The Problems With "Noise Numbers" for Wind Farm Noise Assessment

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Abstract

Human perception responds primarily to sound character rather than sound level. Wind farms are unique sound sources and exhibit special audible and inaudible characteristics that can be described as modulating sound or as a tonal complex. Wind farm compliance measures based on a specified noise number alone will fail to address problems with noise nuisance. The character of wind farm sound, noise emissions from wind farms, noise prediction at residences, and systemic failures in assessment processes are examined. Human perception of wind farm sound is compared with noise assessment measures and complaint histories. The adverse effects on health of persons susceptible to noise from wind farms are examined and a hypothesis, the concept of heightened noise zones (pressure variations), as a marker for cause and effect is advanced. A sound level of LAeq 32 dB outside a residence and above an individual's threshold of hearing inside the home are identified as markers for serious adverse health effects affecting susceptible individuals. The article is referenced to the author's research, measurements, and observations at different wind farms in New Zealand and Victoria, Australia.

Keywords

wind farms, human perception, noise

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 wind farms (Thorne, 2007). 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, and like aircraft, sound emissions are transmitted via the roof and windows. Noise barriers at ground level are generally ineffective in screening or mitigation such sound (Thorne, 2011).

Wind has audible and subaudible characters. 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, as recorded in this article, 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 with 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
- The presence of any sound characteristics that may affect human health

[1]Noise Measurement Services Pty Ltd, Enoggera, Queensland, Australia

Corresponding Author:
Bob Thorne, Noise Measurement Services Pty Ltd, 18 Lade Street, Enoggera, Queensland 4051, Australia
Email: bob@noisemeasurement.com.au

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

- Infrasound below, 20 Hz (perceptible, normally inaudible)
- Low frequencies, 20 to 250 Hz
- Mid frequency, 250 to 2,000 Hz (broadly, although the higher level could be 4,000 Hz)
- High frequency, 2,000 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 (Thorne, 2011). Evidence briefly summarized in this article allows the conclusion 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 3,500 meters 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 is unreasonable.

Research indicates that "ordinary" wind has a laminar or smooth infrasound and low-frequency flow pattern when analyzed 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 article. 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 of monitoring wind turbines at different locales under widely different weather conditions. Figure 1 illustrates the issue: there are the 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 LA95" sound level or "time-average LAeq" sound level) at a specific location, such as a residence.

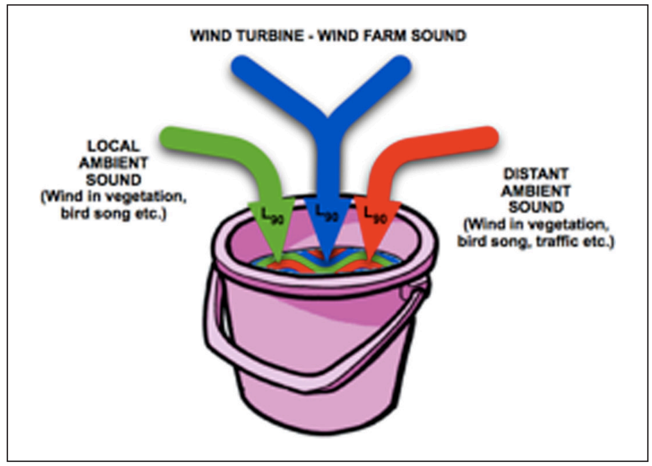

Figure 1. "Bucket of mixed sound" from different sources

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, etc.) 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, unweighted (*Z*) 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 LAeq 35 dB 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.

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 1,000 meters 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 toward 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 toward the nearest towers approximately 1,800 to 2,200 meters 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 southwest 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 (1986) suggest that turbines "shift" from line source to point source decay characteristics at a separation distance of approximately 900 meters. 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 (see Photos 3 and 4). The imaging in Photo 3 shows the different sound levels from the blades of the two turbines.

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 meters behind the turbine. Frequencies below 300 Hz can also be measured.

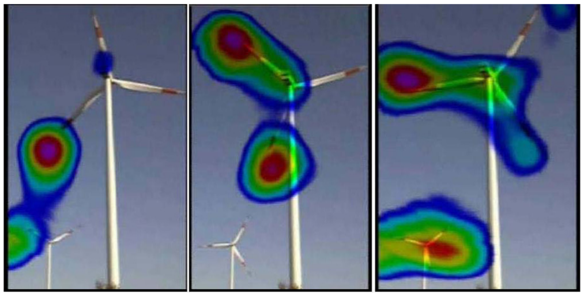

Photo 3. Acoustic photograph of sound sources from two turbines
Source. Acoustic Camera, "Multiple sources wind turbines 300Hz – 7kHz. avi" by permission from HW Technologies, Sydney.

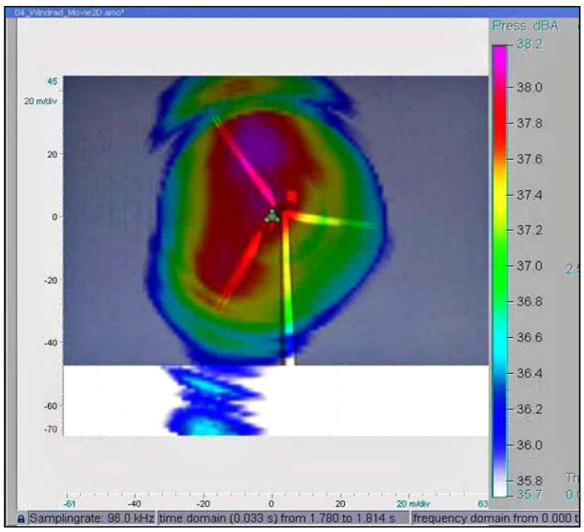

Photo 4. Acoustic photograph of sound sources from a turbine
Source. Acoustic Camera, by permission from HW Technologies, Sydney.

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. I. Shepherd (personal communication, 2010) concludes that increased sound levels will occur and the propagation distance in meters to a defined "criterion" or sound level can be calculated.

The vortex travels 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 (HNZs).

It is hypothesized that an 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 localized patches of heightened noise and/or vibration. The wave train travels in time and the heightened peaks and troughs create a HNZ at an affected residence. The effect has been consistently measured at a residence 1,400 to 2,000 meters 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.

The HNZs can be small in extent—even for low frequencies and infrasound—leading to turbine sounds "disappearing" and "appearing" in areas spaced only a few meters apart. The concept of HNZ goes a long way in 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 HNZs. 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 HNZ 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 cannot 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

Table 1. Average LA95 Sound Levels Recorded at Residence (Levels Rounded)

Date	LA95 Day, 7 a.m. to 6 p.m.	LA95 Evening, 6 p.m. to 10 p.m.	LA95 Night, 10 p.m. to 7 a.m.
October 15	—	35	—
October 16	37	40	32
October 17	34	32	36
October 18	29	26	27
October 19	29	29	25
October 20	34	31	29
October 21	34	29	31
October 22	30	31	33
October 23	32	25	36
October 24	33	35	26
October 25	38	—	—

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 or predicted background sound levels.

Background Sound Levels

Background sound levels are the cornerstone 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?

These questions are answered by observations for a case study, "The Dean Report" (Thorne, 2010), 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 October 15-30, 2009. Ambient A-weighted sound levels were measured generally in accordance with Australian Standard AS1055.1:1997. The ambient sound levels were recorded at 10-minute intervals over a 10-day period (see Table 1). Weather data (wind speed and direction, temperature, and humidity) were recorded for the same time period. Nighttime is recorded as from 10 p.m. the previous day to 7 a.m. on the nominal day.

Table 1 shows the wide range in sound levels at the residence. The levels, at approximately 2,000 meters from the turbines, show the impossibility of determining when or if the wind farm is exceeding a background level of 35 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—cannot 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
- 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 article. My own observations at operational wind farms at distances of around 1,400 meters 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 with 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

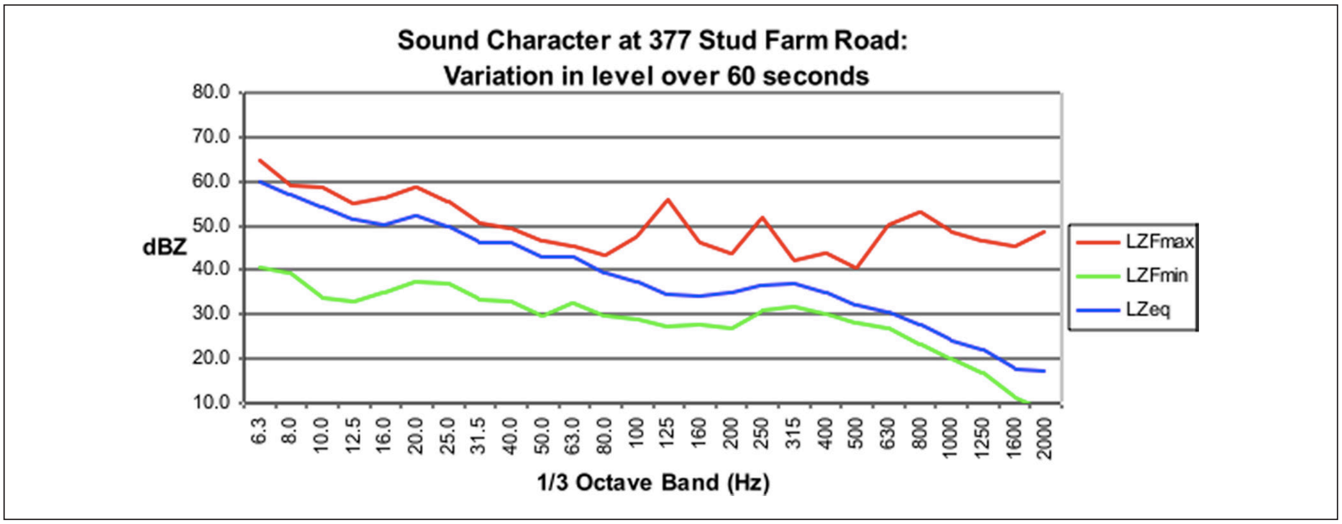

Figure 2. Variation in sound character over 60 seconds

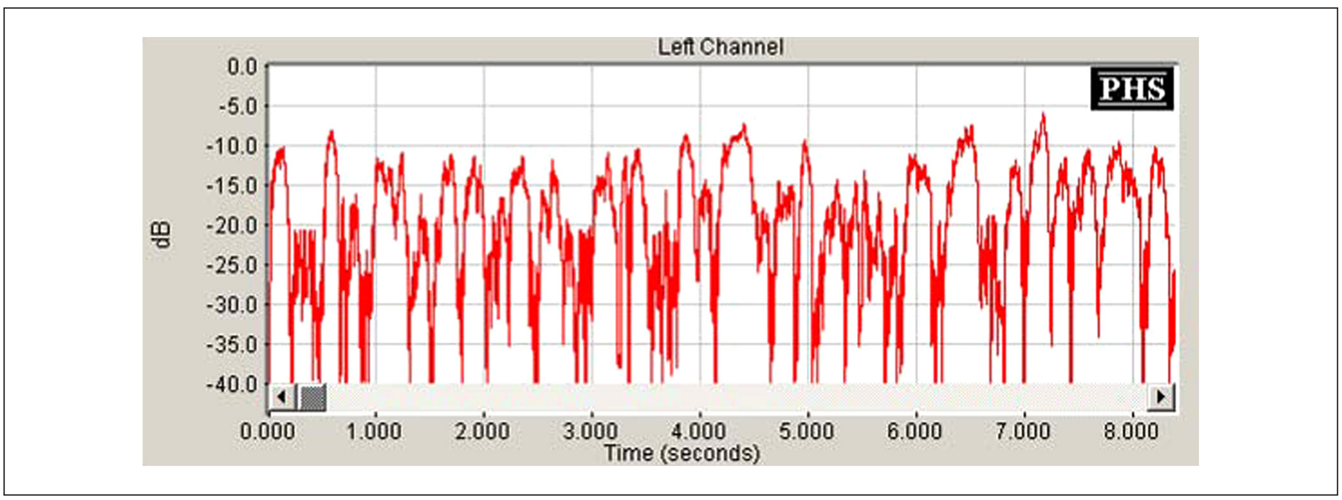

Figure 3. Pulse pattern from an operational wind farm

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 southwest of the residence can be clearly heard at the residence. The sound on Thursday evening at 9:40 p.m., October 15, 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) unweighted sound levels. Unweighted ("*Z*" weight sound levels) are referenced to assess the audibility of the sound.

