Noise Impact Assessment Report
Waubra Wind Farm

Mr & Mrs N Dean

Report No 1537 - Rev 1 - July 2010

NOISE MEASUREMENT SERVICES

DOCUMENT CONTROL PAGE

NOISE MEASUREMENT SERVICES PTY LTD
18 Lade Street Enoggera Qld 4051
PO Box 3429
South Brisbane BC, QLD 4101

Telephone: (7) 3355 9707
Facsimile: (7) 3355 7210
E-mail: info@noisemeasurement.com.au
ABN 70 084 643 023

Revision No	Issue Date	Revision Description	Reviewed By	Issued By
0	23/6/2010	Report	PM	BT
1	10/7/2010	Expand sonograms Minor revisions to text Reading List	PM DS, HB	BT

Copy No(s)	Rev No	Destination
1	1	Mr & Mrs N Dean
2	1	Noise Measurement Services

REPORT FOR **Mr & Mrs N. Dean**

Signed

Dr Bob Thorne

DISCLAIMER

This Report by Noise Measurement Services Pty Ltd is prepared for a particular Client and is based on the agreed objective, scope, conditions and limitations as may be stated in the Executive summary. The Report presents only the information that Noise Measurement Services Pty Ltd believes, in its professional opinion, is relevant and necessary to describe the issues involved. This Report has been peer-reviewed. Critique from persons having researched conclusions different from the author will considered only if such critique is supported by evidence researched by the person presenting the critique and must be supported by a statement of qualifications and experience.

The Report should not be used for anything other than the intended purpose and should not be reproduced, presented or reviewed except in full. The intellectual property of this Report remains with Noise Measurement Services Pty Ltd. The Client is authorised, without payment to Noise Measurement Services Pty Ltd, to provide this Report in full to any third party.

CONTENTS

EXECUTIVE SUMMARY 6

1 INTRODUCTION 9

2 NOISE CRITERIA AND LIMITS 10

Compliance by Noise Numbers 10

Adverse health effects 12

The Problems with Compliance Levels 12

3 PREDICTION OF WAUBRA SOUND LEVELS 14

Background 14

Predicted sound levels 15

4 AMBIENT WAUBRA SOUND LEVELS 19

The Effects Of Weather 26

Audible sound character 28

Sound character at 377 Stud Farm Road and near locale 29

Glossary to Terms 51

5 SOUND AND HEALTH 52

Introduction 52

What is noise 52

Who decides if noise is a health issue? 53

Defining Annoyance 55

Summary 56

6 VIBRATION IMPACT ASSESSMENT 58

Vibration Effects at Stud farm Road 58

Summary of Property Data 60
External in Ground 60
External walls of the property 61
Shed 62
Summary 62

Conclusion 63

7 WIND FARM NOISE AND HUMAN PERCEPTION 64

8 NZS6808 WIND FARM NOISE STANDARD AND UNREASONABLE NOISE 66

BACKGROUND CHAPTERS 68

CHAPTER 1: AUDIBLE SOUND AND NOISE 69

Low Frequency Sound and Infrasound 76

CHAPTER 2: CHARACTERISTICS OF MULTIPLE AND SINGLE WIND TURBINES 81

Wake and Turbulence Effects 85

CHAPTER 3: PREDICTION OF SOUND LEVELS – APPROACHES AND LIMITATIONS 88

CHAPTER 4: ASSESSING INTRUSIVE NOISE AND LOW AMPLITUDE SOUND 95

Introduction 95

Sound Analysis 96

Analysis of Low Amplitude Sound 101

Individual Amenity, Noise and Annoyance 101

Intrusive sound 102

Noise 102

Intrusive Noise 102

Environmental Noise Assessment 104

Assessing Sound and Noise in Objective Terms 106

Perception of Sound and Intrusive Noise 107

CHAPTER 5: RESPONSES OF RESIDENTS NEAR WIND FARMS 109

Community and Individual Noise Exposure 109

The Effects on People near the Waubra Wind Farm, Victoria 110

The Effects on People near the “West Wind’ wind farm, New Zealand 115

The Effects on People near the ‘Te Rere Hau’ Wind Farm, New Zealand 121

CHAPTER 6: INDIVIDUALS’ PERCEPTION OF WIND FARM SOUNDS 125

Introduction 125

The Manawatu – Brisbane Pilot Study 125

A Study of Noise Sensitivity vs. Specific Sounds 129

Noise Annoyance 130

Makara and Waubra studies into adverse health effects 131

Community perception and acceptance of wind farms 132

Conclusions 133

CHAPTER 7: WIND FARMS AND HEALTH EFFECTS 134

Epidemiology, health risks and the real-world... 136

CHAPTER 8: ANNOYANCE, AUDIBILITY, LOW AND INFRASOUND PERCEPTION 137

Human Auditory, Psychoacoustical And Physiological Perception In Relation To Low Frequency Sound 143

CHAPTER 9: FLICKER AND HUMAN PERCEPTION 146

Introduction.. 146

Epilepsy.. 147

Photosensitive Epilepsy 148

Sources Of Flicker Stimulus 149

Turbines As A Source Of Flicker 149

Glint 150

Blade Glint & Turbine Placement 151

Visual Character Affecting Sound Perception 152

STATEMENT OF QUALIFICATIONS AND EXPERIENCE, ROBERT THORNE...................... 154

STATEMENT OF QUALIFICATIONS AND EXPERIENCE, BRUCE RAPLEY......................... 156

STATEMENT OF QUALIFICATIONS AND EXPERIENCE, DR JOHN HEILIG 156

REVIEWER, DR DANIEL SHEPHERD 157

REVIEWER, DR HUUB BAKKER 157

RECOMMENDED READING.. 158

EXECUTIVE SUMMARY

Findings

Mr and Mrs Dean have requested a Report providing an assessment of the potential for adverse effects due to activity from the Waubra wind farm while living in their residences and while working on their farms.

My research to date for this investigation indicates “ordinary” wind has a laminar or smooth infrasound and low-frequency flow pattern when analysed over short periods of time. Wind farm activity appears to create a “pulsing” infrasound and low-frequency pattern. These patterns are illustrated in sonograms in this Report. My hypothesis at this stage is that wind farm sound has an adverse effect on individuals due to this pulsing nature, as well as audible noise due to the wind turbines. These effects may be cumulative. Research into this hypothesis is described further in this Report.

It is concluded, from the information presented, that Mr Dean has been and is currently adversely affected by the presence and activity of the Waubra wind farm. The effects stated by Mr Dean as affecting his health and statutory declarations from his family and residents in the vicinity of the wind farm attest to adverse health effects. Adverse health effects such as sleep disturbance, anxiety, stress and headaches are, in my view, a health nuisance and are objectionable and unreasonable.

Evidence

The evidence presented in the Chapters to this Report has been submitted as expert evidence to different wind farm hearings; Turitea (Board of Inquiry, New Zealand); Berrybank, Mortlake, Stockyard Hill and Moorabool (Panel Hearings, Victoria); as well as being part of submissions for other parties in New Zealand, New South Wales and Victoria. At no time has the evidence been significantly challenged or rebutted by the wind farm applicant, the consultants or the legal practitioners employed by the applicant(s). Some evidential detail has changed between hearings; critique from earlier hearings has been addressed in subsequent evidence. This report is the final in the Victorian evidential series.

In summary, it appears that the individual developers and their advocates have chosen to take the stance that the New Zealand wind farm standard NZS6808 (either the 1998 or 2010 versions) is both adequate and acceptable. For reasons stated in this Report this stance is neither valid nor credible.

The Report is presented in three parts:

- A sound level survey Report presenting measured sound levels at the Dean's properties and assessment of effects;
- Human perception and potential adverse effects of wind farm activity; and
- A series of Chapters to explain the potential effects of wind farm activity in relation to the measured sound characteristics.

Wind farm sound analysis presents three distinct issues:

- The identification of sound that can be directly attributed to the sound of the wind farm/turbines, measured as a background sound level, compared to the sound of the ambient environment without the presence of the wind turbines;
- The sound of any special audible characteristics of the wind farm/turbines, such as distinct tonal complexes and modulation effects (amplitude and frequency) that may affect human health through sleep disturbance, for example; and
- The presence of any sound characteristics that may affect human health.

Wind has audible and sub-audible character. That is, measurement of wind sound will always present sound levels in the audible, low-frequency and infrasonic frequencies. Sound in the low frequencies and infrasound frequencies can be heard if the sounds are loud enough. The sounds, however, may be perceptible rather than heard at relatively lower levels of "loudness".

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

The research recorded in this Report is in addition to the peer-reviewed evidential text *Sound, Noise, Flicker and the Human Perception of Wind Farm Activity* presented at the proposed Turitea Wind Farm Board of Inquiry Hearing, Palmerston North New Zealand, March 2010.

In June 2010 the Australian Government National Health and Medical Research Council released a Paper entitled *"Wind Turbines and Health: A Rapid Review of the Evidence".* The NHMRC paper does not identify its author(s), is not peer-reviewed, and is superficial in comparison to this Report. In my view the NHMRC paper has no standing.

Conclusions

It is concluded that wind farm noise prediction, as implemented under NZS6808 (the New Zealand wind farm standard) is not adequate in assessing potential adverse effect and implementation of the standard does not and will not provide an acceptable level of amenity. Application of the standard does not provide a conservative assessment of sound levels that may be experienced under different meteorological conditions. The reasons for this conclusion are presented in this Report.

It is concluded that, during the term of the survey, for the reasons given in this report it can not be clearly proven or not proven that the wind farm exceeded at the H41 residence the compliance criteria of 40 dB(A) measured as the background level, LA95, or the 'background plus 5dB' sound level, whichever is the greater. This is due to the failure of the approval conditions to provide clear and specific methodologies to measure wind farm sound under compliance testing conditions or under complaint conditions.

It is concluded from the survey that "background" compliance monitoring is not sustainable as there is no proven methodology to accurately measure wind turbine sound, complaints especially, in the presence of ambient sound.

It is concluded that, during the term of the survey, the wind farm exhibited special audible characteristics that can be described as modulating sound or as a tonal complex. The inclusion of the penalty for special audible characteristics may bring the wind farm into non-compliance, for the reasons stated in this Report.

It is concluded that compliance monitoring must include real-time measurement of special audible characteristics such as modulating sound in accordance with the Permit Conditions.

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

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

Recommendations

It is recommended that a longer–term observed study be completed at 377 Stud Farm Road and the near locale in order to verify wind farm sound levels and sound character under varying weather conditions and wind farm operational activity.

It is recommended that an attitudinal and health risk assessment study be undertaken to assess health effects due to wind farm exposure (Waubra locale) and non-exposure (well away from any wind farms) using both objective and subjective measures.

Peer Review

The Report addresses critiques presented by Dr D. Shepherd and Dr H. Bakker.

Dr R. Thorne PhD, MS, FRSH, MIOA, MAAS

1 INTRODUCTION

This report is in response to a request from Mr and Mrs N. Dean for a noise impact assessment of the wind farm at Waubra, Victoria, with respect to their residences and farms. The wind farm is in close proximity to their farm and they report adverse health effects that have occurred since the wind farm started operating. The affected residences are at 377 Stud Farm Road (house 41 on the plan of February 2005) and 325 Talbot Road (house 46 on the plan of February 2005). Mr Dean is primarily concerned about adverse health effects while he or members of his family are working on the land at either Stud Farm Road or Talbot Road.

Plate 1: Waubra Wind Farm and Residences

2 NOISE CRITERIA AND LIMITS

In order to focus on the issues involved, the first consideration is the authority under which the wind farm operates. The wind farm compliance requirements are established under the Department of Sustainability and Environment Permits issued on 26 May 2005; Planning Permits Pyrenees Planning Permit PL-SP/05/0150 and Ballarat Planning Permit PL-SP/05/0152 for the purposes of the Waubra Wind Energy Facility. The facility is operated by Acciona Energy. With respect to noise, the two permits are similar and establish the criteria to be observed and the compliance sound levels to be achieved by the wind farm operator:

Compliance by Noise Numbers

NOISE

14. The operation of the wind energy facility must comply with the New Zealand Standard 'Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators' (NZ 6806:1998) (the 'New Zealand Standard'), in relation to any dwelling existing at the date of approval of this document to the satisfaction of the Minister for Planning.

In determining compliance with the New Zealand Standard, the following apply:

(a) The sound level from the wind energy facility, when measured outdoors within 10 metres of a dwelling at any relevant nominated wind speed, should not exceed the background level (L95) by more than 5dBA or a level of 40dBA L95, whichever is the greater.

(b) When sound has a special audible characteristic, the measured sound level of the source shall have a 5 dB penalty applied.

(c) Compliance at night must be separately assessed with regard to night time data. For these purposes the night is defined as 10.00pm to 7.00am. For sleep protection purposes, a breach of the standard set out at 13 (a), for 10% of the night, amounts to a breach of the condition.

Condition 14 does not apply if an agreement has been reached with a specific landowner through which the landowner accepts predicted noise levels and/or appropriate acoustic attenuation measures are installed for the landowner to ensure a reasonable level of acoustic amenity in relation to the indoor habitable areas of any dwelling, and acknowledges that the operation of the wind energy facility may still generate noise in outdoor areas on the land which may from time to time exceed the New Zealand Standard.

This exemption is limited to dwellings on land on which turbines are erected and where the dwellings are occupied by the persons deriving rent from turbines on the land and their immediate family or persons employed by the wind farm operator and their immediate family.

15. Before the use commences, details of a noise complaint, evaluation and response process must be submitted to and approved by the Minister for Planning to address any alleged breaches of Condition 13. This evaluation process should include, but not be limited to the following components:

(a) A noise complaint telephone service;

(b) Details of validity requirements for noise complaints (that is: date, time, noise description and weather conditions at the receptor);

(c) Response protocol to valid noise complaints;

(d) A register of complaints, responses and rectifications which may be inspected by the Minister for Planning;

(e) Provision for review of the complaint and evaluation process, including review of the process 6 months after commencement of the operation of the wind energy facility.

16. Where condition 14 is found to have been breached, the Minister for Planning shall notify the wind energy facility operator, with a request that steps be taken to ascertain the relevant meteorological circumstances at the time of breach and to noise optimise the operation of the relevant turbine or turbines in such circumstances. If there is a further breach in similar circumstances, the Minister for Planning shall notify the wind energy facility operator, with a request to noise selectively shut down the operation of the relevant turbine or turbines in those circumstances. In circumstances where optimisation or selective shutdown routines have been requested but not reasonably implemented, or have been implemented but have not prevented further instances of recorded breach, the relevant turbine or turbines will be required to be decommissioned and removed.

17. An independent post-construction noise monitoring program must be commissioned by the proponent within 2 months from the commissioning of the first generator and continue for 12 months after the commissioning of the last generator all to the satisfaction of the Minister for Planning. The program must be carried out in accordance with the New Zealand standard as

varied by condition 13 (a), (b) and (c) above. The permit holder must pay the reasonable costs of the monitoring program.

18. An independent report summarising the results of the monitoring program, and the data collected, and indicating compliance or non compliance with the New Zealand Standard, must be forwarded to the Minister for Planning within 45 days of the end of the monitoring period. The results must be written in plain English and formatted for reading by lay people.

19. The Minister for Planning must make a copy of the report and any data available as soon as practicable during office hours for any person to inspect free of charge.

In summary, compliance depends on measurable wind farm sound levels and the measurement of special audible characteristics. Both these issues are discussed in detail in this Report. The reference to 13(a) is incorrect. The reference should be to 14(a). The wind farm is obliged to meet the compliance noise criteria of Condition 14. The standard is NZS6808.

Condition 14 relates to measured background levels under nominated wind speeds. This assumes that background sound levels have been recorded at the residences prior to the wind farm commencing and that the background levels have been recorded properly with a sound level meter that has a noise floor below 20 dBA. Rural background sound levels will drop below 20 dBA at night under low wind conditions at the residence while wind speeds at the turbines may be considerably higher.

Condition 14 of the Waubra wind farm conditions does not state how background sound levels attributable to the wind farm can be separated from background sound levels generated in the general environment. On this basis, compliance can not be determined.

Adverse health effects

Adverse health effects are addressed under the provisions of the Health Act. The provisions of Section 40 of the Health Act would appear to address the potential for nuisance from a wind farm, and should be considered further through legal opinion. The core issues of "dangerous to health" and "offensive" have been covered extensively within this Report within both external authoritative references and firsthand accounts. "Offensive" under the Act means noxious, annoying or injurious to personal comfort. It is the duty of the Council to remedy as far as reasonably possible, all nuisances in the district. The above provisions are matters that must be discussed with a legal representative with respect to the planning permit conditions and any application for mitigation of nuisance conditions.

This Report provides substantive observational, complaint and researched Report for the consideration of nuisance and offensiveness in the context of public health, individual adverse health effects and potential noise from the wind farm. The issues of adverse effect affecting individuals from the operation of the Waubra wind farm are placed in the context of complaint histories from two other large wind farms operating for a similar time to the Waubra wind farm.

The Problems with Compliance Levels

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 1** illustrates the issue: there are 3 separate sets of background influencing sound sources – local ambient, the turbines, and distant sources. It is not possible to separate out the contribution of each source once it is recorded as a single-value (e.g. LA95) at a specific location, such as a residence.

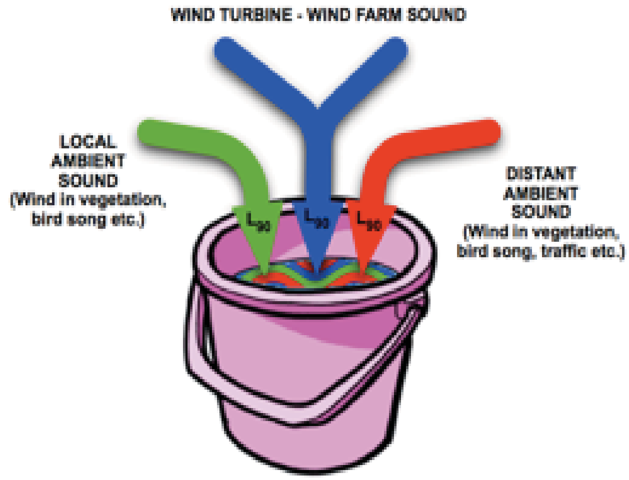


Figure 1: "Bucket of mixed sound" as L_{A95} level.

By way of example, pour a glass of milk (noise specifically from wind farm activity) into a glass of water (the ambient sound around a residence). Add some extra water for distant sound (wind in trees, distant water pumps, and so on) that affects the background. Now remove the milk. Difficult? Impossible. The three components are completely intermingled. Unfortunately the example holds true for whatever combination of 'single-value' acoustical descriptors are used to describe wind farm mixed with ambient sound levels. A practical alternative is to identify a set of sounds that are specific to the wind farm that are not a characteristic of the receiving environment and reference these sounds. The levels are recorded as, for example, Z-unweighted sound levels in third-octave or 1/12 octave bands. Still difficult, but not impossible.

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

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

It is on this fundamental issue that any standard or condition requiring a wind farm to comply with a specific compliance level will fail 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 levels, turn the turbines on, measure the wind farm and ambient sound levels together, assess the variation and then come to some decision as to compliance. This procedure only applies to an audit process and fails, of course, if noise complaints are being investigated when the wind farm noise and the ambient sound are completely mixed together and the wind farm sound is not clearly dominant.

3 PREDICTION OF WAUBRA SOUND LEVELS

Background

The following is an overview assessment of predicted sound levels at the Stud Farm Road residence and nearby locations. Sound level predictions are not “accurate”; they do not present the sound levels that will be heard at any one location at any one time. Rather, a prediction is a mathematical equation referenced to a lot of assumptions and uncertainties. Because of this, the predicted levels are also “uncertain”. The art in prediction is to identify all the assumptions and uncertainties to present a realistic assessment under realistic daily conditions. This is extremely difficult to do and cannot be done with the simplistic prediction method given in the New Zealand standard (1998 or 2010 versions). The reasons for this are given in this Report.

The Stud Farm Road locale is presented in Plate 1. The figure presents the location of the two affected residences, 377 Stud farm Road (377) and 325 Talbot Road (325). The location of the wind turbines in the locale are shown as the white pads on the Plate. More detail is shown in Plate 2. The turbines nearest to the residence at 377 Stud farm Road are approximately 2000 – 2200 metres to the north north-west, 3500 metres to the north-west, and 1740 – 2240 metres to the south / south-west. The turbines nearest to the residence at 325 Talbot Road are between 1950 – 2700 metres to the north-west.

Plate 1: Location of the residences and near wind turbines.

The residences are shown in Plate 2 with their Acciona reference numbers. Residence H41 is 377 Stud Farm Road and residence H46 is 325 Talbot Road.

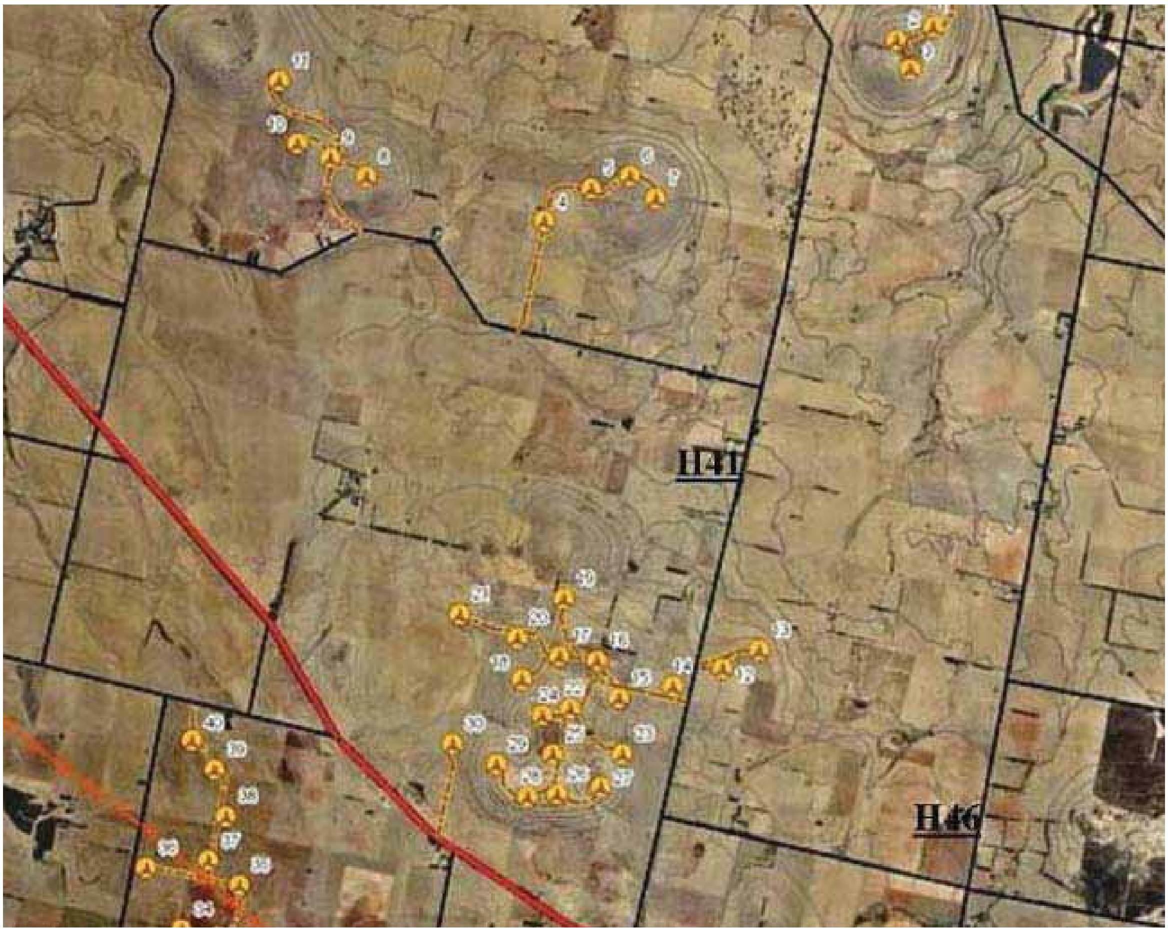


Plate 2: Residences and turbines

Predicted sound levels

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 contained in Appendix C of the 2006 Marshall Day report. The predicted sound levels from the operation of the wind farm are presented in Plate 3. The closest prediction method to the NZS 6808 guideline prediction method is ISO 9613-2 which is implemented by PEN3D. The weather assumptions for the model were calm conditions 20°C, 50% relative humidity and air absorption relative to frequency, temperature and humidity. Digital terrain map topographic information was used to create the model. Turbine locations were assigned according to their Google landform locations. The prediction method is described in detail elsewhere in this Report.

The predicted sound level at the 377 Stud Farm Road (H41) property is 36.4 dB(A) Leq and 33.3 dB(A) Leq at 325 Talbot Road (H46). Table 4 of the Marshall Day Report predicts (assesses) an

LAeq level due to the wind farm as 37 dB(A) at house H40. House H40 is closer to the turbines to the south than H41 so there is very good agreement between the models. No level is calculated By Marshall Day Acoustics for Talbot Road. 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 a prevailing south-west breeze.

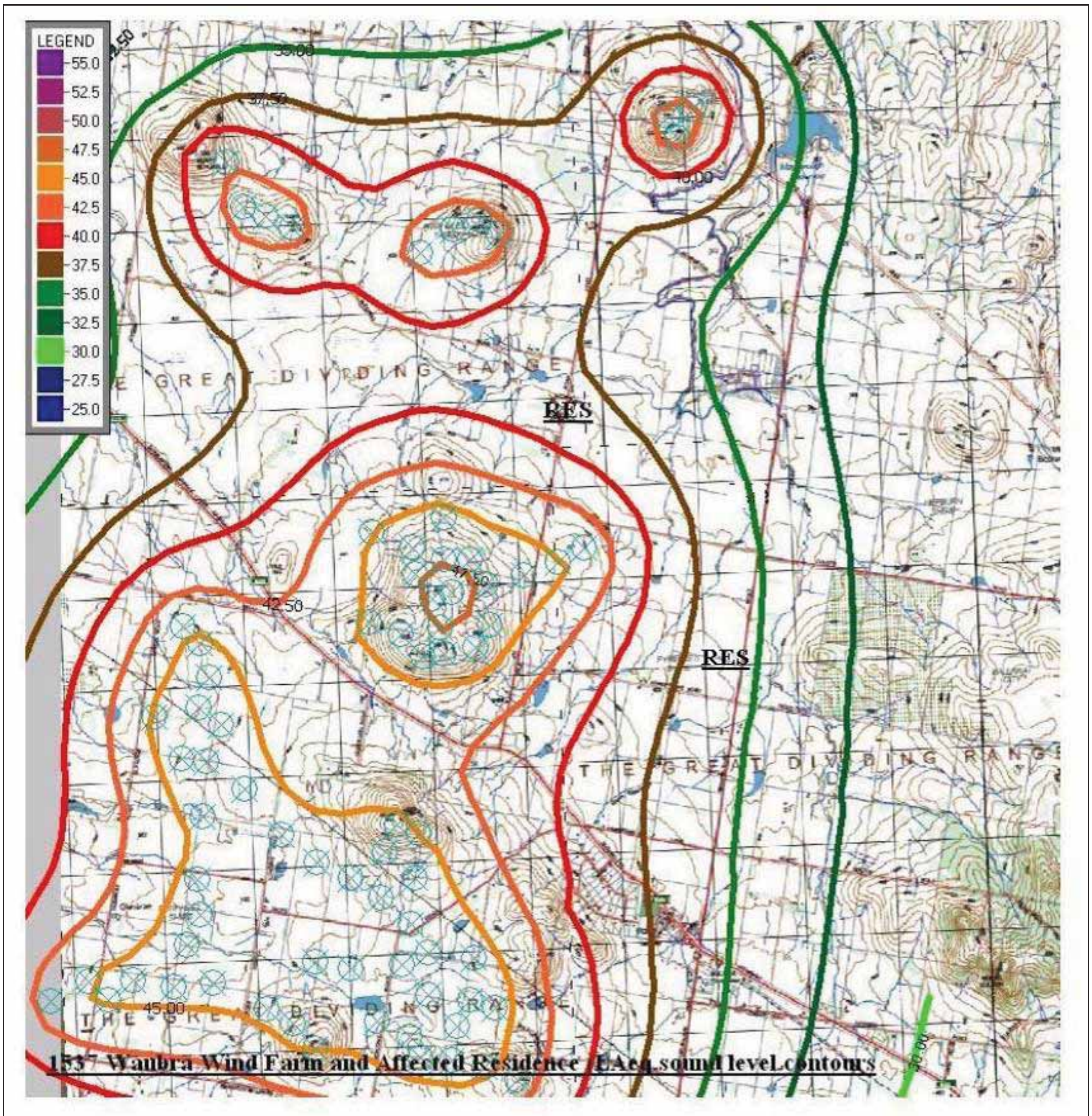


Plate 3: Predicted LAeq Sound Levels for Waubra and the Dean's Residences

New Zealand standard NZS 6808 clause 4.4.2 suggests a reduction of between 1.5 and 2.5 dBA from the predicted LAeq level to the "wind farm L95 level". The <u>calculated</u> background level at H41 is between 34 dBA and 35 dBA. A background L95 criterion limit of 40 dBA is calculated for 9 m/s. Thus an "indicative" L95 level is 40 dBA is calculated from the wind turbine data, NZS 6808 and prediction model.

The noise predictions do not tell the whole story, however. Meteorological conditions, wind turbine spacing and associated wake and turbulence effects, vortex effects, turbine synchronicity, tower height, blade length, and power settings all contribute to sound levels heard or perceived at residences. In addition to this the method of prediction has what is known as "uncertainty". That is, the predicted values are given as a range, ± 3 dB(A) at 1000 metres for the most common prediction method with the predicted value being the "middle" of the range. The uncertainty increases with distance and the effect of two or more turbines operating in phase with a light/strong breeze blowing towards a residence. A variation of 6 to 7 dB(A) can be expected under such adverse conditions. This is explained in more detail later in this Report.

The noise predictions in Plate 3 are not a single line or a single number but, in fact, a range of sound levels from 33 to 39 dB(A) at H41 as shown in **Plate 4.**

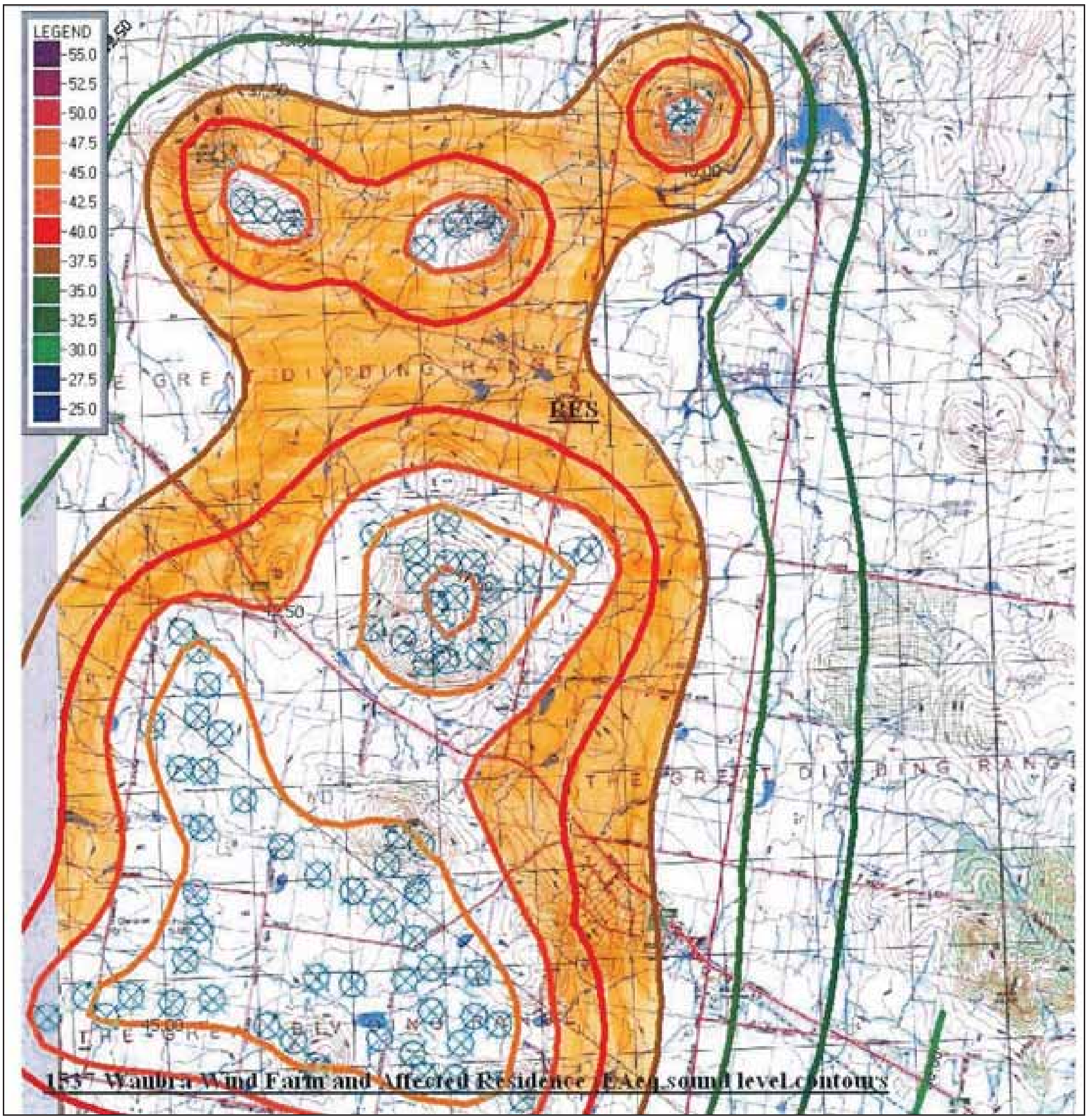


Plate 4: Predicted 40 dB(A) LAeq Zone affecting the Dean's Residences

Note: the orange coloured zone is the area affected by 40 dB(A) LAeq based on the standard prediction assumptions given in the ISO9613-2 standard.

Thus on any given day the wind farm sound levels – assuming the wind farm is operating – could easily vary between 31 to 39 dB(A), measured as the background level LA95. This is without the additional effect of any adverse wind effects or weather effects such as inversions.

The view from the residence towards the nearest towers to the south is shown in Photo 1. This shows the turbines side-on to the residence. The side-on angle of the blades allows the effect known as vortex-shedding affect the residence. If the blades are full-on, as would be the case with a south-west breeze, the residence is affected by cumulative sound as well as wake and turbulence effects. The effects are potentially more noticeable on the land as there is no screening effect from the pressure changes that can occur. The wake effects are observable when the wind blows from one turbine to the other; the effects are not dependent on the direction of the turbines to the observer.

Noise levels predictions can therefore be considered as only approximations of sound levels and can not be given any weight other than this.

4 AMBIENT WAUBRA SOUND LEVELS

This Report is referenced to sound surveys taken at two different times in 2009 under different weather conditions. Although the Stud Farm Road residence is affected by wind turbine noise a series of ambient and background sound levels were recorded in order to gain an indication of the levels within the locale. Ambient recordings were taken over the period 15-30 October 2009.

The following instruments were used to measure the ambient sound levels: Larson Davis 831 Type 1 sound level meters with automatic audio recording facilities and one-third octave band analysis, Rion NL21 Type 2 sound level meters and Rion NC 73 Calibrator. Both the Larson Davis and Rion meters have low noise floors essential for the measurement of background sound levels in rural environments. Additional sampling was taken with Mr Dean's SVAN 959 type 1 sound level meter. This meter has an extended response to 0.8 Hz and measures in one-third octaves. All instrumentation used in this assessment hold a current calibration certificate from a certified NATA calibration laboratory. The operation of the sound level measuring equipment was field calibrated before and after each measurement session and was found to be within 0.1dB of the reference signal.

The primary measurement location was 10 metres from the north-west corner of the residence with clear line of sight to the turbines to the north-west and to the south. The location is referred to as ML1 and consisted of a Rion NL21 sound level meter. The microphone was 1.35m above ground level and not less than 3.5m from any reflecting surface other than the ground. Farm buildings and trees more than 10 metres distant. A weather station (WS) was situated near the noise logger. There was no residential or work activity at the residence during the time of the survey. Additional LD831 monitoring was taken at location ML2 (3.5m from the shed, 8m from the house and 2m above ground), ML3 (at fence 13m from residence, 1.5m above ground) and inside the residence (small bedroom facing the turbines, microphone at mid-window level and 1.2m inside from window). Ambient A-weighted sound levels were measured generally in accordance with Australian Standard AS1055.1:1997 - 'Acoustics-Description and measurement of environmental noise - Part 1: General procedures'. The ambient sound levels were recorded at 10 minute intervals over a 10 day period, **Table 1 and Figure 1.** Weather data (wind speed and direction, temperature and humidity) was recorded for the same time period. Night-time is recorded as from 10pm the previous day to 7am on the nominal day.

Plate 1 presents the locations of sound surveys in October 2009. The survey at 377 Stud farm Road was for a 10 day period; the other surveys were sample-surveys to identify conditions at a point in time. **Plate 2** shows the locations of the survey at 377 Stud Farm Road. The reported data in this Report is primarily for 377 Stud Farm Road.

Plate 1: Sound level survey locations, Waubra

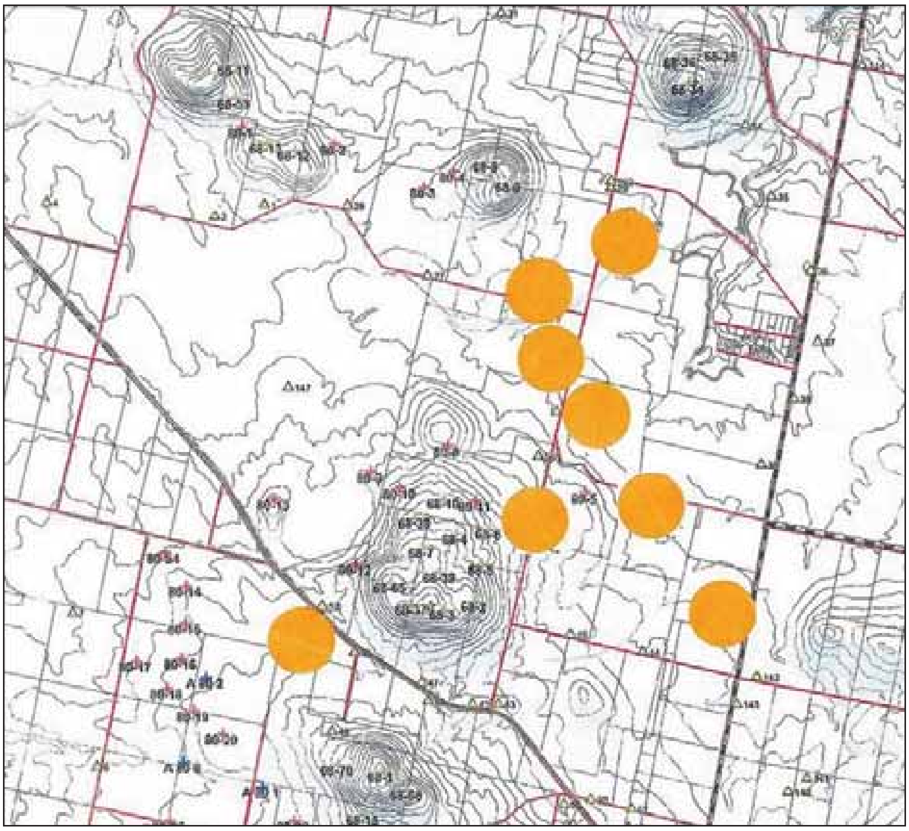


Plate 2: Sound level survey locations, 377 Stud Farm Road

Table 1: Average LA95 background sound levels recorded at Location ML1 (levels rounded)

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

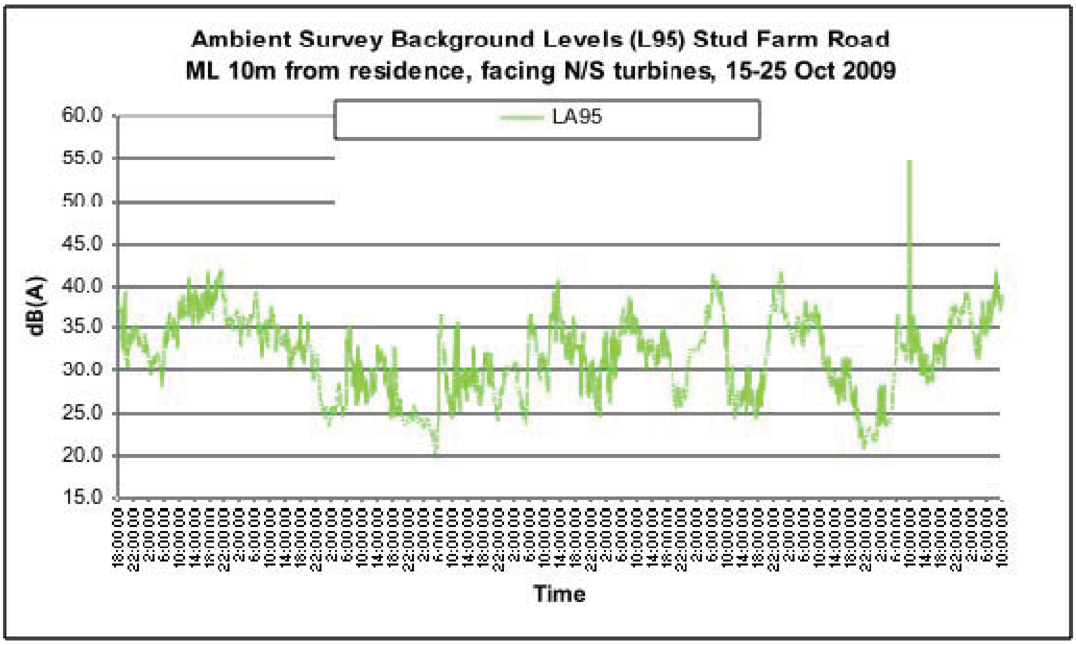


Figure 1: Exterior noise levels at Location ML1 over 10 days

The sound level Table and Figure show the wide range in sound levels at the residence at 377 Stud Farm Road. To assist in the investigations the 831 sound level meter was set to record at set time intervals during the surveys. The sound file is recorded at either 48000 Hz or 16000 Hz sampling rate and each soundfile is 60 seconds or 30 seconds in length, depending on the survey.

At the present time the residence is not occupied and the character of the sound – modulation in particular – can not be determined "all the time" on the basis of personal physical observation by a named person. Modulation can, however, be determined from sound recordings from a calibrated sound level meter at a relevant time and place investigating the sounds of the wind farm. This has been done. A soundfile for Thursday 15 October 2009 at 9:40 pm, for example, has audible modulation (**figure 12**). If, and this needs to be proven, modulation is a continuous feature of the wind farm under normal operational conditions, the background sound levels are adjusted for special audible characteristics such as modulation and the indicative non-compliance is shown in **Table 2.**

Table 2: Compliance at 377 Stud Farm Road with adjustment for Special Audible Characteristics (criterion reduces to 35 dBA)

Date	Day 7am to 6pm	Evening 6pm to 10pm	Night 10pm to 7am
15 October	-	-	-
16	Fail	Fail	-
17	-	-	Fail
18	-	-	-
19	-	-	-
20	-	-	-
21	-	-	-
22	-	-	-
23	-	-	Fail
24	-	-	-
25	Fail	-	-

The important compliance issues are:

(a) daytime compliance does not appear to have any set time period of measurement over which the sound levels must be measured in order for compliance to be proven or not-proven for that specific time period. For example, is a single 10-minute “breach” of the background sound levels a compliance breach or not?

(b) In comparison, the night-time compliance is set at 10% of the night-time period 10pm to 7am. This is a period of 9 hours or 540 minutes. So in any 9 hour period the wind farm needs to exceed the background criteria, plus any penalty for special audible characteristics, for a total of 54 minutes.

Either of these two criteria requires full-time real-time monitoring in order for compliance to be proven or not-proven at any affected residence.

In just one week the sound levels attributed to the wind farm exceeded the 35 dBA criterion suggesting a breach of Condition 14(c) if special audible characteristics are present. Compliance with the planning conditions does not relate only to the time periods outlined in **Table 1,** compliance can be regarded as being in 10 minutes intervals, day and night. The significance of this can be clearly seen in **Figure 1** where any background level over 35 dBA indicates non-compliance. **Figures 2 to 10** illustrate the effect of background levels and the relationship to the noise limit adjusted for the effect of special audible characteristics.

Under the above circumstances, it is concluded that wind farm sound, as assessed in accordance with the procedures described in this Report, exceeds the criterion (35 dBA) for wind farm sound with special audible characteristics on numerous occasions over a 10-day period.

