In the matter of the Moorabool Wind Farm

Hearing before the Planning Panel

Statement of Evidence of Dr Robert Thorne in Support of the Submission by Mr and Mrs J. Willis
19 May 2010

1.0 The Format of this Evidence

1.1 Mr and Mrs Willis have requested my evidence provide an assessment of the potential for adverse effects due to noise from the proposed wind farm at their properties. A brief overview of cumulative effects due to the total wind farm was requested, as well as an assessment of the potential effect of the wind farm on the platypus habitat on the boundary of their property. A statement of my qualifications and experience is provided at the conclusion of this evidence.

1.2 The body of the evidence presents an assessment of the wind farm as it affects the properties of Mr and Mrs Willis. The assessment briefly reviews the noise impact assessment prepared by Marshall Day Acoustics. The potential for complaints due to noise are referenced to two wind farms in New Zealand, Makara (Wellington) and Te Rere Hau (Palmerston North). These two wind farms have between them recorded 1284 formal complaints about noise between April 2009 and 31 March 2010. The acceptability of New Zealand standard NZS6808:1998 and NZS6808:2010 is critiqued.

1.3 Conclusions and recommendations are presented concerning wind farm noise mitigation and the desirability of setting buffer and noise mitigation zones between wind turbines and residences.

1.4 Annexes 1 to 5 provide a summary of the human perception and technical information supporting my recommendations and conclusions.
Annex 1 *"Audible Sound and Noise"*
Annex 2 *"Characteristics of Multiple and Single Wind Turbines"*
Annex 3 *"Predictions of Sound Levels – Approaches and Limitations*"
Annex 4 *"Responses of Residents near Wind Farms"*
Annex 5 *"Annoyance, Audibility, Low and Infrasound Perception"*

1.5 Mr and Mrs Willis also requested an assessment of the potential health effects of lights on top of the turbines. This assessment is included in this evidence as Annex 6 *"Flicker and the Human Perception of Wind Farm Activity"* and has been prepared by Mr Bruce Rapley.

1.6 Annex 7 presents an overview of the evidential text *"Sound, Noise, Flicker and the Human Perception of Wind Farm Activity"* that was prepared for the Board of Inquiry Turitea Wind Farm Proposal Hearing, New Zealand, March 2010. The authors are a team of researchers that provide independent unbiased advice to the community and wind farm developers concerning the potential for adverse effects and mitigation of wind farm activity on people.

2.0 Conclusions and recommendations

2.1 In my view the Marshall Day Acoustics Reports do not present a reliable analysis of the operational sound levels at the Willis family residences. The levels as predicted should not be accepted as a foundation for establishing compliance or setting conditions at any residence.

2.2 In my view the Marshall Day Acoustics Reports do not present a reliable analysis of the background levels overall and a further, longer-term survey using a low-noise floor Class 1 sound level meter, is warranted. The levels as presented should not be accepted as a foundation for establishing compliance or setting conditions at any residence.

2.3 In order to reduce the potential major adverse effects of the proposed wind farm as presented, I conclude that turbines should not be within 2000 metres of any residence or noise sensitive place. This means that turbines BAT01, BAT02, BAT03 and BAT04 should be removed.

2.4 In order to reduce adverse effects of the proposed the wind farm as presented, I conclude that residences or noise sensitive places within 3500 metres of any turbine should be noise-mitigated by agreement with the affected landowners. This means that if turbines BAT07, BAT08, BAT09, BAT10, BAT24, BAT25 and BAT26 are retained then the wind farm facility developer must provide acceptable noise mitigation and immediate complaint management to the potentially affected Willis family residences.

2.5 It is concluded that the design of the wind farm requires significant modification in order to reduce the known adverse effects of noise on people. This will require removal of turbines and redesign to give emphasis to noise mitigation.

Recommendations

The following changes and additions to the ‘model’ Victorian wind farm conditions are recommended to provide certainty of application:

Recommended Standard Conditions

1. No wind turbine shall be installed within 2000 metres of any dwelling or noise sensitive place existing as at the date of issue of this permit, unless with the approval of the landowner.

2. No wind turbine shall be operated within 3500 metres of any dwelling or noise sensitive place existing as at the date of issue of this permit 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 in accordance with the Noise Compliance Plan subject to the final approval of the occupier of that dwelling or noise sensitive place.
3. The operation of the wind farm shall not cause unreasonable noise. "Unreasonable noise" is a sound or vibration that is:
   (i) annoying to a reasonable person;
   (ii) injurious to personal comfort or health, including sleep disturbance;
   (iii) a disturbance to the quiet enjoyment of land including the grazing of stock or keeping of animals;
   (iv) observed to have a detrimental affect on wildlife or the environment.
4. The sound, including low frequency and infrasound, of the wind farm shall not be audible or perceptible within a dwelling or noise sensitive place. As a guide to audibility and perceptibility, the sound shall be non-modulating and shall not exceed the 20 phon equal loudness level contour (ISO226:2003 *Acoustics-Normal equal loudness contours)* and 75 dB (unweighted) in the 5 Hz to 20 Hz one-third octave bands.
5. To avoid any dispute, the definition of modulation is a change in the measured unweighted LZeq turbine sound level of more than 3dB (represented by a rise and subsequent fall in peak-to-trough sound energy levels each of more than 3dB) occurring within a 2 second period not less than 5 times in any one minute and 6 minutes in any hour.
6. Compliance measurements at specified assessment locations shall be with a low noise floor Class 1 sound level meter recording one-third octave band Z-unweighted sound levels to at least 8 Hz and audio recording in uncompressed format with a sampling rate of not less that 16000 Hz.

Recommended Alternative Conditions if 'Noise Numbers' are referenced in the Model Conditions

1. When ground level wind speeds are above an average 3 metres/second within the notional boundary of a dwelling or noise sensitive place, the sound level from the proposed wind farm energy facility, measured as the equivalent continuous A-weighted sound level (LAeq) over any 10 minute period within 10 metres outside the most affected wall of a dwelling or noise sensitive place shall not exceed the measured equivalent continuous sound level (LAeq) of 35 dBA, subject to Condition (3).
2. When ground level wind speeds are below an average 3 metres/second within the notional boundary of a dwelling or noise sensitive place, wind

turbine sound levels shall be measured as being the actual equivalent continuous A-weighted sound level (LAeq) including both the ambient sound levels and the wind farm sound levels as one combined sound level. The combined sound level when measured over any 10 minute period within 10 metres outside the most affected wall of a dwelling or noise sensitive place shall not exceed the measured equivalent continuous sound level (LAeq) of 30 dBA, subject to Condition (3).

3. A penalty of 5 dB for special characteristics shall apply in each of Conditions (1) and (2) unless the wind farm operator can prove that modulation, tonality or other special audible characteristic does not exist. The consequential criteria are 30 dB(A) for Condition (1) and 25 dB(A) for Condition (2).
4. The operation of the wind farm shall not cause unreasonable noise. “Unreasonable noise” is a sound or vibration that is:
   (i) annoying to a reasonable person;
   (ii) injurious to personal comfort or health, including sleep disturbance;
   (iii) a disturbance to the quiet enjoyment of land including the grazing of stock or keeping of animals;
   (iv) observed to have a detrimental affect on wildlife or the environment.
5. The sound, including low frequency and infrasound, of the wind farm shall not be audible or perceptible within a dwelling or noise sensitive place. As a guide to audibility and perceptibility, the sound shall be non-modulating and shall not exceed the 20 phon equal loudness level contour (ISO226:2003 *Acoustics-Normal equal loudness contours)* and 75 dB (unweighted) in the 5 Hz to 20 Hz one-third octave bands.
6. To avoid any dispute, the definition of modulation is a change in the measured unweighted LZeq turbine sound level of more than 3dB (represented by a rise and subsequent fall in peak-to-trough sound energy levels each of more than 3dB) occurring within a 2 second period not less than 5 times in any one minute and 6 minutes in any hour.
7. Background sound levels to be measured at specified assessment locations shall be with a low noise floor Class 1 sound level meter for 12 months prior to the installation of any turbines.
8. Compliance measurements at specified assessment locations shall be with a low noise floor Class 1 sound level meter recording one-third octave band Z-unweighted sound levels to at least 8 Hz and audio recording in uncompressed format with a sampling rate of not less that 16000 Hz.

***Note** to the above ‘Noise Number’ conditions: the metric recommended is the equivalent continuous (LAeq) level rather than the background level (LA90) stated in the New Zealand standard. The reasons for this change are given in the text of this evidence.*

Recommended Standard Complaint Mitigation Conditions

1. Where a complaint that wind farm noise is unreasonable, annoying, disturbing to quiet enjoyment or objectionable or injurious to personal comfort including sleep disturbance is received by the Authorised Council Officer or when condition 4 is found to have been breached, in any part, the Authorised Council Officer shall within 24hours of the complaint or breach notify the wind farm facility operator, with a request to show cause why it should continue to operate that turbine or facility given the apparent breach. The wind farm operator shall also provide the relevant meteorological circumstances at the time of the complaint or breach and to reduce the noise from the operation of the relevant turbine or turbines in such circumstances. The wind farm operator shall provide the wind data, and identify the relevant turbine(s), within 24hours of the request. The Authorised Council Officer shall, within 24hours of notifying the wind farm facility operator of the request, also advise in writing the person(s) making the complaint, a summary of the meteorological conditions, identify the relevant turbine(s) and state the action taken. Failure to reply to a show cause notice based on a complaint is accorded 10 demerit points. Failure to provide complete information is accorded 10 demerit points.

2. In circumstances where thirty (30) demerit points have been recorded concerning the same turbine or turbines or breach in similar circumstances, within 24 hours of the complaint being received that satisfies thirty (30) demerit points, the Authorised Council Officer shall notify the wind farm facility operator with a request to selectively shut down the operation of the relevant turbine or turbines in those circumstances. The request will be complied with within 48 hours of service of the notice. If sound emissions cannot be reduced such that they comply then, subject to further complaint resulting in a total fifty (50) demerit points, the Authorised Council Officer shall issue an abatement notice by requiring the operator of the wind farm facility to immediately cease to operate the noncompliant wind turbine(s) until modifications are made and certified to reduce the noise. Further operation of non-compliant wind turbine(s) shall only be for sound measurement checks as specifically agreed with the Authorised Council Officer to demonstrate compliance. The Authorised Council Officer, within 24hours of serving an abatement notice on the wind farm facility operator, shall advise in writing the person(s) making the complaint of the action taken.

3. In circumstances where one hundred (100) demerit points have been recorded concerning the same turbine or turbines or breach in similar circumstances, the relevant turbine(s) shall be stopped and decommissioned within one month of notification by the Authorised Council Officer, or removed. The Authorised Council Officer, within 24hours of serving notice on the wind farm facility operator, shall advise in writing the persons making the complaint of the

action taken. Failure to comply with the notification shall be subject to an enforcement order lodged by the Authorised Council Officer or affected party. A condition of the enforcement order shall be that the relevant turbine(s) shall be stopped from the date of the enforcement order.

4. In determining whether the sound from the wind farm facility is unreasonable, annoying, disturbing to quiet enjoyment or objectionable or injurious to personal comfort including sleep disturbance, regard must not be had to the number of persons affected or that may be affected by such sound. For the purposes of condition 6, a complaint from an affected resident shall be taken as a complaint notified by the Authorised Council Officer.

Evidential Statement

I confirm that I hold no brief to take any particular stance on the proposed wind farm. My evidence is what I believe is a professional impact assessment of the proposal, based on my training and experience. This evidence is within my area of expertise, except where I rely on what I have been told by another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

The conclusions and recommendations in Section 2 of this evidence have drawn on the evidence prepared by legal advisors for the Turitea Wind Farm proposal, New Zealand, March 2010.

I have made all the enquiries that I consider desirable and appropriate and no matters of significance which I regard as relevant have to my knowledge been withheld from the Panel.

Signed

Dr Robert Thorne
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18 Lade Street, Enoggera, Queensland 4051

3.0 Introduction to the Willis Residences

3.1 This report is in response to a request from Mr and Mrs J. Willis for an assessment of the proposed wind farm at Moorabool, Victoria. The wind farm is in close proximity to their farm and residences. The location of the wind farm is presented in **Plate 1**. The potentially affected residences are marked as A, B and C on **Plates 1, 2, 3 and 4.**

Plate 1: Proposed Moorabool Wind Farm *(source: West Wind documentation)*

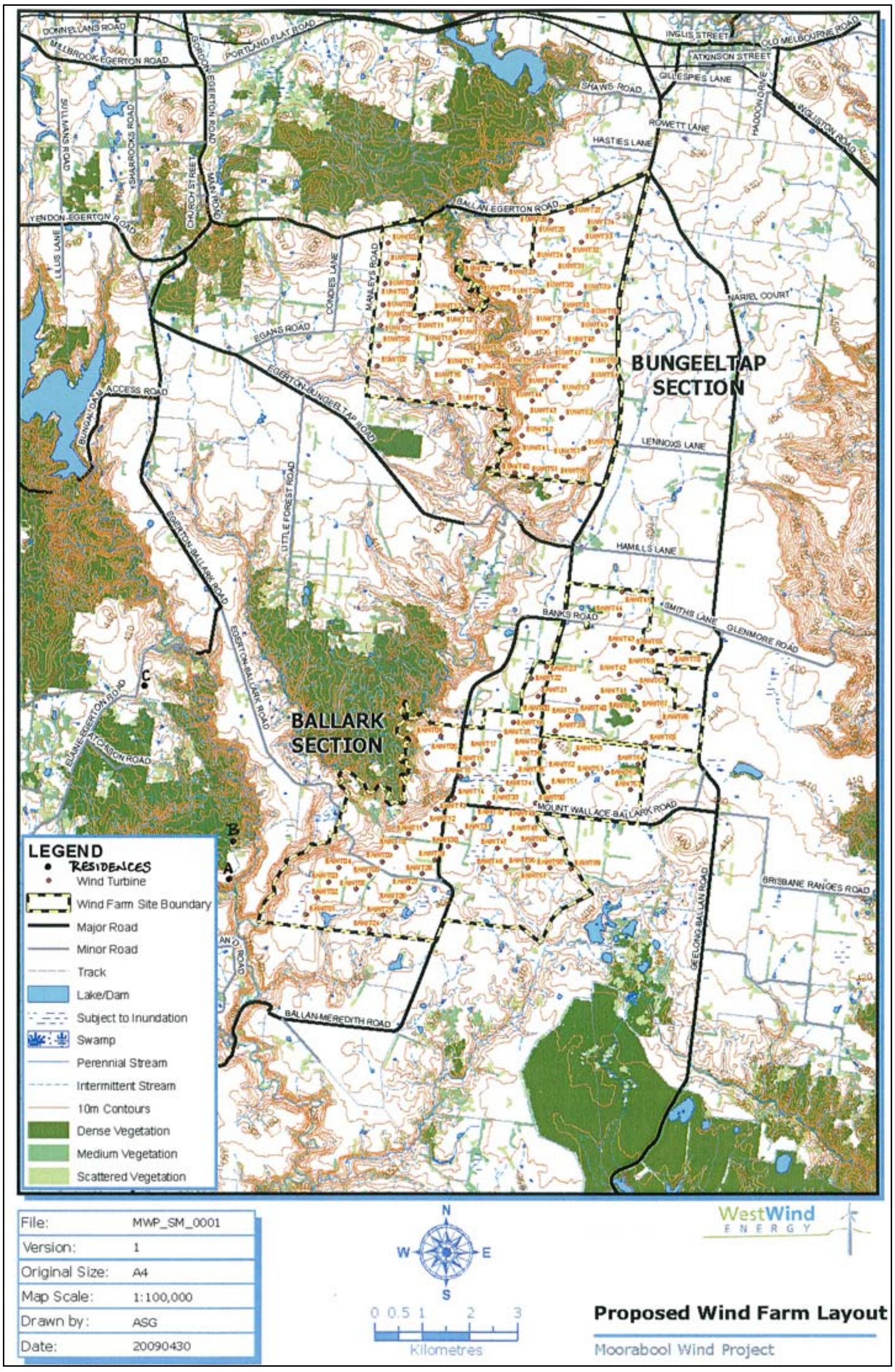


Plate 2: Location of Residence A

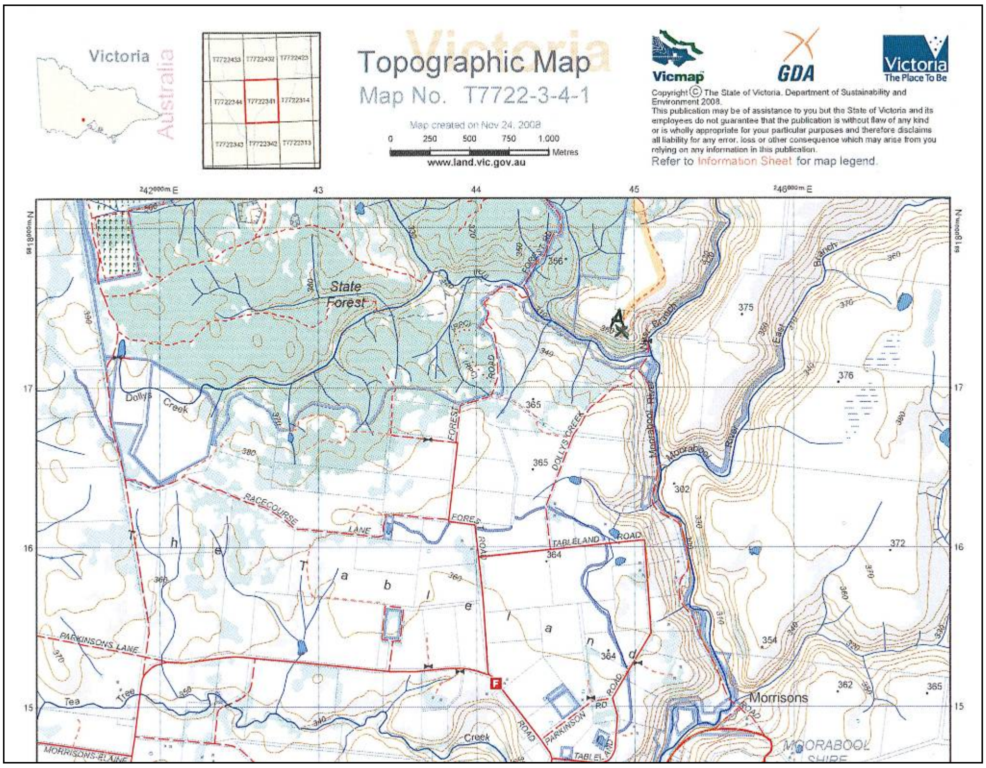
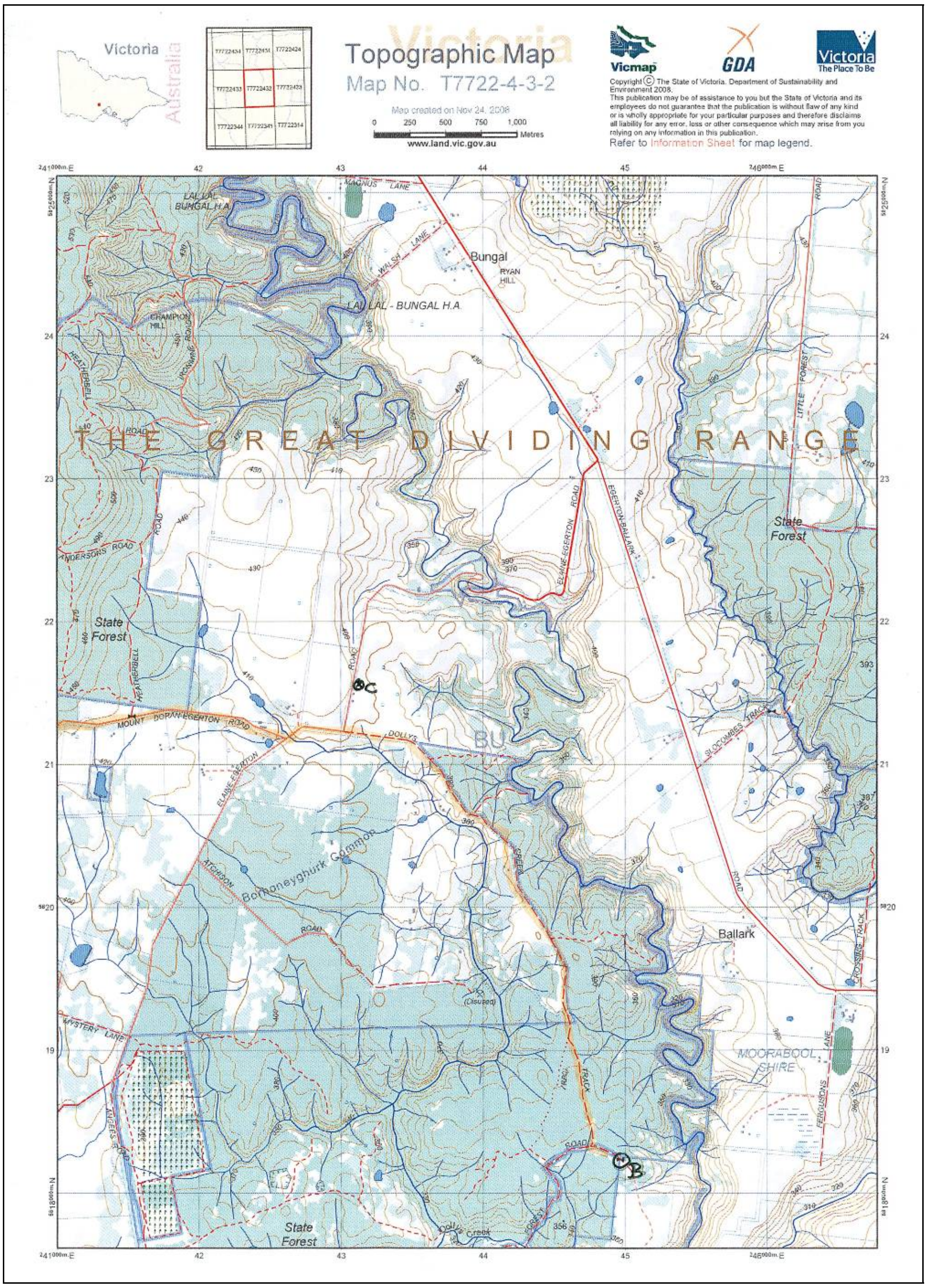


Plate 3: Location of Residences A and B (*source: Google*)

Plate 4: Residences B and C are potentially affected by the proposed Moorabool Wind Farm



Note: Residence C is at 9 Elaine Egerton Road and residence B is at 430 Forest Road.

3.2 The overall environment as seen from the most affected residence (Residence A) is illustrated in **Photos 1 to 3**. Both Residence A and Residence B are potentially affected by the wind farm to the east of the residences. Each residence is screened from the wind farm by a belt of trees (not illustrated in the photos but visible on Plate 3).

3.3 The wind farm will be situated on the plateau in the centre of photo. The proposed towers are approximately 150 metres high to the top of the blade. Approximately 22 to 30 turbines will be visible from Residence A and possibly Residence B, through the existing trees that screen both residences. Although trees do screen the residences observations at other residences and other wind farms show that the sound of turbines can be clearly heard through the sound of wind in vegetation. Wind noise in trees or over vegetation does not mask wind farm noise to any great extent as the character of the sounds are different.

Photo 1: View from near Residence A looking to proposed wind farm to the north

Photo 2: View from near Residence A looking to the centre / southern section of the proposed wind farm

Photo 3: View from near Residence A looking to proposed wind farm and the west branch of the Moorabool River and platypus habitat

Affected residences and critical turbines

3.4 The following turbines are within 2000 metres of Residence A: BAT01, BAT02 and BAT03. Turbine T04 is approximately 2200 metres from the residence. Turbines BAT07, BAT08, BAT09, BAT10, BAT24, BAT25 and BAT26 are within 3500 metres of residence A. The distances have been scaled from Plate 1.

3.5 The following turbines are approximately 2200 metres from Residence B: BAT01, BAT02, BAT03 and BAT04. Turbines BAT07, BAT08, BAT09, BAT10, BAT24 and BAT25 are within 3500 metres of the residence. The distances have been scaled from Plate 1.

3.6 The above distances of 2000 metres indicates the buffer zone in which their should be no turbines. At 2200 metres, based on experience at other wind farms for similar distances, regular complaints would be expected. At 3500 metres each residence is affected by more than 3 turbines and some complaints can be expected. Potential complaints could be moderated by noise mitigation to residences.

3.7 The reasons for potential complaints and guidance to mitigate noise are explained in the Annexes to this evidence.

Background sound levels

3.8 The compliance regime for wind farms in Victoria is based on New Zealand Standard 6808:1998 *Acoustics – The assessment and measurement of sound from wind turbine generators* (or its 2010 replacement "*Acoustics – wind farm noise"*). The standards both require the measurement of background sound levels at potentially affected locations.

3.9 In order to assist in the assessment of potential effects at the residences an ambient sound level survey was conducted by Noise Measurement Services Pty Ltd at 430 Forest Road to assess the background sound levels in the environment. The sound level meter, a Rion NL21 type 2, meter was installed 10 metres from the house on the side facing towards the proposed wind farm. The microphone was 1.35m above ground and the ground was approximately at first floor level (for bedroom equivalence). The sound level recordings are affected by the large stands of trees with wind in branches and leafs elevating background levels. As stated previously, the elevated levels of sound can be readily heard as 'wind farm' or 'wind in trees'.

3.10 Ambient sound pressure levels were measured generally in accordance with Australian Standard AS1055.1:1997 - 'Acoustics-Description and measurement of environmental noise - Part 1: General procedures'. Ambient noise levels were recorded at 10 minute intervals over a 10 day period, **Figure 1**. Weather data (wind speed and direction, temperature and humidity) was recorded at a Ballarat location for the same time period. The weather data indicated some rain events in the first day. The logger was some distance from trees and other sources of noise.

