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TOORA WIND FARM

REVIEW OF THE ENVIRONMENTAL NOISE MONITORING PROGRAM

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INTRODUCTION

Graeme E Harding & Associates has been retained by the South Gippsland Shire to prepare a review of the environmental noise monitoring program of the Toora Wind Farm.

THE BRIEF

- Study documents in regard to Toora WTGs, including permit condition, documents to Council on background noise monitoring and WTG monitoring.
- Prepare review on monitoring procedures, including matters as discussed earlier.
- Prepare advice regarding the whole monitoring program. Legal implications which would need to be referred to a solicitor.

DOCUMENTATION

A list of the documents studied is included in Appendix A. A list of references is included in Appendix B.

SITE DESCRIPTION

Toora Wind Farm is operated by Stanwell Corporation Limited, and is located in the Silcocks Hill area along Silcocks Hill Road.

There are 12 turbines. The towers are nominally 70m high, with rotor blades about 35m in length. The total installed capacity is about 22 megawatts.

Map A1-P-816006-01 titled “Toora Windfarm Development” prepared by Stanwell Corporation Limited, shows the location of turbines and noise logger locations.

WIND TURBINE NOISE

Wind turbines generate electrical power by the extraction of power from wind.

At low wind speeds no power is generated. The “cut in” wind speed is the minimum speed that turbines can generate power. Above this speed the amount of electrical power that can be generated increases rapidly. There is also a maximum wind speed at which wind turbines can operate safely.

The noise level of wind turbines increases with wind speed. At relatively low wind speeds above “cut in” the noise level increases fairly rapidly with increasing wind speed. As the wind speed increases further, the noise level increase is small. The actual noise level versus speed curve depends on the type of turbine.

Noise measurements made near to a wind turbine can be made with good accuracy and repeatability, and are used for noise certification purposes. Wind turbines are typically measured for noise level under International Standard IEC61400-11 (Reference 1).

Under this standard, noise levels of the wind turbine are measured at allowed location and the noise is measured for a range of wind speeds, referenced to a height of 10m.

The standard also specifies a method to calculate the sound power level of the turbine for each wind speed. The sound power level is the acoustic power, in watts as measured in decibels, radiated from the wind turbine. A simple analogy would be a 1 bar radiator radiates 1000 watts of heat, but the radiant temperature (analogous to the sound pressure level) depends on how close or how far you are from the radiator. Wind turbines generally have sound power levels between 95 and 110dB(A).

Mechanical sources include gearbox tooth mesh frequencies, generator noise, cooling fan noise, hydraulic noises, etc.

Aerodynamic noises include self noise due to the interaction of the turbulent boundary layer with the blade trailing edge, noise due to inflow turbulence (turbulence in the wind interacting with the blades), discrete frequency noise due to trailing edge thickness, discrete frequency noise due to laminar boundary layer instabilities (unstable flow close to the surface of the blade), and noise generated by the rotor tips.

A major British report on wind turbines (Reference 2) states that residents who live near wind turbines speak of swishing, whooshing, chomping and thumping noises (p.11). Near to the turbine the (A)-weighted noise level modulates by 2-3dB(A) for typical turbine conditions (p.12). This modulation is greater if measurements are made in 1/3 octaves (this can provide a closer representation of how the ear hears). Close to the turbine the swishing sound occurs in the 800-1000Hz region.

Modern wind turbines have the blades in a vertical plane and rotate on a horizontal axis. The blades are upwind of the tower and are constantly controlled to face into the wind. Some large research units built in America (2 - 4.2MW) prior to 1991 had rotors downward of the towers. Complaints from these turbines occurred for distances up to 2km, and these were about perceived vibration (Reference 3). These studies showed that these turbines produced significant amounts of low frequency energy capable of causing window vibration, wall vibration and also low frequency noise within dwellings. The study also showed that very low frequency noise in the range of 8 to 16Hz reduced in level by only 3dB per doubling of distance. This is unlike the normal frequencies of hearing where reductions of 6dB per doubling of distance are the norm.

However the indications are that turbines with upwind rotors do not have this environmental problem to the same degree, and do not produce low frequency noise under clean airflow conditions.

PROPAGATION EFFECTS

To separate the variation in noise generated by a wind turbine with variations according to wind speed and direction, consider a steady noise source. Then propagation effects to note are (Reference 4):

Upwind propagation

The noise is lower than for no wind; and in the shadow zone can be totally absent and inaudible.

Downwind propagation

The noise is enhanced compared to the no wind situation. The noise can vary significantly from moment to moment and time to time.

Temperature Inversion

In a region at a distance from the sound source the noise is strongly enhanced, closer in there may even be a zone of silence. Temperature inversions occur under stable atmospheric conditions often on clear evenings or nights.

Shielding or Barrier Effects

Hills or ridges between the source and receiver will reduce the received noise; but under temperature inversion effects or down wind propagation the sound passes over the hill and the barrier affect is reduced or nullified.

Ground Absorption

When a rise in the ground between the source and receiver is close to line of sight the noise will be reduced by ground absorption; the ground absorption can vary seasonally.

Air Absorption

High frequency sound is rapidly absorbed by air, particularly in the range of 2 to 4kHz.

PLANNING PERMIT CONDITIONS

The South Gippsland Shire Council issued Planning Permit No. 2000/125 under the South Gippsland Planning Scheme to Stanwell Corporation Limited for the use and development of land to a Wind Energy Facility.

The permit allows for the use based upon endorsed plans and conditions.

The conditions which are relevant to noise issues are as follows:

12. The operations of the wind farm must comply with the New Zealand Standard "Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators" (NZ 6808:1998) (the "New Zealand Standard").