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 analyzing the sound into amplitude variation over the 60 seconds (see Figure 3). The figure shows the regular pulsing or modulation that is typical of blade passing the tower.

The background ambient sound levels for the assessment in Figure 2 references ambient levels recorded at the residence when the turbines were not operating. 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 analyzed 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.

From just this short survey it can be concluded that the wind farm was in noncompliance with a 40 dB(A) background criterion that includes a penalty for special audible characteristics. Sound from wind farms can be easily heard

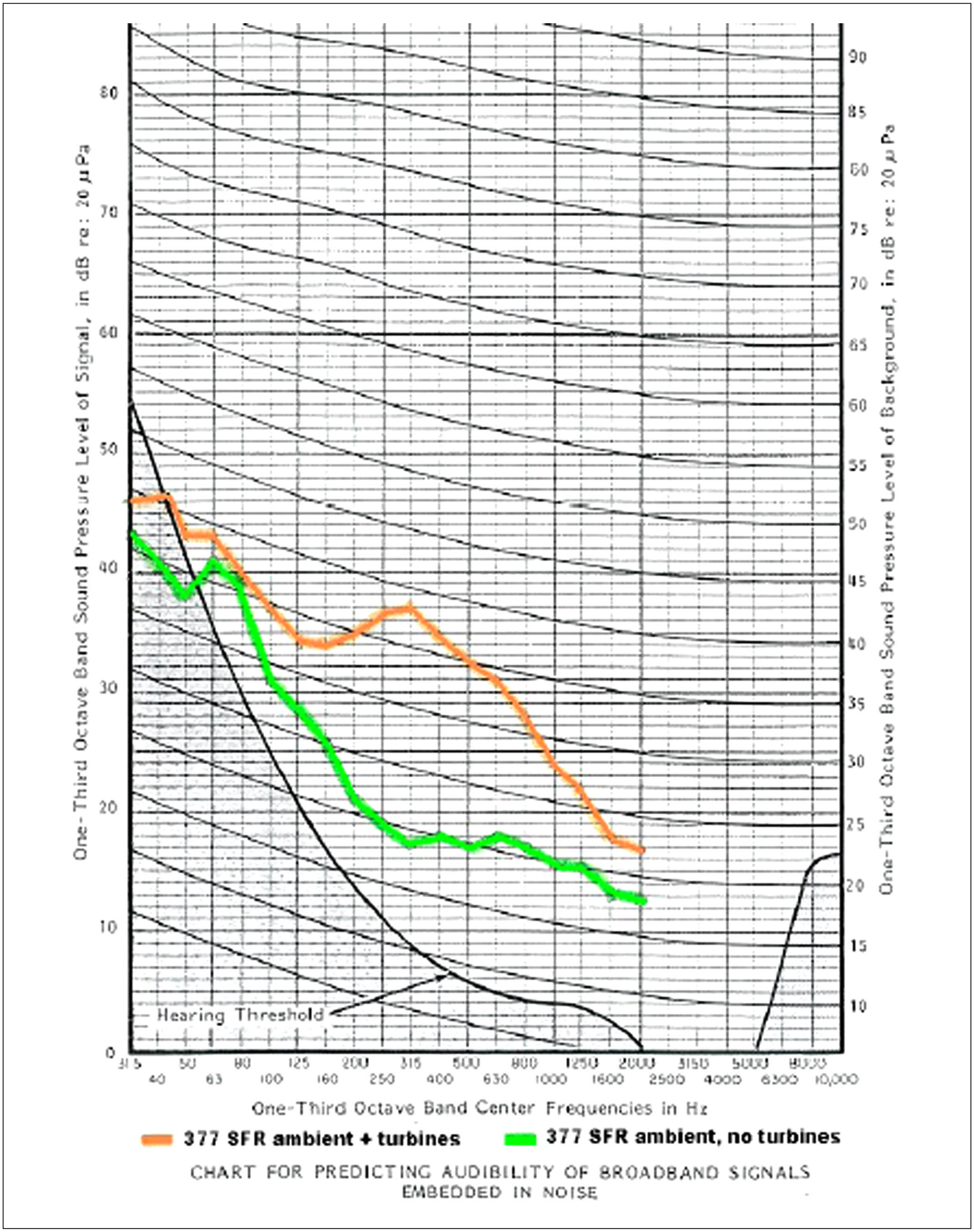

Figure 4. Audibility of wind turbines at a residence

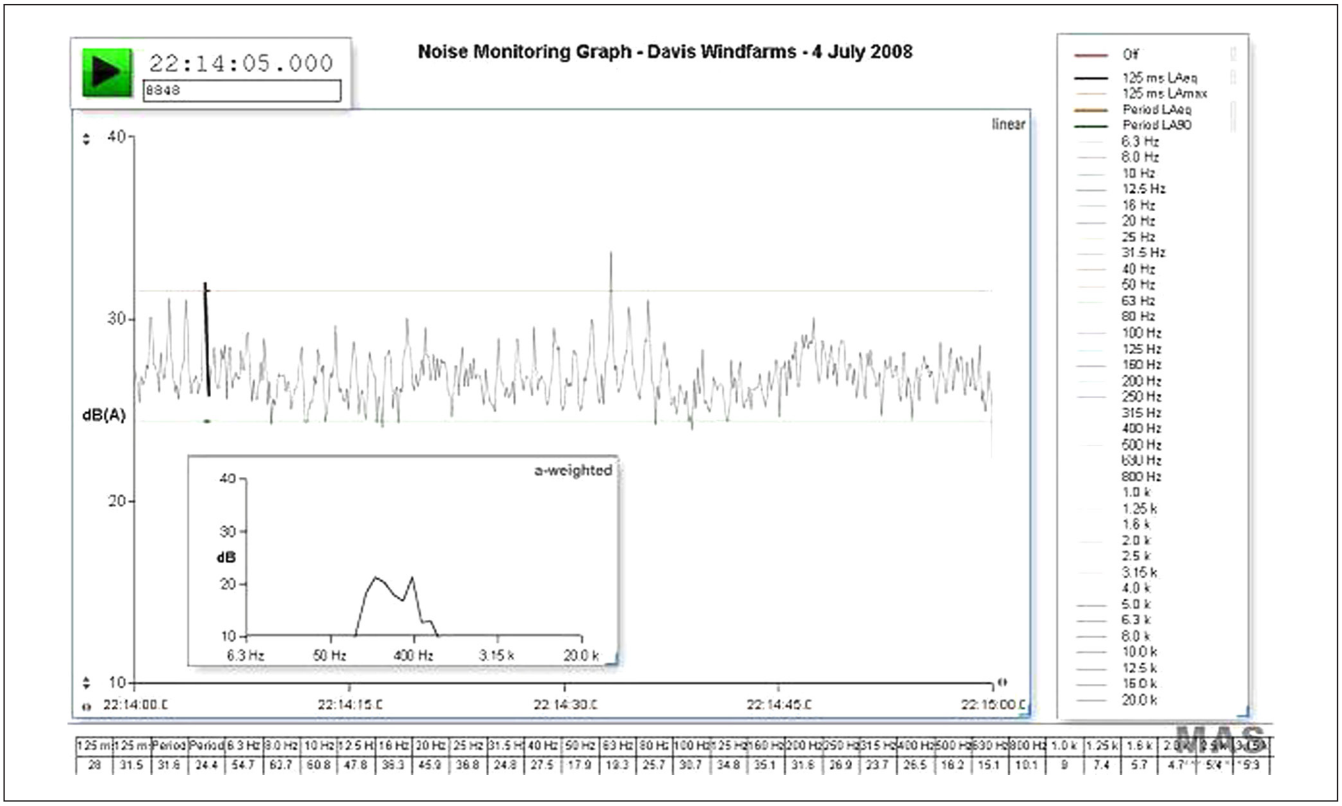

Figure 5. Sound of wind turbines at 930 meters, inside residence

at distances of 2,000 meters; such sound was measured as the background level over the range 29 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. It is concluded that the reason for this is 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 meters from a set of wind turbines. The modulating character of the sound is clearly defined in the first 5 seconds as a pattern of three spikes. The chart shows that low levels of sound are clearly audible inside a dwelling. The interior level for the 60 seconds is LAeq 31.6 dB. There are clear and distinctive audible, low-frequency, and infrasound levels. The residents (the United Kingdom) have vacated the dwelling.

In the Waubra case study, the sounds of the wind turbines were recorded at the residence and in the locale. 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 the time period 19:40 October 15, 2009, to 01:40 October 16, 2009. The wind dropped after 20:10 and the sound levels decreased.

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.

Figure 8 represents a time slice for the beginning of the survey when the sound of the turbines was audible outside. The inside background (LA90, LA95) sound levels are compared with 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 level is LAeq 32.5 dB. At 8 p.m., 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.

