-weighted ('Z' weight sound levels) are referenced to assess the audibility of the sound.

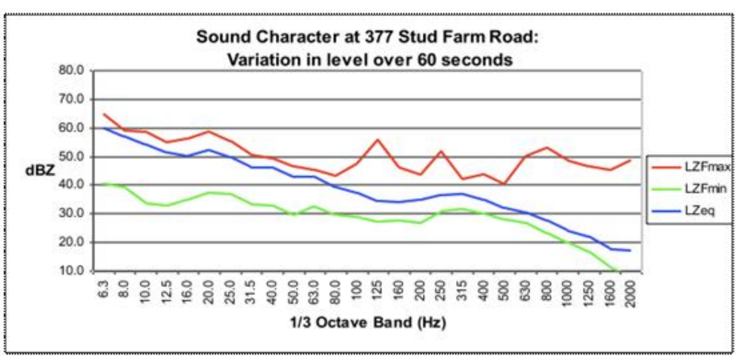


Figure 2: Variation in sound character over 60 seconds

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.

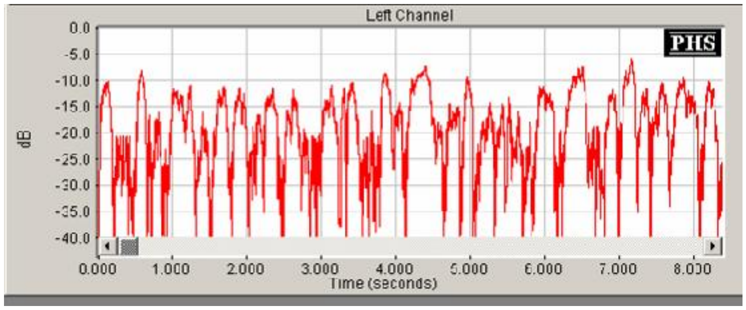


Figure 3: Pulse pattern from an operational wind farm

The background ambient sound levels for the assessment in **Figure 2** references ambient levels recorded at the residence when the turbines were not operating. 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 on the Thursday and illustrated 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.

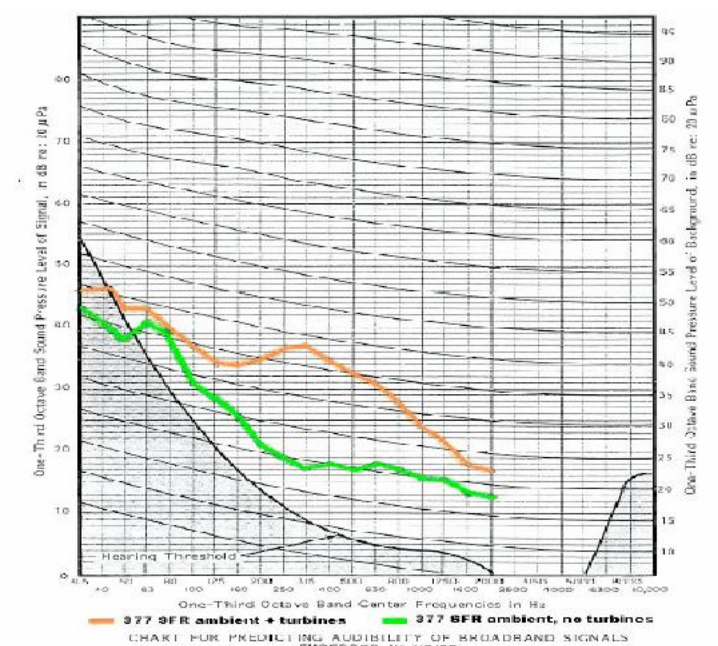


Figure 4: Audibility of wind turbines at a residence

From just this short survey it can concluded that the wind farm was in non-compliance with a 40 dB(A) background criterion that includes a penalty for special audible characteristics. Sound from wind farms can be easily heard at distances of 2000 metres; such sound was measured as the background level over the range 29 dB(A) to 40 dB(A) with conditions of calm to light breeze. The sound was modulating and readily observed and recorded. The sound can be defined as being both unreasonable and a nuisance. But in this case the sound is also causing adverse health effects to exposed residents. The reason for this is, I conclude, from the effects of audible nuisance noise and infrasound.

Low Frequency Sound and Infrasound

The issue of low frequency sound and infrasound has been a controversial topic for many years. **Figure 5** illustrates 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. The interior level for the 60 sconds is LAeq 31.6 dB(A). There are clear and distinctive audible, low frequency and infrasound levels. The residents have vacated this dwelling.

Wind farms and wind in general generate both low frequency sound and infrasound, Figures 7 to 11, from Manawatu and Makara New Zealand. The character of sound is presented as a sonogram in order to identify the characteristics of sound. The following sonograms are comparative and of 60 second or 2 minute clips to illustrate effect. They are not calibrated to each other or to the measured sound levels (nominally 10 minute surveys). Figure 7 presents the sound of a wind turbine at the wind turbine platform. Figure 8 presents the sound character of a large wind farm clearly audible through screening trees at a distance of 2200 metres. Figure 9 presents the character of the soundscape at the location of figure 2 without audible sound from the wind farm. The sonograms illustrate the low "loudness" and the distinctive character or dissonance of the sound.

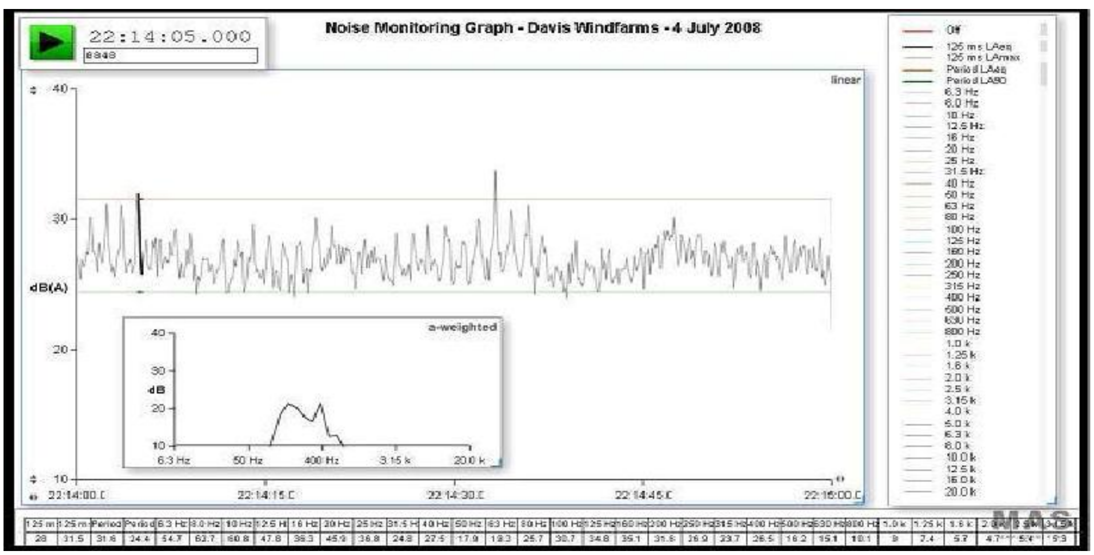


Figure 5: sound of wind turbines at 930 metres, inside residence

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 modulating sound. The sonograms and third octave band charts following are provided to illustrate the character of the sound. The method used to display sound character, modulation, tonality or tonal complexes is through sonograms[3]. These show sound at various frequencies over time as shown in **Figure 6**. They can be thought of like a sheet of music or an old pianola roll; the left axis is

[3] Various methodologies are available to display sonograms or modulation. For this Paper the methodology by Dr H. Bakker, Astute Engineering, is preferred.

frequency—musical pitch—while the bottom axis is time. Amplitude and frequency modulation can be identified in the sonograms by distinctive regular patterning at 1 second (or longer or shorter) intervals. Tonality and tonal complexes can also be identified using sonograms.

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

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 these 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. **Figure 6** illustrates how a sonogram is defined in terms of pitch and loudness.

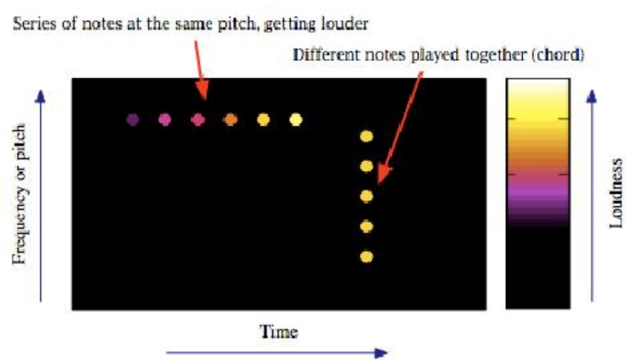


Figure 6: How to interpret a sonogram

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. It seems likely that the rumble/thump that is described by many residents is caused by the effect of the downstream wake on neighbouring turbines. This effect can be illustrated in a sonogram. Wind turbine modulation has been demonstrated to exist in three, geographically separate wind farms.

In this case the initial survey was able to capture the sounds of the southern wind turbines at the residence. **Figures 6 and 7** illustrate the sound levels and character of the sound, including ambient wind, outside the residence. The initial survey was only for this time period, 19:40 15 October to 01:40 16 October 2009. The wind dropped after 20:10pm and the sound levels decreased.