13. Prior to the commissioning of any turbine, details of a noise complaint and evaluation process must be submitted to and approved by the Responsible Authority to address any breaches of the New Zealand Standard. This evaluation process should include, but not be limited to the following components:

    a. A noise complaint telephone hotline, enabling twenty four (24) hour contact with a designated response officer (not to be a recorded message).
    b. Details of validity requirements for noise complaint (ie: date, time, noise description, and weather conditions at receptor).
    c. Response protocol to valid noise complaints.
    d. Register of noise complaints, responses and rectification which may be inspected by the Responsible Authority.

14. A pre-construction noise monitoring program must be undertaken by the Permit Applicant to the satisfaction of the Responsible Authority as follows:
    a. A pre-construction monitoring program must be conducted before the start of construction of the wind farm for a period of 28 continuous days.
    b. Measurements must be taken in accordance with the New Zealand Standard and Condition 17.
    c. The results of the pre-construction monitoring program must be forwarded to the Responsible Authority prior to the start of the construction of the Wind farm.

15. An initial post-construction noise monitoring program must be undertaken by the Permit Applicant to the satisfaction of the Responsible Authority as follows:
    a. Post-construction monitoring must commence two months from the commissioning of the first turbine and continue for a minimum of 12 months after the commissioning of the last turbine.
    b. Measurements must be taken in accordance with the New Zealand Standard and Condition 17.
    c. The results of the monitoring program of the preceding month must be forwarded to the Responsible Authority within 30 days of the end of each month. The Responsible Authority must make the results available to members of the public upon request.

16. A follow-up noise monitoring program must be undertaken by the Permit Applicant to the satisfaction of the Responsible Authority as follows:
    a. Follow-up noise monitoring must take place every 6 months for a period of 7 continuous days; it must commence 6 months after the end of the initial noise–monitoring period in Condition 15 and must take place for a minimum of 2 years.
    b. Measurements must be taken in accordance with the New Zealand Standard and Condition 17.
    c. The results of each 7-day monitoring period must be forwarded to the Responsible Authority within 30 days of the end of that period. The Responsible Authority must make the results available to members of the public upon request.

17. The monitoring programs specified in Conditions 14016 must be undertaken by the Permit Applicant at the following locations:
    a. The existing dwellings located on Volume 9620 Folio 378 and Volume 9629 Folio 790.
    b. A site approximately 400 metres west of Turbine 6 as identified on Plan A1-P-816001-02.
    c. Any other sites as required by the Responsible Authority.

THE NEW ZEALAND STANDARD

The New Zealand Standard NZS 6808:1998, Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators was specifically developed for the measurement of the noise from wind turbines in the presence of wind (Reference 5).

For most industrial sounds, noise measurements are made under calm conditions, The background noise under these conditions is usually due to distant traffic, distant industry, or in the case of measurements made in the country, distant insect and birds.

The acceptable level of noise from industry is often based on background noise levels, particularly when the background noise levels are high (or low). For example, State Environment Protection Policy "Control of Noise from Commerce, Industry and Trade" No. N-1, bases the noise limit on the background level when this is high; usually due to traffic, or unusually low.

Wind turbines, on the other hand, operate when the wind is high. At low wind speeds no power is generated. The "cut-in" wind speed is the minimum wind speed that power can be generated and above this the noise from the wind turbine increases with wind speed. At a wind speed of about 8 m/s measured at 10 m height, the noise from modern wind turbines is normally near the maximum, with only a smaller increase with increasing speed.

On the other hand, the background noise in the country when the wind is blowing is mainly due to foliage noise. Even at fairly low wind speeds, foliage noise can be significant and the level of foliage noise will increase with increasing wind speed.

Because the noise from modern wind turbines increases rapidly with increasing wind speed then increases slowly, while the background noise due to foliage noise is relatively low at low wind speed; then continues to increase; the noise from wind turbines is most prominent at wind speeds of about 8m/s. (Appendix D, page 2)

Further, the likelihood of annoyance at any time depends on the noise level and character of the wind turbine, and the background level at the time. The difference between the level of noise from the turbines and the background noise level is a significant measure of the audibility of the turbines. Residents will be most annoyed when the background noise level is lowest, and the turbine noise levels are highest.

It can be shown that the background level does vary with wind direction (See Appendix C), and it can also be shown that the background level due to foliage noise can depend on time of day (References 6 and 7 and Appendix C) for a particular wind speed.

The importance of investigating the effects of wind direction and time of day on the background levels is noted under 4.5.5 of NZS. Clearly, where it is suspected that background levels may be dependent on wind direction and time of day, this is investigated in the determination of the background levels, and hence the setting of acceptable limits.

Now, under the Standard:

1. Background sound levels are to be measured as L_{95} levels at the residential property using a data logger. The L_{95} level is the A-weighted sound level that is exceeded for 95% of the time. In practice the L_{95} level can be thought of the average of the minimum pointer deflections of the sound level meter. The noise measurements are to be made over 10 minute periods and are measured concurrently with the wind speed and direction taken within the wind farm site (measured preferably at the hub height of the wind turbine). The Standard states that 10 to 14 days of monitoring will be required to obtain sufficient data for wind speeds between 5 and 8 m/s. (4.5.1. and 4.5.3.). It is assumed if point 4.5.5 applies, then more measurements may be required.

   4.5.5 of the Standard states that it may be necessary to correlate background sound levels with wind speed for different wind directions and/or time of day. The standard does not state why this should be done. Best practice indicates that this approach should possibly be adopted for all cases, except where it can be shown otherwise.

2. As a guide to the level of acceptability under the Standard, the sound level from the wind turbine(s) for any wind speed should not exceed the average background sound level (L_{95}) by more than 5dB(A) or 40dB(A), whichever is the greater (4.4.2).

3. For post installation compliance level testing, measurements where practical shall be made at the same locations, consistent with the measurement of background sound levels (5.2.1.).

4. An assessment of special audible characteristics should be undertaken, and if present, a +5dB(A) penalty shall be applied to the measured level (5.2.3. and 5.3.2.).