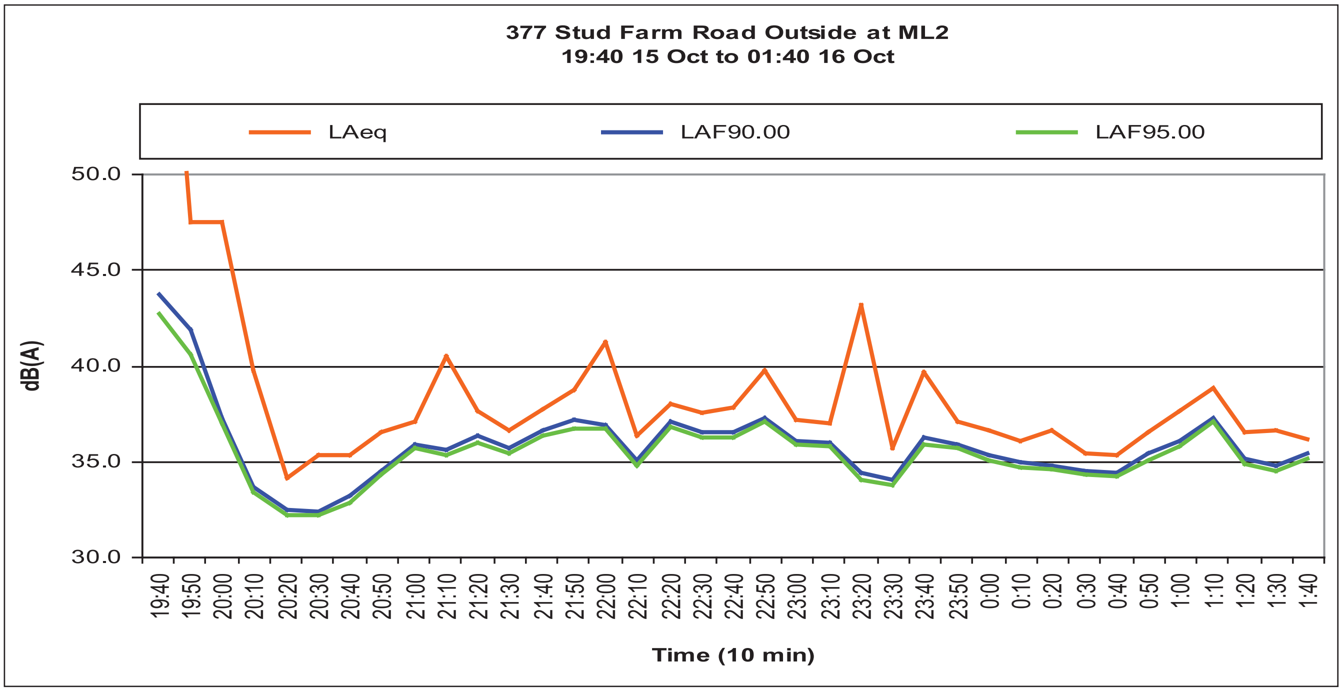

Figure 6. Outdoor sound levels for the initial survey

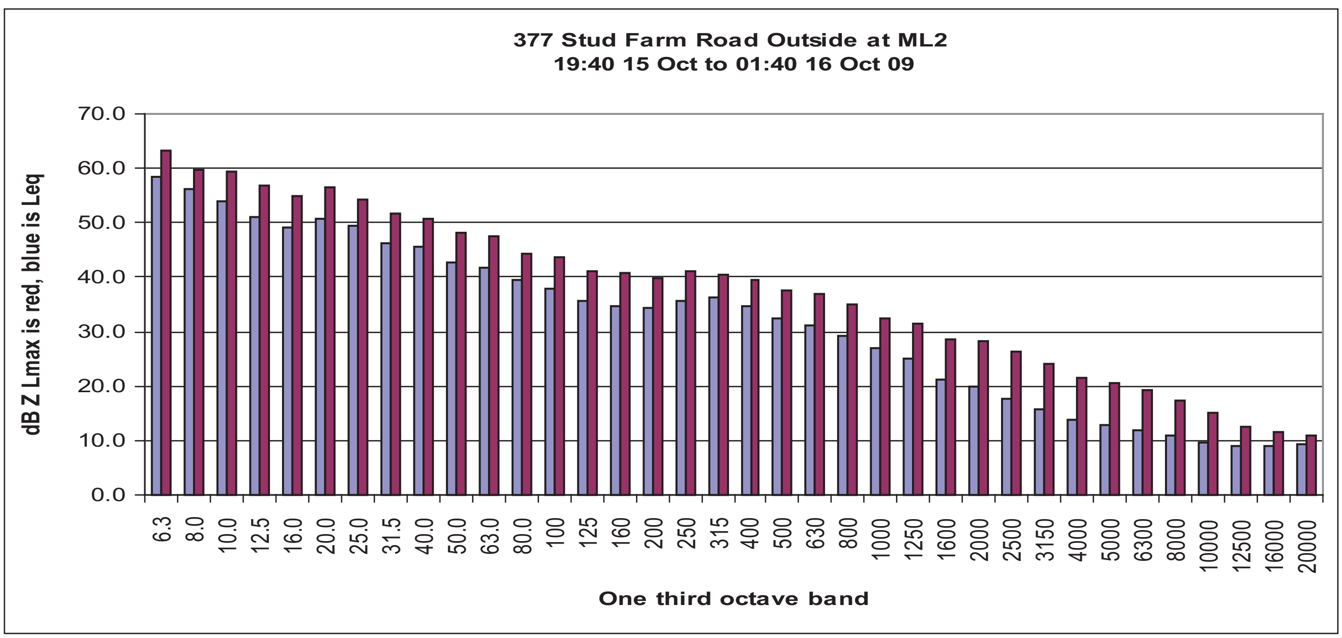

Figure 7. Outdoor sound character for the initial survey

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.

Sound levels were recorded inside the residence main bedroom over the time period 9:12 a.m. October 12, 2009, to 10:02 a.m. October 13, 2009 (see Figure 10). The wind farm was in operation at this time. The sound levels were

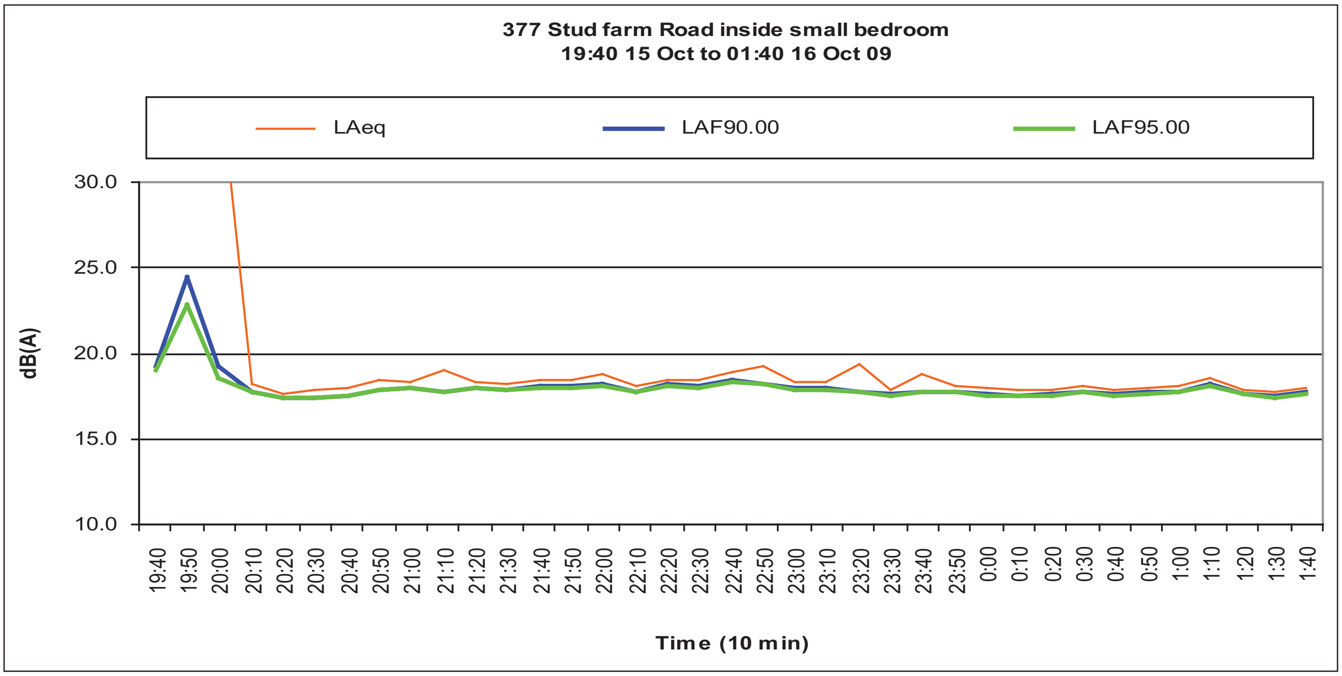

Figure 8. Indoor sound levels for the initial survey

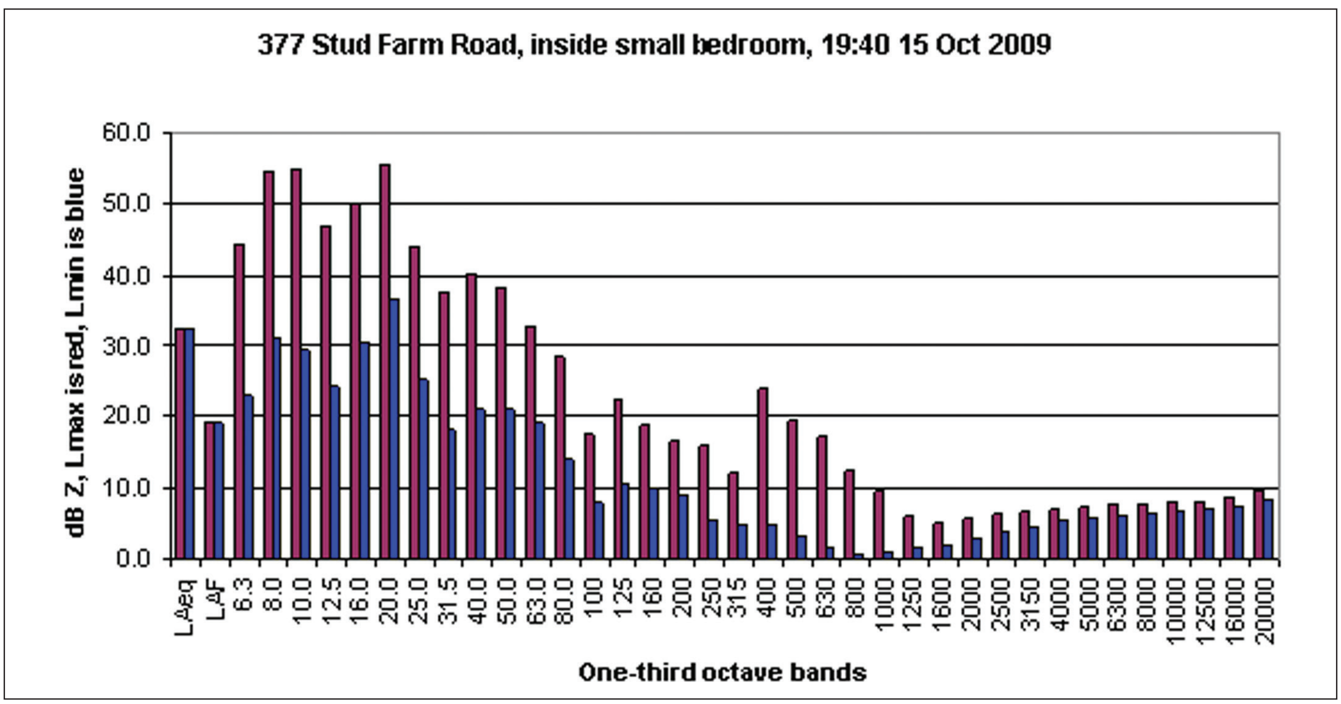

Figure 9. Indoor sound character for the initial survey

recorded in third octave bands every 30 seconds and the average levels for this time period are presented in the following. The SVAN sound level meter is able to record to a lower frequency compared with the Larson Davis 831 meter.

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.

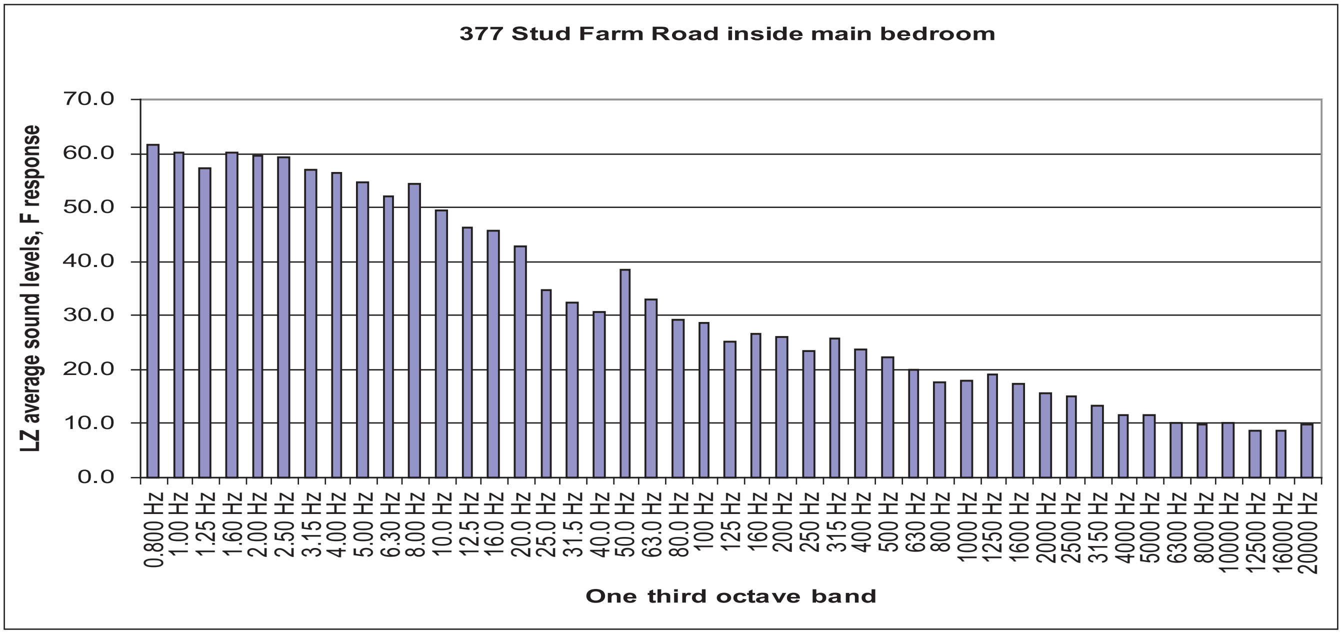

Figure 10. Indoor sound character (main bedroom)

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 following:

- The significant amount of sound energy in the low-frequency and infrasonic ranges.
- The variation of 20 dB 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. Charts are provided as examples of the sound character. The sonograms are taken from recorded audio files that are 60 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.

The study by Thorne (2010) records that wind turbine sound at the residence is perceptible and can be analyzed 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 presented are provided to illustrate the character of the sound. The method developed by H. Bakker, Astute Engineering, New Zealand (personal communication, 2010) displays sound character, modulation, tonality, or tonal complexes through sonograms. These show sound at various frequencies over time as shown in Plate 1. They 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. 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 color indicates the loudness in unweighted dB (SPL) with the color bar at the right providing a key to the "loudness" in decibels associated with each color. 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 color 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.