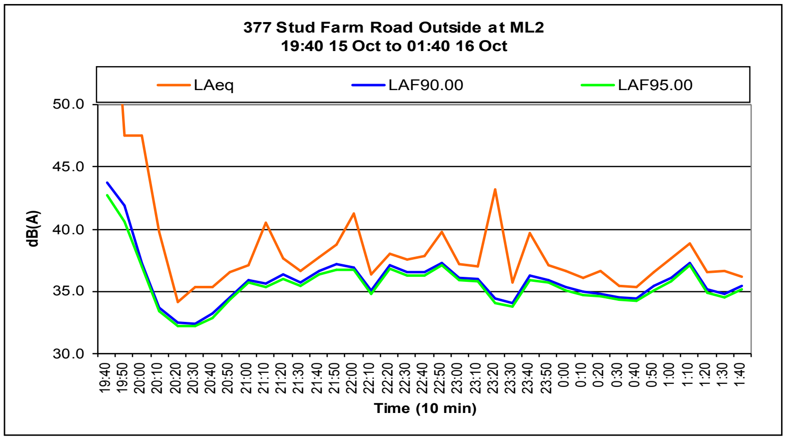


Figure 6: Outdoor sound levels for the initial survey

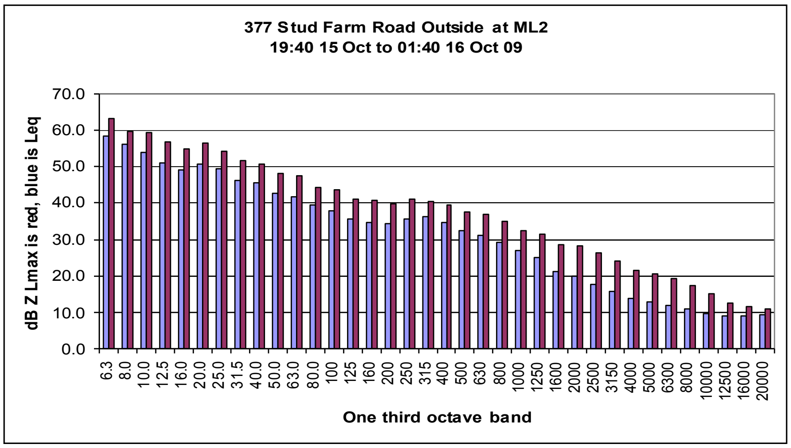


Figure 7: Outdoor sound character for the initial survey

The outdoor sound levels indicate fluctuating background (LA90, LA95) sound levels with significant variations in the 'time-averaged' level, LAeq. The variations are not unusual. The LA95 level for the time period is 33.9 dB(A). The overall sound character shows slight variation between the time-averaged level, LZeq and the maximum levels LZmax in each third octave band. The variation, however, is in the order of 6 dB or more in each band and this is audible.

The initial survey recorded the sound levels inside the residence. **Figures 8 and 9** illustrate the sound levels and character of the sound, including ambient wind. The initial survey was only for this time period, 19:40 15 October to 01:40 16 October 2009.

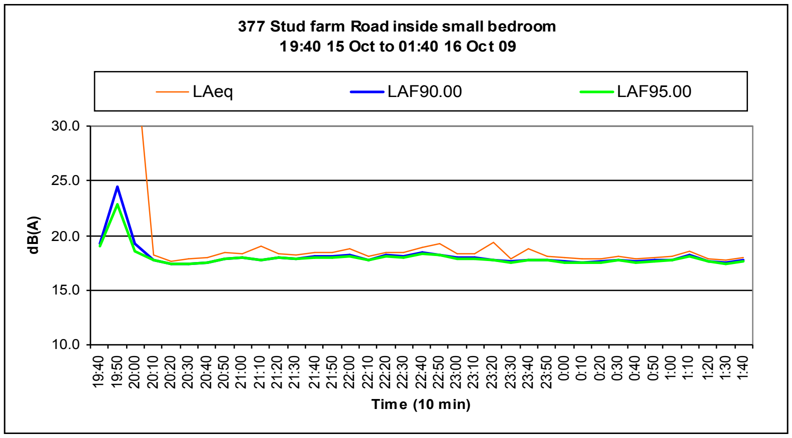


Figure 8: Indoor sound levels for the initial survey

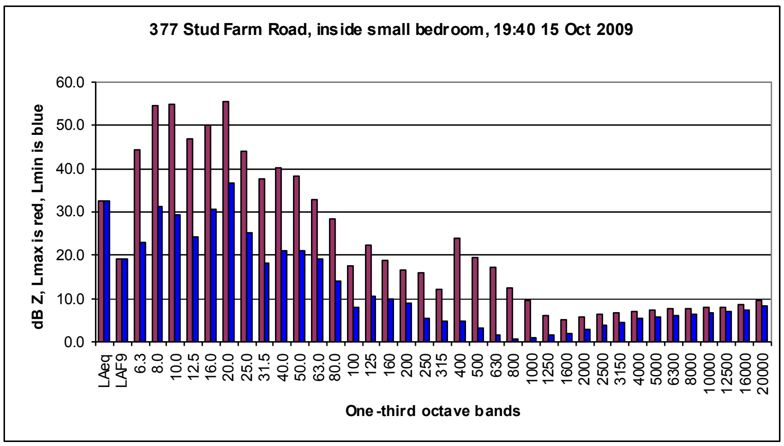


Figure 9: Indoor sound character for the initial survey

Figure 9 represents a time-slice for the beginning of survey when the sound of the turbines was audible outside. The inside sound levels background (LA95) sound levels compared to the 'time-averaged' level, LAeq. The consistency in level is not unusual for inside a home. The LA95 level for the time period is 17.4 dB(A). The average (LAeq) level is 32.5 dB(A). At 8pm the wind dropped and the sound levels within the home decreased, with an average (LAeq) sound level of 18 dB(A), just above the background level.

The caution here is that sound levels vary significantly over very short (10 minutes, for example) periods of time. Thus an assessment on an average longer-term level **(Figure 8)** may not truly represent the short-term effect of varying sound character **(Figure 9).**

The observation from **Figure 9** is that the overall sound character shows substantial variation between the 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.

Previously recorded sound levels inside the residence main bedroom over the time period 9:12 am 12 October 09 to 10:02 am 13 October 09, **Figure 10**. The wind farm was in operation at this time. The sound levels were recorded in third octave bands every 30 seconds and the average levels for this time period are presented following. The SVAN sound level meter is able to record to a lower frequency compared to the Larson Davis 831 meter.

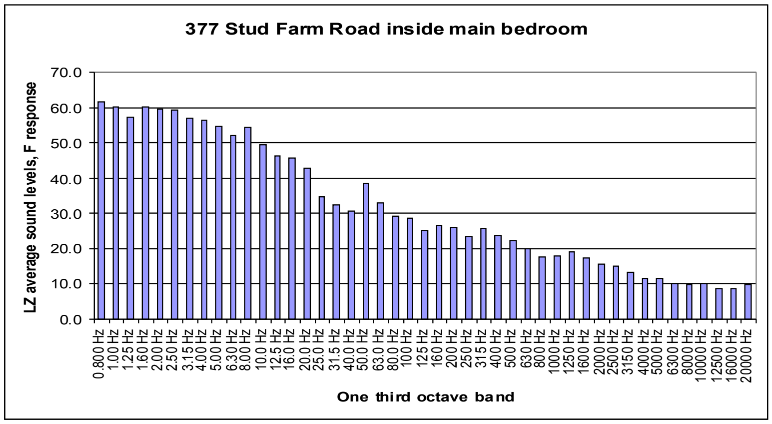


Figure 10: Indoor sound character (main bedroom)

The character of the sound levels is similar to the time-average level outside but there is significant variation between the levels in the two bedrooms. The point is to show that rooms in a residence can and will show significantly different characteristics. What may be inaudible or not perceptible in one room can be easily heard or perceived in another room on the same side of the house. The other concern is that the main bedroom appears to have little sound reduction from outside to inside. The recorded levels are with turbine activity and it is concluded that ambient and wind farm activity will be audible within the bedrooms.