BACKGROUND SOUND LEVELS MEASURED AT TOORA

As noted in the previous section, acceptable limits for windfarms when assessed under NZS 6808 are based on:

- the average background sound level (L_{95}) + 5dBA for any given windspeed, or
- 40dB(A)

whichever is the greater,

The accurate and repeatable assessment of the background sound level is pivotal, as the acceptable limits are based on the background sound levels.

Toora Wind Farm Noise Modelling

Background sound measurements were carried out by Pacific Air and Environment for the Stanwell Corporation and contained in the report "Toora Wind Farm Noise Modelling, Toora, Vic", May 2000, Job. No. 1071, Version 1.1. The background level measurements were made at 2 locations over a period of 8 days.

The report states that:

> "Both sites were selected to be representative of the location of the dwellings in the area as well as being relatively close to a fixed anemometer to enable correlations to be made between wind speed and noise level.
>
> Site one was located adjacent to the road on a property owned by Stanwell. This site had some protection from the surrounding hills, although it was not in a valley and therefore was still exposed to direct wind. It also had some trees that were approximately 100 metres distant.
>
> Site two was located at a point approximately 150 metres to the east of Mr and Mrs Piontek's house, adjacent to the stockyard. This site was exposed to wind from a number of directions and was not influenced by the direct effect of wind in any trees.
>
> The two sites would be unlikely to be exposed to the noise of wind in particular trees, but both would have had some influence from wind in distant trees. These levels would therefore be expected to be representative of most locations around the proposed wind farm. However, particular sites located very close to trees may, on some occasions, experience higher noise levels during times of significant wind due to the noise of wind in the trees or lower noise levels when the trees screen the wind.
>
> Despite both sites being representative of the region, we will use the lowest background noise levels (Site 2) to err on the side of caution"

The results of the background monitoring were given on page 5 of the report as shown in the following table. Note that at the time of the Pacific Air and Environment Report it was thought that limits may be based on the procedures given in Policy No. N-1 (Reference 8), and not the procedures in NZS 6808. Consequently, in accordance with the procedures of the Policy, background levels were divided into Day (7 am to 6 pm), Evening (6 pm to 10 pm) and Night (10 pm to 7 am).

The results of this analysis, as given in the Report, are shown below:

Table 1: Background Noise Levels (Site 2), dB(A)

Wind Speed m/s	4 m/s	6 m/s	8 m/s	10 m/s	12 m/s
Day	40.5	42.0	43.5	45.0	46.5
Evening	35.0	37.7	40.4	43.0	45.8
Night	33.2	36.5	39.9	43.2	46.5

It is not clear from the Pacific Air and Environmental Report whether 1 hourly L_{90} data were used, as required by Policy No. N-1, or whether 10 minute L_{95} data were used, as required by NZS 6808. It is also noted that 8 days of data is a very small sample.

In any case, the following important conclusions can be drawn.

Table 1 shows that for low wind speeds, in particular, the background sound level for the Night period was significantly lower than the background level during the Day period. For 6m/s for example, the background level during the Night was (42.0 – 36.5) = 5.5dB(A) quieter. Clearly, these results show that background sound levels were <u>not</u> just dependent on wind speed, but are also dependent on the time of day.

<u>Pre-Construction Background Sound Monitoring</u>

Results of pre-construction background sound monitoring were initially contained in Report A4-P-816014-01-A, 12 October 2001. Monitoring was carried out on 3 sites L1, L2 and L3.

Additional background sound monitoring was carried out at Site L4 and Report A4-P-816014-01-B 8 February 2002 contains data for all four sites: L1, L2, L3 and L4. The attached table is extracted from the report and shows the dates of the background monitoring, etc.

"Figure 1 Noise Monitoring Location

Site	**Monitoring Period**	**Total Days**
L1	25/07/01 – 04/08/01 and 30/08/01 – 17/09/01	30
L2	25/07/01 – 04/08/01 and 30/08/01 – 17/09/01	30
L3	25/07/01 – 29/08/01	35
L4	18/12/01 - 31/01/02	44

The loss of a windshield from the logger at site L1 and the malfunction of the logger at site L2 resulted in data being unusable at these sites from 4/8/01 until 29/8/01."

The measurements of wind speeds were made at 10m height. NZS 6808 requires that wind speeds should be monitored "preferably at the WTG hub height" (4.5.6, Note). While this is acceptable for measuring backgrounds, measurements of wind speed at 10 m height can cause problems post installation compliance testing (Reference 6). Further the standard requires compliance testing with "anemometer consistent with the background measurements". Measuring of 10m height is considered appropriate, even though it does not conform with the NZS 6808 recommendation.

The results of the background levels, based on the given regression curves are given below:

Background Noise L_{90} dB(A)	Wind Speed (m/s)									
	2	4	6	8	10	12	14	16	18	20
Site L1	23.5	26.7	29.9	33.1	36.3	39.6	42.8	46.0	49.2	52.4
Site L2	26.7	30.7	34.7	38.7	42.7	46.7	50.7	54.7	58.7	62.7
Site L3	29.8	32.4	35.1	37.7	40.3	42.9	45.6	48.2	50.8	53.5
Site L4	26.2	30.8	35.3	39.9	44.5	49.1	53.6	58.2	62.8	67.4

Note that assessments were made using the L_{90} index, while NZS 6808 requires that the L_{95} index to be used. This is a significant technical oversight, and has the effect of resulting in slightly higher background levels, and consequently, slightly higher acceptable limits. However this error was rectified later in Report A4-P-816014-3.

Pre-operation background sound monitoring

Results of pre-operation background sound monitoring were initially reported in A4-P-816014-02 dated 18 September 2002.

The purpose of this monitoring was to establish the background sound levels just prior to operations.