3.11 The sound levels are higher than expected and this could lead to incorrect baseline levels being used for wind farm compliance monitoring. In my view, based on these readings and those from other locales in the wider district, background sound levels need to be recorded over an extended period of time, nominally of 12 months.

3.12 Figure 1 shows the wide range in sound levels at the residence at 430 Forest Road. The high background sound levels at night are typical of the operation of air conditioning or refrigeration system that, it is understood, operated during the survey. It is possible for the rumble of the air conditioning plant to sometimes mask the audible sound from the wind farm. It will not, however, do this all the time, nor will it modify the potential effects of low frequency and infrasound on people in the residences (A and B).

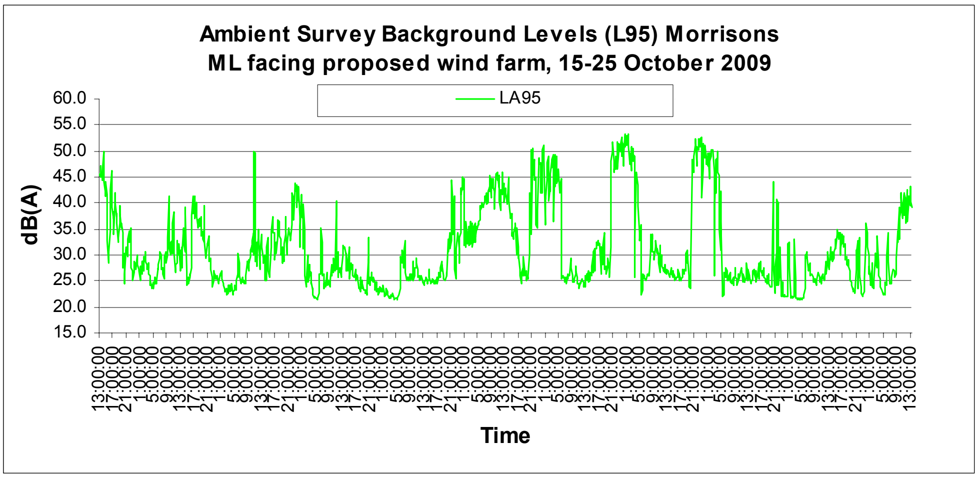


Figure 1: Exterior background sound levels at Location ML1 over 10 days

3.13 The quietest time of day background levels are in the order of 26-27 dB(A), evening background levels are 25-27 dB(A) and night-time background levels are 23-25 dB(A). With turbines generating 34-35 dB(A) Leq the sounds of the turbines will be clearly audible over the background levels.

3.14 Observations over an extended period of months at wind farms in New Zealand and Victoria has shown that the operation of the turbines may be clearly heard at the residences under a wide range of meteorological conditions. These conditions range from calm wind conditions at a residence to wind over 5 metres / second and extensive “tree-leaf rattle”. The sound can be described as a steady rumble with a mixture of rumble – thumps. Wind in the trees or vegetation did not mask this sound.

3.15 It is concluded that wind turbine sound at the residences (A and B) will be audible on occasion and can be analysed and assessed in a meaningful way. The sound character of a wind farm is clearly different from the locale and is defined as being an industrial activity in a rural environment.

4.14 From data recorded at Ballan the expected prevailing winds are from the north-west swinging to the south-east. **Figure 2** presents the mid-morning and mid-afternoon wind roses for Ballan. For the purposes of discussion I am assuming a similar pattern for night-time. Some residences or noise sensitive places will be more subject to the prevailing breeze than others at different times. This is complex wind pattern and there are a relatively large number of potentially affected residences around the proposed wind farm

4.15 Under these circumstances sound travels very clearly. It is standard practice in modelling a risk assessment of a wind farm or other industrial activity to make allowance for analysis uncertainty when undertaking predictions. This is explained further in **Annexes 1 to 3** to this evidence.

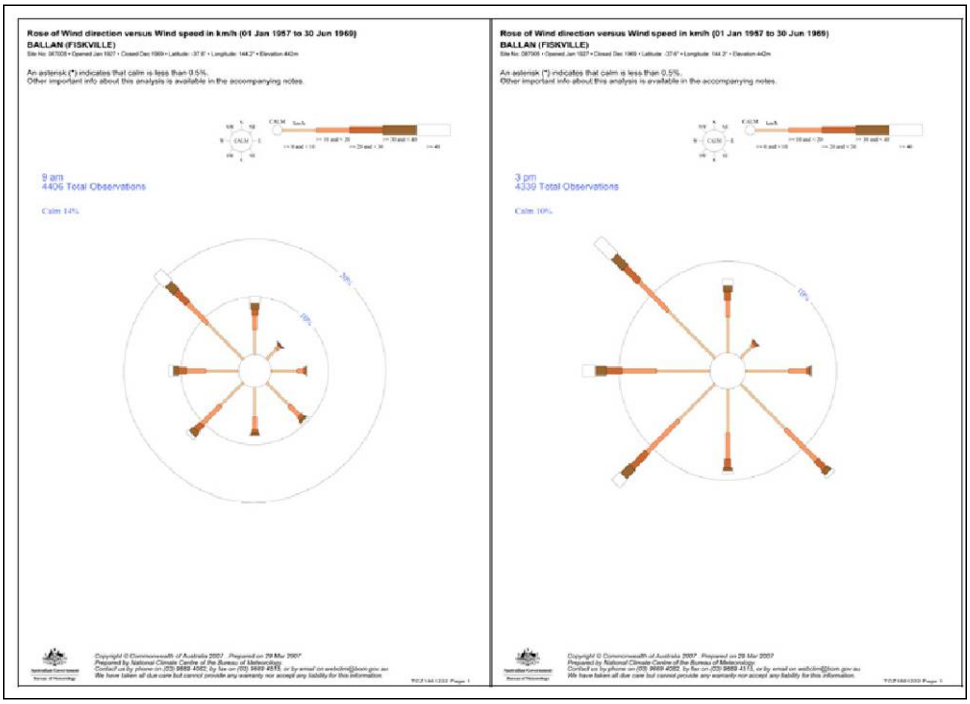


Figure 2: wind rose, Ballan (Fiskville), mid-morning and mid-afternoon

4.0 The Proposal and Potential Effect of the Wind Farm on the Willis Residences

4.1 This evidence does not consider the wider noise levels from the total wind farm. It is understood the complete wind farm consists of 110 turbines and is associated with the Yaloak wind farm of 14 turbines.

4.2 Residences A and B are potentially adversely affected by the wind farm. The distance from the nearest turbines to the east to Residence A is approximately 1800 metres. The distance from the nearest turbines to the east to Residence B is approximately 2200 metres. There are approximately 10 turbines within 3500 metres of both residences. Residence C is 5800 metres from the nearest turbines.

4.3 In order to gain an initial understanding of the potential noise levels from the wind farm Noise Measurement Services Pty Ltd prepared a noise map of the locality based on the 9 m/s turbine sound power information for an Enercon E82 wind turbine (sound power level of 104 dBA or 118 dBLin). The predicted sound levels from the operation of the wind farm are presented in **Plate 5.** The closest prediction method to the NZS 6808:1998 guideline prediction method is *ISO 9613-2 (1996) Acoustics – Attenuation of sound propagation outdoors Part 2: General*

Method of Calculation which is implemented by PEN3D. The 2010 edition of the standard applies ISO9613-2 as the prediction method. The PEN3D application of the prediction method is described in **Annex 3** of this evidence.

4.4 The 1998 version of the New Zealand standard at clause 4.4.2 states that:

> "As a guide to the limits of acceptability, the sound level from the WTG (or windfarm) should not exceed, at any residential site, and at any of the nominated windspeeds, the background sound level (L95) by more than 5 dBA, or a level of 40 dBA L95, whichever is the greater".

4.5 The latest New Zealand wind farm standard NZS 6808:2010 allows the adoption of a lower noise criterion of 35 dB(A), L90, evening and night-time. This, as explained later, is for a high amenity area which would apply to the Willis residences. The nominal "limit" under NZS 6808:2010 is, therefore, reduced from 40 dB(A) to 35 dB(A). It is appropriate to allow this reduction under the 1998 standard.

4.6 The New Zealand wind farm standards NZS 6808:1998 and 2010 apply a penalty for wind farms that exhibit special audible characteristics. As shown later in this evidence, modulation is an operational characteristic of wind turbines. Modulation is specifically defined as a special audible characteristic in both editions of the standard. Thus the nominal "limit" under NZS 6808:2010 is reduced from 35 dB(A) to **30 dB(A), L90, for evening and night-time.**

4.7 In order to assess the potential for noise at the residences I have made a basic calculation, **Plate 5**. The calculation assumptions are given in **Annex 3.** The predicted sound level at Residence A is 34.9 dB(A) Leq and 34.4 dB(A) Leq at Residence B. Residence C has a predicted sound level of 27.9 dB(A) Leq.

4.8 The red 40 dB(A) Leq contour lines clearly show that no matter what weather conditions (wind direction) apply the sound of the wind turbines will be in the order of around 37 to 40 dB(A) Leq. This is without any allowance for adverse weather conditions such as easterly, south-easterly or south-westerly breeze.

4.9 It is concluded that Residences A and B both have the potential to be adversely affected by wind farm noise. Removal of the four turbines BAT01, BAT02, BAT03 and BAT04 brings the predicted windfarm sound level at Residence A to 32.7 dB(A) Leq and 32.8 dB(A) Leq at Residence B. This represents a nominal 2 dB(A) decrease in level. Removing turbines BAT07, BAT08, BAT09 and BAT10 brings the predicted windfarm sound level at Residence A to 31.4 dB(A) Leq and 31.5 dB(A) Leq at Residence B.

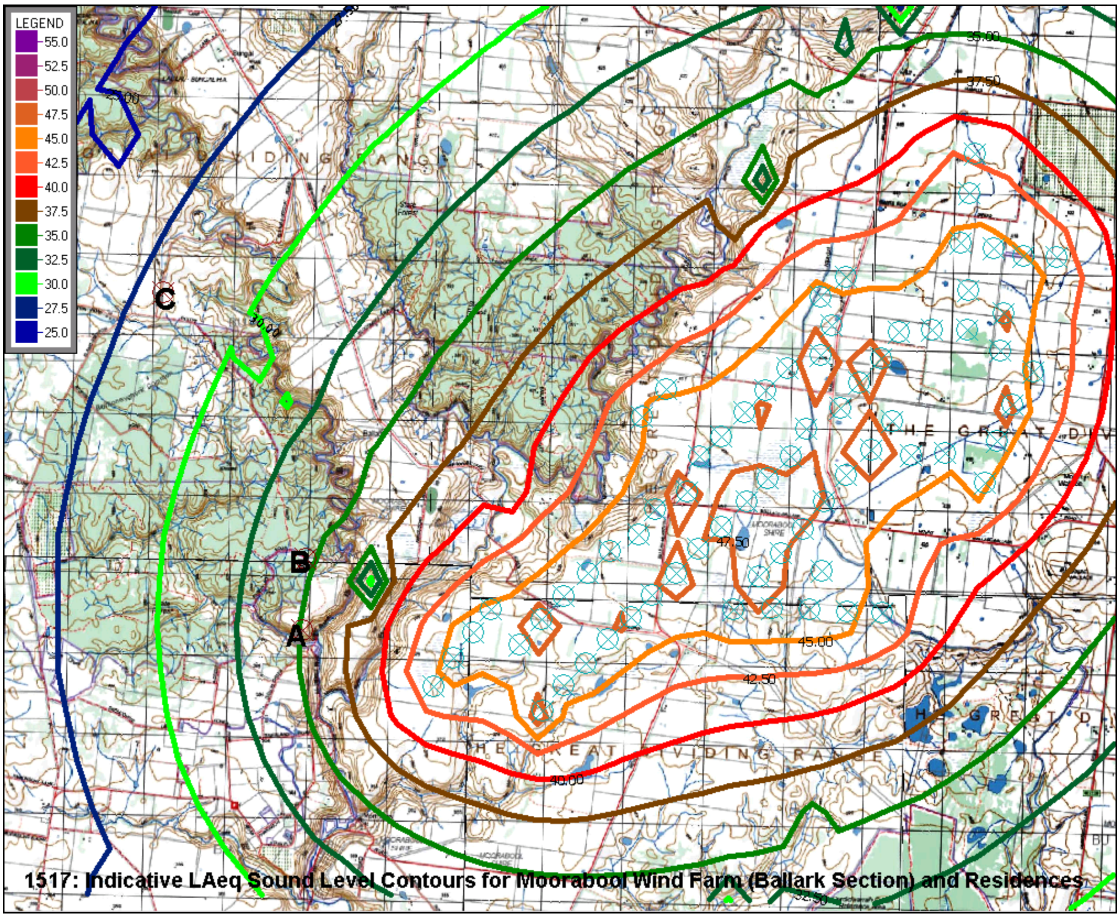


Plate 5: Predicted LAeq Sound Levels for Wind Farm and Residences

4.10 The "adjustment" between the calculated or predicted Leq levels and the background L95 levels is given in NZS6808:1998 which states that overseas studies have shown that L95 is typically 1.5 – 2.5 dB lower than Leq measured over the same time period.

4.11 The wind farm is non-complying at the Willis residences under these circumstances when special audible characteristics are present.

4.12 Wind farm activity, however, introduces changes to the wind patterns. In particular, as explained further in this evidence, there is good reason to consider the effects of low frequency sound and infrasound. The expression sub-audible character is given in this evidence to differentiate between low frequency sound (which has a solid foundation in hearing response) and infrasound, which has a less solid foundation in hearing response. Infrasound, however, has characteristics that may lead to adverse health effects. However, there is sufficient peer-reviewed research and solid acoustical foundation for analysis to be made. Of most importance, because of possible health effects, are the 5 Hz to 20 Hz bands, with 20 Hz band being a good indicator of effect. This is still the subject of debate, as outlined in this evidence (**Annex 4**).

5.0 The Proposal and Potential Effect of the Wind Farm on Residences within the Community, the Marshall Day Acoustics Report

5.1 The Moorabool proposal is for a wind farm consisting of two locales: Bungeeltap section to the north and Ballark Section to the south; Plate 1. This evidence discusses the development generally and the Ballark – Morrisons section in particular.

5.2 The noise levels predicted by Marshall Day Acoustics The Marshall Report 001 R01 2009136 'Moorabool Wind Farm Noise Impact Assessment' dated 24 November 2009 does not discuss these circumstances and the assessment is inadequate, in my view. A further report 001 R03 200912av entitled 'Moorabool and Yaloak Wind Farms' dated 21 December 2009 provides further predictions but does not present any detailed analysis or risk assessment. This assessment is also inadequate, in my view.

5.3 Predicted sound levels are presented as (it is understood) LAeq levels in the Marshall Day Acoustics Reports. The predictions are based on Enercon E82 wind turbines with a hub height of 78 metres (this report) or 85 metres (Marshall Day Report). Blade length or rotor diameter is not stated but assumed to be 82 metres (Enercon datasheet). The Marshall Day Acoustics report does not provide the detail of the certified noise emission test report for the wind turbine. It is not possible, therefore, to verify any claims made in the report with respect to sound power levels, tonality, audibility or other characteristics of wind turbine noise emission, nor can they state that special audible characteristics will not exist.

5.4 The indicative sound power levels and one-third octave band sound power spectrum for the chosen turbine, the Enercon E82 are presented in the Marshall Day Report 001 R01 2009136 'Moorabool Wind Farm Noise Impact Assessment' dated 24 November 2009. The stated prediction method is the New Zealand 1998 Standard calculation method. The calculation method is not acceptable for a complex wind farm such as Moorabool. The calculation method is suitable only for the preliminary assessment of a single wind turbine as it does not allow for the interaction between turbines nor for varying topography. The Marshall Day predictions are not 'conservative', as claimed. A conservative assessment will include all measures of uncertainty and will include all variables in analysis.

5.5 Neither Report presents any detail concerning variability in wind farm sound levels, nor does it present any indication of the uncertainty inherent in noise predictions for complex wind farms.

5.6 The Report presents predicted noise levels for a selection of assessable receivers. It is normal practice to include all residences or noise sensitive places within a 35 LAeq or 40 LAeq contour. The Report presents noise contours in Map BA-1 rev A, Ballark Section. The mapping suggests (to me) that the predictions have been made using SoundPLAN, although the prediction method is not clear.

5.7 As far as I can ascertain, the predicted level at Residence A (House AS17aa in the Marshall Day Report) is 34 LAeq, Residence B is also approximately 34 LAeq and Residence C (House AS20aa) is well below 35 LAeq.

5.8 Marshall Day have previously acknowledged the use of SoundPLAN implementing *ISO 9613-2 (1996) Acoustics – Attenuation of sound propagation outdoors Part 2: General Method of Calculation*. The second report, 001 R03 200912av entitled 'Moorabool and Yaloak Wind Farms' dated 21 December 2009 provides further predictions and references the prediction method in ISO9613-2 as well as the methodologies in CONCAWE. The Report not present any detailed analysis or risk assessment.

5.9 The assumptions for the predictions are limited under ISO9613-2:1996 and the model is not able to accommodate varying meteorological conditions. ISO9613 states that the average propagation equation of the standard holds under downwind conditions and well developed moderate ground based temperature inversion. This is not necessarily correct for wind turbine assessments, in my view. ISO 9613-2 states that prediction has an estimated accuracy for broadband noise of ±3 dB at 1000 metres. The standard does not provide any guidance as to accuracy beyond 1000 metres. Sound level predictions and assumptions must, therefore, be treated with caution. The Marshall Reports do not address accuracy of prediction or advise that predictions must be treated with caution.

5.10 Wind turbines, when developed into clusters, exhibit wake and turbulence characteristics that lead to enhanced noise levels. These characteristics are due to the cumulative effects of the turbines and their spacing within the clusters. This is explained further in **Annex 1 to 3** of this evidence. The Marshall Report does not address noise emissions under these circumstances.

5.11 The Marshall Reports do not address accuracy of prediction or advise that predictions must be treated with caution. It is concluded that the Reports are not conservative in nature; rather, they are lacking in a robust analysis of wind farm noise and the application of New Zealand Standard 6808 issue 1998 or 2010.

6.0 Background Sound Levels – Marshall Day Reports

6.1 Accurate background sound level measurements are necessary because the compliance assessment methodology under NZS 6808 requires a comparison between background levels and wind speeds at the wind farm.

6.2 The background sound levels recorded by Marshall Day Acoustics in Section 6 of their report do not drop below around 23 to 24 dB(A). This is evidenced by the 'flat-lining' in the noise data. The type of sound logger is not clear but I understand that Marshall Day Acoustics use ARL 215 or 316 sound loggers in their surveys. In my view the choice of instrument in not appropriate for recording the background sound levels under NZS 6808 as the sound level meters are not recording the true, low, background sound levels that will exist at night in rural locales. It is common for rural night-time levels to drop to 18 dB(A) or less. Under NZS 6808 and NZS 6801:1991 *Measurement of sound* type 1 instruments are preferred.

6.3 There are two basic types of sound level meter: low noise floor and high noise floor. Low noise meters are used in quiet environments, such as rural settings. High noise floor meters are typically used in noisier environments, such as traffic surveys in urban areas. Low noise floor type 1 meters such as a Larson Davis 831 or Svan 958 may typically have a noise floor around 12dB(A) to less than 17 dB. A high noise floor meter such as a type 2 Acoustics Research Laboratory (ARL) type 215 or 315 (or type 1 model 316) may typically have a noise floor of 24dB(A) to 26dB(A) or near 22 dB(A) if set to this by ARL. By comparison, Rion NL21 type 2 sound level meters are low-noise and typically have a noise floor of 9dB(A) to 10 dB(A).

6.4 In my view, a background sound level survey taken using an ARL 215 or 315/316 sound logger will not measure true 'quiet' background levels as it can not go below 24 dB(A) and at this level it is recording the inherent noise within the electronics of the system. It is standard practice to select a sound level meter that has a very low inherent noise floor. In my view the Marshall Day Acoustics Report does not present a reliable analysis of the background levels at the residences cited in their Report and a further, longer-term survey, is required to include seasonal variations. Limited monitoring presents limited data and large sampling errors occur when recalculated as day / evening / night levels. The levels presented should not be accepted, in my view, as a foundation for setting conditions.

6.5 Details of wind direction and atmospheric conditions and effect are not presented in the Marshall Day Reports although such data is a critical requirement for an assessment of effect under NZS 6808. Reference to different mast heights for wind speed data are adapted in prediction calculations.

6.6 The Marshall Day Reports do not present detailed meteorological data although this information is essential for any sound prediction assessment. Sound propagation varies significantly under different wind conditions, especially:

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

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

This later condition (b) is sometimes called the 'van den Berg effect'. It is a common condition and is explained further in **Annex 3.**

7.0 NZS6808 – The "Wind Farm Noise" Standard and Unreasonable Noise

7.1 New Zealand Standard, *NZS 6808:1998 Acoustics-The assessment and measurement of sound from wind turbine generators* is referenced as being the basis for assessment of effect of a wind farm in Victoria. The standard is referenced in the *'Policy and planning guidelines for development of wind energy facilities in Victoria 2009'* and model permit conditions. The revised 2010 standard has, I understand, been 'adopted' by VCAT[1].

7.2 NZS 6808:1998 and its replacement NZS 6808:2010 *Acoustics – Wind farm noise* both lack a methodology to separate background sound levels created by the wind turbines (whether for compliance testing purposes or for complaint assessment) from background sound levels existing at a specific time and place due to wind movement, vegetation movements, bird song and so on.

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

7.4 There is guidance in Victoria under the EPA Guidelines[2]. The EPA Guidelines provide that where rural background sound levels are very low (less than 25 dB(A)

[1] The Sister's Wind Farm Pty Ltd v Mayne Shire Council & Ors (No. P2107/2009) applying to wind farms under 30 MW.
[2] Interim Guidelines for Control of Noise from Industry in Country Victoria (N3-89).

at night or 30 dB(A) during the day or evening) the minimum limits for noise from the industry should be: day (45dB(A)), evening (37 dB(A)) and night (32 dB(A)). It is concluded that the residences will meet this guidance and can considered as a being a low-noise locale.

7.5 The night-time background levels at Residence B achieve the level considered under the VCAT decision (paragraphs 16 and 17). Para 17, in part, says: *"We further find that the area impacted by The Sisters proposal is a quiet location as evidenced by the background noise level measurements made by the applicant which were below 35 dB(A) at wind speeds up to 6 m/s".*

7.6 It is concluded from the EPA Guidelines and VCAT decision that a lower background (L90) compliance level of 35 dB(A) is appropriate at the Willis residences. The compliance level is subject to the penalty for special audible characteristics.

7.7 New Zealand standards do not operate as regulations although they do have some status under the local government planning schemes if the Standard is specifically cited. The over-arching authority for noise control is the Resource Management Act 1991 and the provisions dealing with unreasonable noise.

7.8 Neither of the standards is prescriptive. The authority to set "acceptable" sound levels, noise criteria or compliance level(s) that are to be met is the prerogative of the responsible Minister.

7.9 It is understood that there is a general duty of care on the occupier of land to avoid unreasonable noise. The occupier of land is obliged to adopt the best practicable option to ensure that the emission of noise from that land does not exceed a reasonable level. "Noise" includes vibration.

7.10 Based on my observations and experience, my proposed definition for 'unreasonable noise' is:

"Unreasonable noise" is a sound or vibration that is:

(i) annoying to a reasonable person;
(ii) injurious to personal comfort or health, including sleep disturbance;
(iii) a disturbance to the quiet enjoyment of land including the grazing of stock or keeping of animals;
(iv) observed to have a detrimental affect on wildlife or the environment.

7.11 The wind farm standard is silent on the issue of ground borne vibration affecting residences that may be regenerated within the dwelling as audible sound. My research in New Zealand suggests that ground vibration from turbines can regenerate as audible sound within a dwelling 3500 metres from a wind turbine situated over a solid foundation of volcanic rock. Although not a matter under NZS6808, ground-borne vibration is an issue that should, in my opinion, have been addressed by the Marshall Day Acoustics Report.

7.12 NZS 6808 refers to wind turbine noise standard IEC 61400-11:2002 '*Wind Turbine Generators Part 11, Acoustic noise measurement techniques'*, Wind turbine sound levels are presented in their test certificates as LAeq levels, not background (LA_{90} or LA_{95}) levels. Emission levels are to be reported as A-weighted Leq sound levels in one-third octave bands and audibility.

7.13 Audibility under the wind turbine standard is given as a tone. Annex A, an informative annex to IEC 61400-11, states that:

> *In addition to those characteristics of wind turbine noise described in the main text of this emission may also possess some, or all of the following:*
>
> - *Infrasound;*
> - *Low frequency noise;*
> - *Impulsivity;*
> - *Low-frequency modulation of broad band or tonal noise;*
> - *Other, such as a whine, hiss, screech, or hum, etc., distinct pulses in the noise, such as bangs, clatters, clicks or thumps, etc.*

7.14 The Standard does not provide any detailed methods of analysis or assessment. It does state, however:

> *It should be noted that certain aspects of infrasound, low frequency noise, impulsivity and amplitude modulation are not fully understood at present. Thus it may prove that measurement positions farther away from the wind turbine than those specified may be preferable for the determination of these characteristics.*

7.15 The Marshall Day Reports state the certification tests for the turbines but do not present any information concerning the matters raised in the previous two paragraphs. This means, in my view, that the whole of the Marshall Day assessment is uncertain and is not in conformance with the New Zealand Standard, especially the 2010 edition. Consequently the Reports cannot be relied upon as a reliable assessment of potential noise from the wind farm.