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:

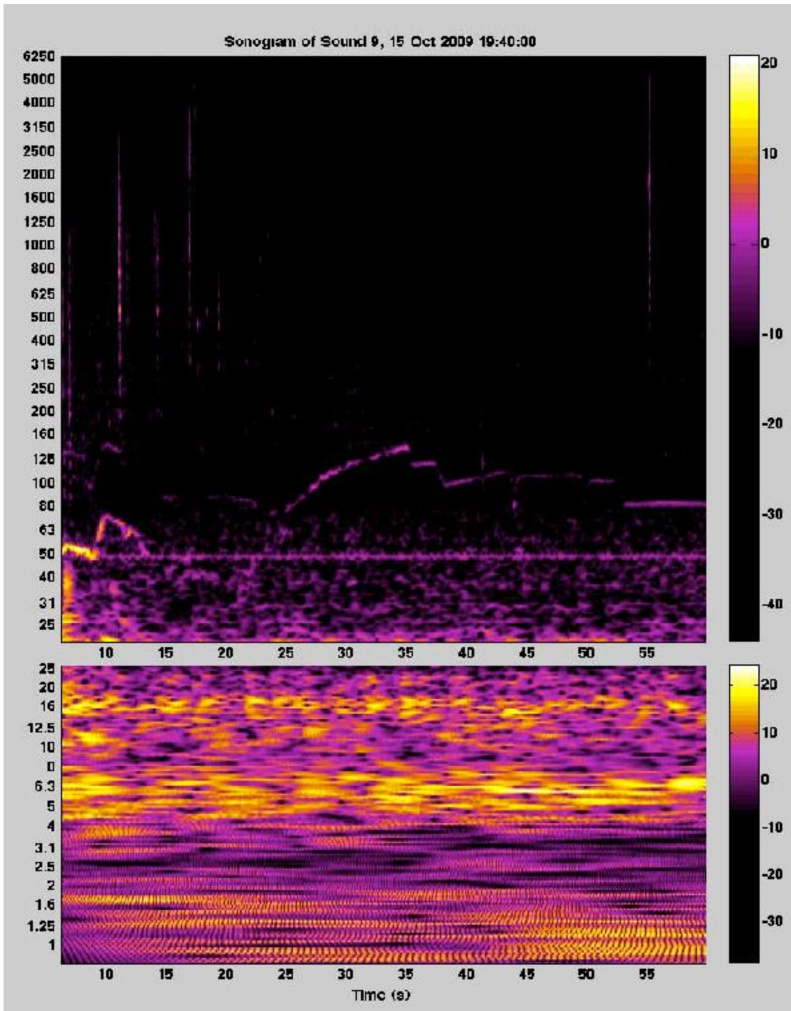
- The significant amount of sound energy in the low frequency and infrasonic ranges
- The variation of 20 decibles between high and low values in the sonograms between the yellow bands and the purple bands. This variation is audible under observed conditions.

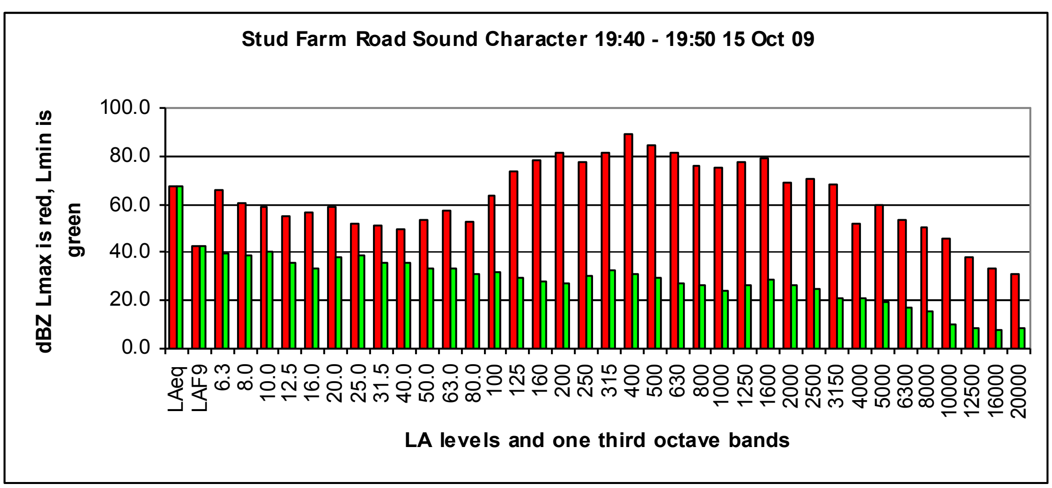
The overall levels in one-third octave band charts are provided to illustrate the difference between maximum and minimum sound levels in the measurement time period. These correspond to the peak and trough values and give a "first-cut" assessment of whether or not audible modulation, audible tonality, 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.

The case study illustrates the difficulties in measuring and assessing wind turbine sound. Sound level criteria referenced to an A-weighted sound descriptor do not accurately describe the sound or perception of a wind turbine or a wind farm.

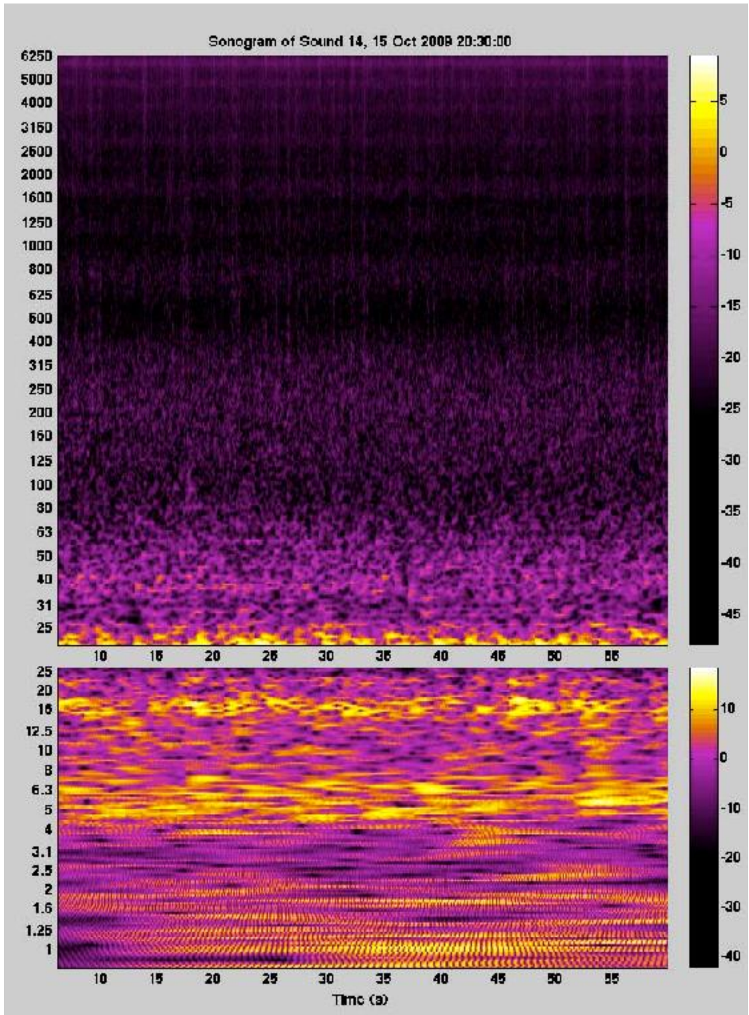
Sound Character at Residence.

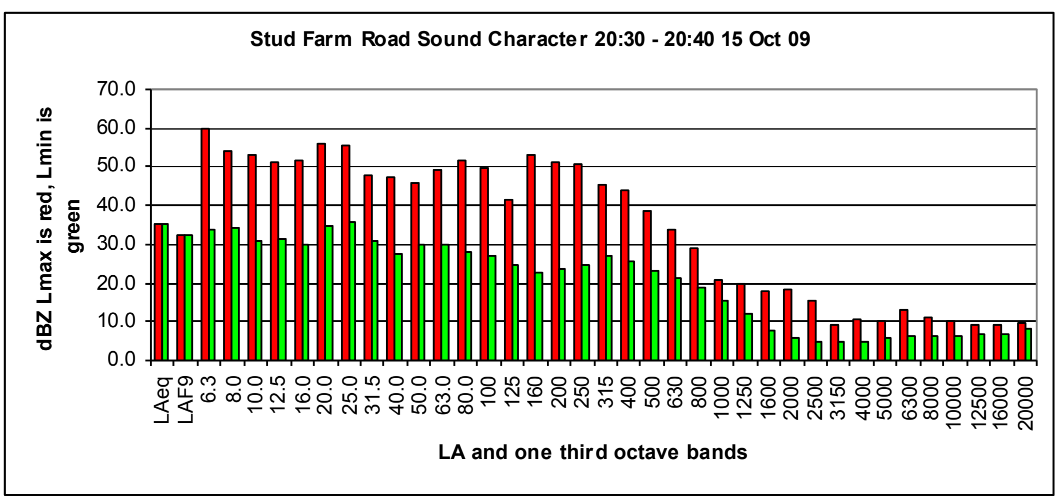
Sound of wind farm audible at 7:40pm outside residence, as well as wind in trees, voices, setting-up activity and a distant vehicle. The sonogram shows a distinctive 50 Hz tone from a nearby electrical source, as well as strong readings at 20 Hz, 16 Hz and 6.3 Hz. These are indicator frequencies for potential adverse health response. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass frequency. The high frequency content (800-5000 Hz) is not evident in the sonogram or the 60sec audio file.