The four background sound monitoring locations and the anemometer location were the same as those utilised in the 2001 assessment. The following table is extracted from the report and shows the dates of the background monitoring:

Site	**Monitoring Period**	**Total Days**
L1	29/07/2002 – 19/08/2002	22
L2	29/07/2002 – 19/08/2002	22
L3	29/07/2002 – 19/08/2002	22
L4	29/07/2002 – 19/08/2002	22

Stanwell Corporation Limited decided to analyse the data in a different manner than previously.

The procedure adapted was to delete background data from the analysis for wind speeds less than the wind speed that turbines would operate. The report stated:

> "Note: the analysis of pre-construction background levels utilised data across the full range of monitored wind-speeds. Subsequent to that assessment discussions between SCL staff and experts in this area (including members of the recently formed Standards Australia Committee EV016 – Wind Turbine Noise) have indicated that it is appropriate to use data for wind speeds between turbine cut-in and rated windspeed. This approach has been utilised for the current assessment."

The results of the background levels, based on the regression curves, are given below.

July/August 2002

Pre-Operation Background Noise L_{90} (dB(A))	Wind Speed (m/s)					
	4	6	8	10	12	14
Site L1	30	33	37	42	46	51
Site L2	33	40	46	50	55	58
Site L3	34	37	40	44	47	51
Site L4	34	41	47	53	57	60

The results of the previous background measurements from the pre-construction noise report were also included in this report and these are given below.

July/August 2001 (L1, L2, L3) and December/January 2001/2 (L4)

Pre-Construction Background Noise L_{90} (dB(A))	Wind Speed (m/s)					
	4	6	8	10	12	14
Site L1	27	30	33	36	40	43
Site L2	31	35	39	43	47	51
Site L3	32	35	38	40	43	46
Site L4	31	35	40	45	49	54

Stanwell Corporation Limited determined that the "background levels" measured in July/August 2002 were higher than those recorded during the earlier assessment.

Further comments were "The level of increase is highest at high windspeeds. As identified in references (5) & (6) and recognised by acoustic practitioners, the background noise at a specific location may vary over time. This may be due to seasonal changes, environmental changes (including vegetation) and climatic conditions. The Draft SA Windfarm Environmental Noise Guidelines identifies the importance of verifying that background noise levels have not changed from the period of an initial assessment to the period during which compliance is being assessed. It is important that the 2002 background data, which is representative of current site conditions, is utilised for the purposes of compliance assessment."

The procedure adopted by Stanwell Corporation Limited of deleting data for those speeds less than the wind speeds that turbines do not operate is generally considered appropriate. However, this is only appropriate if the wind speed at 10m height correlates directly with the cut-off speed at hub height, and this is not always true (refer to Reference 6).

Again measurements were made using the L_{90} index, while NZS6808 requires that the L_{95} index is to be used. This was later rectified.

The following table shows the difference in the background sound level data between the pre-operation background noise monitoring and the pre-construction background sound levels.

L_{90} Noise level differences between Pre-operation and Pre-construction Background Measurements, dB(A)

	Wind Speed (m/s)					
	4	6	8	10	12	14
Site L1	3	3	4	6	6	8
Site L2	2	5	7	7	8	7
Site L3	2	2	2	4	4	5
Site L:4	3	6	7	8	8	6

By calculation, the average difference is about 5.1dB(A).

The very large differences in average L_{90} levels particularly for L4 (residential site) indicates the methods used to determine background levels were not repeatable within realistic limits. As the acceptable limits are based on background levels, if the background levels are found to be not repeatable then the noise limits will not be repeatable. It is considered that differences of greater than 2dB are not acceptable.

It is also worth noting that in every case the background level is higher for the second set of measurements. One would expect some differences in data to range from negative values through to positive values, but this has not occurred. This will be discussed further in the next section.

Following the issue of the above report, the Environment Protection Authority (EPA) was also concerned about the large range in noise levels between the pre-construction monitoring and the pre-operation monitoring.

The concerns were succinctly noted in a letter from the EPA dated 02 October 2002 to the South Gippsland Shire Council, and the relevant sections are noted below:

> "The tables on page 10 provide a summary of the different background sound levels measured during the time periods of the initial background monitoring of July/August 2002. The background sound levels between the two monitoring periods vary up to 8dB(A). Although there is reference to this not being unexpected, we are surprised at the level of change. It is unlikely that changes to vegetation would lead to this level of variation particularly given the well established trees at locations L2 and L4. Variations in weather (primarily in wind direction) conditions may influence the result however the data is linked to wind speed therefore one would expect little difference except for changes in wind direction or if the data was heavily influenced by consistent rain. Given the data was collected at the same time of year then one may expect an even closer correlation.
>
> The general shift in background sound levels suggests that there has been a change in the methodology between the two monitoring programs. This may be for example a change in the wind monitoring location between the two monitoring periods. It would be prudent for Stanwell to examine the data and methodology closer to justify the shift in background sound levels. If this shift cannot be attributed to a change in the method, then the data from the first noise monitoring program is as relevant at the pre-construction noise monitoring data. If this is the case then the data should be integrated into the data set for establishing noise limits.
>
> The wind speed is not measured at the hub height as recommended by NZS 6808:1998. The report states that the assessment was carried our in accordance with the standard. It would be useful to provide some discussion about the possible implications this may have on the results.

> The close proximity of L2 and L4 to the cypress trees has influenced the background sound levels. It is questionable if these locations comply with 4.5.2 of NZS 6808:1998. The foot note suggests that "some of the tree induced noise may be considered" for sites surrounded by trees, however this level of tree born noise must not represent the general background sound levels. Because the noise spectra from tree born noise and the turbines is different, it would not be prudent to hinge on a total masking of the turbine noise on tree noise. The close proximity of the monitoring point to the trees may be technically having this effect by monitoring the wind born noise from the trees and setting artificially high noise limits. Further, the risk of relying on these trees influencing the background levels, is that Stanwell does not have control over the trees and in this case the complainant does. If the trees were removed the background sound levels at particularly L4 would change significantly.
>
> The regression coefficient values are generally fairly low, therefore you may consider trying other lines of best fit. By eye some of the regressions appear to be cubic whilst others may be linear."