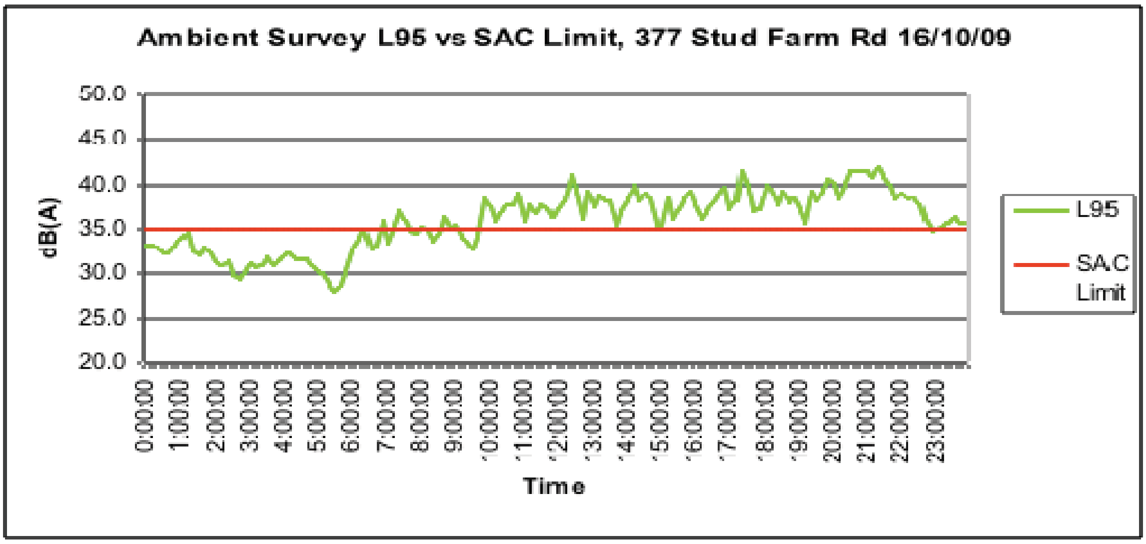


Figure 2: Background sound levels and SAC limit, 16/10/09

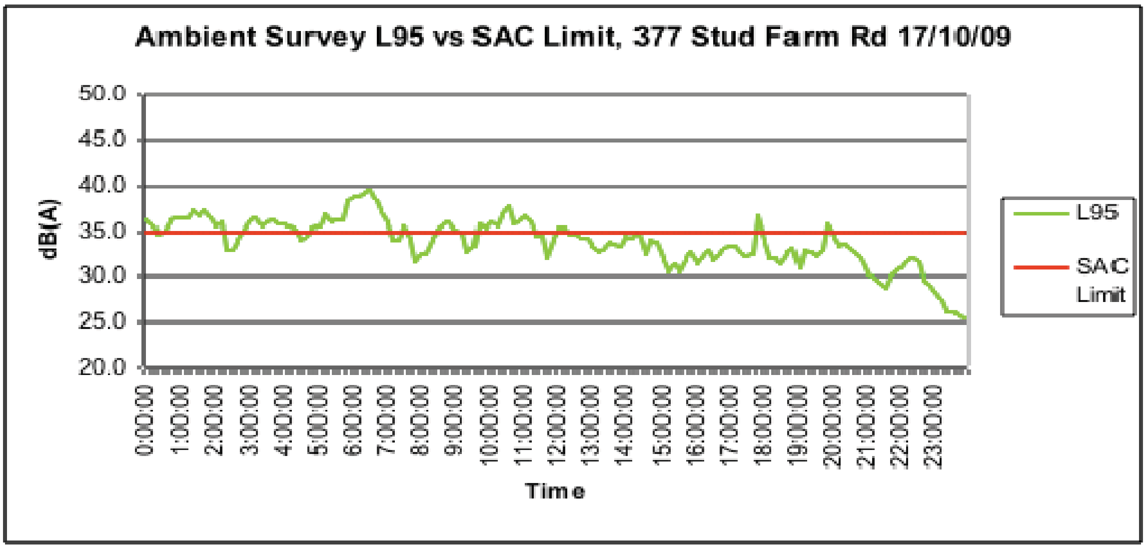


Figure 3: Background sound levels and SAC limit, 17/10/09

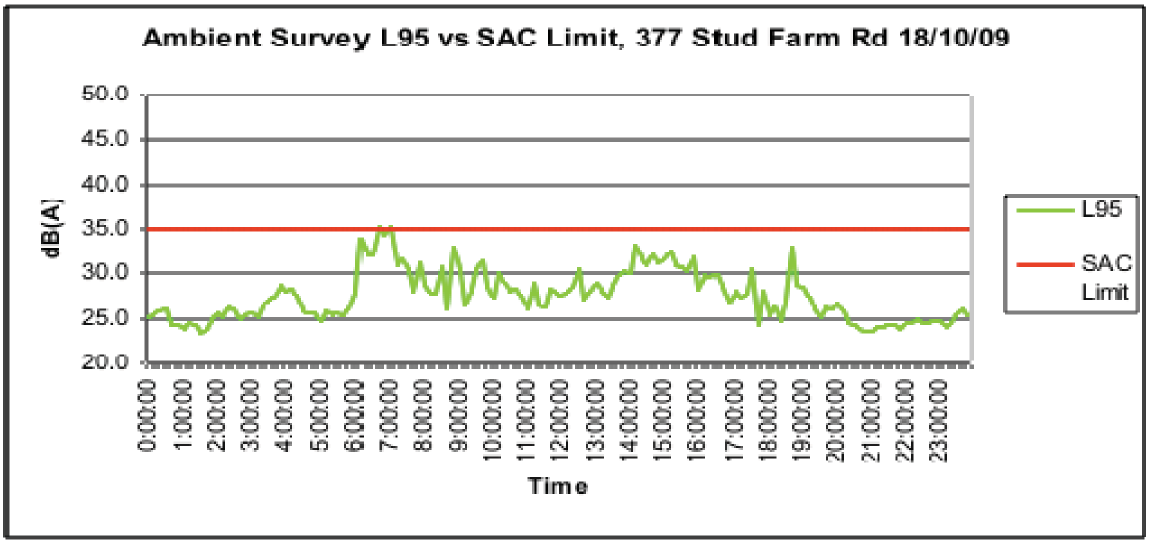


Figure 4: Background sound levels and SAC limit, 18/10/09

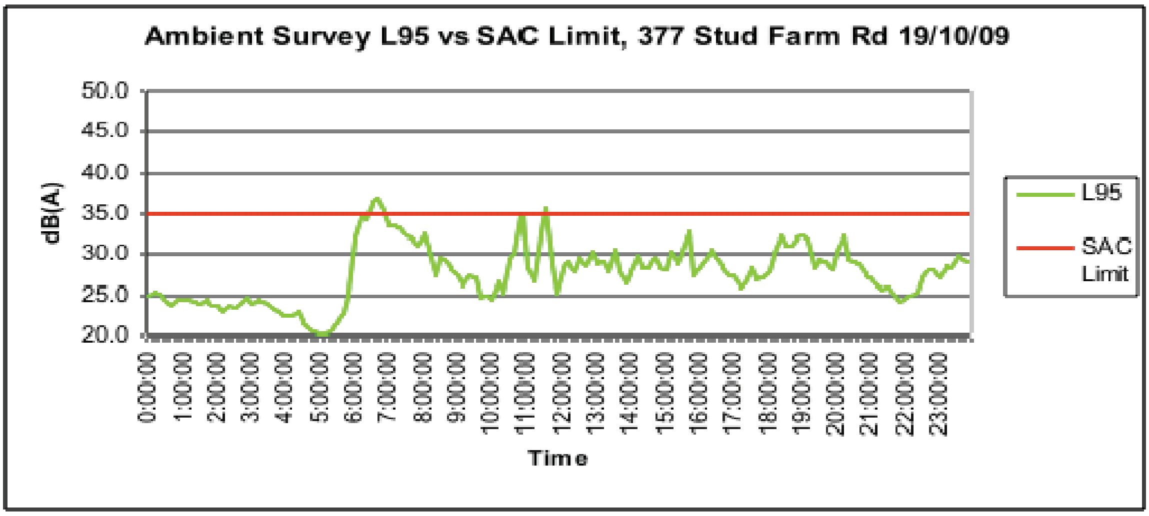


Figure 5: Background sound levels and SAC limit, 19/10/09

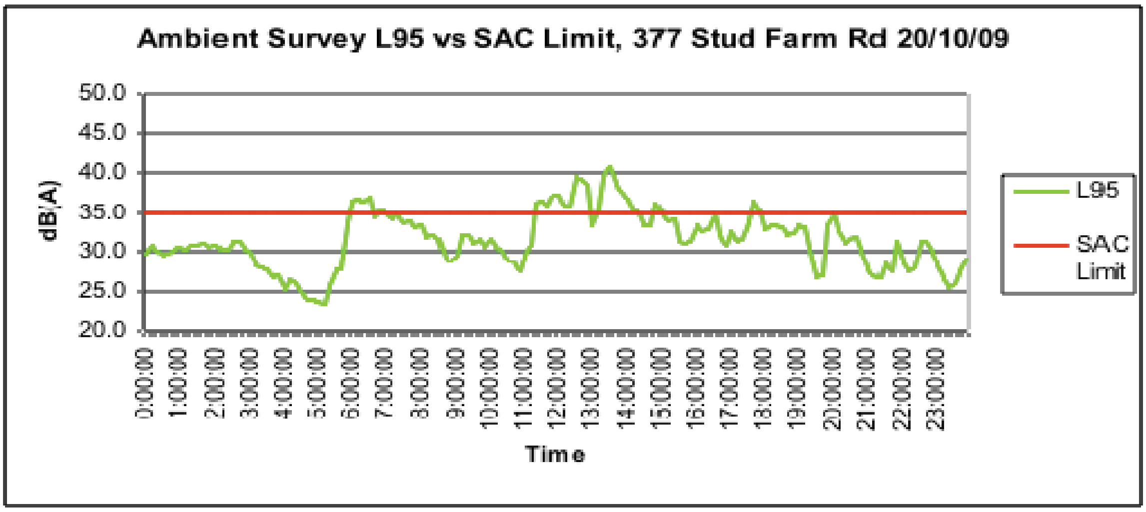


Figure 6: Background sound levels and SAC limit, 20/10/09

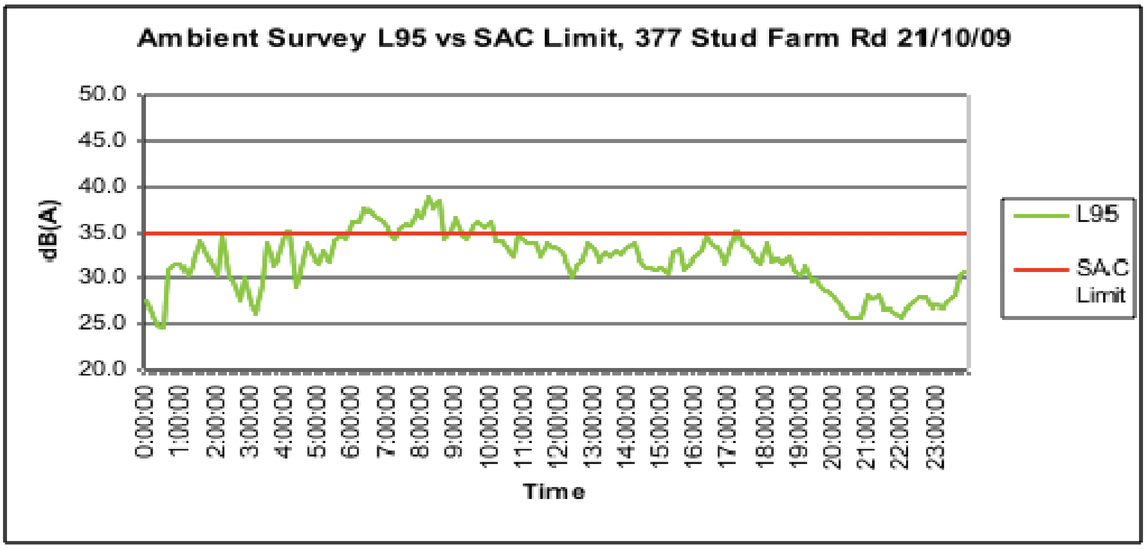


Figure 7: Background sound levels and SAC limit, 21/10/09

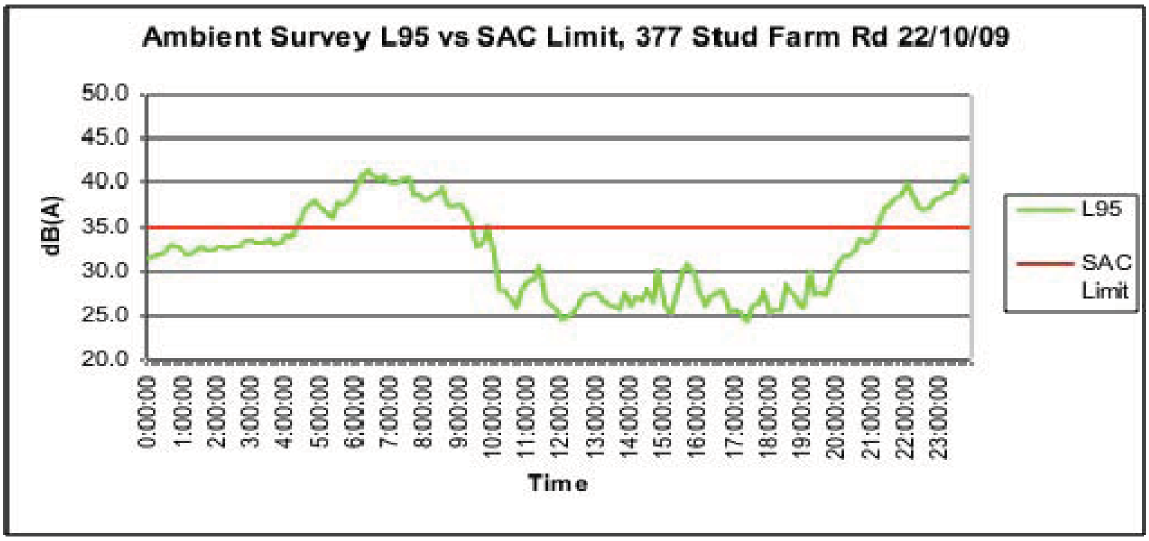


Figure 8: Background sound levels and SAC limit, 22/10/09

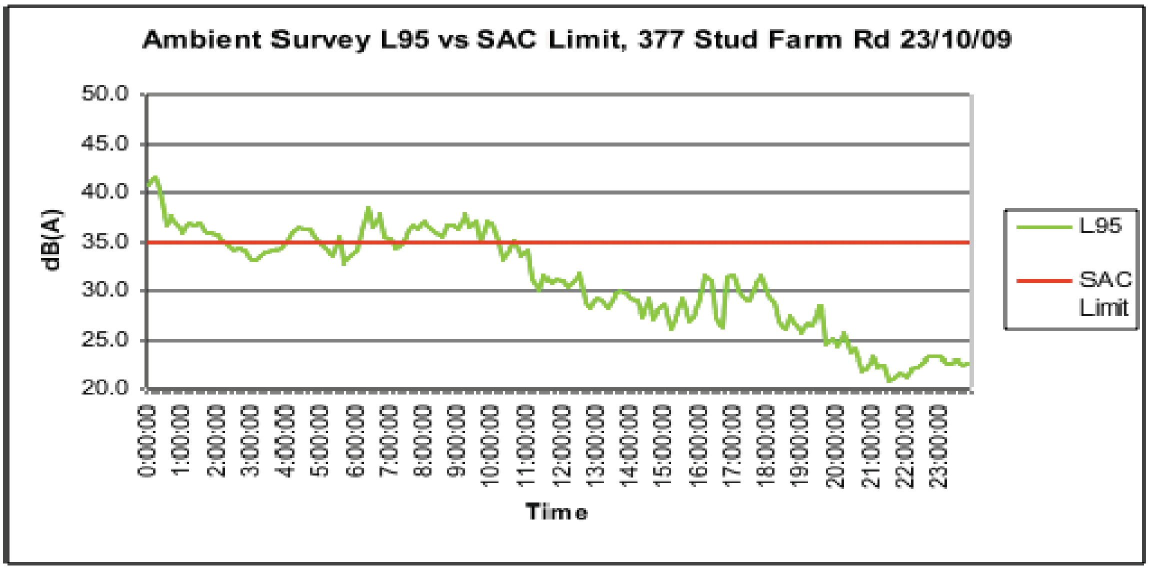


Figure 9: Background sound levels and SAC limit, 23/10/09

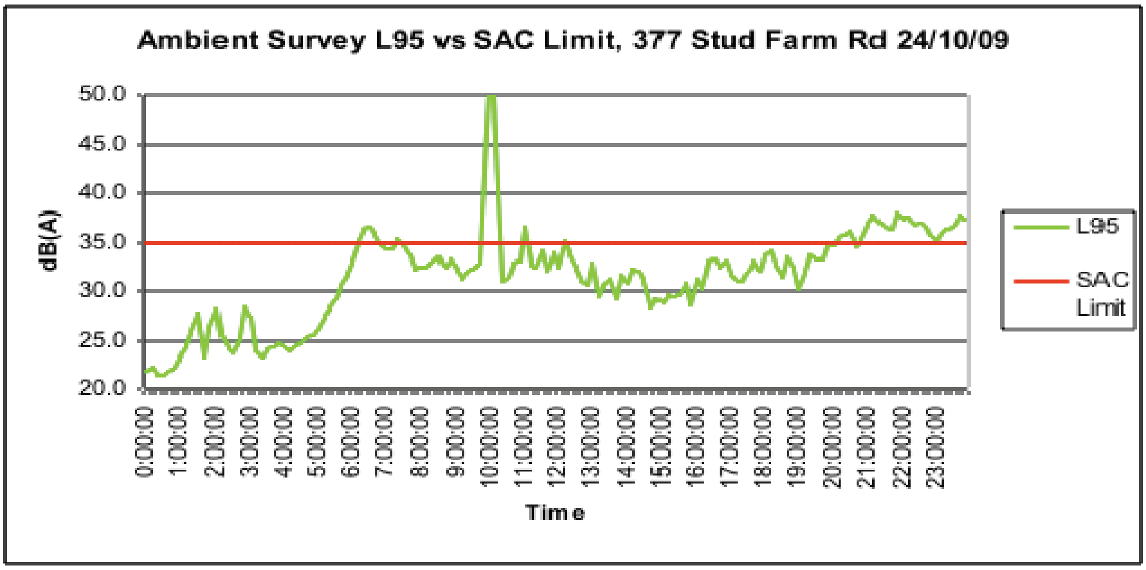


Figure 10: Background sound levels and SAC limit, 24/10/09
Note: The high spike in Figure 10 is not due to wind farm noise and must be discounted.

The Effects Of Weather

From data recorded at Ballarat aerodrome the expected prevailing winds are from the north-west swinging to the south-east. **Figure 11** presents the mid-morning and mid-afternoon wind roses for Ballarat. For the purposes of discussion I am assuming a similar pattern for night-time and for the Waubra locale. Some residences or noise sensitive places will be more subject to the prevailing breeze than others at different times. This is a complex wind pattern and there are a relatively large number of potentially affected residences around the Waubra wind farm

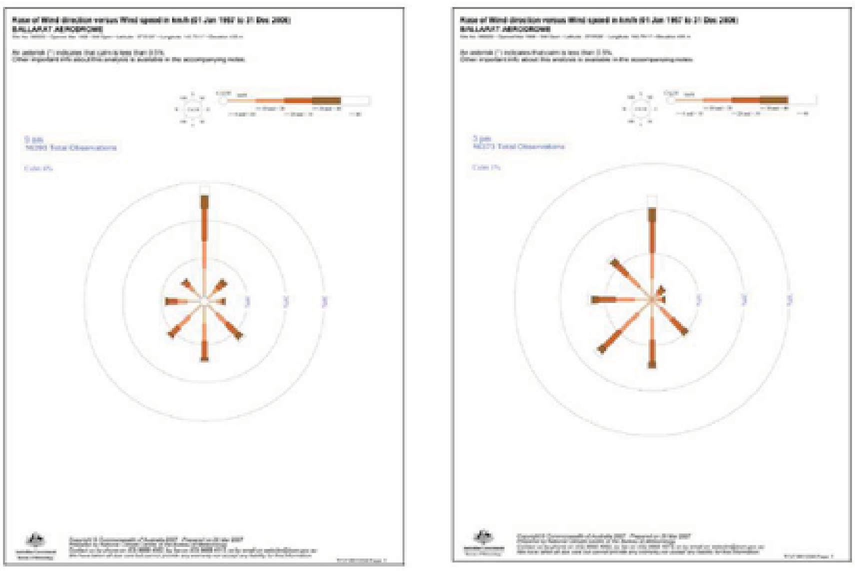


Figure 11: wind rose, Ballarat Aerodrome, mid-morning and mid-afternoon

Sound propagation varies significantly under different wind conditions, especially:

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

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

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

It is my standard practice in modeling a risk assessment of a wind farm or other industrial activity to make allowance for stability factors and uncertainty when undertaking predictions. This is explained further in this Report.

Weather data was recorded at the residence over the time of the survey. Typical data recorded in 10 minute intervals is shown in Table 3. The data shows the considerable variation in weather (temperature, wind speed and direction, and relative pressure) at ground level near the residence. The wind at the residence is classed as a light breeze and sound recording with an ordinary wind screen over the sound level meters microphone is acceptable.

Table 3: Example of recorded weather data at 377 Stud Farm Road

date	time	outdoor temp	**wind m/s**	**direction**	Hpa	24hr rainfall mm
16/10/2009	12:00	13.1	**2.7**	**SW**	1019.7	0.6
16/10/2009	12:10	12.6	**2**	**S**	1019.8	0.6
16/10/2009	12:20	14.6	**1**	**SW**	1019.7	0.6
16/10/2009	12:30	15.3	**2.7**	**SW**	1019.6	0.6
16/10/2009	12:40	16	**2**	**SW**	1019.7	0.6
16/10/2009	12:50	15.1	**0.7**	**N**	1019.7	0.6
16/10/2009	13:00	16.3	**1**	**SE**	1019.7	0.6
16/10/2009	13:10	16.5	**1**	**SW**	1019.7	0.6
16/10/2009	13:20	15.6	**2.7**	**SE**	1019.7	0.6
16/10/2009	13:30	15.5	**1**	**SW**	1019.8	0.6
16/10/2009	13:40	15.7	**2.7**	**S**	1019.7	0.6
16/10/2009	13:50	16	**2.4**	**S**	1019.6	0.6
16/10/2009	14:00	16.9	**2**	**S**	1019.7	0.6
16/10/2009	14:10	16.4	**1.4**	**S**	1019.7	0.6
16/10/2009	14:20	16.8	**2**	**NW**	1019.5	0.6
16/10/2009	14:30	17.1	**1.4**	**S**	1019.4	0.6
16/10/2009	14:40	16.1	**2.4**	**S**	1019.6	0.6
16/10/2009	14:50	13.6	**2**	**W**	1019.9	0.6
16/10/2009	15:00	13.2	**1**	**W**	1019.8	0.6
16/10/2009	15:10	15.5	**1.7**	**SEE**	1019.8	0.6
16/10/2009	15:20	16.5	**1.7**	**S**	1019.7	0.6
16/10/2009	15:30	15.3	**1.7**	**W**	1019.9	0.6
16/10/2009	15:40	15.7	**1.7**	**SW**	1019.8	0.6
16/10/2009	15:50	14	**2**	**SW**	1020.2	0.6
16/10/2009	16:00	13.3	**2**	**SE**	1020.3	0.6
16/10/2009	16:10	12.8	**1.4**	**SE**	1020.1	0.6
16/10/2009	16:20	12.5	**1.7**	**SW**	1020.2	0.6
16/10/2009	16:30	14.6	**2.4**	**SW**	1020.2	0.6
16/10/2009	16:40	13.5	**1.7**	**S**	1020.5	0.6
16/10/2009	16:50	13.6	**2**	**SW**	1020.6	0.6
16/10/2009	17:00	15.2	**2**	**S**	1020.7	0.6

Audible sound character

The operation of the turbines to the south-west of the residence at 377 Stud Farm Road can be clearly heard at the residence. The sound on Thursday evening at 9:40 pm, 15 October 2009, can be described as a steady rumble with a mixture of rumble – thumps. Wind in the trees or vegetation is not intrusive. **Figure 11** presents the variation between maximum, minimum and average (Leq) un-weighted sound levels. Un-weighted ('Z' weight sound levels) are referenced for audibility, as explained in the Background Chapters to this Report.

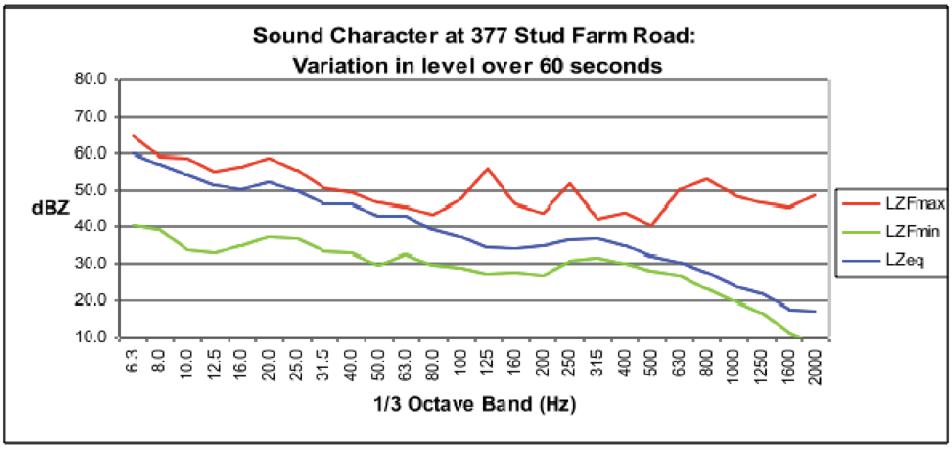


Figure 11: Variation in sound character over 60 seconds

In 60 seconds the sound character varies regularly by more than 20 dB; this level of variation will be audible. The generally accepted variation for a clear sense of audibility is 3 dB. Far finer detail is available by analysing the sound into amplitude variation over the 60 seconds, **Figure 12**. The figure shows the regular pulsing or modulation that is typical of blade passing the tower.

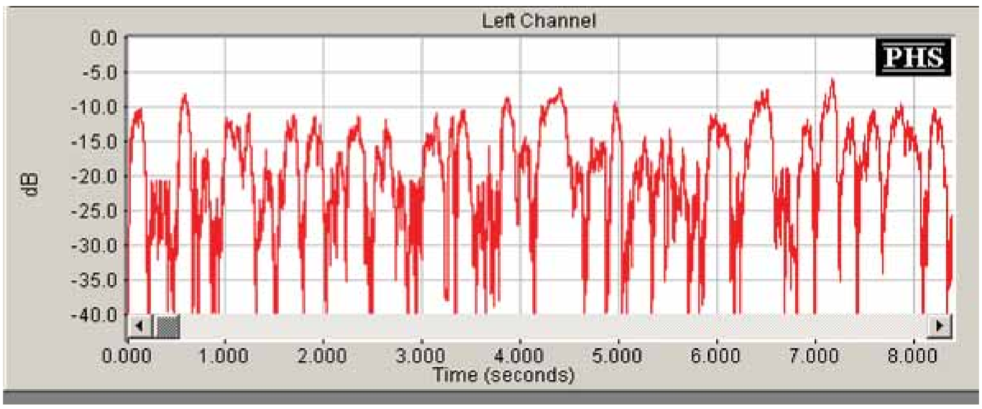


Figure 12: Pulse pattern from an operational wind farm

The background ambient sound levels for the assessment in **Figure 11** references ambient levels recorded at 377 Stud Farm Road when the turbines were not operating. The soundfile contains birdsong. There was no wind in trees or vegetation noise.

In order to confirm that a sound is audible to a person of 'normal' hearing an analysis of broadband sound – such as the sounds recorded on the Thursday and illustrated in **figure 11** can be further analysed for audibility. The higher the orange line is above the green line in **Figure 13** the more clearly the signal can be heard. As a guide, a 3 dB shift can be readily heard. The sound is also compared against the hearing threshold level for a 'normal' person.

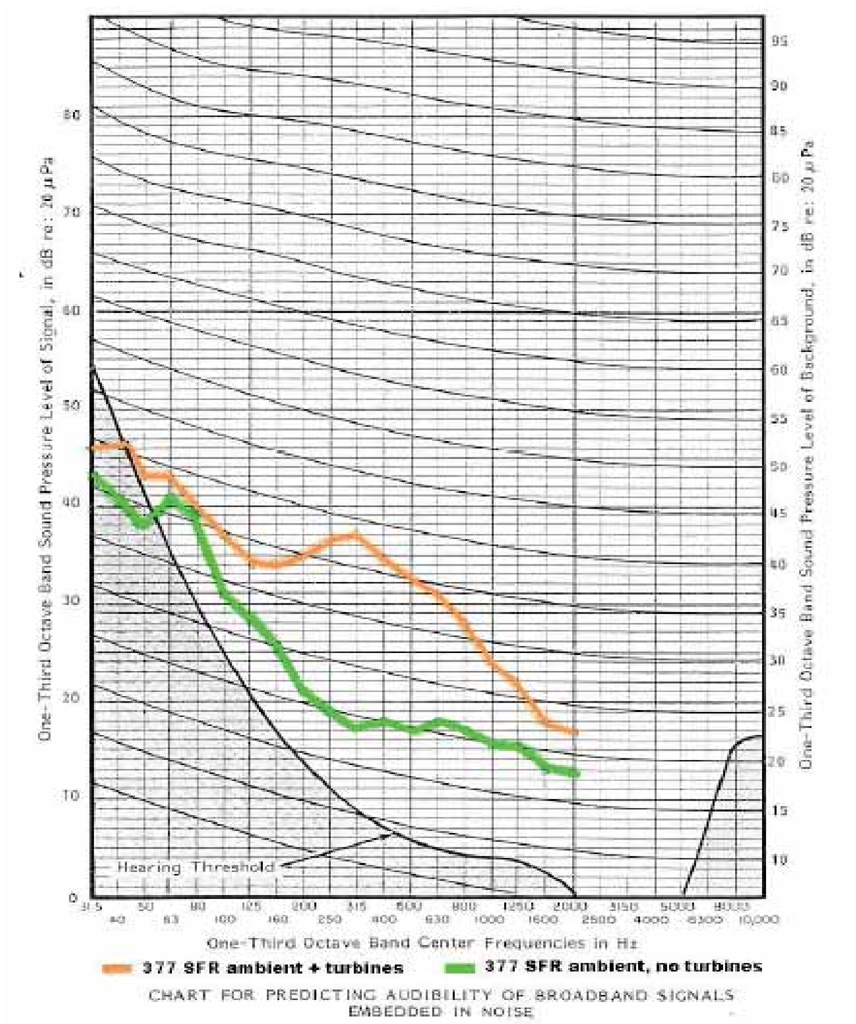


Figure 13: Audibility of wind turbines at 377 Stud Farm Road

Sound character at 377 Stud Farm Road and near locale

It is concluded that wind turbine sound at 377 Stud Farm Road is perceptible and can be analysed and assessed in a meaningful way. The sound character of the wind farm is clearly different from the locale and indicates the presence of special audible characteristics (modulation) as described in NZS 6808. The sonograms and third octave band charts following are provided to illustrate the character of the sound. The method used to display sound character, modulation, tonality or tonal complexes is through sonograms[1]. These show sound at various frequencies over time as shown in **Figure 14**. They can be thought of like a sheet of music or an old pianola roll; the left axis is frequency—musical pitch—while the bottom axis is time. Amplitude and frequency modulation can be identified in the sonograms by distinctive regular patterning at 1 second (or longer or shorter) intervals. Tonality and tonal complexes can also be identified using sonograms.

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

The colour indicates the loudness in unweighted dB (SPL) with the colour bar at the right providing a key to the 'loudness' in decibels associated with each colour. The values (-30 to 20, for example) on the right-hand side of the sonogram are decibel levels. Loud notes appear yellow or while; soft notes would appear purple or black. (In these sonograms much of the colour scale has been made black so that peaks stand out better.) Generally the sonograms are not calibrated against measured sound level but present a comparison between peak and trough (maximum and minimum) levels in a short period of time. At the time of recording it is possible to include reference sound levels in order to assess the sonogram values against measured values. **Figure 14** illustrates how a sonogram is defined in terms of pitch and loudness.

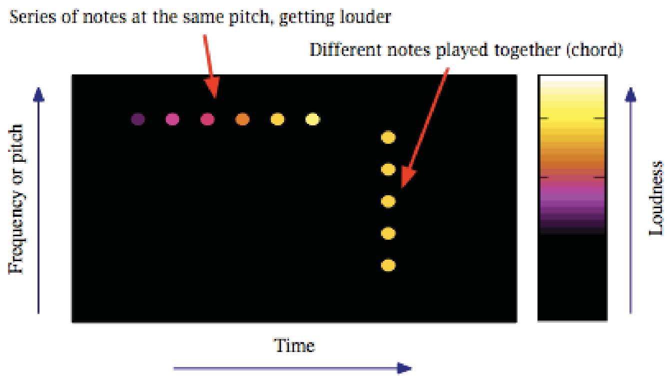


Figure 14: How to interpret a sonogram

There are two types of sonograms shown; one is for audible frequencies (20Hz to 1000Hz), while the other is for low frequencies (0.8Hz to 20Hz), referred to as *infrasound*.

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

The use of sonograms can show the presence of modulation. It seems likely that the rumble/thump that is described by many residents is caused by the effect of the downstream wake on neighbouring turbines. This effect can be illustrated in a sonogram. Wind turbine modulation has been demonstrated to exist in three, geographically separate wind farms. Each of these exhibit special audible characteristics and would require a lower noise threshold for compliance. This approach is confirmed by NZS6808:2010 clause CB3.1 which states, in part:

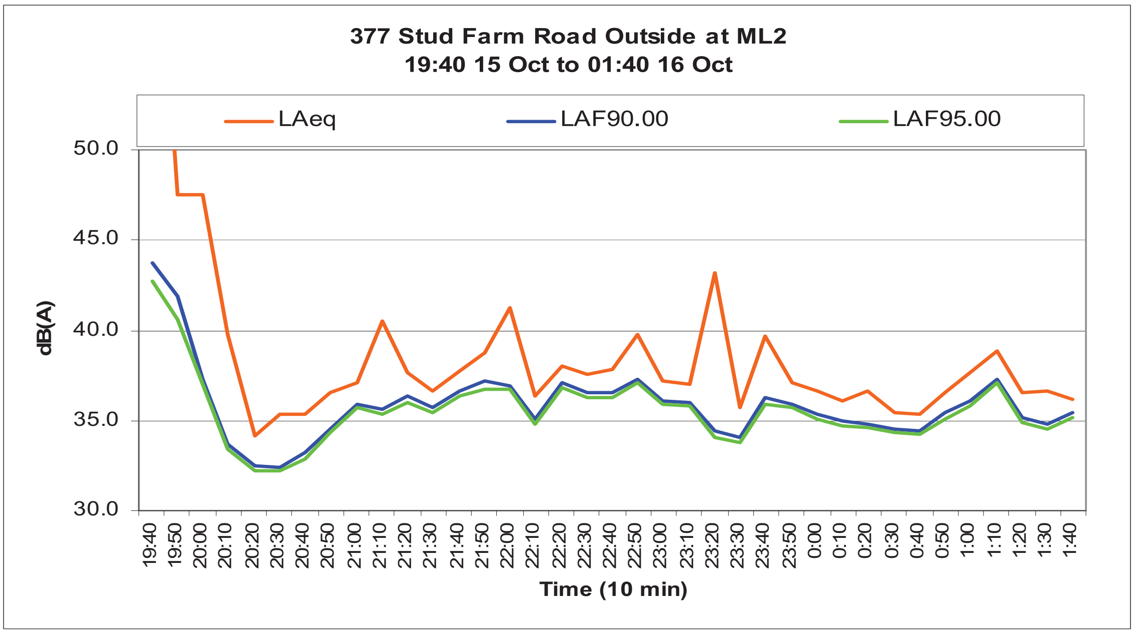
> *By the very nature of wind turbine blades passing in front of a support tower, some amplitude modulation will always be present in the sound of a rotating wind turbine although this will not always be audible at distances from the wind farm.*

NZS 6808:1998 does not have a test for modulation. NZS6808:2010 has an interim test for modulation that is in accordance with the Approval Conditions derived for the West Wind wind farm, Makara New Zealand[2]. The West Wind method, which is in force, has two specific options:

> *A test for modulation is if the measured peak to trough levels exceed 5 dBA on a regularly varying basis or if the spectral characteristics, third octave band levels, exhibit a peak to trough variation that exceeds 6dB on a regular basis in respect of the blade pass frequency.*

Sound character for the initial survey at the residence

The initial survey was able to capture the sounds of the southern wind turbines at the residence. **Figures 15 and 16** illustrate the sound levels and character of the sound, including ambient wind, outside the residence at location ML2. The initial survey was only for this time period, 19:40 15 October to 01:40 16 October 2009. The wind dropped after 20:10pm and the sound levels decreased, especially inside the home.



[2] Condition 35, Environment Court Decision W059/2007 and clause B3.2 of NZS6808:2010

Figure 15: Outdoor sound levels at ML2 for the initial survey

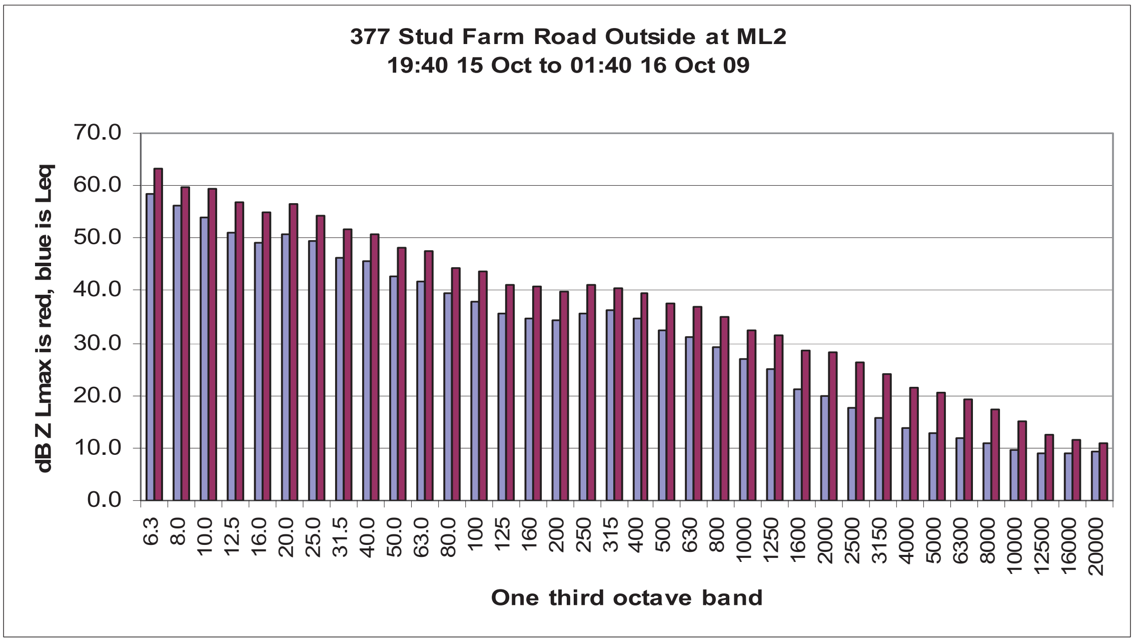


Figure 16: Outdoor sound character at ML2 for the initial survey

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

The initial survey recorded the sound levels inside the residence at location ML4. **Figures 17 and 18** illustrate the sound levels and character of the sound, including ambient wind. The initial survey was only for this time period, 19:40 15 October to 01:40 16 October 2009.

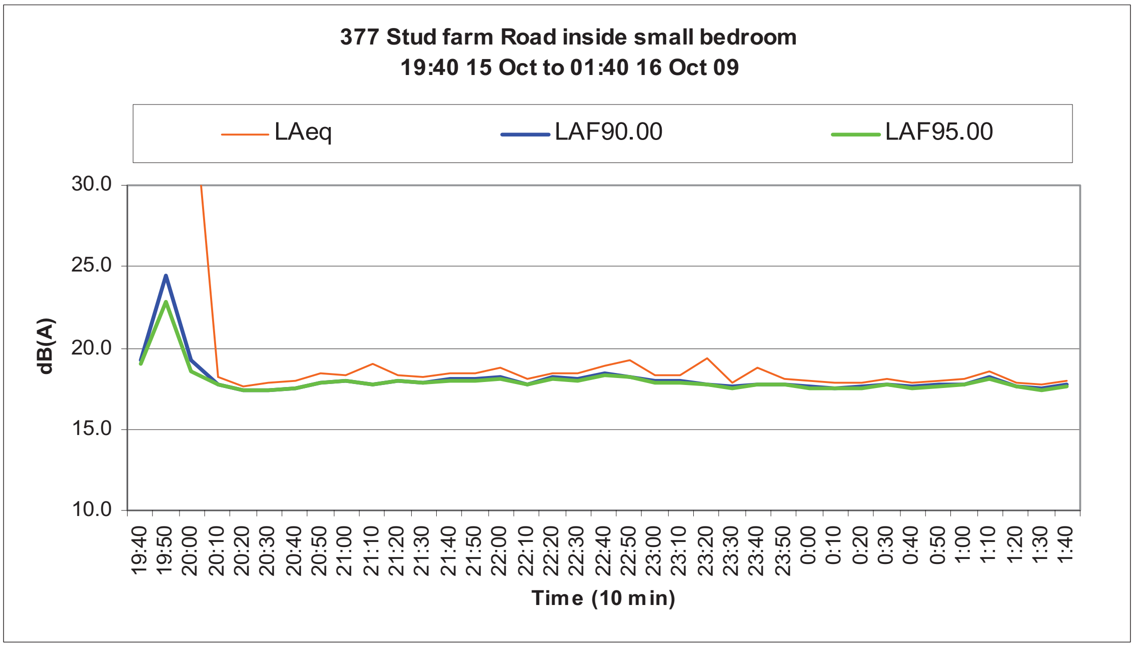


Figure 17: Indoor sound levels at ML4 for the initial survey

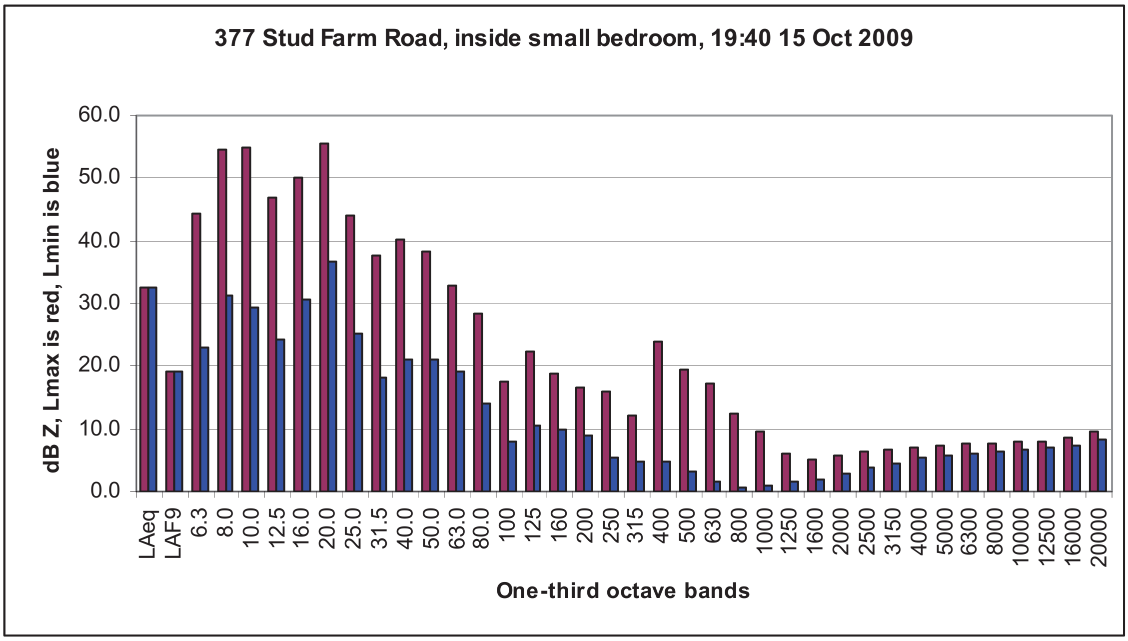


Figure 18: Indoor sound character at ML4 for the initial survey

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

The caution here is that sound levels vary significantly over very short (10 minutes, for example) periods of time. Thus an assessment on an average longer-term level (Figure 17) may not truly represent the short-term effect of varying sound character (Figure 18).

The observation from Figure 18 is that the overall sound character shows substantial variation between the minimum level, LZmin and the maximum levels LZmax in each third octave band. The variation is significant above 20 Hz because this is when the difference in sound levels becomes audible. The levels show the failure of A-weighted statistical levels in presenting the true sound character.

Previously Mr Dean had recorded the sound levels inside the Waubra house main bedroom over the time period 9:12 am 12 October 09 to 10:02 am 13 October 09, Figure 19. The wind farm was in operation at this time. The sound levels were recorded in third octave bands every 30 seconds and the average levels for this time period are presented following. The SVAN sound level meter is able to record to a lower frequency compared to the Larson Davis meter.