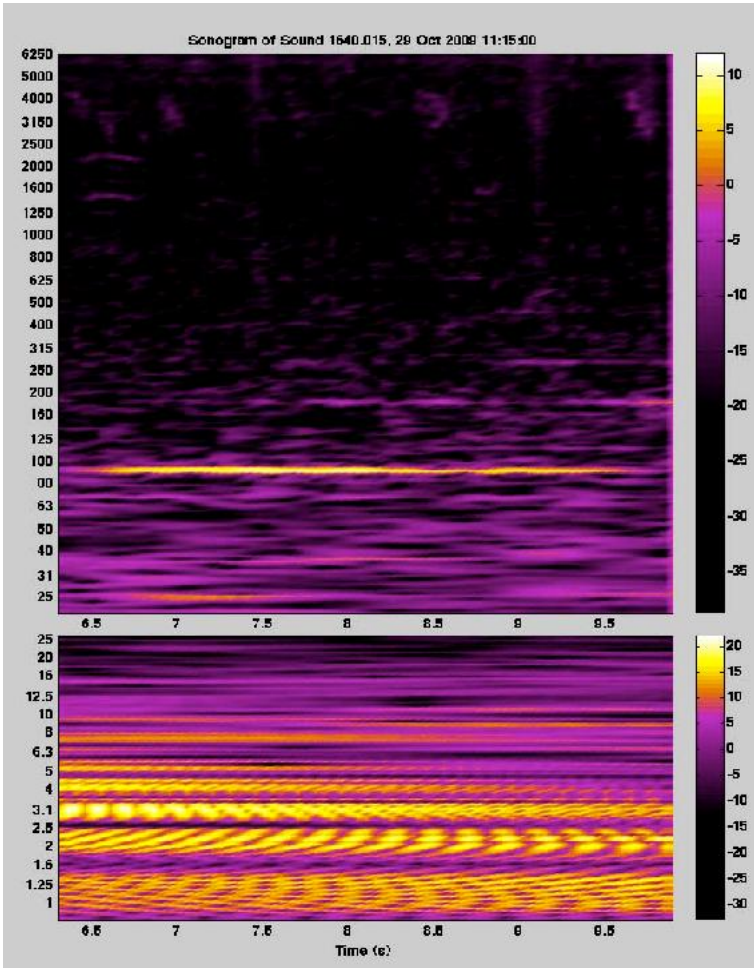


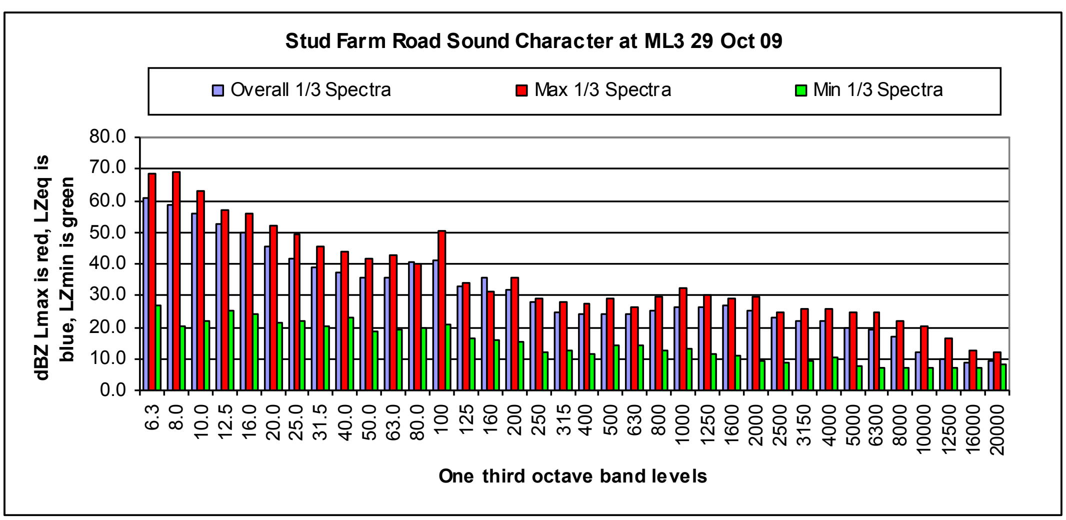
Sound Character at Residence.
15 October 2009 at 8:30pm
The soundfile was recorded with no-one present. The audio file has wind and wind farm sounds. There are strong readings at 20 Hz, 16 Hz and 6.3 Hz. These are indicator frequencies for potential adverse health response. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass frequency. The high frequency content (800-5000 Hz) is not strongly evident in the sonogram or the 60sec audio file.





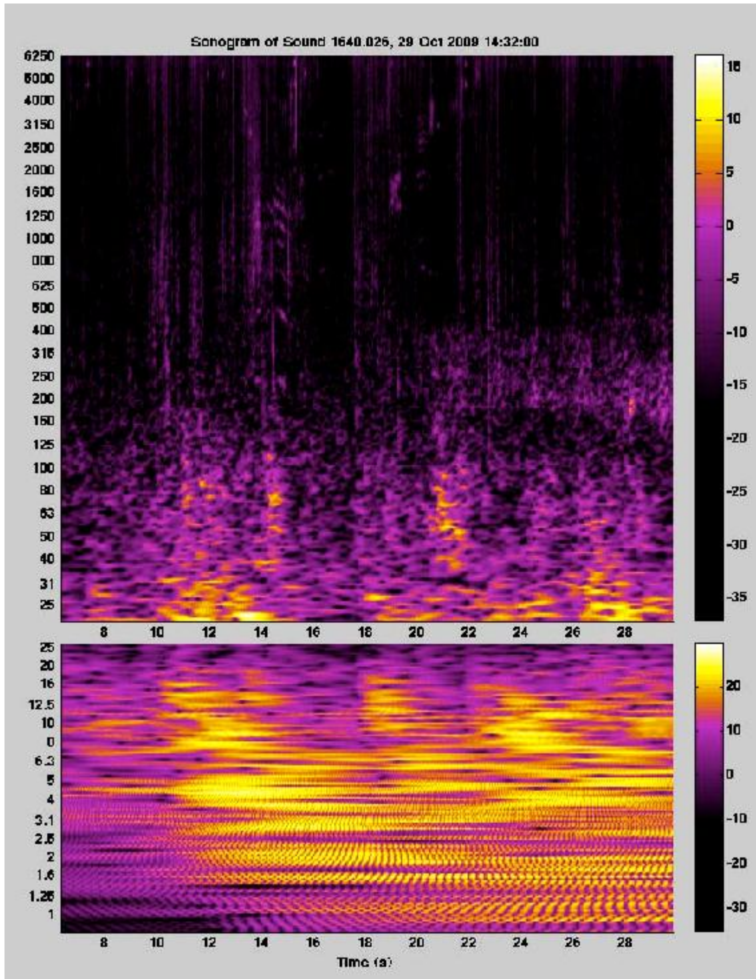
Sound Character at Residence.
29 October 09 at 11:15am
Wind farm not audible outside residence. Turbines to south and north do not appear to be turning
The wind pattern is completely different from the previous readings at the start of the survey. There is a distinctive 90 Hz tone from an aircraft. Animal and bird noise provide the character. The strong readings at 20 Hz, 16 Hz and 6.3 Hz have gone. The 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. The LAeq level is 36.3 dB(A) and the background LA95 level is 28.2 dB(A).

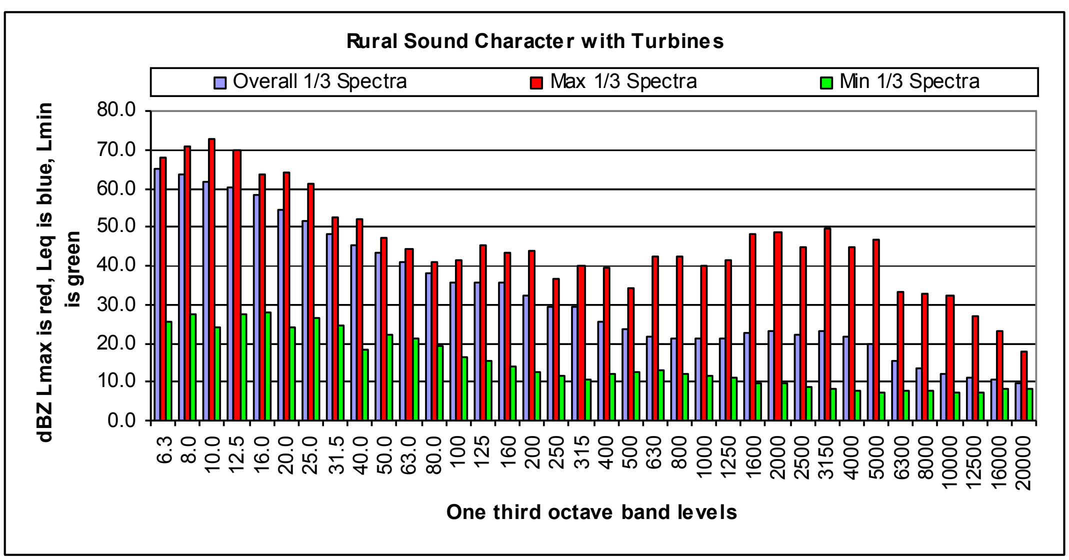




Sound Character at cross road between Talbot and Stud Farm Road.