8.0 Wind farm noise and animals

8.1 I have been provided with anecdotal evidence that the sound of turbines can affect the habitats and lifestyles of animals. Birds (brolga and wedge tail eagles, for example), laying hens, bats, sheep cattle, stud horses and frogs have been identified as being at risk. Birds are especially at risk due to their breeding areas and flight paths. The habitat of platypus can be affected by low levels of vibration.

8.2 The general sound from wind turbines may cause distress to animals through the "startle effect" when for example, turbines buzz or creak and bang as they adjust into the wind. This effect is recorded at Makara, New Zealand, where sheep become distressed by the noise. The turbines are within 1000 metres of the paddocks holding the sheep.

8.3 The potential effects of noise on animals outside the scope of NZS 6808 but is an issue that should be considered as part of a risk assessment. This is a matter that has not been addressed in the Marshall Day Acoustics Report.

Platypus Habitat

8.4 It is understood that the west branch of the Moorabool River that is in the valley to the immediate east of residences A and B is a habitat to 6 families of platypus. The valley and river, it is understood, are protected by a Nature Covenant.

8.5 Platypus are sensitive to noise and vibration[3]. Vibration receptors showed maintained responses to sinusoidal vibration of the skin um to 600 Hz. With respect to mechanoreceptors in the skin of the bill they note that "A curious feature of the responses that deserves further attention in the future is that the optima frequency of 150-250 Hz appears to be rather lower than that of other mammalian vibration receptors..."

8.6 It is possible for wind towers to cause ground vibration. The level of vibration may or may not extend to the river and may or may not affect the habitat and ecosystem of the platypus. It is, however, a potential problem with a unknown risk and the precautionary principle applies to the protection of their habitat.

[3] Gregory JE, Iggo A, McIntyre AK, & U Proske 1988 *Receptors in the bill of the Platypus,* Journal of Physiology, 400, pp. 349-366

9.0 Wind farm noise and human perception

9.1 Investigations in New Zealand have proven that the sound(s) of wind turbines are audible at low amplitudes inside homes. Such sound has readily identifiable perceptual dissonance and has a direct relationship to annoyance and sleep disturbance.

9.2 My observations and measurements indicate that a wind farm is a source of noise (sound and vibration). It is a highly complex source of noise and is, in my opinion, unique due to its complexity and human perception. The receivers of the noise (that is, people) are highly complex in response. People do not respond to "single number" sound levels or noise levels for that matter. In the event, the installation of turbines at Makara (New Zealand) has resulted in widespread complaint concerning sleep disturbance due to unreasonable noise. My observations within a Makara residence show that outdoor levels of modulated sound below Leq 30 dB(A) are clearly audible within the home at night under calm weather conditions outside.

9.3 Based on my observations in the Manawatu, at Makara and in Waubra, it is my opinion that a background sound level of 40 dB(A) due to wind farm noise is too high at residences. It is, based on the evidence I have recorded at different wind farms, a level at which severe annoyance due to noise can be expected.

9.4 At the West Wind (Makara New Zealand) Hearing Dr van den Berg and I received agreement from the Experts' Caucus to present a separate statement to the agreed matters-

> *"We believe that the conditions here agreed upon will protect residents from severe annoyance and sleep disturbance, but not from annoyance and loss of amenity. We believe annoyance and loss of amenity will be protected when the wind turbine noise limit would be 30 dBA L_{95} in conditions of low wind speed at the dwellings and modulation restricted to 3 dB."*

9.5 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 characteristics" on a regular basis resulting in sleep disturbance, annoyance and stress. Prudent risk management requires consideration of such effects.

9.6 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.

9.7 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 large 2.3MW machines situated approximately 1200 metres to 2200 metres from residences.

9.8 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.

9.9 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. The character of such sound is presented in **Annexes 1 to 3** of this evidence.

9.10 A summary of audibility and the perception of low frequency sound and infrasound is presented in **Annex 4**. Such levels give a guide to acceptability for audible and perceptible sound but may cause adverse health effects if such sound has a modulating nature.

9.11 An analysis of the complaint history has been made. The character of 650 complaints has been sorted by type, **figure 3**. 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) and is, in fact, closer to 30 dB(A). Of the indoor complaints, 4.5% specifically mention sleep disturbance. Further analysis of the complaints is being made. The outcome of the analyses 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.

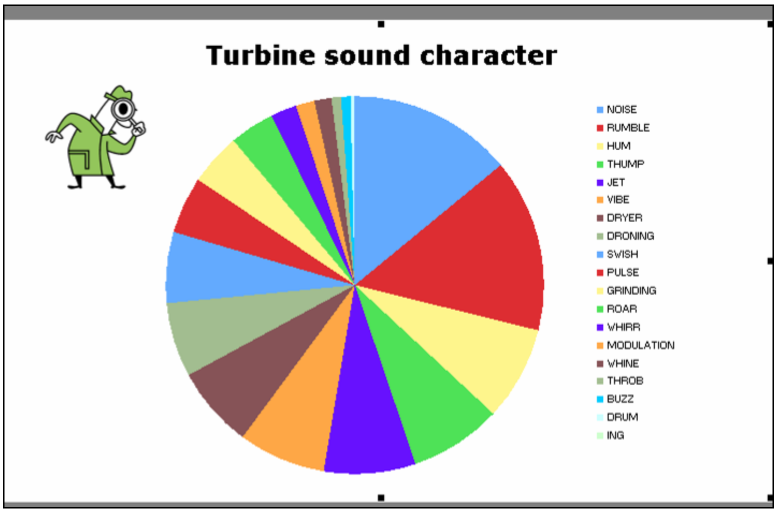


Figure 3: Character of wind farm sound

9.12 The Makara complaints are not limited to a small locale, **Figure 4.** Complaints are over 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 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 West Wind compliance report[4] indicates over the period 1 June 2009 to 31 January 2010 787 noise complaints were received from 64 houses. Of this, 57% were from 10 houses and 79% from 20 houses. The complainants are evenly spread along the 'face' of the wind farm.

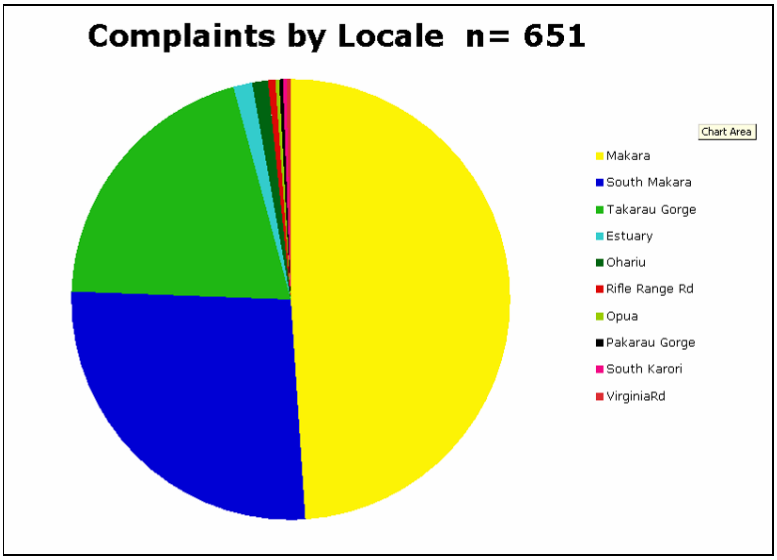


Figure 4: Complaints concerning Makara wind farm

[4] Project West Wind Wind Farm Noise Compliance Assessment version 2.0, Hayes Mckenzie Partnership, 17 March 2010

9.13 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.

9.14 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. The complainants, from aerial photos of the locale, appear to represent most, if not all, of the non-stakeholder residents within 3 to 4 kilometres of the wind farm.

9. 15 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.

9.16 As part of the submissions in other Hearings I have been made aware of complaints about noise affecting people near the wind farms at Toora, Wonthaggi, Cape Bridgewater, Waubra and Capital. Apart from Waubra I have not yet interviewed people affected.

9.17 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.

9.18 I am of the opinion, based on my own research, that wind farm noise can and does create unreasonable noise within residences and consequential adverse effects in the sense of sleep disturbance, annoyance and potential adverse health effects to residents living within 2000 metres of large wind turbines set in a wind farm. These risks are quantifiable and are of high probability. The effect is significantly more than minor.

9.19 Based on my observations within the Manawatu and Makara I am of the opinion that wind farm sound can be heard and recorded within residences situated within 3500 metres of large turbines set in a wind farm. The risk of adverse effect due to sleep disturbance and annoyance is quantifiable and is of high probability. The effect is significantly more than minor.

10.0 Flicker and Human Perception

10.1 Based on my discussions with people living near operational wind farms I conclude that visual amenity also affects the perception of sound from sources of noise. This is outside the scope of NZS 6808 but is an issue that should be considered as part of a risk assessment. Perception of noise is enhanced when the turbines have visual dominance. By day, blade glint and flicker increase perception. At night, the red warning lights cause blade glint and strobing effects. Light bounce from low cloud creates visual dominance.

10.2 A paper written by Mr Bruce Rapley presenting human perception and the health issues that identify the potential cumulative effects on human perception when audible and visual cues are combined is provided in **Annex 6.**

11.0 Practical Noise Management

11.1 As previously stated the most significant issue for the practical management of wind farm noise is that NZS 6808:1998 lacks a methodology to separate single-value background LA90 or LAeq sound levels created by the wind turbines from background LA90 or LAeq sound levels existing at a specific time and place due to wind movement, vegetation movements, bird song and so on. The “different” background levels cannot be separated using the standard’s approach unless the turbines are switched off.

11.2 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. My observations are made on the basis of 5 years’ monitoring wind turbines at different locales under widely different weather conditions. **Figure 5** illustrates the issue: there are 3 separate sets of background influencing sound sources – local ambient, the turbines, and distant sources. It is not possible to separate out the contribution of each source once it is recorded as a single-value (e.g. LA90) at a specific location, such as a residence.

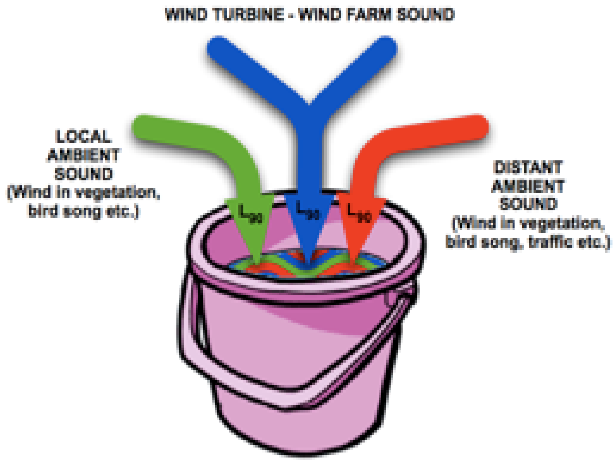


Figure 5: "Bucket of mixed background sound" as L_{90} level.

11.3 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.

11.4 Obviously loud levels of sound from a wind farm in excess of 40 dB(A) L90 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).

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

11.6 It is on this fundamental issue that any standard or condition requiring a wind farm to comply with a specific background level will fail where the standard of proof is for the matter to be proved on the balance of probabilities. If there is any reasonable doubt then the balance of probabilities is negative. The only possible way is to turn the turbines off, measure the ambient background, 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.

11.7 The ability to comply with a condition is a matter that should have been addressed in the Marshall Day report, in my view, as it is a technical matter that should be considered in setting permit conditions.

Setback or Buffer Distances

11.8 There is an alternative procedure, however, and that is the setting of compliance under setback or buffer distances. This approach is not unusual and has been used, I understand, in Spain[5]. The alternatives to a 2000 metre 'no turbine' setback was compensation to the affected parties in the order of 1.8 million euros. The setback distance was to protect a bed-and-breakfast business but some 200 people were potentially affected by the wind farm.

11.9 The calculation for a setback of 2000 metres with no turbines (unless the landowner agrees, of course) is solidly based in complaint histories and noise mitigation as presented in this evidence. A noise mitigation zone of 3500 metres is also solidly based in complaint histories. Depending on the type of turbines and weather conditions a sound level of approximately 30-35 dB(A) can be expected at 2000 metres.

11.10 A distance of 2000 metres is, based on my experience and calculations, the minimum buffer between the nearest wind turbines and residences or noise sensitive places. This buffer distance does not reduce perceived noise to zero; rather, it provides a buffer between distances of known severe annoyance to moderate annoyance.

11.11 A distance of 3500 metres is, based on my experience and calculations, the buffer zone in which wind turbine noise mitigation may be required to residences or noise sensitive places. This mitigation zone does not reduce perceived noise to zero; rather, it provides a working zone between distances of known moderate annoyance to infrequent annoyance.

11.12 Wind farm analysis presents three distinct sound and noise measurement concerns, each of which is highly significant in its own right:

- 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;

[5] Id Cendoj: 28079130032009100260, Body: Supreme Court. Litigation Division, Headquarters: Madrid, Section: 3, Appeal No.: 6431/2006, In the town of Madrid, two of July two thousand and nine

- The sound of any special 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.

11.13 Methodologies and instrumentation are readily available to test for and measure modulation, tonality and impulsiveness of sound from wind turbines. The methods require audio recording in uncompressed form of the sound.

11.14 Noise perception depends on the same process of streaming and assignment, which argues for music and noise perception sharing similar auditory properties but defined by stream fusion for music and stream segregation for noise. Under stream segregation the character of a noise is retained independently of the overall sound. A fundamental ability of an individual is that person's ability to hear, identify, locate and track different sounds in an environment at the same time and over time. This form of analysis is critical to our sense of hearing and informational responses. It is also critical to the perception of rapidly changing sound character from a wind farm.

Risk management

11.15 In summary, therefore, best practice for management and mitigation of noise from wind farms considers normal risk assessment:

- Identify the hazards
- Assess the risks that may result because of the hazards
- Decide on the control measures to prevent or minimise risks
- Implement control measures
- Monitor and review the effectiveness of the measures

11.16 Neither the 1998 nor the 2010 New Zealand wind farm standard adopt risk management for the assessment and mitigation of wind farm noise and they must, therefore, be treated with caution. The "acceptable numbers" approach taken by the standards is unproven and, based on New Zealand noise complaints for Te Rere Hau and Makara, significantly fails to avoid or mitigate unreasonable noise.

11.17 In summary, the setback or buffer zones are not areas that will be 'noise-free' or completely free of potential adverse health effects. The buffers are distances where levels indicative of severe annoyance or potential adverse health effects will gradually mitigate to moderate or infrequent annoyance and potential adverse health effects.

12.0 Unreasonable or disturbing noise

12.1 Unreasonable or disturbing noise will occur when the sound from a wind farm disturbs sleep and thereby causes anxiety, annoyance and stress. That unreasonable or disturbing noise can occur is well documented in peer-reviewed and impartial research. My research over 5 years and in New Zealand and Australia indicates the existence of noise induced sleep disturbance and adverse health effects due to wind farm noise. A summary is presented in **Annex 4.** Audibility, low frequency and infrasound effects are presented in **Annex 5.** Reference to an evidential text, *Sound, Noise Flicker and the Human Perception of Wind Farm Activity*, is given in **Annex 7.**

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

12.3 Despite the differences in opinion as to cause there is remarkable agreement between the parties – residents, clinicians and acousticians – as to observable health effects from unreasonable or disturbing noise.

12.4 Based on my investigations and in my opinion, there are clear and definable markers for adverse health effects due to unreasonable or disturbing noise after a wind farm starts operation. It is the mechanism of the physical or mental process from one to the other that is not yet defined or agreed.

13.0 Permit conditions

13.1 The noise management conditions presented in the model wind farm permit conditions have been reviewed. The Conditions mandate NZS6808. It is recommended that future conditions do not mandate the 1998 standard because:

- The standard (in both 1998 and 2010 editions) fails certainty by not stating how sound levels attributable to the wind farm can be separated from sound levels generated in the general environment; and
- Both the 1998 and 2010 standards recommend a sound level criterion of 40 dB(A) that have been conclusively shown to cause severe annoyance.

- A permit condition of 35 dB(A) is more appropriate and is permitted for quiet environments.
- The inclusion of the 5 dB penalty for special audible characteristics provides a noise limit of 30 dB(A) at any residence.

13.2 Taking a background level of 40 dB(A) as the upper limit and a background level of 30 dBA (L95) or less as the lower guideline level, it is appropriate to define "NZS6808" background sound levels in 3 bands to identify different levels of wind farm 'noise' effect immediately outside a residence:

- Potential severe risk of sleep disturbance or annoyance 40dB(A) L95
- Potential moderate risk of sleep disturbance or annoyance 35dB(A) L95
- Potential low risk of sleep disturbance or annoyance 30dB(A) L95

13.3 The 2010 revision of 6808 acknowledges the importance of low background areas or locales may require a higher degree of protection. A lower level of **35 dB(A) L90** is appropriate and relevant for this wind farm and locale.

13.4 My conclusion is that a wind farm is a highly complex source of noise (sound and vibration). The receivers of the noise (that is, people) are highly complex in response. People do not respond to "single number" sound levels or noise levels for that matter.

13.5 The use of L90 as a compliance level is not supported by research evidence and is not a practical measure. The centile level cannot be predicted but must be assessed from **long-term** (12 month) on-site monitoring. The centile level is not amenable to assessment of special audible characteristics. Finally, the centile level does not give surety of assessment for either the wind farm operator or residents.

13.6 A noise compliance level of 35 dB(A) measured as the LAeq,10min level, adjusted for tonality, or the background (L90) level plus 5 dB(A), whichever is the greater, is applied in South Australia and New South Wales.

13.7 From my observations of operational wind farms there is high probability that the wind farm will exhibit adverse "special audible characteristics" under certain weather conditions and prudent risk management requires an adjustment of +5 dB to be added to the nominal compliance level of 35 dB(A) bringing it to 30 dB(A).

13.8 Based on my own experience with industrial noise in low background sound environments and my observations at operational wind farms I submit different noise limits for different levels of amenity for wind turbine sound heard immediately outside a residence or noise sensitive place, referenced to the equivalent continuous sound level, LAeq:

- Potential severe risk of sleep disturbance or annoyance 40dB(A) Leq
- Potential moderate risk of sleep disturbance or annoyance 35dB(A) Leq
- Potential low risk of sleep disturbance or annoyance 30dB(A) Leq

13.9 The benefit of the equivalent continuous sound level, LAeq, is that it is directly related to sound power level data and noise predictions calculations. The metric does not need to be adjusted in any way. The equivalent continuous sound level is a standard metric and its various forms, such as the day-night level, allow for international human response and exposure assessment.

Annex 1: Audible Sound and Noise

1. 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, Figure 1:

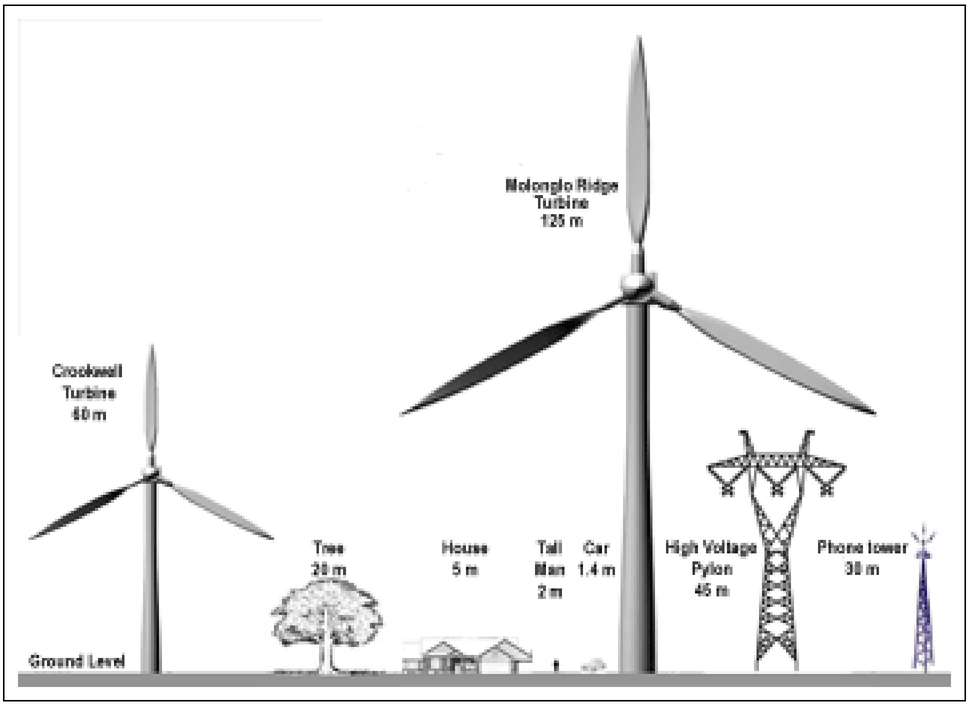


Figure 1: Relative heights of turbines to dwellings
(Source: Molonglo Landscape Guardians, by permission)

2. 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

3. 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.

4. Technically, wind turbines in Australia and New Zealand can be classed as “upwind turbines” where the blades are upwind of the tower. As explained by Hubbard and Shepherd, the noise is created by the blade’s interaction with the aerodynamic wake of the tower[6]:

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

5. Upwind turbines show a lesser amplitude modulated time history and do not have the sharp pressure peak that characterises the downwind turbine. Hubbard and Shepherd (figure 2 taken from their figure 7-7) illustrate the nature of noise radiation patterns for broadband noise. The pattern for low frequency noise (8 Hz is given as the example) is broadly similar but with a more ‘pinched’ waist.

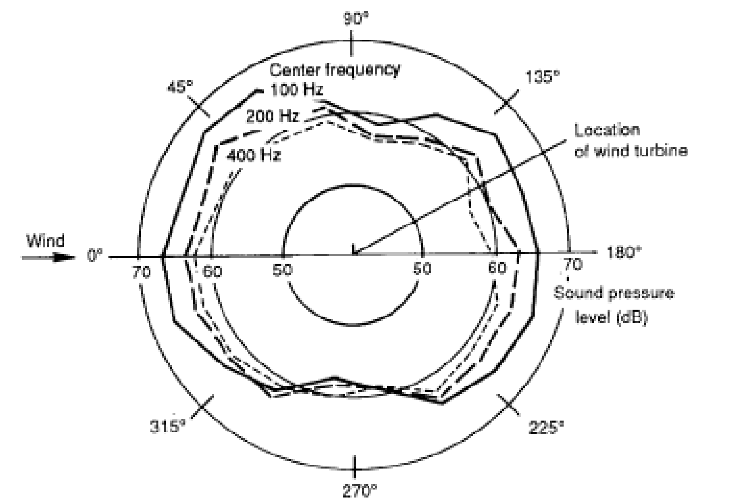


Figure 7-7. Example radiation patterns for broadband noise 200 m from a large-scale HAWT (one-third-octave bands, wind speed = 12.1 m/s, power = 2050 kW) [Shepherd, Willshire, and Hubbard 1988]

Figure 2: wind turbine sound pattern

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

6. Hubbard and Shepherd state, with respect to distance effects:

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

7. Shepherd and Hubbard [7] 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, figures 3 and 4:

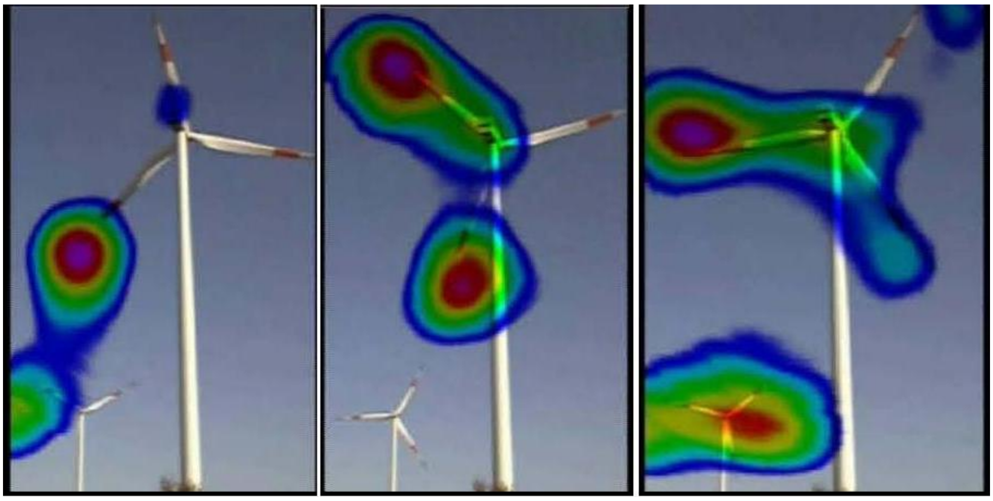


Figure 3: Acoustic photograph of sound sources from two turbines.
Source: Acoustic Camera, 'Multiple sources wind turbines 300Hz – 7kHz.avi" by permission from HW Technologies, Sydney)

8. The pattern in Figure 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.

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

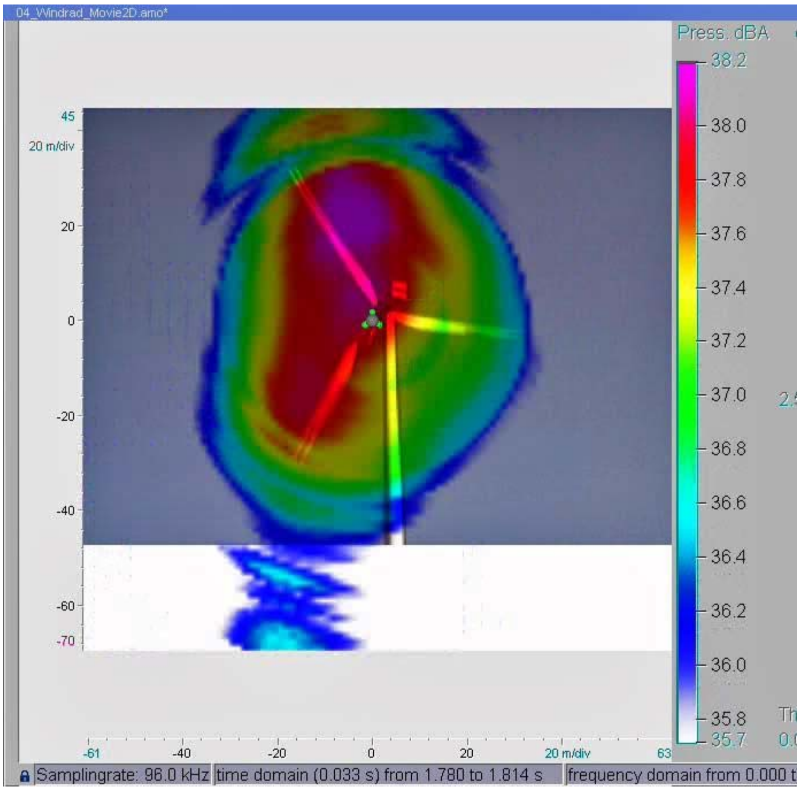


Figure 4: Acoustic photograph of sound sources from a turbine.
Source: Acoustic Camera, by permission from HW Technologies, Sydney)

9. 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.[8]

10. The vortices 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 effect is illustrated in Figure 5, showing wake disturbance from turbines at sea (equivalent effect to on-shore turbines on flat to low undulating land). The effect of smooth air hitting the turbines and being disturbed due to wake and turbulence is clearly visible. The turbulent air illustrates 'pulsing' of the previously smooth air.