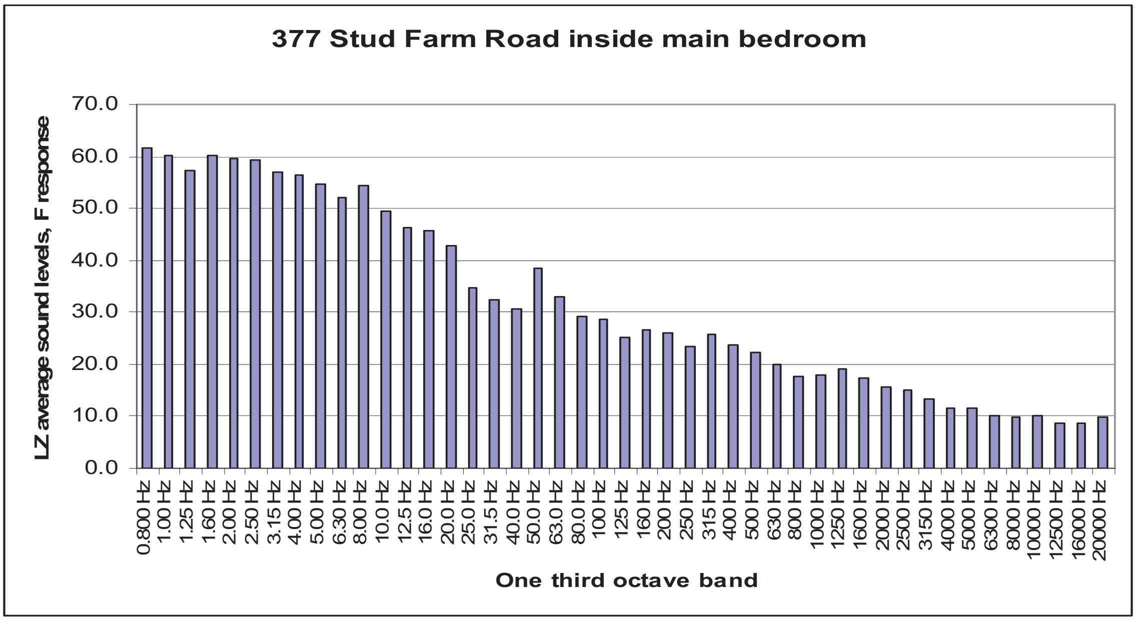


Figure 19: Indoor sound character (main bedroom)

The character of the sound levels is similar to the time-average level outside but there is significant variation between the levels in the two bedrooms. The audibility of a sound for a person with 'normal' hearing can be assessed under **figure 13.**

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

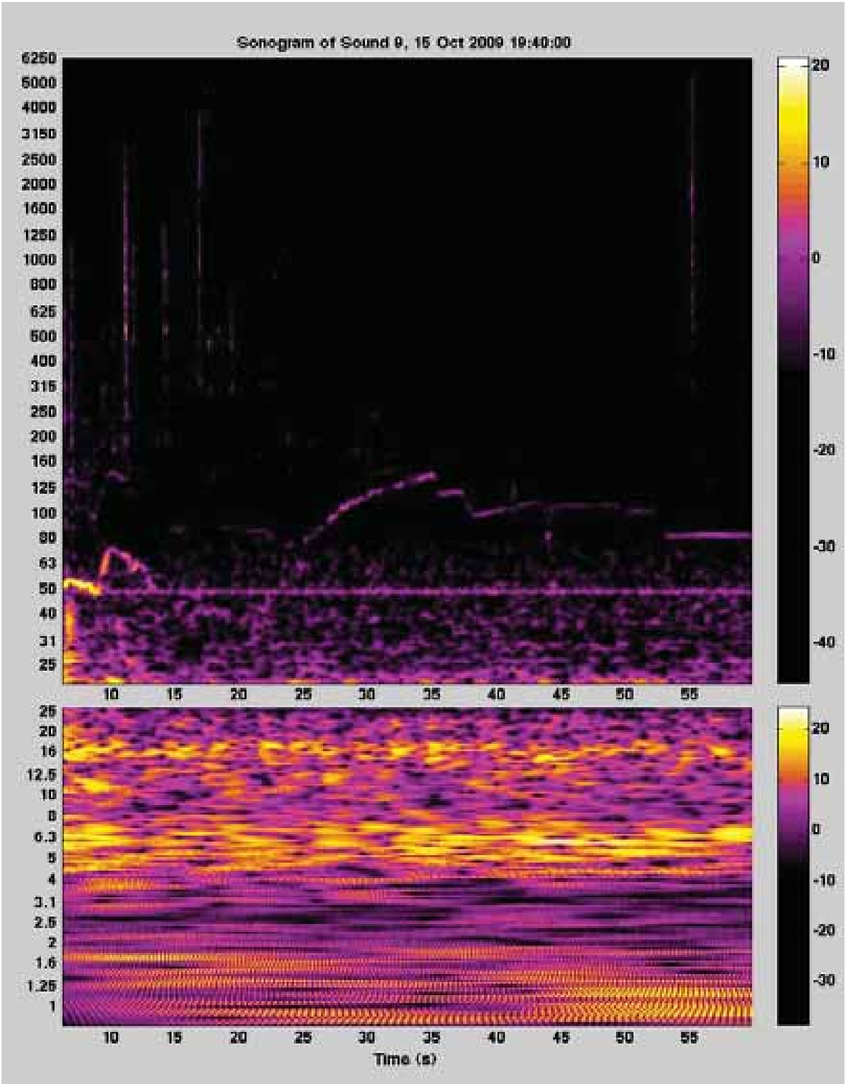
The following sonograms are presented to illustrate specific locations with and without turbine activity. The sonograms illustrate the presence of turbines even though the activity may not be audible. Different time segments are used to illustrate the effects. The important features are:

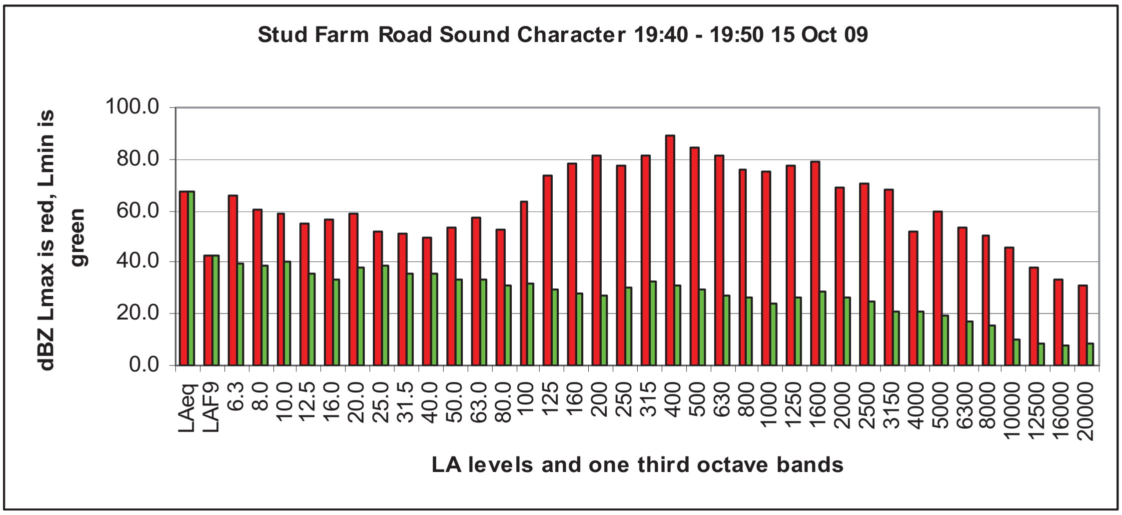
- The significant amount of sound energy in the low frequency and infrasonic ranges
- The variation of 20 decibles between high and low values in the sonograms between the yellow bands and the purple bands. This variation is audible under observed conditions.

The overall levels in one-third octave band charts are provided to illustrate the difference between maximum and minimum sound levels in the measurement time period. These correspond to the peak and trough values and give a "first-cut" assessment of whether or not audible modulation, audible tonality, perceptible modulation or perceptible tonality may exist. The charts are provided as examples of the sound character. The sonograms are taken from the recorded audio files which are 60 second or 30 seconds in length. Hence the displayed sonogram charts can differ from the one third octave band charts which are calculated over a full 10 minutes.

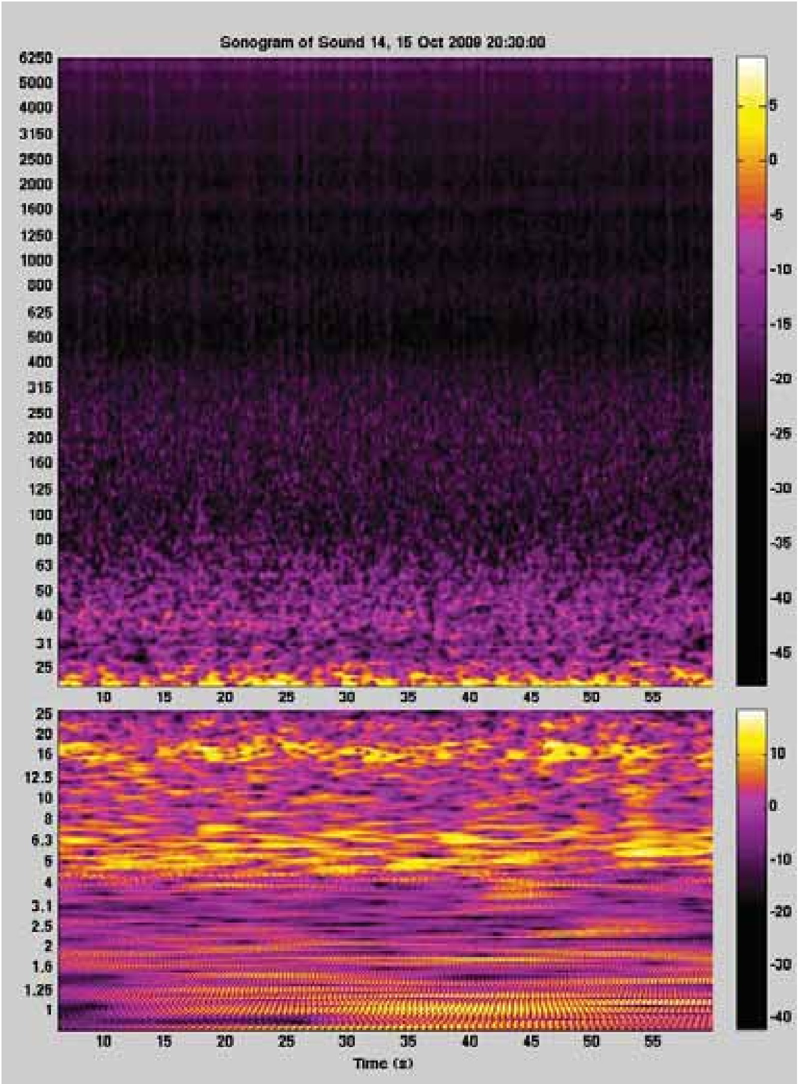
Sound Character at 377 Stud Farm Road.

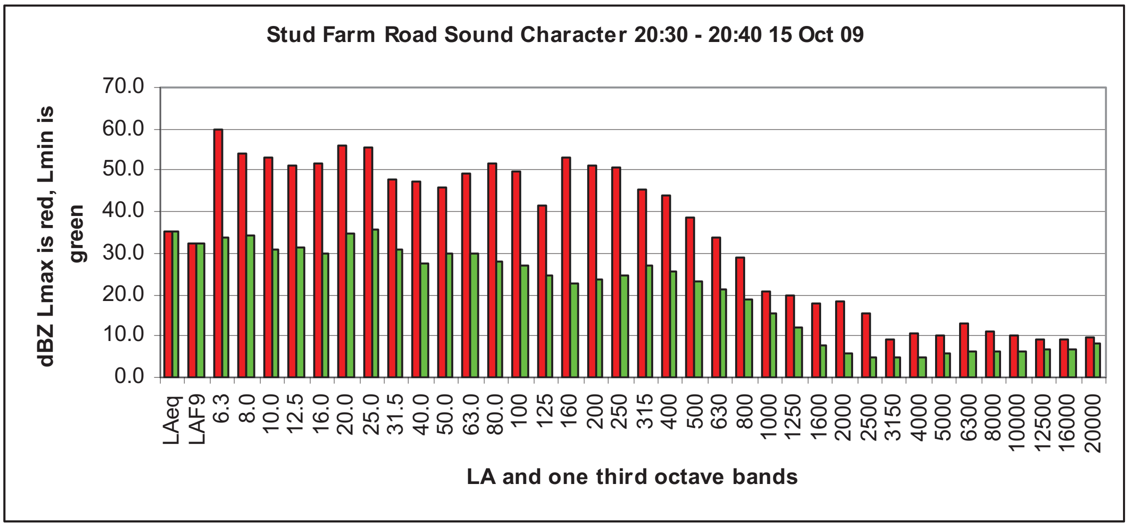
Sound of wind farm audible at 7:40pm outside residence, as well as wind in trees, voices, setting-up activity and a distant vehicle. The sonogram shows a distinctive 50 Hz tone from a nearby electrical source, as well as strong readings at 20 Hz, 16 Hz and 6.3 Hz. These are indicator frequencies for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



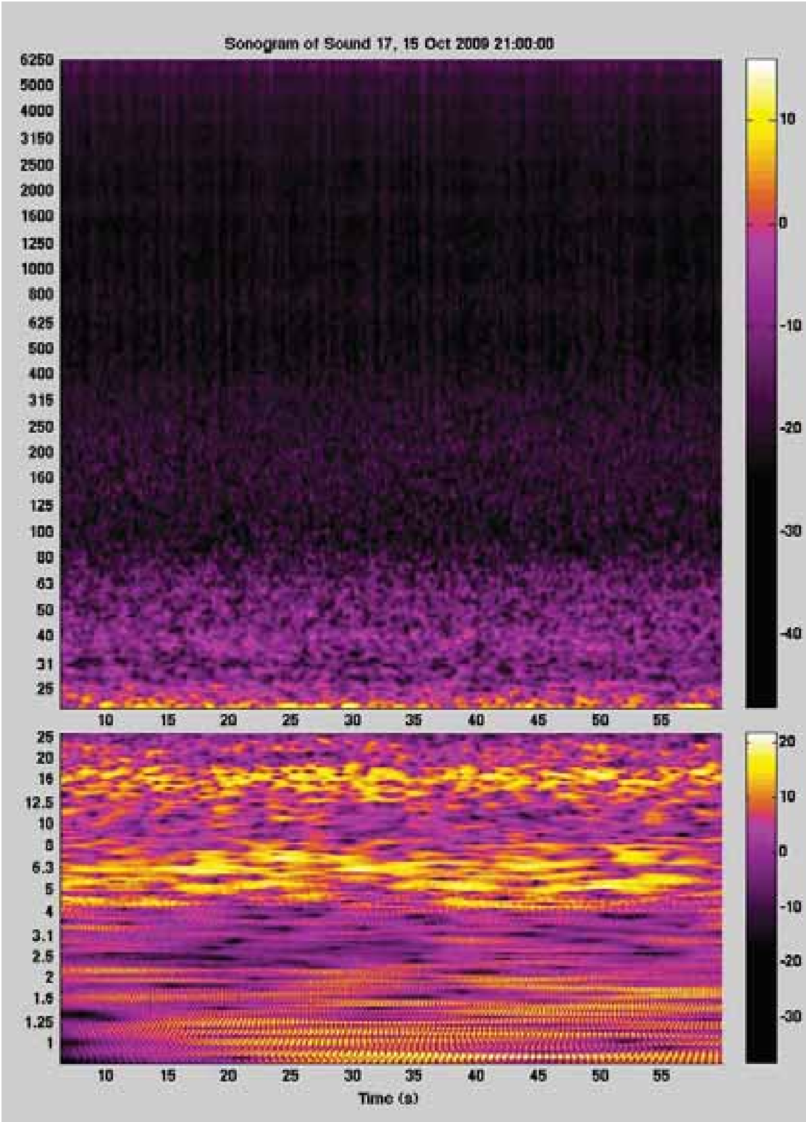


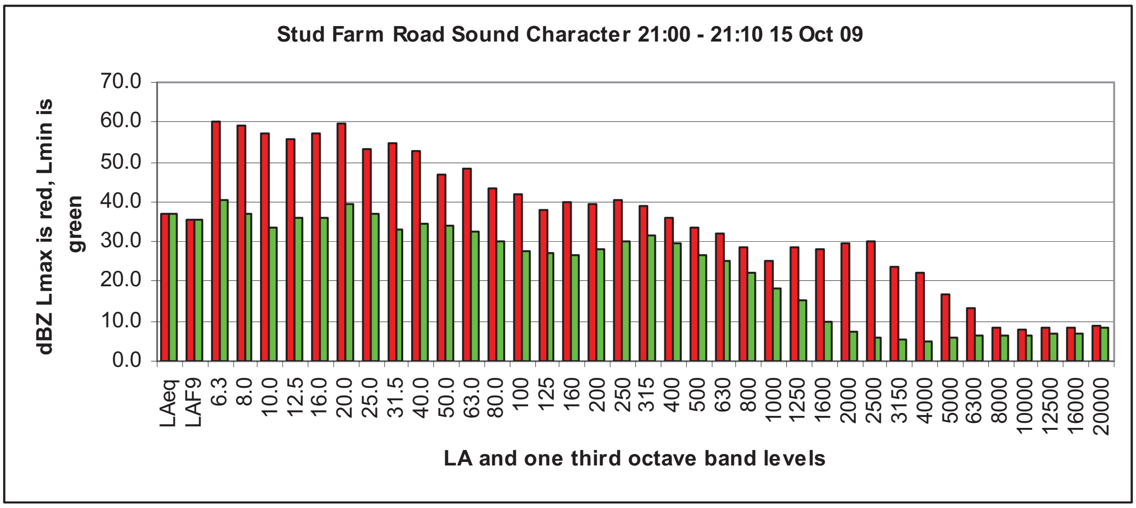
Sound Character at 377 Stud Farm Road.
15 October 2009 at 8:30pm
The soundfile was recorded with no-one present. The audio file has wind and wind farm sounds. There are strong readings at 20 Hz, 16 Hz and 6.3 Hz. These are indicator frequencies for potential adverse health response. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass frequency. The high frequency content (800-5000 Hz) is not strongly evident in the sonogram or the 60sec audio file.



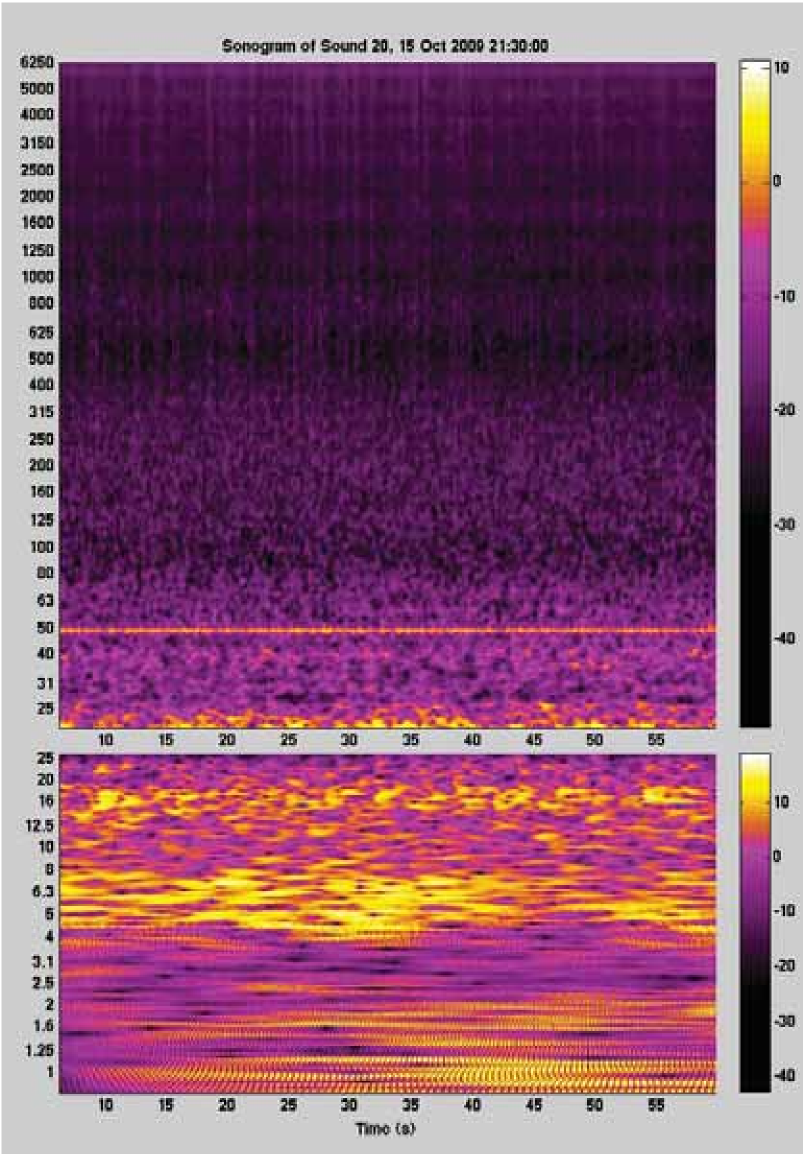


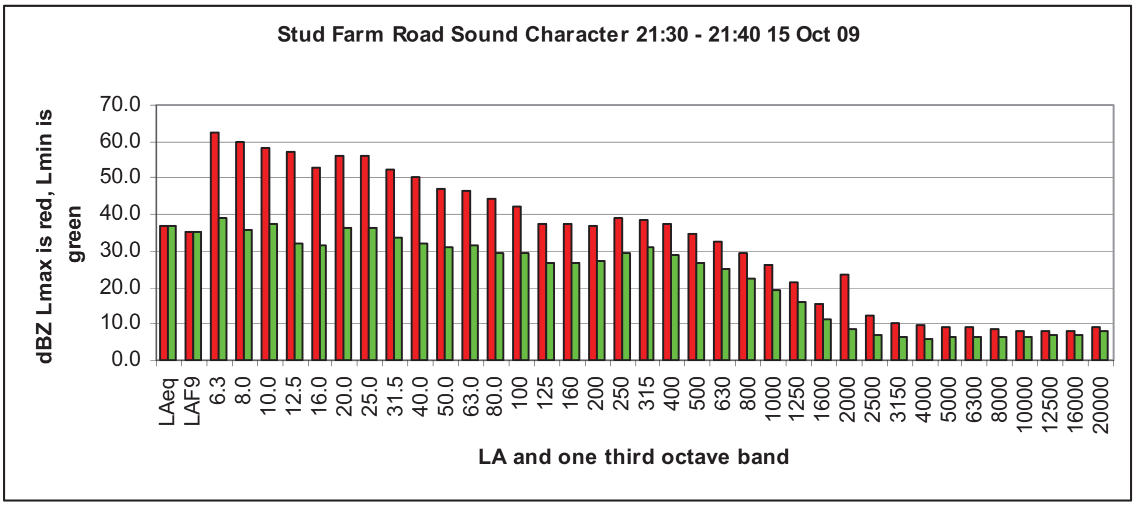
Sound Character at 377 Stud Farm Road.
15 October 2009 at 9:00pm
The soundfile was recorded with no-one present. The audio file has wind and wind farm sounds. There are strong readings at 20 Hz, 16 Hz and 6.3 Hz. These are indicator frequencies for potential adverse health response. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass frequency. The high frequency content (1600-4000 Hz) is not evident in the sonogram or the 60sec audio file.



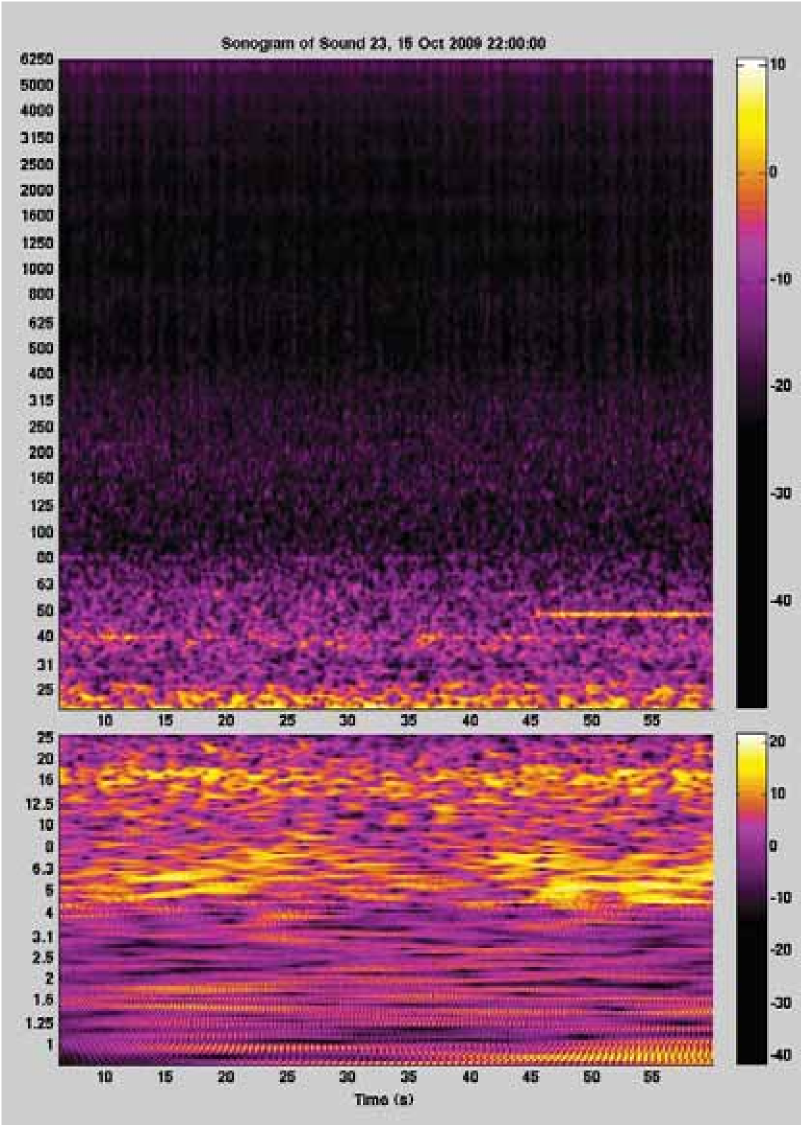


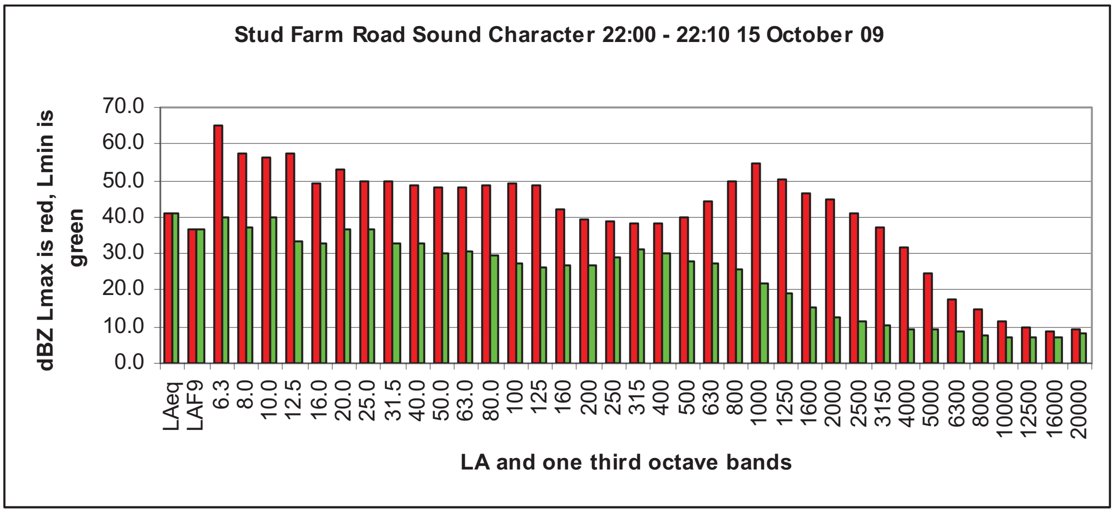
Sound Character at 377 Stud Farm Road.
15 October 2009 at 9:30pm
The soundfile was recorded with no-one present. The audio file has wind and wind farm sounds. There are strong readings at 20 Hz, 16 Hz and 6.3 Hz. These are indicator frequencies for potential adverse health response. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass frequency. The 50Hz tone is from an electrical source, such as a pump.



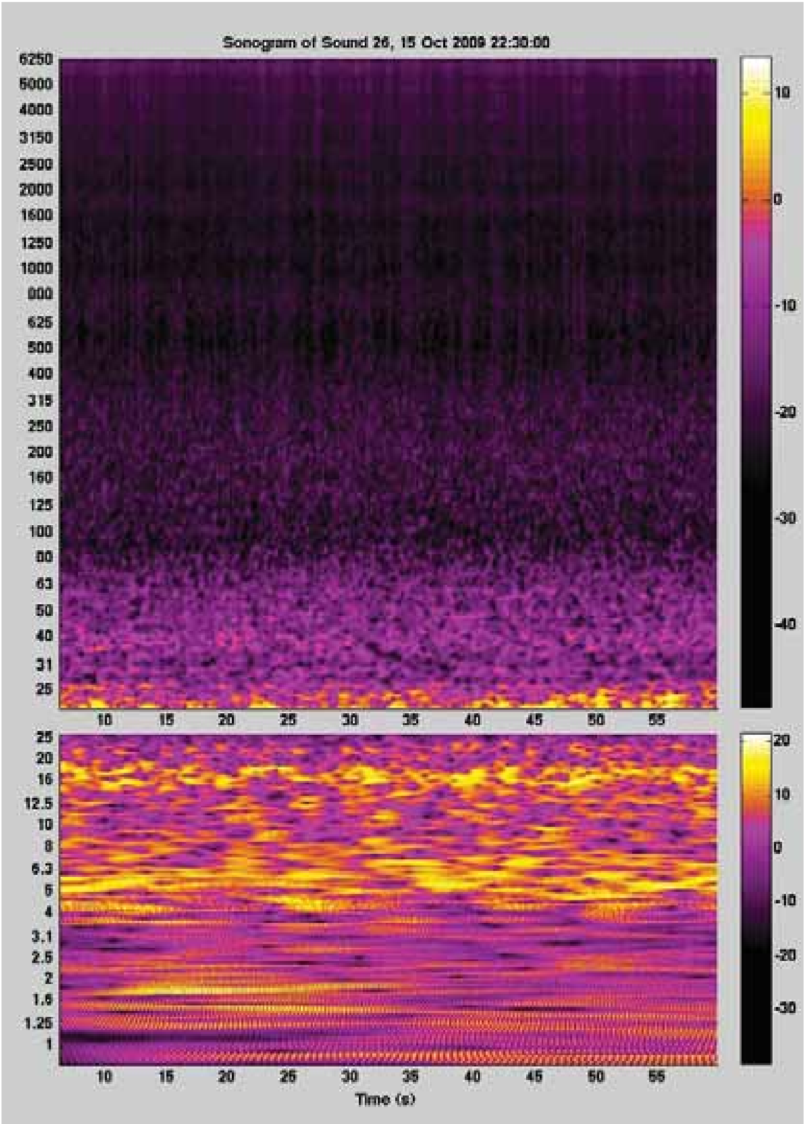


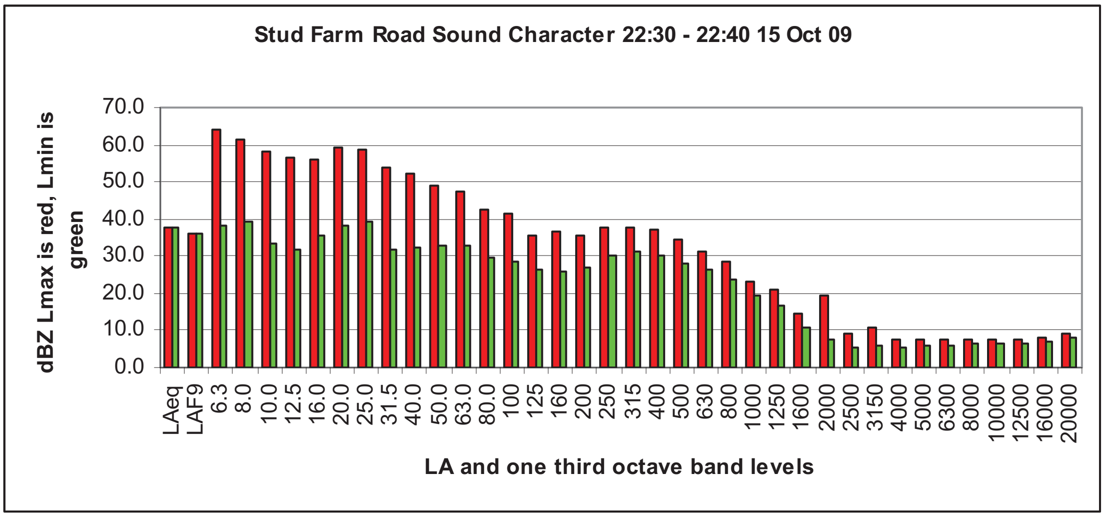
Sound Character at 377 Stud Farm Road.
15 October 2009 at 10:00pm
The soundfile was recorded with no-one present. The audio file has wind and wind farm sounds. There are strong readings at 20 Hz, 16 Hz and 6.3 Hz. These are indicator frequencies for potential adverse health response. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass frequency. The 50Hz tone is from an electrical source, such as a pump. The high frequency content (800-5000 Hz) is not evident in the sonogram or the 60sec audio file.



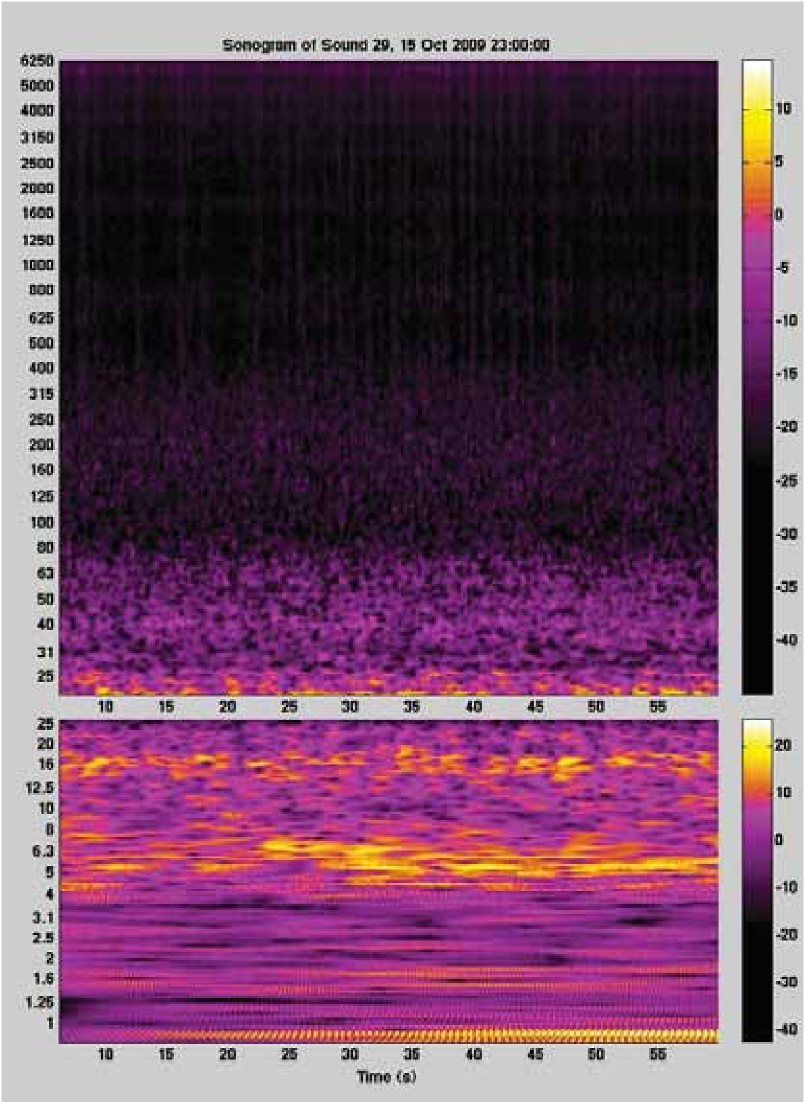


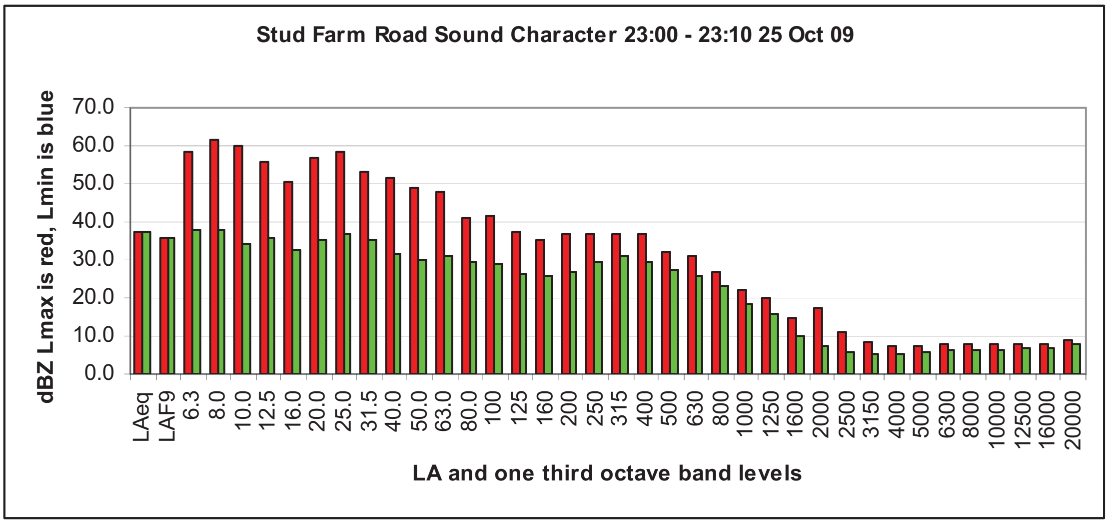
Sound Character at 377 Stud Farm Road.
15 October 2009 at 10:30pm
The soundfile was recorded with no-one present. The audio file has wind and wind farm sounds. There are strong readings at 20 Hz, 16 Hz and 6.3 Hz. These are indicator frequencies for potential adverse health response. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass frequency. The 50Hz tone has gone. The medium frequency content (250-1000 Hz) is just evident in the sonogram.



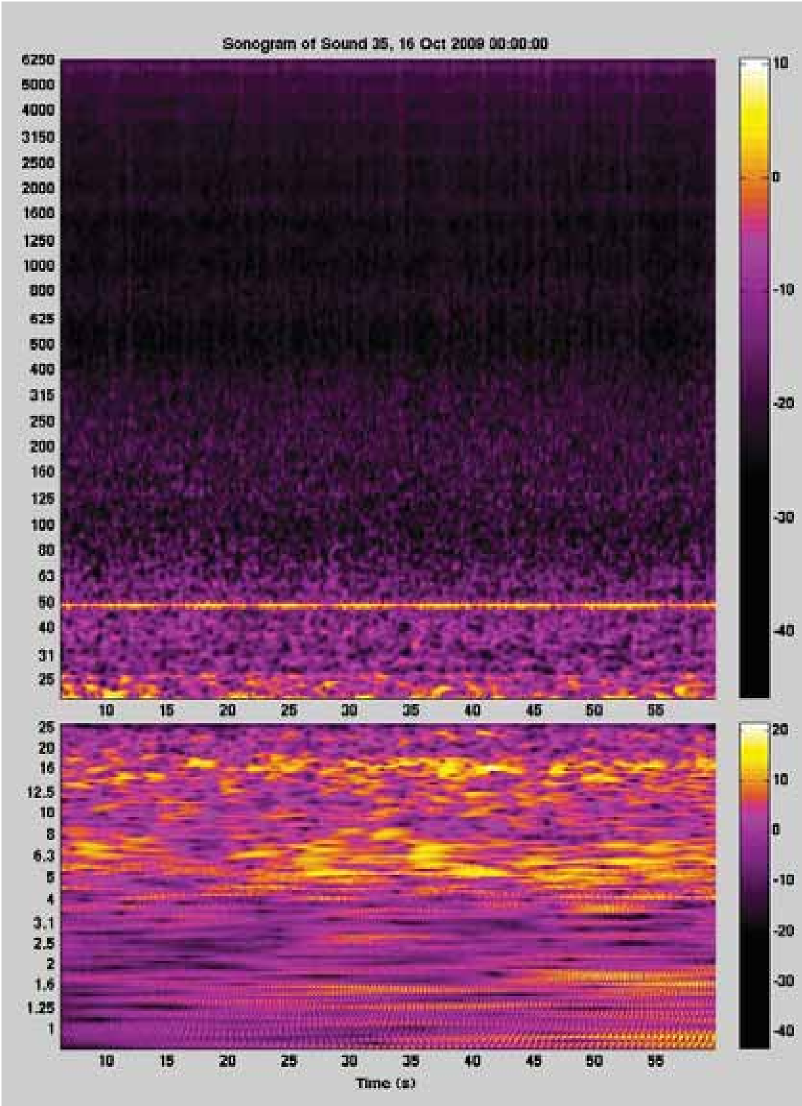


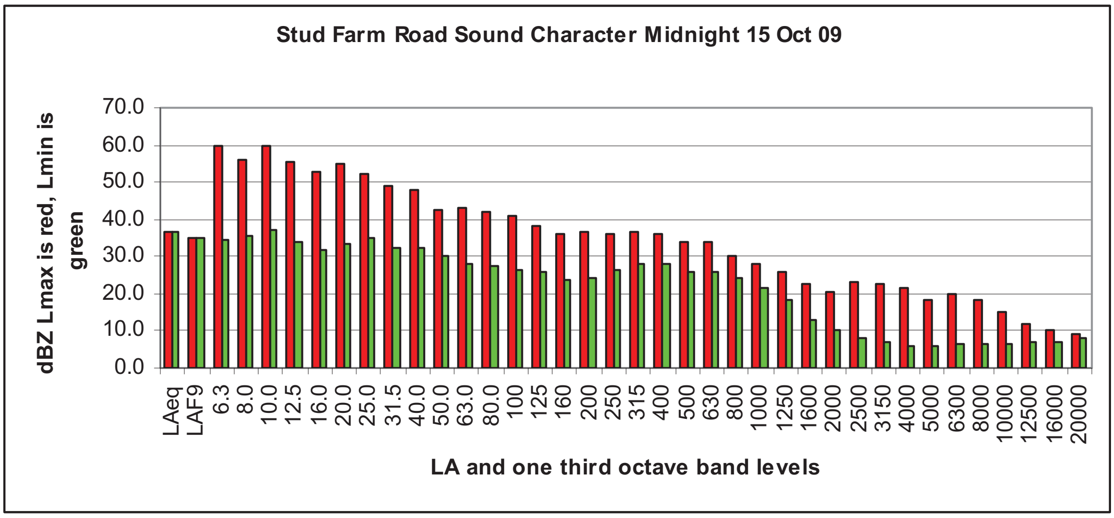
Sound Character at 377 Stud Farm Road.
15 October 2009 at 11:00pm
The soundfile was recorded with no-one present. The audio file has wind and wind farm sounds. There are strong readings at 20 Hz, 16 Hz and 6.3 Hz. These are indicator frequencies for potential adverse health response. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass frequency. The medium frequency content (250-1000 Hz) is just evident in the sonogram.



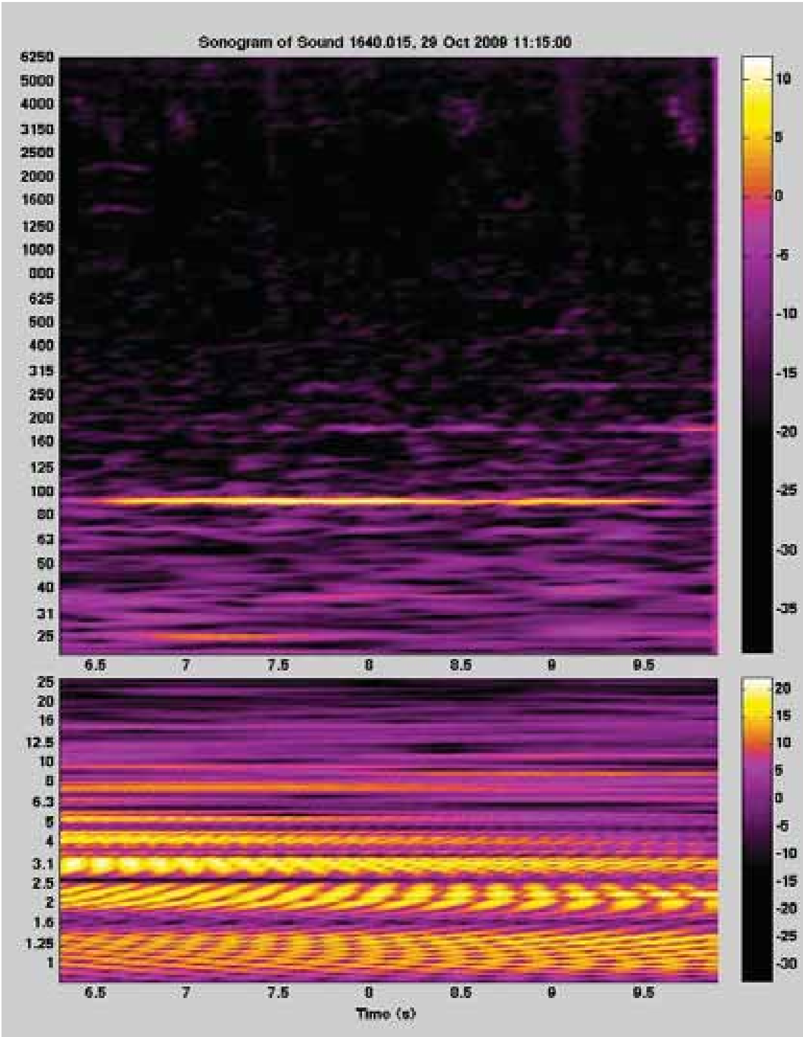


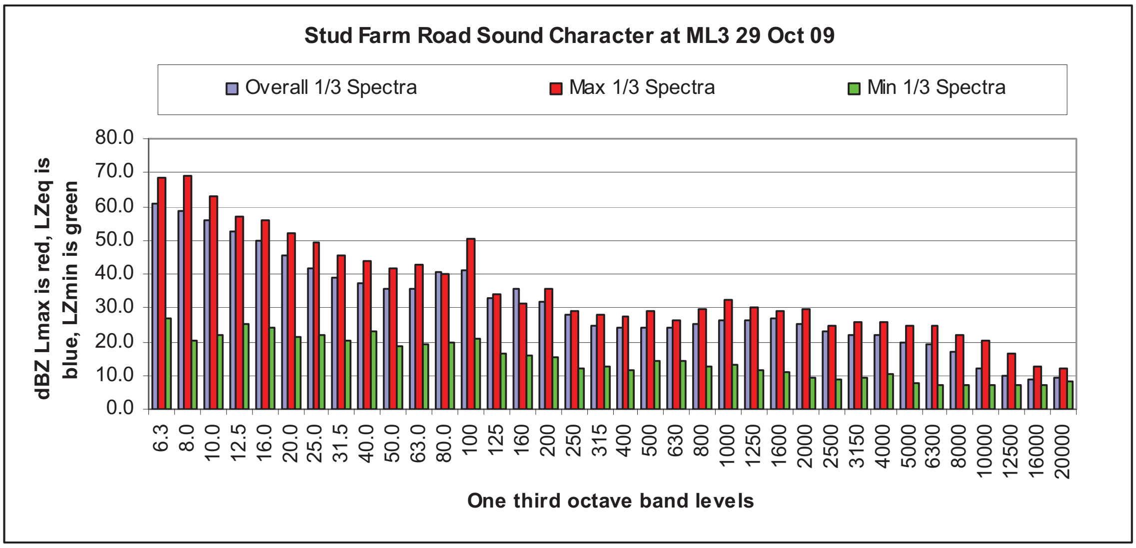
Sound Character at 377 Stud Farm Road.
15 October 2009 at midnight
The soundfile was recorded with no-one present. The audio file has wind and wind farm sounds. There are strong readings at 20 Hz, 16 Hz and 6.3 Hz. These are indicator frequencies for potential adverse health response. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass frequency. The medium frequency content (250-1000 Hz) is just evident in the sonogram. The 50Hz tone has returned (LZeq 41.1 dB, LZmax 42.7 dB, LZmin 29.9 dB).