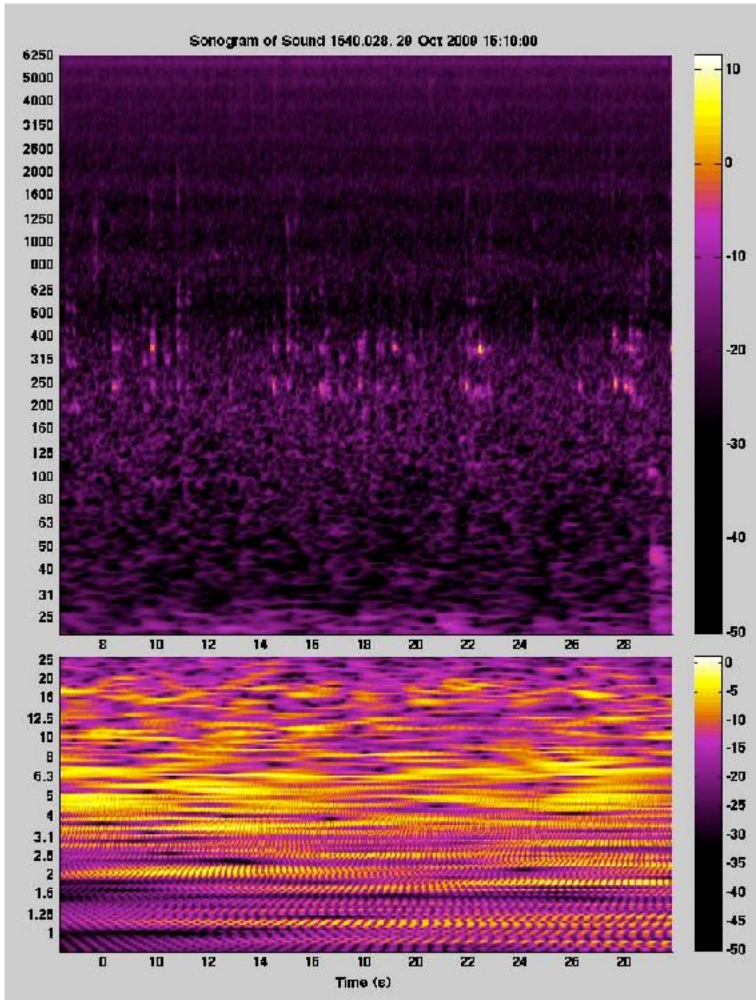
The wind farm was audible at the measurement location as a distant rumble and some of the nearest visible turbines approximately 500m to 1500 m distant were moving slowly, as though they were starting up. The sound is similar to an aircraft overhead, although the sound wasn't from a plane. There are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

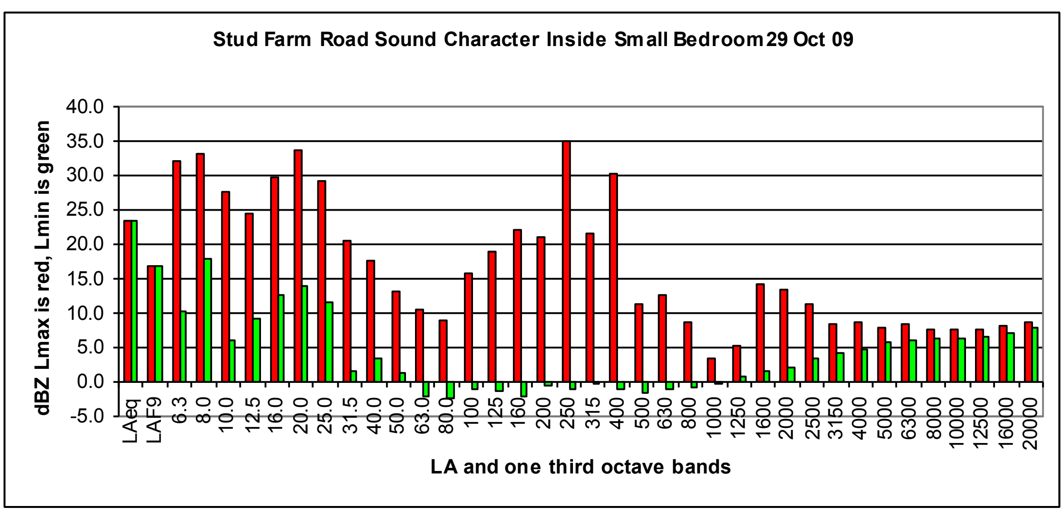




Sound Character Inside Residence

29 October 09 at 3:10pm. Sound levels measured inside the 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. These are indicators of potential adverse effect. There was no ground level breeze outside during the recording. The LAeq level is 25.4 dB(A) and the LA95 level is 16.6 dB(A).





Responses of Residents Living Near Wind Farms

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 sound must be audible or perceptible to cause an adverse response in the person affected.

Previous wind farm investigations in New Zealand and Victoria Australia 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. Adverse health effects are reported and as these effects did not occur before the wind farms became operational a reasonable hypothesis is that the wind farm activity has a causal relationship.

The following three examples illustrate the effects of wind farms on residents living within the locale.

The Effects on People Living Near the Waubra Wind Farm, Victoria, Australia

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

Family E Papers 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

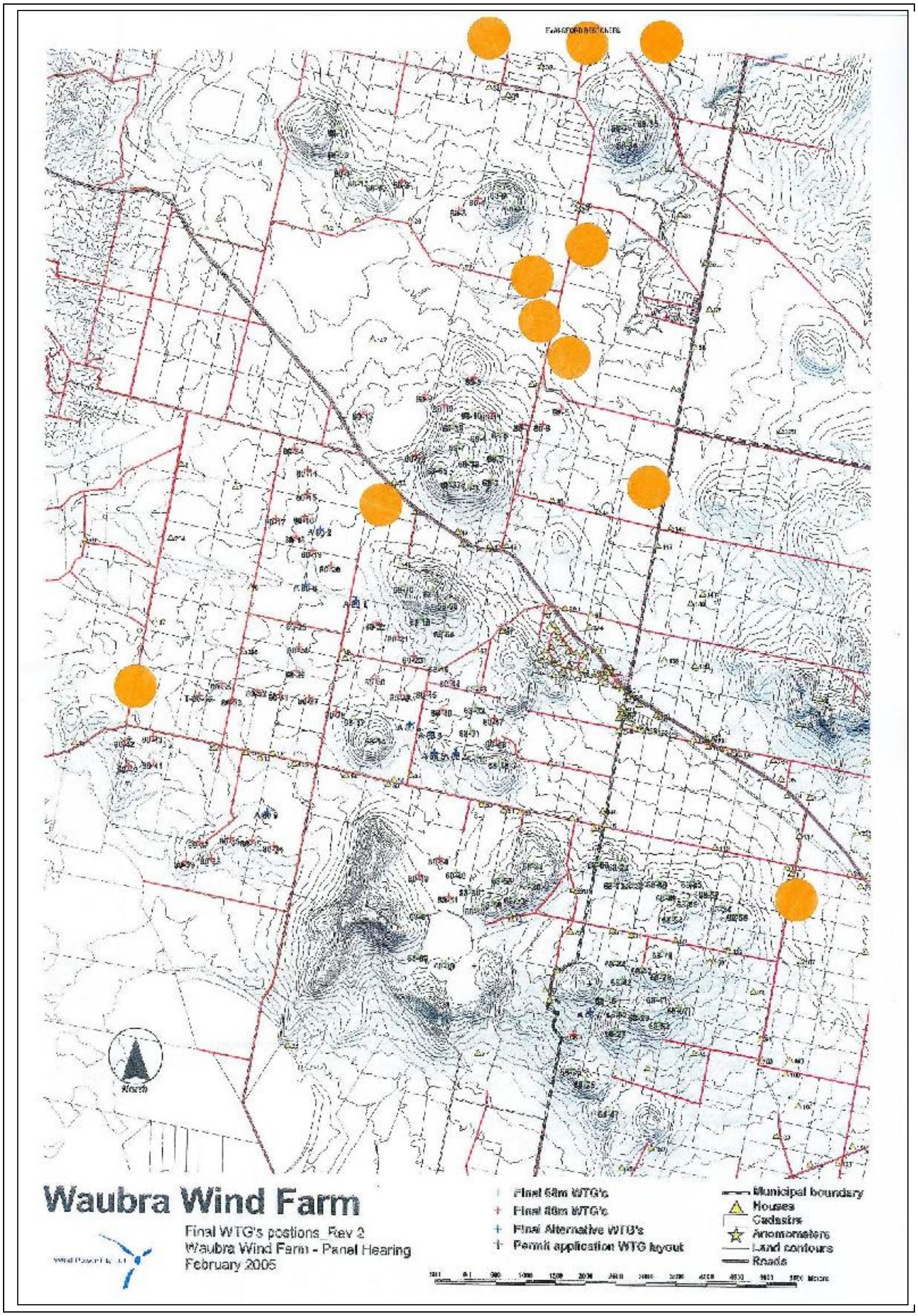
> *"The sound of the turbines when functioning is on most days so intrusive that it affects my concentration and thought processes when performing complex tasks. I suffer from sleep interruption as a direct result of the noise which then affects my ability to function at 100% the following day. One is 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.

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.