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

Figure 5: Downstream wake and turbulence effects

(Source:http://www.treehugger.com/files/2010/01/offshore-wind-farm-photo-wake-effect.php)

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

12. A further effect is observed by van den Berg is when two or more turbines are or nearly synchronous, when the blade passing pulses coincide then go out of phase again. With exact synchronicity there is a fixed interference pattern, with near synchronicity synchronous arrival of pulses will change over time and place. Dr Van den Berg notes that of the relatively high annoyance level and characterisation of wind turbine sound such as swishing or beating may be explained by the increased fluctuation of the sound. Figure 4 illustrates the sound character of a wind turbine. In a stable atmosphere van den Berg measured fluctuation levels of 4 to 6 dB for a single turbine. Individuals are highly sensitive to these forms of sound fluctuations.

13. Individuals are also highly sensitive to changes in frequency modulation variations of approximately 4 Hz. Such variations can be expected in wind farm

designs such as this development. Mitigation of known adverse noise effect is a function of good wind farm design.

14. Wind is important to wind turbines and a locality is chosen that provides plenty of it. Wind is, in terms of wind farms, a highly commercial product. Stable atmospheric conditions that give rise to noise propagation at ground level are prevalent over the year, however. The presence of stable conditions is critical for noise analysis, as noted by van den Berg [9]. He notes that:

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

15 Observations of the turbines at a New Zealand wind farm indicate that under operational conditions there are approximately 55 blade tower / blade pass-bys per minute for a single turbine. The pulse pattern in **Figure 6** is higher than this and corresponds to the capture a more than one turbine – as is expected of a working wind farm. The pulses are irregular as is expected due to a distance of 1200 – 1800 metres between the wind farm and the residence.

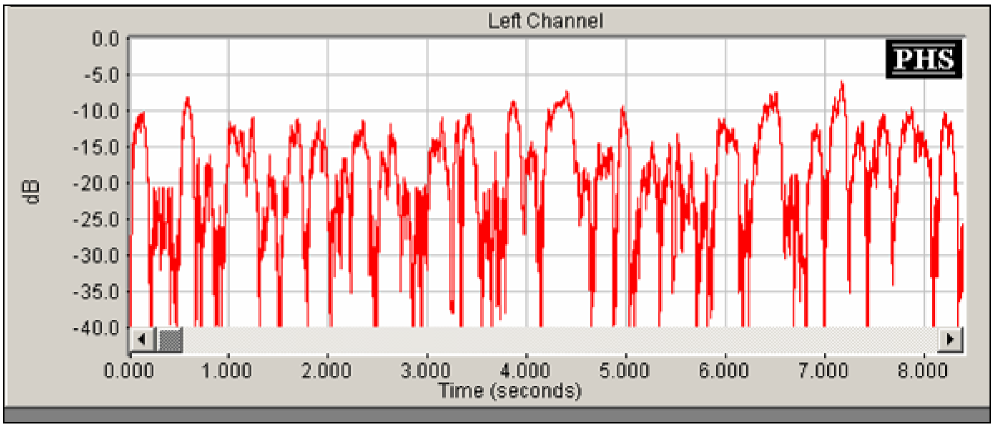


Figure 6: Pulse pattern from a New Zealand wind farm

16. Wind turbines in a stable atmosphere generate more sound than in a neutral atmosphere, while at the same time the wind velocity near the ground is so low that the natural ambient sound due to rustling vegetation is weaker. As a result the contrast between wind turbine sound and natural ambient sound is more pronounced in stable than neutral conditions. This situation enhances the ability to

[9] van den Berg, G. P., (2006). The Sounds of High Winds: the effect of atmospheric stability on wind turbine sound and microphone noise. Science Shop, Netherlands

hear the trailing edge sound from the turbine blades. The differences in wind speed lead to variations in the sound radiated by blade tips that reach their highest values when the tip passes the mast. Van den Berg calculates the variation as approximately 5 dB at night and 2 dB in daytime.

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

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

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

and:

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

19. The character of the "ground-level" atmosphere in the vicinity of the residences within approximately 5000 metres of the wind farm therefore becomes critical in understanding the potential for noise from the wind farm. Under downwind conditions the sound generated by the turbines is affected by downwind refraction [10]. As an aid for wind farm design downwind conditions can be modelled in detail using exSOUND2000+, a noise prediction model that has been developed from the wind turbine noise prediction model WiTuProp [11]. The program is useful for a small number of turbines compared to the contouring ability of the programs previously described.

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

- Wind farms have significant potential for annoyance due to sound modulation effects even though these effects are of a low amplitude

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

[11] exSOUND2000+ is available from DELTA (www.delta.dk). The program WiTuProp is no longer available.

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

21. It is concluded from my observations, interviews and measurements that:

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

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

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

23. Wind farm sound has a character that is similar to the pre-wind farm character. The 'new' character exhibits distinctive regular patterning as shown in the next section that infers the sound is not smooth or laminar, as in unaffected wind sound. This character can be defined further for different wind farm locales and for different types of wind turbines operating under different conditions. The presence of modulation and tonality can also be shown.

Low Frequency Sound and Infrasound

24. The issue of low frequency sound and infrasound has been a controversial topic for many years. Figures 7 and 8 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.

25. Wind farms and wind in general generate both low frequency sound and infrasound, Figures 9 to 13, 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 9 presents the sound of a wind turbine at the wind turbine platform. Figure 10 presents the sound character of a large wind farm clearly audible through screening trees at a distance of 2200 metres. Figure 11 presents the character of the soundscape at without audible sound from the wind farm. The sonograms illustrate the low "loudness" and the distinctive character or dissonance of the sound.

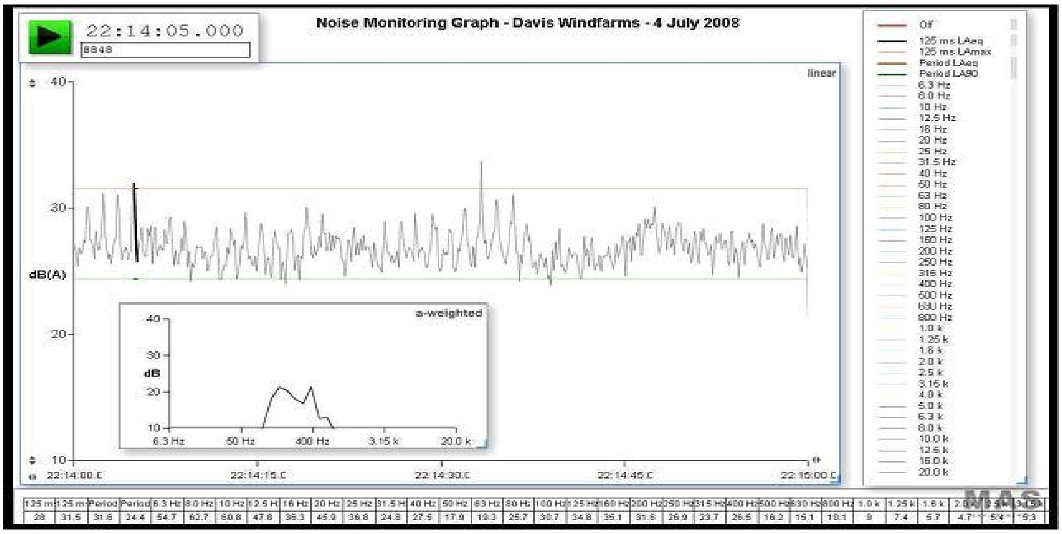


Figure 7: sound of wind turbines at 930 metres, inside residence

26. Figure 8 illustrates sound character inside the bedroom. 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.

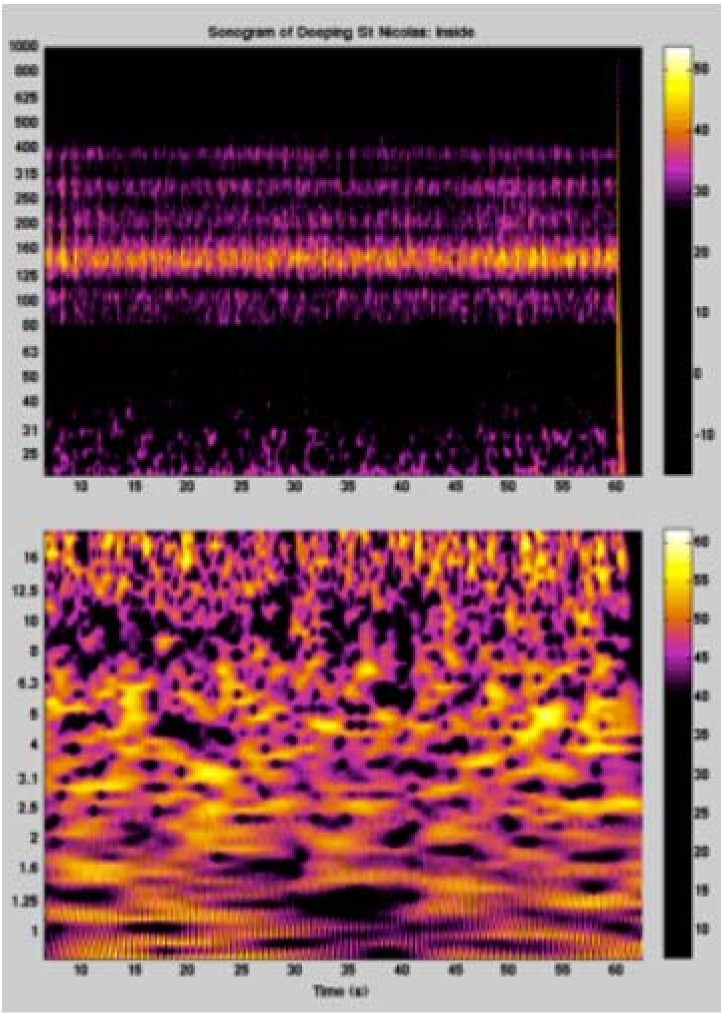


Figure 8: sound of wind turbines at 930 metres, inside residence

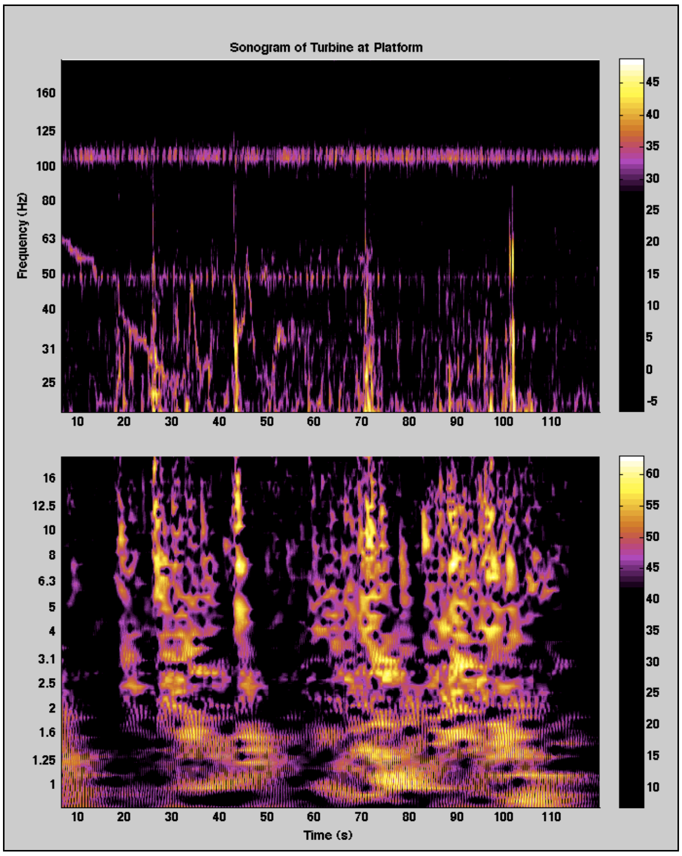


Figure 9: sound of a wind turbine at the Te Apiti turbine platform

27. Figure 9 shows a distinctive tonal complex at around 48 Hz. The sound character from the wind farm with this type of turbine is shown at 2200 metres (figure 10). The non-audible sonogram (figure 11) does not show this characteristic.

28. The sound levels at the wind turbine (Figure 9) were LAeq 52 dB(A) and a background level (LA90) of 32 dB(A).

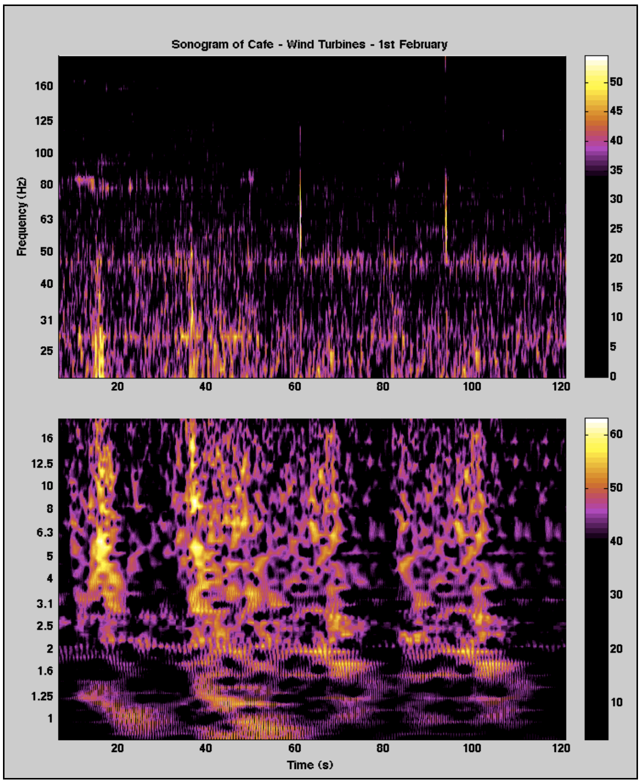


Figure 10: Audible sound of wind farm at 2200 metres over grassland and trees

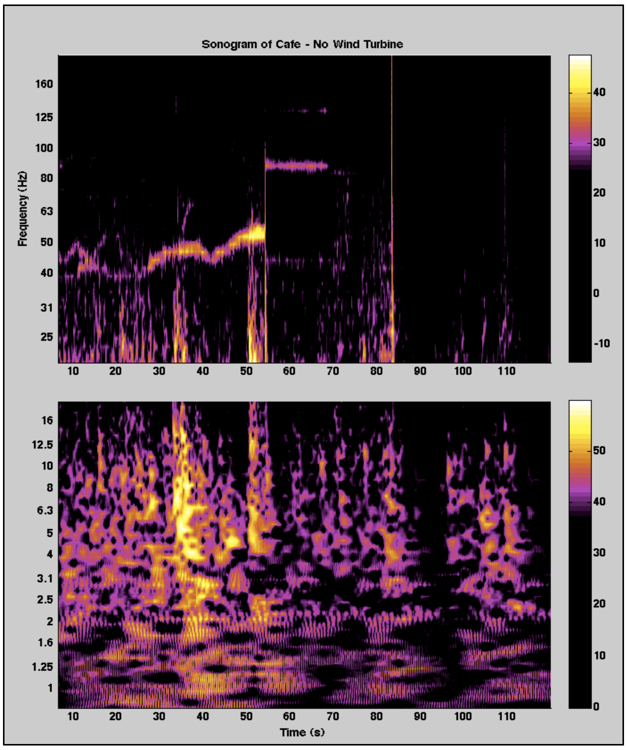


Figure 11: Same location as figure 6 but wind farm not audible

29. The Café sound levels (figure 10) are LAeq 40 dB(A) and a background level (LA90) of 32 dB(A). Without the turbine sounds (figure 11) the levels had increased to LAeq 49 dB(A) and a background level (LA90) of 33 dB(A) due to bird song and a light breeze in the trees that was blowing towards the wind farm.

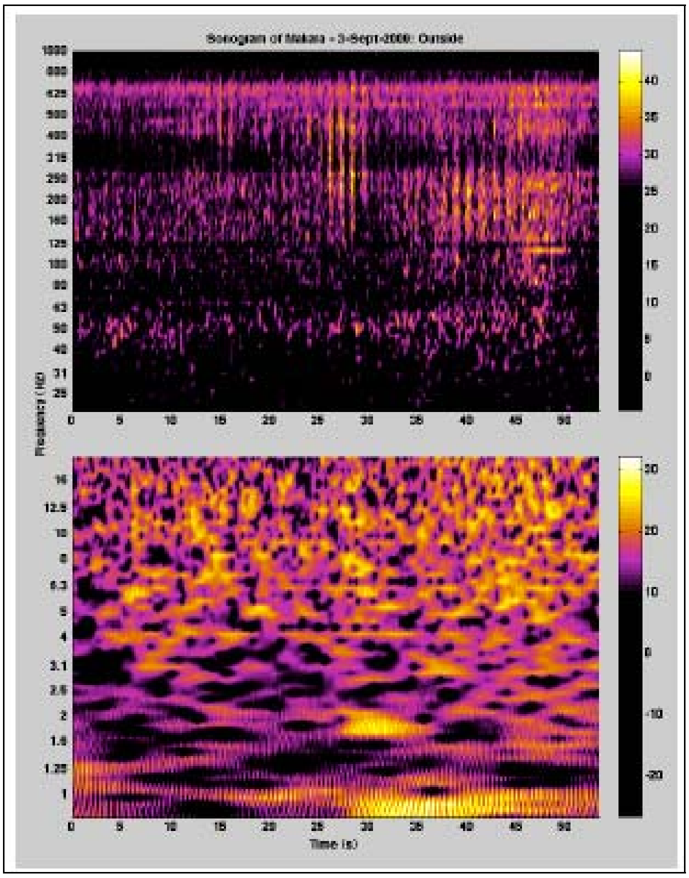


Figure 12: sound of wind turbines at 1200 - 1300 metres, outside residence

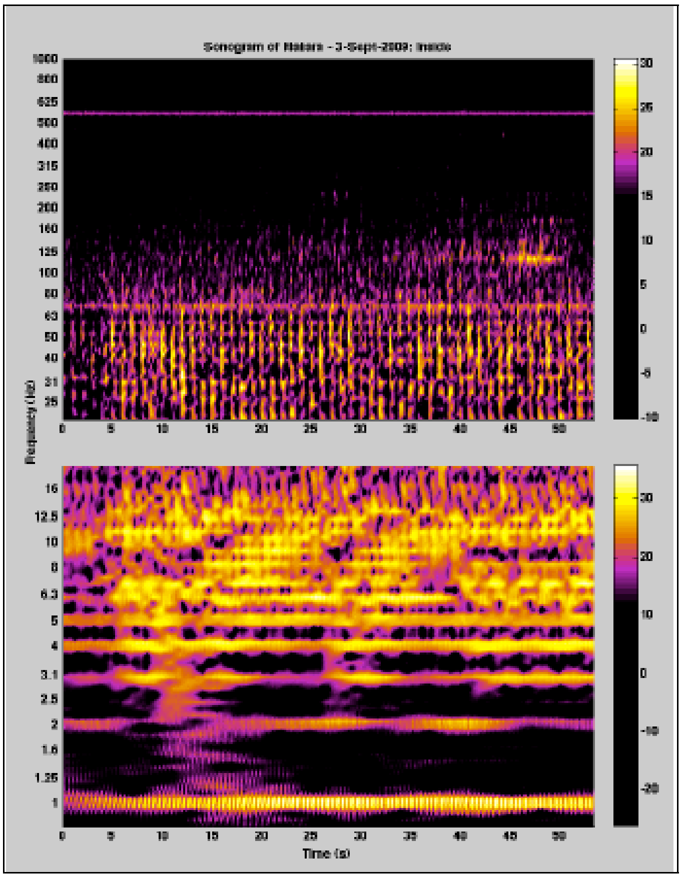


Figure 13: sound of wind turbines at 1200 -1300 metres, inside residence

30. Thus ambient conditions play a significant part in recording sound levels. The exterior ambient levels for an earlier survey residential survey at Makara was 30 dB(A) LAeq and 29 dB(A) L90. The interior level was 18 dB(A) LAeq with the rumble-thump of the turbines clearly audible. The background level had dropped to the noise floor of the class 1 instrument, at 12 dB(A).

31. In figures 12 and 13 the difference in character between outside and inside levels are clearly shown. The variation is due to building construction and room resonance.

32. The concern with wind farm noise conditions is not just the exterior ambient level but the interior ambient level. Any noise conditions written for an exterior background (LA90) level of 40 dB(A) will fail and will cause for severe annoyance complaint.

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

34. Infrasound is, as far as can be told at the moment, airborne in nature and may present propagation directivity irrespective of wind speed and direction. Propagation has only a 3 dB reduction per doubling of distance for a single turbine[12]. Previous investigations indicated that ground-borne vibration may be an issue causing building resonance but these effects are highly localised to specific ground conditions and wind direction. The resonance effects infrasound may have on specific types of building construction can be defined mathematically for specific building elements.

35. While acknowledging the difficulties wind farms developers may have in presenting this type of analysis in their Environmental Impact Statement it is, in my opinion, their responsibility to do so under their normal duty of care responsibility and the precautionary principle relating to risk analysis. They have the ability to interact with other wind farm operators in similar areas and can, therefore, create an information database that will allow prediction and assessment of effects. As a practical measure the 'precautionary principle' would dictate that a developer should be aware of the potential for adverse effects from audible/low frequency sound/infrasound on people within 3500 metres of the proposed wind farm.

[12] Ceranna L, Hartmann G and Henger M, 2005, *The inaudible noise of wind turbines*, presented at the Infrasound Workshop Tahiti, pp1-23

Conclusions

1. It is concluded that a wind farm, overall and at an observer-source distance of approximately 900 metres from the turbines, exhibits the characteristics of a line source, rather than a point source.

2. When listening to turbines in a wind farm the sources are not distinct to a fixed location. Even a single turbine has a number of clearly identifiable sources as illustrated previously.

3. Noise predictions for potential wind farm developments must include assessment and calculation of special audible and intrusive characteristics due to modulation, tonality and turbulence / wake effects. My observations and measurements of wind farms in the Manawatu, Wellington and Victoria indicate that wind farms exhibit special characteristics do exist, they can be measured, and they can be perceived by people. The characteristics cause sleep disturbance, annoyance and potential adverse health effects.

Annex 2: Characteristics of Multiple and Single Wind Turbines

1. This is a summary of part a Paper by Bakker and Rapley and illustrates characteristics of multiple and single wind turbines. The concept of Heightened Noise Zones created when multiple wind turbines are in operation is presented. The concept is presented to illustrate the complexity of sound from a wind farm. The sound character of a single turbine is presented in comparison.

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

3. A simulation is presented in Figures 1 to 3 to envisage the sound amplitudes and sound propagation - dispersion patterns from the turbines at Makara. This is a very simple simulation and must be taken as being illustrative only of potential effects). A single turbine is shown in Figure 1.

4. The peaks and troughs from the inter-action of the blades and tower are shown as clean, radiating waves. Figure 2 illustrates the highly complex propagation pattern at a residence with five turbines in a line (vee formation in Figure 3) operating approximately 1200 -1300 metres distant. The node/antinode (read quiet/loud) points vary but can be about 4 metres apart. The maximum levels reach about more than 4 times the level of one turbine. Figures 1 to 3 present a simple simulation and would be much more complex if geography etc. was included. The simulations were created to test the effects of low frequency sound using 20 Hz, 48 Hz and 66 Hz bands.

5. Figures 4 and 5 present the effect of one turbine and 5 turbines to illustrate the difference between a single source and the cumulative effect of multiple sources.