There are two types of sonograms shown, one is for audible frequencies (20-1,000 Hz) and the other is for low frequencies (0.8-20 Hz), referred to as *infrasound*. The use of sonograms can show the presence of modulation. The rumble/thump of

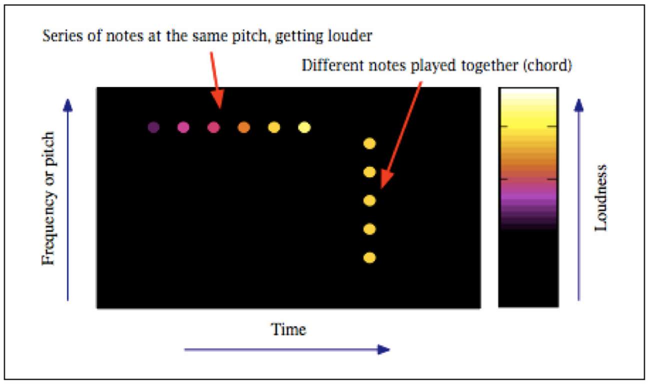

Plate 1. How to interpret a sonogram

wind turbine modulation has been demonstrated to exist in three geographically separate wind farms.

Sound Character at Residence, Plate 2

Plate 2 illustrates the sound of wind farm audible at 7:40 p.m. 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. Higher frequency contents (800-5,000 Hz) not evident in the sonogram are evident in the third octave bands.

Sound Character at Residence, Plate 3

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 (800-5,000 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.

Sound Character at Residence, Plate 4

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.

Sound Character Between Two Sets of Turbines, Plate 5

The wind farm was audible at the measurement location as a distant rumble and some of the nearest visible turbines approximately 500 to 1,500 meters distant were moving slowly, as though they were starting up. The sound is similar to an aircraft overhead, although the sound was not 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.

Sound Character Inside Residence, Plate 6

Sound levels measured inside a small bedroom. The audible sound character (200-400 Hz) 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 nonperceptible infrasound and audible midrange frequencies within the bedroom.

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 1 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 neighborhood. It is customary, therefore, to use a suitable single-number evaluation for community neighborhood 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 (Thorne, 2007).

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 3,500 meters of a wind farm are potentially affected by audible noise and vibration from large turbines, such as those proposed. Residences within 1,000 to 2,000 meters 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 (Thorne, 2007, 2011).

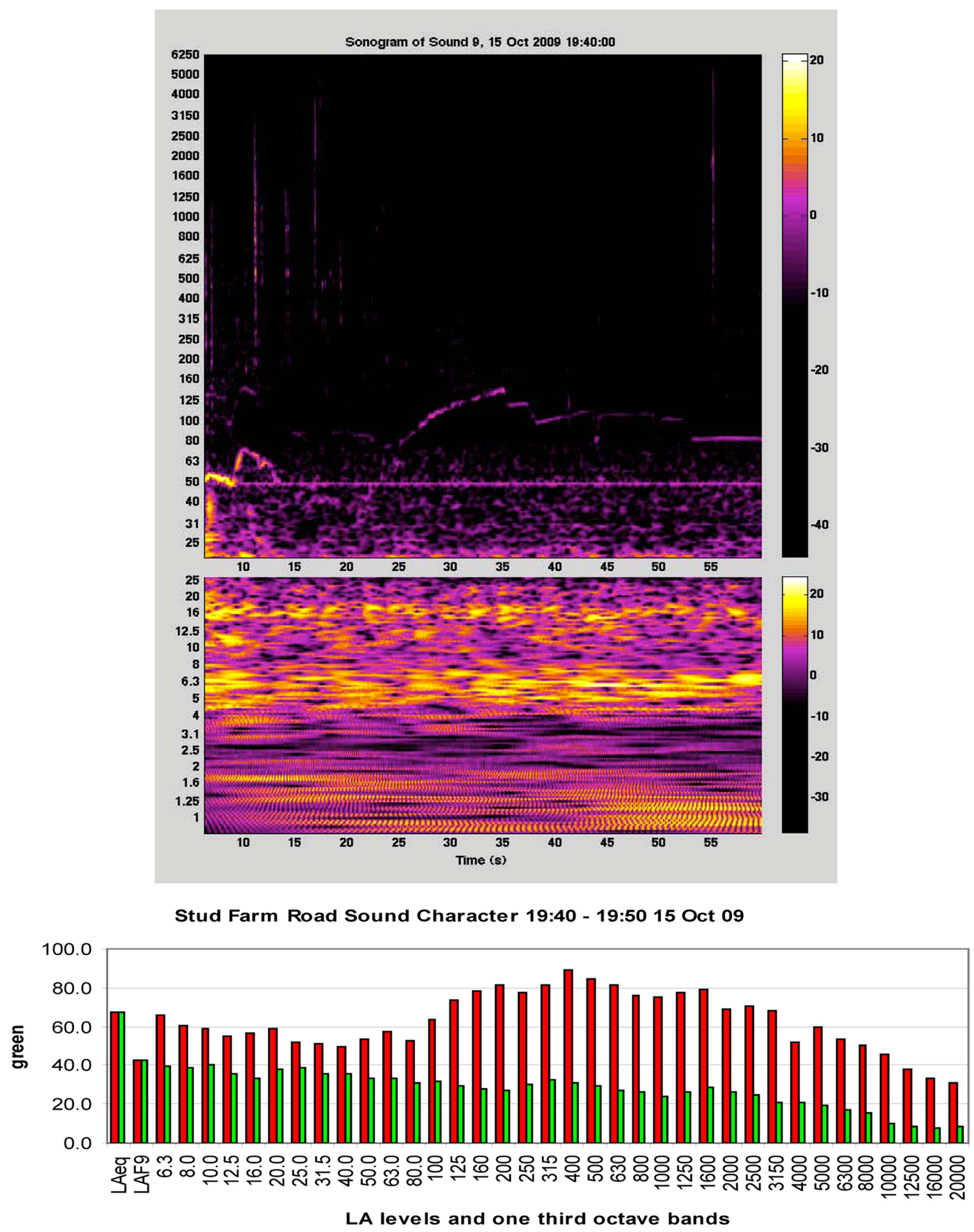

Plate 2. Sound of wind farm audible outside residence

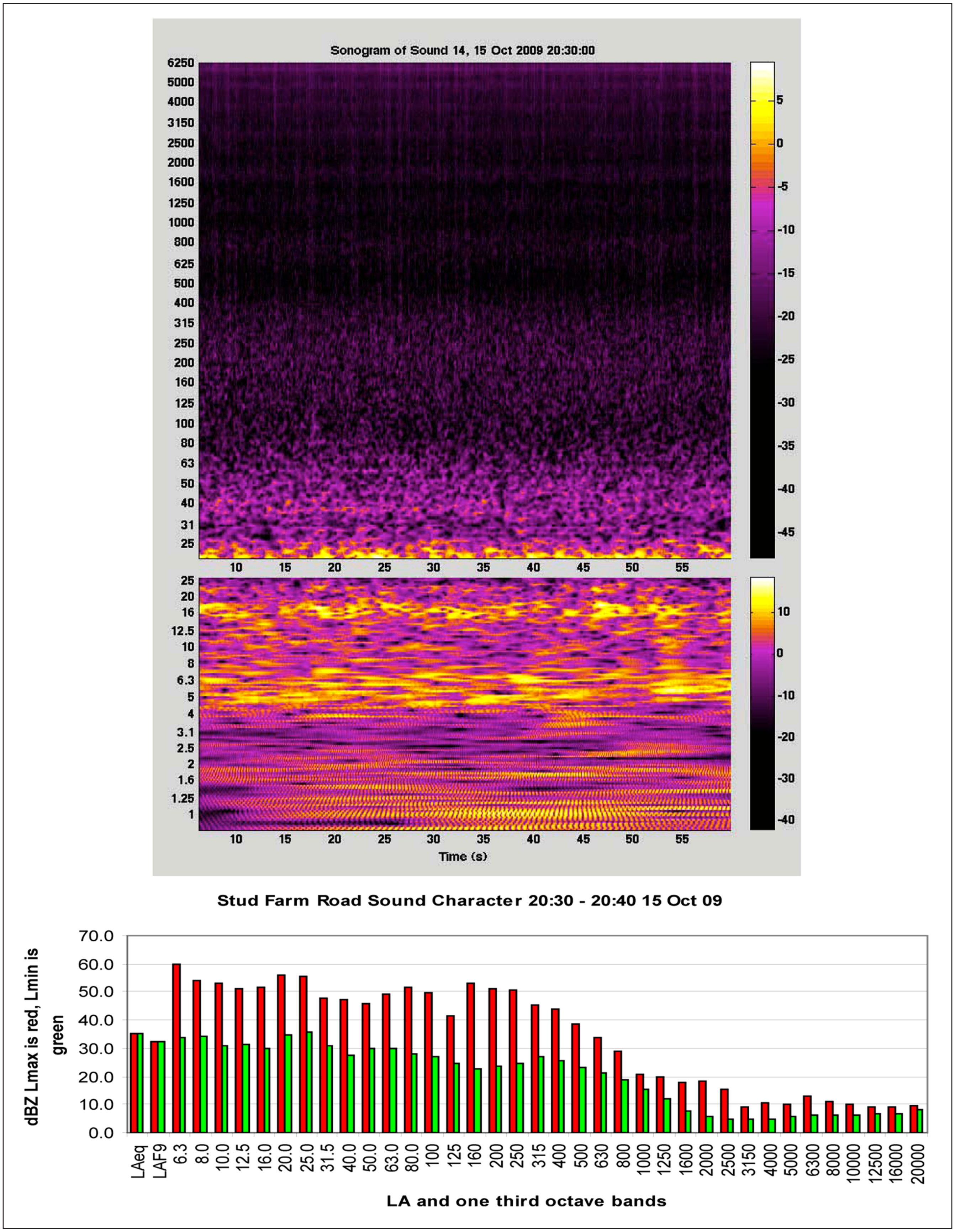

Plate 3. Sound of wind farm audible outside residence (low frequencies identified)