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



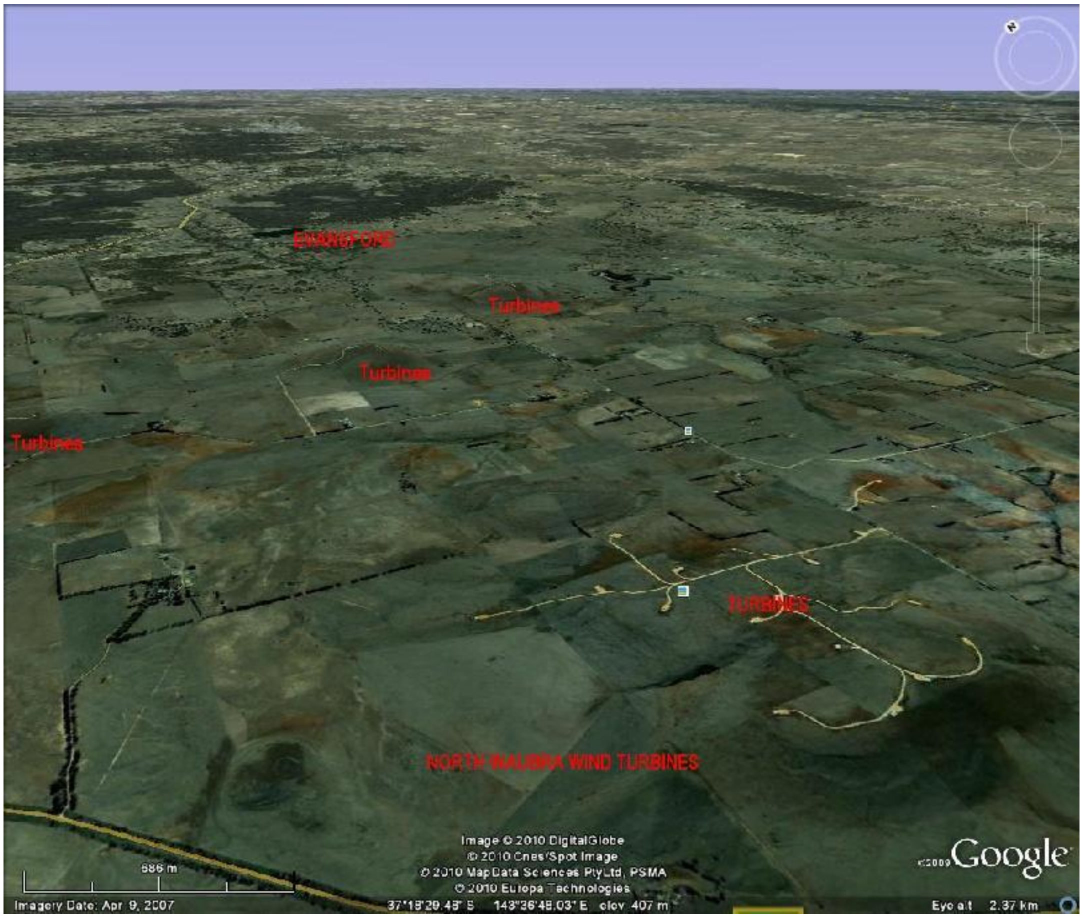
Note: the locales affected by wind farm noise are identified by the orange circles.

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



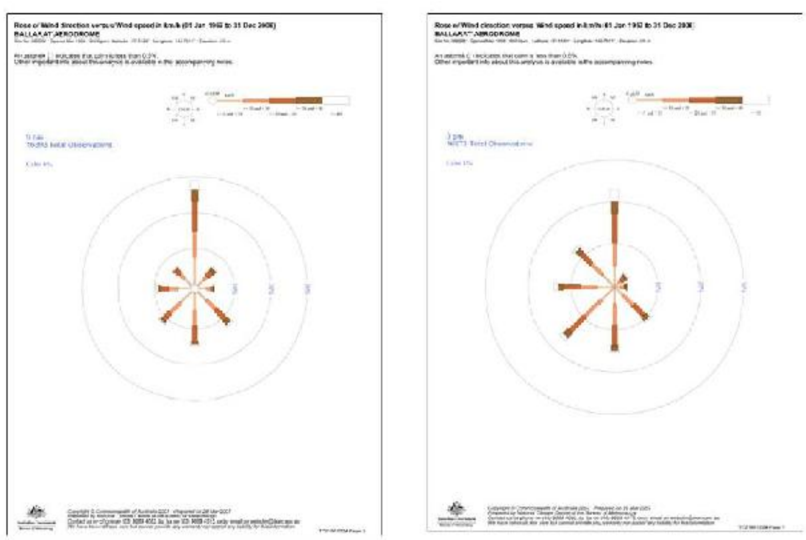


Figure W1: wind rose, Ballarat Aerodrome, mid-morning and mid-afternoon

The Effects on People Living Near the 'West Wind' wind farm, New Zealand

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

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

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

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

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

An analysis of the complaint history has been made. The character of 650 complaints has been sorted by type, figure WW1. Rumble, with 252 mentions, is the most common characteristic. Hum and thump are the next most common annoying sounds. In comparing complaints of noise outside to inside, of 650 complaints, only 23 specifically mention the noise as being outside. This, from my measurements, would be outdoor background levels of much less than 40 dB(A), around 28 to 30 dB(A) L95. Of the indoor complaints, 4.5% specifically mention sleep disturbance. Further analysis of specific complaints is presented in **Table WW1,** following. The number of turbines affecting a locale is noted, when identified by a resident.

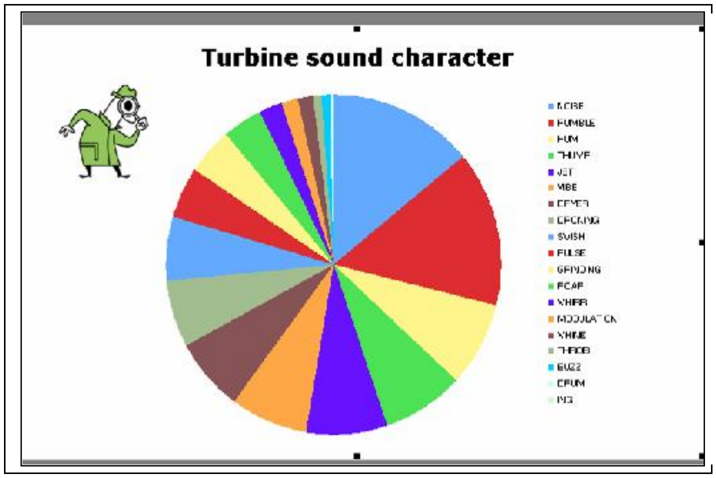


Figure WW1: Westwind complaints by turbine character

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

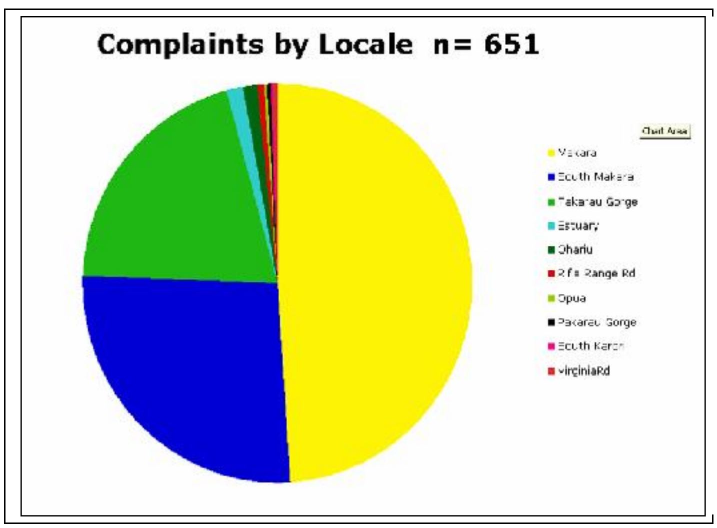


Figure WW2: Westwind complaints by locale

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

> *We have had a persistent level of disturbance noise now for several hours throughout the evening that is now preventing us sleeping since 11:15 pm. The predominant noise is a continuous loud booming rumble that is even more noticeable after a gust at ground level. When the wind noise drops, the background noise from the turbine continues and is also felt as a*

vibration being transmitted through the ground. Even with wind noise the vibrations in the house continue. The varying wind speed also causes a beating noise from the blades that occurs in cycles creating yet another form of noise disturbance.