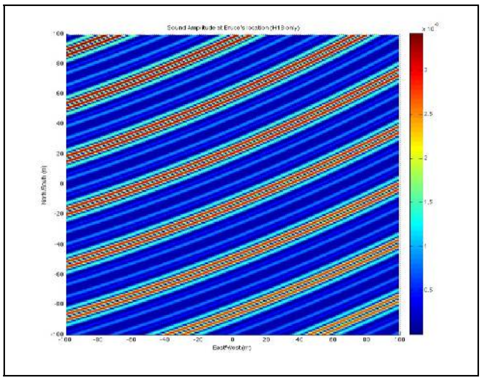


Figure 1: Propagation pattern from a single turbine

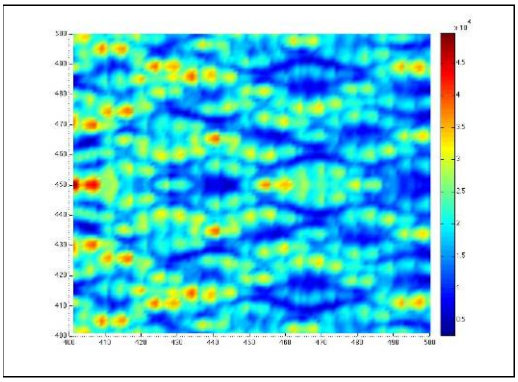


Figure 2: Propagation pattern from 5 turbines in a line formation

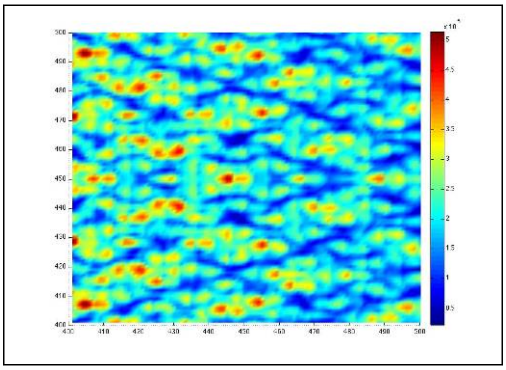


Figure 3: Propagation pattern from 5 turbines in a vee formation

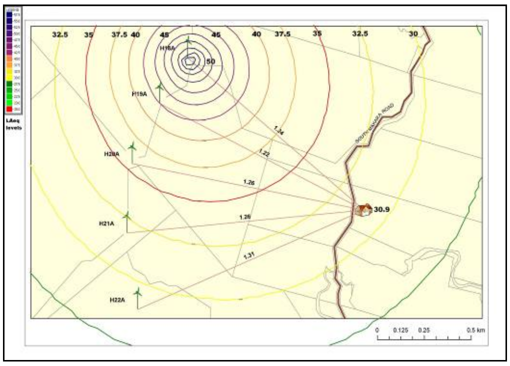


Figure 4: one turbine operating, sound level contours and predicted sound level at residence

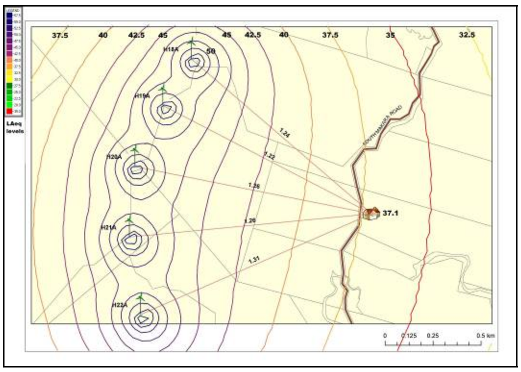


Figure 5: five turbines operating, sound level contours and predicted sound level at residence

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

7. Figure 6 illustrates the situation at Makara where at least one turbine is causing a low rumbling sound that is clearly audible during the day within the ordinary sounds in the environment including bird song. The sound is heard as a “rumble-thump” and occurs every 1.2 seconds (approximately). A lot of the sound is coming from the 10 Hz – 50 Hz end with a peak at about 35 Hz and another peak at 118 Hz and harmonics with fundamental frequencies in the 300 Hz – 400 Hz range.

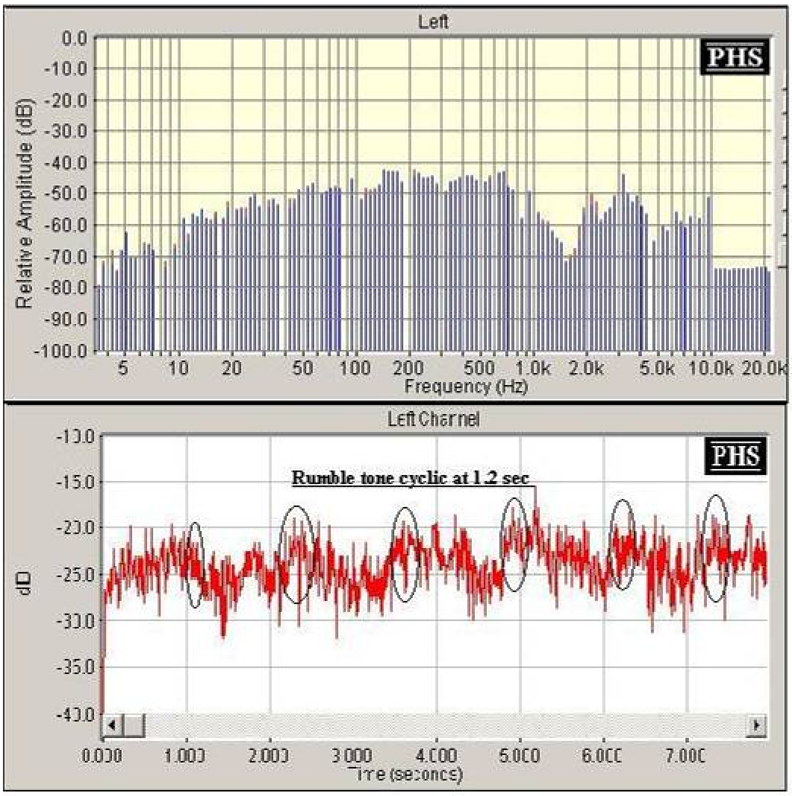


Figure 6: Turbine rumble

8. This effect is compounded at night when ambient sound levels are low or when more than one turbine are “in line” in such a way as to increase audible or inaudible noise at affected residences. Figures 7 to 11 illustrate the mechanism of sound and vibration transfer from a complex wind farm.

9. The 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 (Figures 10 and 11). The wave train travels in time and the heightened peaks and troughs create a Heightened Noise Zone at any affected residence. 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 lensing underground and over trees and wind shear are confounding factors that can be calculated with a degree of reliability.

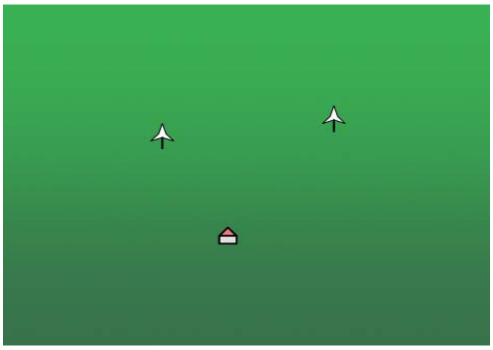


Figure 7: A residence potentially affected by 2 turbines

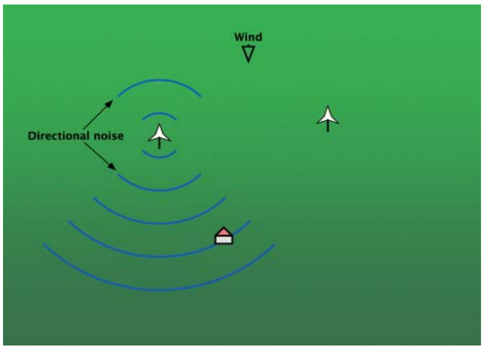


Figure 8: Noise from one turbine

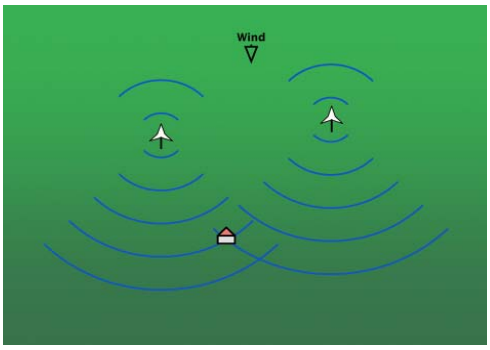


Figure 9: Noise from 2 turbines

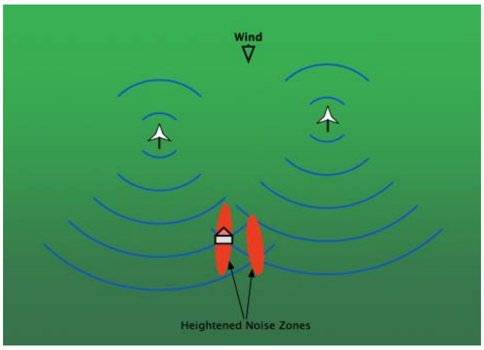


Figure 10: Noise from 2 turbines creating Heightened Noise Zones

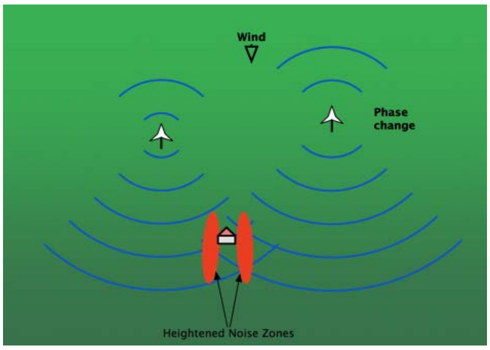


Figure 11: Noise from 2 turbines under slightly different conditions moving Heightened Noise Zones

10. 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 HNZ. 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.

11. If the circles represent the peaks of sound waves (high pressure) then where they cross will represent a point (*anti-nodal* point) where the peak sound pressures of two or more wave fronts add together creating a loud point. The spaces between the circles will represent the troughs of sound waves (low pressure). Where they cross the trough sound pressures of two or more wave fronts add together creating a loud point. Where circles meet spaces, the peak of a sound wave (high pressure) meets the trough of a sound wave (low pressure) and, when added together, cancel out. This is a quiet point or *node*.

12. For the simple, two-turbine situation shown in Figures 10 and 11, the circle-crossings are seen to occur in straight lines diverging away from the turbines. Between them are the nodal points where a circle meets a space. The former are called *anti-nodal lines* and the latter are called *nodal lines*. The Heightened Noise Zones can be seen to lie on the anti-nodal lines.

Wake and Turbulence Effects

13. Modulation is a basic characteristic of a wind turbine as the sound levels increase and decrease as the blades pass the tower and ‘pulsing’ due to wake and turbulence interference. The effect can be enhanced when a number of turbines are in synchrony or near synchrony and when wind directivity enhances propagation. Modulation affects both audible and inaudible sound and is a characteristic in wake and turbulence effects.

14. 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.[13]

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

15. Wake effects are created when highly turbulent air leaving a turbine interacts with lower-speed air. Wake effects with pockets of smooth (laminar), lower-speed air are present within 3 rotor diameters downwind of a turbine and mostly dissipated at a distance of 10 rotor diameters. Figure 12 shows the spacings at Makara, New Zealand, where the red circle is at 5 rotor diameters and the gradual non-disturbance zone at 10 rotor diameters. If a second turbine is situated within 10 rotor diameters of the first turbine the blades of the second turbine can suddenly enter into a pocket of slower air in the wake caused by the first turbine.

16. In the situation where a wind gust occurs behind each turbine there is a wake, essentially in two parts:

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

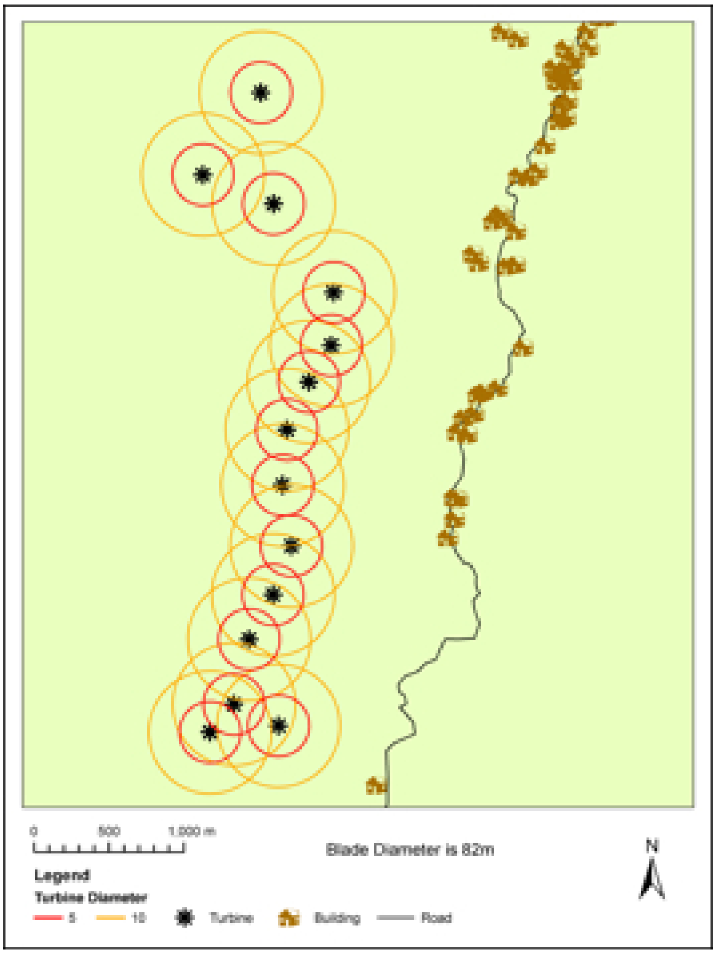


Figure 12: Wind turbines at Makara showing their spacing with regard to 5 and10 blade-diameter circles. *Source: Research graphics by S. R. Summers.*

17. The smooth inner wake eventually breaks down into turbulence that soon mixes the air with that surrounding it and is restored to the bulk wind speed. A turbine downstream at this point will see air more-or-less unaffected by the

upstream turbine. When the wind speed increases, such as due to a wind gust, the length of the smooth wake is extended. Should the smooth wake extend to the downwind turbine, it will interact with the turbine blades to cause increased sound until the wind gust dies and the smooth wakes retracts.

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

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

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

21. The Sustainable Energy Development Authority (SEDA) New South Wales Wind Energy Handbook 2002 confirms separation distances by stating (p. 53):

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

22. The SEDA guideline may be appropriate for wind-power efficiency but is not sufficient for noise mitigation. A separation distance of 10 rotor diameters is recommended (see para 14 of this section).

Annex 3: Prediction of Sound Levels – Approaches and Limitations

Introduction

1. This evidence has been prepared with PEN3D based on the approach to sound propagation described in *ISO 9613-2 (1996) Acoustics – Attenuation of sound propagation outdoors Part 2: General Method of Calculation* and *NZS 6808:1998 Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators.*

2. PEN3D can also implement Pasquill Stability Categories (also known as the CONCAWE implementation) as described in New Zealand Standard 6801:2008 *Acoustics-Measurement of Environmental Sound*. The method was previously presented in NZS6801:1999. This evidence does not use the CONCAWE.

Limits to Accuracy of Prediction

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

4. ISO9613 states that the average propagation equation of the standard holds under well developed moderate ground based temperature inversion but this is not necessarily correct. Note 24 to the standard provides-

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

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

Verification of Modelling Assumptions

6. In order to verify the assumptions for the present case, two different sound propagation models were referenced to PEN3D. The base-case referenced is the final noise predictions' report (Report 1610-R3 Draft) for the Project West Wind Makara wind farm, Wellington, prepared by the Hayes McKenzie Partnership. The Hayes McKenzie report sets out very clearly the assumptions used in their predictions.

7. Hayes McKenzie do not use hub height as the source height for the sound power levels but a height above the actual tip height of the wind turbine. The Report states: *The increase in height is to allow for the potential bending of sound waves by the flow of air over the hill sides. This has the effect of increasing the apparent height of the source.* NZS 6808 however, adopts the hub height as being the source height.

8. The verification testing assumed the Hayes McKenzie predictions as the nominal benchmark. Hayes McKenzie prepared their predictions under ISO 9613 implemented by CADNA-A. The first verification check implemented ISO 9613 under SoundPLAN using the Hayes McKenzie assumptions and a further series of verification tests were implemented under PEN3D. The verification tests under PEN3D implemented two different source heights (at hub height of 68m and above maximum blade tip height at 135m) and the effects of moderate temperature inversion conditions.

9. The predictions indicate that, overall, PEN3D is predicting levels slightly above CadnaA. SoundPLAN is predicting slightly lower than CadnaA for the same daytime assumptions. Both alternates are within margins of error in relation to "baseline" CadnaA. There is a slight difference between PEN3D predictions for night-time (moderate inversion) conditions and daytime levels. ("Slight" is taken as ±2 dB across all predictions).

10. The variation between PEN3D hub height and blade tip predictions, however, can shift levels upward by about 4 - 7 dB(A). This means that ISO9613, using hub height as the source, has the risk of <u>under-predicting</u> the sound levels at receivers.

11. The verification predictions confirm the importance of meteorological conditions on sound propagation and potential for increased sound levels under night-time conditions when moderate temperature inversions occur in order to assess the potential for any adverse effect or potential effect of high probability due to the operation of the wind farm.

12. Sound prediction calculations are most often made to present sound levels at some defined location or in broad “sweeps” or contours. The prediction noise contours are calculated on “grids” over the whole of the locality. The contour levels (30, 35, 40, for example) are calculated by linear interpolation between the levels at adjacent grid points. The sound levels calculated are the equivalent energy / time average Leq levels in dB(A).

13. The assumptions for the prediction calculations for this evidence are-

- Receiver height: 1.8m
- Day: Temperature 25°C, relative humidity 50%
- Night: Temperature 8°C, relative humidity 80%
- Ground condition: Mixed grassland and trees
- Digital terrain model: VicMap
- Wind conditions (rated wind speed of 12 m/s at hub height of 80m) at downwind receptor locations
- Turbine octave band sound power data referenced from Marshall Day Report Rp 001 R01 2009136 Table 1, 8m/s at 10m AGL. Figure 1 of the report states the overall sound power level as 104 dB(A) at 8m/s, 10m AGL
- All turbines for a particular scenario operational
- Turbine sound power calculated at hub height

Enercon E82 Sound Power Levels (dB Lin):

31.5	63	125	250	500	1000	2000	4000	8000
-	81.4	87.9	92.6	98.1	100.5	95.3	84.5	77.1

14. Sound power octave-band levels for individual turbine types can vary considerably (especially in the lower frequencies) while the overall sound power levels may be very similar between makes / models.

Caution With Predictions

15. Under downwind conditions the sound generated by the turbines is affected by downwind refraction. There can be considerable variation in sound levels due to atmospheric conditions and the presence of stable conditions are critical for noise prediction and analysis because, as established by van den Berg (2005, pp. 79-81):

- a turbine operating at high speed into a stable atmosphere can give rise to fluctuation increases in turbine sound power level of approximately 5 dB
- fluctuations from 2 or more turbines may arrive simultaneously for a period of time and increase the sound power level by approximately 9 dB

- In-phase beats caused by the interaction of several turbines increases the pulse height by 3 to 5dB
- The enhanced levels are not consistent and will change as the wind changes

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

- ±3dB due to propagation variations inherent in the model being used (e.g. ISO9613-2)
- +4dB to +7dB due to the height used in locating the sound source above ground, ground effects and site specific meteorological effects

This presents a possible variation of -3dB to +10dB over the "nominal calculated level" for sound level predictions at 1000 metres. Some acoustic consultants like to emphasise that their predictions using ISO 9613-2 are "conservative". As 'conservative' has the meaning of "purposefully or deliberately low (of an estimate)" it is more correct to state that their predictions are unrealistically low and present a false and misleading calculation.

Consideration of Variable Weather Conditions

17. The primary concern is with weather data. Accurate weather data is needed to allow good for reliable sound level predictions.

18. Weather (wind direction, wind speed and the presence of temperature inversions) will all change the levels of received sound at residences. Weather data needs to be recorded from the wind towers (at hub height) and at residences (a minimum 3m above ground) for reliable sound level predictions.

19. The received noise levels at residences will vary subject to varying meteorological conditions in the locality (wind speed and direction, temperature, humidity, inversions). Data at residences will be quite variable and potential noise from the turbines will be affected by this. These potential noise effects are predicted to occur during cool, stable conditions particularly in early morning and evenings.

20. As a starting point for assessment, it is reasonable to assume that a certain percentage of the weather experienced in the locality at residential level will support or promote adverse noise propagation from the wind farm. This prediction is for a potentially frequent event with high probability of adverse effect.

21. A wind rose at the wind measurement towers (at a point 80m above ground) is the most useful but this data is rarely presented in the wind farm developer's documentation. Alternative sources of data from nearby met stations or residential sources are often necessary.

22. Notes: weather conditions are described as:

- **'Normal' or 'Neutral'** conditions occur where the temperature slowly increases with height such as overcast conditions and / or when the wind is high enough to cause mixing of any atmospheric layers. These conditions can occur day or night; they will always prevail when it is fairly windy, overcast or at the beginning or end of the day.
- **'Stable'** conditions occur at night when a layer of cold air is trapped close to the ground, under warmer air. This is the reverse of normal conditions and is known as temperature inversion. Any noise generated in the cooler layer is 'trapped' within it and unusually high noise levels can be experienced. During the night the generation of stability is determined by considering the surface wind speed and cloud cover. Clear skies lead to a rapid heat loss from the surface at night and the development of strong inversion conditions.
- **Inversions** occur at night when there is little cloud cover; the ground itself cools and this cools the layer of air close to it. If there is significant cloud cover, this tends to radiate heat back towards the ground and inhibits the formation of the inversion. If winds are significant the turbulence mixes the layers and again inhibits the formation of an inversion layer.

Inversion layers

23. van den Berg comments that wind farm noise can be higher than calculated because of an inversion layer adding more downward refracted sound. This occurrence could be more significant where high inversion layers occur more often. The effect is most noticeable at night under highly stable conditions.

Calculation of Variation in Levels for Different Blade Characteristics and Wind Speeds

24. Individual turbines exhibit variation in sound levels or 'swish' due to different blade characteristics, wind speeds and hub heights. Table 1 is based on the thesis by Fritz van den Berg (2006) using data for the Vestas V90 turbine. It assumes the most sensitive atmospheric condition of a very stable atmosphere and nominal wind speeds (8, 12 and 15m/s). The calculation is for sound from trailing edge (TE) created sound or "swish". The level of aerodynamic wind turbine noise

depends on the angle of attack: the angle between the blade and the incoming air flow. This is the variation between the blade at its highest point to its lowest point, plus the variation caused by passing the tower.

25. Of the three factors (wind velocity gradient, wind direction gradient and reduced large scale turbulence) influencing blade swish, the largest effect comes from the wind speed gradient. That is, the changes in wind speed.

26. The table shows the results for differing blade lengths and wind speeds at 80 metre hub height. The rotational velocity is calculated referenced to the Vestas V90 turbine. Other turbines will have slightly different characteristics.

Table 1: Trailing edge sound level variations for the Vestas V90

	Hub Height 80m, Wind Speed 8m/s				
	Blade Length (m)				
	36	**38**	**42**	**46**	**51**
Tip speed (m/s)	47.5	50.1	55.4	61	67.3
Windspeed at lowest point (m/s)	5.4	5.3	4.9	4.6	4.1
dα (°)	1.4	1.6	1.9	2.3	2.9
Blade-passing dα (°)	3.2	3.2	3.2	3.2	3.2
Total dα (°)	4.6	4.8	5.1	5.5	6.1
ΔSPL_{TE} 1 turbine (dB)	**6**	**6**	**6**	**7**	**8**

	Hub Height 80m, Wind Speed 12m/s				
	Blade Length (m)				
	36	**38**	**42**	**46**	**51**
Tip speed (m/s)	61.8	65.3	72.1	79	87.6
Windspeed at lowest point (m/s)	8.1	7.9	7.4	6.9	6.2
dα (°)	2.7	3.0	3.8	4.6	5.8
Blade-passing dα (°)	3.2	3.2	3.2	3.2	3.2
Total dα (°)	5.9	6.2	7.0	7.8	9.0
ΔSPL_{TE} 1 turbine (dB)	**8**	**8**	**9**	**10**	**12**

	Hub Height 80m, Wind Speed 15m/s				
	Blade Length (m)				
	36	**38**	**42**	**46**	**51**
Tip speed (m/s)	69.4	73.2	80.9	89	98.3
Windspeed at lowest point (m/s)	10.2	9.9	9.2	8.6	7.8
dα (°)	3.8	4.3	5.3	6.4	8.1
Blade-passing dα (°)	3.2	3.2	3.2	3.2	3.2
Total dα (°)	7.0	7.5	8.5	9.6	11.3
ΔSPL_{TE} 1 turbine (dB)	**9**	**10**	**12**	**13**	**16**

Absolute Sound Variation at a Receiver

27. In summary, the Absolute Sound Variation at a receiver depends on:

(a) the true sound power level of the turbine(s) at the specified wind speed

(b) the reduction in sound level due to ground effects

(c) the increase or reduction in sound level due to atmospheric (meteorological) variations and wind direction

(d) the variation due to modulation effects from wind velocity gradient

(e) increase and reduction in sound levels due to wake and turbulence modulation effects due to turbine placement and wind direction

(f) increased sound levels due to synchronicity effects of turbines in phase due to turbine placement and wind direction

(g) building resonance effects for residents inside a dwelling

Risk management

28. In summary, therefore, best practice for management and mitigation of noise from wind farms considers normal risk assessment:

- Identify the hazards
- Assess the risks that may result because of the hazards
- Decide on the control measures to prevent or minimise risks
- Implement control measures
- Monitor and review the effectiveness of the measures

Neither the 1998 nor the 2010 New Zealand wind farm standard adopt risk management for the assessment and mitigation of wind farm noise and they must, therefore, be treated with caution. The “acceptable numbers” approach taken by the standards is unproven and, based on New Zealand noise complaints for Te Rere Hau and Makara, significantly fails to avoid or mitigate unreasonable noise.

Conclusions

1. All the above variations must be considered in a professional prediction analysis. Predictions that are presented in this way should state the uncertainty involved. Where-ever possible uncertainty should be expressed as a confidence level, e.g. as 90% or as ±xbB(A). Assessments that do not meet this level of predictive certainty should be considered as being unreliable.