In a letter to the South Gippsland Shire dated 25 October 2002 Stanwell Corporation Limited provided the following comments on the large variation in noise levels of the two sets of data:

> "SCL has undertaken further analysis of the methodology utilised and noise data collected during the two assessments.
>
> Review of data monitoring procedures and locations has confirmed that there were no identifiable differences between the two assessments and that the monitoring was undertaken in accordance with New Zealand Standard NZS 6808:1998 as per the planning permit requirements.
>
> SCL has analysed the two background data sets using the methodology suggested by Clause 4.5.5 of NZS 6808:1998, i.e. segmenting and separately correlating the data on the basis of wind direction. We have found that a degree of difference in noise levels may be attributed to the difference in the distribution of wind direction between the two assessments.
>
> Additionally, as suggested by EPA, we have undertaken initial analysis utilising the combined background data sets for a single location (L4). While the regression for the entirety of the combined data exhibits a low co-efficient of regression, partitioning and separate correlation of the data within 45 degree wind-direction segments results in markedly higher correlation co-efficients. We are currently pursuing this line of analysis for the remainder of the monitoring locations and will provide further detail of the results to South Gippsland Shire Council and the EPA in the near future.
>
> Further to the EPA's comment that the two sets of "data were collected at the same time of year". We note that this is not the case at Location L4 (which exhibited the greatest difference between data sets). The two monitoring periods were in opposing seasons (summer and winter for the pre-construction and pre-commissioning assessment respectively)."

Revised Background Noise Monitoring Assessment

In the revised report A4-P-816014-03 dated 23 May 2003 Stanwell decided to aggregate both pre-construction and pre-operation data for each site. The results of this analysis were as follows. Note that data is now correctly presented as L_{95} data.

Aggregated background sound levels – Pre-construction and pre-operation data

Background SPL	Wind Speed (m/s) 10m AGL									
	3.5	4	5	6	7	8	9	10	11	12
L1	26.7	26.8	27.8	29.7	32.2	34.9	37.7	40.1	42.2	43.0
L2	29.9	30.8	33.2	36.0	39.0	42.1	45.1	47.9	50.3	52.1
L3	31.4	31.6	32.3	33.7	35.0	37.4	39.6	41.7	43.7	45.4
L4	29.1	30.2	33.0	36.1	39.5	42.9	46.1	48.8	50.8	51.9

* Based upon average of the background sound pressure levels noise levels ($L_{95dB(A),\ 10min}$) as assessed during the pre-construction and pre-operation background noise assessments.

As noted earlier, the previous report showed a very large difference in background levels for the same wind speed between the pre-construction and pre-operation data. In the discussion section of the May 2003 report Stanwell Corporation Limited states:

> "A comparison of the two sets of monitoring results show that background levels in July/August 2002 are higher than those recorded during the earlier assessment. The level of increase is highest at high wind speeds. As identified in section 6.5-6.6 and recognised by acoustic practitioners, the background noise at a specific location may very over time.
>
> This may be due to seasonal changes, environmental changes (including vegetation) and climatic conditions. The Environment Noise Guidelines: Wind farms (SA EPA) identifies the importance of verifying that background noise levels have not changed from the period of an initial assessment to the period during which compliance is being assessed. It is important that the 2002 background data, which is representative of current site conditions, is utilised for the purposes of compliance assessment and hence why limits within this report are based upon both pre-construction and pre-operation monitoring results."

It is considered, however that the differences between the two sets of data are so large, that data should not have been aggregated unless a full investigation of the difference was carried out.

NZS 6808 states that "it may be necessary to correlate background sound levels with wind speed for different wind directions and/or time of day" (4.5.5, last para). This could be a simple explanation for the differences in noise level. Stanwell Corporation Limited carried out some extra investigations which showed a correlation between direction and background levels, but this was not further pursued.

If upon full investigation, the noise levels were correlated with wind direction and/or time of day, then background sound levels for each condition should have been the basis of setting noise limits. As noted earlier in Pacific Air & Environment's report "Toora Wind Farm Noise Modelling – Toora, Vic", the background level was dependant on the time of day.

There are other possible explanations for the large differences in levels. These are given below:

(a) Calibration errors. If the calibrator used to calibrate equipment for the pre-construction monitoring was correct, while the calibrator used for the pre-operation monitoring was in error by –5dB, then the pre-operation monitoring results would be about 5dB high. This, however, seems unlikely as the monitoring equipment noise for the two series of monitoring tests (illustrated by the minimum level the instruments can record on the graphs) are similar.

(b) Noise during the pre-operation phase that did not occur during the pre-construction phase. This could include equipment being used to construct the facility, etc. It is not known if the was the case.

On balance, given the preliminary study carried out by Stanwell Corporation Limited, the large variation in background levels are probably due to wind direction.

Finally, it would appear that robust background sound levels were not established prior to the wind farm operation.

MEASUREMENT OF NOISE FROM WIND TURBINES

As noted earlier, background sound levels are affected by foliage noise, thus the background level is dependent on wind speed.

Wind turbines only operate when there is wind. Consequently any noise measurement of wind turbines will include a contribution of noise due to foliage.

Note that the level of foliage noise is not only dependent on wind speed. The wind speed is usually measured at the wind farm. Thus depending on the geography of the site, and meteorological conditions, the background noise can also be dependent on wind direction and to a lesser extent on wind profile.

Similarly, the noise from a wind turbine is also not just dependent on wind speed. The noise level is also dependent on wind direction and wind speed profile (refer Appendix C).