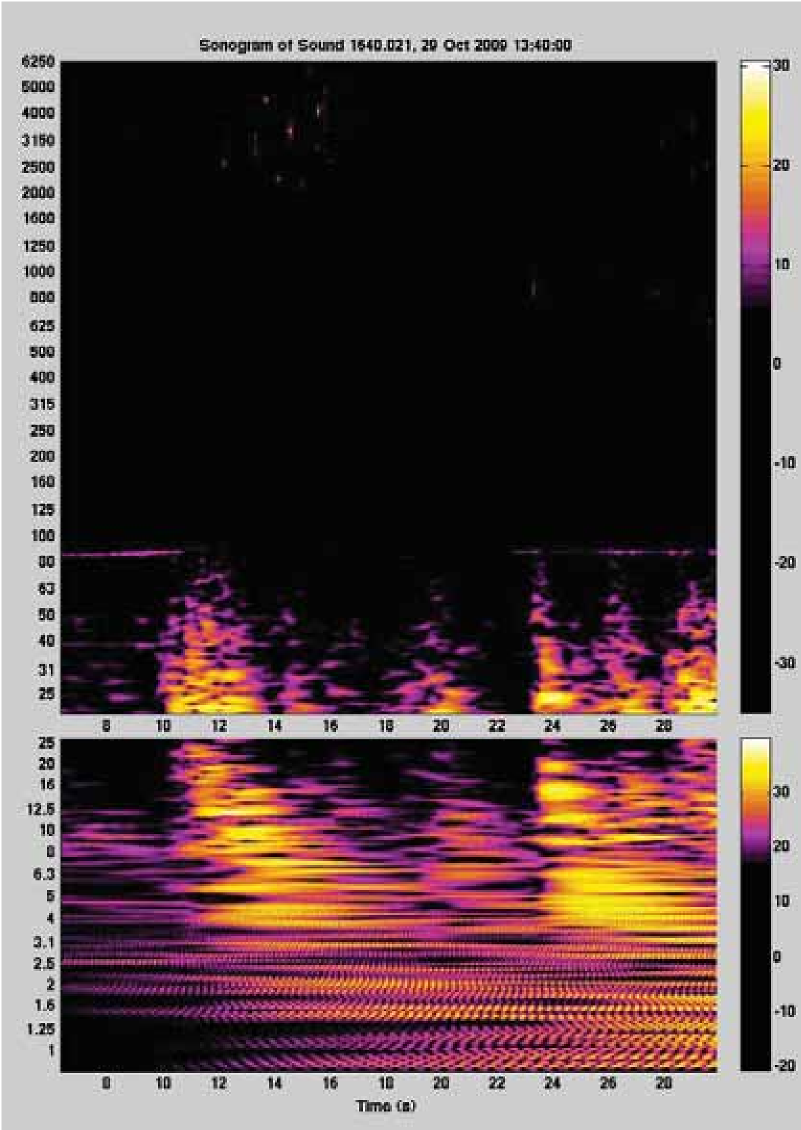


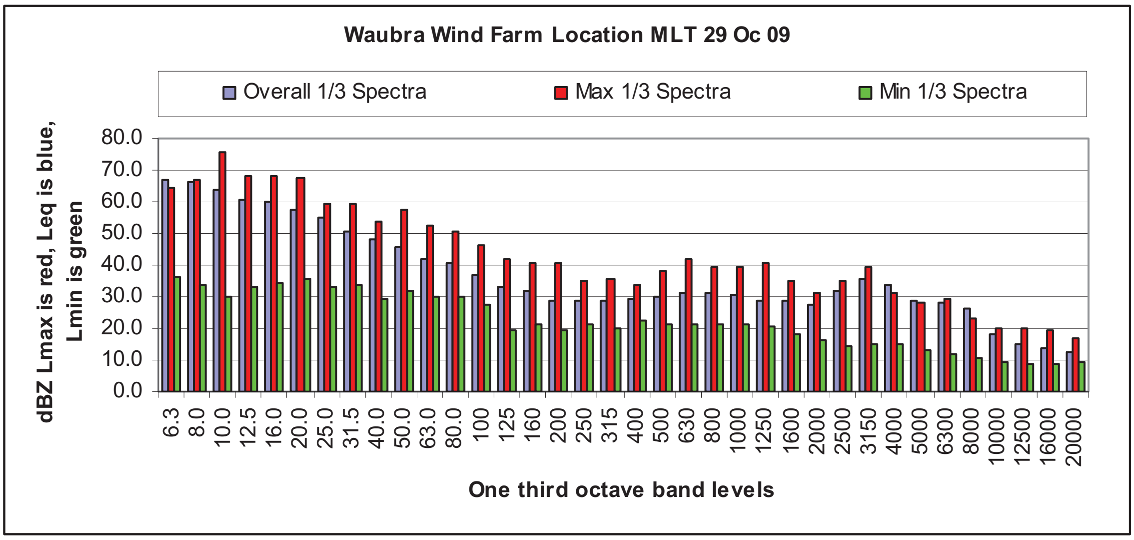
Sound Character at 377 Stud Farm Road.
29 October 09 at 11:15am
Wind farm not audible outside residence. Turbines to south and north do not appear to be turning The wind pattern is completely different from the previous readings at the start of the survey. There is a distinctive 90 Hz tone from an aircraft. Animal and bird noise provide the character. The strong readings at 20 Hz, 16 Hz and 6.3 Hz have gone. The regular bands or modulations at around 1 Hz indicate wind turbine blade noise has gone and instead there are smooth bands of sound from “ordinary” wind flow. The LAeq level is 36.3 dB(A) and the background LA95 level is 28.2 dB(A).



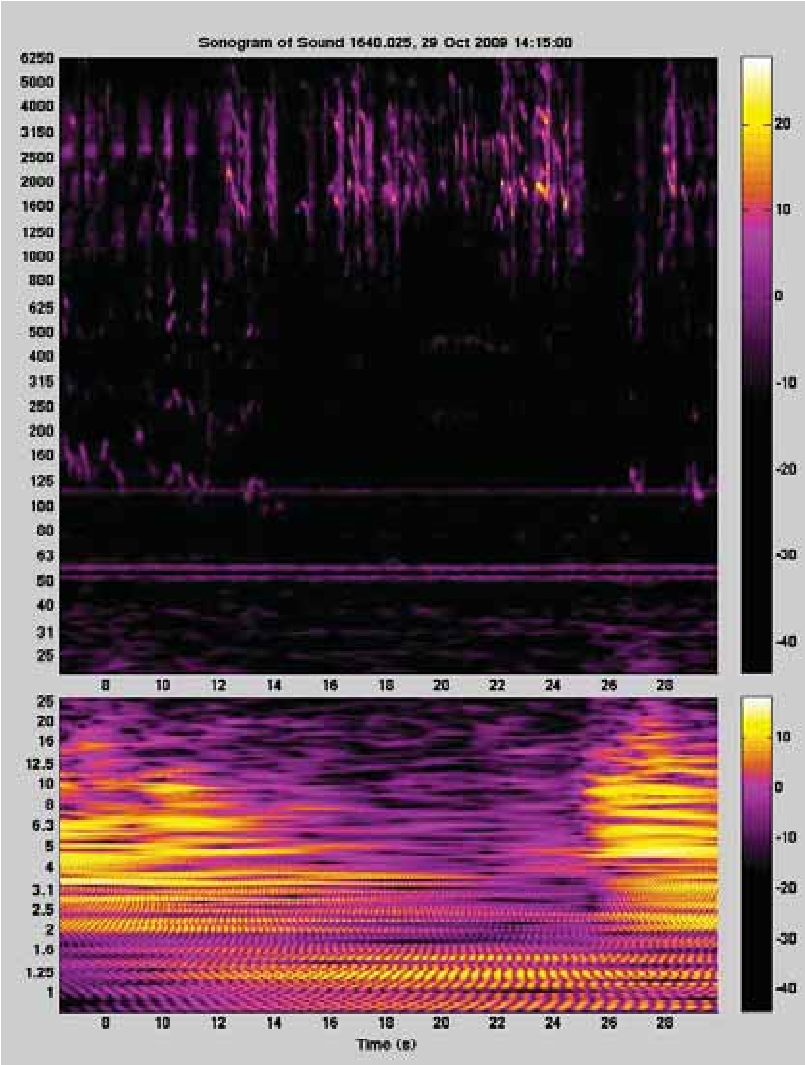


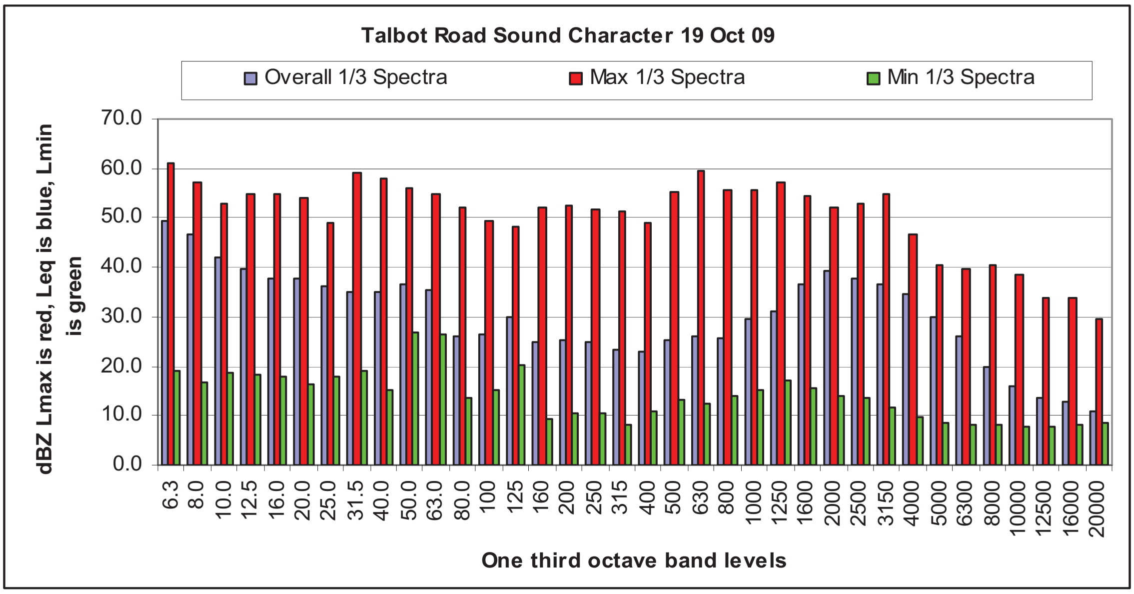
Sound Character at Local resident (T).
Wind farm not audible outside residence but the nearby turbines to south and north were observed to be moving slowly. The ambient is from bird song and some local activity. There are significant bands of sound at 20-40 Hz, 16 Hz, 10 Hz and 6.3 Hz. The regular bands or modulations at around 1 to 2 Hz indicate wind turbine noise and there are smooth bands of sound at regular intervals. The LAeq level is 42.8 dB(A) and the LA95 level is 34.1 dB(A).



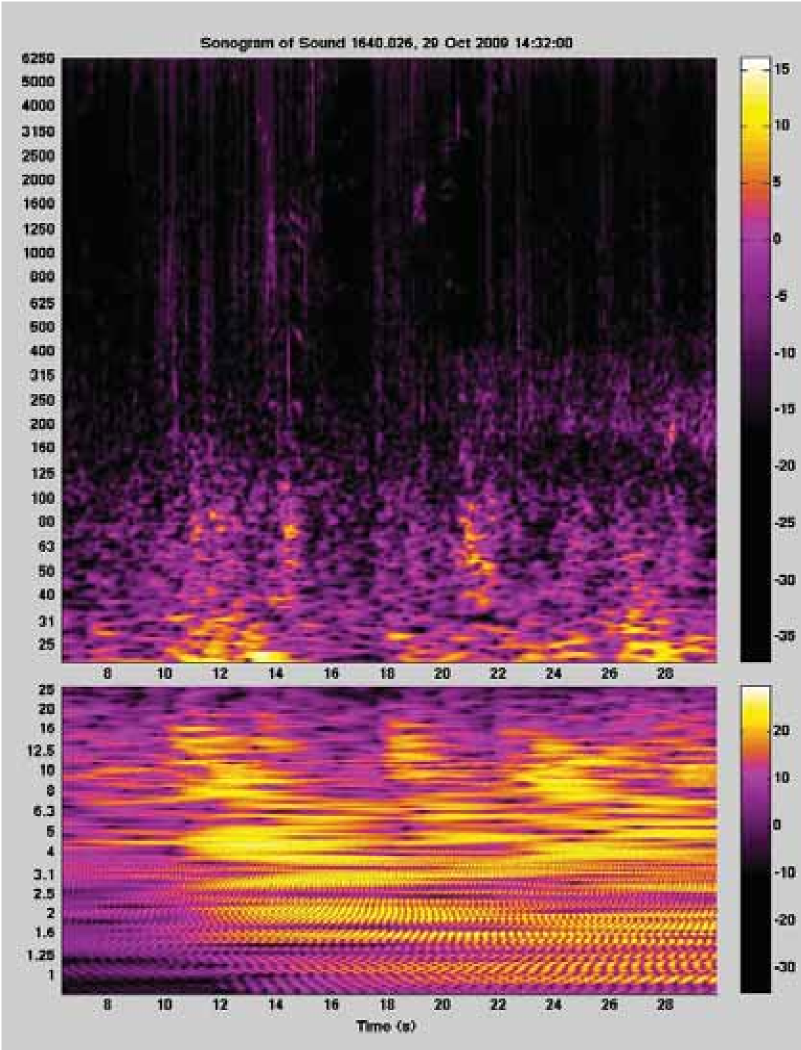


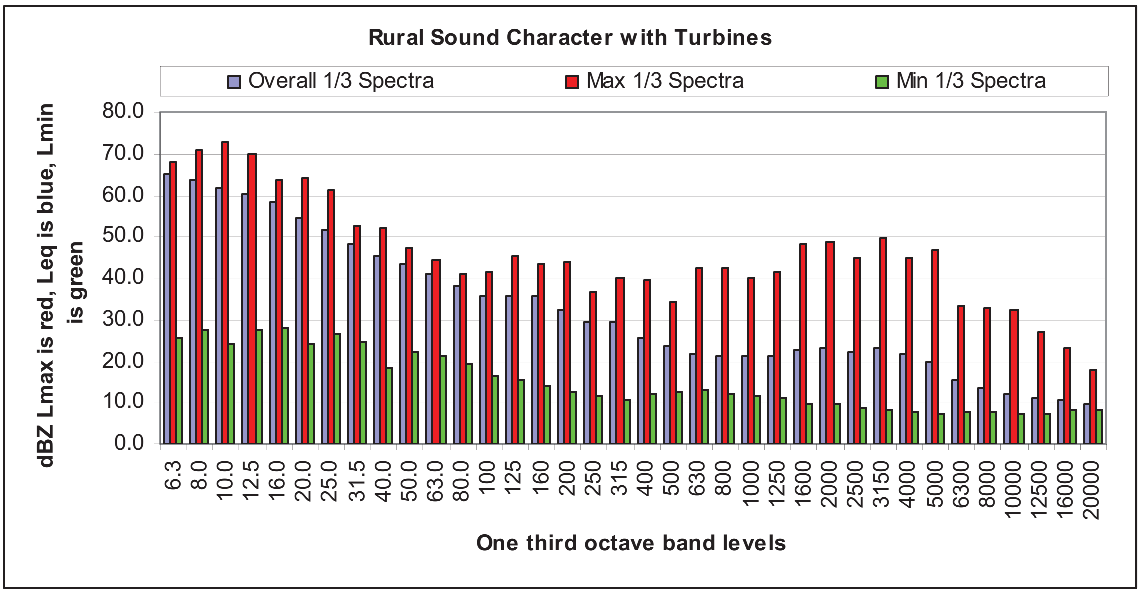
Sound Character at Talbot Road.
Wind farm not audible outside residence but the distant turbines to the west were moving slowly. There are distinctive 120 Hz, 52 Hz and 60 Hz tones from a nearby source. The strong readings at 20 Hz, 16 Hz and 6.3 Hz have gone. The regular bands or modulations at around 1 Hz indicate wind turbine blade pass frequency. The high levels at between 1250 Hz and 4000 Hz are parrots in nearby trees. There was no ground level breeze during the recording.



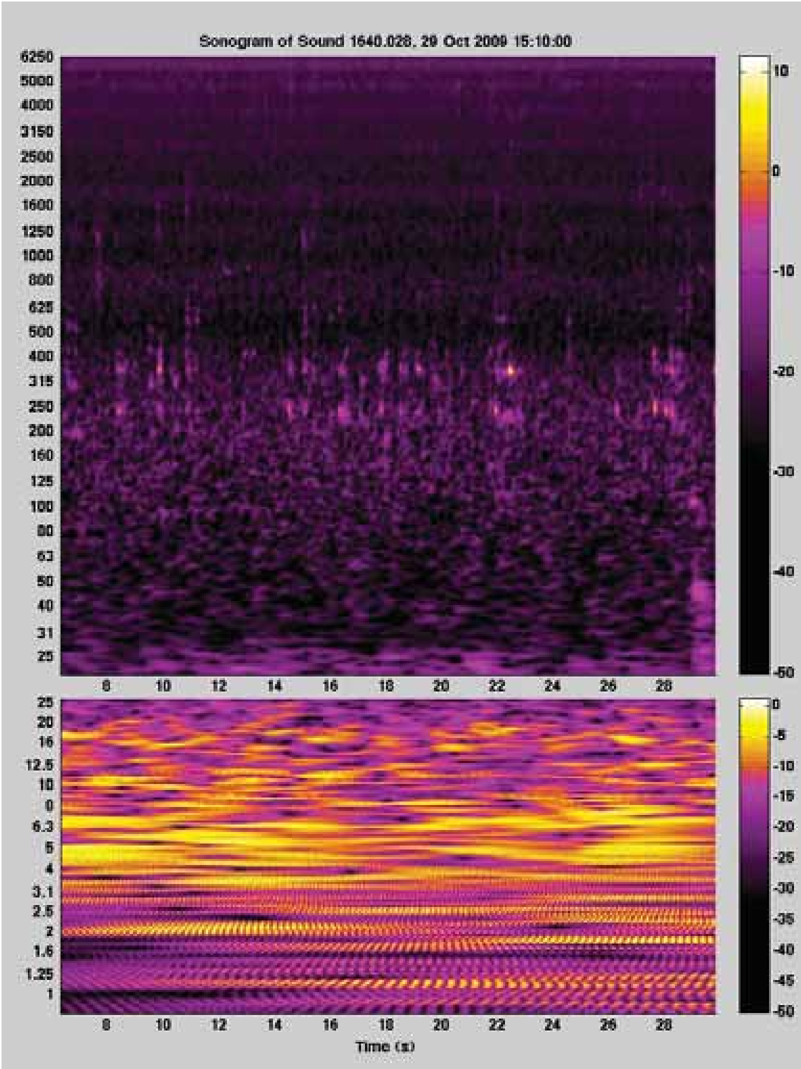


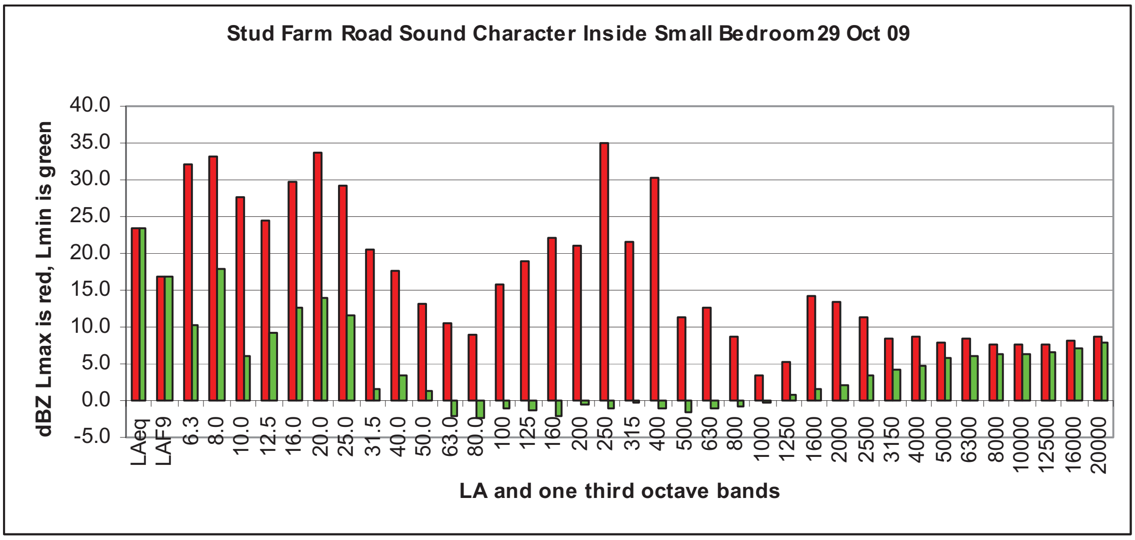
Sound Character at cross road between Talbot and Stud Farm Road.
The wind farm was audible at the measurement location as a distant rumble and some of the nearest visible turbines approximately 500m to 1500 m distant were moving slowly, as though they were starting up. The sound is similar to an aircraft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



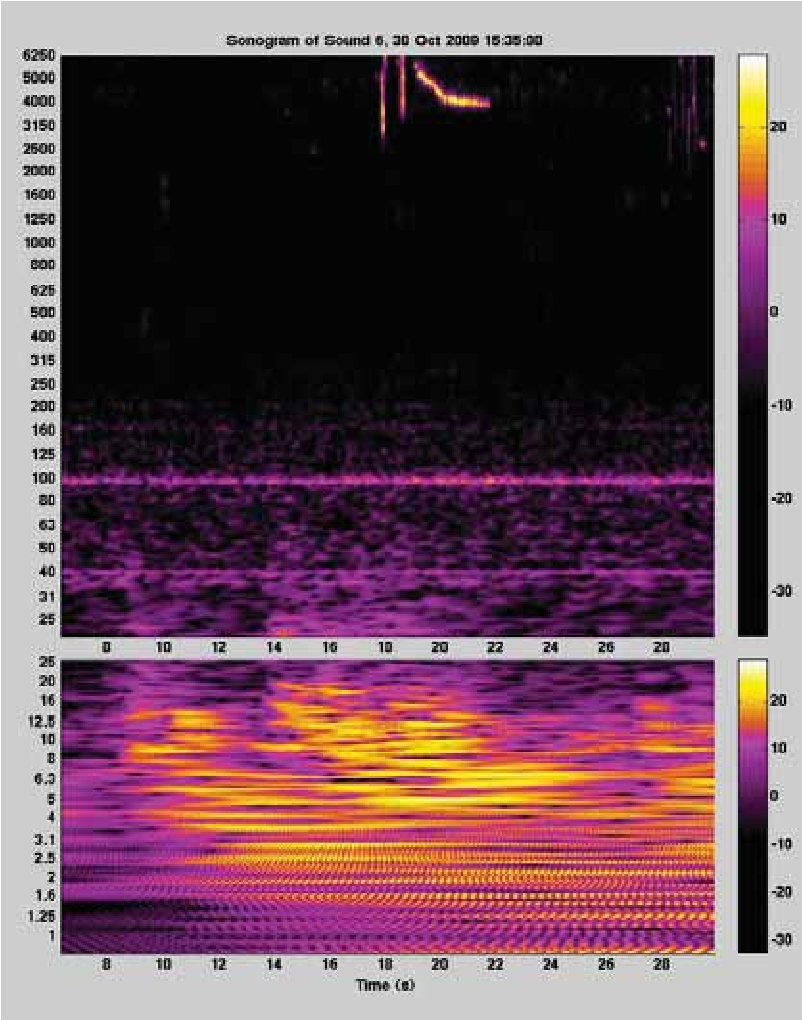


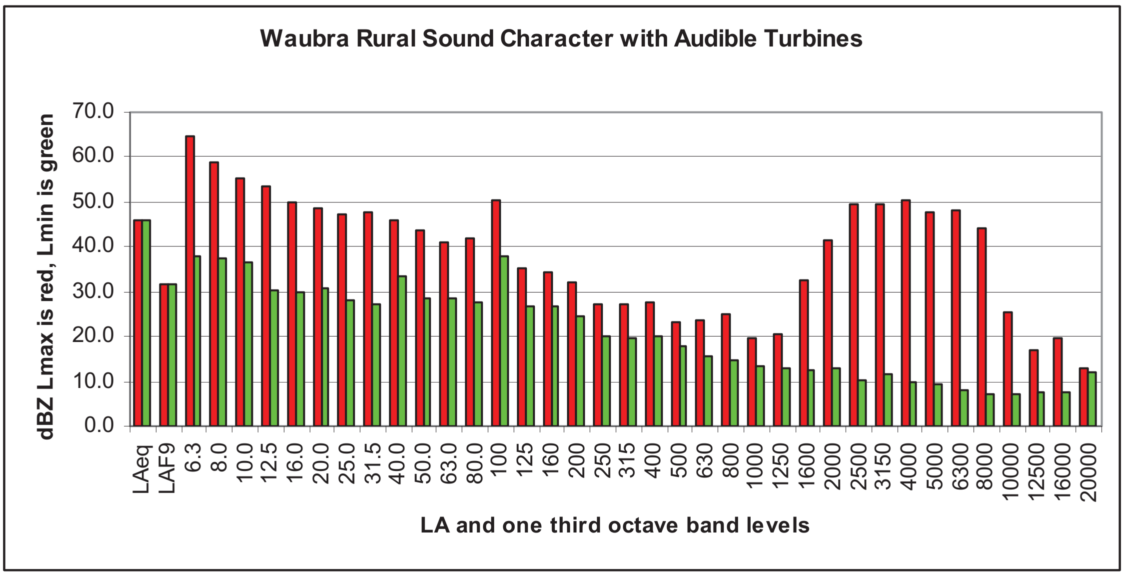
Sound Character Inside Residence at 377 Stud Farm Road.
29 October 09 at 3:10pm. Sound levels measured inside the small bedroom. The audible sound character (200-400Hz) is from distant voices within the house. Wind farm not audible outside residence; turbines to the north turning slowly, turbines to the south not turning. There are strong readings at 20 Hz and below on a regular basis. These are indicators of potential adverse effect. There was no ground level breeze outside during the recording. The LAeq level is 25.4 dB(A) and the LA95 level is 16.6 dB(A).



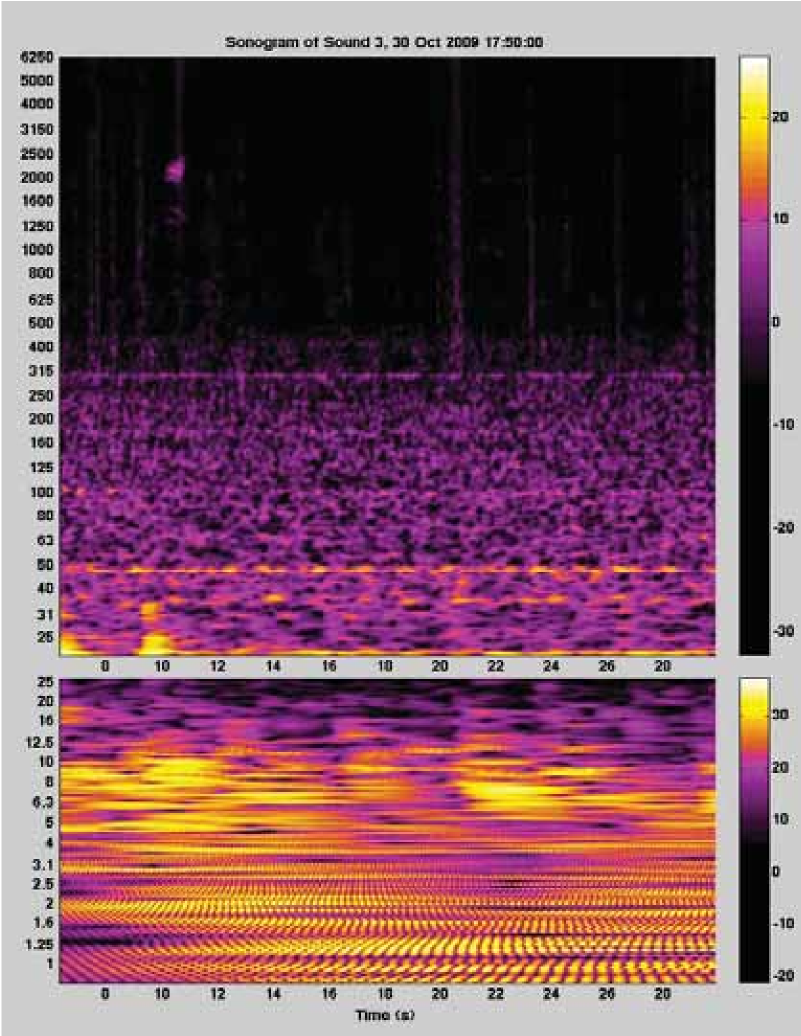


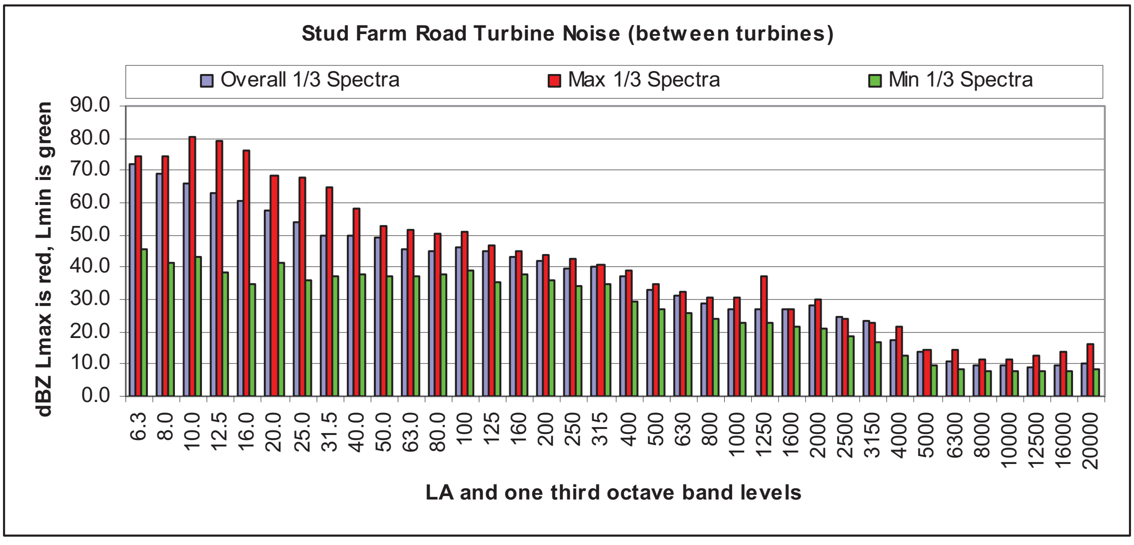
Sound Character at cross road between Talbot Road and Stud Farm Road.
30 Oct 09. 3:35pm Sound recording of operating turbines approx 500m to 1500m distant. The high frequency “yellow” sound (4000-6250Hz) is from bird song. There was no ground level breeze during the recording. The ragged yellow line running across at 100 Hz is wind turbine noise; a low hum. The yellow line across the bottom of the lower plot indicates that there is modulation of this hum at about 0.8 Hz. There are strong readings at 20 Hz and below on a regular basis. These are indicators of potential adverse effect. The LAeq level is 46.1 dB(A) and the LA95 level is 31.6 dB(A). The turbines are clearly audible.





Sound Character at Stud Farm Road.
30 Oct 09 5:50pm. Sound recording on road between two sets of turbines. There was no ground level breeze during the recording. The turbines on both sides of the road were turning, with one turbine just starting at the time of recording. There are strong tones at 50 Hz and 38 Hz. The yellow line across the bottom of the lower plot indicates that there is modulation of this hum at about 0.8 Hz. There are strong readings at 20 Hz and below on a regular basis. These are indicators of potential adverse effect. The LAeq level is 41.7 dB(A) and the LA95 level is 40.2 dB(A) over the 3 minute recording. The turbines are clearly audible and have significant low frequency and infrasound characteristics. There is some animal noise in the 250-400Hz bands.





An infrasound analysis for the same time period is shown in the following chart, **Figure 20**. The chart is a single 25ms snapshot (SVAN 959 sound level meter) illustrating the character of the environment when two sets of turbines working on either side of Stud Farm Road are operating. The chart shows the high level of infrasound in the environment. When both sets of turbines are operating there is a perceptible pressure drop that is experienced as a person travels in a vehicle along the road. The effect is to make a person's ears "pop". This effect has been observed and felt by more than one person on more than one day.

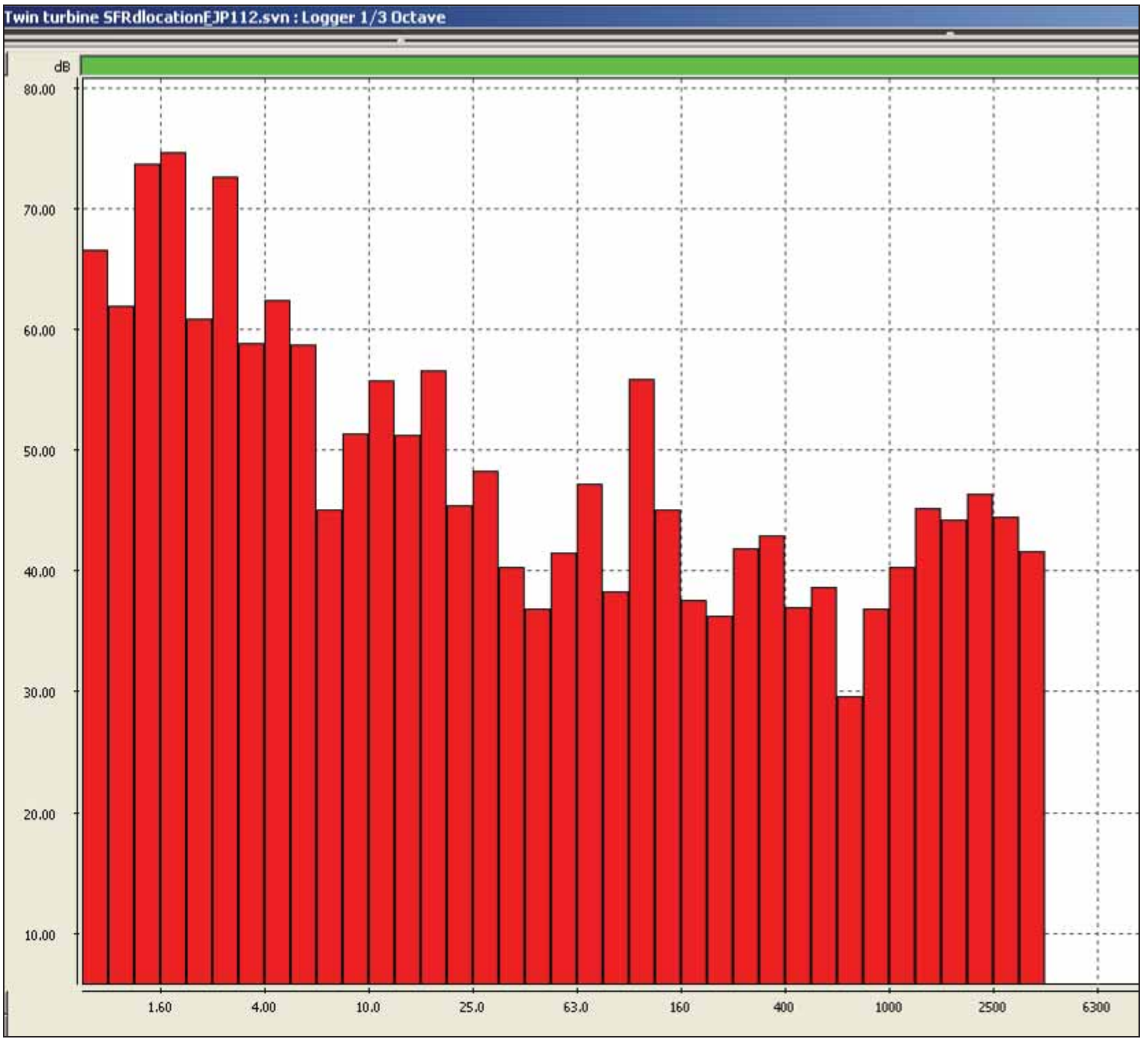


Figure 20: a single 25ms snapshot of turbine sound, 30 October 09, 5:50pm

The ambient sound level characteristics described in this section illustrate the difficulty in identifying sound character in accordance with NZS 6808:1998. The revised standard is slightly better in that it has an interim guide to analysing for modulation. Research into sound character analysis and presentation is a continuing part of our research program.

It is concluded from the analyses in this section that wind farm activity at the Dean residences and farms can be measured and assessed objectively in terms of sound level and sound character including audible sound, low frequency sound and infrasound.

Glossary to Terms

Event maximum sound pressure level (LA%,adj,T), LA01

The L01 level is calculated as the sound level equalled and exceeded for 1% of the measurement time, for example 6 seconds in any 10 minute interval. LA01 is an appropriate level to characterise single events, such as from impulsive or distinctive pass-by noise. The level can be adjusted for tonality or impulsiveness.

Average maximum sound pressure level (LA%,adj, T), LA10

The “L10” level is an indicator of “steady-state” noise or intrusive noise conditions from traffic, music and other relatively non-impulsive sound sources. The LA10 level is calculated as the sound level equalled and exceeded for 10% the measurement time, for example 60 seconds in any 10 minute interval.

Background sound pressure level (LA90,T), LA90 or LA95

Commonly called the "L95" or "background" level and is an indicator of the quietest times of day, evening or night. The LA95 level is calculated as the sound level equalled and exceeded for 95% the measurement time. The level is recorded in the absence of any noise under investigation and is not adjusted for tonality or impulsiveness.

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

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

Façade-adjusted and Free-Field levels

The façade-adjusted sound level is that measured at a distance of 1.0 metre from a wall or facade. The level is nominally 2.5 dB higher than the free-field level. In comparison, the free-field sound level is measured at a distance of more than 3.5 metres from a wall or facade.

A-weighted or Z-weighted

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

The expression ‘LAF95’, for example, means the A-weighted sound level, fast response, exceeded for 95% of the measurement time. ‘Fast’ response is a standard method of measuring sound levels.

Third Octave Band

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

5 SOUND AND HEALTH

Introduction

This Introduction is by B. Rapley as recorded in 'Sound, Noise, Flicker and the Human Perception of Wind Farm Activity' introducing the monograph by Dr D. Shepherd.

> To understand the nature of the potential hazard, it is necessary to understand the nature of sound and the way it interacts with the human body. Dr. Daniel Shepherd takes on this task, providing a tutorial on the nature of the phenomenon and the method of interaction with human physiology. He makes the important point that, contrary to popular belief, we do not become used to noise (unwanted sound). To assume that someone can simply learn to accommodate a noise and ignore it is largely untrue. Dr Shepherd concludes that there is now convincing evidence in the literature that community noise causes annoyance, disrupts sleep, impairs children's school performance and negatively affects cardiovascular health. It also impedes rest, relaxation and recreational activity.
>
> The latest research indicates that nuisance noise from wind farms is associated with psychological distress, stress, difficulties with falling asleep and sleep interruption. Furthermore, it is very hard to predict how annoyance from noise will compromise the health of susceptible individuals by considering the physical properties of the noise. This surely raises red flags for both those setting noise standards and those involved with policing consents. On these issues alone it is clear that there must be far more care in the siting of any future wind farms and a better understanding of how to mitigate the noise and compensate the affected individuals. The age-old question still exists: when do the needs of the many outweigh the needs of the few?

Brief excerpts from Dr Shepherd's monograph follow. For the complete monograph and references see 'Sound, Noise, Flicker and the Human Perception of Wind Farm Activity' the evidential text for the proposed Turitea wind farm (New Zealand) hearing.

What is noise

Sufficient evidence now exists to link community noise to health problems, with one literature review concluding the following:

> "It can be seen that these international groups of experts considered that there was sufficient evidence for the effects of noise on health regarding annoyance, school performance, ischaemic heart disease, hypertension and various aspects of sleep disturbance."

While the WHO noise report states:

> "People may feel a variety of negative emotions when exposed to community noise and may report anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation or exhaustion…"

The WHO has identified noise as a key issue in most European countries and acknowledges both the increase in levels of community noise and the discontentment from the exposed communities. Many health institutions now view the growth of community noise as unsustainable and note that noise exposure is not simply limited to a direct and cumulative impairment to health, but to future generations who will be affected through the degradation of residential, social and learning environments. These warnings are in line with the stance taken by the WHO, which states:

> "The growth in noise pollution is unsustainable because it involves direct, as well as cumulative, adverse health effects. It also adversely affects future generations and has socio-cultural, aesthetic and economic effects."

While it can be convincingly argued that community noise can be a source of stress and depression and anxiety, there is currently no compelling evidence to suggest that community noise induces serious mental disorders such as psychosis or neurosis. A WHO report on the relationship between health and noise demonstrated that those strongly annoyed by traffic noise were more at risk of depression, hypertension and migraines. On wind turbines, the French Academy of Medicine states:

> "People living near the towers, the heights of which vary from 10 to 100 meters, sometimes complain of functional disturbances similar to those observed in syndromes of chronic sound trauma. Studies conducted in the neighbourhoods of airports have clearly demonstrated that chronic invasive sound involves neurobiological reactions associated with an increased frequency of hypertension and cardiovascular illness. Unfortunately, no such study has been done near wind turbines. But, the sounds emitted by the blades being low frequency, which therefore travel easily and vary according to the wind, they constitute a permanent risk for the people exposed to them."

Who decides if noise is a health issue?

Numerous reports from credible institutions (e.g., the WHO) and universities around the world have demonstrated that noise negatively affects our physiological and psychological processes. These findings have been replicated in laboratories, which confer greater experimental control at the cost of ecological validity, and in the real world, which provide ecological validity at the cost of experiment control. Researchers who are experts in human physiology, human psychology or both have undertaken such research. On occasion these researchers will invite acousticians to assist in the generation (for laboratory studies) or measurement (for real world studies) of sound waves to increase the value of their research. Thus while the contribution of acousticians can be critical in the research process, there has been a noticeable trend in the field of public policy that, when the effects of noise on the community are being debated, acousticians are adopting the role of health experts. British medical doctor Dr Harry reports the alarming prevalence of acousticians giving evidence concerning the health effects of sound emitted from wind turbines:

> "…the acoustic experts have made statements categorically saying that the low frequency noise from turbines does not have an effect on health. I feel that these comments are made outside their area of expertise and should be ignored until proper medical, epidemiological studies are carried out by independent researchers."

Another American practitioner, Dr Nina Pierpont, portrays the role of the acoustician in the monitoring of WTI sound levels as hired report writers rubber stamping a pre-existing script:

1. The WTI is emitting sound of this character and magnitude.
2. Acousticians have decided that there will be no adverse health effects for sounds of this character or magnitude.
3. Anyone claiming compromised health due to the sound emanating from the WTI is a hypochondriac, mentally ill or a liar.
4. Case closed.

This somewhat mercenary portrayal will, however, resonate with some communities in the Manawatu region who would claim to have been on the receiving end of such treatment. For example, the Manawatu Standard reported the following statement from Meridian Energy, the owner of a newly established wind turbine installation, that "it's a small number of people making a big noise about nothing" when locals complained of a rumbling sound that "bombarded us with noise and vibration." Meridian Energy justified these comments on the basis of the advice they had received from their employed 'health consultants' who were, in fact, acousticians providing information far beyond their expertise.

Regarding Pierpont's first point, a comment is justified on the value of the acoustic measurements undertaken using modern processes. Acousticians make a common mistake in believing that just because a sound frequency does not reveal itself in the physical measurement of acoustic energy (i.e., on a spectrograph) then that frequency cannot be perceived. This is contra to how the auditory system operates and the phenomena of the missing fundamental and dichotic pitch make immediate nonsense of such claims. Along with the resident nonlinearities of the auditory system there are other psychoacoustical phenomena such as stochastic resonance that account for the perception of tonal components that fail to register on an acoustician's sound meter. Stochastic resonance is a phenomenon by which sub-threshold signals (e.g., a tone) are boosted above threshold by a coupling of energy between the signal and the noise background.

Every trained psychoacoustician knows that sensation does not perfectly mimic physics. Instead, we process stimuli in a 'top-down' manner and our judgments on what is happening in the immediate environment are reliant on how the brain interprets the sensory information, with this interpretation involving many non-sensory factors. Therefore, more weight should be placed on psychoacoustical, as opposed to acoustical, measurements in determining the effects of wind turbine noise. After all, a machine cannot be relied upon to tell a human what they are, and what they are not, hearing. Acousticians should be invited to the party: they can inform debate with physical measurements, but unless sufficiently qualified they should not be estimating the potential health effects associated with noise. Ultimately, medical practitioners, physiologists and psychologists are required for these judgments.

Defining Annoyance

The WHO reports that noise annoyance can express itself through malaise, fear, threat, uncertainty, restricted liberty, excitability or defencelessness. Furthermore, annoyance may be underwritten by fear and anger, especially if one believes that they are being harmed unnecessarily. A study in Australia reported that of those claiming to be seriously annoyed by noise, approximately ten percent reported becoming excessively aggressive due to the impact of the noise. Research informs us that unwanted sound can be bothersome and becomes a social problem when the noise is man-made.

Before exploring noise-induced annoyance in more detail, some consideration should be given to the definition of annoyance, as there are explicit differences between the everyday usage of the term and the medical usage of the term. The word annoyance is often misinterpreted by the general public as a feeling caused by the presence of a minor irritant. The medical usage, in contrast, exists as a precise technical term and defines annoyance as a mental state capable of degrading health.

Noise containing lower frequency components generally elicits stronger negative evaluations than noise that does not. Research has shown that low frequency noise increases cortisol levels in those who are sensitive to noise and can interfere with cognitive processes. That noise consisting of low frequency components can induce stress in the listener has been known for some time. Such noise is currently being applied in some countries to manage unruly crowds. The WHO state:

> “It should be noted that a large proportion of low-frequency components in noise may increase the adverse effects on health… It should be noted that the low frequency noise, for example, from ventilation systems, can disturb rest and sleep even at low sound pressure level… Special attention should be given to: noise sources in an environment with low background sound levels; combinations of noise and vibrations; and to noise sources with low-frequency components.”

And further:

> “The evidence on low frequency noise is sufficiently strong to warrant immediate concern… Health effects due to low frequency components in noise are estimated to be more severe than for community noises in general.”

The description of 'feeling' rather than hearing the sound is an indication that low frequencies are present. Lower frequencies correspond to the resonating frequencies of our body organs and in their presence encourage them to vibrate. For example, the head resonates at 20–30Hertz and the abdomen 4–8Hertz. A study examining the chronic effects of low frequency vibration and subsequent psychological and physiological consequence are reported in Table 1 (Rasmussen: Cited in Harry. In fact, the weight of opinion supports the claim that low frequency noise is produced by wind turbines, with the displacement of air by the blades and the turbulence around the blade surface the likely cause. These low frequencies can produce a seismic characteristic leading to those in the proximity of wind turbines to complain not only of audible noise but also noise that they can feel. Low frequency sounds modulate the perception of other audible frequencies and can be sensed as a vibration of the chest or throat. Residents neighbouring wind turbines in the USA have described:

> "… distressing sensation of having to breathe in sync with the rhythmic thumps of the turbine blades, especially at night when trying to sleep."

Casella, reporting on the effects of low frequency turbine noise, makes the observation that, compared to medium and high frequencies, low frequency levels decay slowly with distance, are less attenuated by conventionally designed structures, cause certain building material to vibrate and can sometimes resonate with rooms, undergoing amplification thereby. The relationship between low frequency wind turbine noise and building type creates an interesting proposition in which the low frequency sound may be louder inside the house than out. As the engineering experts attest:

> "Modern home construction techniques used for most wood frame homes result in walls and roofs that cannot block wind turbine low frequencies from penetrating into the interior….When low frequency sound is present outside homes and other occupied structures; it is often more likely to be an indoor problem than an outdoor one. This is very true for wind turbine sounds."

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

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

Summary

In summary:

- Sound is what we hear; noise is unwanted sound.
- Sound, be it unwanted or wanted, influences not only the way we think and behave, but also our physiological systems including cardiovascular and gastrointestinal activities, and hormone secretion.