2. It is concluded that sound level predictions must be treated with extreme caution. Predicted levels should be presented as a range, as a minimum to identify the variations stated in ISO9613.

Annex 4: Responses of Residents Near Wind Farms

The Manawatu Wind Farm Pilot Study

1. In 2007- 8 I undertook a series of attitudinal and acoustical studies[14] in the Manawatu and Brisbane in order to assess the differences between a rural population and an urban population with respect to a specific set of sounds including noise from wind turbines.

2. The Manawatu – Brisbane Pilot Study was established as a focus study investigating wind farm issues. The Manawatu group are rural residents and are an 'environmentally aware' population. The participants were chosen on the basis that the research required responses from persons who had an interest in their environment and who would be willing to answer lengthy questionnaires.

3. It was anticipated that the Manawatu group would exhibit a wide range of noise sensitivities as the group was drawn from different 'zones' within the Manawatu: wind-farm affected urban and/or rural locales, and 'greenfields' unaffected by wind farms. The participants were invited to be part of the study and the invitations were issued through local community organisations. A total of 60 people were selected in the Manawatu although not all were able to complete all the survey materials within the time available.

4. A control group of 16 people was selected in Brisbane although not all were able to fully participate in the time available. The Brisbane group was self-selected from invitations to musicians, teachers, lawyers and acoustical professionals. The Brisbane group was defined on the basis of previous investigations that indicated these occupations showed considerable attention to detail and focussed on issues more than 'ordinary' individuals. It was anticipated that this group would be significantly noise-sensitive.

5. The Zone map for the Manawatu is presented in **figure 1**. Zones 1 and 2 are potentially affected by wind farm noise. Zone 1 participants were from the urban township of Ashhurst. Zone 2 participants were from the rural area near three major operating wind farms. Zone 3 is greenfields but may be affected by wind farm noise to the north. Zone 4 is greenfields and unaffected by wind farm noise. Many of the participants can be considered as having a rural lifestyle with significant urban interaction.

[14] Thorne, R, 2008, Assessing Intrusive Noise and Low Amplitude Sound, PhD Thesis, Massey University, New Zealand.

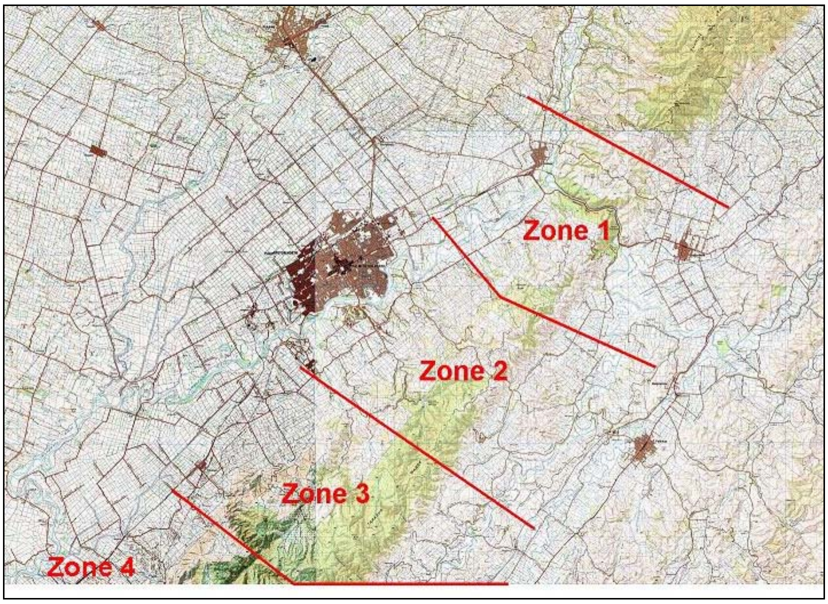


Figure 1: Manawatu Study Zones

6. Personality noise sensitivity questionnaires (Weinstein, LEF and NoiSeQ formats) were administered to respondents in each zone. The LEF noise sensitivity questionnaire encompasses statements about a wide variety of environmental noises in a range of situations that affect the whole population. Brisbane is deemed to be the 'control' population.

7. The analysis of the results from 69 responses (57 in the Manawatu, 12 in Brisbane) indicates that Zone 3 responses are statistically different from the other zones and the Brisbane control. All respondents to the survey are considered to be noise sensitive. This is an unexpected outcome from the study.

8. The responses to the noise annoyance questions indicate noise is sometimes a problem in both groups, with the local environment heard as being quiet / very quiet. The percentages in the responses have been rounded to the nearest whole number.

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

10. In response to the question "Thinking about where you live, could you please say how quiet or noisy you think your area is?" in the Manawatu 84% of the respondents recorded their locality as being quiet or very quiet, 13% as

moderately noisy, while 3% found their locality noisy or very noisy. For the Brisbane group 67% of the respondents recorded their locality as being quiet or very quiet, 17% as moderately noisy and 17% found their locality noisy or very noisy.

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

12. The question "does noise affect you while..?" provided a range of responses, **Table 1**. Noise during relaxation and sleeping causes the most affect.

Table 1: Responses to 'Does noise affect you while…'

Locale	Reading		Watching TV		Listening Talking		Relaxing		Sleeping	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Manawatu	13%	87%	13%	87%	13%	87%	48%	52%	52%	48%
Brisbane	33%	67%	33%	67%	25%	75%	50%	50%	25%	75%

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

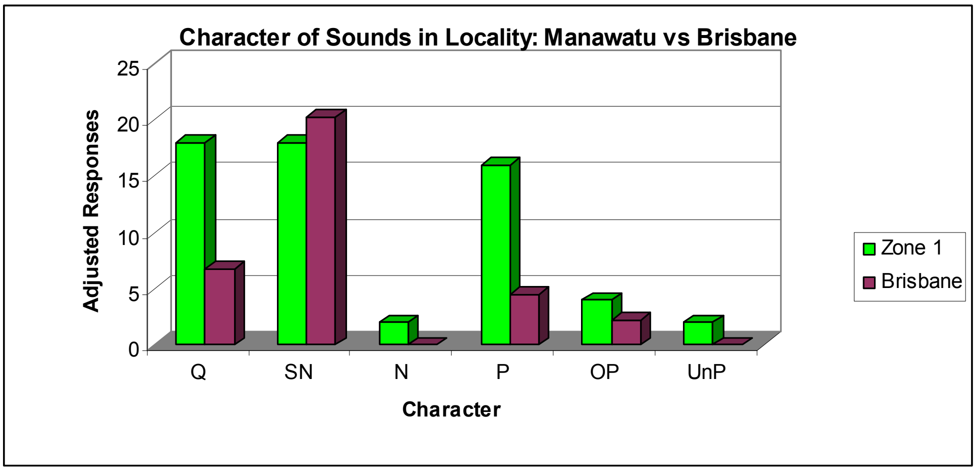


Figure 2: Character of the environment, Manawatu vs Brisbane

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

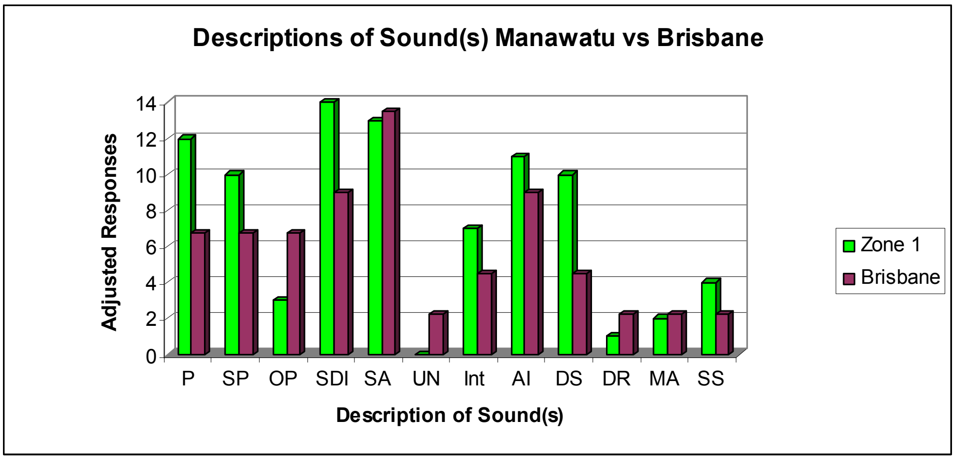


Figure 3: Description of sound(s) in the environment, Manawatu vs Brisbane

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

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

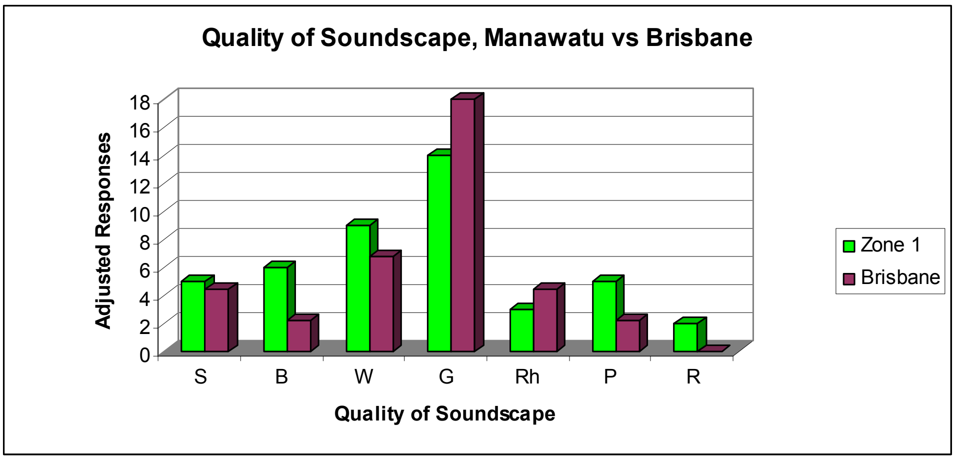


Figure 4: Qualities of Soundscape, Manawatu vs Brisbane

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

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

A study of noise sensitivity vs. specific sounds

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

17. A Manawatu focus group of 13 persons were self-selected by invitation from the previous Manawatu study. Approximately 50% of the group was from Zone 1 and 50% from Zone 3.

18. A Brisbane group of 14 persons were self-selected by invitation from a group of people interested either in music or in acoustics. Individuals in this group may or may not have an interest in environmental issues. It was concluded that this is an acceptable component within the study design. An “Annoyance” questionnaire was included for consistency in application of the surveys. The survey was circulated by means of meetings in Manawatu and Brisbane and copies of the soundfiles and questionnaires distributed to persons interested in participating.

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

20. As there are two different groups (Manawatu and Brisbane) a test was required to check whether both groups are compatible or equivalent with respect to the noise sensitivity. An equivalence test of the two groups with respect to global noise sensitivity shows the groups are not compatible with respect to this characteristic.

21. Analysis of the data indicates that a statistically significant difference exists between the mean ranks of the Manawatu (M) and Brisbane (B) groups. NoiSeQ assigns question items to five subscales: leisure, work, habitation, communication and sleep. The design of the questionnaire allows a value for global noise sensitivity as well as the subscales. NoiSeQ is an appropriate method for noise sensitivity analysis and has the additional benefit of being able to be referenced to the standard environmental questionnaires presented in this work. The differences between individuals appear in the noise sensitivity rankings of the groups, **Figure 5,** as “more than average”, “average” and “less than average”.

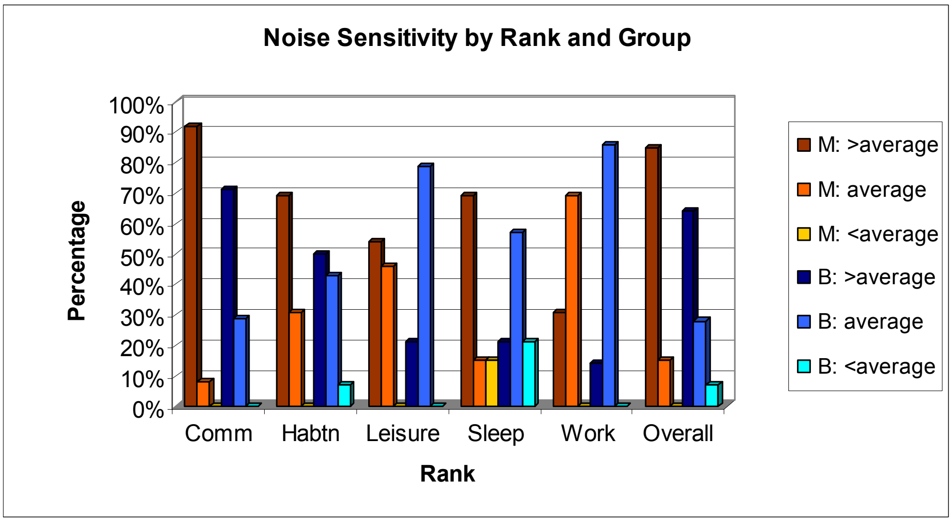


Figure 5: NoiSeQ Noise Sensitivity: sensitivity by rank and group as percentage

Noise Annoyance

22. In response to the question "Do you find noise in your environment (including your home environment) a problem?" (Q.1) 62% within Manawatu have some experience of noise being a problem sometimes, 15% did not and 23% did find noise a problem. In the Brisbane group, 43% found noise a problem sometimes, 43% did not and 14% did find noise a problem.

23. The question "does noise affect you while..?" provided a range of responses, Table 2. Noise during relaxing and sleeping causes the most affect.

Table 2: Responses to 'Does noise affect you while…'

Locale	Reading		Watching TV		Listening Talking		Relaxing		Sleeping	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Manawatu	8%	92%	0	100	15%	85%	31%	69%	31%	69%
Brisbane	29%	71%	0	100	7%	93%	36%	64%	7%	93%

Soundfiles to identify characteristics

24. An outcome of the observations and interviews of the pilot study indicated a need to establish a baseline reference point with sounds of known characteristics that could be reviewed by any person at any time. The purpose was (and is) to identify the perceptions of the sound as experienced by the person listening to the sound. The study was expanded by presenting a series of environmental sounds or 'soundfiles' to be judged by the respondents.

25. The perceptual responses help to characterise the groups of sounds investigated for individual response. A significant outcome is shown in the perception of wind farm noise between the Manawatu and Brisbane groups. The Manawatu group has a negative outlook to the sounds while the Brisbane group are not negatively inclined towards wind farm noise.

26. It was the character of the sound that was under review, not the 'loudness' of the sound. The character or characteristics of the sounds as perceived by the respondent's are presented in **figures 6 to 8.** The responses are recorded as percentages.

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

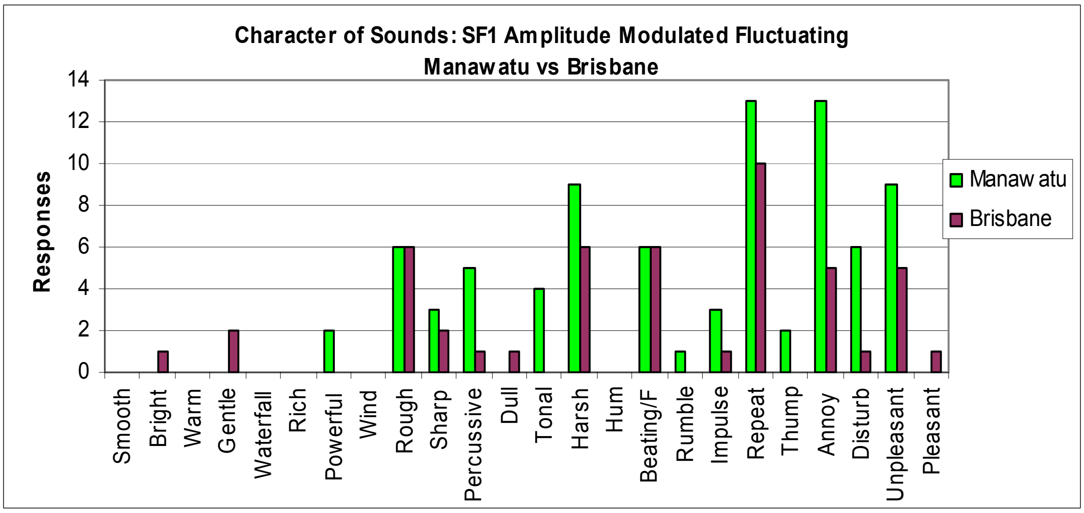


Figure 6: Responses to the character of soundfile 1

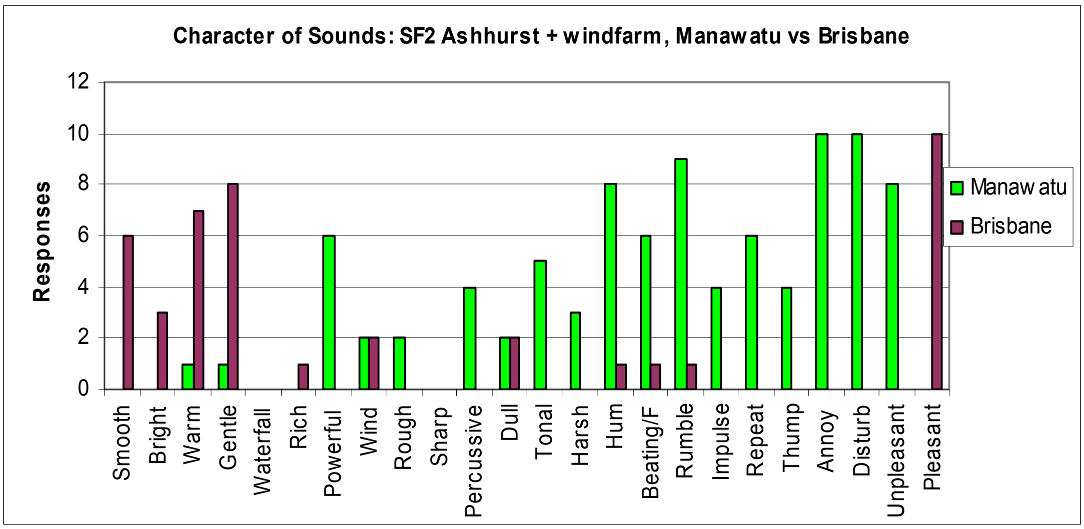


Figure 7: Responses to the character of soundfile 2

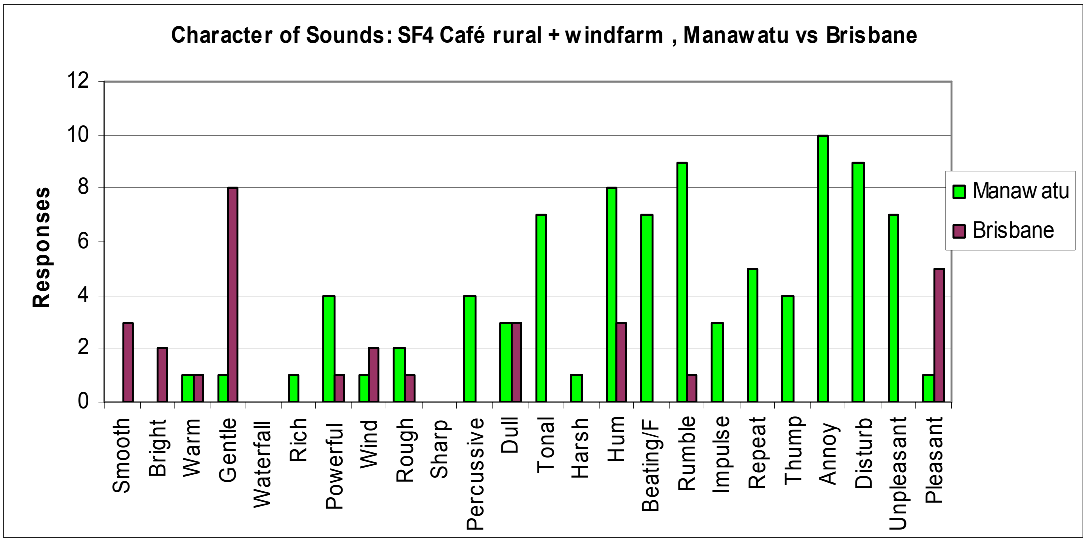


Figure 8: Responses to the character of soundfile 3

28. It is therefore concluded that there are significant differences between the two groups, not only in noise sensitivity (which is a personality trait) but also in perception and responses to similar situations.

29. This has two possible explanations: the Manawatu group has an unbiased negative response due to pre-knowledge and environmental awareness. Or, the group has a biased negative response due to pre-knowledge and environmental awareness. Either way it would suggest that any attitudinal study that asks questions concerning environmental modification (whether wind farm, waste dump or any other similar industrial activity) will be significantly biased if the respondents have no first-hand experience of the activity.

30. Further discussions with colleagues from different countries indicate a significant cultural influence into the acceptance or rejection of noise in the environment.

31. Based on my research I hold the opinion that a proposed wind farm will not be acceptable within a rural community as the evidence is that wind farms are held very negatively by the community most affected. The cumulative effects of more than one wind-farm must also be considered. This is an issue that may also need to be faced by the community with respect to large-scale development of wind farms in a relatively small, defined locale.

Community and Individual Noise Exposure

32. Community noise exposure is commonly measured in terms of a noise exposure measure, such as the time-average (Leq) level or day-night level (Ldn). It is common practice for both these measures to be A-weighted. 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). A noise exposure chart is presented in Figure 5.1 of the next Annexure.

33. 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.

34. 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.

35. Individuals are relatively powerless to force change or obtain noise mitigation. Coincidently, based upon New Zealand, Victorian and Queensland experiences, community groups also seem to experience the same problem.

36. The fundamental issue both sectors have is significant difficulty in either sourcing relevant information or receiving the information in a form that makes sense to the persons involved.

37. There is no defined relationship that can predict when a noise is reasonable or unreasonable; for this to happen, the sound must be perceptible, intrusive and have a salience that causes an adverse response in the person listening.

38. Noise exposure can be defined in terms of audibility and intrusive noise referenced to before, during and after some identified noise event. The reaction modifiers for individuals include:

- Attitude to noise source
- Attitude to information content in the noise
- Perceived control over the noise
- Sensitivity to noise (in general and specific)
- Sensitivity to specific character of the noise

39. Based upon the work described previously, these reaction modifiers can be integrated into definitions for intrusive sound, noise and intrusive noise that allow quantification in measurable terms and qualification as:

- **Intrusive sound** is a sound that, by its characteristics, is audible and intrudes upon the well-being or amenity of an individual.

- **Noise** is a sound that is perceptible to an individual and has definable characteristics that modify the individual's emotional and informational responses to that sound from pleasurable or neutral to adverse.

The Effects on People by Wind farms in New Zealand and Victoria

40. Previous wind farm investigations in New Zealand and Victoria 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.

41. In Victoria, for example, 5 different families near a wind farm were interviewed, all of whom report some adverse reaction since the commissioning of a nearby wind farm earlier this 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.

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

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

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

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

45. Family D reports suffering from sleep disturbance, headaches, nausea and tachychardia since the turbines started operating.

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

> *"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*.

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

Victorian responses in comparison to the Makara wind farm

48. The Victorian interviews provided responses that are both different and similar in nature to those recorded for the Turitea Wind Farm Hearing in New Zealand. The Turitea evidence also presented formal complaints from residents affected by the Makara wind farm. The people from the locale of the Makara Wind farm report sleep disturbance, annoyance and stress since the wind farm was commissioned this year (operating in April, fully operational in October). Between April and October 2009 a total of 479 formal noise complaints had been lodged by Makara residents concerning noise from the wind farm. The turbines are in the order of 1200 – 2200 metres distant from the residences that provided written complaints.

49. 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 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.*

50. The Victorian wind farm started operation near the residents reported in this section in May 2009. Both locales prior to the wind farms were essentially rural in nature. The Makara environment has the wind turbines on ridges with the residents most often in the valley. The Victorian environment has the turbines situated on relatively low hills situated in rolling to flat rural country. Residents near both wind farms report similar health, sleep disturbance and annoyance reactions.

The Health Effects Debate

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

and evidence to regulatory authorities hearing applications for wind farm planning permissions.

52. Recent evidence tendered by Mr Rick James to the Public Service Commission of Wisconsin, Exhibit 808 PSC Ref#:121105 5 October 2009 presents an overview critique of wind farm acoustical and health related matters. Mr James is practising (US) acoustic engineer of 35 years' experience and who for many years has been investigating wind turbine noise, and with Mr Kamperman has developed guidelines for safe siting of wind turbines to prevent health risks[15]. His evidence has been presented at wind farms hearings world-wide and he, in association with Mr Kamperman, submitted a detailed critique[16] of NZS 6808 in that standards' review process.

53. The 2007 thesis by Dr Eja Pedersen "Human Response to Wind Turbine Noise: Perception, annoyance and moderating factors" was written with the aim to describe and gain an understanding of how people who live in the vicinity of wind turbines are affected by wind turbine noise and how individual, situational and visual factors, as well as sound properties, moderate the response.

54. Dr Frits van den Berg is a respected physicist who has given extensive evidence before wind farms hearings world-wide. He has published his thesis as a reference text "The sounds of high winds: the effect of atmospheric stability on wind turbine sound and microphone noise." Dr Nina Pierpont has written a peer-reviewed text "Wind Turbine Syndrome" that, in its electronic draft form (March 2009) has been extensively debated by people who agree or disagree with her research concerning wind turbine activity and adverse health effects. Dr Pierpont also refers to the work by Dr Amanda Harry in the UK, "Wind turbines, noise and health"[17].

55. The wind farm industry consults with Dr Geoff Leventhall, a specialist in low frequency noise problems. Dr Leventhall does not agree that low frequency noise below the threshold of human hearing can have negative impacts on human health (his testimony before the Public Service Commission of Wisconsin, Docket No. 6630-CE-302 PSC Ref#:121870 20 October 2009). In his Paper "Infrasound from Wind Turbines – Fact, Fiction or Deception[18]" he states, in part, that:
"Infrasound from wind turbines is below the audible threshold and of no consequence. The problem noise from wind turbines is the fluctuating swish".