A second resident says:

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

And a third resident says

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

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

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

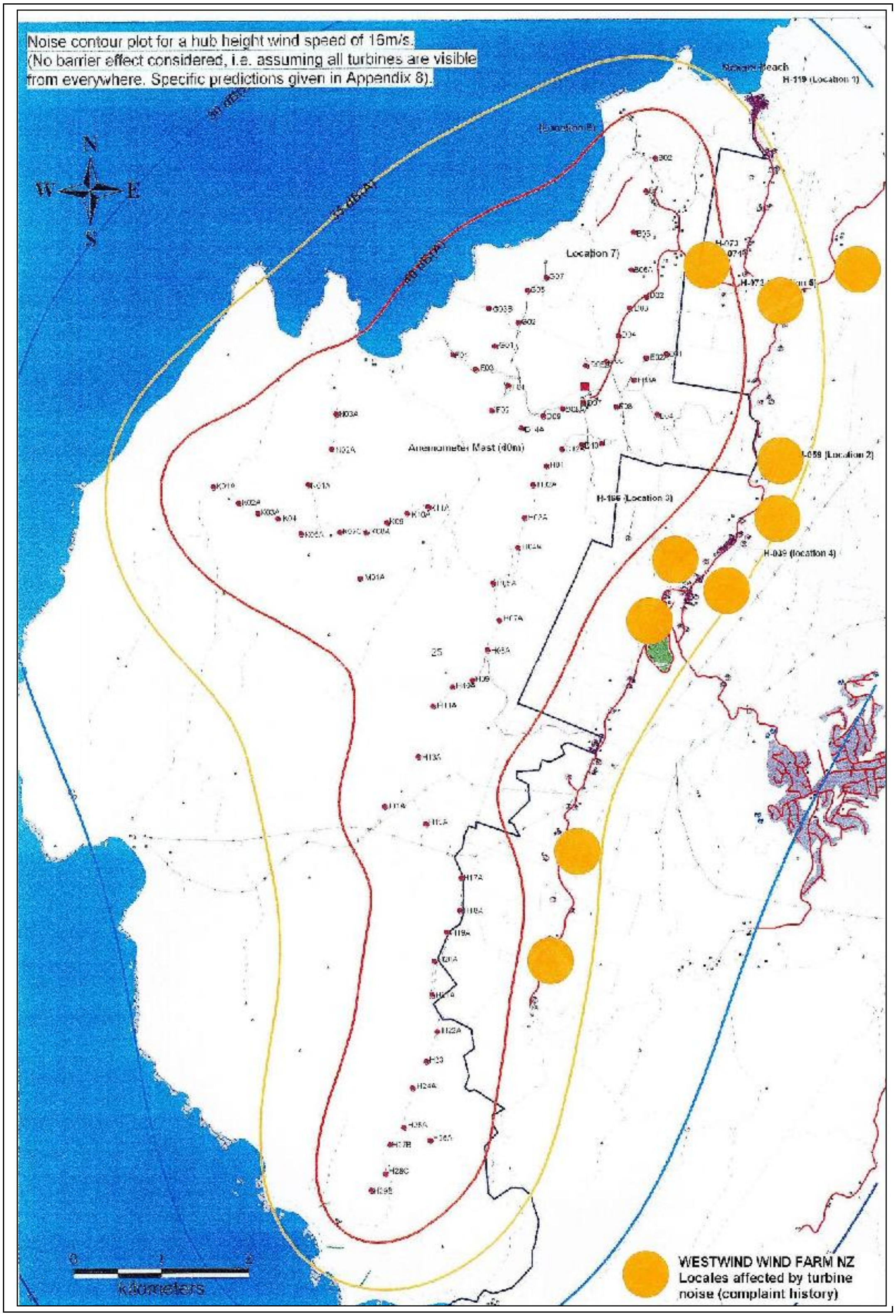


Table WW1: Westwind affects, perception and complaint analysis to November 2009

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 2	1200-1300 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. 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.

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

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

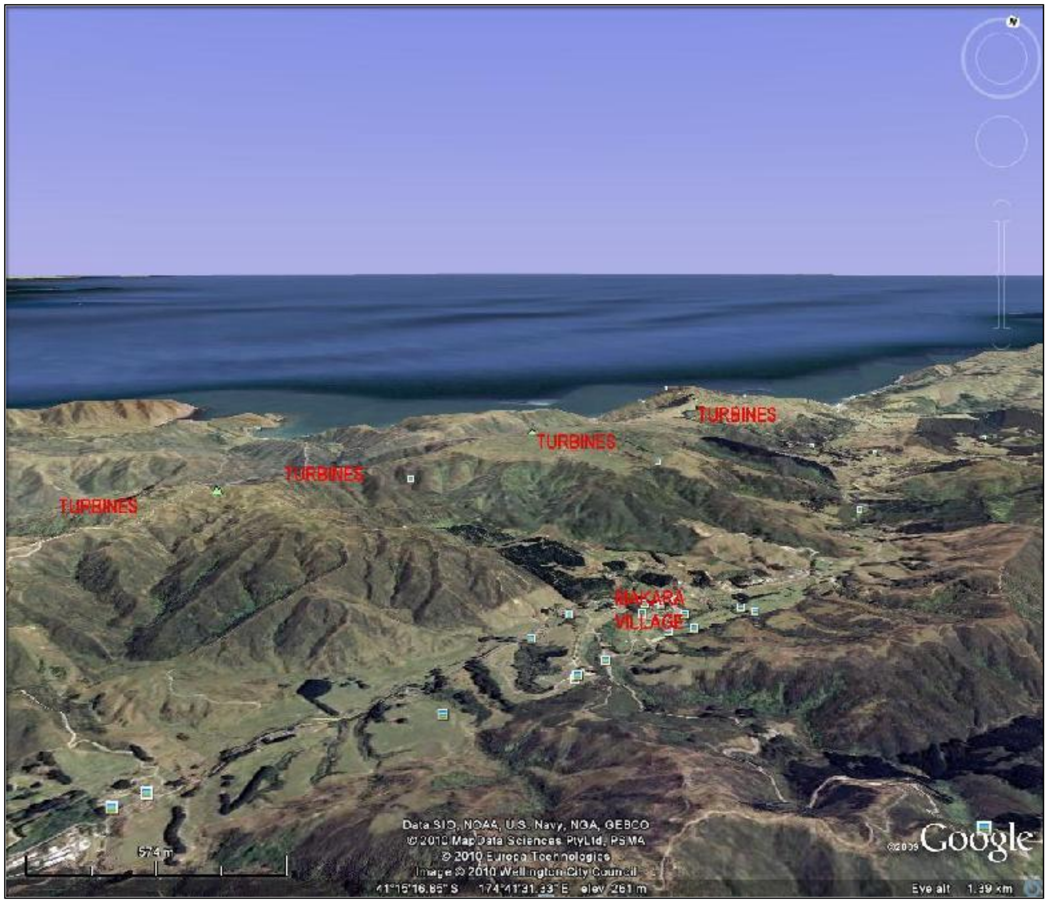
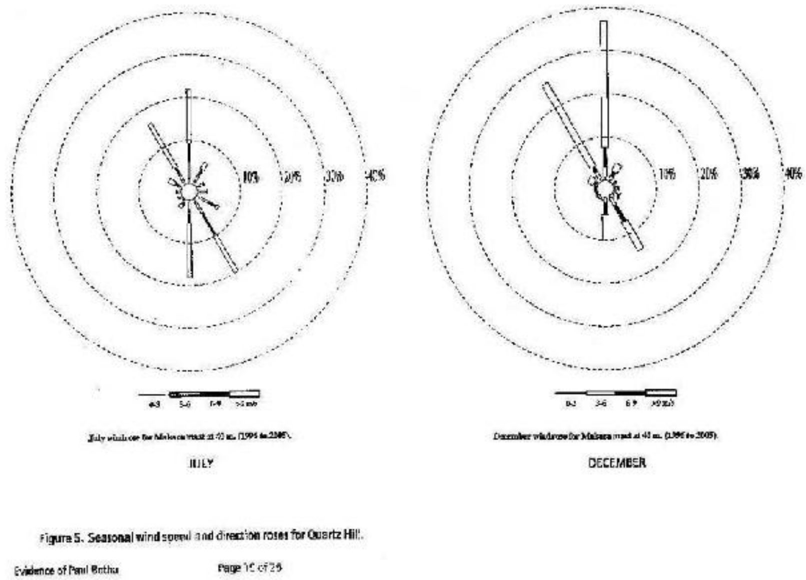


Figure WW3: Prevailing winds for Makara at the wind farm mast (40m)



The Effects on People Living 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. This, in my view, indicates issues with wind farm placement and design that can be mitigated by careful consideration of turbine choice, turbine siting design and consideration of neighbours and long-term meteorological conditions.

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.

The number of complaints are very high for wind farms that supposedly are complying with their approval conditions. While the background levels may be achieved and this has yet to be proven, the wind farms in my view are a significant source of unreasonable noise.

The number and history of the complaints emphasises the importance of buffer zones and wind farm design so noise can be mitigated by careful consideration of turbine choice, turbine placement, consideration of neighbours and long-term meteorological conditions.