- It is often claimed that continual exposure to a noise results in habituation, that is, one gets used to the noise. Such a proposition is not supported by either research or anecdotal evidence.
- There is now convincing evidence in the literature to conclude that community noise induces annoyance, disrupts sleep, impairs children's school performance and negatively impacts cardiovascular health. It also impedes rest, relaxation and recreation activities.
- The latest research indicates that annoyance with wind turbine noise is associated with psychological distress, stress, difficulties in falling asleep and sleep interruption.
- Annoyance from noise, which can compromise health in susceptible individuals, is poorly predicted by the physical properties of the noise.
- Community noise, including noise emanating from wind turbines, can induce sleep disturbances by waking a sleeper, altering sleep patterns, reducing dream sleep, increasing body movement and changing cardiovascular responses.
- Inadequate sleep has been associated not just with fatigue, sleepiness and cognitive impairment but also with an increased risk of obesity, impaired glucose tolerance (risk of diabetes), high blood pressure, heart disease, cancer, depression and impaired immunity as shown by susceptibility to the common cold virus.
- The evidence as it stands indicates that wind turbine noise has the potential to degrade psychological, physical, environmental and social well-being. All these factors combine to determine an individual's quality of life.
- Wind turbine installations need to be sited with care and consideration with respect to the communities hosting them.

6 VIBRATION IMPACT ASSESSMENT

The following is a summary of the Report prepared by Heilig and Partners as an independent assessment of tower and seismic vibration in order to assess the potential for adverse effects at the Stud Farm Road residence. The full report has been forwarded under separate cover.

The Report by Heilig and Partners was commissioned to assess the potential for adverse effects in comparison to a seismic study[3] near a New Zealand wind farm. In that study seismic and acoustic measurements were undertaken at a residential site at the base of the Tararua Ranges close to a wind farm to determine whether nuisance noise reported by the residents could be detected and whether it could be traced to the windfarm. Extraneous events were eliminated from the measurements by using only night time records, by removing known events and by eliminating events that did not correlate with the timing of the residents' perception. The remaining events were characterised by bursts of around 10 seconds duration and with broad peaks in the power spectra at 28Hz and 10Hz. It was concluded from this study that the noise 'perceived' by the residents is measurable, consists of separate acoustic and seismic parts and can cause annoyance by disturbing sleep.

Vibration Effects at Stud farm Road

Further to the measurement of vibration from the operation of the wind turbines at the Waubra Wind Farm, the following is a summary of the measurements collected at multiple locations about the Waubra property. Measurements of vibration were collected both internal to the property and on the exterior, including walls, shed and in the ground. In addition, vibration measurements were taken directly on a turbine tower and about the base of the tower. A total of 18 measurements sites were considered in the analyses.

The measured levels of vibration on the property vary according to each of the above aspects, however the peak levels have remained low with the exception of the walls of the shed where levels up to 0.04m/s^2 have been recorded. Vibration on the house, either internally or externally, have remained less than 0.01m/s^2 and within the values suggested in British Standard BS6472:1992 *Evaluation of human exposure to vibration in buildings (1Hz to 80Hz).*

On the basis of the measured values only, it is the professional opinion of Heilig & Partners that the values are low and remain in compliance with the British Standard. It is considered pertinent to supplement these measurements through additional monitoring with high sensitivity, low frequency, low amplitude accelerometers capable of detecting changes in acceleration of

[3] Bakker, H, Bennett D, Rapley B, Thorne R 2009 *Seismic Effect in Residents from 3 MW Wind Turbines*, presented at the Third International Meeting on Wind Turbine Noise, Aalborg, Denmark, 17-19 June 2009.

0.00004m/s^2. Such devices will unambiguously confirm the presence of any vibration, its amplitude, the frequency and the variability throughout the property.

Measurement Equipment

Vibration data were collected using a VISONG low frequency accelerometer with frequency capabilities varying upwards from 0.5Hz. The tri-axial sensor was firmly bonded to measurement surface and attached to a calibrated Instantel Minimate Plus data acquisition system operating at a sampling frequency of 1024 samples per second. The system allowed for a resolution of 0.004m/s^2 with a peak measureable level of 100m/s^2. Each monitoring location was sampled for a period of 20 seconds and for three discrete sample periods. Data for each sample period are attached to this technical letter.

Measurement Comparisons

The British Standard BS6472[4], or other similarly worded documents such as the New South Wales Environmental Protection Act EPA Vibration Guide[5], provide acceptable levels of vibration from both impulsive and continuous sources of vibration. Impulsive events are classed as those with durations of seconds and persisting infrequently during the day. Continuous events are better aligned with those from sources such as wind turbines.

A review of these documents provides for acceptable values depending upon both the nature of the premises subjected to the vibration, the time of the activity (night or day) and the orientation of the persons within the property, either standing or lying down. The documents cover dominant frequencies in the range of 1Hz to 80Hz. The acceptable level is expressed in terms of both the amplitude of vibration and the corresponding dominant frequency. The table below provides a summary of the acceptable values, noting that the acceptable level varies continuously according to the discrete frequency and the table below lists values for a selection of these frequencies.

Period of day	*Acceptance*	*Acceptable vibration (parallel to body)*	*Acceptable vibration (perpendicular to body)*
Daytime	Preferred	0.014 m/s^2	0.01 m/s^2
	Maximum	0.028 m/s^2	0.02 m/s^2
Evening	Preferred	0.01 m/s^2	0.007 m/s^2
	Maximum	0.02 m/s^2	0.014 m/s^2

Table 1 - Summary of acceptable base line acceleration values (peak) as per BS6472

The criteria presented in the above table are considered appropriate when assessing and evaluating the effects of human exposure to vibration from industry sources. It is noted that when

[4] British Standard BS6472:1992 Evaluation of human exposure to vibration in buildings (1Hz to 80Hz). BSI (1992), ”BS6472:1992 – Guide to Evaluation of human exposure to vibration in buildings (1Hz to 80Hz)”

[5] Department of Environment and Conservation (NSW), 2006. "Assessing vibration: a technical guideline", February 2006

applying the criteria, the vibration may enter the body along different orthogonal axes (right to left side, head to toe).

There is considered a low probability of adverse comment or building disturbance to building occupants at vibration levels below the preferred values listed in the table. The values presented in the above table are considered appropriate for a residence, noting that the same standard/s also provides data for other areas, including areas considered critical, commonly defined as operating theatres, precision laboratories or where sensitive activities are occurring, where the level is approximately **half** of those values listed in the table. Similarly, less susceptible activities, such as educational facilities allow vibration **twice** that given in the table whilst other industrial places like workshops, an allowable level **four** times the tabled values is suggested.

Summary of Property Data

Vibration measurements were collected at the multiple locations around the property to best permit an assessment of the possible impacts of the potential overpressure pulses, including:

- On external walls of the property, both in the direction facing the turbines where the impact of any low frequency overpressure pulses is expected to be greatest. Measurements were also collected on the sheltered side of the property away from the turbines. Any variations in the measured levels are expected to provided an indication of the source of any elevated vibration levels;
- In the ground outside of the property to identify the presence of any low frequency vibration that could be transmitted from the turbine blades, through the tower, into the ground and possibly into the property via the building foundations;
- On the foundations of the property to identify any disparity between vibration measured in the ground outside of the property and that measured inside;
- On internal walls within the property to differentiate between vibration effects from walls directly exposed to the possible low frequency pulses versus those which, if measurable, whose only source would be through the building foundations;
- On the shed of the property to ascertain and possible differences in vibration as a function of different wall masses, rigidity (when compared to the external house walls) and stiffness.
- For the window on the side of the property facing the turbine, the frequency of vibration is lower again and contains components in the 15 to 25Hz window. Some further may detail lower components and warrant the use of the improved sensitivity accelerometers. At present though, I am struggling to see frequencies less than 10Hz.

External in Ground

Vibration measurements were sampled at multiple locations outside of the property to establish the presence of any wind tower generated vibration. Sites included on the concrete slab adjacent to the property as well as an isolated concrete pad removed from any coupling to the building, as shown adjacent.

The measured data show no instances of vibration above 0.005m/s^2 at any the external ground locations. These data confirm no measurable presence of tower generated vibration which is consistent with the low levels of vibration measured at the tower. Similarly the data confirm no opportunity for vibration within the ground to excite natural frequencies, or other frequencies, of the building and increase perceptibility within the property.

External walls of the property

Measurements taken on the external walls of the property show maximum vibration amplitudes less than 0.01m/s^2 . The sensors were positioned on the walls at approximate mid wall height and in areas expected to generate maximum deflection from any external forces, such as naturally occurring from the wind or from other possible turbine effects. Measured levels on the different facades of the property, including those most exposed to the turbine as well as the sheltered areas (near the water tank), show similar responses, all less than 0.01m/s^2. Whilst there are occasional elevated pulses, these are more likely associated with movement within the property, walking on floors, closing of doors *etc*. rather than a consequence of external forces.

It is concluded that the absence of any variation in external response as a function of the different locations around the dwelling confirms no low frequency overpressure pulses generated by the operation of the wind turbine, or were insufficient to induce measurable secondary vibration into the walls of the property. Measured vibrations at all locations are less than the suggested limits in the British Standard as being acceptable to the "*vast majority*" of persons. Additional monitoring with very high sensitivity accelerometers may identify a low amplitude source of vibration, although its amplitude would necessarily be well less than 0.01m/s^2. Understandably any such secondary response will remain within the limits identified in the relevant standards.

Internal walls of the property

Similar measurements on the internal walls of the property confirm no additional vibration above that measured on the external walls. This confirms that vibration from the operation of the wind turbine has not propagated from the tower through the ground and created resonance in the property through amplification of the building foundations. Vibration measurements were collected in the "*billiard room*", as shown adjacent, where the wall was not exposed to any external forces of wind or possibly low frequency overpressure. Other measurements were taken in the small bedroom where additional noise measurements were being collected and showed similar responses.

An analysis of the results from each of the internal walls show the level of vibration in the absence of external effects such as wind or other overpressure is less 0.02m/s^2. The internal walls show no disparity when compared to the measurements taken on the external walls.

In additional to the internal walls, measurements were collected on the pillow of the bed in the bedroom directly facing the turbines (referred to as location#17). The peak level recorded was

$0.02m/s^2$ and although the signal displayed different characteristics in terms of the frequency. The variation in frequency is most likely associated with the "*loose*" coupling between the sensor and the pillow however could possibly be explored further with a high sensitivity accelerometer and additional measurements on the bed and/or bed frame.

Shed

Of all monitoring locations and data collected during the study, the vibration measurements recorded on either of the wall panels or the foundation of the garden shed show the greatest amplitude. The reduced rigidity, reduced stiffness and an overall reduced mass of the walls allows for greater deflection and a corresponding increase in the vibration levels, most likely as a consequence of the wind impacting upon the walls of the shed. Sensors were positioned on the side nearest to the turbines as well as the other side with the measurements on the former showing vibration up to $0.04m/s^2$. The sensor was again positioned to record maximum expected amplitudes, as shown in the adjacent photograph. The monitoring site is referenced as locations 10, 11 and 12.

Whilst these measured vibrations are elevated above the background values, the levels continue to remain with the acceptable values listed in the relevant standards.

Vibration data collected on the floor of the shed shows minimal vibration with peaks less than $0.01m/s^2$.

Summary

A review of the measurements collected at the Waubra Wind Farm on Tower 5B-6 and the adjacent residential property show measureable levels of vibration on the tower and the base, although the amplitude and frequency of the vibration are considered well less than those considered necessary to allow for measurable levels of vibration at distances of several hundred metres. The amplitude during repositioning of the turbine head peaked at around $0.1m/s^2$ with values during normal turbine operation less than $0.03m/s^2$. In general, many of the measurements taken near the tower are considered compliant with the values listed in the British Standard as being acceptable for long term, continuous vibration. It is the opinion of Heilig & Partners that the vibration induced directly into the ground from the operation of the turbine is unlikely to possess sufficient energy to permit measurable levels at properties several hundred metres from the tower. It may however be appropriate to substantiate this assertion through use of additional measurements in the ground at regular intervals from the tower with a very low amplitude sensor.

Measurements taken on the residential property show external forces, such as wind induced overpressure, can impact on the building walls and generate measurable vibration. the level of vibration is dependent upon:

- The level of overpressure, or wind speed;

- The orientation of the wall relative to the overpressure (ie. wind ward direction) with wall elements facing the wind subjected to higher vibration that those on the sheltered side of the building removed from the wind effects,
- The rigidity of the wall with well supported, stiffer and anchored walls, such as those of the house, generating a far lower level of vibration than those of a flexible sheeting like the shed of the same property.

The measured levels of vibration on the property vary according to each of the above aspects, however the peak levels have remained low with the exception of the walls of the shed where levels up to $0.04 m/s^2$ have been recorded. Vibration on the house, either internally or externally, have remained less than $0.01 m/s^2$ and within the values suggested in the British Standard.

Conclusion

On the basis of the measured values only, it is the professional opinion of Heilig & Partners that the values are low and remain in compliance with the British Standard. It is considered pertinent to supplement these measurements through additional monitoring with high sensitivity, low frequency, low amplitude accelerometers capable of detecting changes in acceleration of $0.00004 m/s^2$. Such devices will unambiguously confirm the presence of any vibration, its amplitude, the frequency and the variability throughout the property.

7 WIND FARM NOISE AND HUMAN PERCEPTION

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. This Report presents the effects of wind farm noise on residents near the Waubra wind farm and two wind farms in New Zealand and identifies concerns with potential adverse health effects, including audible, low frequency and infrasound effects.

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 Waubra and Te Rere Hau and 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.

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) (or 38 dB(A) LAeq) due to wind farm noise is too high at residences. 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.”*

The LA95 background sound level of 30 dB(A) is broadly equivalent to 32 dB(A) LAeq.

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 the effect is significantly more than minor.

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 the effect is significantly more than minor.

Based on anecdotal evidence I have heard from affected people visual amenity also affects the perception of sound from sources of noise. This effect 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.

As previously stated the most significant issue for the practical management of wind farm noise is that the New Zealand standard lacks a methodology to separate single-value LA95 sound levels created by the wind turbines from ambient LA95 sound levels existing at a specific time and place due to wind movement, vegetation movements, bird song and so on. The “different” background levels <u>cannot be separated using the standard’s approach unless the turbines are switched off.</u>

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 Victoria and New Zealand indicates the existence of noise induced sleep disturbance and adverse health effects due to wind farm noise.

The expression sub-audible character is given in this Report 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. 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. This is still the subject of debate, as outlined in this Report. However, there is sufficient peer-reviewed research and solid acoustical foundation for analysis to be made.

The above issues are debated in more detail in 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.

8 NZS6808 Wind Farm Noise Standard and Unreasonable Noise

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. In addition specific conditions have been applied to the operation of the wind farm as part of the resource consent.

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

NZS 6808:2010 is different from the 1998 edition by recognising a 35 dB(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

In order to assist possible interpretation of the sound of the wind farm as a nuisance condition or injurious to personal comfort the general rule is, as I understand it, that the occupier of land is obliged to adopt the best practicable option to ensure the emission of noise from that land does not exceed a reasonable level. "Best practicable option" means the best method for preventing or minimising the adverse effects on the environment having regard, among other things, to—

(a) The nature of the discharge or emission and the sensitivity of the receiving environment to adverse effects; and

(b) The financial implications, and the effects on the environment, of that option when compared with other options; and

(c) The current state of technical knowledge and the likelihood that the option can be successfully applied.

Based on my observations and experience and the observations and experiences of others, a 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.

It would be expected that the wind farm operator would have made considerable technical data available for the compliance / certification reports. 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.

Audibility under the wind turbine standard is given as a tone. Chapter A, an informative Chapter to IEC 61400-11, states that:
In addition to those characteristics of wind turbine noise described in the main text of this emission may also possess some, or all of the following:

- *Infrasound;*
- *Low frequency noise;*
- *Impulsivity;*
- *Low-frequency modulation of broad band or tonal noise;*
- *Other, such as a whine, hiss, screech, or hum, etc., distinct pulses in the noise, such as bangs, clatters, clicks or thumps, etc.*

Notwithstanding the opinions in literature and wind farm applications provided by other acoustic consultants my survey indicates that the provisions of IEC 61400-11 dealing with the characteristics described in the previous paragraph can be measured and assessed and are 'special audible characteristics' in accordance with NZS6808. As best practice a 5 dB penalty must be applied to all measurements and predictions unless the contrary can be proven. This is the correct, conservative approach, to compliance issues under the Permit conditions and NZS6808:1998 or 2010.

BACKGROUND CHAPTERS

Chapter 1: Audible Sound and Noise

Wind farms and wind turbines are a unique source of sound and noise. The noise generation from a wind farm is like no other noise source or set of noise sources. The sounds are often of low amplitude (volume or loudness) and are constantly shifting in character ("waves on beach", "rumble-thump", "plane never landing", etc). People who are not exposed to the sounds of a wind farm find it very difficult to understand the problems of people who do live near to wind farms. Some people who live near wind farms are disturbed by the sounds of the farms, others are not. In some cases adverse health effects are reported, in other cases such effects do not appear evident. Thus wind farm noise is not like, for example, traffic noise or the continuous hum from plant and machinery. Wind turbines such as those proposed are large noise sources relative to dwellings, Figure 1:

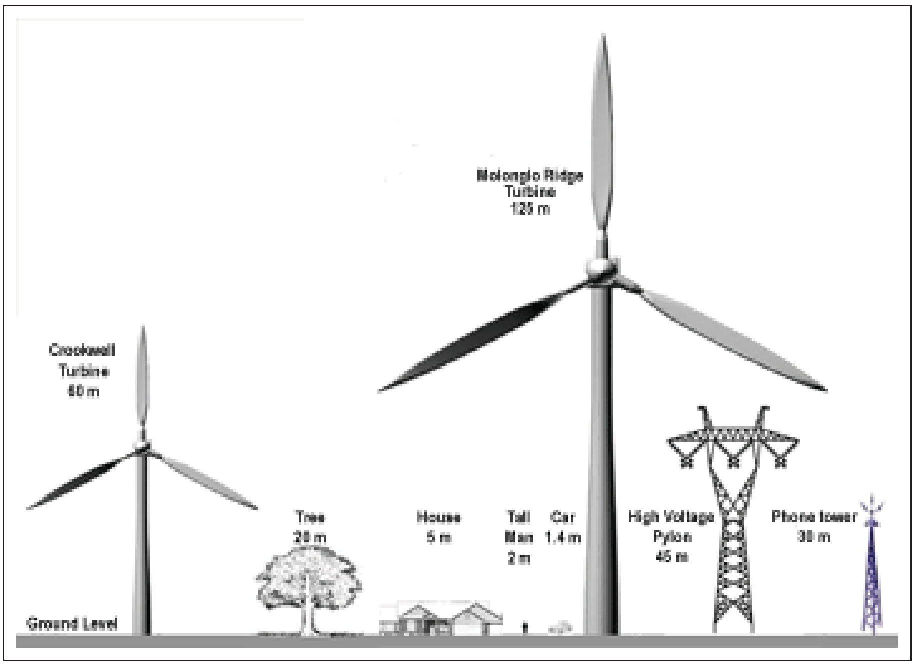


Figure 1: Relative heights of turbines to dwellings

(Source: Molonglo Landscape Guardians, by permission)

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

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

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

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."*

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.

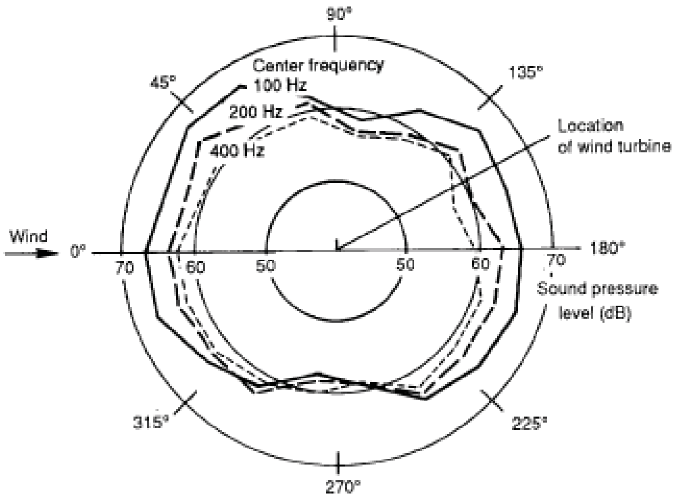


Figure 7-7. Example radiation patterns for broadband noise 200 m from a large-scale HAWT (one-third-octave bands, wind speed = 12.1 m/s, power = 2050 kW) [Shepherd, Willshire, and Hubbard 1988]

Figure 2: wind turbine sound pattern

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*

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

rate is only -3 dB per doubling of distance... Some arrays of multiple wind turbines in wind power stations may also acoustically behave like line sources."

Shepherd and Hubbard [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:

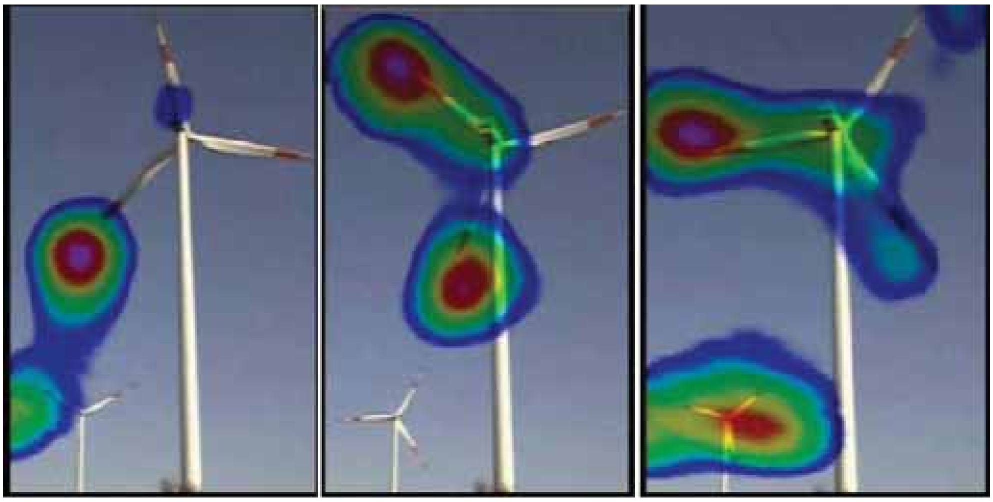


Figure 3: Acoustic photograph of sound sources from two turbines.
Source: Acoustic Camera, 'Multiple sources wind turbines 300Hz – 7kHz.avi" by permission from HW Technologies, Sydney)

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.

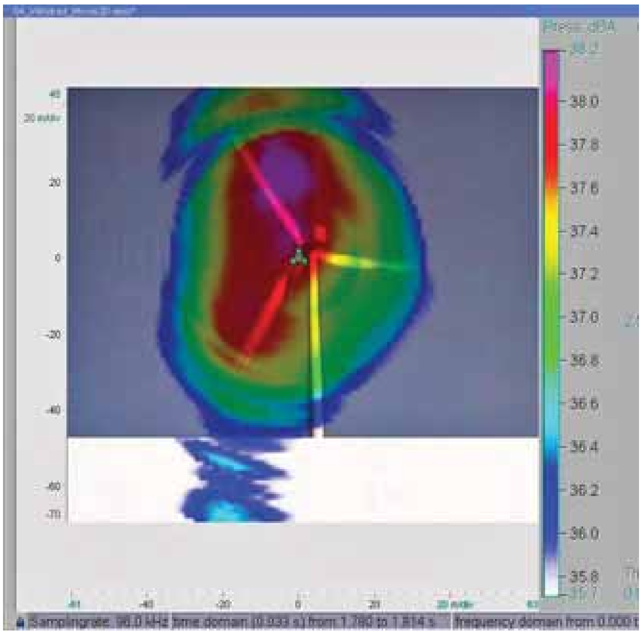


Figure 4: Acoustic photograph of sound sources from a turbine.
Source: Acoustic Camera, by permission from HW Technologies, Sydney)

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]

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

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

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.

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.

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.

Wind turbines in a stable atmosphere generate more sound than in a neutral atmosphere, while at the same time the wind velocity near the ground is so low that the natural ambient sound due to rustling vegetation is weaker. As a result the contrast between wind turbine sound and natural ambient sound is more pronounced in stable than neutral conditions. This situation enhances the ability to hear the trailing edge sound from the turbine blades. The differences in wind speed lead to variations in the sound radiated by blade tips that reach their highest values when the tip passes the mast. Van den Berg calculates the variation as approximately 5 dB at night and 2 dB in daytime.

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

The mechanisms of annoyance are significantly influenced to sound modulation ('rumble/thump') and the cessation /commencement of sound ('when will that noise start again?'). In "The measurement of low frequency noise at three UK wind farms" 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."*

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

[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

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.

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

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

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

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.

[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.

Low Frequency Sound and Infrasound

The issue of low frequency sound and infrasound has been a controversial topic for many years. Figures 5 and 6 illustrate audible sound as well as both low frequency and infrasound as heard inside a bedroom approximately 930 metres from a set of wind turbines. The modulating character of the sound is clearly defined in the first 5 seconds as a pattern of 3 spikes. The chart shows that low levels of sound are clearly audible inside a dwelling.

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

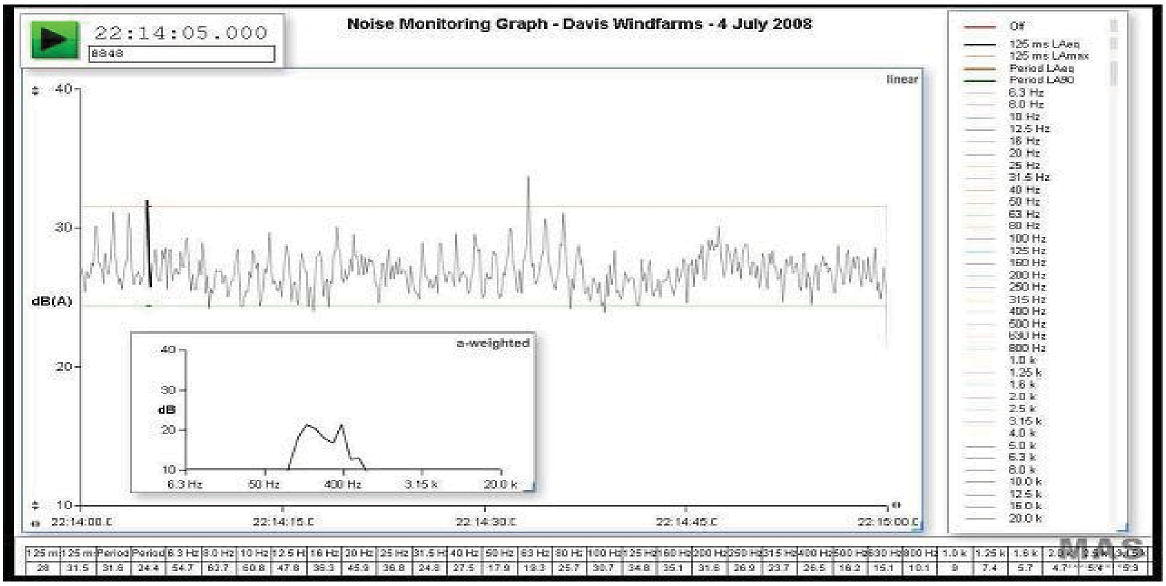


Figure 5: sound of wind turbines at 930 metres, inside residence

Figure 6 illustrates sound <u>character</u> 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 7 shows a distinctive tonal complex at around 48 Hz. The sound levels at the wind turbine (Figure 7) were LAeq 52 dB(A) and a background level (LA90) of 32 dB(A). The sound character from the wind farm with this type of Vestas turbine is shown at 2200 metres (figure 8) at a Cafe. The turbines are not audible in sonogram (figure 9).

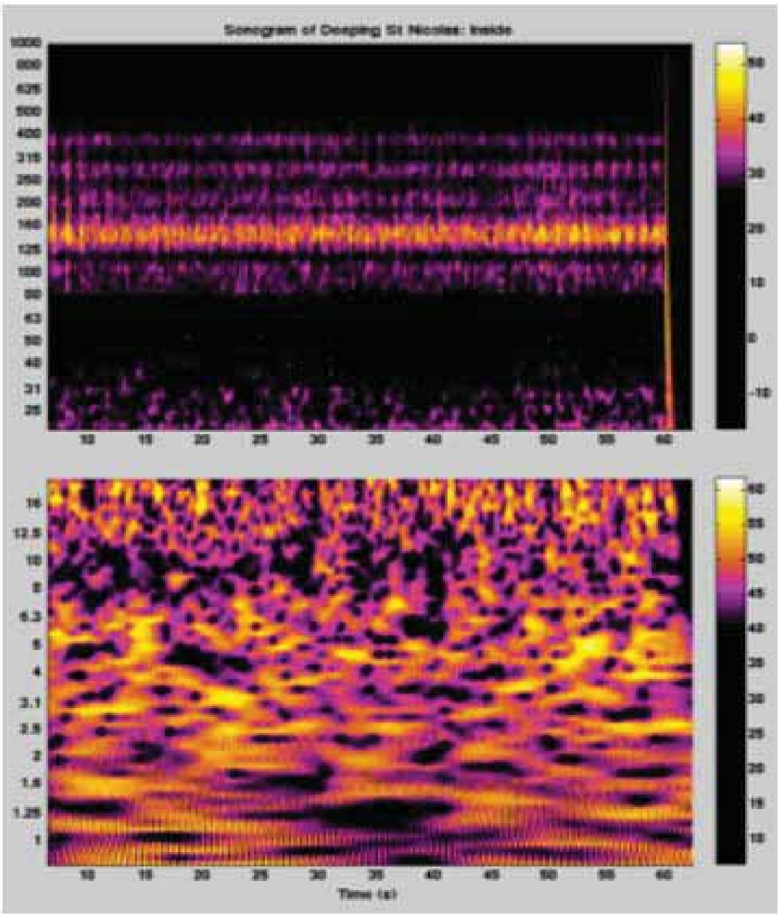


Figure 6: sound of wind turbines at 930 metres, inside residence

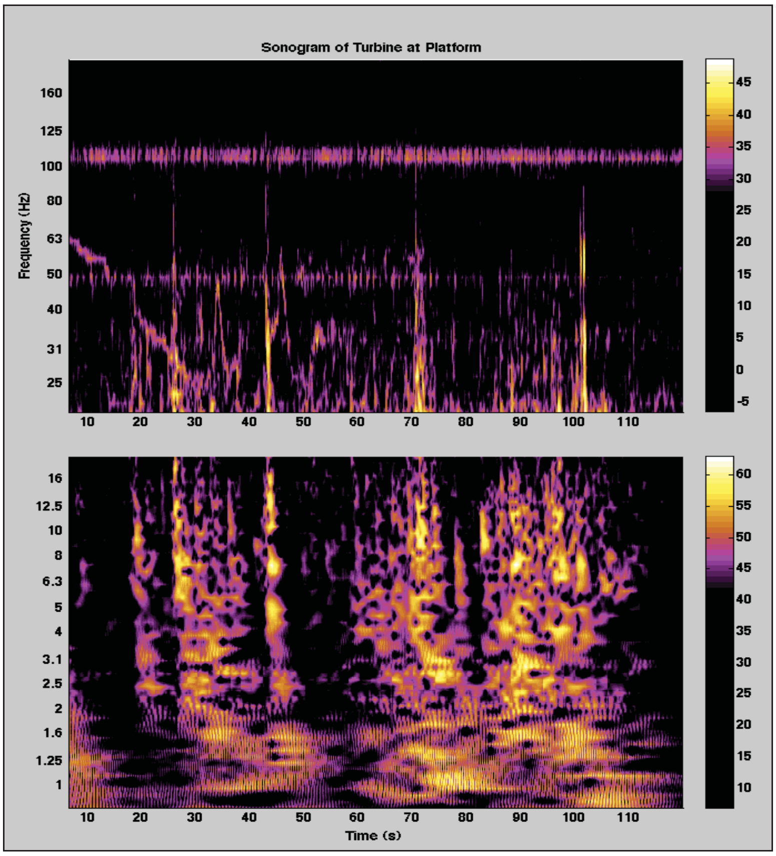


Figure 7: sound of a wind turbine at the turbine platform

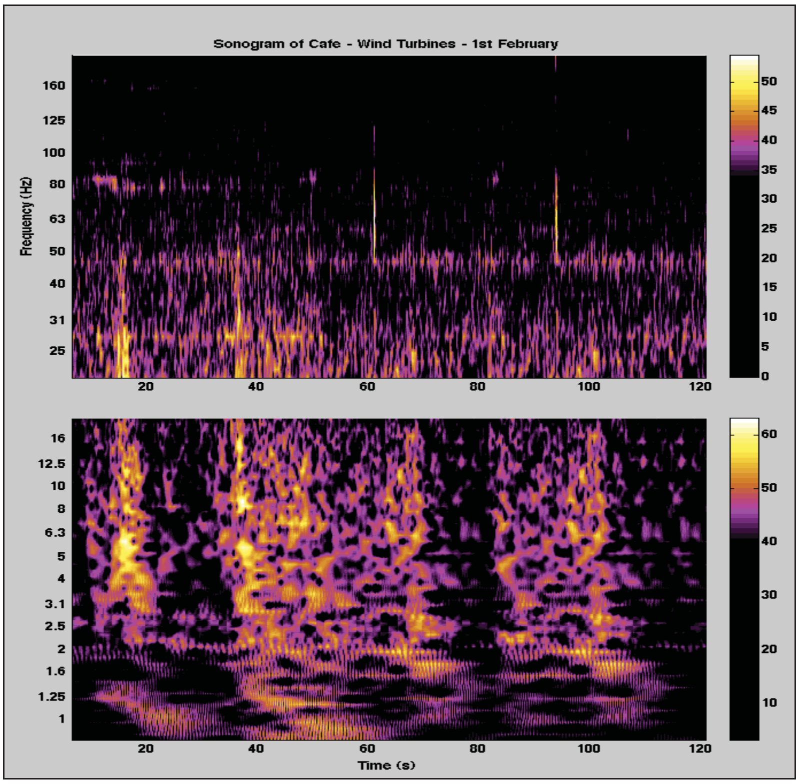


Figure 8: Audible sound of wind farm at 2200 metres over grassland and trees

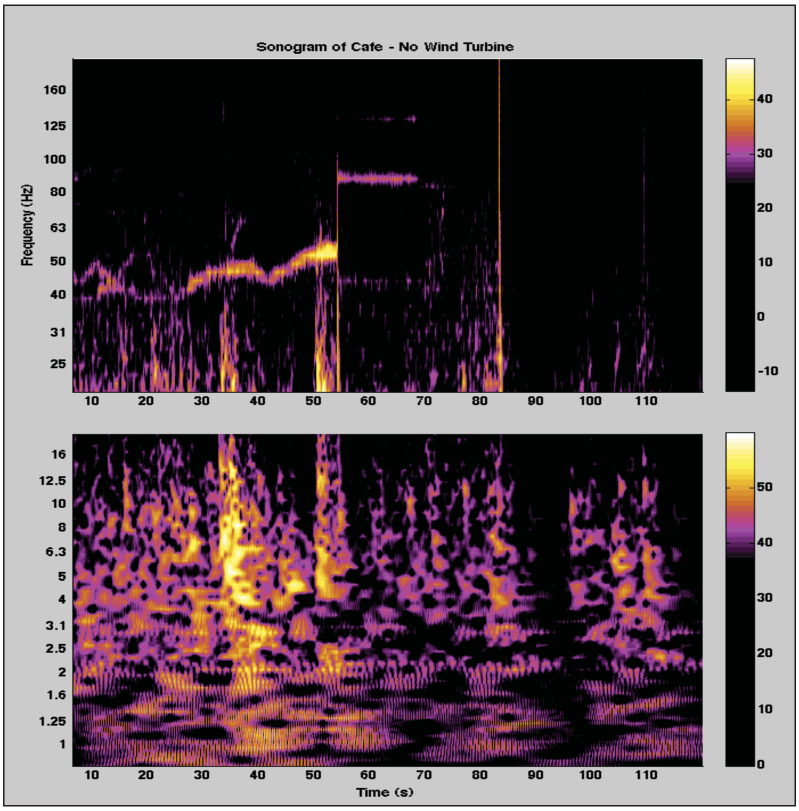


Figure 9: Same location as figure 8 but wind farm not audible

The sound levels for the Cafe (figure 8) were LAeq 40 dB(A) and a background level (LA90) of 32 dB(A). Without the turbine sounds (figure 9) 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.

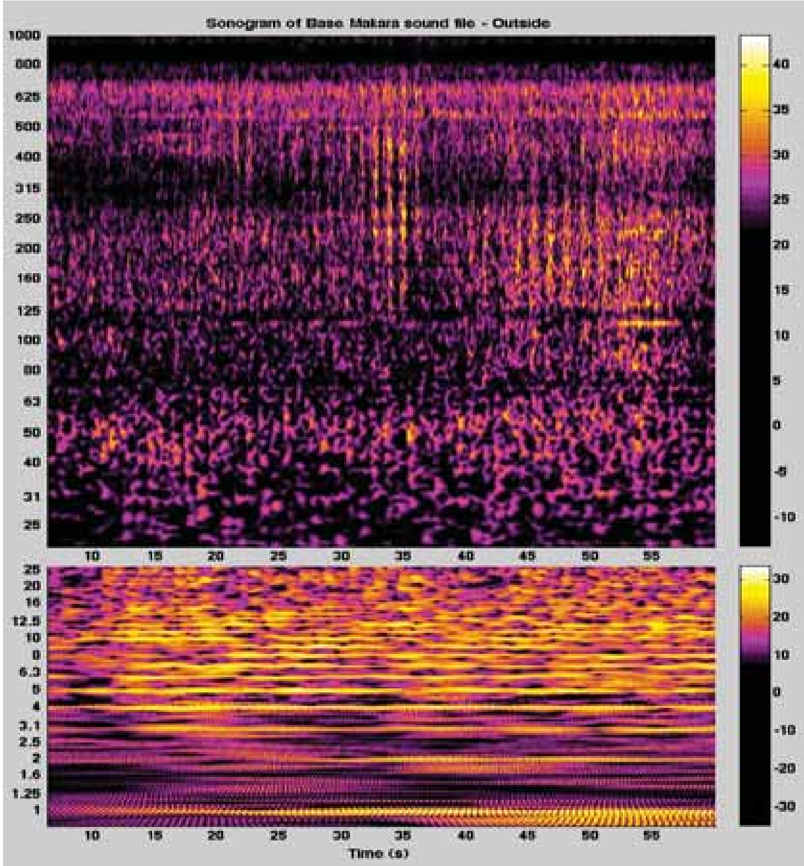


Figure 10: sound of wind turbines at 1200 - 1300 metres, outside residence

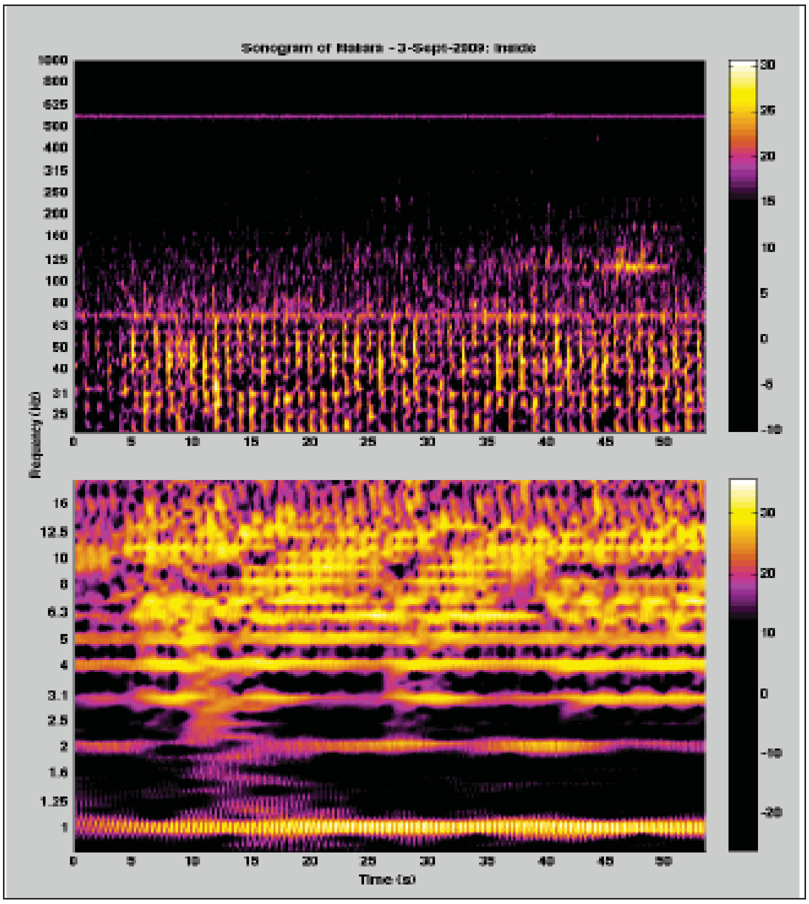


Figure 11: sound of wind turbines at 1200 -1300 metres, inside residence

Thus ambient conditions play a significant part in recording sound levels. The exterior ambient levels for the residential survey at Makara (Figures 10 and 11) 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).

In figures 10 and 11 the difference in character between outside and inside levels are clearly shown. The variation is due to building construction and room resonance.

Conclusions

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.

Chapter 2: Characteristics of Multiple and Single Wind Turbines

This is a summary of part a Paper by Bakker and Rapley[12] 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.

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.

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.

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.

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.

[12] A Paper recorded in the evidential text *“Sound, Noise, Flicker and the Human Perception of Wind Farm Activity”* prepared for the Board of Inquiry Turitea Wind Farm Proposal Hearing, New Zealand, March 2010.

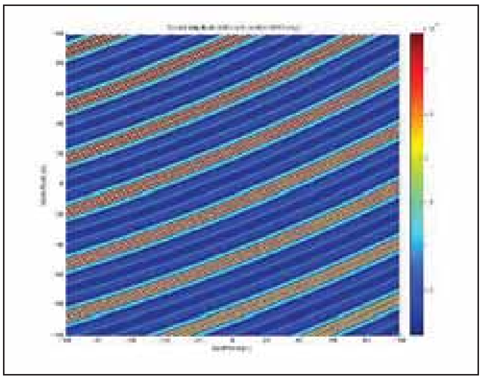


Figure 1: Propagation pattern from a single turbine

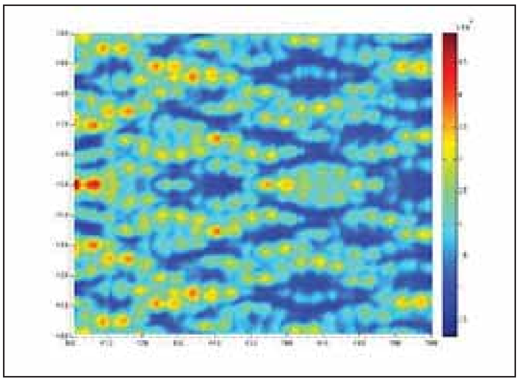


Figure 2: Propagation pattern from 5 turbines in a line formation

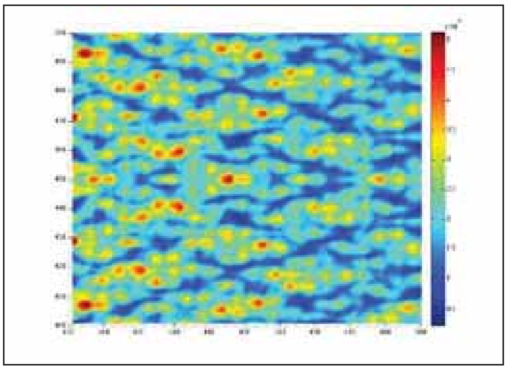


Figure 3: Propagation pattern from 5 turbines in a vee formation

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

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”.

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.

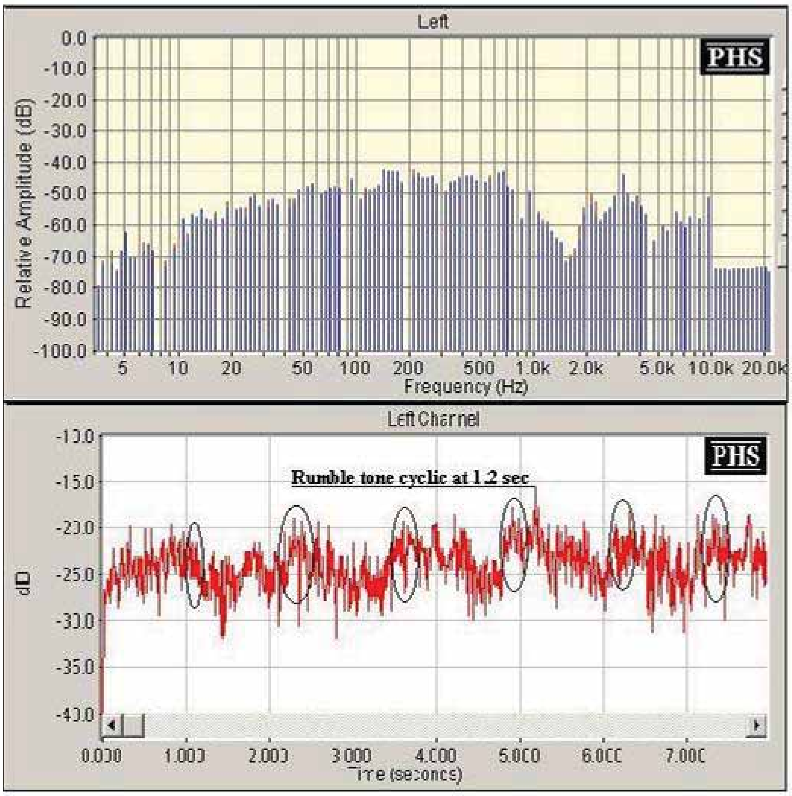


Figure 6: Turbine rumble

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.

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 wind shear are confounding factors that can be calculated with a degree of reliability, figure 11.