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[15] Kamperman, George and Richard R. James (2008). Simple guidelines for siting wind turbines to prevent health risks. INCE NOISE_CON 2008 pp. 1122-1128
[16] DZ6808 Review submissions, September 2009, pp. 219-274 released under the Official Information Act
[17] http://www.windturbine noisehealthhumanrights.com/wtnoise_health_2007_a_barry.pdf
[18] Canadian Acoustics, Special Issue, Vol 34 No.2 2006, pp 29-36

56. In his Paper "Wind Turbine Syndrome – An appraisal" dated 26 August 2009, Dr Leventhall critiques the work of Dr Nina Pierpont[19] concerning the symptoms of Wind Turbine Syndrome:

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

(In later correspondence[20] Dr Leventhall confirms his belief that there is no such thing as wind turbine syndrome).

57. He says, at p.9 of his Paper:

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

58. At page 11 he states:

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

59. There is now a significant body of evidence presented to different hearings in the United States to show that residents, qualified acousticians and medical practitioners have concerns about wind farm noise.

60. There is, despite the differences in opinion as to cause, remarkable agreement between the parties – residents, clinicians and acousticians – as to observable health effects from unwanted sound and noise.

61. There is clear agreement between the research findings by Dr Pierpont and the acoustical experiences of Dr Leventhall with respect to the symptoms of extreme psychological stress from environmental noise, particularly low frequency noise:

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

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[19] "Wind Turbine Syndrome" p.18 (prepublication draft dated June 30, 2009, published by K Selected Books).
[20] Personal correspondence from Dr Leventhall to C. Delaire, Marshall Day Acoustics, provided in response to a query for the Stockyard Hill Wind Farm application, Victoria, May 2010.

There is, however, significant difference between the views of Dr Leventhall and Dr Pierpont. In the correspondence (ref18) Dr Leventhall makes it clear:

> *"…what I have said is that the symptons which she claims to have been caused by infrasound from wind turbines are well know [sic] stress effects of audible noise. Wind turbine noise is just noise – not specially different from other noises. …"*

62. There appears to be a clear and definable marker 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 started operation. It is the mechanism of the physical or mental process from one to the other that is not yet defined or agreed.

63. At the Turitea (New Zealand) Board of Inquiry Hearing, Dr Dixon (a senior physician) stated[21]: "I am sure I have no need to indicate to members of the Board the significance mental and physical effects of sleep deprivation even for one night, yet alone on a repetitive basis". Dr Dixon referred to the history of the link between smoking and lung cancer, as well as other health concerns. In referring to the book "Wind Turbine Syndrome" he stated:

> "And I think this book would be dismissed at our peril and while, as I say, we do not have absolute proof, there are lots of issues to sort through in the coming years, but we need to be particularly wary of the possible effects of wind turbines on health."

Conclusions

64. What is clear from the current debate is the 'duty of care' obligation on an applicant for a wind farm to properly and fully identify and mitigate objectionable noise - nuisance conditions arising from the operation of the wind farm. The precautionary principle applies and the duty rests on the wind farm developer and directly or indirectly, the State Government, the Shire / City Council, owners of the land on which the turbines are situated and the acoustical consultant(s) advising the developer.

[21] Transcript of proceedings, Board of Inquiry, Turitea Wind Farm Proposal Hearing, p. 3492

Annex 5: Annoyance, Audibility, Low and Infrasound Perception

1. Unreasonable noise is noise that intrudes upon the amenity of a person and due to its unpleasantness causes annoyance and distress. The mechanism for this transformation of sound to noise varies widely from person to person.

2. The World Health Organization[22] defines annoyance as *"a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them".* Used as a general term to cover negative reactions to noise, it may include anger, dissatisfaction, helplessness, depression, anxiety, distraction, agitation or exhaustion.

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

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

4. There has been considerable research into noise annoyance from turbines, such as that reported by Pedersen and Persson Waye,[23] identifying the relationship between noise from turbines and transportation. **Figure 5.1** presents the relationship derived by Pedersen and Waye showing the effect of "percent people highly annoyed" by noise from transportation and from wind turbines. <u>Annoyance from wind turbine noise occurs at noise levels far lower than for traffic noise.</u>

[22] "Guidelines for Community Noise, World Health Organization, 2000, p31
[23] 'Perception and annoyance due to wind turbine noise-a dose-response relationship, Pedersen E and Persson Waye K, J Acoust. Soc. Am 116 (6) December 2004

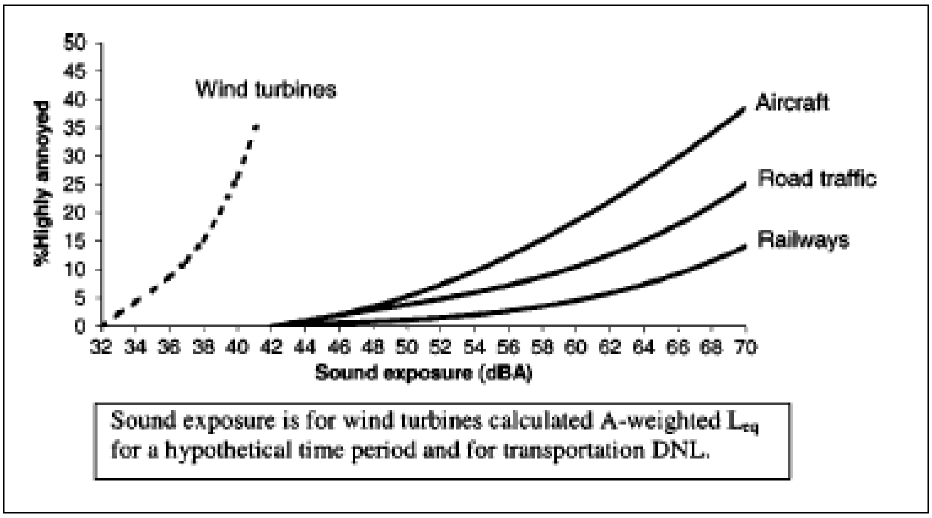

Figure 5.1: Wind turbine noise levels and persons highly annoyed by the noise *Source: Pedersen and Persson Waye, ref.23.*

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

6. This suggests that based on the sound levels in this evidence, a significant percentage of the population exposed to wind turbine noise will, at some stage during the operation of the windfarm, be highly annoyed by the noise from the turbines. The design life of a wind farm is in the order of 20 to 40 years, indicating that this wind farm has the potential to be a long-term sporadic source of high-to-moderate noise annoyance.

7. Individual amenity is evaluated with respect to personal noise sensitivity, personal and cultural expectations and attitudes to noise in the environment and habituation effects. Noise intrusion, as a personality variable, is dependent on noise sensitivity.

8. The importance of noise sensitivity assessment, as a measure of human response, is the strong association between noise sensitivity and annoyance. Noise sensitivity has a strong influence on annoyance and is independent of the noise exposure. Job[24] has found that-

[24] Job, RFS, Hatfield, J, Peploe, P, Carter, NL, Taylor, R & Morrell, S 1999a, 'Reaction to combined noise sources: The roles of general and specific noise sensitivities', In Proceedings of Inter-noise '99, December 6-8, Florida, pp. 1189-1194

Only a small percentage (typically less than 20%) of the variation in individual reaction is accounted for by noise exposure. …
Variables, such as attitude to the noise source and sensitivity to noise, account for more variation in reaction than does noise exposure.

9. Noise affects individuals and the community by modifying the nature of the environment that attracts and holds people to the locality. Acoustical amenity, therefore, can be described as the enjoyment of a place without unreasonable exposure to unwanted sound that is a by-product from some activity.

10. The physical measures for the assessment of unreasonable noise on an individual can be described as-

- Measures of audibility of a sound as heard by an individual;
- Measures of adverse effect on individual amenity;
- Measures of acceptability of intrusive sound by an individual;

11. The effects of noise on individual amenity are divisible into five categories-

- Significant adverse effect (anger, annoyance and stress reactions).
- Moderate adverse effect.
- Adverse effects more than minor.
- An adverse effect, but no more than minor (minor irritation).
- No adverse effect, pleasurable sounds or peace and tranquillity.

12. My field work observations over the years' indicate that low-amplitude intrusive noise is often significantly more audible at night and can be highly audible at considerable distances, especially on cold or cool nights and if there is a slight breeze blowing from noise source to the person.

13. This is due not only to the increase in noise over the background level but also the distinct difference in the character of the noise, or its audibility, in comparison to the environment without the noise.

14. People are unique in their individual hearing response. A sound audible to one person may be inaudible to another and, therefore, a method is needed to define, measure and assess "audible sound". A sound is said to be audible if it can be heard within the ambient sound (soundscape) of the locality. That is, the sound is not masked by the soundscape. This is a signal-to-noise phenomenon and can be defined in terms of sound detectability. Audibility can be considered as a psychophysical quantitative relationship between physical and psychological events:

- the physical relationship is considered as being the role of signal detection

- the psychological or behavioural and perceptive reactions of an individual are considered as psychoacoustical or sound quality relationships

15. A method for the prediction of the audibility of noise sources is detailed in the report *Graphic Method for Predicting Audbility of Noise Sources* (1982) by Bolt, Beranek and Newman for the US Flight Dynamics Laboratory (publication AFWAL-TR-82-3086. The report provides technical rationale and relationships between signal-to-noise ratio and frequency that govern detectability of acoustic signals by human observers and provides methods to:

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

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

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

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

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

19. Human sound perception can be described in terms of equal loudness contours. Strictly speaking these are not measures of audibility but they do provide a useful starting point for comparison between sound levels by frequency (tone). An equal loudness contour is a measure of sound pressure, over the frequency spectrum with pure continuous tones, for which a listener perceives an equal

loudness. Loudness level contours are defined in International Standard ISO 226:2003 *Acoustics-Normal equal loudness contours*, Figure 5.2. The revised ISO 2003 contours are in red, the 1961 contours are in blue. The 40 phon equal loudness contour is used to calculate the decibel A-weighted scale (dBA).

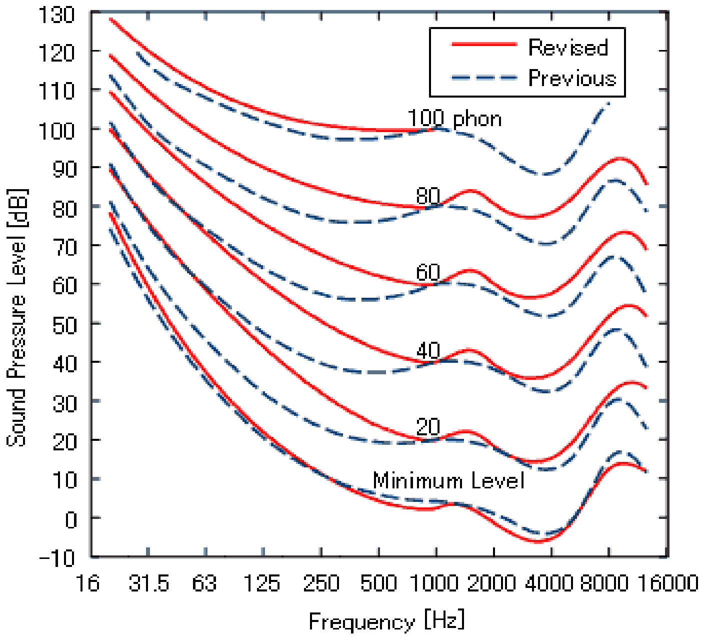

Figure 5.2: Equal loudness level contours vs sound pressure levels (reference source: http://www.aist.go.jp/aist_e/latest_research/2003/20031114/20031114.html)

20. The research by Moller and Pedersen[25] into hearing at low and infrasonic frequencies extends our ability to assess the potential for audible sound from a wind farm. They say:

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

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

changes with decreasing frequency. Pure tones become gradually less continuous the tonal sensation ceases around 20 Hz, and below 10 Hz it is possible to perceive the single cycles of the sound. A sensation of pressure at the eardrums also occurs. The dynamic range of the auditory system decreases with decreasing frequency. This compression can be seen in the equal-loudness-level contours, and it implies that a slight increase in level can change the perceived loudness from barely audible to loud. Combined with the natural spread in thresholds, it may have the effect that a sound, which is inaudible to some people, may be loud to others. Some investigations give evidence of persons with an extraordinary sensitivity in the low and infrasonic frequency range, but further research is needed in order to confirm and explain this phenomenon.

21. From this and other data Moller and Pedersen propose a normal hearing threshold below 20 Hz, figure 5.3.

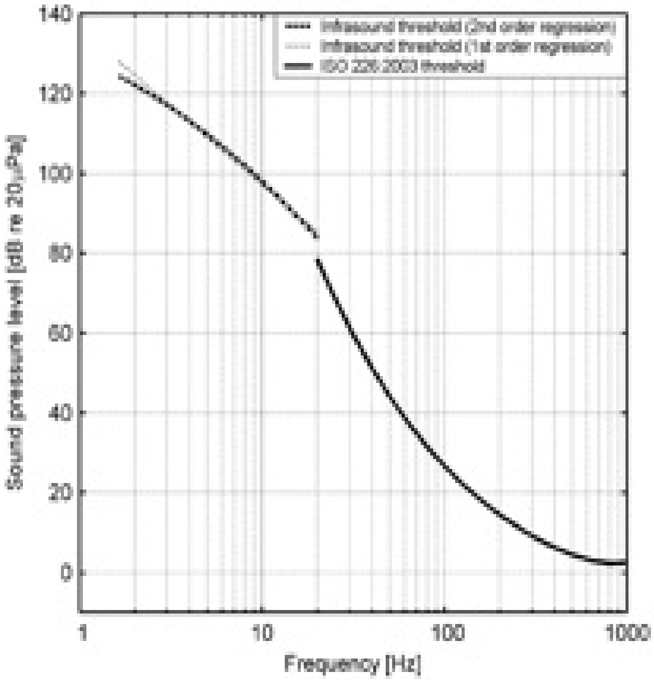

Figure 5.3: Hearing threshold contours (from Moller and Pedersen Figure 10)

22. Moller and Pedersen observe that especially sensitive persons, however, may have extraordinary high hearing sensitivity at low frequencies, figure 5.4. Infrasound may, therefore, be perceptible to sensitive persons at levels far lower than that nominally accepted as being the thresholds for persons with normal hearing. At 8 Hz, for example, levels of 78 dB to 88 dB may be perceptible.

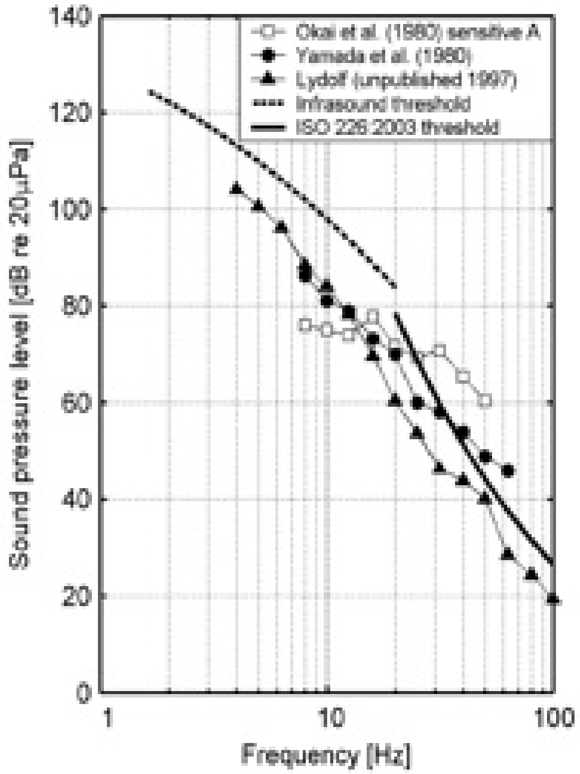

Figure 5.4: Hearing thresholds of three especially sensitive persons (from Moller and Pedersen Figure 12)

Conclusions

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

2. Inappropriate noise assessment is a significant problem if some form of simplistic standardized physical measure such as the ‘A-weighting’ or ‘background measures’ are used to describe the potential effects of ‘sound’ and ‘noise’. Such measures do not represent human hearing or perception.

Annex 6: Flicker and the Human Perception of Wind Farm Activity

1.1 This Annex has been prepared by Mr Bruce Rapley, Atkinson and Rapley Consultants, Palmerston North, New Zealand.

2.1 The generation of electricity from wind turbines is a relatively new technology that promises inexpensive and green, generation options. Turbines produce a range of possible hazards to the human community. In particular, wind turbines produce phenomena including blade flicker; shadow flicker and glint. These all have potential to cause annoyance to the human population, and in a small number of cases, may even trigger physiological responses in individuals with epilepsy.

2.2 The placement of wind farms should also consider the effect on natural countryside as this is, in many cases, of great potential to tourism, notwithstanding the ambience of the area for local residents who will undoubtedly have purchased properties with specific regard to the local landscape. Imagine a beautiful lake that suddenly supports a major industrial complex, such as a coal fired power station. Human society, if it is to retain some aesthetic value and quality of life, must include the value of such natural environments when considering the placement of a major industrial complex. Likewise, wind turbines must be considered as major industrial complexes that is what they are. Therefore, their placement must be within keeping of the local environment. Industrial zones exist for a reason. So do rural zones. Many would see that the two are incompatible.

2.3 While wind turbines promise a clean, green source of inexpensive electricity, but to claim that they are devoid of negative impacts on local communities is to fly in the face of considerable world-wide experience. Communities across the globe have discovered that far from living up to the promise of being ‘good neighbours’, wind turbine installations instead produce a cocktail of irritating and potentially dangerous side effects.

2.4 The first negative impact is seen to emerge at the construction stage where residents commonly report the visual intrusion of these massive structures on their skyline far exceeds what they believed would be the visual impact. Despite the attempts of developers to provide graphic evidence by way of landscape photographs with the proposed turbines superimposed on them, the reality is that for local residents, the final product far exceeds their initial understanding of the extent of the visual impact. Towering structures loom large on their landscape and are, to many, a blight on their once-peaceful vistas. This is a case of reality striking and no amount of visual modelling can compare to seeing the actual structures sprouting from the ground, often on prominent hills (for obvious reasons). Figure 1 illustrates the relative scale of turbines to residences.

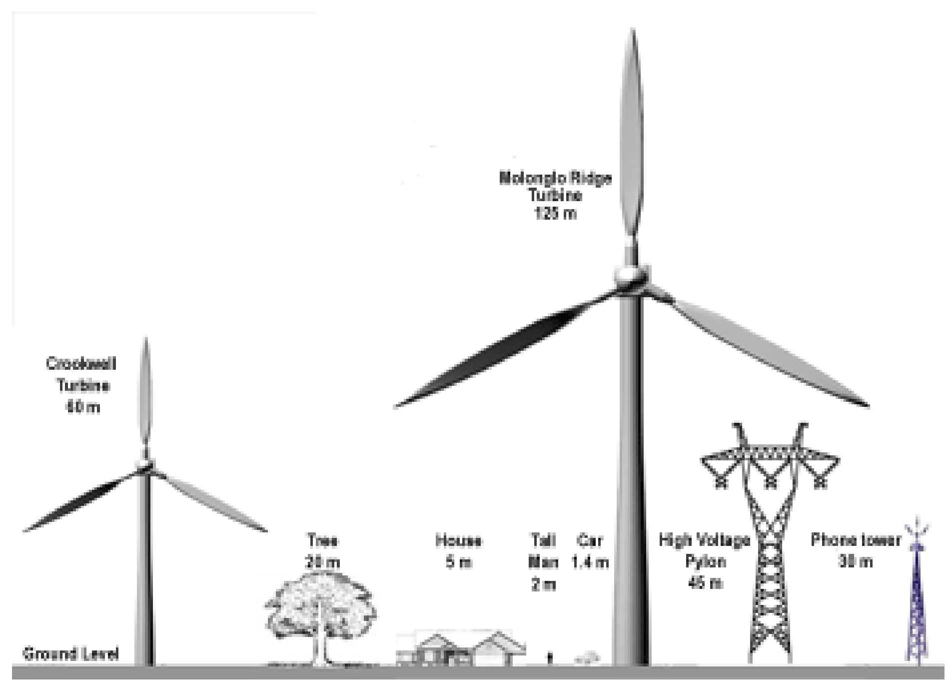

Figure 1: Relative heights of turbines to dwellings
(Source: Molonglo Landscape Guardians, by permission)

2.5 Once the shock of the degree of visual intrusion has been encountered, the sheer magnitude of construction disruption is something that has been seen to alarm many communities. Disruption to road transport and the noise of construction is beyond what most residents imagined would be the case. At this point, many residents begin to feel disenfranchised and misled. They report feeling “invaded”.

2.6 The potential health risks from blade flicker; shadow flicker and glint are considered in the following sections.

3.0 EPILEPSY

3.1 Epilepsy is defined by the World Health Organisation as a chronic disorder of the brain that affects people of all ages. It is characterised by recurrent seizures that are physical reactions to sudden, usually brief, excessive electrical discharges in a group of brain cells. Different parts of the brain can be the site of such discharges.

3.2 Seizures can range from the briefest lapses of attention or muscle jerks, to severe and prolonged convulsions of the muscles. Seizures can also vary in frequency from one in a lifetime to several per day in severe cases. Epilepsy increases a person's risk of premature death by two or three times, compared to the average in the general population.

3.3 One seizure does not signal epilepsy. Up to 10% of people throughout the world will have one seizure during their life. Epilepsy, the disorder, is defined by two or more unprovoked seizures. People with seizures tend to have more physical problems such as broken bones, bruising and higher rates of other diseases or psychological issues.

3.4 The estimated proportion of the general population with active epilepsy, that is, continuing seizures or the need for treatment of them, at any given time is between 4 to 10 per 1000 people. The causes of common epilepsy (idiopathic epilepsy) are unknown and account for around 60% of people with the disorder. Epilepsy with a known cause is called secondary epilepsy, or symptomatic epilepsy. Common causes include brain damage through oxygen deprivation at birth or other trauma, a severe blow to the head, a stroke that starves the brain of oxygen. an infection such as meningitis or a brain tumour. Epilepsy tends to run in families so there may be a genetic component.

4.0 PHOTOSENSITIVE EPILEPSY

4.1 Photosensitive epilepsy is a form of epilepsy in which seizures can be triggered by visual stimuli that form patterns in time or space, such as: flashing lights; bold, regular patterns or regular moving patterns. It is seen in approximately 5% of people with epilepsy which may account for 2,500,000 people world-wide. This may equate to 1 in 4000 of the general population who may suffer an epileptic attack caused by flickering visual stimulation. It is important to note that the rate for 7-9 years olds is approximately 5 times greater than the rest of the population. Further, photosensitivity persists in 75% of the affected population, so it is not just a transitory phase in most cases.

4.2 Diagnosis for photosensitive epilepsy involves exposing the subject to strobe lights or geometric patterns while undergoing an EEG (electroencephalogram). For those so diagnosed, treatment using medication can be effective and the knowledge to avoid such stimuli will be of great practical benefit to them.

4.3 A wide variety of stimuli have been known to stimulate seizures in photosensitive epileptics. These may include: watching television or playing video games; strobe lights such as are found at night clubs; driving at dawn or dusk past a line of trees; looking at fast moving objects, often through a window; geometric patterns or other moving images.

4.4 Factors that determine if the stimuli will produce a seizure include the rate of the flashing (flickering); how much of the field of view is exposed to the flickering and the relative contrast of the flicker. It is generally believed that flickering lights in the general range of 5 to 30 Hz (cycles per second) are prime contenders for causing seizures in those afflicted with photosensitive epilepsy. It is important to know that this can vary widely for particular individuals. It is also worth considering that static objects of particular geometric shape can cause seizures, so flicker rate is not the only problem. With geometric objects, it may have something to do with the eye's natural oscillation known as physiological nystagmus. This is an involuntary flickering of the eye that is a necessary part of the focus mechanism. However in the case of a photosensitive epileptic, this may, on occasion, be partly responsible for a seizure. While physiological nystagmus is necessary for the correct operation of the rod (black and white) and cone (colour) sensing cells in the eye, it can also be a medical condition, if excessive.

5.0 SOURCES OF FLICKER STIMULUS

5.1 There are many sources of flicker that exist within the human environment capable of stimulating an attack in photosensitive epileptics. These include: faulty fluorescent lights; strobe lighting in night clubs; flashing lights on bicycles; rotating helicopter blades; computer and video screens; television; venetian blinds; ceiling fans; driving past a line of trees with the sun behind them; flashing indicator lights on vehicles. All these sources are recorded in the literature as having stimulated epileptic seizures in such sensitive individuals.

5.2 For all these sources, the range of frequencies known to trigger epileptic attacks ranges from around 5 Hz (cycles per second) which affects 10% of the affected population, to around 18 Hz that triggers 90% of photosensitive epileptics. The top end frequency tapers off towards 60 Hz that affects around 10% of the population. In the case of television, computer and videos screens, it is not just the rate of flicker of the basic image, known as the raster, but also the speed of the presentation or movement of the graphic content displayed. It must be remembered that even static images may trigger photosensitive epileptics if the geometric requirements are met. It is also important to understand that any statistics that relate to the incidence of such phenomena are population based, so there will be a natural distribution which means that some individuals will fall significantly outside the ‘normal’ range.

6.0 TURBINES AS A SOURCE OF FLICKER

6.1 In respect of flicker as a trigger for photosensitive epileptics, blade flicker (where the sun is directly occluded by the passing blades) and shadow flicker (the shadow of rotating blades striking the ground or buildings) will be considered together, as both may cause flicker on the retina of an observer.