Under the Permit conditions, noise from the wind turbines is to conform to the New Zealand Standard NZS 6808 at residential premises.

NZS 6808 requirements for the assessment of compliance level testing are summarised as follows:

1. "The section outlines a precise method for the post installation compliance testing from WTGs in the far field, i.e. at distances where the cyclic variations due to blade rotation are no long audible" (5.1.1).

2. "The procedure is based on the method outlined in 4.5 (*Background sound level measurements*) with the exception that the WTGs will now be operational" (5.1.1).

3. "….. measurements shall be taken of the sound level, and in addition, consideration needs to be given as to whether there are any special audible characteristics of the sound which may justify analysis and possible application of a penalty which must be taken into account when determining acceptability" (5.1.2).

4. "Sound from WTGs shall, where practical, be measured at the same locations where the sound levels were determined" (5.2.1).

5. "The method of measurement shall be consistent with the measurement of background sound levels" (5.2.1).

6. "Sound from WTG that has special audible characteristics (clearly audible tones, impulses, or modulation of sound levels) is likely to arouse adverse community response at lower levels than sound without such characteristics. At present, there is no simple objective procedure available to quantify special audible characteristics, and subjective assessment is therefore necessary, supported by objective evidence (e.g. frequency analysis) where appropriate" (5.3.1).

7. "When sound has a special audible characteristic, the measured sound level of the source shall have a 5dB penalty applied. This is because the subjective reaction to a sound containing a special audible characteristic is generally found to be similar to a sound 5dB louder, but without the special audible characteristic. A maximum penalty of 5dB shall be applied by adjustment of the measured sound level by arithmetic addition of +5dB" (5.3.2).

8. "To determine conformance with the limits set out in 4.4.2, a comparison shall be made between the best fit regression line of the background sound levels and the regression curve of the operational wind farm corrected for any special audible characteristics" (5.4).

It is worth noting that the post installation sound compliance testing is to be used in the far field, "i.e. at distances where the cyclic variations due to blade rotation are no longer discernible".

If the blade rotation is discernible then it would seem the correct interpretation of the Standard is that cyclic variations due to blade rotation are a "special audible characteristic", and a penalty is to be applied to the measured level.

The alternative interpretation of the NZS 6808 is that it is not to be used where cyclic variations are discernible.

NOISE LEVELS FROM THE TOORA WIND FARM

A4-P-816122-01 (Preliminary) (monitoring between 09/09/2002 to 17/09/2002)

This report dated 12 December 2002 titled "Assessment of noise from the Toora Wind Farm" provides the results of noise monitoring at the four sites.

The methodology used by Stanwell Corporation Limited was as described below:

> "Data analysis was undertaken in accordance with NZS:6808.
>
> Noise data was plotted versus wind speed for each noise monitoring location. A correlation between wind speed and background noise levels exists for the data from each location. A second order polynomial regression was applied to the data. For the purposes of the regression, only data for the wind speeds between 3.5 m/s (turbine cut-in) and 14 m/s (rated wind speed) has been utilised.
>
> As outlined in NZS 6808, this data is representative of both background and windfarm noise. The data must be "adjusted for background" in order to determine the noise from the windfarm alone. The adjustment for background noise was undertaken in accordance with IEC61400-11 Clause 5.2. As the background noise is between 3 & 6dB(A) below the combined windfarm & background noise. It is appropriate to adjust the combined level by –1.3dB(A) to determine the noise produced by the windfarm.

The curve of windfarm noise versus wind speed is compared with the noise limits which have been previously determined (1)."

The results of the analysis were as follows:

Sound Levels L_{90} (dB(A))	Wind Speed (m/s)					
	4	6	8	10	12	14
Site L1 – wtgs	39	42	44	47	49	52
Site L1 – limit	N/A	N/A	N/A	N/A	N/A	N/A
Site L2 – wtgs	38	41	45	49	55	61
Site L2 – limit	40	45	51	55	60	63
Site L3 – wtgs	35	37	41	45	50	56
Site L3 – limit	40	42	45	49	52	56
Site L4 – wtgs	35	42	47	52	56	59
Site L4 – limit	40	46	52	58	62	65

Stanwell Corporation Limited provides the following comments to these measurements.

"The data assessed in this report is preliminary in nature. The data is from a 9 day monitoring period commencing on 9/9/02, the date at which all twelve of the windfarm turbines became operational. It must be noted that the turbines are still undergoing final "adjustments" and for this reason the results of the current assessment can only be considered as indicative.

Bearing this in mind, this assessment indicates compliance of the windfarm at all monitoring locations and wind speeds."

The results provided in the table are shown as L_{90}. The charts of turbine and background noise level versus wind speed for the various locations are also shown as L_{90} levels. NZS 6808 requires that all measurements are to be made using the L_{95} index. This error was later rectified.

NZS 6808 also states that:

"Sound from WTG that has special audible characteristics (clearly audible tones, impulses, or modulation of sound levels) is likely to arouse adverse community response at lower levels than sound without such characteristics. At present, there is no simple objective procedure available to quantify special audible characteristics, and subjective assessment is therefore necessary, supported by objective evidence (e.g. frequency analysis) where appropriate" (5.3.1).

"When sound has a special audible characteristic, the measured sound level of the source shall have a 5dB penalty applied. This is because the subjective reaction to a sound containing a special audible characteristic is generally found to be similar to a sound 5dB louder, but without the special audible characteristic. A maximum penalty of 5dB shall be applied by adjustment of the measured sound level by arithmetic addition of +5dB" (5.3.2).

Residents living very close to the Toora wind farm complain about the rhythmic noise from the turbines and thus the blade rotation is "clearly discernible". This would appear to be a special characteristic and a penalty should be applied to the measurement level.