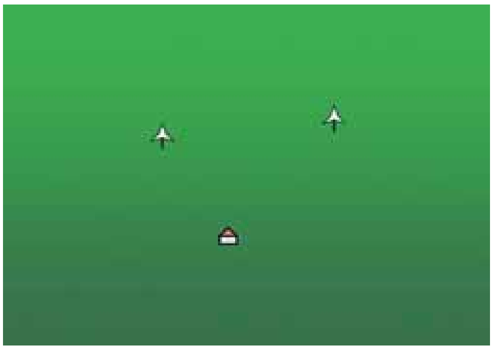


Figure 7: A residence potentially affected by 2 turbines

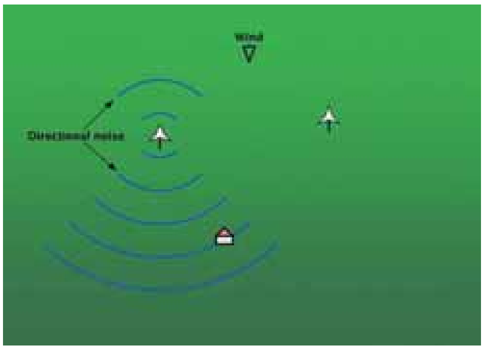


Figure 8: Noise from one turbine

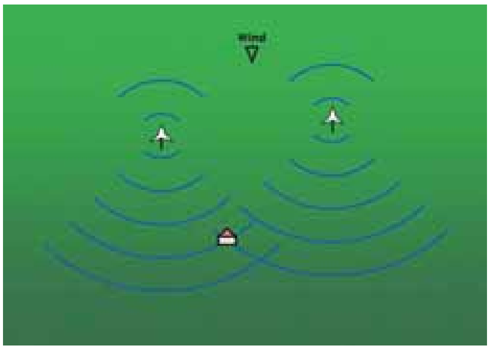


Figure 9: Noise from 2 turbines

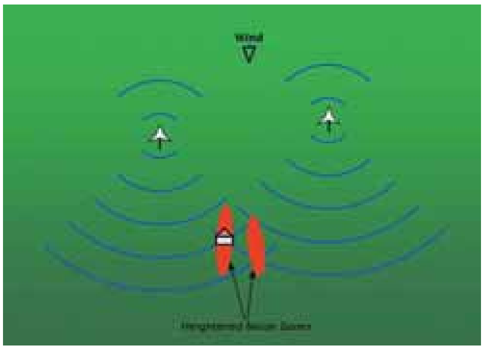


Figure 10: Noise from 2 turbines creating Heightened Noise Zones

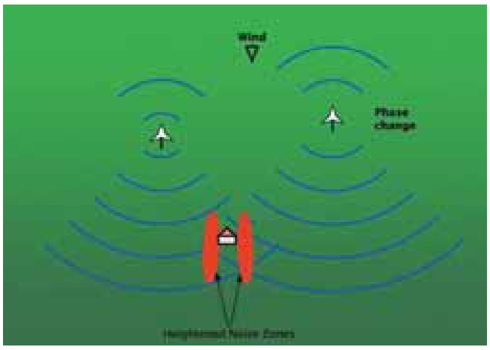


Figure 11: Noise from 2 turbines under slightly different conditions moving Heightened Noise Zones

The Heightened Noise Zones can be small in extent – even for low frequencies – leading to turbine sounds 'disappearing' and 'appearing' in areas spaced only a few metres apart.

The concept of Heightened Noise Zone goes a long way to explaining the problem of wind farm noise and its variability on residents. The other factor is the variability of the background sound levels as affected within the Heightened Noise Zones. The turbine sound levels have the effect of lifting the background (when in phase or acting together). The background drops when in the trough between the crest of the Heightened Noise Zone levels. However, this effect can change quite quickly depending on wind direction, temperature conditions and turbine activity.

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.

These attributes of Heightened Noise Zones – small size and dependence on time-related factors like wind direction – explain much of the problem of wind farm noise and its variability as heard by residents.

Wake and Turbulence Effects

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.

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]

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.

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

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

- 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.

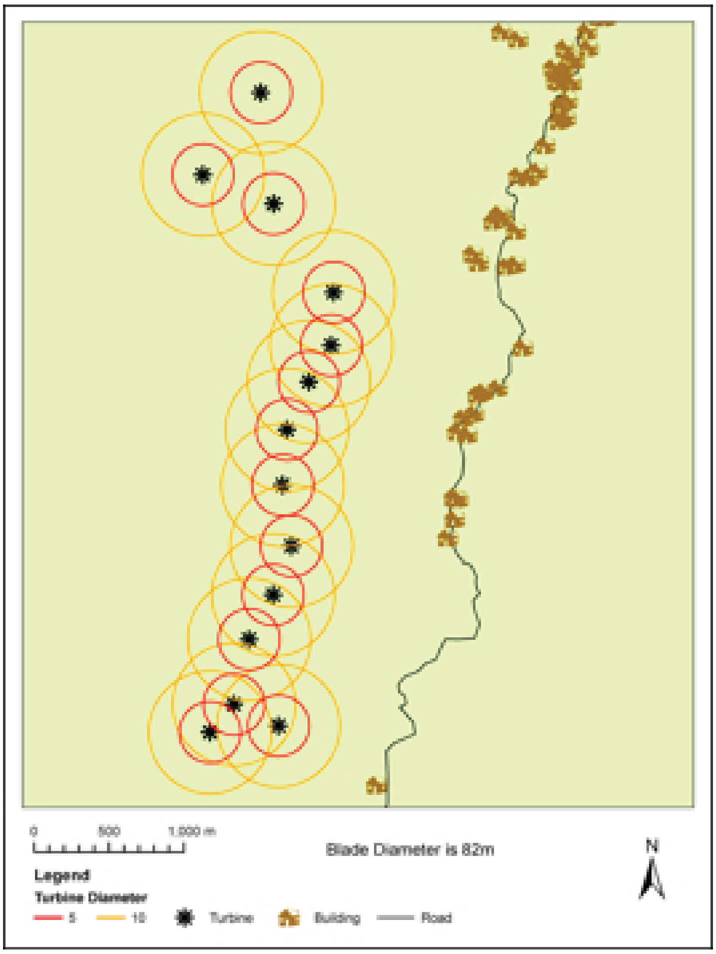


Figure 12: Wind turbines at Makara showing their spacing with regard to 5 and10 blade-diameter circles. *Source: Research graphics by S. R. Summers.*

The smooth inner wake eventually breaks down into turbulence that soon mixes the air with that surrounding it and is restored to the bulk wind speed. A turbine downstream at this point will see air more-or-less unaffected by the upstream turbine. When the wind speed increases, such as due to a wind gust, the length of the smooth wake is extended. Should the smooth wake extend to the downwind turbine, it will interact with the turbine blades to cause increased sound until the wind gust dies and the smooth wakes retracts.

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

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

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

The 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.*

Chapter 3: Prediction of Sound Levels – Approaches and Limitations

Introduction

This Report 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.*

PEN3D can also implement Pasquill Stability Categories (also known as the CONCAWE implementation). This Report does not use the CONCAWE propagation model.

Limits to Accuracy of Prediction

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.

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.*

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 Modeling Assumptions

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 for the Vestas V90 3MW and Siemens 2.3MW turbines.

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.* The hub height is most often referenced as being the source height.

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.

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).

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.

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.

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).

The assumptions for the prediction calculations for the noise prediction of this Report 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: from reports

- Wind conditions (rated wind speed of 9 m/s at hub height of 80m) at downwind receptor locations
- Turbine octave band sound power data referenced from the applicant's acoustic report as the Repower MD 70 1.5MW turbine Sound Power Level 103 (dB A) at 9m/s
- All turbines for a particular scenario operational
- Turbine sound power calculated at hub height as 116 dB(Lin)

31.5	63	125	250	500	1000	2000	4000	8000
116	103	105	105	102	97	95	89	74

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

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

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

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

<u>This presents a possible variation of -3dB to +10dB over the "nominal calculated level" for sound level predictions at 1000 metres.</u>

Best practice would suggest that the consideration of these uncertainties is the best, and most conservative, approach to wind farm noise prediction.

Consideration of Variable Weather Conditions

The primary concern is with weather data. Accurate weather data is needed to allow good for reliable sound level predictions. This issue has been clearly raised by Clark, G., in his evidence to the Taralga Wind Farm Modification Application, reference number 'NSW Land & Environment Court Proc 11216 of 2007.' 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 and blade tip heights) and at residences (a minimum 3m above ground) for reliable sound level predictions.

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

A wind rose at the wind measurement towers (at a point 80m above ground) is the most useful but this data is rarely presented in an applicant's documentation. Alternative sources of data from nearby met stations or residential sources are often necessary but provides only a cursory overview of wind direction near ground level.

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 conditions

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

The following Table 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.

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.

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.

	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**

A further effect is whether the wind turbine is considered as point source or as a line source. As discussed previously, the placement of the wind turbines can be considered as a line source at distnace further than 900 metres from the turbines. Thus a wind farm can be considered as a discrete line source consisting of multiple "point sources" that can be identified by distance and spacing (mechanical noise, generator noise, blade swish, blade past tower, wake and turbulence interference effects and vortex shedding). These emission "point sources" are identifiable, **Figure 1.** The figure illustrates a turbine with a hub height of 59 metres and rotor diameter of 82 metres. The sound sources from the blades are not fixed; they change as the blades rotate and as the turbine moves on its axis into the wind. Only the hub and tower sources are relatively fixed in height and these also move as the turbine moves on its axis.

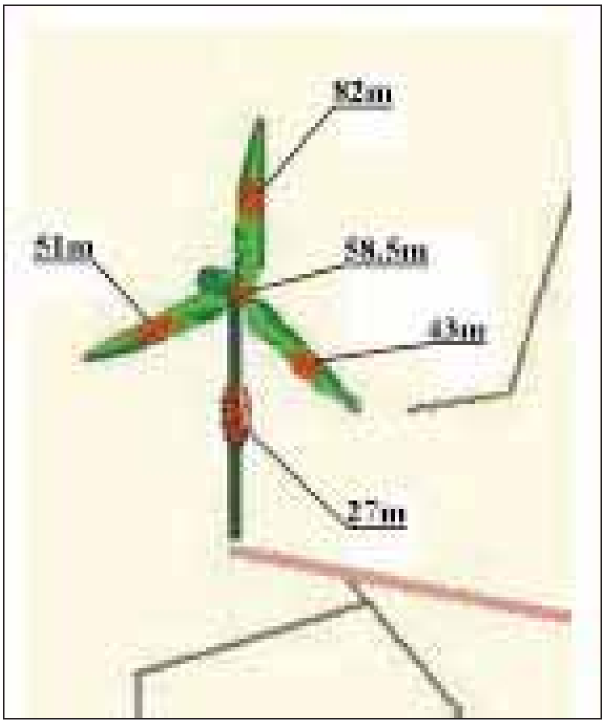


Figure 1: Noise emission "points" from a wind turbine.

(Note: wake, turbulence and votice effects are not illustrated)

Absolute Sound Variation at a Receiver

In summary, the Absolute Sound Variation at a receiver depends on measures of uncertainty, for example:

(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

Chapter 4: Assessing Intrusive Noise and Low Amplitude Sound

Introduction

The sound from a wind farm is essentially of an intrusive nature and is of low amplitude. That is, it is not very loud and it has varying character depending on wind speed and direction. This Paper presents a synopsis of the methodology to assess low amplitude intrusive noise with respect to an individual. The methodology has unique practical application in wind farm noise analysis as it combines human perception with sound measurement and a process to integrate disparate information into a meaningful whole, as illustrated in figure 1.

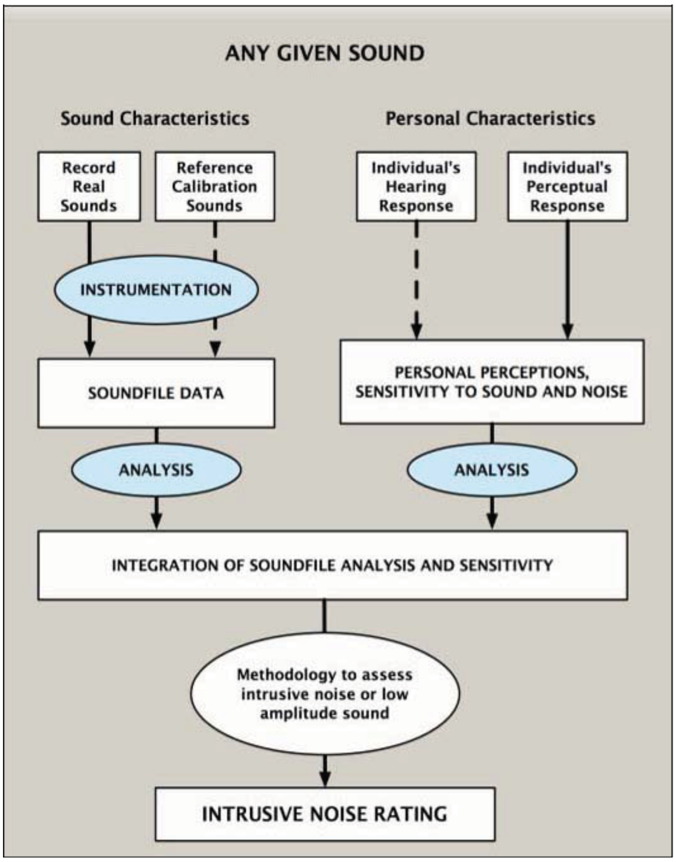


Figure 1: Methodology for measuring and assessing low amplitude sound and intrusive noise

The methodology presented in figure 1 is in three parts:

1. The first part is data gathering: a sound is analysed in a structured, standard manner for its acoustic and sound quality characteristics. The person who is interested in the sound is able to undertake a series of environmental and noise sensitivity tests in order to evaluate personal sensitivity and perceptions with respect to the sound.

2. The second part is data processing: The sound quality measures and personal perceptions are integrated into a structured analytical methodology referenced to subjective analysis and objective criteria for which the relativities between non-parametric and parametric data are structurally encapsulated.

3. The third part of the methodology calculates an intrusive noise rating: The information derived from the first two parts of the methodology is structured into a decision process for sound and intrusive noise, with special consideration given to low amplitude sound analysis.

Sound is NOT noise. Sound is a physical construct or measure of sound pressure level. Noise, however, is how a person perceives specific sounds. This emphasis on definition is very important because it is the character, as well as the sound level of the sound from wind turbines that determines whether the "noise" is reasonable or unreasonable.

Noise is often quoted as being "unwanted sound". This definition is meaningless. To understand the issues with wind farm noise as distinct from sound it is necessary to establish some working definitions. Sound is generally perceived as being neutral in, for example, the concept of soundscape.

Intrusive sound is sound that can be heard by a person. By its characteristics it is audible and intrudes upon the wellbeing or amenity of an individual. At this point, however, the sound is not "noise".

Sound Analysis

Sound analysis commences with the capture of the 'sound of interest'. The process takes real-world sounds presented in a Windows™ PCM .wav format sound file. The sound file is analysed for its overall character and then for those segments (if necessary) containing identified "noise" is analysed. The work presents the varied measures that were considered for inclusion in the analysis methodology.

The sound file is automatically analysed in relation to the measures of dissonance, loudness, pitch and sound level. The objective component of the methodology, illustrated in figure 2, integrates common musical, acoustical and psycho-acoustical attributes or measures. Based on the investigations made for this work the most relevant sound quality measures are loudness, loudness level, pitch salience, spectrum and tonal dissonance, tonality and modified unbiased annoyance.

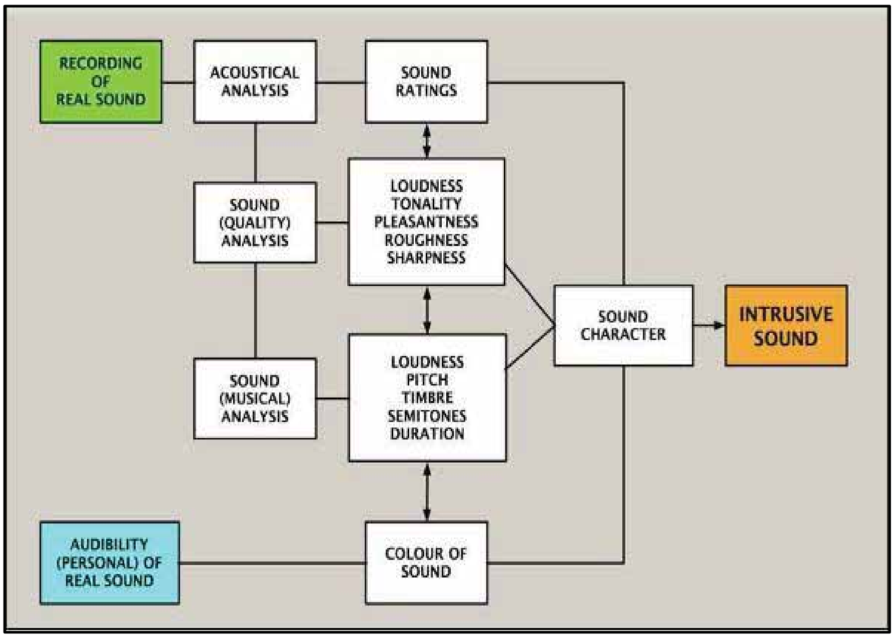


Figure 2: Objective and subjective decision processes to characterise intrusive sound

Intrusive sound is related to overall sound level; acoustical prominence features such as tonality or impulsiveness; audibility; and dissonance characteristics such as an audible beat, fluctuation, hum, modulation or rumble. The complete sound file, or any distinct part of the sound file, is analysed for all measures and all data is retained in a comma-separated variable summary format output file. Only some of the measures, however, are brought forward into a summary display output file.

The most relevant acoustical measures displayed are audibility, equivalent continuous sound pressure level (A-weighted), instantaneous sound pressure level (A-weighted), overall statistical measures (90% and 10%, A-weighted), a time history of sound levels (A-weighted) over the analysis period, and one-third octave bands (Z-weighted).

The sound file is analysed for the unbiased sound quality measures including modified unbiased annoyance ((incorporating loudness, tonal dissonance and sharpness), audibility, salience, tonality and modulation. Modified unbiased annoyance is the primary measure of sound intrusion and, combined with individual perception, the primary objective measure of noise intrusion. The modified unbiased annoyance UBAm measure applies loudness (N10 in sones), Aures sharpness (in acums) and a new approach to fluctuation by implementing Sethare's Tonal Dissonance, TD(S) in sets, to account for frequency as well as amplitude fluctuation. The UBAm measure has an effect on sound-file measured values by emphasising the contribution of dissonance and tonalness.

The calculation is given in ‘intrusion units, iu’:

$$UBAm = d(N_{10})^{1.3} \left\{ \begin{matrix} 1 + 0.25(S-1) \bullet lg(N_{10} + 10) + 0.3TD(S)^{1+N_{10}} \\ 0.3 + N_{0} \end{matrix} \right\}$$

Loudness (N10) is the loudness in sone which is exceeded for 10% of the time. (The exponent in the first expression is 1.3). UBAm is modified for night-time. The value of ‘d’ in equation A.1 for the day is 1, for night-time the value of d = 1+ (N10/5)0.5.

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

- the physical relationship is considered as being the role of signal detection
- the psychological or behavioural and perceptive reactions of an individual are considered as psychoacoustical or sound quality relationships

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

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

Making a decisions about a sound requires listening to its audible characteristics but as the perception of these sounds vary from person to person other methods need to be made to communicate meaning or awareness.

The chart in figure 3 presents a different way of looking at sound, in terms of mean pitch salience. Sound character is represented by the prominence of the semitones within the graphic. This format allows very low amplitude sound character to be displayed in a meaningful way and the charts provide visual indication as to the variability of the sound and its potential for intrusion. A person sees that the quieter the sound the lower the value of the salience values.

Pitch salience can be described as being like the sounds played on a piano keyboard. Semitones are similar to the individual keys on the keyboard. A combination of keys can sound pleasant or harmonious, or jarring and discordant. One key can be "played" louder than another immediately next to it and a person can readily hear the difference. Sound, noise and intrusive noise can be described in exactly the same way. A discordant note equals noise. Played often enough (not necessarily loudly) it can become intrusive. Soon it becomes annoying, then stressful, and so on.

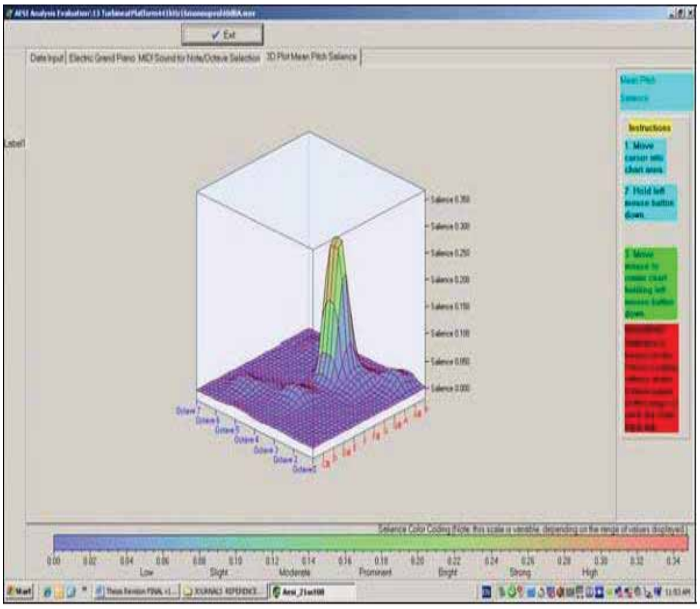


Figure 3: Example of a sound analysed in 3D mean pitch salience format

The visual format displays sound character in a meaningful way and the different charts provide visual indication as to the variability of the sound and its potential for intrusion. A variation in colour, for example green to red, indicates the semitones are significantly different and the prominence of the notes / narrowband sound is noticeable within the sound. The salience values indicate differing levels of prominence with some levels more noticeable than others.

The tonality method as presented in *International Standard ISO 1996-2 Acoustics – Description, assessment and measurement of environmental noise – Part 2: Determination of environmental noise levels; Annex C: Objective method for assessing the audibility of tones in noise – Engineering method* is identified as the practical tonal analysis method for this work. The method is similar to Joint Nordic Method 2. The method includes procedures for steady and varying tones, narrow-band noise, low-frequency tones, and the result is a graduated 0 dB to 6 dB adjustment. The issue of identifying a real tone in a critical band appears to be the most difficult problem with the tonal analysis methods. The tonal audibility, ΔL_{ta}, is expressed in decibels above the masking threshold. With an effective analysis bandwidth of 5% of a critical band, just audible tones normally appear as local maxima of at least 8 dB above the masking noise in the averaged spectra.

Modulation is perhaps the most ‘difficult’ of the sound quality measures in that it has wide definition and can be interchanged colloquially with almost similar physical processes, such as beating or pulsing. Modulation, as defined in American National Standard ANSI S3.20-1973 *Pyschoacoustical Terminology*, is:

> The variation in the value of some parameter characterizing a periodic oscillation. Thus, amplitude modulation of a sinusoidal oscillation is a variation in the amplitude of the sinusoidal oscillation.

Essentially, under this definition, modulation is the variation of amplitude or frequency of a carrier frequency. In music it can be described as a change in stress, pitch or loudness or the changing from one key or tonal centre to another. Modulation depth is the amplitude level at which the signal is varied and is expressed in percent or decibels. Modulation is similar to the roughness of a tonality.

Vassilakis[14] states his definitions of various aspects of modulation. In describing ‘modulation’ he states that the term was introduced into acoustics and psychoacoustics literature from radio engineering to describe distortions of any arbitrary wave profile. ‘Amplitude’ is defined in terms of relative rather than absolute reference points. ‘Amplitude fluctuation’ is described perceptually as beating, roughness combination tones (depending on fluctuation rate per second). ‘Amplitude modulation’ is a spectral modification process that produces discrete upper and lower sidebands determined by the modulation frequency and the modulation depth *m*. ‘Amplitude modulation depth’ is a measure of the spectral energy spread of an amplitude modulated signal. ‘Beating’ is the most familiar perceptual manifestation of amplitude fluctuation and describes loudness fluctuations perceived when sound signals with an amplitude fluctuation rate of ~≤ 20 per second reach the ear.

For wind farm analysis modulation, by amplitude, is defined as a peak to trough variation that exceeds 3dB on a regular basis (3dB is taken as negligible, 6dB as unreasonable and 9dB taken as excessive); by frequency, modulation is defined as a variation that exceeds one semi-tone on a regular basis.

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

A wind farm development creates a complex nature of adverse wind farm noise effects on people requiring an analysis of effect as well as the simple sound level calculations.

[14] Vassilakis, PN 2001, Perceptual and physical properties of amplitude fluctuation and their musical significance, PhD theis, University of California, pp 261-266.

Analysis of Low Amplitude Sound

The work applies audibility, loudness, salience prominence and modified unbiased annoyance as the most significant measures for low amplitude sound. Analysis of low amplitude sound presents significant issues recording and measurement instrumentation, methods of measurement and assessment. The work has identified the issues with recording and measurement instrumentation. Instrumentation usage can be readily divided into two parts: sounds above 20 dB(A) and sounds below 20 dB(A).

Sounds above 20 dB(A) can be recorded and measured with standard commercial type 1 or 2 instruments or recorded within a computer audio system without significant degradation due to signal noise. For sounds below 20 dB(A) to the nominal threshold of hearing, however, specialised instrumentation is required to ensure a clean signal. Specialised instrumentation is also necessary to capture audio events and unique sound levels that would occur below 25 dBA. This instrumentation is required in order to capture the “rumble / thump” sounds from wind farms or the character of the ambient sound in low background at rural locations.

Individual Amenity, Noise and Annoyance

Amenity has the general meaning of: Those natural or physical qualities and characteristics of an area that contributes to people’s appreciation of its pleasantness, aesthetic coherence, and cultural and recreational attributes.

The relationship between individual amenity and the adverse effects of noise is fundamental in the description of intrusive noise. For a sound to become noise, it must be unwanted by the recipient. Noise intrudes upon the amenity of a person and due to its unpleasantness causes annoyance and distress. The mechanism for this transformation of sound to noise varies widely from person to person.

An individual may react differently to noise from a combination of sources than to noise from a single source at the same level. Significantly, other persons in the vicinity may not hear or be disturbed by the noise. Individuals possess, however, a stable personality trait for noise sensitivity that provides a foundation for the assessment of individual acceptability of a particular sound under general and specific conditions. Individual amenity is a complex mix of personal noise sensitivity, personal and cultural attitudes to noise in the environment, and habituation effects.

The assessment of “intrusive” noise, or “nuisance” noise, is subject to individual sensitivity to the noise in question (that is, why is the sound noise?). Audibility and intrusive noise can therefore be defined in terms of effect, referenced to before, during and after some identified noise event. The reaction modifiers for individuals include:

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

Based upon my research 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

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

Noise

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

Intrusive Noise

Intrusive noise, to an individual, is a sound whose variance in character (such as audibility, dissonance, duration, loudness, tonality, pitch or timbre) is perceived adversely compared to the character of the environment in the absence of that sound.

Amenity

Amenity is the pleasantness or a useful feature of a place. Quiet and tranquility are common attributes sought by an individual. Amenity values are based upon how people feel about an area, its pleasantness or some other value that makes it a desirable place to live.

Noise affects the way individuals and the community feel about their environment and how these "amenity" values form part of the economic values placed on the environment by the community as a whole. The adverse intrusion of a sound into the well-being or amenity of an individual is a significant precursor to annoyance. The amenity of an individual can, therefore, be defined in terms of the effects of sound exposure and character of sound in the environment.

Significant adverse effect. The sound is deemed to be noise irrespective of subjective response causing annoyance or anger and has adverse health reactions including sleep disturbance;

- Nuisance adverse effect causing anger, annoyance, or adverse health reactions including sleep disturbance;
- Adverse effects more than minor;
- An adverse effect, but no more than minor (minor irritation);

- No adverse effect, pleasurable sounds or peace and tranquillity.

Based on the foregoing, it is practical to define "unreasonable noise" as being the first two dot points, the transition stage between unreasonable and reasonable noise as the third dot point "adverse effects more than minor", and "reasonable noise" as being the fourth dot point. The fifth dot point infers no noise whatsoever.

In terms of noise, therefore, a person has cause for complaint about noise and is acting in a not unreasonable manner if he or she is:

- Awoken or suffering from disturbed sleep due to noise
- Disturbed by noise while relaxing within his or her home
- Annoyed by noise inside or outside the home
- Reacting to the sound because the individual finds that the sound contains perceptually negative information

An individual's comfort within an environment and sensitivity to noise are affected by that individual's exposure and habituation to different types of sounds. The subjective component of the methodology outlined in figure 1 presents the various indicators a person may subconsciously perceive and apply when listening to a sound. The criterion 'personal space' includes an individual's emotional state and sensitivity to a particular sound.

Having heard a sound and made an instantaneous value of that sound, an individual immediately characterises the sound as pleasant or unpleasant, acceptable or unacceptable, a sound that can be accommodated or intrusive noise. Figure 4 presents the relationships in a format to describe why the same sound does not always provoke the same intensity of disturbance or annoyance at different times in the same individual.

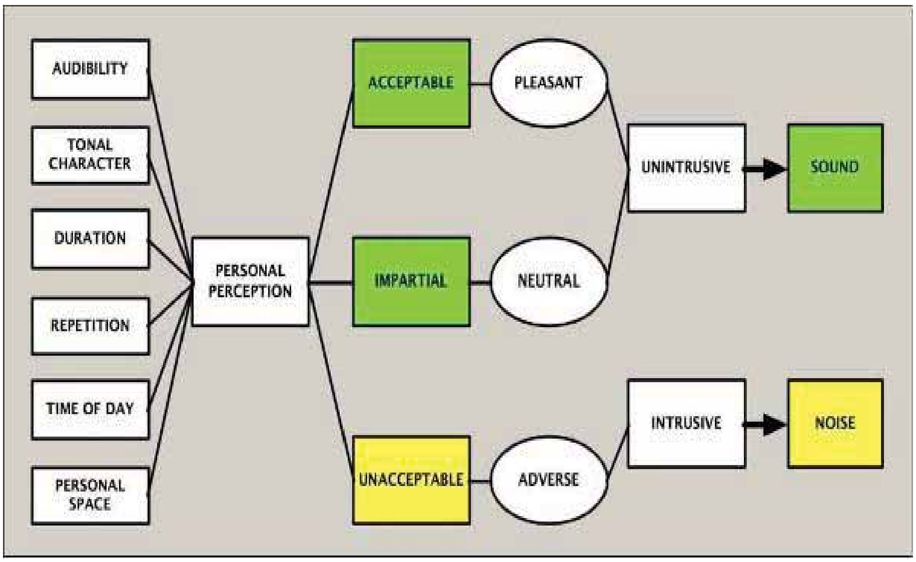


Figure 4: Subjective decision processes to differentiate between sound and noise.

The processes presented in figure 4 are common features in how an individual responds to a sound and makes perceptive choice that the sound is “good”, “annoying but can be lived with” or “intrusive – get rid of it”.

A person can change his or her perception about a sound but tends towards a stable response with a set “value” for the sound. That is, ultimately, the sound is either accepted or rejected as a nuisance.

The audibility of a sound is its most common feature – a sound must be audible to be heard by a person. This is the essential problem with all sound – noise assessment systems: a person is an individual and his or her responses cannot be mimicked by a machine. Equally, one individual cannot tell another individual what he or she hears and how he or she should respond to that sound. Audibility is aided by the character of the sound: if the sound is similar to the locale then, even if the sound is audible, it is more likely to be accepted.

If the character of the sound is foreign to the existing environment then it has less chance of being accepted. To an individual, the time of the day the sound is heard is important with unusual sounds in the early morning being less acceptable than if they are heard during the day. Sounds that disturb sleep are nearly always unacceptable even if they have some potential benefit to the individual. The number of times a sound is heard and the duration of the sound is important but, even though there are some studies for transportation noise they do not relate to low amplitude sound.

If a sound affects the personal space of a person while at home, inside or outside, that sound has a high degree of probability as being a disturbance. Additionally, if the sound has information content that the person does not want to hear that sound is perceived negatively. Personal perception therefore combines a variety of attributes that cannot be measured by instrumentation.

Environmental Noise Assessment

Environmental noise assessment has long been the sole province of regulatory authorities. Over recent years, as found from the literature reviews pertaining to this work, people have been questioning not only the mandated noise criteria but also the why-and-how of the development of the criteria and the methodologies for measurement and assessment.

This section reviews briefly two very different regulatory approaches for noise management and compares these approaches to the perceived needs of individuals and communities.

The first approach. Environmental noise assessment in Victoria and internationally to a large degree, is management of sound from various sources to some pre-determined 'baseline' sound level. This level may be daily exposure (such as the United States' day-night level) or for some shorter or longer period of time. Implicit in the assessment is that a certain proportion of the community will be highly annoyed by the source of noise at the baseline sound level set.

This proportion is in the order of 10 to 20 percent of the exposed population depending on the source of noise and the baseline sound level. This approach does not seek to protect individual values but rather something between individual amenity and a pre-determined baseline amenity for the community-at-large.

Noise performance standards are applied unless there is significant proven reason why some other indicator should be adopted. There appears to be little or no requirement within the Victorian system for an applicant to provide a full and detailed assessment of wind farm noise emissions or immissions in terms of nominal 'pre-approved' permit conditions.

Consequently, individuals and local communities in Victoria appear to have very little redress against noise from industrial activities unless such noise is so unreasonable or excessive the territorial local authority is forced to take legal action for mitigation.

The second approach. Individual amenity is protected based upon an analysis of the nature of the sound source, the nature of the receiving environment and the potential for adverse effect on the individual due to the sounds. This approach is mandated in Queensland where environmental protection legislation is based on preventing nuisance and environmental harm.

- Environmental harm is any adverse effect or potential adverse effect of whatever magnitude, duration or frequency on an environmental value.
- Environmental nuisance is unreasonable interference or likely interference with an environmental value.

The environmental values to be enhanced or protected under Queensland's Environmental Protection (Noise) Policy 2008 are:

- the qualities of the acoustic environment that are conducive to protecting the health and biodiversity of ecosystems; and
- the qualities of the acoustic environment that are conducive to human health and wellbeing, including by ensuring a suitable acoustic environment for individuals to do any of the following: sleep; study / learning; involvement in recreation, including relaxation and conversation; and .
- the qualities of the acoustic environment that are conducive to protecting the amenity of the community.

The two approaches tend to come together at approximately 45 to 55 dB(A) L_{Aeq} for transportation sources. Significant differences between the approaches appear, however, when low amplitude sound is considered. Sound levels from any source at the receiver of below 50 dB(A) are far more complex to assess and individual response becomes a major factor rather than the level of sound exposure.

As sound levels approach 30 dB(A) at the receiver individual response and noise sensitivity become important considerations as well as the nature or characteristics of the sounds as heard by the individual. These levels are often below nominal baseline sound levels for a particular source and the question arises whether the sounds are reasonable or unreasonable and whether the individual is reasonable or unreasonable in his or her responses.

The Queensland approach is significantly more complex in application and is often referenced to existing measured background sound levels with the activity limited to creating “average maximum” noise only a few decibels (0 dB to 5 dB) above the background. The audibility of the sound is also considered

While the approach is complex compared to the Victorian approach it presents, in my opinion, a better outcome for both individuals and industry as the rules are clearly defined, relatively inexpensive to progress, provide certainty and are effective.

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

All people are individuals and one person cannot, in terms of noise, state what another person hears or feels. The concept is important, however, in the assessment of low amplitude sound and noise because it has a direct relationship to the transitional phase of when adverse effects become more than minor.

There is no defined relationship that can predict when a noise is reasonable or unreasonable; for this to happen, the sound must be intrusive and then have that added salience that makes it an adverse effect to the person listening. The person may or may not be unreasonable in their attitude. The environmental awareness and noise sensitivity questions of this work presents a methodology providing objective measures to these highly subjective perceptions.

Assessing Sound and Noise in Objective Terms

The “level” of noise must be established in terms of fact and degree. A decision tree to assist this process must identify attitudinal, noise sensitivity, community and individual responses; benefit-cost analysis; levels of adverse effect and unreasonable noise criteria.

The decision processes consider desirable amenity inside and outside a home. The standard of amenity and potential for noise mitigation can be assessed when the sounds from any particular source are heard at or within a home.

A perceived sound is quantified in terms of amenity and potential for noise intrusion when the sound(s) from any particular source are heard at or within a home. The decision process is presented following. The categories and assessment methodologies presented in Table 1 have been developed as outcomes from my research work.

Amenity categories for average maximum and ambient levels applying to sounds when measured at a residence can be expressed as:

- 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.

Consideration is given to:

- Special audible characteristics: means a sound that has distinct characteristics such as impulsiveness, modulation or tonality that makes the sound stand out from other sounds in the same soundscape.
- Low noise ambient soundscapes with low background (measured as either the L_{90} or L_{95} sound levels)
- Sporadic complaint can be expected if single event maximum levels heard inside a bedroom are more than 5 dB(A) above night-time background levels (referenced to 10 minute measurement intervals)
- Complaint can be expected if L_{Aeq} levels containing distinctive adverse sound characteristics heard inside a bedroom are more than 5 dB(A) above night-time background levels (referenced to 10 minute measurement intervals)

Perception of Sound and Intrusive Noise

Personal perception of a sound is investigated through assessment of personal noise sensitivity, personal perception of the characteristics of the sound. Noise includes vibration in any form that can be "felt" by a person. The perceptual response questionnaires are designed to describe an individual's:

- sensitivity to the disturbance created by the sound, such as sleep disturbance or annoyance, as indicated by a personal noise response assessment
- sensitivity to noise, as indicated by a noise sensitivity questionnaire

- perception of the sound as indicated by a sound-file analysis questionnaire

The perception analyses assess personal responses to avoid, remedy or mitigate sleep disturbance or disturbance with relaxation or enjoyment of the property. Intrusive sound is defined as such by the person affected by the sound. The program, however, uses the modified unbiased annoyance calculation to establish the potential for intrusive sound and, by correlation with the personal perception assessments, provides refined analysis. Personal perception of the sound and the environment in which the sound is heard is fundamental to assessing the potential for noise intrusion and annoyance. There are no 'right or wrong' answers to the questionnaires.

The fundamental purpose of the decision process is confirming that a particular sound exists. If the person can hear a sound and analyse it then that is all that is needed to establish effect.

In summary, a reasonable level of sound is a level that:

- does not annoy any person while inside their home.
- does not disturb the sleep or relaxation or wellbeing of any person while inside their home.
- is not intrusive outside the home in any area where a person may relax.
- does not cause annoyance, anxiety, stress, or a loss of personal wellbeing whether inside or outside a home.

Chapter 5: Responses of Residents Near Wind Farms

Community and Individual Noise Exposure

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

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

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

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

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.

The Effects on People near the Waubra Wind Farm, Victoria

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

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

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

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

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

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

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

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

and

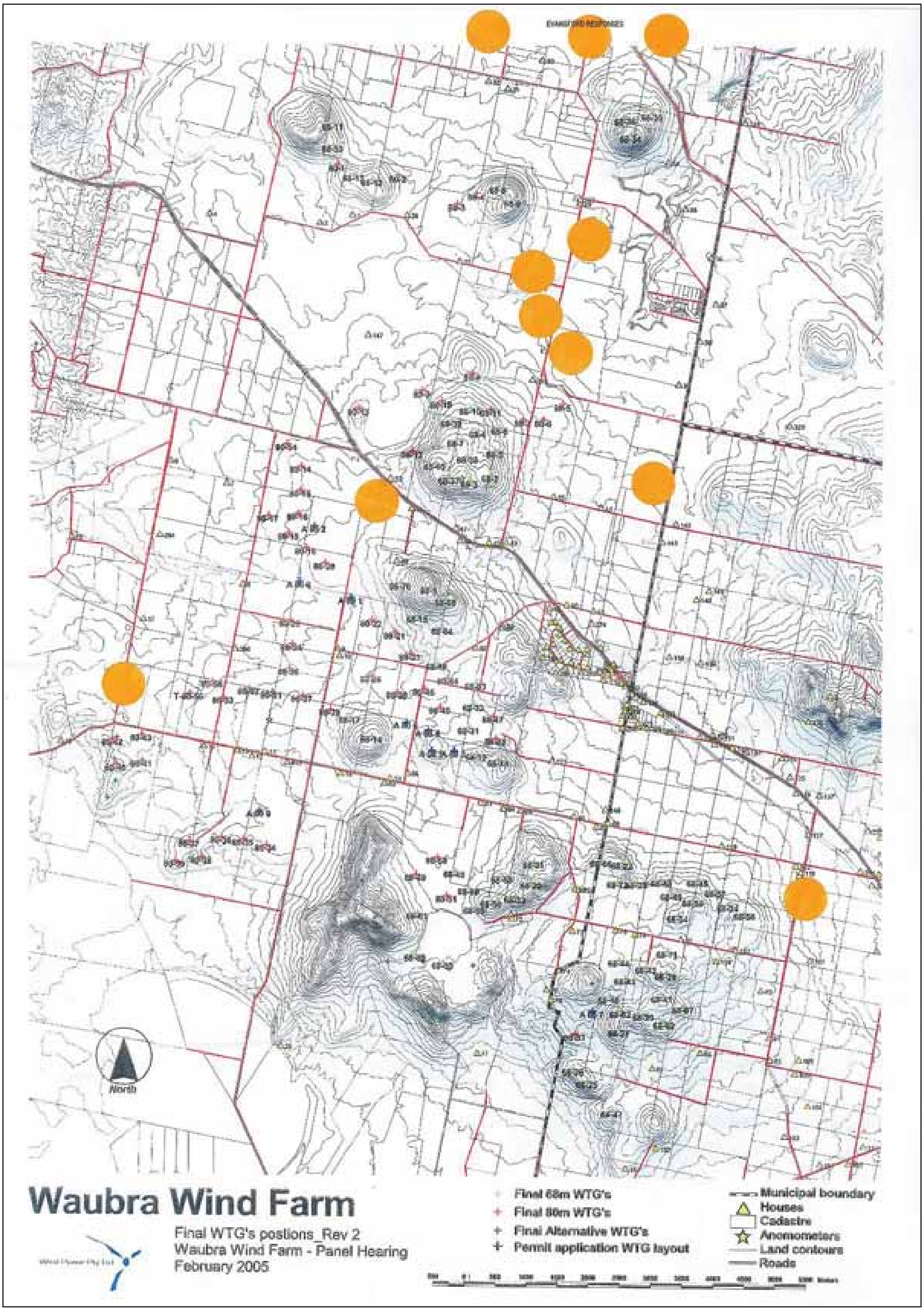
> *"The sound of the turbines when functioning is on most days so intrusive that it affects my concentration and thought processes when performing complex tasks. I suffer from sleep interruption as a direct result of the noise which then affects my ability to function at 100% the following day. One is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

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

Statutory declarations (June 2010) concerning noise issues have been declared by residents affected by the Waubra wind farm. Noise from the turbines is being experienced by residents within approximately 1000 metres of the nearest turbines and at distances of approximately 3000 to 4000 metres distant from the nearest turbines. The locales where the residents experience noise are shown in Plate W1. The noise and health effects experienced by residents are presented in Table W1.

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

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



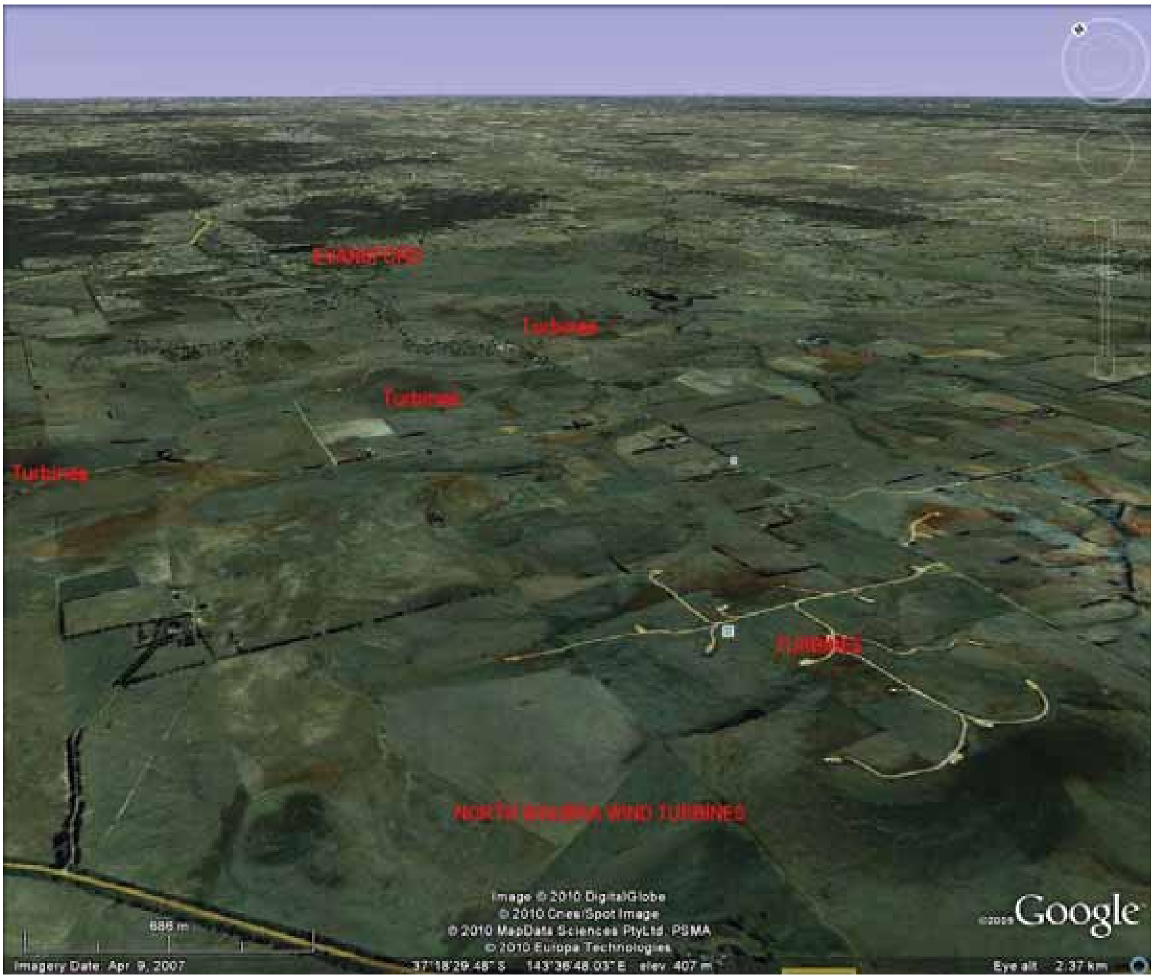
Note: the locales affected by wind farm noise are identified by the orange circles.

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

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

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

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



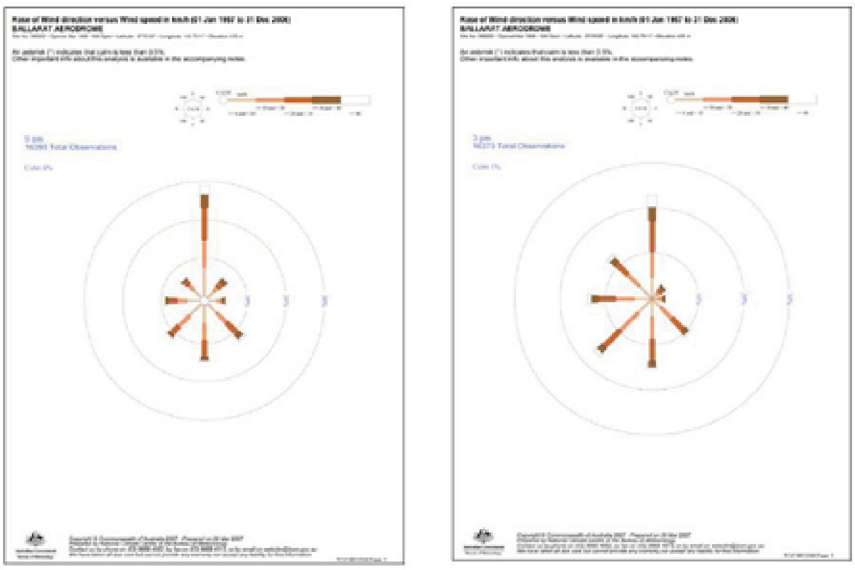


Figure W1: wind rose, Ballarat Aerodrome, mid-morning and mid-afternoon

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

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

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

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

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

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

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

Further analysis of specific complaints is presented in **Table WW1,** following. The number of turbines affecting a locale is noted, when identified by a resident.