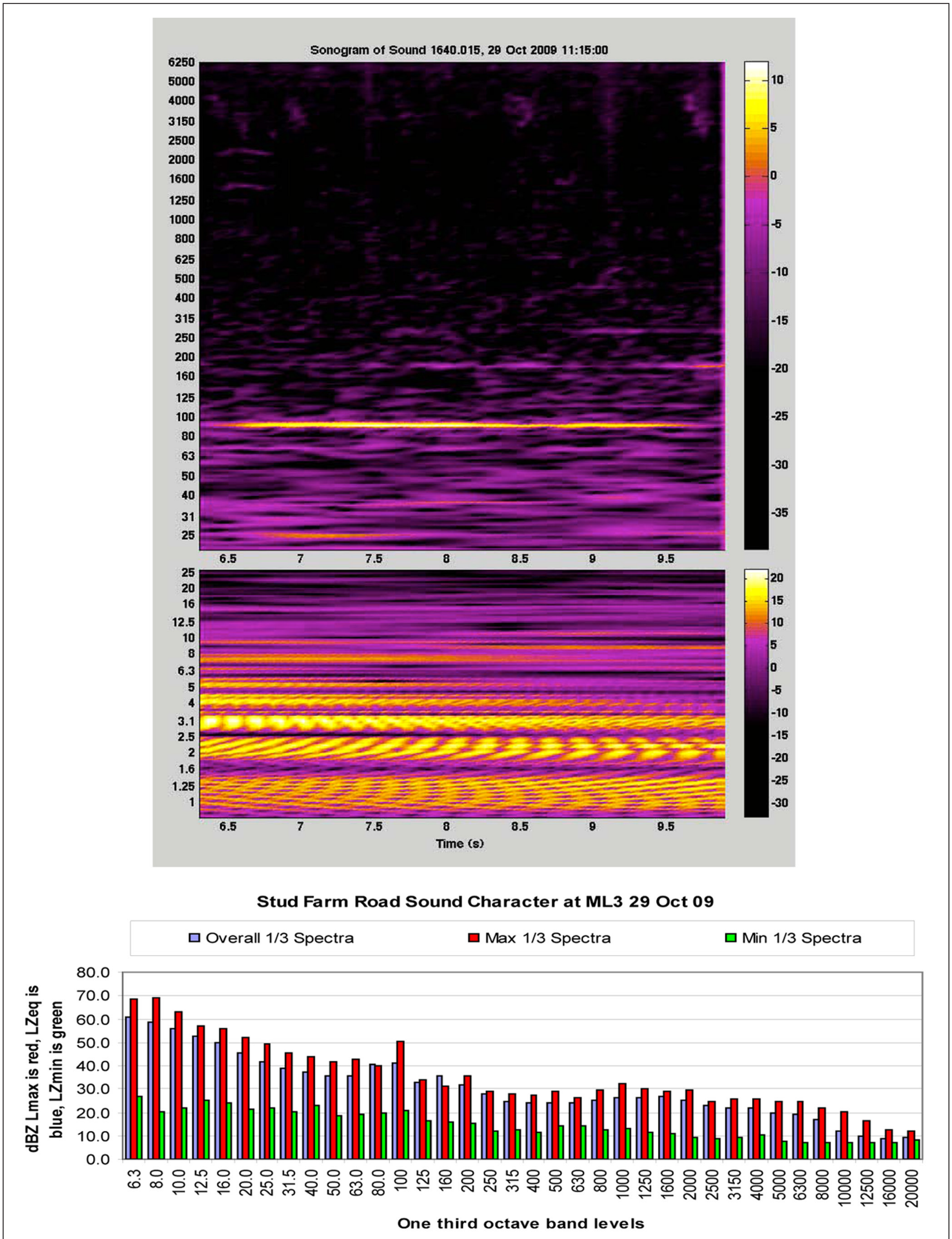

Plate 4. Sound of wind farm not audible outside residence

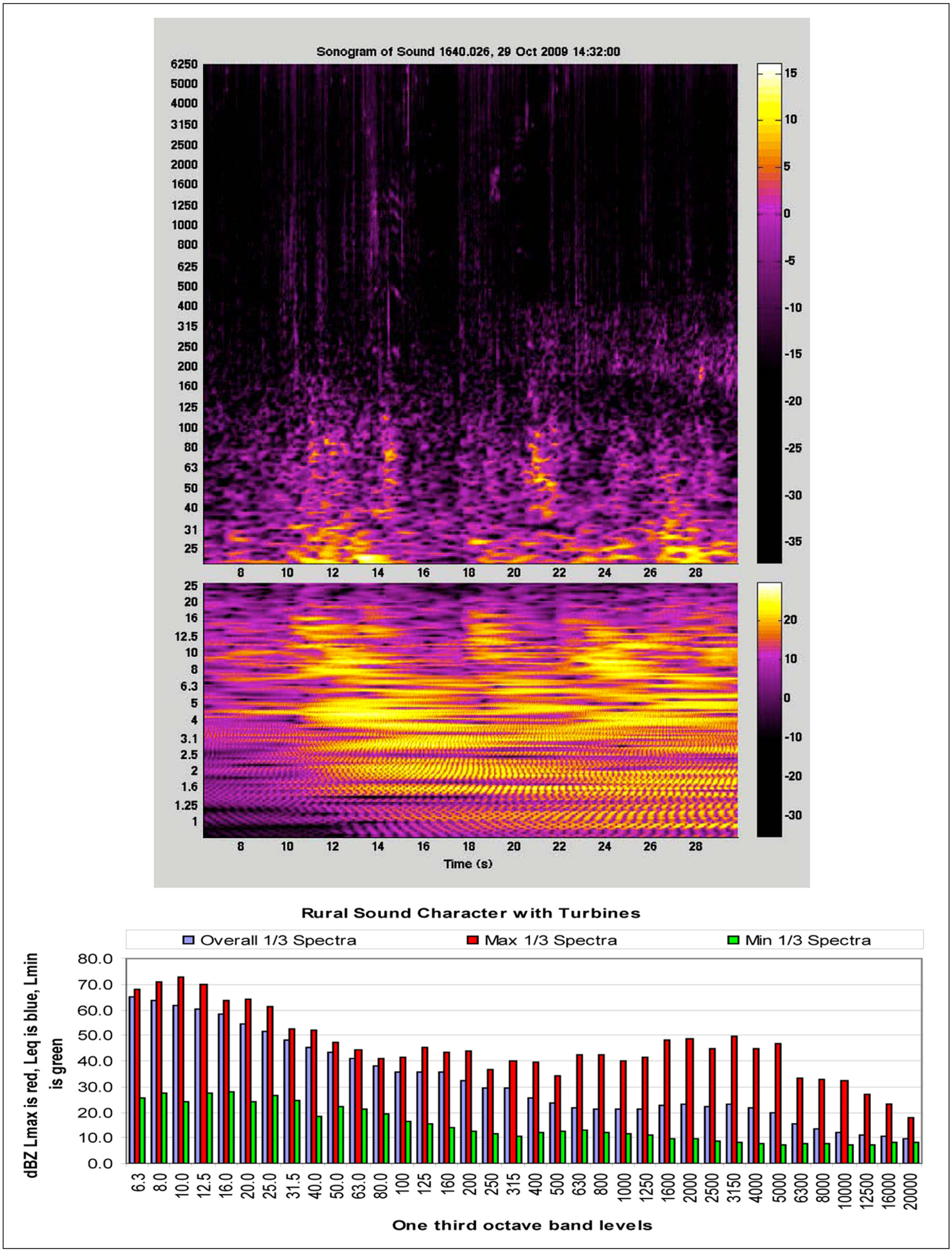

Plate 5. Sound character of wind farm turbines

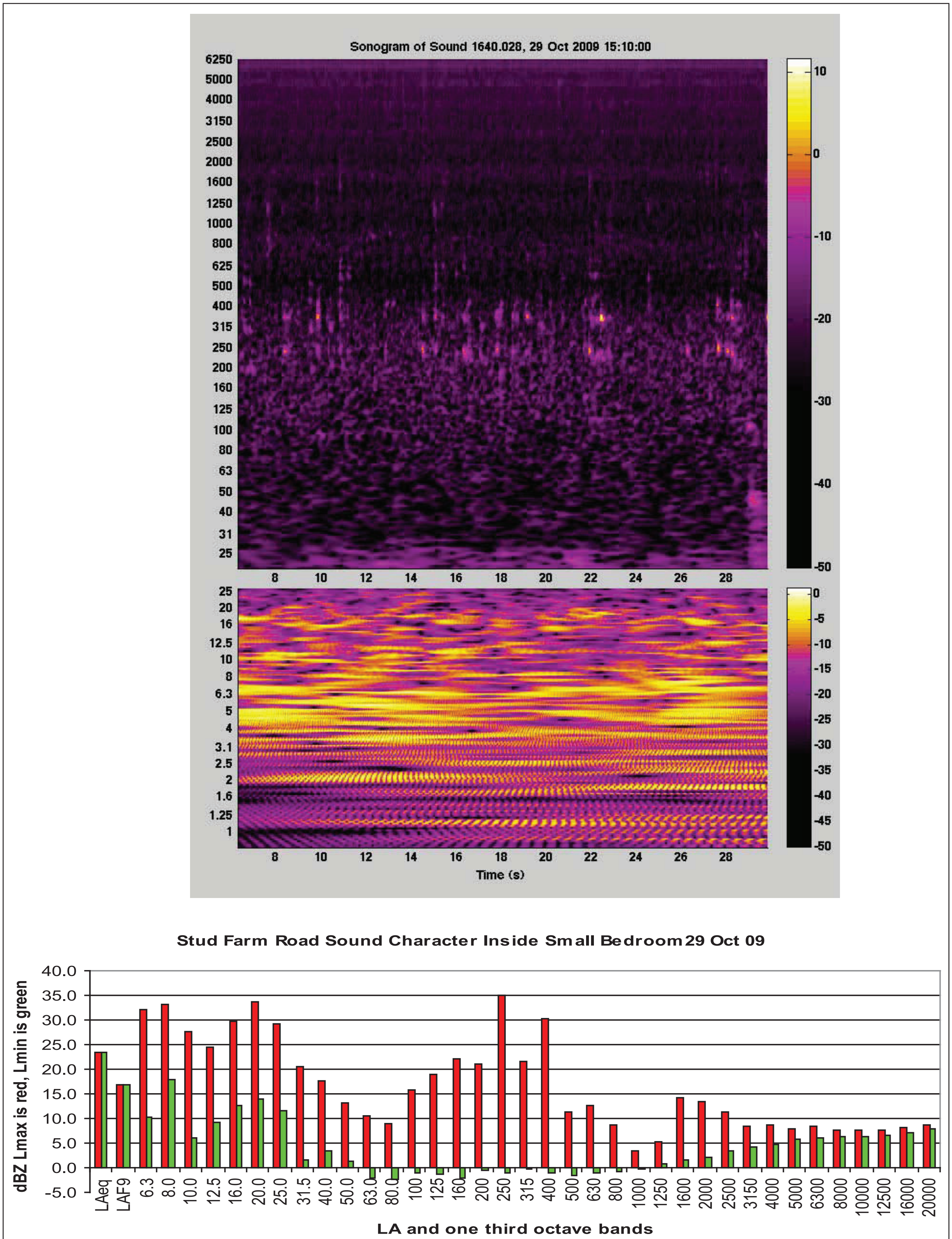

Plate 6. Sound character of wind farm inside a dwelling

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 in 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 five different families near the northern section of the wind farm, all of whom indicated some adverse reaction since the commissioning of a nearby wind farm earlier in the year. The families are all within approximately 1,000 to 2,000 meters 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 indicated 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, and 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 the following:

> 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 indicated tinnitus, dizziness, and headaches since the turbines have started operating. The family also indicated sleep disturbance at night with the sound of the turbines interrupting sleep pattern, vibration in chest at times, and tiredness and trouble concentrating during the day. The family did not have problems sleeping when not at Waubra overnight.

Family C indicated that the noise coming from the turbines at night disturbed sleep. During the day there was noise that causes bad headaches, sore eyes causing impaired vision, earache, and irritability.

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

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

> Some days when the wind is in the north-east my eyes feel swollen and are being pushed out of the sockets. I have a buzzing in my ears. On these days I feel it very difficult to summon memory and difficult to concentrate.
>
> 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 1,000 meters of the nearest turbines and at distances of approximately 3,000 to 4,000 meters 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. The locale is affected by southwest winds at turbine level but can be relatively calm at residences. The prevailing winds at Ballarat airport are shown in Figure W1. The measured wind directions are given to illustrate the importance of accurate wind data in predicting or assessing complaints.