6.2 Single wind turbines commonly have three blades that rotate around 28 - 30 times per minute can generate a flicker rate of around 1.5 Hz. This is generally considered to be below the common threshold of 5 Hz known to trigger epileptic attacks. If a sensitive individual views two or more turbines in line, then the combined effects of the multiple blades may certainly fall within the danger zone of 3 to 30 Hz. It will also depend on the exact angle of the sun with respect to the turbines and the observer, and the distance of the observer from the turbines as the area of the retina stimulated is also important. If 15% of the retina is subjected to flicker this will trigger epileptic attacks in 10% of the affected population. This figure rises to 100% of the affected population when 50% of the retina is involved. Thus, it is easy to see that for a small but significant percentage of the population, multiple turbines do certainly pose a potential risk of triggering photosensitive epileptics to an attack. If they were driving a vehicle at such a time, the results could be disastrous.

6.3 The potential for harm from flicker is a factor needing to be taken into account by wind farm designers in order to minimise the negative health effects on the human population. More research needs to be undertaken to determine the safe distances between wind farm installations and human population.

7.0 GLINT

7.1 When light reflects off the blades of a turbine, it is termed *Glint*. Its occurrence depends on a combination of circumstances arising from the orientation of the nacelle, the angle of the blade and the relative position of the sun. The reflectiveness of the surface of the blade is also important and is to some extent influenced by the colour and age. The use of matt surfaces may mitigate to reduce glint. While some manufacturers claim to be already using low reflectivity surface finishes on their blades, residents near wind turbine farms continue to report annoyance from blade glint during the day. Another annoying features is the red reflection from safety lights installed for aircraft.

7.2 In some locations the wind farm is required to fit all turbines with red safety lights for aircraft. These lights must be fitted with shrouds to minimise the possibility of glint at night. Residents report that such shrouds have not always been fitted immediately and that the glittering light display is both annoying and detracts from the natural beauty of their environment. While it is difficult to shroud lights, as this limits the viewing angle from an aircraft's perspective, the nuisance value of failing to do so needs to be entered into the equation. Wind turbine designers need to consider the effect of such an invasive technology on local residents and their views must be given serious consideration. Photo 1 illustrates the effect of warning lights on blades and visual effects.

Photo 1: Warning lights and visual effects, a local wind farm

7.3 Blade glint can be a distraction, particularly to drivers where roads align with turbine placement. The phenomenon is able to be viewed at a distance of several kilometres and can thus be a distraction for motorists. One reason for glint's destructive influence is that the rotation of the blades can place the frequency of the effect into the range that is normally used for visual alerts. Indicators on vehicles are but one example of this visual alert stimulation. The frequency is usually in the range of a Hz or two as this has proved to be the most effective at attracting attention. Emergency vehicles utilise this physiological trigger zone to draw attention to a hazardous situation: fire, ambulance and police would be significantly disadvantaged if this were not true. Blade glint simply happens to fall, unfortunately, into this physiological important range. It is also important to remember that emergency signals are used sparingly and only in situations where real danger is a significant possibility. To draw the attention of a driver away from the road could result in a disastrous outcome.

7.4 While not reducing the significance of blade glint falling into the emergency attention zone of visual acuity, the simple human annoyance and destruction of the visual appeal of one's surroundings is also a significant detractor for local residents. To reduce the quality of life for residents close to a wind turbine installation is to put the supposed benefits for the many above the detriment to the few. Balance is called for, particularly when placement could be a simple solution to many of the negative impact effects of wind turbine farms.

8.0 BLADE GLINT & TURBINE PLACEMENT

8.1 When deciding on the location of a new wind turbine farm, due consideration must be given to the possible effects of glint on both residents in the near vicinity, as well as motorists who may traverse roads that align with the turbines. Any untoward visual intrusion from the turbines should be minimised as far as practicable by avoiding the production of visual stimuli such as pulsed glare that might arise from a rotating reflective surface. While not necessarily harmful in the medical sense, the irritation would certainly inhibit the process of mitigating the intrusive nature of wind farm installations on the landscape.

8.2 Industrial installations should have minimal impact on local residents and their placement should include a process that includes considerable consultation with local residents and the full disclosure of any possible impact. Residents near wind farms are quick to criticise developers for failure to do this. In many instances, residents have stated directly and emphatically that they have been lied to by the developers. Such poor public relations do little to smooth the process of continued industrialisation of our landscape. Better communication and honesty is required if this situation is not to proliferate as the drive to develop more wind farms accelerates.

8.3 Any application for siting a wind farm should include a modelling approach that will necessarily include the approximate number of hours per year where meteorological conditions will provide sufficient sunlight to cause annoyance from glint. Average annual cloud cover should be determined from historical records. The atmosphere will also have a strong influence on the visual distraction and annoyance created by rotating blades. The presence of aerosols such as smoke, dust or moisture, will affect the turbines ability to produce both shadows and glint. In some circumstances, such particles in the atmosphere may actually increase glint by producing a larger, though more diffused, image.

8.4 In order to mitigate the possible negative effects of turbines (flicker and glint), the distance from residents and roads needs to be taken into account. The siting of landscape obstructions such as hills and trees may also mitigate visual disturbance.

8.5 The modelling of wind turbines as discs to determine shadow or glint path will overestimate the flicker and glint effect. As the blades are non-uniform, with the thickest part close to the hub and the thinnest being at the tips, depending on the exact position of the sun with respect to the turbine blade, different sized shadows will be cast. Direct sunlight is diffused through the atmosphere resulting in a maximum distance from the wind turbine that a shadow can be cast. The maximum distance is dependent on the human visual threshold that is dependent on the variation of the light perceived. When the blade tip casts a shadow or reflects light, the diffusion of the direct sunlight means that the light variation threshold occurs closer to the wind turbine than when the sun is reflected from or occluded by the blade closer to the hub where the chord is at its maximum. This means that the maximum shadow length cast by the blade, or reflection as glint, is less at the tip than nearer the hub.

8.6 The final factor that is relevant to shadow flicker, and to some degree, glint, is the percentage of time that the turbines are actually rotating. As wind is a very irregular resource, it is unlikely that the turbines will be rotating continuously. Wind data can be obtained that will allow designers to predict the average number of operating hours when sufficient wind is available to operate the turbines. This value can then be assessed considering the individual proposal. One important point is that even static blades can cause glint, so this is likely to be a more persistent problem when the sun's angle is appropriate.

8.7 Minimum guidelines to manage flicker or glint are:

- shadow flicker or blade glint must not fall on any habitable structure or area used for normal habitation;
- Warning lights must not be visible from any residence;
- shadow flicker or blade glint must not fall on any road or residential amenity.

8.8 Once construction has been completed the turbines are commissioned and begin to operate, the final insult to the residents is the unexpected noise of the complex.

9.0 VISUAL CHARACTER AFFECTING SOUND PERCEPTION

9.1 Turbines are towering structures that impose themselves visually and acoustically on their neighbours. The reality is that wind turbines are neither quiet nor unobtrusive. Rather they impose on the once-natural landscape in what many describe as an untidy mess, littering the landscape, detracting from visual amenity and affecting tourism where that is based on the natural beauty of the countryside.

9.2 Many communities report disturbed sleep leading to increased anxiety and a plethora of medical complaints that include headaches, dizziness and vertigo, decreased digestive function and emotional anger. These symptoms should come as no surprise as they are reported world-wide and affected individuals now number in the thousands.

9.3 For some the 'noise' effect of turbines is increased due to the visual effects; that is, "If I can see them, I can hear them". This effect is the interaction of multiple stimuli creating a physiological and / or emotional response that is greater than the individual 'original' visual or acoustical stimuli.

9.3 Turbines produce a range of disturbing frequencies out of place in the natural soundscape extending from the audible range down into infra-sound. Residents frequently report that developers have claimed that the gentle sounds of the turbines will be absorbed or masked by the natural sounds of the environment. The wind in the trees, the sound of a stream. Residents report this as entirely untrue and an insult to their intelligence. Research undertaken by the author and many others has proved these claims of natural sound masking to be without foundation. In the words of the residents: "We have been lied to".

9.4 Further research has shown that the acoustic energy from wind turbines is capable of resonating houses, effectively turning them into three-dimensional loud speakers in which the affected residents are now expected to live. The phenomenon of natural resonance combines to produce a cocktail of annoying sounds which not only disturb the peace and tranquility once-enjoyed by the residents, but also stimulate a number of disturbing physiological effects which manifest in the physical symptoms described above.

9.5 In the opinion of the author, backed up by residents' surveys and scientific measurements and analysis of the noise of turbine farms, these new generating technologies are proving to be a significant detractor for those living within 10 kilometres of them. More research is urgently needed to determine the extent of the nuisance effects and what setbacks are required to minimise the negative effects on resident communities. The long term medical implications are considerable and need to be researched before any further applications for wind farms are consented. Failure to do this, in the opinion of the author, will significantly effect the utilisation of this technology and will produce long-term consequences that will be to the detriment of the whole of society.

Mr Bruce Rapley

Mr Rapley has prepared the evidence in this Annex “Flicker and the Human Perception of Wind Farm Activity”. The Annex is referenced to identify the potential cumulative effects on human perception when audible and visual cues are combined. Mr Rapley is not called to attend this Hearing.

Bruce Rapley has a BSc in Biological Systems and a Master of Philosophy in Technology, both from Massey University, New Zealand. After gaining his BSc, Bruce worked in Plant Physiology and Biochemistry at Massey University in technical and tutoring roles and managed the engineering facility for 14 years. During his 26 years in the university, Bruce developed his passion for scientific research, creating an international reputation in bioelectromagnetics: (the effect of exogenous magnetic fields on living systems). Bioelectromagnetics forms the basis of his master’s thesis in technology systems.

In 2004 Bruce left the university system to create Atkinson & Rapley Consulting Ltd. He took on the role of project manager and designer of a new virtual instrumentation system for measuring and analysing environmental noise: SAM - the Spectro Acoustic Metering System. In order to accomplish this, Bruce set up a calibration laboratory as well as a manufacturing facility to produce the associated equipment and accessories required for the spectro-acoustic meter. Bruce continues to work in consulting and technology research and development, predominantly in the area of environmental acoustics and the effects of technology including bioelectromagnetics on human health.

Annex 7: Sound, Noise, Flicker and the Human Perception of Wind Farm Activity

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CURRICULUM VITAE OF AUTHORS

Dr Daniel Shepherd

Dr Daniel Shepherd received a PhD in psychoacoustics from the University of Auckland, New Zealand, in 2005. Since this time he has attained the position of Senior Lecturer at the Auckland University of Technology, where he lectures in the Faculty of Health in addition to being the Head of Postgraduate Studies in the School of Public Health and Psychosocial Studies. He is an Honorary Research Fellow at the University of Auckland, where he has researched and taught in the Departments of Psychology, Chemistry, and Audiology. The central theme of Daniel's research is the human response to sound, both audiometrically and psychometrically. Past and current research projects, many of them published in academic journals, include new methods in audiometric assessment; the quantification of noise sensitivity and noise annoyance; the relationship between noise sensitivity and quality of life; the development of a model of noise-induced stress; the electrophysiological characteristics of noise sensitive individuals, and; the psychological and physiological determinants of noise sensitivity. Dr Shepherd has represented and consulted with a number of community groups faced with intrusive noise, and argues that noise in the community must be managed with care if it is not to become a health risk.

Dr Huub Bakker

Dr Huub Bakker received a PhD in chemical engineering from the University of Canterbury, New Zealand, in 1989. After working with the DSIR on Advanced Process Control Benefit Studies he became a lecturer at Massey University in Palmerston North where he is currently employed as a Senior Lecturer in the School of Engineering and Advanced Technology. He has published in a broad range of areas including; process control, control systems engineering, mathematical modelling, simulation, distance education, tele-presence systems, evaporators, aerobic digesters, predictive maintenance, image processing, machine vision, software development, wireless positioning systems, physical properties of dairy products, industrial automation, measurement of sound and seismic signals, DSP-based measurement systems. Dr Bakker has acted as a consultant in a number of areas including; process automation, remote measurement and tele-presence systems, mechanical design and IT infrastructure.

Dr Bob Thorne

Dr Bob Thorne established Awhitu Services Ltd, an environmental consultancy, in 1973 in New Zealand. Noise Measurement Services Pty Ltd was established in Queensland in 1999 to narrow the consultancy focus to environmental acoustics. In between times his professional experience has been involved in both the private and public sectors, in the broad fields of environmental and public health. His work in public service has included a senior position as Director of Planning and Regulatory Services for a New Zealand local government, and as a Principal Environmental Officer for the Department of Environment and Heritage (now the EPA) in Queensland. The work undertaken by Noise Measurement Services Pty Ltd involves specialised acoustical and psychoacoustical investigations for public authority, commercial and industrial clients. His current research work involves using 'smart' technology for intrusive noise assessment and environmental monitoring systems with simplified data analysis and information retrieval protocols. A specific application is personalised sound reinforcement for hearing assistive devices. General acoustical work includes environmental noise surveys, social surveys and analysis, health impact assessment and noise impact prediction modelling. Bob holds a PhD from Massey University New Zealand in health science with the topic ‘Assessing intrusive sound and low amplitude sound’. Bob is the Principal of Noise Measurement Services Pty Ltd, Research and Development director for IEDISystems Pty Ltd and an Environmental Health Research Associate in the Institute of Food, Nutrition and Human Health, Massey University.

Dr John Heilig

Dr John Heilig is an engineer (PhD Mining Engineering, University of Queensland) with in excess of 20 years extensive specialised international experience in vibration related engineering. John professional competencies include: optimisation of excavation design, both underground, including tunnelling, and open-pit to maximise cost effectiveness; control and minimisation of ground and airborne vibrations (blasting and mechanically induced) from mining, quarrying and construction activities; dilapidation surveys of infrastructure, including identifying the extent of the surveys and the area which dilapidation surveys should be undertaken; structural and vibration monitoring from blasting and other mechanical methods of construction and the comparison of these vibration levels with Australian Standards and other criteria to avoid structural damage and minimise human annoyance. To assist this work John has developed, tested and proven, vibration related computer based data acquisition and remote monitoring systems for monitoring and control purposes with specialised vibration prediction and modelling programs as part of the vibration assessment methodologies.

Professor Philip Dickinson

Philip Dickinson is semi-retired and Professor of Acoustics at Massey University Wellington New Zealand. He is a graduate of London University with degrees in mathematics and physics, and received his Ph.D., in acoustics from the Institute of Sound and Vibration Research in the University of Southampton. As Senior Research Fellow at the Institute of Sound and Vibration Research, he produced one of the very first mathematical models to predict the noise from aircraft operations – a model that has formed the basis for most computer models in use today for that purpose. He followed this as Associate Professor of Bioengineering, and Adjunct Professor of Electrical Engineering at the University of Utah. In 1982 he accepted the position of Associate Director of the Acoustics Institute in Auckland University New Zealand, and then worked with the NZ Department of Health (now Ministry of Health) as their Principal Scientist. For many years Philip Dickinson was New Zealand's (and Australia's) representative on International Standards Committees for acoustical instrumentation, and has represented both countries at international meetings. He is the principal author of a number of national and international standards and is a working member of several national and international acoustics standards working groups.

Philip Dickinson is a fellow of a number of scientific societies; has given invited lectures to more than 20 universities and professional bodies including the Russian Academy of Sciences, NATO, the United States Airforce, the United States Navy (Southern Division) , the Royal Aeronautical Society and the Royal Society of New Zealand; has lectured to Local Authorities, Architects, Town Planners, and invited audiences throughout the United Kingdom, the United States, Canada, Indonesia, Australia and New Zealand; and has more than a hundred publications to his name including six major scientific treatises.

Mr Bruce Rapley

Bruce Rapley has a BSc in Biological Systems and a Master of Philosophy in Technology, both from Massey University, New Zealand. After gaining his BSc, Bruce worked in Plant Physiology and Biochemistry at Massey University in technical and tutoring roles and managed the engineering facility for 14 years. After working as a tutor in technology for two years he was appointed Marketing Manager for the department. In his role as a promoter of technology and science, he developed the Science Alive programme, encourage young students to enter the sciences as a precursor to a career in technology and engineering. Bruce wrote a manual for forensic science and developed The Forensic Experience, a hands-on learning programme working with the New Zealand Police teaching the application of science as experienced through real forensic analysis of crime scenes. During his 26 years in the university, Bruce developed his passion for scientific research, creating an international reputation in bioelectromagnetics: (the effect of exogenous magnetic fields on living systems). Bioelectromagnetics forms the basis of his master's thesis in technology systems.

In 2004 Bruce left the university system to create Atkinson & Rapley Consulting Ltd. Here he was to apply his diverse skills and knowledge base to a variety of community-based consulting projects involving science, technology, social marketing, market research, project management and assessment and product development. He utilises the Delphic Systems approach for business, environment and community consulting projects. In 2004 Bruce took on the role of project manager and designer of a new virtual instrumentation system for measuring and analysing environmental noise: SAM - the Spectro Acoustic Metering System. In order to accomplish this, Bruce set up a calibration laboratory as well as a manufacturing facility to produce the associated equipment and accessories required for the spectro acoustic meter. Bruce continues to work in consulting and technology research and development, predominantly in the area of environmental acoustics and the effects of technology on human health - including bioelectromagnetics.

Mr Mark Simpson

Mark Simpson is a mechanical engineer, a graduate of the University of Queensland. After graduating in 1985 he commenced work as a consulting engineer in the field of acoustics, vibration and air quality with WBM. Mark worked throughout Queensland on a wide variety of projects including numerous major architectural projects, noise control of equipment, environmental and mechanical design studies. After a period of 7 years Mark joined Dames & Moore (now URS) and was attached to the nation-wide air quality and noise group. Mark carried out studies throughout Australia. After a period of 18 months Mark jointly commenced Kamst & Simpson (now ASK Consulting Engineers). Over the following 12 years Mark continued to consult in the area of noise, vibration and air quality. In July 2005 Mark commenced Noise Mapping Australia to continue consulting in the area of noise, vibration and air quality. Mark has always maintained high level technical capability in the area of noise, vibration and air quality. His particular specialities are the modelling and assessment of environmental noise, vibration and air quality associated with major projects. This includes regenerated noise from tunnelling vibrations. The PEN3D environmental noise modelling software developed by Mark has been purchased by Acoustical consultants in Victoria, NSW and Queensland. Specialised models have been developed for quarry blast analysis (airblast overpressure referenced to blast-pad design) and wind farm sound propagation. At Noise Mapping Australia Mark has continued to consult on major projects and has or is currently working on impact studies for several major mining developments as well as the construction phase of the North-South bypass tunnel and Airport Link project.

Dr Dave Bennett

Dr Bennett is a director of several public companies, namely: Trans-Orient Petroleum Ltd, Rift Oil Plc, Tiger Petroleum NL. Dr Bennett has a BA (Cantab) in Natural Sciences (Physics/Maths); an M Sc (Leeds) in Exploration Geophysics, and a PhD (Australia National University) in Geophysics. In his work capacity he acts as adviser to various NZ energy and electricity generation companies, and has played a significant role in the discovery of several of NZ's existing oil and gas fields. He led the commissioning of a 1 MW power plant using associated gas from a Taranaki oil field. He has chaired full day sessions of the annual NZ Electricity Conference. Also of relevance is that he has considerable experience in conducting seismic surveys, where energy is propagated through the ground from explosive or vibratory sources. In this capacity I have had direct dealings with residents affected by noise propagation through the ground and affecting their residences in the form of audible noise and/or vibration. Dr Bennett is a resident of the Makara Valley near Wellington, sited close to Meridian's proposed West Wind wind turbine complex.

Mr Max Thorne

Max is the Chief Executive Officer and is a Director for Noise Measurement Services Pty Ltd, an environmental noise consultancy and IEDISystems Pty Ltd, a research and development company working with smart-systems for sound reinforcement. After seven years with Noise Measurement Services, Max has significant experience in noise survey work and the industry generally. Max is a qualified legal practitioner having been admitted as a barrister and solicitor of the High Court of New Zealand in 1996. He qualified with a Bachelor of Laws (Otago University) in 1995. For five years he was a solicitor for New Zealand’s largest manager of civil litigation and had responsibility for managing a large number of proceedings, including negotiated settlements and researching and advising on civil procedure, preparing briefs for Counsel, conducting complex procedural matters at District and High Court Level, conducting Examination hearings and liaising and negotiating with the Courts, training and mentoring other qualified and non-qualified staff, and developing procedures and precedent documents. His further experience included drafting pleadings for Barrister specialising in Civil Litigation, including contractual disputes, building/construction. In 1999 Max moved to England and worked as Financial Controller to group of companies directed by Harvey Goldsmith CBE, Promoter. Max separately worked for other companies in the entertainment industry, and an engineering firm specialising in mechanical services. In 1999 Max represented the National Environmental Noise Service on behalf of the Ministry of Health (New Zealand) at a working party of the World Health Organisation at Kings College, London UK. The resultant document was the *Guidelines for Community Noise,* which remains one of the most frequently cited guidelines for community noise assessment, perception and control.

Mr Bryan Leyland

Bryan Leyland MSc, FIEE, FIMechE, FIPENZ, is an Electrical and Mechanical Engineer specialising in power generation and power systems. He was the IPENZ "Communicator of the Year" 2001. Bryan's career started in 1956 as a cadet engineer for the Auckland Electric Power Board. In 1961 he sailed to Tahiti on a yacht and then on to USA on a sailing ship. After nine years varied experience he returned to NZ in 1970 to work for Lloyd Mandeno, one of NZ's great engineers. In 1974 he set up his own consulting firm. The firm merged with Sinclair Knight Merz in 1998. He retired from Sinclair Knight Merz in 2002 and now acts as a power industry consultant. Since 1992, he has often warned of the need to prepare for the run-down of the Maui field, the need for government to monitor supply and demand and the increasing risk of blackouts and shortages.

He has never believed that our electricity "market" would work. He proposed an alternative market based on coordinated operation and competitive generation.

He has acted as an expert witness for people opposing wind farms. His evidence concentrated on the high cost of wind power and the problems and costs it imposes on the rest of the system.

He has been interested in climate change for several years and his views have changed as he has learned more about the uncertainties underlying claims of manmade global warming.

He has worked in the UK, Middle East, Africa, Asia and the Pacific.

Statement of Qualifications and Experience, Dr Robert Thorne

1.1 My name is Robert Thorne. I am the Principal of Noise Measurement Services Pty Ltd, Brisbane Australia. I have had 36 years' experience in the measurement and assessment of noise and the effects of noise on people. This experience has been gained in both public service and private practice.

1.2 I hold the degree of Doctor of Philosophy in Health Science from Massey University. The research topic was "Assessing Intrusive Noise and Low Amplitude Sound". I specialise in the measurement of low background sound levels and the assessment on noise on people. Wind farms with their unique characteristics of sound and noise are of particular interest.

1.3 I hold specialised qualifications in acoustics with the New Zealand Diploma in Science (environmental noise, 1985) and the post-graduate Diploma in Acoustics from the Institute of Acoustics (UK), 1985. I am qualified in health engineering (Royal Society for the Promotion of Health (NZ) Diploma in Health Engineering, 1981). I am a Fellow of the Royal Society for the Promotion of Health (UK) and a member of various acoustical societies.

1.4 I have a long standing interest in health education and risk assessment and have been involved in the preparation of New Zealand Standards dealing with noise.

1.5 In 2007 I was appointed as a Committee Member representing the Australian Acoustical Society on the International Institute of Noise Control Engineering Technical Study Group 7. The Group is working on a global approach to noise control policies in order that an effective international noise control policy may be developed and implemented.

1.6 I have professional experience in the development, conduct and presentation of acoustical and attitudinal surveys. In 1992-93, for example, I undertook extensive acoustical and attitudinal studies for 5 local governments in the South Island, New Zealand. The research was based on the USEPA methodologies and approximately 1200 interviews and 290 acoustical surveys were conducted. A summary of the surveys was presented at the 1993 New Zealand Acoustical Society Conference. I have maintained my involvement in acoustical and attitudinal studies since then.

1.7 As a Principal Environmental Officer in the Department of Environment and Heritage (now the Environmental Protection Agency EPA) Queensland I was responsible for drafting, promoting and costing the Environmental Protection (Policy) Noise 1997. The Policy was recently revised (2009). The purpose of the Policy is the defining of a balance between the opportunity for industry to exist, and the acoustical amenity within the home and private open space outside the home. Queensland legislation also places considerable emphasis on background sound levels and intrusive sound, as well as the audibility and characteristics of potential noise in order for a proper assessment to be made of noise intrusion.

1.8 My previous work experience included approximately 18 years in total as an environmental health officer for various Councils in New Zealand. In these varied roles I had daily interaction with the public and daily experience with noise complaints under the Noise Control Act. For approximately 3 years I worked for a NZ local authority in the position of Director of Planning and Regulatory Services. Later, for two years I was an advisor with the NZ National Environmental Noise Service as part of its health promotion duties to assist Health and Hospital Services to improve, protect and promote public health.

1.9 I am an Environmental Health Research Associate with the Institute of Food, Nutrition and Human Health, Massey University, New Zealand.

1.10 My experience with the acoustical nature of wind farms includes acoustical and human assessments before the New Zealand Environment Court with respect to the West Wind (Makara) wind farm, the Motorimu wind farm and the Turitea wind farm. My involvement with these three wind farms has been since 2005. I have also investigated complaints of noise from the Te Apiti, Tararua, Te Rere Hau and Makara (New Zealand) and Waubra (Victoria) wind farms. I am currently involved with other wind farm hearings in Victoria and New South Wales.

1.11 As part of my doctoral research into assessing intrusive noise and low amplitude sound I spent some two years' studying the effects of wind farms on people in the Manawatu. The basic research was to develop a method of assessment for intrusive noise and instrumentation for low amplitude sound. The research work included attitudinal and acoustical studies with people affected by wind farms and people not affected. My research is published in my thesis.