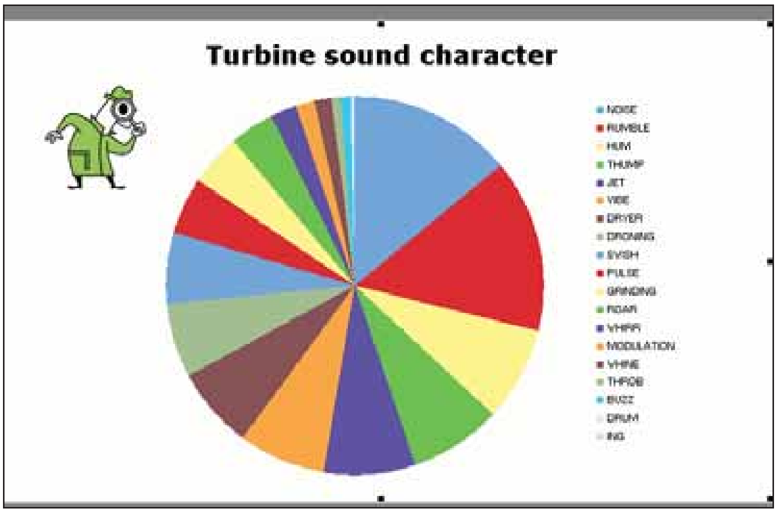


Figure WW1: Westwind complaints by turbine character

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

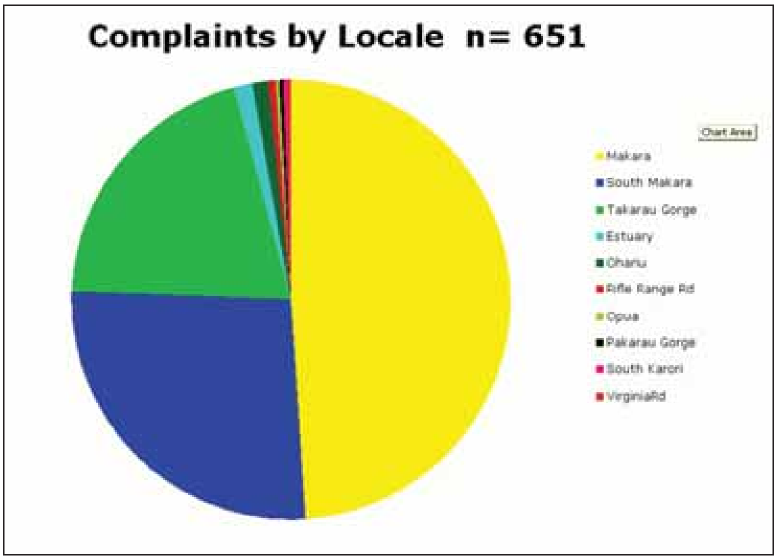


Figure WW2: Westwind complaints by locale

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

> *We have had a persistent level of disturbance noise now for several hours throughout the evening that is now preventing us sleeping since 11:15 pm. The predominant noise is a continuous loud booming rumble that is even more noticeable after a gust at ground level. When the wind noise drops, the background noise from the turbine continues and is also felt as a vibration being transmitted through the ground. Even with wind noise the vibrations in the house continue. The varying wind speed also causes a beating noise from the blades that occurs in cycles creating yet another form of noise disturbance.*

A second resident says:

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

And a third resident says

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

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

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

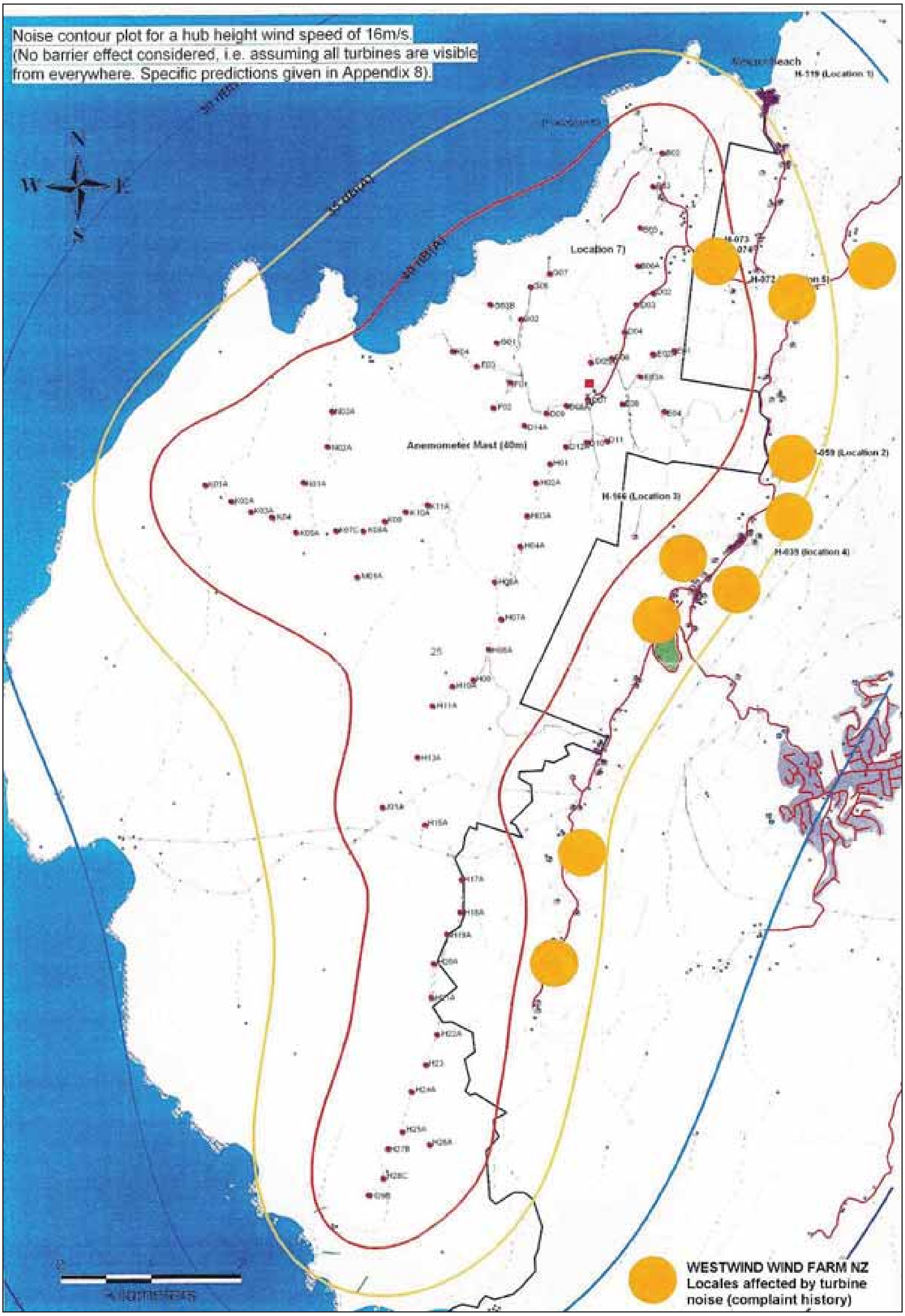


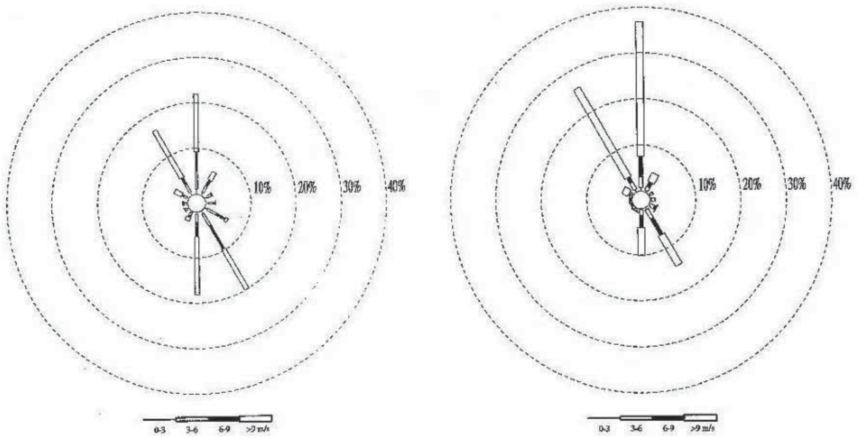
Table WW1: Westwind affects, perception and complaint analysis to November 2009

Locale	Distance	Noise affect
1	1200-1300	Kept awake with turbine noise pulsing in bedroom. Sleep disturbance. Sounds not masked by wind in trees or stream
2	1200-1300	Possible to hear and feel the turbines (20 of them) over usual household noises during the day and evenings. At night disturbs sleep patterns and affects health and well-being. Can hear the noise through the bed pillow. Sounds like a tumble dryer.
2	1200-1300	Can hear the turbines inside and outside the house during the day and at night. Disturbs sleep and affects health (tiredness). Family is stressed.
3	1700	Sound is a rhythmic humming heard inside and outside the house during the day and at night. Northwest wind brings noise, southerly does not. Noise is highest when it is calm at the house but windy at the turbines. Turbines audible inside the home with TV on. Noise is a low hum
4	1750	When the wind is from the north to north-west the noise penetrates into the home. Persistent deep rumbling around 1 second interval and lasts for 10-20 seconds then abates. Awakens and disturbs sleep. Generates annoyance and irritability.
4	1700	Disturbs sleep. Turbines are heard when it is calm at the house and windy at the turbines. Annoyance, nausea, earaches and stress.
5	2100	Turbines audible in bedroom. Awaken and disturbs sleep. Creates pressure in head and headache. Feeling tired and distressed.
6	2000	Northwest wind brings noise and disturbs sleep.
7	1250	Northwest sound is constant thumping, pulsing. Cannot stand being in the house or around the property, sick feeling, headaches, tight chest. Can be heard at night cannot sleep, get agitated and wound-up. Has ruined peace and tranquillity.
7	1250	Northwest wind, mild to wild, sound is constant thrumming. Noise is intensified in the house and more noticeable at night. Feeling of nausea precludes sleep. Disturbed and sleepless nights.
8	1500-2000	Turbine noise heard within the home. Severe sleep deprivation from interrupted sleep and lack of sleep. Fear of causing an accident on the farm due to lack of sleep. Noise at night is a southerly with a grinding rumbling sound. Noise from the northwest grinding a 'plane takeoff' noise. Lot of ringing in ears. Easily heard above the background noise. Depression due to noise at night and lack of sleep.
9	750	Noise from the southerly winds rumbling, grinding all day and night. Trouble sleeping.
10	2200	Regular sleep disturbance, sound like a plane. Louder inside the home than outside. Northwest wind thumping or rumbling sound, noise and vibration in the home (double glazed). Headaches. Low frequency humming. Awakenings and sleep deprivation.

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

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

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



July windrose for Makara mast at 40 m. (1996 to 2005).

JULY

December windrose for Makara mast at 40 m. (1996 to 2005).

DECEMBER

Figure 5. Seasonal wind speed and direction roses for Quartz Hill.

Evidence of Paul Botha Page 19 of 26

The Effects on People near the 'Te Rere Hau' Wind Farm, New Zealand

In the period May 2009 to 31 March 2010 a total of 378 complaints about noise were made to Palmerston North City Council New Zealand concerning the Te Rere Hau wind farm. The complaints have been made by persons within approximately 2300 metres south, 3100 metres south-west and 2100 to the north of the centre of the '97' turbine wind farm. Complaints concern both the loudness and character (grinding, swishing) of the sound from the turbines. The turbines are of a smaller 500kW design.

The Te Rere Hau wind farm complaints are important as they reflect the concerns of a rural community with relatively few people living within 3500 metres of the centre of the wind farm. Te Rere Hau is a densely packed design with wind turbines arranged in a grid pattern. In the 10 months for which records have been seen, 21 different residents complained about noise, with 2 residents logging more than 40 complaints each and a further 8 logging more than 10 complaints each. This, in my view, indicates issues with wind farm placement and design that can be mitigated by careful consideration of turbine choice, turbine siting design and consideration of neighbours and long-term meteorological conditions.

The following Plate, TRH Plate 1, presents the impact of the wind farm on nearby residences. The number of complaints lodged by the residents is indicated on the Figure. The Table TRH 1 following the plate, for a single residence, illustrates the common thread of the noise problems found and the relationship to weather conditions. The residence is approximately 1200 metres from the nearest row of wind turbines. The position of the wind farm on a plateau above the residences is illustrated in Plate TRH 2. The measured wind directions are given in TRH Plate 3 to illustrate the importance of accurate wind data in predicting or assessing complaints.

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

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

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

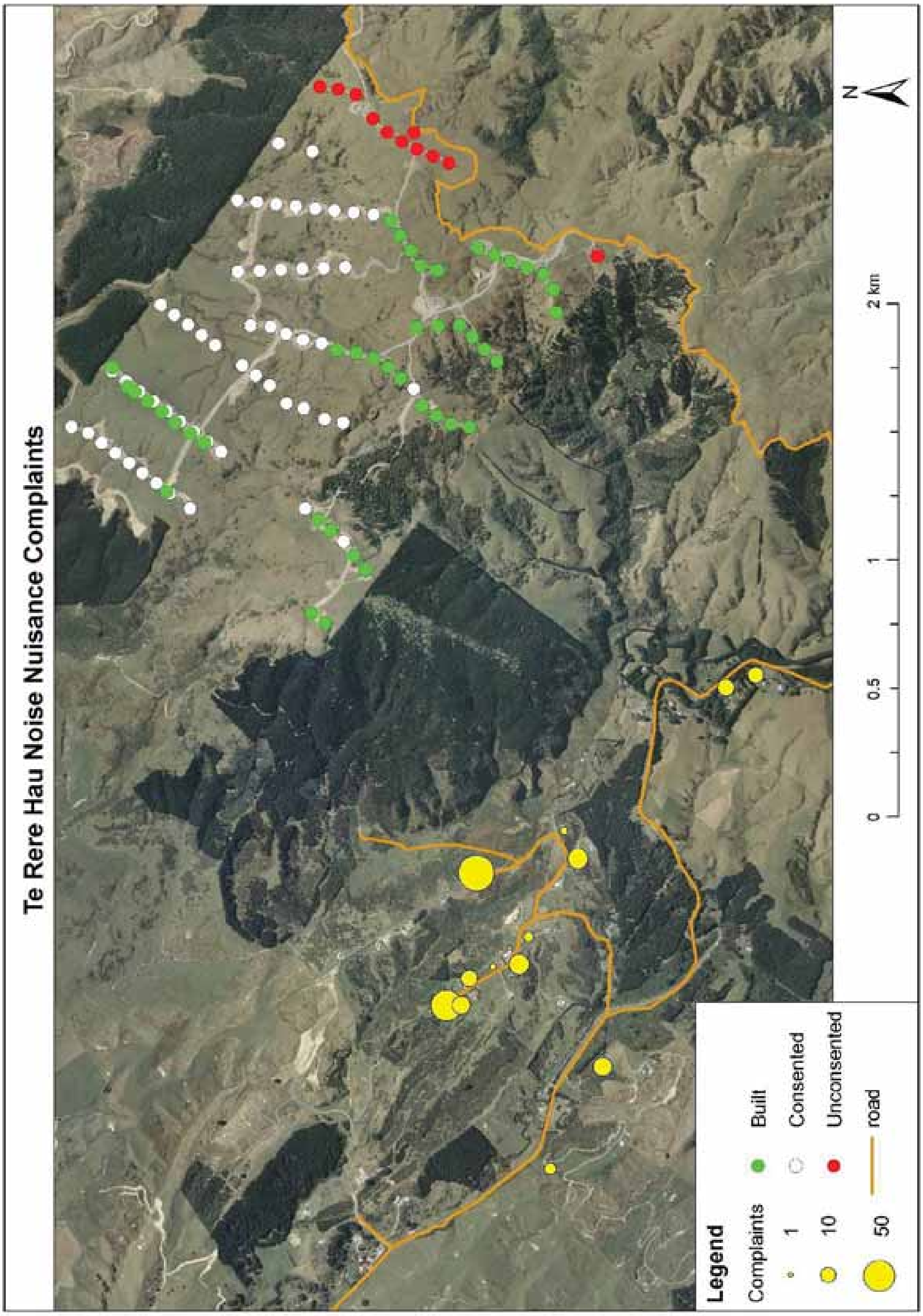


Table TRH 1: Te Rere Hau noise complaints, August 2009 to February 2010, single residence

Date / Time	Wind Direction	Complaint
07/08/09 5.45pm		Noise from windfarm
20/08/09 6.55am	S-SE	Windfarm loud this morning
20/08/09 8.45am	S-SE	Loud wind mills at 5.00am
21/08/09 6.32am	E	Windfarm noise
22/08/09 12.51pm	E	Medium strength, swooshing & grinding, only 1/2 on
29/08/09 8.45am	W	Very loud again today
15/09/09 6.31pm	E	Loud noise coming from windfarm
11/10/09 10.48am	W	Light wind, windfarm extremely loud
21/11/09 5.42am	W	WF too loud
05/08/09 7.02am		Noise from te Rere hau this morning
09/08/09 6.02pm		Excessive noise Te Rere hau
11/08/09 1.03pm		Windmills beeping noise every 2 minutes
04/09/09 8.05am	E	Continuous noise last half hour
09/09/09 11.24am	W	Started turbines 103&104, now noisy
11/09/09 6.21am	N	Light Northerly, noisy since he got up
19/09/09 10.49am	S	Very noisy again today
20/09/09 8.13am	E	Loud noise
28/09/09 7.15am	NE	Windfarm noise
07/10/09 5.32pm	W	Light wind, loud noise from wind farm
08/10/09 7.42am	W	Light wind swooshing noise this morning
09/10/09 7.02am	NE	Light wind, windfarm really loud this morning
10/10/09 9.59am	S	Light wind, would like to complain about noise
12/10/09 7.48am	N	Light wind loud noise from windfarm
20/10/09 3.53pm	S	Loud noise at wind farm
08/11/09 9.36am	0	Still, noisy today
16/11/09 7.25am	W	Lots of noise coming from windfarm this morning
17/11/09 6.27pm	W	Light wind, very loud tonight
20/11/09 7.22am	W	Noise complaint
22/11/09 7.16pm	E	Light wind WF very noisy
04/12/09 6.18am	W	Noisy this morning
07/12/09 6.21pm	W	Loud windfarm
09/12/09 6.50am	W	Light wind, droning noise
15/12/09 7.28am	S	Noisy wind turbines
19/12/09 7.04pm	W	Light wind noise from turbines over days whirring
25/12/09 8.59am	W	Light Westerly, very loud today
16/01/10 9.09am		Noise
17/01/10 7.44am	S	Light-medium Southerly wind farm quite loud today
17/01/10 6.58pm	S	Southerly wind wind mill noise
18/01/10 7.26am	SE	Medium wind, wind turbine noise last hour this am
18/01/10 6.45pm	E	Noise very bad
18/01/10 10.54pm	SE	Extremely loud
19/01/10 7.28pm	W	Turbines causing a lot of noise tonight
21/01/10 8.21pm	E	Loud noise from the turbines
25/01/10 4.43pm	E	Wind mill noise
26/01/10 8.12am	E	Medium wind, wind turbines making a lot of noise
28/01/10 7.27pm	E	Light wind, turbines are noisy again this evening
29/01/10 10.21am	E	Loud noise from blades & mechanical noise
29/01/10 6.12pm	E	Med wind same noise as usual coming from turbines
02/02/10 6.51pm	E	Loud noise from win farm
03/02/10 7.19pm	E	Noise from wind farm
04/02/10 7.01am	E	Noise loud this morning
05/02/10 6.22am	E	Light, loud today
05/02/10 5.57pm	E	Light wind, same whirring gearbox noise as usual
07/02/10 12.49pm	NW	Excessive noise
08/02/10 6.58am		Wind farm very loud this morning
08/02/10 8.16pm	E	Light wind
10/02/10 7.11am	N	Te Rere Hau noisy this morning
15/02/10 8.14pm	E	Medium wind
16/02/10 7.50am	E	Turbine noise in east direction at least hour

Plate TRH 3: Te Rere Hau Wind Farm in Relation to residences

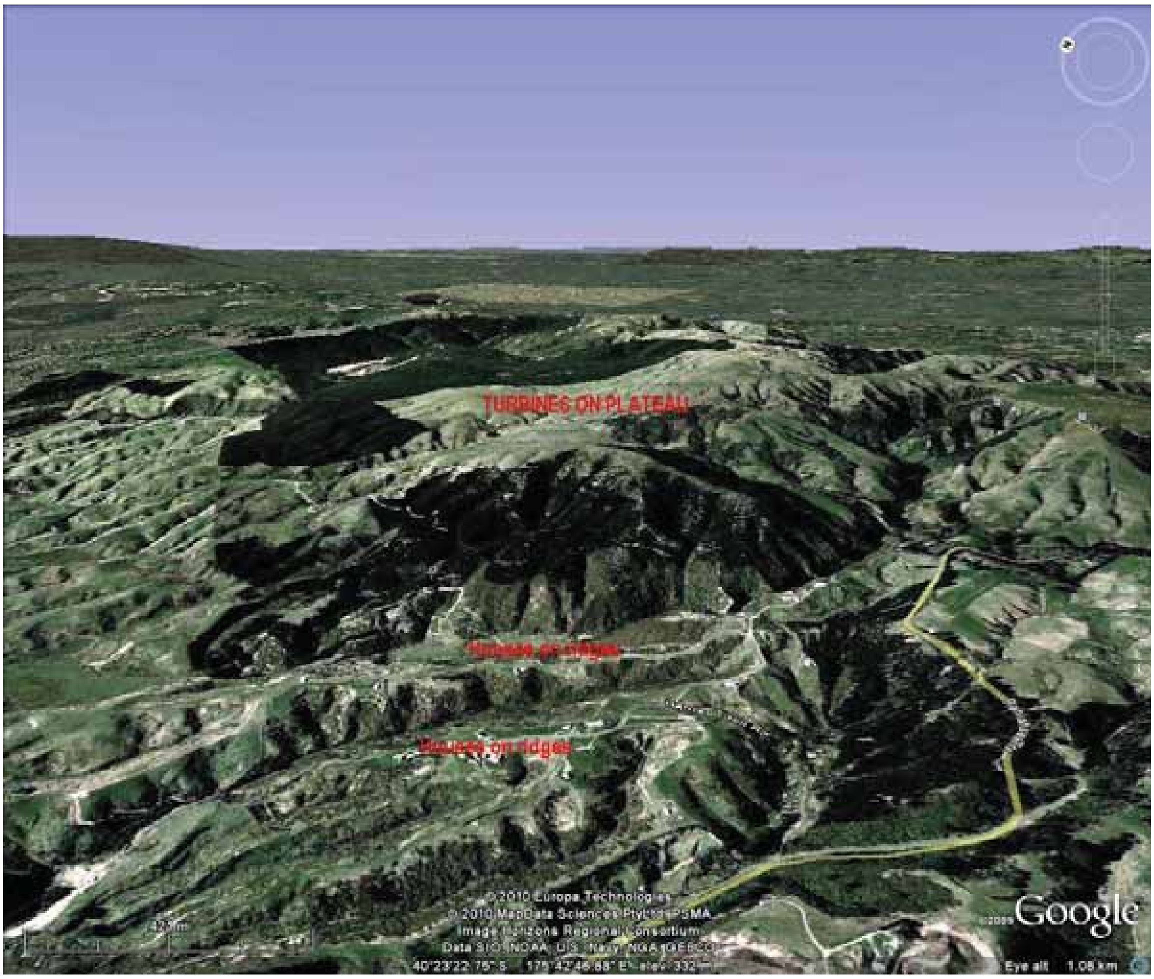
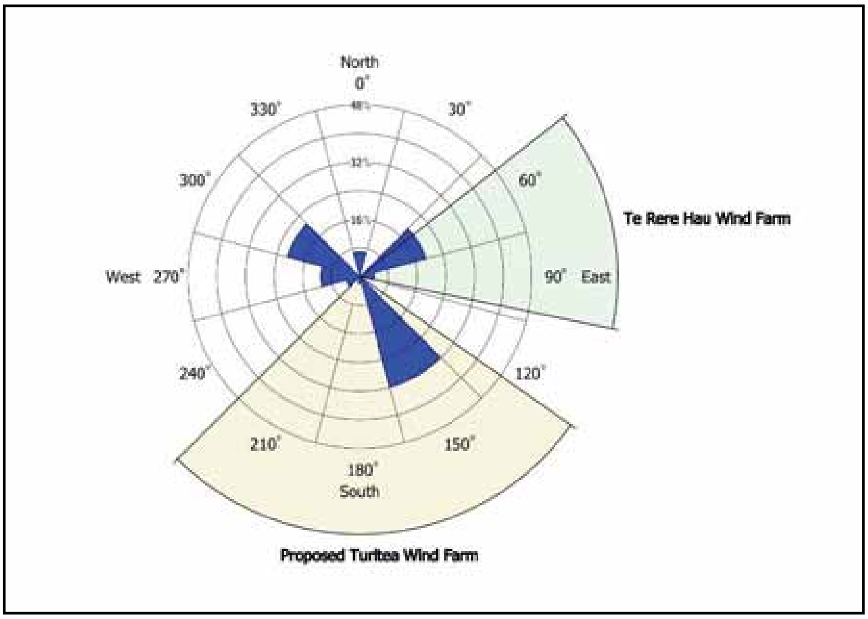


Figure TRH 1: Wind Rose for May to September 2009 illustrating existing wind farm effect (Te rere Hau) and effect from a proposed wind farm (Turitea) to the south



Chapter 6: Individuals' Perception of Wind Farm Sounds

Introduction

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

The practical difficulty in locale measurements is that many of them are needed to describe a neighbourhood. It is customary, therefore, to use a suitable single-number evaluation for community neighbourhood noise exposure. Individuals, however, are different in their tolerance to specific sounds: there is a distinct duration – intensity relationship that varies depending on the character of the sound. There is no defined relationship that can predict when a noise is reasonable or unreasonable; for this to happen, the sound must be audible, intrusive and have a salience that causes an adverse response in the person listening.

This Chapter discusses the differences between two distinct groups of people: one rural, one urban, and their responses to different sounds. The issues raised have application to wind farm developments in a wider context than Manawatu – Brisbane but its primary purpose is to hightlight evidenced differences in human perception.

The Manawatu – Brisbane Pilot Study

The Manawatu – Brisbane Pilot Study was undertaken by myself over 2007 – 2008 as a peer-reviewed study offered to respondents of an earlier survey investigating wind farm issues. A series of attitudinal and acoustical studies in the Manawatu and Brisbane in order to assess the differences between a rural population and an urban population with respect to a specific set of sounds.

The Manawatu respondent's were determined as being an 'environmentally aware' population. The group was chosen on the basis that this segment of the research required responses from persons who had an interest in their environment and who would be willing to answer a lengthy questionnaire. The occupational status of the Manawatu group was not identified. It was anticipated that the Manawatu group would exhibit a wide range of noise sensitivities as the group was drawn from different 'zones' within the Manawatu: wind-farm affected urban and/or rural locales, and 'green-fields' unaffected by wind farms.

A comparison group was selected in Brisbane. The Brisbane group was self-selected from invitations to musicians, teachers, lawyers and acoustical professionals. The Brisbane group was defined on the basis of previous investigations that indicated these occupations showed considerable attention to detail and focussed on issues more than 'ordinary' individuals. It was anticipated that this group would be significantly noise-sensitive.

The Zone map for the Manawatu is presented in figure 1. Zones 1 and 2 are potentially affected by wind farm noise, Zone 3 is green-fields but may be affected by wind farm noise to the north. Zone 4 is green-fields and unaffected by wind farm noise. The overall six of the locale in Figure 1 is 27 km by 10 km.

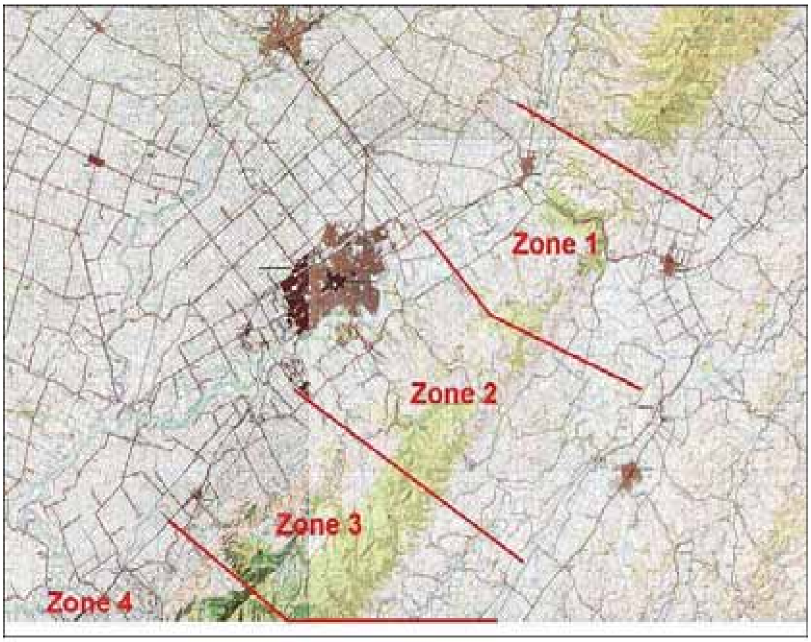


Figure 1: Manawatu Study Zones

Personality noise sensitivity questionnaires were administered in to respondents in each zone. Brisbane was deemed to be the 'unbiased control' population. The analysis of the results from 69 responses (57 in the Manawatu, 12 in Brisbane) indicates that Zone 3 responses are statistically different from the other zones and the Brisbane group. All respondents to the survey are considered to be noise sensitive. This is an unexpected outcome from the study where a more spread distribution was anticipated.

The responses to the noise annoyance questions indicate noise is sometimes a problem in both groups, with the local environment heard as being quiet / very quiet.

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

In response to the question "Thinking about where you live, could you please say how quiet or noisy you think your area is?" in the Manawatu 84% of the respondents recorded their locality as being quiet or very quiet, 13% as moderately noisy, while 3% found their locality noisy or very noisy. For the Brisbane group 67% of the respondents recorded their locality as being quiet or very quiet, 17% as moderately noisy and 17% found their locality noisy or very noisy.

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

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

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

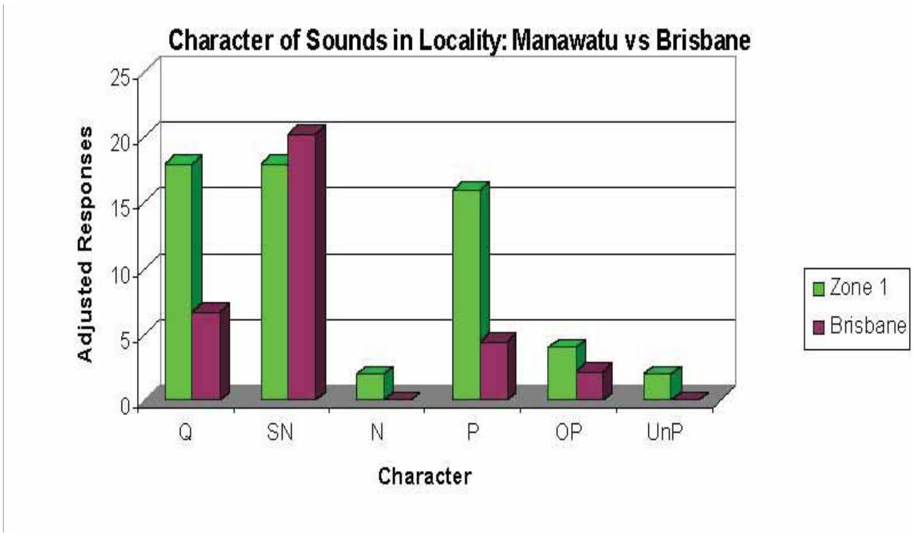


Figure 2: Character of the environment – Manawatu vs Brisbane.

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

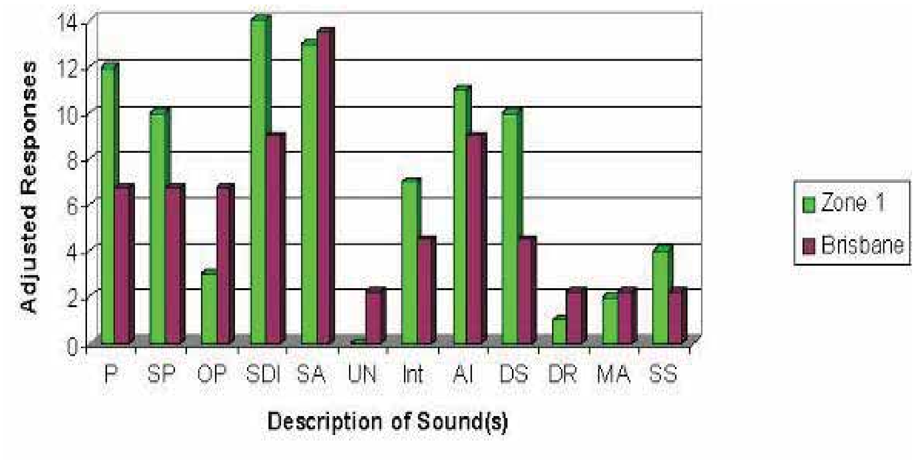


Figure 3: Description of sound(s) in the environment - Manawatu vs Brisbane.

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

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

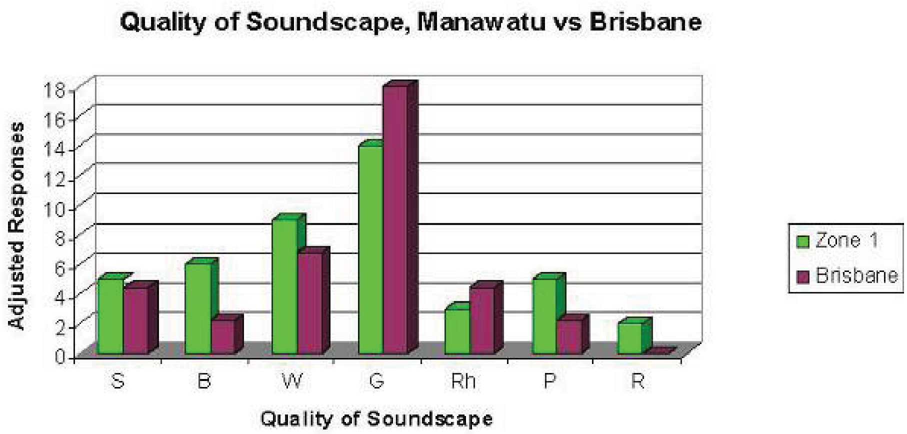


Figure 4: Qualities of Soundscape - Manawatu vs Brisbane.

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

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

A Study of Noise Sensitivity vs. Specific Sounds

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

The Manawatu focus group of 13 persons were self-selected by invitation from the previous Manawatu study. Approximately 50% of the group was from Zone 1 and 50% from Zone 3. The Brisbane group of 14 persons were self-selected by invitation from a group of people interested either in music or in acoustics. Individuals in this group may or may not have an interest in environmental issues. It was concluded that this is an acceptable component within the study design. An "Annoyance" questionnaire was included for consistency in application of the surveys.

The NoiSeQ noise sensitivity questionnaire is divided into an overall scale and sub-scales. The sub-scales are communication, habitation, leisure, sleep and work. The sensitivity of the respondents can vary depending on the sub-scale being measured. Higher values indicate higher noise sensitivity. As there are two different groups (Manawatu and Brisbane) a test was required to check whether both groups are compatible or equivalent with respect to the noise sensitivity. An equivalence test of the two groups with respect to global noise sensitivity shows the groups are not compatible with respect to this characteristic. Analysis of the data indicates that a statistically significant difference exists between the mean ranks of the Manawatu (M) and Brisbane (B) groups. The differences appear in the noise sensitivity rankings of the groups, Figure 5, as "more than average", "average" and "less than average".

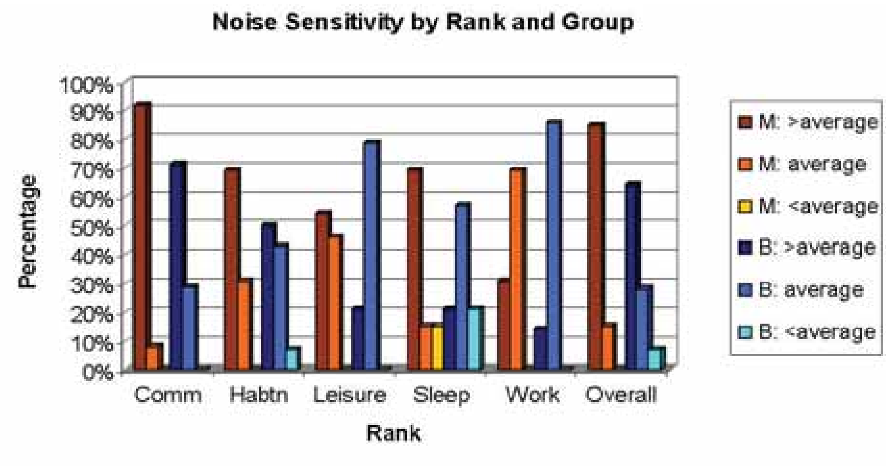


Figure 5: NoiSeQ Noise Sensitivity by rank and group as a percentage.

Noise Annoyance

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

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

An outcome of the observations and interviews of the pilot study indicated a need to establish a baseline reference point with sounds of known characteristics that could be reviewed by any person at any time. The purpose was (and is) to identify the perceptions of the sound as experienced by the person listening to the sound. The study was expanded by presenting a series of environmental sounds or 'sound files' to be judged by the respondents. The Manawatu group had the benefit of discussion concerning the sounds but all responses were made independently. The Brisbane group was not made aware of the nature of any of the sound files apart from the sound-file title. The perceptual responses help to characterise the groups of sounds investigated for individual response. A significant outcome is shown in the perception of wind farm noise between the Manawatu and Brisbane groups. The Manawatu group has a negative outlook to the sounds while the Brisbane group are not negatively inclined towards wind farm noise. It was the character of the sound that was under review, not the 'loudness' of the sound. The character or characteristics of the sounds as perceived by the respondent's are presented in figures 6 to 8. The responses are recorded as percentages.

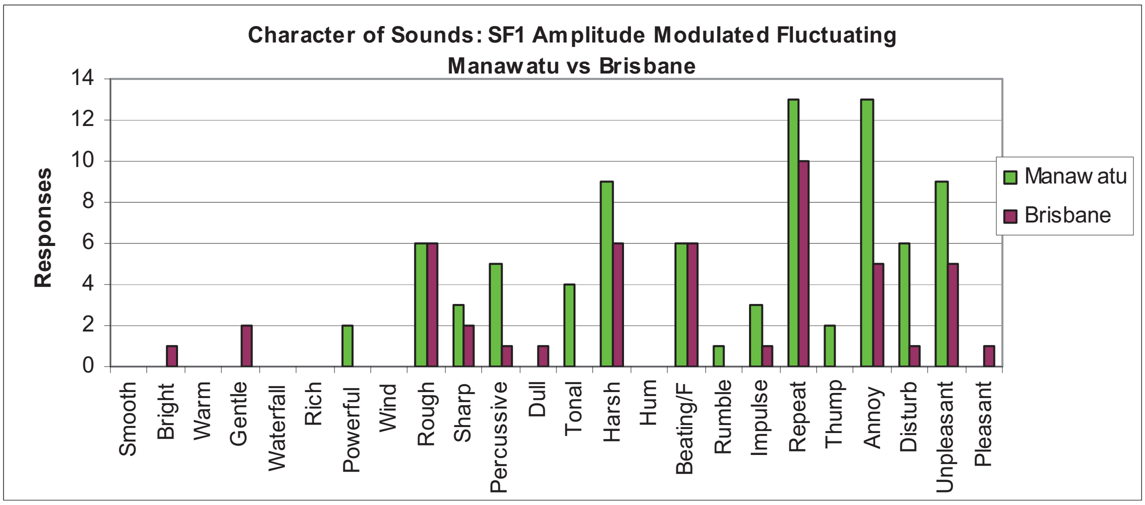


Figure 6: Responses to the character of SF1.

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

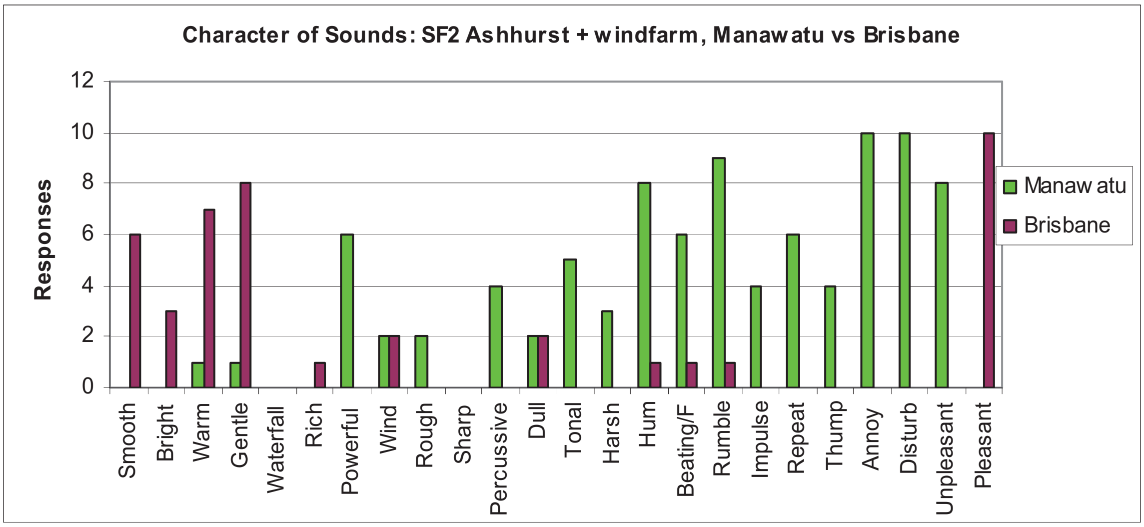


Figure 7: Responses to the character of SF2

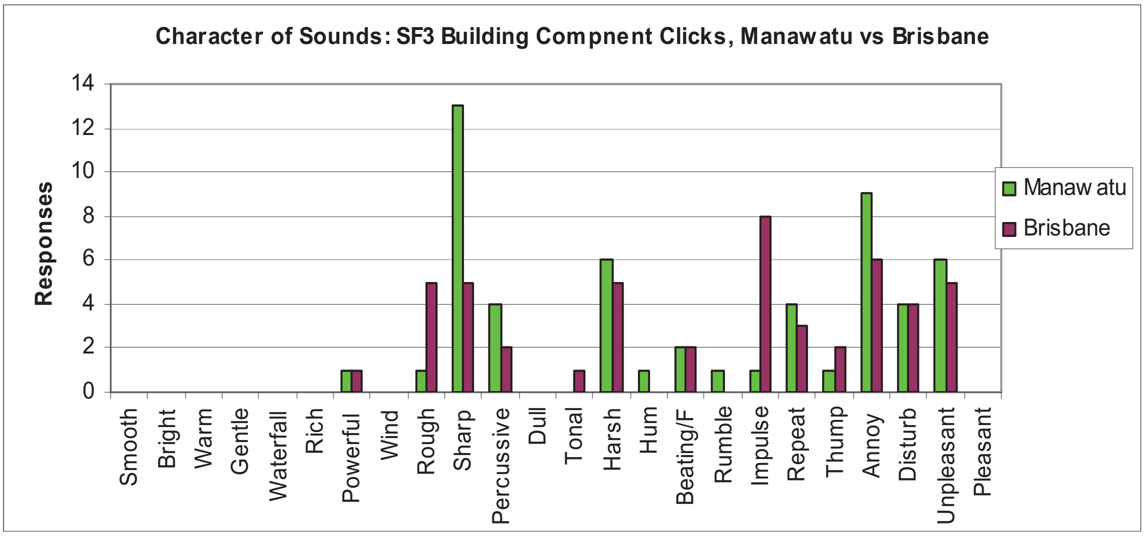


Figure 8: Responses to the character of SF3.

Makara and Waubra studies into adverse health effects

Further perception studies have been conducted at Makara (existing windfarm, Wellington, New Zealand) and Waubra (existing windfarm, Victoria, Australia) locales. The results of personal interviews with 5 groups at Makara, 5 groups at Waubra and 2 groups at proposed windfarm locales in Victoria present considerable response variation compared to the Manawatu and Brisbane groups.

The Makara and Waubra groups have only recently experienced (mid-2009) the operation of the wind farm in their locality, compared to "long-term" experience in the Manawatu. The experiences of the "new" vs "long-term" groups are starkly different. The new groups experience audible noise at distances of around 2000 metres, as well as reported adverse health effects of sleep disturbance, headaches, nausea, stress and anxiety. These adverse health effects have been reported independently; that is, no one group or respondents in any one group were aware of the comments made by the other people.

Adverse health effects have been reported by Pierpont (ref) and Harry (ref) and have been critiqued in evidence (both for and against) at the Glacier Hills Wind Park Hearing (ref). It is not the purpose of this Paper to critique the submitted evidence except to say that investigation of "unusual events" is a basic principle in environmental assessment and health risk analysis.

The Makara and Waubra effects do not appear to be due to ground-borne vibration, a potential effect in the Manawatu. The physical acoustical levels are below the normally accepted levels for effect from low frequency or infrasound. The data from these studies is still being analysed at the time of writing of this Paper.

In the cases reported no claim is made for causality as considerable further study is required before there is sufficient evidence to support or reject the conclusions to this Paper.

Community perception and acceptance of wind farms

The Turitea wind farm hearing heard professional opinion concerning community perception and acceptance of wind farms. The Palmerston North City Council commissioned a social impact assessment (expert: Baines JT). The developer commissioned a public perception survey (expert: Kalafatelis E). The overall impression given, however, by the Baines and Kalafatelis evidence is that the community generally accepts wind farm development subject to checks and balances. What the Board of Inquiry thinks of these two surveys will not be known until 2010.

Research[15] has been undertaken in New Zealand as to submitters opinions and attitudes to wind farms between the submissions period and post-commissioning. New Zealand research[16] has also provided studies into the public perceptions of wind energy developments. It is not in the scope of this Report to review the studies. One sentence in the conclusion presented in the study by Graham, Stephenson and Smith perhaps best sums up the complexity of opinion:

> "... Understanding the multiple factors that underlie resistance or support for wind energy developments is a crucial step in informing renewable energy policy. ..."

[15] Wild T, 2008, Attitudes to Wind Farms: the Dynamics of Submitters Opinions, Masters Thesis, University of Otago
[16] Graham JB, Stephenson JR and Smith IJ, 2008, Public perceptions of wind energy developments: case studies from New Zealand, University of Otago

In the context of this Report, the community deriving the benefits from the wind farm must understand and mitigate the cost to individuals affected by the operation of the wind farm.