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 1,200 to 1,300 meters from 5 turbines and within 3,500 meters 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

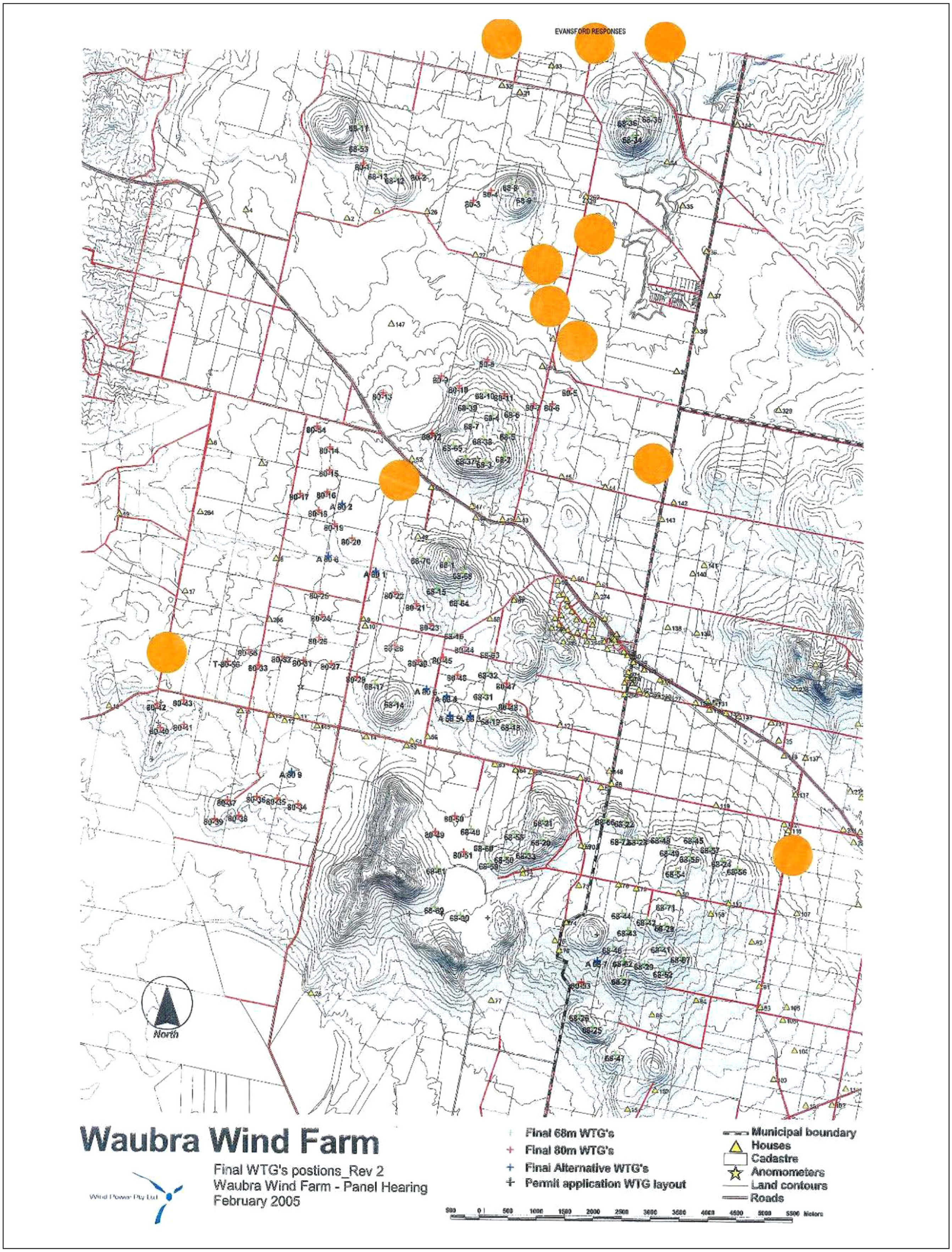

Plate W1. Locales in Waubra affected by Waubra wind farm turbine noise
Note. The locales affected by wind farm noise are identified by the orange circles.

Table W1. Waubra Wind Farm Perception and Complaint Analysis

Locale	Distance	Effects of Noise
1	1,500-2,500	Sleep disturbance, headaches, affects eyes and back of head, tinnitus. Worst affect is while working the farm. Heart pressure changes.
2	1,000	Sleep disturbance, headaches, high blood pressure.
3	1,000-1,300	Sore eyes and headaches when the turbines are operating.
4	1,250-3,000	Sleep disturbance. Affects people working on the farm. Headaches, earaches, blood pressure changes, and poor eye sight.
5	1,300-2,200	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	2,000-2,300	Headaches and pressure in ears when working on the farm.
7	550-1,400	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	1,000-3,500	Headaches when working farm within 1500 meters of turbines. Dizziness when two turbines inline and in sync, effect went when approximately 300 meters 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	3,500-4,300	Frequently suffer from headaches, tinnitus, irritability, sleepless nights, lack of concentration, heart palpitations. Turbines exhibit a loud droning noise and pulsating whoosh.
10	3,400-3,800	Headaches, ringing in ears when turbines are operating. Pressure in ears, heart palpitations, and anxiety attacks. Awaken at night, sleep disturbance.
11	3,000-4,600	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	1,000-1,200	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.

Note. "Distance" is the distance in meters 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.

data and sonograms for compliance and unreasonable noise assessment. The complaint data are retained by the City Council. Statistical data are retained by the wind farm operator and summarized for the Council. Audio data for real-time analysis of special audible characteristics are not recorded by either the Council or the wind farm operator. Audio data are recorded, however, by one affected resident.

In the period April 2009 to March 31, 2010, a total of 906 complaints were made to the Wellington City Council, New Zealand, concerning noise from the wind farm at Makara. These complaints were made by residents living near to and affected by the wind farm. An analysis of the complaint history was made by acoustical consultants working for the wind farm company. From 64 households in a population of approximately 140 occupied residences, 57% of the complaints were from 10 households and 79% were from 20 households.

The character of the 650 complaints was sorted by an independent researcher. Rumble, with 252 mentions, was 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 mentioned the noise as being outside.

In personal interviews at Makara, some residents identified nausea as a problem. In the most severely affected cases known, the residents have bought 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. Of the indoor complaints, 4.5% specifically mentioned sleep disturbance.

The Makara complaints were limited to a small locale. Complaints were from the whole of the district, that is, a distance of approximately 12 km. 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 2,000 meters; the locale "South Makara" is a line of residences facing a line of 25 turbines within 2,000 meters 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.

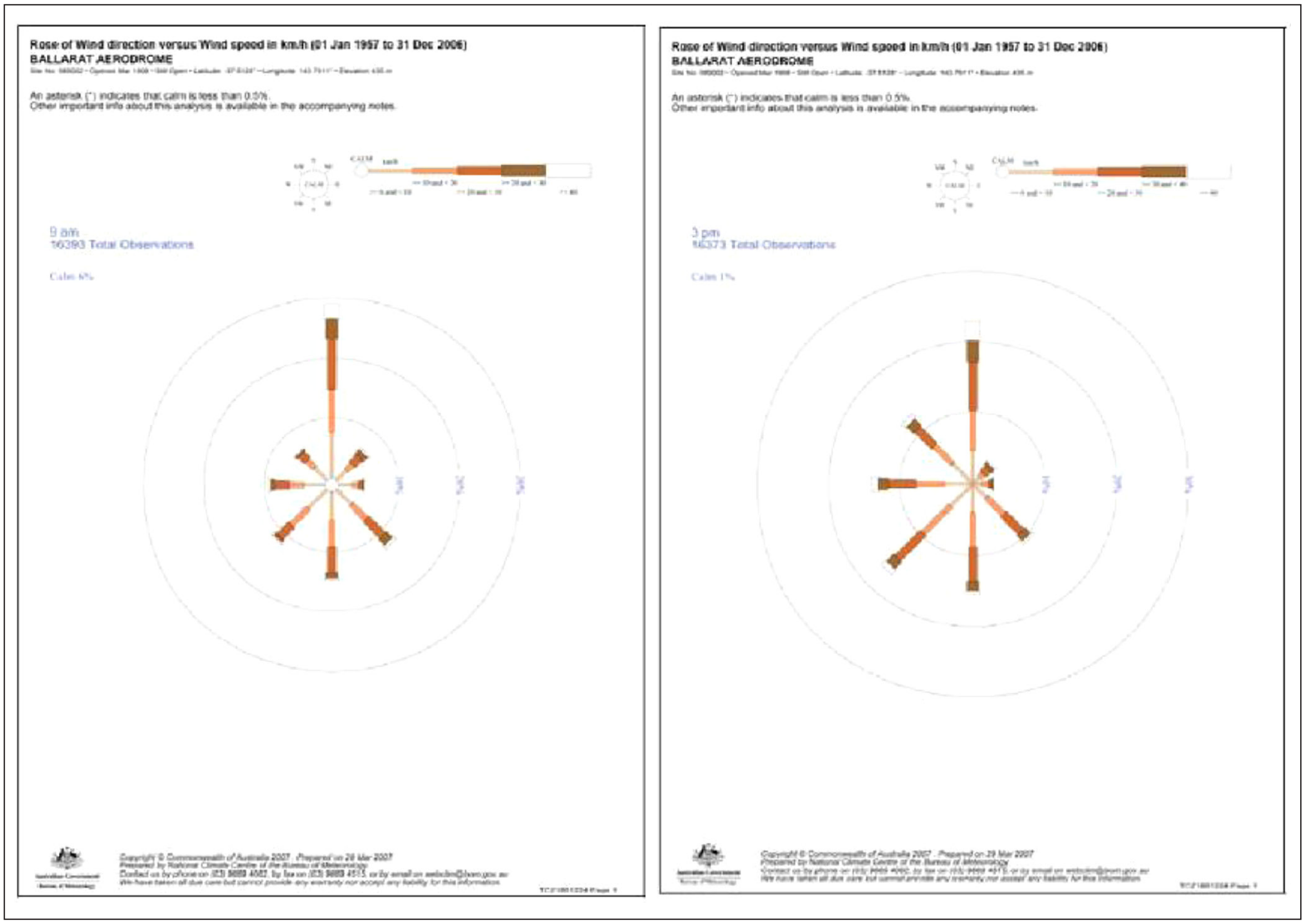

Figure W1. Wind rose, Ballarat Aerodrome, mid-morning and mid-afternoon

The turbines are Siemens 2.3 MW machines situated approximately 1,200 to 2,200 meters from residences.

Nausea and sleep disturbance were reported by one visitor to a residence 2,200 meters 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 complaint (March 2010) about the operation of the wind farm expressed the following:

> 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 p.m. 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 said the following:

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

And a third resident said the following:

> 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 1.35 km away. There are however 27 turbines within 2.5 km (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

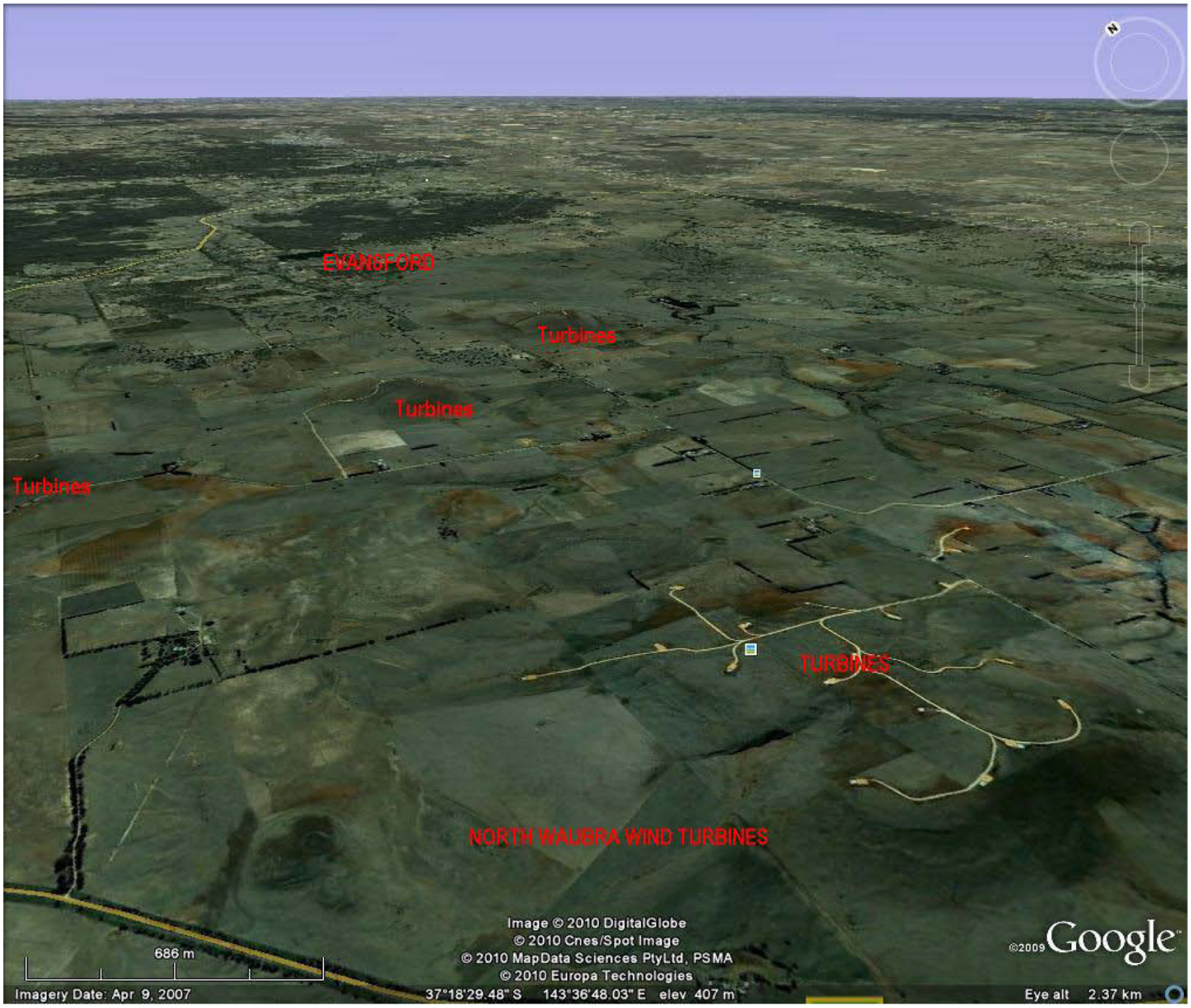

Plate W2. North Waubra locale, residents and the Waubra wind farm

the turbines' mast at 40 meters above ground is shown in Figure WW1. The measured wind directions are given to illustrate the importance of accurate wind data in predicting or assessing complaints.