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

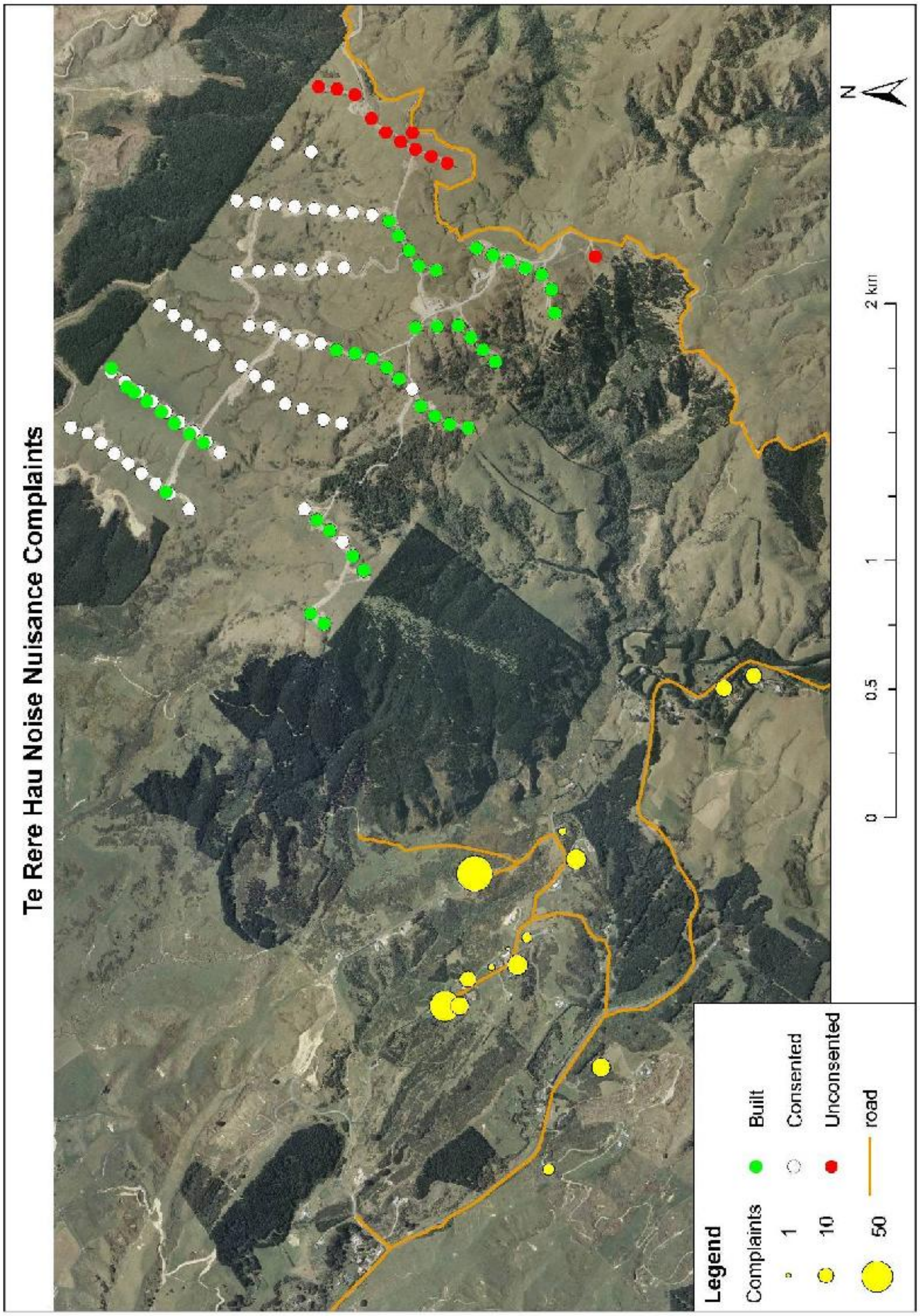


Table TRH 1: Te Rere Hau noise complaints, August 2009 to February 2010, single residence

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

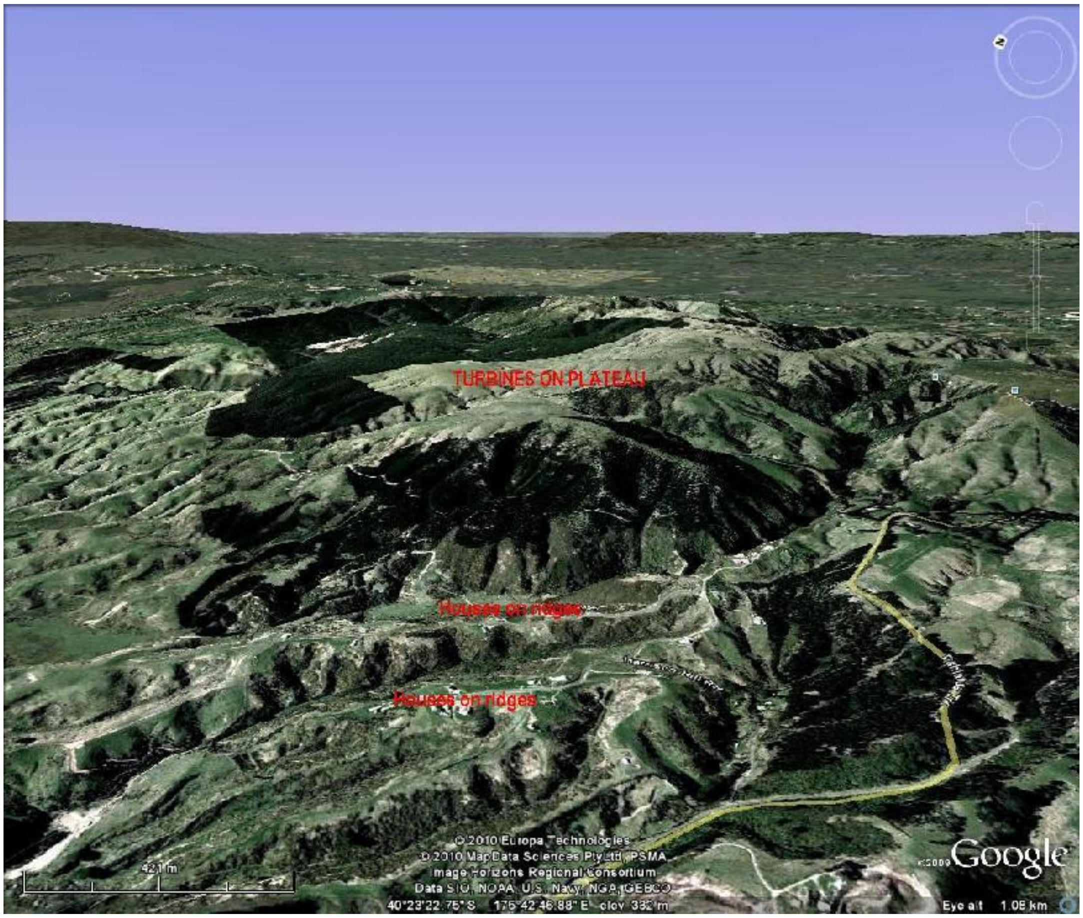
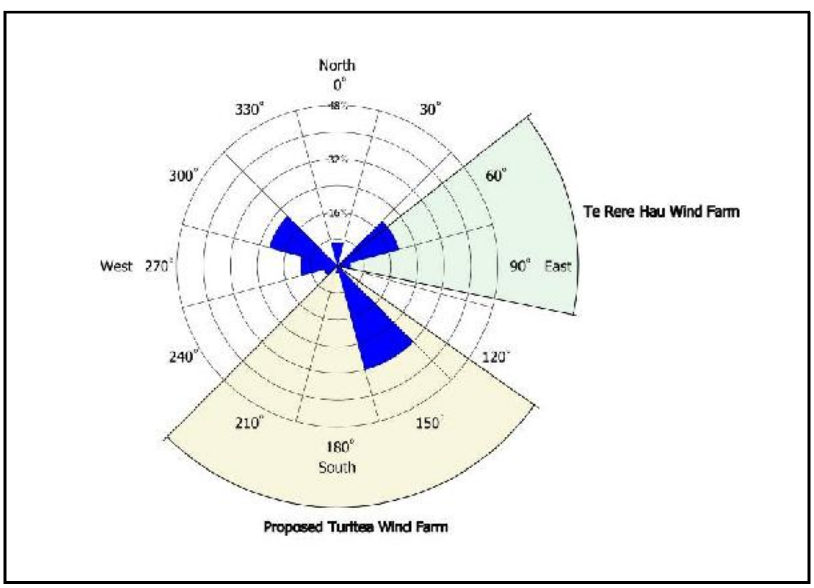


Figure TRH 1: Wind Rose for May to September 2009 illustrating existing wind farm effect (Te rere Hau) and effect from a proposed wind farm (Turitea) to the south



CONCLUSIONS

Personal perception of a sound is investigated through assessment of personal noise sensitivity, personal perception of the characteristics of the sound and observable adverse health effects. Noise includes vibration in any form that can be "felt" by a person. There is, in my opinion and despite the differences in opinion as to cause, considerable agreement between the parties – residents, clinicians and acousticians – as to observable health effects from unwanted sound. There are clear and definable markers for adverse health effects before and after the establishment of a wind farm and clear and agreed health effects due to stress after a wind farm has started operation. It is the mechanism of the physical or mental process from one to the other that is not yet defined or agreed between affected persons, clinicians and psychoacousticians. There has, however, been considerable work recently (May-June 2010) on the possible mechanism between infrasound and adverse health effects.

It is concluded that:

- Wind farm reports and approval conditions (if approvals are issued) must provide clear and specific methodologies to measure wind farm sound under compliance testing conditions or under complaint conditions when turbine sound is part of the ambient sound.

- "Background" compliance monitoring is not sustainable as there is no proven methodology to accurately measure wind turbine sound, complaints especially, in the presence of ambient sound.

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

- 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.

- Noise numbers and sound character analyses are meaningless if they are not firmly linked to human perception and risk of adverse health effects.

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

- 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.

Recommended Reading

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Glossary of Terms

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 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. The level is recorded in the absence of any noise under investigation and is not adjusted for tonality or impulsiveness.

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

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

A-weighted or Z-weighted

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

Third Octave Band

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