Conclusions

(1) It is concluded that there are significant differences between the Manawatu and Brisbane groups, not only in noise sensitivity but also in perception and responses to similar situations. This has two possible explanations: the Manawatu group has an unbiased negative response due to pre-knowledge and environmental awareness. Or, the group has a biased negative response due to pre-knowledge and environmental awareness.

(2) It is concluded that any attitudinal study that asks questions concerning environmental modification (whether wind farm, waste dump or any other similar industrial activity) will be significantly biased if the respondents have no first-hand experience of the activity. The decision process developed from this work recognises this ‘enviro-cultural’ influence.

(3) It is concluded that the unbiased annoyance approach to wind farm assessment is a viable alternative to existing objective measures. The calculated unbiased annoyance values for green-fields unaffected by wind turbines are 36-40 points (night). The residential and rural wind farm affected unbiased annoyance values are 109 to 419 points (night) indicating a trend line for perception values for adverse effect between “minor”, “more than minor” and “significant”.

(4) There are observed adverse health responses from residents living within the locality of operating wind farms. These effects are, in my opinion, sufficient for investigations to be made for assessment of adverse health effects due to unreasonable noise or objectionable noise from wind farms.

(5) It is concluded that New Zealand Standard NZS 6808:1998 is not adequate or appropriate as an assessment methodology for risk assessment of adverse health effects from wind farm noise.

Chapter 7: Wind Farms and Health Effects

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

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[17]. His evidence has been presented at wind farms hearings world-wide.

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

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"[18].

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[19]" he states, in part, that:

[17] Kamperman, George and Richard R. James (2008). Simple guidelines for siting wind turbines to prevent health risks. INCE NOISE_CON 2008 pp. 1122-1128
[18] http://www.windturbine noisehealthhumanrights.com/wtnoise_health_2007_a_barry.pdf
[19] Canadian Acoustics, Special Issue, Vol 34 No.2 2006, pp 29-36

> *"Infrasound from wind turbines is below the audible threshold and of no consequence. The problem noise from wind turbines is the fluctuating swish".*

In his Paper "Wind Turbine Syndrome – An appraisal" dated 26 August 2009, Dr Leventhall critiques the work of Dr Nina Pierpont[20] but does agree with Dr Pierpont 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[21] Dr Leventhall confirms his belief that there is no such thing as wind turbine syndrome).

Dr Leventhall 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)."*

and 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."*

There is, in my opinion and despite the differences in opinion as to cause, considerable agreement between the parties – residents, clinicians and acousticians – as to observable health effects from unwanted sound. In this case, it is unwanted sound from a wind farm.

Conclusively, in my opinion, there are clear and definable markers for adverse health effects before and after the establishment of the wind farm and clear and agreed health effects due to stress after the 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 between affected persons, clinicians and psychoacousticians. There has, however, been considerable work recently (May-June 2010) on the possible mechanism between infrasound and adverse health effects. A summary of this work is presented further in this Report.

[20] "Wind Turbine Syndrome" p.18 (prepublication draft dated June 30, 2009, published by K Selected Books).
[21] 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.

Epidemiology, health risks and the real-world

Epidemiology is the study of actual health outcomes on people and is the only science that can directly inform about actual health risks from real-world exposures. In his evidence[22] before the Public services Commission of Wisconsin Dr Phillips states that *real world exposures and the human body and mind are so complex that we cannot effectively predict and measure health effects except by studying people and their exposures directly.* Based on his knowledge of epidemiology and scientific methods and his reading of the available studies and reports he summaries that:

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

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

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

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

[22] Phillips,C.V., (2010). An analysis of the epidemiology and related evidence on the health effects of wind turbines on local residents. Evidence before the Public Service Commission of Wisconsin. PSC Ref#: 134274. Retrieved from: http://www.windaction.org/documents/28175. Dr Phillips can be contacted at: cvphilo@gmail.com

Chapter 8: Annoyance, Audibility, Low and Infrasound Perception

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.

The World Health Organization[23] 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.

There has been considerable research into noise annoyance from turbines, such as that reported by Pedersen and Persson Waye,[24] identifying the relationship between noise from turbines and transportation. **Figure 1** presents the relationship derived by Pedersen and Persson 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>

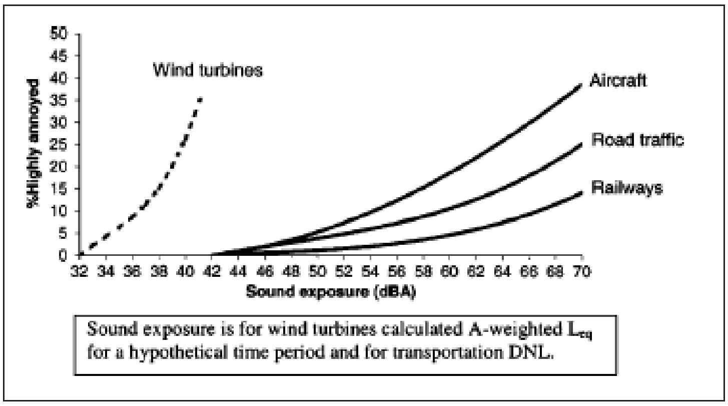


Figure 1: Wind turbine noise levels and persons highly annoyed by the noise
Source: Pedersen and Persson Waye

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 noise 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.

[23] "Guidelines for Community Noise, World Health Organization, 2000, p31
[24] '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

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.

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[25] has found that-

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

Noise affects individuals and the community by modifying the nature of the environment that attracts and holds people to the locality. Acoustical amenity, therefore, can be described as the enjoyment of a place without unreasonable exposure to unwanted sound that is a by-product from some activity. Individual amenity is evaluated with respect to personal noise sensitivity, personal and cultural expectations and attitudes to noise in the environment and habituation effects. Noise intrusion, as a personality variable, is dependent on noise sensitivity.

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;

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.

[25] 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

'Noise' can therefore be defined as:

> *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.*

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

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

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

- the physical relationship is considered as being the role of signal detection
- the psychological or behavioural and perceptive reactions of an individual are considered as psychoacoustical or sound quality relationships

A method for the prediction of the audibility of noise sources is detailed in 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

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

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

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

Human sound perception can be described in terms of equal loudness contours. Strictly speaking these are not measures of audibility but they do provide a useful starting point for comparison between sound levels by frequency (tone). An equal loudness contour is a measure of sound pressure, over the frequency spectrum with pure continuous tones, for which a listener perceives an equal loudness. Loudness level contours are defined in International Standard ISO 226:2003 *Acoustics-Normal equal loudness contours*, Figure 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).

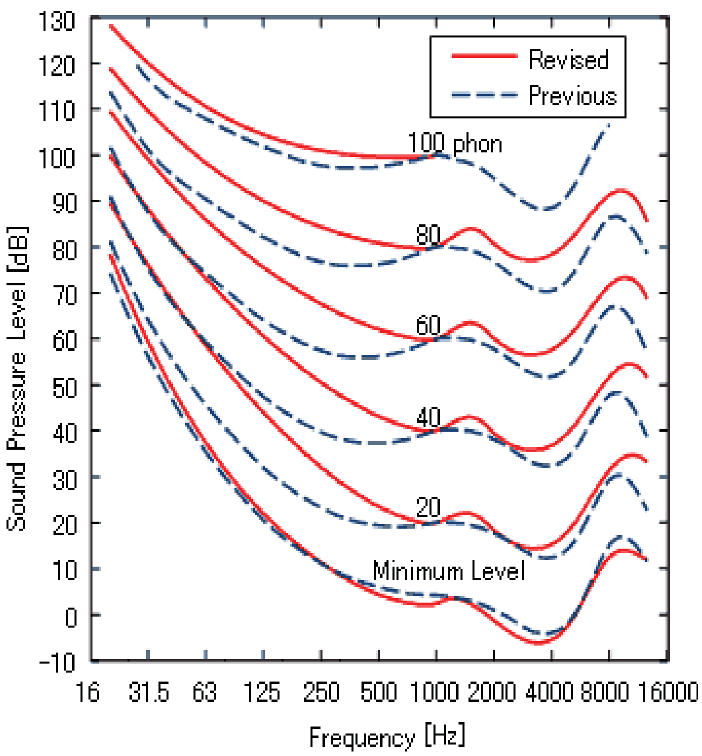


Figure 2: Equal loudness level contours vs sound pressure levels

(reference source: http://www.aist.go.jp/aist_e/latest_research/2003/20031114/20031114.html)

The research by Moller and Pedersen[26] 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 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.

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

Moller and Pedersen observe that especially sensitive persons, however, may have extraordinary high hearing sensitivity at low frequencies, figure 3. 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.

[26] 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

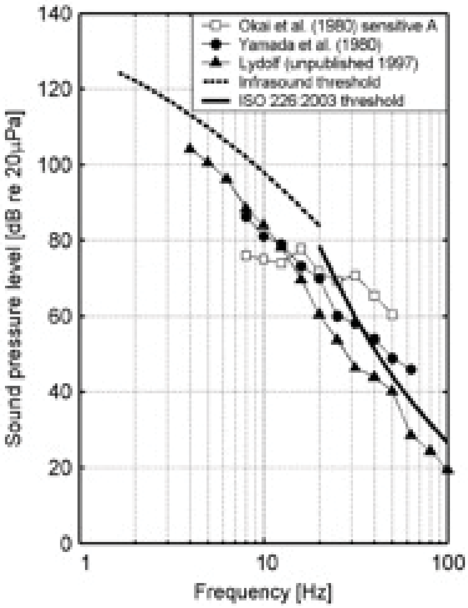


Figure 3: Hearing thresholds of three especially sensitive persons (Moller and Pedersen Figure 12)

Significant research[27],[28],[29],[30] is being conducted into the effects of infrasound on perception and the vestibular system. This research is starting to fill in knowledge-gaps with respect to human response and adverse health effects.

Salt and Hullar conclude that the commonly held belief that low frequency sounds you cannot hear cannot affect the inner ear is incorrect. Their paper shows how the outer hair cells of the cochlea are stimulated by very low frequency sounds at up to 40 dB below the level that is heard. There are many possible ways that low frequency sounds may influence the ear at levels that are totally unrelated to hearing sensitivity. As some structures of the ear respond to low frequency sound at levels below those that are heard, the practice of A-weighting (or G-weighting) sound measurements grossly underestimates the possible influence of these sounds on the physiology of the ear. The high infrasound component of wind turbine noise may account for high annoyance ratings, sleep disturbance and reduced quality of life for those living near wind turbines.

[27] Rapley, B, review, pers comm. May 2010, summary provided in previous chapter
[28] Barrand, JS, doctoral student thesis in preparation , pers comm., May 2010
[29] Todd NPMcA, Rosengren SM, & Colebatch JG, 2008, Tuning and sensitivity of the human vestibular system to low-frequency vibration. Neuroscience Letters, 444 (2008) 36-41
[30] Salt AN & Hullar TE, 2010, Response of the ear to low frequency sounds, infrasound and wind turbines, preprint pers comm., to be published in Hearing Research

Human Auditory, Psychoacoustical And Physiological Perception In Relation To Low Frequency Sound

Preamble

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 professional evidence and reports to regulatory authorities hearing applications for wind farm planning permissions. Observed responses from people living near to operational wind turbines include annoyance, sleep disturbance, general malaise, anxiety, dizziness (co-ordinating balance), headaches, tight scalp, hearing pressure sensitivity and aches in the legs.

This paper presents, for discussion purposes, the hypothesis that there are measurable adverse effects due to dissonant low frequency pressure waves from wind turbines on human auditory, psychoacoustical and physiological perception. All of the information detailed in this hypothesis is readily available in standard anatomy, physiology, neurology and neurobehavioral text books.

The nature of sound

Sound can be transmitted through the air [acoustic], ground or water [seismic]. While the ear cannot hear low frequencies as easily as higher tones, they can still be perceived. The vestibular system is more sensitive to these low frequencies and reacts by sending anomalous signals to the brain, which, when put together with signals from other balance sensors, confuses the brain which can cause a cascade of unpleasant sensations as a result.

- Sound is what we call pulsations in air pressure where the direction of the pulsation/rarefaction is parallel to the direction in which it radiates.
- Sound impacts on the ear drum and is transferred to the cochlea via three little bones: malleus, stapes, incus.
- The cochlea consists of a coiled membrane with a double membrane dividing the ‘tube’ into two distinct parts. Between these two dividing membranes are a series of hair cells which are sensitive to frequencies between 20 Hz (cycles per second) to 20,000 Hz.
- High frequencies have a short wavelength and are detected near the entrance ot the cochlea while low frequencies with long wavelengths are detected towards the end of the cochlea.
- Damage to the hair cells results in a reduction in hearing with deafness the end result.

Balance and the vestibular system

- The inner ear also contains the major organs for detecting balance, known as the Vestibular System.

- Three semicircular tubes are orientated in such a way as to detect movement in the forward/backward, left/right and up/down directions. This is achieved by the dynamic movement causing fluid in the tubes to move, swishing little flaps called cupula backwards and forwards. These flaps contain hair cells just like the cochlea, but the send signals to the brain which are interpreted as movement, not sound.
- Two organs, the utricle and saccule, detect static balance, or tilt. This is achieved by little crystals of calcium carbonate which rests on a jelly-like substance in which there are more hair cells. Tilting the head causes gravity to move the little crystals and the signals are interpreted by the brain as the angle of our head.
- The body has several other sensors which are used to determine balance. These include the eyes; stretch receptors in the muscles and tendons, and visceral graviceptors in the gut.
- The eyes observe the environment looking for vertical and horizontal lines. Vertical lines such as trees or buildings are compared to the natural horizon to determine our position.
- Stretch receptors in the muscles and tendons tell the brain how our body, arms and legs are orientated, giving us another set of data points for determining our balance.
- Graviceptors in the gut detect the position of the major organs and the blood. This is essential to insure that sufficient blood reaches the brain at all times.
- Nerves from the vestibular system are routed through the medial vestibular nuclues on their way to the neck and eye muscles via the 8th cranial nerve, bypassing conscious thought processes.
- Other nerves from the vestibular system are routed through the lateral vestibular nucleus on their way to the cerebellum for more processing and the muscles of the arms, legs etc. also via the 8th cranial nerve.
- This short circuit system is necessary to allow us to react quickly to changing balance situations and allow us to move very quickly to catch prey or avoid danger. Think of riding a bike. These direct connections allow us to maintain balance without thinking about it. If we had to consciously think about every subtle change we needed to make in order to maintain balance it would be a very problematic process and we could not go very fast. Just remember how difficult it was to learn to ride a bike initially.
- The vestibular system is most sensitive to sounds around 100 Hz. If sound waves are in this low frequency region, they can impact on the vestibular system, particularly if they are transmitted through the bone directly, rather than just through the air. This is why some people can ‘hear’ the wind turbines when the put their head on a pillow at night.
- Low frequency sounds, like those emitted from wind turbines, can directly impact on the vestibular system and may interfere with balance.
- Low frequency sounds can also affect the visceral gravisensors by impacting on the chest and abdomen from the outside, or from the inside via air in the lungs. The lungs are open to external air and sounds can certainly penetrate this free pathway. Low frequency sound waves can thus enter the body and vibrate the diaphragm which is a layer of muscle dividing the lungs, heart etc. off from the intestines. The liver is directly

attached to the diaphragm and can thus be pummelled via the air entering the lungs and vibrating the diaphragm.

- Errant signals from the vestibular system and the visceral gravisensors in the chest and abdomen are then conflicting with information from the utricle and saccule (static balance), the semicircular canals (dynamic balance) as well as the eyes and the muscles. The brain can thus become confused and a common outcome is vertigo - dizziness. Vomiting can also occur as is common in seasickness.

Impact of low frequency sound

- Low frequency sound can also impact negatively on the body. Frequencies below 100 Hz, particularly in the lower range and at low power (loudness) can trigger the sympathetic nervous system as these sounds are typically indicative of danger.
- Over millions of years, fish, amphibians, reptiles and mammals have all evolved with an in-built sensitivity to low amplitude, low frequency sound. In nature these correspond to potentially dangerous situations such as earthquakes, land slides, trees falling, predators approaching etc. All animals respond by becoming more alert. It is a simple survival mechanism all animals possess. Otherwise, they would not have survived to evolve.
- Stimulation of the sypathetic nervous system is commonly referred to as the ‘fight or flight’ response. It is characterised by an increase in awareness. Blood is diverted from the central gut which effectively turns off digestion so that it can be better placed in the muscles in case rapid movement is required.
- The eyes dilate to let in more light, quite automatically, even if it is quite bright. This is a residual response from a time when it had survival advantage.
- Adrenaline floods the body to prepare for a rapid retreat to safety or a fight if necessary.
- Cortisol levels rise which adds to the general sate of heightened arousal and fear kicks in.
- Cortisol is a hormone produced by the adrenal gland in response to stress (among other things). Its production is controlled by hypothalamus. Its primary functions are to increase blood sugar and stores of sugar in the liver (glycogen). It also aids in fat, protein and carbohydrate metabolism and can suppress the immune system. It prepares us for high energy activity as a survival mechanism.
- Prolonged exposure to low frequency, low amplitude sound puts the body into a heightened state of awareness and underlying fear. This is worsened if the direction of the threat cannot be easily determined. Sleep will become highly disturbed, even if actual waking does not occur.
- Sleep cycles will be disrupted with fatigue and tiredness becoming common place. Cognitive (thinking) ability will be impaired which may lead to mistakes and accidents as the body is less able to function normally. This adverse effect can be accentuated if quick decisions are required, such as driving a motor vehicle or operating dangerous machinery.

CHAPTER 9: FLICKER AND HUMAN PERCEPTION

Introduction

This Chapter has been prepared by Mr Bruce Rapley.

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.

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.

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.

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.

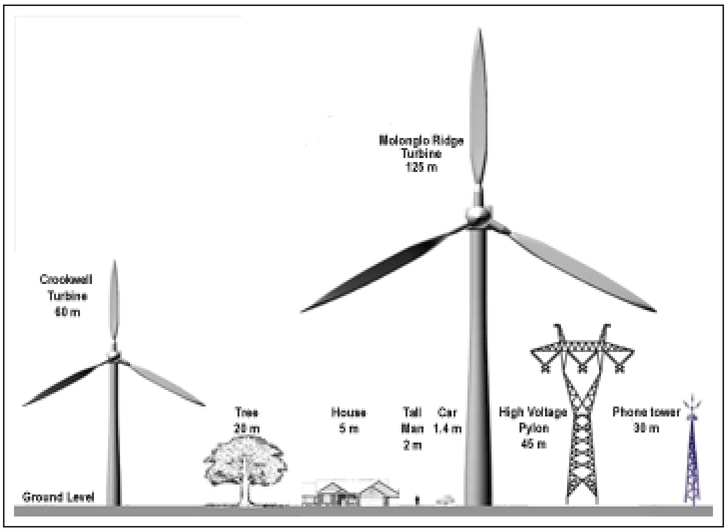


Figure 1: Relative heights of turbines to dwellings

(Source: Molonglo Landscape Guardians, by permission)

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”.

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

Epilepsy

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.

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.

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.

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.

Photosensitive Epilepsy

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.

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.

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.

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.

Sources Of Flicker Stimulus

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.

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.

Turbines As A Source Of Flicker

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.

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, for a small but significant percentage of the population, multiple turbines 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.

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.

Glint

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.

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

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.

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.

Blade Glint & Turbine Placement

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.

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.

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.

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.

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.

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.

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.

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.

Visual Character Affecting Sound Perception

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.

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.

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.

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".

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.

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.

Statement of Qualifications and Experience, Robert Thorne

Hi, my name is Robert (Bob) Thorne. I am the Principal of Noise Measurement Services Pty Ltd, Brisbane Australia. My professional background is the measurement of low background sound levels and the assessment on noise as it affects people. Wind farms with their unique characteristics of sound and noise are of particular interest.

In 2009 I was awarded a PhD in Health Science from Massey University, New Zealand. I hold specialist 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, now re-incorporated) and a member of various acoustical societies. 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.

The development, conduct and presentation of acoustical and attitudinal surveys is a particular interest. 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. Since this major study I have maintained my involvement in acoustical and attitudinal studies.

With respect to public health promotion, nuisance evaluation and risk assessment I have approximately 18 years professional experience as an environmental health officer for various Councils in New Zealand. In varied roles I had daily interaction with the public for public health nuisance assessment. Later this work included 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. 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.

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.

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.

In the past 5 years I have prepared noise and perception assessments of 15 wind farms; 6 in New Zealand and 9 in Victoria. My experience with 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 the impact of the Makara wind farm has been since August 2005 to July 2010. As part of my research work I have also investigated complaints of noise from the Te Apiti, Tararua, and Te Rere Hau (New Zealand) and Waubra (Victoria) wind farms. I have prepared impact assessments for residents potentially affected by the Berrybank, Chepstowe, Mortlake, Mortlake South, The Sisters, Yaloak, Stockyard Hill and Moorabool (Victoria) wind farms. I am a co-author of the Proposed Turitea Wind Farm Board of Inquiry evidential text *Sound, noise, flicker and the human perception of wind farm activity*[31], submitted March 2010.

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. The detail of my research is published in my thesis *Assessing Intrusive Noise and Low Amplitude Sound*. In 2010 I was appointed as an Environmental Health Research Associate with the Institute of Food, Nutrition and Human Health, Massey University, New Zealand.

[31] Rapley BI & Bakker HHC (2010) Editors, www.atkinsonrapley.co.nz, ISBN 9780473165598 (internet)

Statement of Qualifications and Experience, Bruce Rapley

Bruce Rapley, after initially training in business management, transferred to Massey University in Palmerston North to follow his passion for biological science, gaining a BSc in Biological Systems in 1983. Subsequently, Bruce worked in Plant Physiology and Biochemistry at Massey University in both technical and tutoring roles for four years before transferring to technology where he managed the engineering facility for 14 years. During this time he was able to combine his passion for biology with his long time interest in technology, gaining a Masters degree in 1994 in bioelectromagnetics: the study of the effects of exogenous magnetic fields on living systems. Bruce has since developed an international reputation in this field with numerous international publications and presentations at conferences on bioelectromagnetics and human health. In 2004 Bruce left the university system to create Atkinson & Rapley Consulting Ltd with Garth Atkinson. Here he applied his diverse skills and knowledge base to a variety of community-based consulting projects involving science, technology, social marketing and project management. Using the Delphic Systems methodology, he was able to assist many clients in a diverse range of areas from business management to environmental issues. He took on the role of project manager for 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, technology research and development, now with a strong focus in the area of environmental acoustics and its effects on human health.

Statement of Qualifications and Experience, 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.

Reviewer, Dr Daniel Shepherd

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. Daniel is associated with the World Health Organisation, Quality of Life Group.

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.

Reviewer, 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.

Recommended Reading

In addition to the references in the Report the following are recommended reading to the issue of sound, noise, human perception, adverse effects and wind farm activity

1. Pierpont, N., (2009), Wind turbine syndrome: A Report on a natural experiment, ISBN 978-0-9841827-0-1, K-Selected Books, Santa Fe, New Mexico, USA.
2. Pedersen, E., and Persson Waye, K., (2004). Perception and annoyance due to wind turbine noise: a dose response relationship. Journal of the Acoustical Society of America, 116(6), pp3460-3470.
3. Pedersen, E., and Persson Waye, K., (2007). Wind turbine noise, annoyance and self-reported health and wellbeing in different living conditions. Occupational Environmental Medicine, 64, pp480-486.
4. Berglund, B., Lindval, T., and Schwela, D., (Eds) (2000). Guidelines for community noise. World Health Organization, Geneva, Switzerland.
5. Davis, J., (2007). Noise Pollution from Wind Turbines. Presented at the Second International meeting on wind turbine noise, Lyon, France.
6. Berglund, B., and Nilsson, M. E., (1997). Intrusiveness and dominant source identification for combined community noises. Proceedings of the thirteenth annual meeting of the international society for psychophysics, Poznan, Poland.
7. IEHMRC Institute for the Environment and Health, (1997). The non-auditory effects of noise. Report 10, ISBN 1 899110143, Leicester, England.
8. EnHealth Council, (2004). The health effects of environmental noise – other than hearing loss. ISBN 0-642-823049, The Australian Government Department of Health and Aging, Australia.
9. Job, R. F. S., (1988). Community Response to Noise: A review of factors influencing the relationship between noise exposure and reaction. Journal of the Acoustical Society of America, 83, pp991-1001.
10. Niemann, H., and Maschke, C., (2004). WHO Lares: Report on noise effects and morbidity. World Health Organisation, Geneva.
11. Pierpont, N., (2006). Wind Turbine System. Testimony before the New York State Legislature Energy Committee. Retrieved from:
    http://www.ninapierpont.com/?s=wind
12. Selye, H., (1975). Stress Without Distress. Lippincott, New York, USA.
13. Harry, A., (2007). Wind Turbines, Noise and Health. Retrieved from:
    http://www.flatgroup.co.uk/pdf/wtnoise_health_2007_a_barry.pdf
14. Vainio, M & Paque G (eds.) 2002. Highlights of the workshop on the 'State-of-the-art in noise valuation', Final Report. European Commission-DG Environment, Brussels.
15. Castelo Branco, N. A. A., Alves-Pereira, M., (2004). Vibroacoustic disease. Noise & Health, 6(23), 320.
16. Castelo Branco, N. A. A., (1999). The clinical stages of vibroacoustic disease. Aviation Space Environmental Medicine, 70 (3, Suppl), pA329.
17. Navrud, S 2002, The state-of-the-art on economic valuation of noise, Report to European Commission DG Environment, Norway: Agricultural University.
18. Alves-Pereira, M., and Castelo Branco, N. A. A., (2007). Public Health and noise exposure: the importance of low frequency noise. Proceedings the InterNoise Conference, Istanbul, Turkey, pp3–20.
19. Flindell, I. H., and Stallen, P. J., (1999). Nonacoustical factors in environmental noise. Noise and Health, 3, p11–16.
20. Miedema, H. M., and Vos, H., (1999). Demographic and attitudinal factors that modify annoyance from transportation noise. Journal of Acoustical Society of America, 105(6), pp3336-3344.
21. Miller, J. D., (1974). Effects of noise on people. Journal of the Acoustical Society of America. 56(3), pp729-764.
22. Zimmer, K and Ellermeier, W. (1999). Psychometric Properties of four measures of noise sensitivity. Journal of Environmental Psychology, 19(3), pp295–302.
23. Maris, E., Stallen, P. J., Vermunt, R., and Steensma, H., (2007). Noise within the social context: annoyance reduction through fair procedures. Journal of the Acoustical Society of America, 121(4), pp2000-2010.
24. European Union. (2000). The Noise Policy of the European Union – Year 2. Luxembourg.

25. Nelson, D. A. (2007). Perceived loudness of wind turbine noise in the presence of ambient sound. Presented at the Second International Meeting on Wind Turbine Noise, September 20 –21, Lyon, France.
26. Griffiths, R., and Raw, G. J., (1989). Adaptation to changes in traffic noise exposure. Journal of Sound and Vibration. 132(2), pp331-336.
27. Schomer, P., (2001). A White Paper: Assessment of noise annoyance. Schomer and Associates Inc, Champaign, Illinois.
28. Leventhall, H. G., (2006). 'Infrasound from Wind Turbines – Fact, Fiction or Deception'. Canadian Acoustics, Special issue, 34(2), pp 29–36.
29. Hardoy, M.C., (2005). Exposure to aircraft noise and risk of psychiatric disorders. Social psychiatry and Epidemiology, 40, pp24-26.
30. Berglund, B. and Lindvall, T., (Eds) (1995). Community Noise. Archives of the Center for Sensory Research. 2(1), pp1-195. ISBN 91-887-8402-9.
31. Persson, W., Bengtsson, J., Rylander, R., Hucklebridge, F., Evans, P., and Chow, A., (2002). Low frequency noise enhances cortisol among noise sensitive subjects. Life Sciences, 70, pp745-758.
32. Casella, S., (2001). Low Frequency Noise Update. DEFRA Noise Programme, Department of the Environment, Northern Ireland, Scottish Executive, National Assembly for Wales, pp1–11.
33. van den Berg, G. P., (2004). Do wind turbines produce significant low frequency sound levels? Eleventh Meeting on Low Frequency Noise and Vibration and its Control. August 30–September 1, Maastricht, Holland.
34. Nosulenko, V. N., (1990). Problems of Ecological Psychoacoustics. Proceedings of the Sixth annual meeting of the international society of psychophysics, Wurzburg, Germany, pp135–138.
35. Phipps, R. A, Amati, M., McCoard, S., Fisher R.M., (2007). Visual and Noise Effects Reported by Residents Living Close to Manawatu Wind Farms: Preliminary Survey Results. New Zealand Planners Institute Conference, Palmerston North, 27-30 March 2007
36. World Health Organisation. (2009). Night noise guidelines for Europe. Copenhagen.
37. Devlin, E., (2005). Factors Effecting Public Acceptance of Wind Turbines in Sweden. Wind Engineering. 29(6), p503-511.
38. Belojevic, G., Jakovljevic, B., Aleksic, O., (1997). Subjective reactions to traffic noise with regard to some personality traits. Environ Int 23 (2), pp221–226.
39. World Health Organisation (1997). WHOQOL. Measuring quality of life. Geneva: WHO.
40. Kuwano, S., and Seiichiro, N., (1990). Continuous Judgment of Loudness and Annoyance. Proceedings of the Sixth Annual Meeting of the International Society of Psychophysics, Wurzburg, Germany, pp129–134.
41. Basner, M., (2008). Nocturnal aircraft noise exposure increases objectively assessed daytime sleepiness. Somnologie 12(2), pp110-117.
42. Wind Energy Association. http://www.wwindea.org.
43. Kryter, K. D., (2007). Acoustical, sensory, and psychological research data and procedures for their use in predicting the effects of environmental noises. Journal of the Acoustical Society of America, 122(5), pp2601-2614.
44. Fidell, S., (2003). The Schultz curve 25 years later: a research perspective. Journal of the Acoustical Society of America, 114(6), pp3007-3015.
45. Schick, A., (1990). Proceedings of the Sixth Annual Meeting of the International Society of Psychophysics, Wurzburg, Germany.
46. Bolin, K., (2009). Wind Turbine Noise and Natural Sounds: Masking, Propagation and Modeling. Doctoral dissertation, Kungliga Tekniska Hogskolan, Stockholm.
47. Schütte, M., Markes, A., Wenning, E. & Griefahn, B., (2007). The development of the noise sensitivity questionnaire. Noise & Health. Jan-Mar 2007, 9, pp15–24.
48. Stephens, D. G., Shepherd, K. P., Hubbard, H. H., and Grosveld, F. W., (1982). Guide to the evaluation of human exposure to noise from large wind turbines. NASA Technical Memorandum 83288, Langley Research Centre.
49. Gross, C., (2007). Community perspectives of wind energy in Australia: The application of a justice and community fairness framework to increase social acceptance. Energy Policy. 35, pp2727-2736.
50. Risto, T. (2008). Comparison of electricity generation costs. Research report EN A-56, Kivistö Aija Lappeenranta University of Technology.
51. Maris, E., Stallen, P.J., Vermunt, R., and Steensma, H., (2007). Evaluating noise in the social context: the effect of procedural unfairness on noise annoyance judgements. Journal of the Acoustical Society of America, 122(4), pp3483–3494.

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

53. French Academy of Medicine. (2006). Repercussions of wind turbine operations on human health. Retrieved from:
http://ventdubocage.net/documentsoriginaux/sante/eoliennes.pdf

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

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

56. International Standard ISO 9613–2 :1996E Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation. (1996) International Organization for Standardization, Genève, Switzerland.

57. ETSU, (1996). The Assessment & Rating of Noise from Wind Farms. Final Report, ETSU R97 for the UK Department of Trade and Industry, UK.

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

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

60. Williams H. L., (1970). Auditory stimulation, sleep loss and the EEG stages of sleep. Physiological Effects of Noise, Welch B L & Welch S W. (Eds) Plenum Press.

61. Westman, J. C., and Walters, J. R., (1981). Noise and stress: A comprehensive approach. Environmental Health Perspectives, 41, pp291–309.

62. Ingard, U., (1953). A review of the influence of meteorological conditions on sound propagation. JASA. 25 pp405-411.

63. Bolt, Beranek and Newman, (1970). Source and control of ground vehicle noise. Report 2058.

64. Schlichting H. S., (1979). Boundary Layer Theory McGraw Hill, New York.

65. Hubbard, H. H., Shepherd, K. P., (1991). Aeroacoustics of large wind turbines. J Acoust. Soc. Am., 89(6), June 1991.

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

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

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

69. Hayes McKenzie Partnership Ltd, (2006). The measurement of low frequency noise at three UK wind farms. Report to DTI, URN number 06/1412. Retrieved from:
http://www.berr.gov.uk/energy/sources/renewables/explained/wind/onshore-offshore/page31267.html

70. van den Berg, G. P., (2006). The sounds of high winds - the effect of atmospheric stability on wind turbine sound and microphone noise. Science Shop for Physics, Netherlands.

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

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

73. Alves-Pereira, M., and Castelo Branco, N. A. A., (2007). In-home wind turbine noise is conducive to vibroacoustic disease. Second International Meeting on Wind Turbine Noise, Lyon, France.

74. Van Gerven, P. W. M., Vos, H., Boxtel, M. P. J., Janssen, S. A., and Miedema, H. M. E., (2009). Annoyance from environmental noise across the lifespan. Journal of the Acoustical Society of America, 126(1), pp187–194.

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

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

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

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

79. Styles, P., Stimpson, I., Toon, S., England, R. and Wright, M., (2005), Microseismic and Infrasound Monitoring of Low Frequency noise and Vibration from Wind Farms: Recommendations on the Siting of Wind Farms in the Vicinity of Eskdalemuir, Scotland. Report, Keele University, Keele, UK.
80. Styles, P., Toon, S., (2005). Wind Farm Noise, Article, British Wind Energy Association. Retrieved from:
http://www.bwea.com/ref/lfn_keele.html.
81. EnerNex Corporation. (2010). Eastern Wind Integration and Transmission Study. National Renewable Energy Laboratory, US Department of Energy. Retrieved from:
http://www.nrel.gov/wind/systemsintegration/ewits.html
82. Vestas. (2008). V90 - 3.0MW An efficient way to more power. Product Brochure, Vestas Wind Systems A/S, Randers, Denmark
83. Shepherd, I., (2010) Wake Induced Turbine Noise (Draft). Personal Communication.
84. Wußow, S., Sitzki, L., Hahm, T., (2007). 3D-simulation of the Turbulent Wake Behind a Wind Turbine. Journal of Physics: Conference Series 75 012033, pp1–8.
85. Bakker, H. H. C., Bennett, D. J., Rapley, B. and Thorne R., (2009). Seismic Effect on Residents from 3 MW Wind Turbines, Third International Meeting on Wind Turbine Noise, Aalborg, Denmark.
86. IEC, (2002). IEC61672-1:2002, Electroacoustics – sound level meters – Part 1 Specifications. International Electrotechnical Commission. Geneva, Switzerland.
87. Thorne, R., (2008). Assessing intrusive noise and low amplitude sound. Doctoral thesis, Massey University, Palmerston North, New Zealand.
88. Yost, W. A., (2000). Fundamentals of Hearing, 4th ed. Academic Press. California.
89. Fletcher, H., (1940). Auditory Patterns. Reviews of Modern Physics, 12, pp47–65.
90. Zwicker, E., & Fastl, H., (1999). Psycho-acoustics facts and models, 2nd ed. Springer-Verlag Berlin Heidelberg, Berlin.
91. Bolt, Beranek and Newman (1982) Graphic Method for Predicting Audibility of Noise Sources, US Flight Dynamics Laboratory Air Force Systems Command, publication AFWAL–TR–82–3086
92. International Standards Organization, (2003). ISO 226, Acoustics-Normal equal loudness contours. International Standards Organization.
93. Kamperman, G. and James, R. R., (2008). Simple guidelines for siting wind turbines to prevent health risks. INCE NOISE_CON 2008, pp.1122-1128.
94. DZ6808:2009 Review submissions, (2009), 283 pages; released under the Official Information Act.
95. Stigwood, M., (2008). Evidence to the Public Enquiry into the proposed North Dover Wind Park. PINS Ref: APP/X2220/A/08/2071880/NWF.
96. Leventhall, H.G., (2009). Wind Turbine Syndrome - An appraisal. Testimony before the Public Service Commission of Wisconsin, PSC Ref#121877 20 October 2009
97. Environment Court Decision W5/94: Cox v Kapiti Coast District Council.
98. Environment Court Decision W031/2007 Meridian Energy (et al.) vs Wellington City Council (et al.)
99. Environment Court Decision W59/2007 Meridian Energy West Wind decision
100. Hayes, M. D., (2007), Affidavit-in-Reply to the Environment Court New Zealand, West Wind Proceedings, Decision W59/2007, Clause 34.
101. Standfeld, S. A., (1992). Noise, noise sensitivity, and psychiatric disorders: epidemiological and psychophysiological studies. Psychological Medicine, 22, pp1–44.
102. International Electrotechnical Commission, (2002). IEC 61400-11, 2nd edition, Wind turbine generator systems - Part 11: Acoustic noise measurement techniques. International Electrotechnical Commission.
103. International Standards Organization, (2007). ISO 1996-2 second edition, Acoustics - description, assessment and measurement of environmental noise - part 2: Determination of environmental noise levels. International Standards Organization.
104. American National Standard, (1973). ANSI S3.20, Psychoacoustical Terminology. Standards Secretariat Acoustical Society of America, New York.
105. Vassilakis, P. N., (2001). Perceptual and physical properties of amplitude fluctuation and their musical significance. PhD thesis, University of California
106. Vasudevan, R. N., and Gordon, C. G., (1977). Experimental study of annoyance due to low frequency environmental noise. Applied Acoustics 10, pp57–69.
107. Australian Standard AS/NZS 2107:2000, Acoustics-Recommended design sound levels and reverberation times for building interiors, Sydney: Standards Australia International Ltd.
108. Wild T., (2008). Attitudes to Wind Farms: the Dynamics of Submitters Opinions. Masters Thesis, University of Otago, Dunedin, New Zealand.

109. Graham, J. B., Stephenson, J. R. and Smith I. J., (2008). Public perceptions of wind energy developments: case studies from New Zealand. Report, University of Otago, Dunedin, New Zealand.

110. Collocott, T. C., Dobson, A. B., (1975). Chambers Dictionary of Science and Technology. Bowker British Library Kickout, UK. ISBN 0-550-18018-4.

111. Parker, S., (1985). McGraw Hill Dictionary of Physics. McGraw Hill, Blacklick, Ohio. ISBN 0-07-045418-3.

112. Harris, C., (1998). Handbook of Acoustical Measurements and Noise Control. American Institute of Physics. Melville, New York. ISBN 1-56396-774-X.

113. Beranek, L. L., (1988). Acoustical Measurements. Acoustical Society of America. Massachusetts.

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

115. British Standard BS6472:1992, (1992). Guide to Evaluation of Human Exposure to Vibration in Buildings (1Hz to 80Hz). British Standards Institution.

116. Assessing vibration: a technical guideline, (2006). Department of Environment and Conservation, New South Wales, Australia.

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

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

119. Clark, G. H., (2007). Meteorological aspects of noise propagation in the atmosphere – application to the Taralga wind-farm. Evidence to the Taralga wind farm modification hearing, reference NSW Land & Environment Court Proc 11216 of 2007.

120. Tonin, R., (2009), Winchelsea Wind farm P2395/2008 and P2654/2008 Joint Report of Acoustic Experts, 26 February 2009, quoted with the permission of Dr Tonin.

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

122. James, R. R., (2008). Statement of Evidence of Richard Russell James at Resource Consent Hearing, Wellington, New Zealand, 2 September 2008.

123. World Health Organisation, (2009). Fact Sheet No. 999, January 2009.

124. Epilepsy Action Australia, (2008). Understanding Epilepsy. Retrieved from: http://www.epilepsy.org.au/understanding_epilepsy.asp.

125. Harding, G. F. A., Jeavons, P. M., (1994). Photosensitive Epilepsy. MacKeith Press, London.

126. Fish, D. R., Quirk, J. A., Smith, S. J. M., Sander, J. W. A. S., Shorvon, S. D., Allen, P. J., (1993). National survey of photosensitivity and seizures included by electronic screen games (video games, console games, computer games). Interim findings, Department of Trade and Industry, London.

127. Harding, G. F. A., Edson, A., Jeavons, P. M., (1997). Persistence of photosensitivity. Epilepsia, 38, pp663-669.

128. Gastaut, H., Tassinari, C. A., (1966). Triggering mechanisms of epilepsy. The electroclinical point of view, 7, pp85-138.

129. Cushman, J. T., Floccare, D. J., (2007). Flicker illness: an under recognised but preventable complication of helicopter transport. Pre hospital Emergency Care, 11(1), pp85-88.

130. Harding, G., Harding, P., Wilkins, A., (2008). Wind turbines, flicker, an photosensitive epilepsy: Characterising the flashing that may precipitate seizures and optimising guidelines to prevent them. Epilepsia, 49(6), pp1095-1098

131. Binnie, C. D., Emmett, J., Gardiner, P., Harding, G. F. A., Harrison, D, Wilkins, A. J., (2002). Characterising the flashing television images that precipitate seizures. SMPTE Journal, July/August, pp323-329.

132. Clark, A. D., (1991). A case of shadow flicker/flashing assessment and solution. Techno Policy Group, Open University, Walton Hall, Milton Keynes.

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

134. Glaze, A. L., Ellis, J. M., (2003). Pilot Study of distracted drivers. Report, Transportation and Safety Training Centre, Centre for Public Policy, Virginia Commonwealth University, Virginia, USA.

135. Barregard, L., Bonde, E., and Ohrstrom, E., (2009). Risk of hypertension from exposure to road traffic noise in a population based sample. Occup. Environ. Med. 66, pp410-415.

136. Basner, M., Glatz, C., Griefahn, B., Penzel, T., Samel, A., (2008). Aircraft noise: Effects on macro- and microstructure of sleep. Sleep Medicine, 9 (4), pp382-387.

137. Belojevic, G., et al. (2008). Urban road traffic noise and blood pressure and heart rate in preschool children. Environment International. 34, pp226-231.

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

139. Bowdler, D., (2008). Amplitude modulation of Wind Turbine Noise. A Review of the Evidence. Acoustics Bulletin, 33(4). Retrieved from: http://www.ioa.org.uk/uploads/publication-documents/Acoustics%20Bulletin%20Vol33No4.pdf.pdf

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

141. Bruck, D., Thomas, I., and Rouillard, V., (2009). How does the pitch and pattern of a signal affect auditory arousal thresholds? Journal of Sleep Research, 18 (2). pp196–203. ISSN 0962-1105

142. Butré J-L. (2005). French St. Crepin windplant noise survey results (2005), cited as a personal communication from J-L Butre, Ventducobage, 11-5-05 in Pierpont N. 2006[13].

143. Carter, S., Williams, S., Paterson, J., and Lusitini, L., (2009). Do perceptions of neighbourhood problems contribute to maternal health?: Findings from the Pacific Islands Families study. Health and Place. 15, pp622–630.

144. Cui, B., Wu, M., & She, X. (2009). Effects of Chronic Noise on Spatial Learning and memory of rats. Journal of Occupational Health. 51, pp152-158.

145. Dratva, J., (2010). Impact of road traffic noise annoyance on health-related quality of life: results from a population-based study. Quality of Life Research. 19, pp37–46.

146. Fields, J. M., (1993). Effect of Personal and Situational Variables on Noise Annoyance in Residential Areas. Journal of the Acoustical Society of America. 93, pp2753–2763.

147. Griefahn, B., et al., (2008). Autonomic arousals related to traffic noise during sleep. Sleep. 31, pp569-577.

148. Haralabidis, A. S., et al., (2009). Acute effects of night-time noise exposure on blood pressure in populations living near airports. European Heart Journal. March 2008, 29, pp658–664.

149. Berglund, B., and Lindvall, T., (1990). Public health implications of environmental noise. Environment International, 16(46), p,313-601.

150. Heinonen-Guzejev, M., Heikki, S., Vuorinen, Mussalo-Rauhamaa, H., Heikkilä, K., Koskenvuo, M., and Kaprio, J., (2005). Genetic Component of Noise Sensitivity, Twin Research and Human Genetics. 8, pp245–249.

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

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

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

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

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

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

157. Nissenbaum, M. A., (2010). Industrial Wind Turbines and Health Effects in Mars Hill, Maine. A Retrospective Controlled Study – Preliminary Findings as of November, 2009. Personal Communication.

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

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

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

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

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

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

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

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

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

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

168. Saremi, M., et al., (2008). Sleep related arousals caused by different types of train. Journal of Sleep Research .17, Supplement 1, p394.

169. Bergman, A., (1990). Auditory Scene Analysis. MIT Press, Cambridge MA.

170. Alain, C., Arnott, S. R., Hevenor, Graham, S., and Grady, C. L., (2001). 'What' and 'where' in the human auditory system. PNAS, 19(21), pp12301–12306.

171. Berry, B. F. and and Flindell, I. H., (1998). Noise effects research: The importance of estimating noise exposure properly. Proceedings of Noise Effects '98, November 22-26, Sydney, pp627–630.

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

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

174. World Health Organization, (1946). Am J Public Health Nations Health. November 36(11), pp1315–1323.

175. World Health Organization, (2003). Investing in Mental Health. World Health Organization. Geneva. Retrieved from:
http://www.who.int/mental_health/en/investing_in_mnh_final.pdf

176. World Health Organisation, (2008). World health report 2008 - Primary Health Care: Now more than ever. World Health Organization. Geneva. Retrieved from:
http://www.who.int/whr/2008/whr08_en.pdf

177. World Health Organisation, (2007). Report on the first planning meeting on night noise guidelines. World Health Organization. Geneva. Retrieved from:
http://www.euro.who.int/Document/NOH/1st_NNGL.pdf

178. van den Berg, G. P., (2005). The beat is getting stronger: The effect of atmospheric stability on low frequency modulated sound by wind turbines. Journal of Low Frequency Noise, Vibration and Active Control. 24(1), pp1–24.

179. Phillips,C.V., (2010). An analysis of the epidemiology and related evidence on the health effects of wind turbines on local residents. Evidence before the Public Service Commission of Wisconsin. PSC Ref#: 134274. Retrieved from: http://www.windaction.org/documents/28175. Dr Phillips can be contacted at: cvphilo@gmail.com

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

181. Salt, A.C & Hullar, T.E., (2010) Response of the ear to low frequency sounds, infrasound and wind turbines. Access from http://oto.wustl.edu/cochlea/

182. Colby, W.D., et al. (2009) Wind turbine sound and health effects; an expert panel review. Prepared for the American Wind Energy Association and Canadian Wind Energy Association.

183. Horner, B. et al. (2010) An analysis of the American/Canadian Wind Energy Association sponsored "Wind turbine sound and health effects An expert panel review, December 2009. Prepared for the Society for Wind Vigilance. Retrieved from www.windvigilence.com

184. Bakker, H. & Rapley, B. editors. (2010) Sound, noise, flicker and the human perception of wind farm activity. Turitea wind farm proposal evidential text available from www.atkinsonrapley.co.nz