The Effects on People Living Near the "Te Rere Hau" Wind Farm, New Zealand. In the period from May 2009 to March 31, 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 were made by persons within approximately 2,300 meters south, 3,100 meters southwest, and 2,100 meters to the north of the center of the "97"-turbine wind farm. Complaints concerned both the loudness and character (grinding, swishing) of the sound from the turbines, a two-blade 500 kW 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 3,500 meters of the center 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 indicates issues with wind farm placement and design that can be mitigated by careful consideration of turbine choice, turbine siting design, and

Table WW1. West Wind Perception and Complaint Analysis Till November 2009

Locale	Distance	Effects of Noise
1	1,200-1,300	Kept awake with turbine noise pulsing in bedroom. Sleep disturbance. Sounds not masked by wind in trees or stream.
2	1,200-1,300	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	1,200-1,300	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	1,700	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	1,750	When the wind is from the north to northwest the noise penetrates into the home. Persistent deep rumbling around 1-second interval and lasts for 10 to 20 seconds and then abates. Awakens and disturbs sleep. Generates annoyance and irritability.
4	1,700	Disturbs sleep. Turbines are heard when it is calm at the house and windy at the turbines. Annoyance, nausea, earaches, and stress.
5	2,100	Turbines audible in bedroom. Awaken and disturbs sleep. Creates pressure in head and headache. Feeling tired and distressed.
6	2,000	Northwest wind brings noise and disturbs sleep.
7	1,250	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 tranquility.
7	1,250	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	1,500-2,000	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	2,200	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.

Note. "Distance" is the distance in meters between the locale and the nearest turbines. Each locale contains one or more affected families.

consideration of neighbors and long-term meteorological conditions. Plate TRH1 presents the impact of the wind farm on nearby residences. The number of complaints lodged by the residents is indicated in the plate. Table TRH1, for a single residence, illustrates the common thread of the noise problems found and the relationship to weather conditions. The residence is approximately 1,200 meters from the nearest row of wind turbines. The position of the wind farm on a plateau above the residences is illustrated in Plate TRH2. The measured wind directions are given in Plate TRH3 and illustrate the importance of accurate wind data in predicting or assessing complaints. The complaint numbers 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 are a significant source of unreasonable noise. The number and history of the complaints emphasizes the importance of buffer zones and wind farm design so noise can be mitigated by careful consideration of turbine choice, turbine placement, consideration of neighbors, and long-term meteorological conditions.

Real-World Noise Compliance Problem at a Wind Farm

The Te Rere Hau wind farm in New Zealand is presently the subject of a legal review of its compliance and the methodologies applied to measure background sound levels and compliance levels (*PNCC v. NZ Windfarms*, 2010). In brief, it is understood that specific issues raised are the following:

- 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]

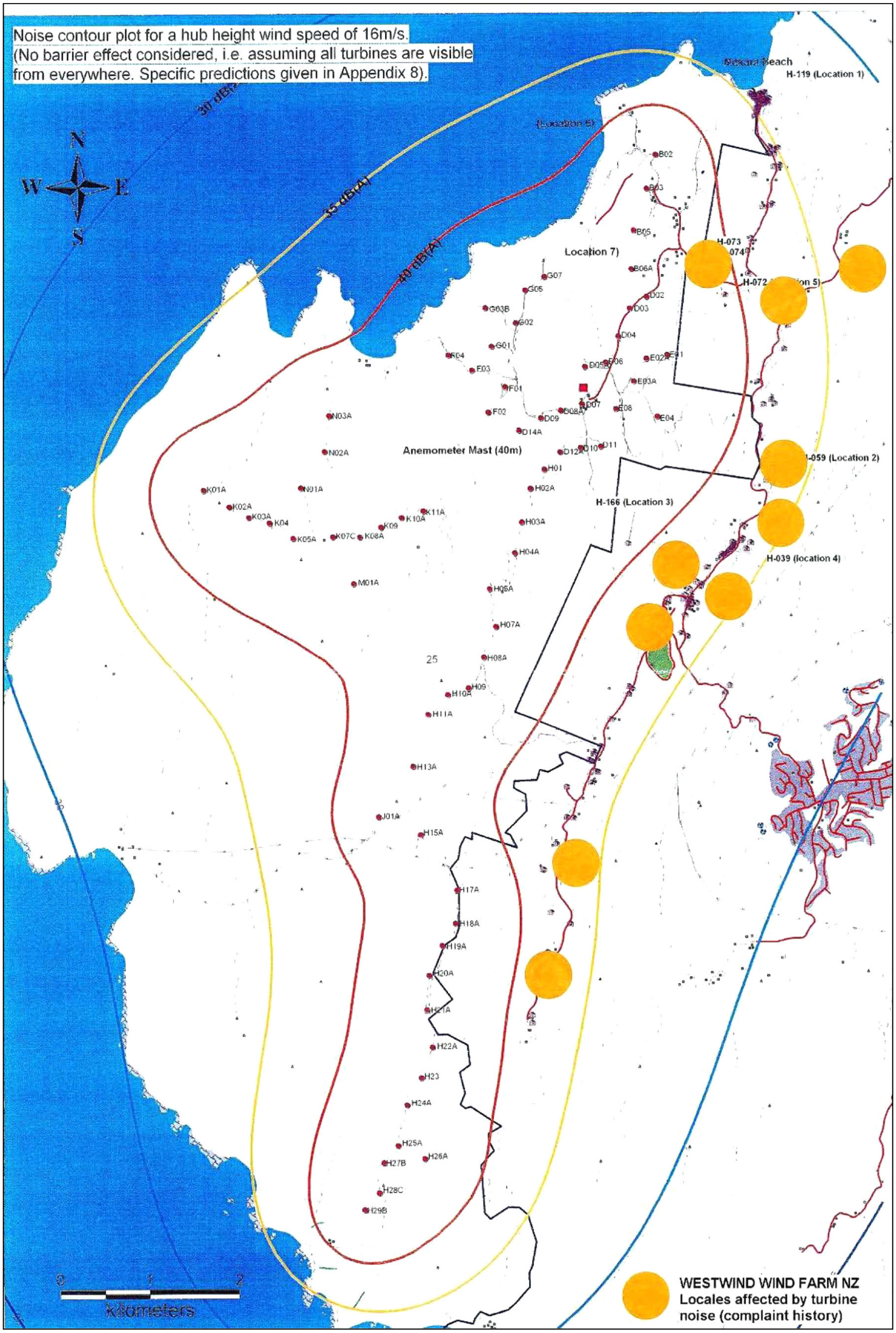

Plate WW1. Locales in Makara affected by "West Wind" wind farm turbine noise

Plate WW2. Makara Valley residents and the "West Wind" wind farm
Note. The turbines (marked in red) are situated on the top of the range and the residents are in the valley (Makara Village and blue squares)

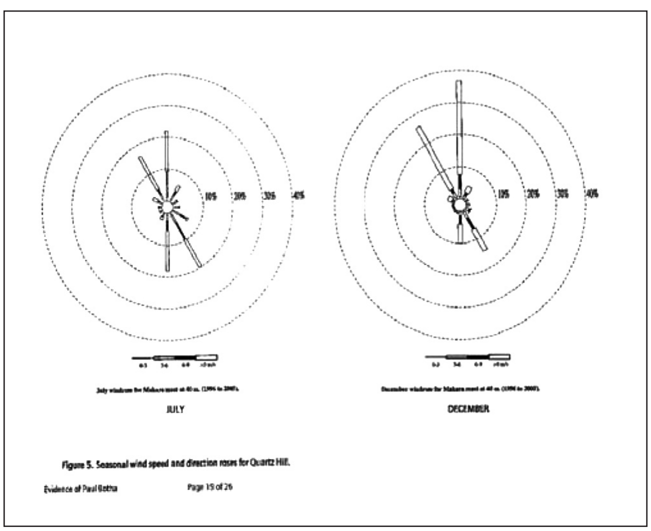

Plate WW1. Prevailing winds for Makara at the wind farm mast (40 meters)

- 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
- 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 December 21, 2010.