Further, under 6.0 Documentation, under 6.4 Compliance level testing, it is stated that:

"In addition to requirements of 5.4 the following shall be documented:

(s) "Assessment of special audible characteristics"

The report has not included an assessment of special characteristics, nor has any statement been made whether special characteristics were audible or not.

If the noise levels from the turbines were say modulated at any residential measurement point due to the rotation of the blades, then this should have been included in the report.

A4-P-816171-01 and A4-P-816172-01 (monitoring between 19/10/2002 and 19/11/2002)

These reports provide the monitoring at the four sites and are titled "Results of the Toora Wind Farm Monitoring Program" and "Assessment of Noise from the Toora Wind Farm" respectively. The reports were dated 12 December 2002.

The relevant residential sites are L3 and L4.

These reports show all graphs and attached logger data as L_{90} levels. NZS 6808 requires measurements to be made using the L_{95} index. This error was later rectified.

No tables are given in the reports of the difference between the measured turbine levels and the background levels for various speeds. However from the graphs it can be concluded that an excess of about 2dB for 6m/s wind speed occurred at site L4.

Stanwell Corporation Limited comments on the exceedences were as follows:

> "It needs to be noted that this assessment can only be utilised to "indicate" compliance. This assessment relies heavily on the assumption that the background noise levels during the assessment period are comparable to those measured previously.
>
> Whilst there is a "technical" exceedence of the limit at L4 at 6m/s, the exceedence is within the error of the measurement methodology. In addition, the results indicate that the noise levels at L4 are likely to be influenced by background levels. Noise modelling predictions of the wind farm indicate that noise levels generated by the wind farm at location L2, L3 and L4 are expected to be comparable. Hence the higher noise levels measured at location L4 in comparison to L2 and L3 are most likely "background-induced".
>
> This conclusion is backed up by comparison of the L4 noise level to those at L1. L1 is located closer to the turbines; hence the windfarm noise at location L4 must be less than at L1.
>
> Bearing the above points in mind, it is reasonable to conclude that the wind farm complies with condition 12 of the planning permit."

Stanwell Corporation Limited considered that the excess noise at L4 at 6m/s wind speed a "technical" exceedence, and the exceedence is "within the error of measurement methodology". NZS 6808 does not provide guidelines as to a breach of limits when some months the emissions exceed the limits, while in other months the levels conform.

Further, Stanwell Corporation Limited states that the higher noise levels are "most likely background induced". As the background sound levels are wind speed dependent, this statement would require noise levels due to foliage noise to have increased. No evidence was given as to why this would occur.

Other possible explanations are:

- the noise from the wind turbines exceeded the sound limit, or
- if the background level was higher, then this may be due to winds blowing in a specific direction during the period, and backgrounds are higher under this wind direction. As noted earlier NZS 6808 states that "It may be necessary to separately correlate background sound levels with wind speed for different directions and/or time of day". This approach may provide higher background levels under winds in this direction, which may remove the exceedence, but this approach was not followed by Stanwell Corporation Limited.

As noted previously, NZS 6808 requires the assessment of special characteristics, such as tones, impulses or modulation of sound levels likely to arouse adverse community response to lower levels than sound without such characteristics.

Stanwell Corporation Limited did not report on the existence or not of any of these special characteristics.

A4-P-816171-01B (monitoring between 19 October 2002 and 19 November 2002)

This report dated 11 May 2003 and titled "Results of Toora Wind Farm Noise Monitoring Program" is a major revision of the previous reports.

The levels are now correctly reported as L_{95} levels, not L_{90} levels.

The report states "Noise emission from the turbines as measured at the nominated monitoring points are not considered tonal and therefore an adjustment for tonality has not been included in the assessment".

The graph of sound pressure level versus wind speed at 10m AGL (m/s) indicates a noise excess at 6m/s at site L4.

No mention of the excess is given in the discussion.

A polynomial description of the (Turbine and Background) sound pressure level versus wind speed is given in Appendix 3, but as the terms have been truncated it was not possible to reproduce the curve from the equation. It was also beyond the scope of the brief to reanalyse the raw data to obtain the correct equation.

However, based upon the excess at site L4 was in the order of 1 or 2dB. Further the source emissions were considered by Stanwell Corporation Limited to be "not tonal". However, no assessment is noted as to whether the "cyclic variations due to blade rotation were no longer discernible". If the noise does have cyclic variations, at residential sites, then it has a special characteristic which should attract a penalty.

A4-P-816172-02 and A4-P-816171-02-B (monitoring between 19/11/2002 and 19/12/2002).

These reports are respectively "Assessment of Noise from the Toora Wind Farm" and the "Results of the Toora Wind Farm Noise Monitoring Program", and dated 15 January 2003 and 11 April 2003.

The results of the sound pressure level versus wind speed in A4-P-816172-02 are based on the L_{90} index which does not conform to NZS 6808. The results in A4-816171-02-B are however given in the L_{95} index.

The Stanwell Corporation report stated "For the period between 19th November and 19th December 2002, the calculated wind farm sound pressure levels are within +0.5dB of the limits for sensitive receptors L3 and L4".

Based on the polynomials given in Appendix 3, the values of (turbine and background) L_{95} level versus wind speed are shown in the following tables, as are L_{95} background levels for the relevant residential sites L3 and L4.