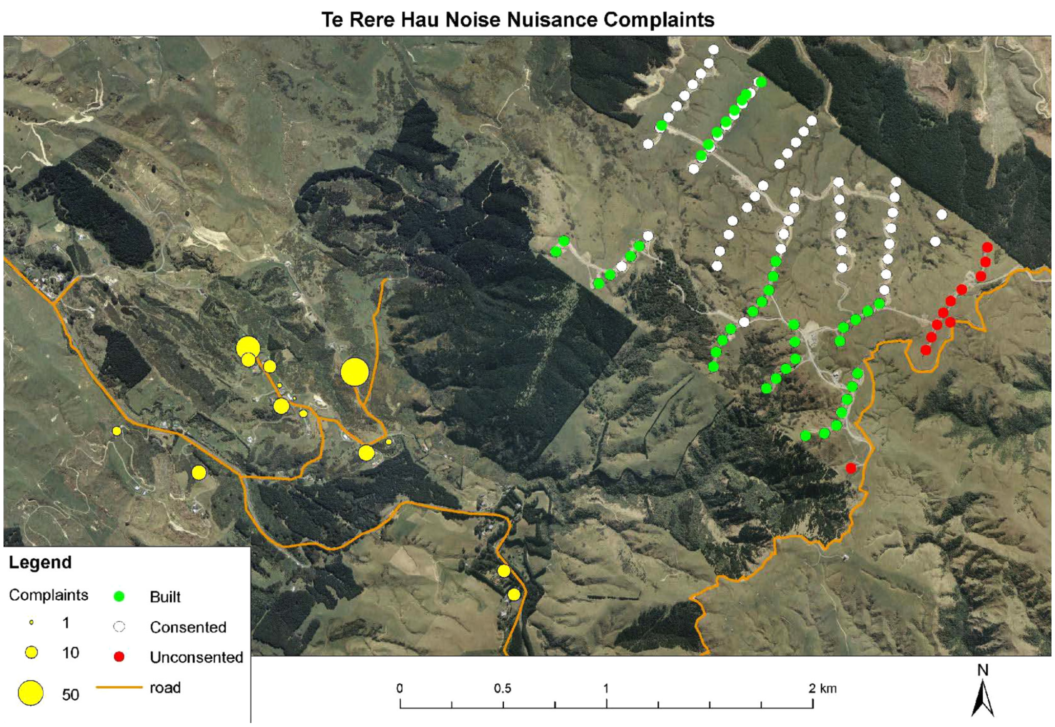

Plate TRH1. Te Rere Hau wind farm complaints by location

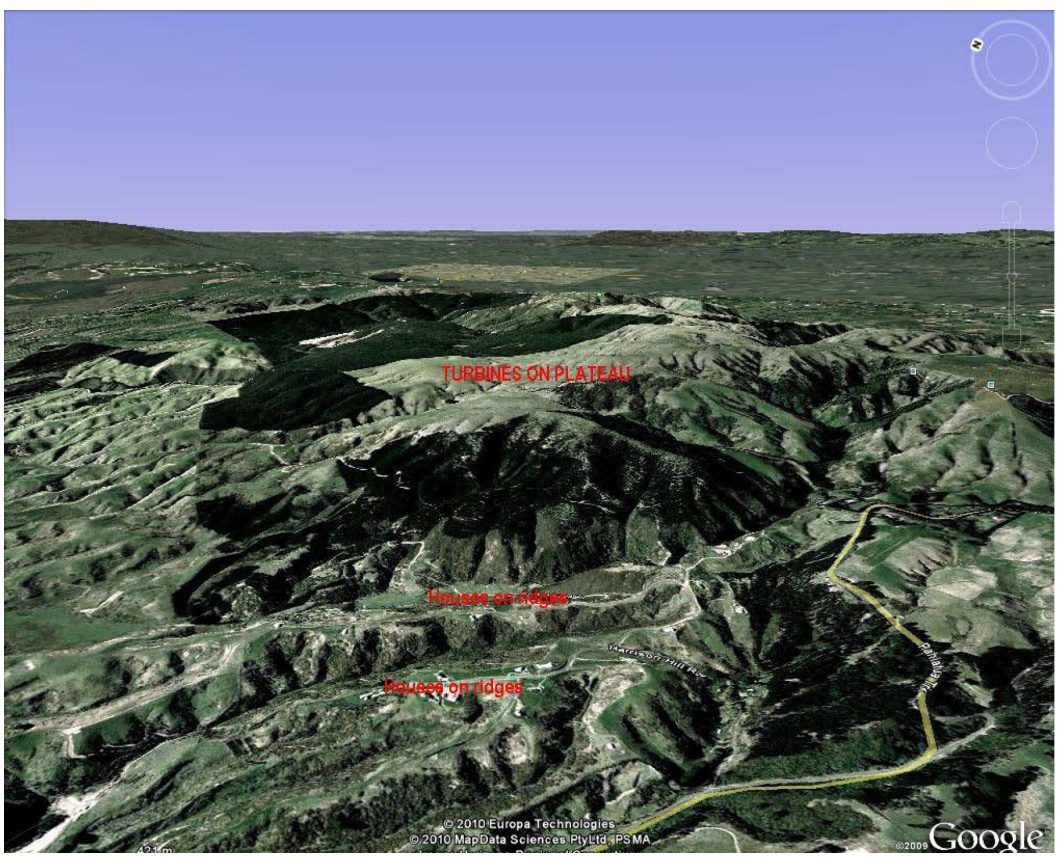

Plate TRH2. Te Rere Hau wind farm in relation to residences

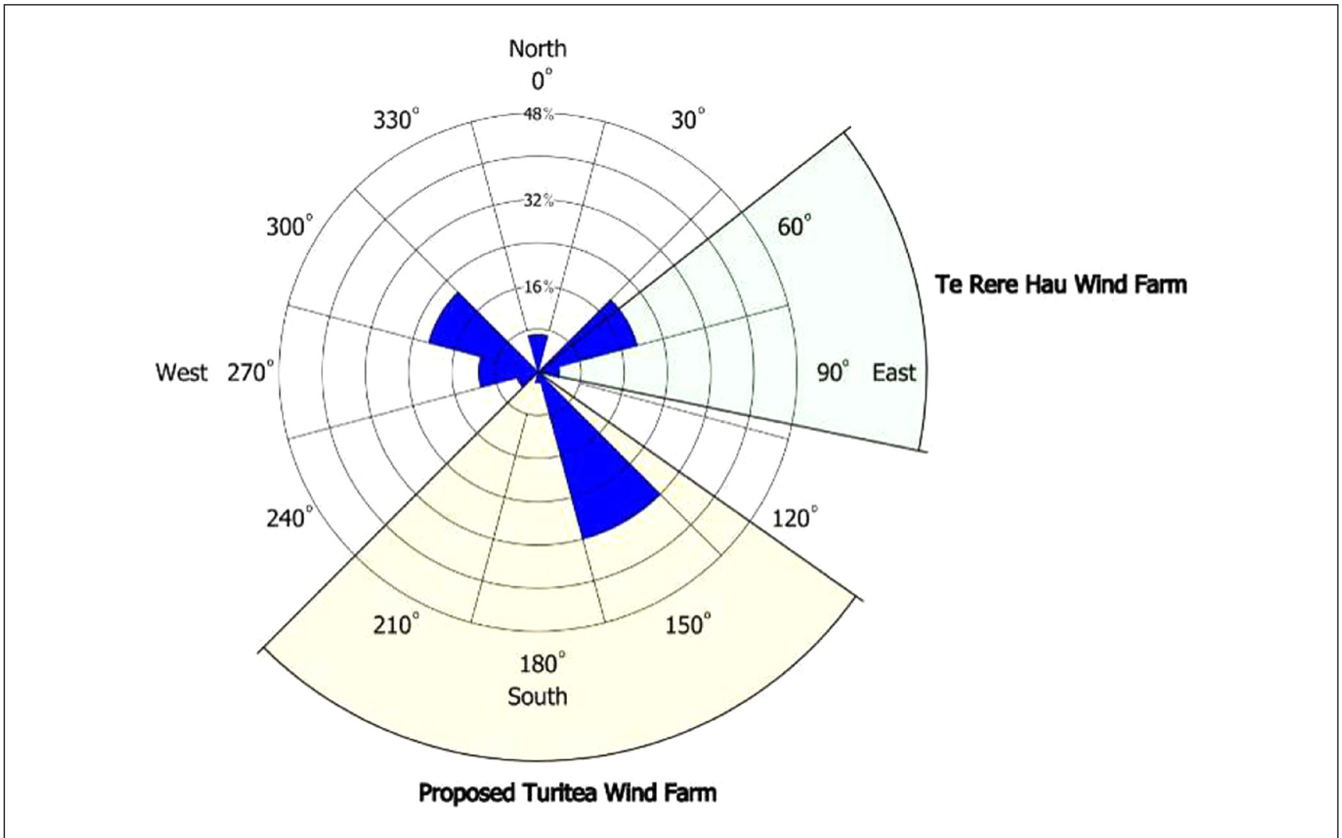

Figure TRH1. Wind Rose for May to September 2009 illustrating existing wind farm (Te Rere Hau) and effect from a proposed wind farm (Turitea) to the south

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, 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.

- It is concluded that, for the reasons given in this article, compliance criteria of a single value, such as 35 dB(A) measured as the equivalent level, LAeq; 40 dB(A) measured as the background level, LA95; or the "background plus 5dB" sound level, whichever is the greater are not acceptable. This is due to the general failure of approval conditions to provide clear and specific methodologies to measure wind farm sound under compliance testing conditions or under complaint conditions when turbine sound is part of the ambient sound.
- It is concluded that wind farms exhibit special audible characteristics that can be described as modulating sound, impulsiveness, or as a tonal complex. Compliance monitoring must include real-time measurement of special audible characteristics and infrasound.
- It is concluded that frequent short-term variations in air pressure (infrasound) may lead to adverse health effects in individuals.
- It is concluded that meteorological conditions, wind turbine spacing, and associated wake and turbulence effects, vortex effects, wind shear, turbine synchronicity, tower height, blade length, and power settings all contribute to sound levels heard or perceived at residences. Current noise prediction models are simplistic, have a high degree of uncertainty, and do not make allowance for these significant variables.
- It is concluded that noise numbers and sound character analyses are meaningless if they are not firmly linked to human perception and risk of adverse effects.

Table TRH1. Te Rere Hau Noise Complaints, August 2009 to February 2010, Single Residence

Date and Time	Wind Direction	Complaint
07/08/09, 5.45 p.m.		Noise from wind farm
20/08/09 6.55 a.m.	South-southeast	Wind farm loud this morning
20/08/09, 8.45 a.m.	South-southeast	Loud wind mills at 5.00a.m.
21/08/09, 6.32 a.m.	East	Wind farm noise
22/08/09, 12.51 p.m.	East	Medium strength, swooshing, and grinding, only ½ on
29/08/09, 8.45 a.m.	West	Very loud again today
15/09/09, 6.31 p.m.	East	Loud noise coming from wind farm
11/05/09, 10.48 a.m.	West	Light wind, wind farm extremely loud
21/11/09, 5.42 a.m.	West	WF too loud
05/08/09, 7.02 a.m.		Noise from Te Rere Hau this morning
09/08/09, 6.02 p.m.		Excessive noise Te Rere Hau
11/08/09, 1.03 p.m.		Windmills beeping noise every 2 minutes
04/09/09, 8.05 a.m.	East	Continuous noise last half hour
09/09/09, 11.24 a.m.	West	Started turbines 103 and 104, now noisy
11/09/09, 6.21 a.m.	North	Light northerly, noise since he got up
19/09/09, 10.49 a.m.	South	Very noisy again today
20/09/09, 8.13 a.m.	East	Loud noise
28/09/09, 7.15 a.m.	Northeast	Wind farm noise
07/10/09, 5.32 p.m.	West	Light wind, loud noise from wind farm
08/10/09, 7.42 a.m.	West	Light wind, swooshing noise this morning
09/10/09, 7.02 a.m.	Northeast	Light wind, wind farm really loud this morning
10/10/09, 9.59 a.m.	South	Light wind, would like to complain about noise
12/10/09, 7.48 a.m.	North	Light wind loud noise from wind farm
20/10/09, 3.53 p.m.	South	Loud noise at wind farm
08/11/09, 9.36 a.m.		Still, noise today
16/11/09, 7.25 a.m.	West	Lots of noise coming from wind farm this morning
17/11/09, 6.27 p.m.	West	Light wind, very loud tonight
20/11/09, 7.22 a.m.	West	Noise complaint
22/11/09, 7.16 p.m.	East	Light wind, wind farm very noisy
04/12/09, 6.18 a.m.	West	Noisy this morning
07/12/09 6.21 p.m.	West	Loud wind farm
09/12/09, 6.50 a.m.	West	Light wind, droning noise
15/12/09, 7.28 a.m.	South	Noisy wind turbines
19/12/09, 7.04 p.m.	West	Light wind noise from turbines over days whirring
25/12/09 8.59 a.m.	West	Light westerly, very loud today
16/01/10, 9.09 a.m.		Noise
17/01/10, 7.44 a.m.	South	Light-medium southerly wind farm quite loud today
17/01/10, 6.58 p.m.	South	Southerly wind, wind mill noise
18/01/10, 7.26 a.m.	Southeast	Medium wind, wind turbine noise last hour
18/01/10, 6.45 p.m.	East	Noise very bad
18/01/10, 10.54 p.m.	Southeast	Extremely loud
19/01/10, 7.28 p.m.	West	Turbines causing a lot of noise tonight
21/01/10, 8.21 p.m.	East	Loud noise from the turbines
25/01/10, 4.43 p.m.	East	Wind mill noise
26/01/10 8.12 a.m.	East	Medium wind, wind turbines making a lot of noise
28/01/10, 7.27 p.m.	East	Light wind, turbines are noisy again this evening
29/01/10, 10.21 a.m.	East	Loud noise from blades and mechanical noise
29/01/10, 6.12 p.m.	East	Med wind same noise as usual coming from turbines
02/02/10, 6.51 p.m.	East	Loud noise from wind farm
03/02/10, 7.19 p.m.	East	Noise from wind farm
04/02/10 7.01 a.m.	East	Noise loud this morning
05/02/10, 6.22 a.m.	East	Light, loud today
05/02/10, 5.57 p.m.	East	Light wind, same whirring gearbox noise as usual
07/02/10, 12.49 p.m.	Northwest	Excessive noise
08/02/10, 6.58 a.m.		Wind farm very loud this morning
08/02/10, 8.16 p.m.	East	Light wind
10/02/10, 7.11 a.m.	North	Te Rere Hau noisy this morning
15/02/10, 8.14 p.m.	East	Medium wind
16/02/10, 7.50 a.m.	East	Turbine noise in east direction at least hour

- It is concluded that no large-scale wind turbine should be installed within 2,000 meters of any dwelling or noise-sensitive place unless with the approval of the landowner.
- It is concluded that no large-scale wind turbine should be operated within 3,500 meters 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.

In my opinion, based on my training, experience, measurements, and observations, 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 32dB outside the residence and (b) above the individual's threshold of hearing inside the home.

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Bio

Bob Thorne, MSc, PhD, is the principal consultant of Noise Measurement Services Pty Ltd, Brisbane, Australia. He holds a PhD from Massey University, New Zealand, in health science and is an environmental health research associate in the Institute of Food, Nutrition and Human Health at Massey University. His research work involves using advanced specialized technology for intrusive noise assessment, and a specific application is personalized sound reinforcement for hearing assistive devices.