The results of the analysis are given below:

Noise Levels, dB(A)

Site L3										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	32.5	34.3	37.4	39.5	41.0	42.0	42.7	43.3	43.9	44.8
Background, L95	31.4	31.6	32.3	33.7	35.0	37.4	39.6	41.7	43.7	45.4
Turbines alone, L95	25.8	31.1	35.7	38.2	39.8	40.2	39.9	38.2	31.3	N/A
Background+5, or 40, L95	40.0	40.0	40.0	40.0	40.0	42.4	44.6	46.7	48.7	50.4
Excess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N/A
Site L4										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	34.4	36.3	39.7	42.7	45.2	47.3	49.1	50.5	51.6	52.4
Background, L95	29.1	30.2	33.0	36.1	39.5	42.9	46.1	48.8	50.8	51.9
Turbines alone, L95	32.9	35.1	38.7	41.6	43.8	45.4	46.0	45.6	43.8	42.8
Background+5, or 40, L95	40.0	40.0	40.0	41.1	44.5	47.9	51.1	53.8	55.8	56.9
Excess	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0

(Note then in the above table, a simple acoustic power calculation was used to determine the turbines alone level. The results may differ slightly from the methodology used by Stanwell Corporation Limited).

The above shows maximum exceedence of 0.5 dB at Site L4 at 6m/s wind speed.

This is in general agreement with the Stanwell Corporation Limited report.

No comment was made on this report whether any special audible characteristics were present as required under NZS 6808.

A4-P-816171-03 and A4-816171-03-B (monitoring between 19/12/2002 and 19/01/2003)

These reports are titled "Results of Toora Wind Farm Noise Monitoring Program" and dated 5 February 2003 and 11 April 2003. The second report supersedes the first.

The second report states that "for the period between 19th December 2002 and 19th January 2003 the calculated wind farm sound pressure levels are below the limits at the noise sensitive receptors (locations L3 and L4)."

No polynomial equations were given in the report of the turbine sound pressure level versus wind speed curves, thus it is not possible to calculate an accurate difference between the turbine levels and the limit.

Visual assessment of the turbines indicates the wind farm conforms to the noise limit, provided there were no special audible characteristics emitted from the turbines. No assessment was made in the report whether any special audible characteristics were present.

A4-P-816171-04 and A4-P-816171-04-B (monitoring between 19/01/2003 and 19/02/2003

These reports are titled "Results of Toora Wind Farm Noise Monitoring Program" and dated 3 March 2003 and 11 April 2003. The second report supersedes the first.

The second report states that "for the period between 19th January and 19th February 2003, the calculated wind farm sound pressure levels are below the limits at the sensitive receptors (locations L3 and L4)."

No polynomial equations were given in the report of the turbine sound pressure level versus wind speed curves, thus it is not possible to calculate an accurate difference between the turbine levels and the limit. Visual assessment of the curves indicates the wind farm mainly conforms with the noise limit at L3, and just conforms with the noise limit at L4, provided no special audible characteristics were emitted from the turbines.

The report stated the noise was not tonal, however it did not state whether any other special audible characteristics were present, such as cyclic variations.

A4-P-816171-05 (monitoring between 19/02/2003 and 19/03/2003)

This report is titled "Results of Toora Wind Farm Noise Monitoring Program" and is dated 11 April 2003. The report states that "for the period between 19th February and 19th March 2003, the calculated wind farm sound pressure levels are below the limits at sensitive receptor L3. However, for a narrow band of wind speeds and directions, turbine may be audible within the ambient noise spectrum at L4."

Based on the polynomial the values of the (Turbine + Background) L_{95} levels versus wind speed are shown in the following tables, as are the L_{95} background levels for the relevant residential sites L3 and L4.

The results of this analysis are given below:

Noise Levels, dB(A)

Site L3										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	32.1	34.0	36.9	38.9	40.3	41.5	42.8	44.4	46.7	50.0
Background, L95	31.4	31.6	32.3	33.7	35.0	37.4	39.6	41.7	43.7	45.4
Turbines alone, L95	23.8	30.2	35.0	37.3	38.9	39.4	40.0	41.1	43.7	48.2
Background+5, or 40, L95	40.0	40.0	40.0	40.0	40.0	42.4	44.6	46.7	48.7	50.4
Excess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Site L4										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	36.7	38.2	40.8	43.1	45.2	47.0	48.7	50.2	51.6	53.0
Background, L95	29.1	30.2	33.0	36.1	39.5	42.9	46.1	48.8	50.8	51.9
Turbines alone, L95	35.9	37.4	40.0	42.2	43.8	44.9	45.1	44.5	43.8	46.4
Background+5, or 40, L95	40.0	40.0	40.0	41.1	44.5	47.9	51.1	53.8	55.8	56.9
Excess	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0

The above shows a maximum exceedence of 1.1dB at Site 4 at 6m/s wind speed. This is in general agreement with the Stanwell Corporation Limited report.

That report stated the noise was not tonal, however it did not state whether any other special characteristics were present such as cyclic variations.

A4-P-816171-06 (monitoring between 19/03/2003 and 19/04/2003)

The report is titled "Results of Toora Wind Farm Noise Monitoring Program" and is dated 6 May 2003.

The report states that "for the period between 19th March and 19th April 2003 the calculated wind farm sound pressure levels are below the noise limits at the sensitive receptors (Location L3 and L4)."

The polynomial values of the (Turbine + Background) L_{95} levels versus wind speed and the L_{95} levels of background versus wind speed, for the relevant residential sites L3 and L4 are given in the following table. Results of this analysis are given below:

Noise Levels, dB(A)

Site L3										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	31.8	31.9	32.8	34.5	36.7	39.2	41.8	44.3	46.6	48.3
Background, L95	31.4	31.6	32.3	33.7	35.0	37.4	39.6	41.7	43.7	45.4
Turbines alone, L95	21.0	20.0	23.3	26.6	31.7	34.4	37.8	40.9	43.4	45.2
Background+5, or 40, L95	40.0	40.0	40.0	40.0	40.0	42.4	44.6	46.7	48.7	50.4
Excess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Site L4										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	36.2	37.3	39.7	42.1	44.4	46.8	49.0	51.2	53.3	55.3
Background, L95	29.1	30.2	33.0	36.1	39.5	42.9	46.1	48.8	50.8	51.9
Turbines alone, L95	35.2	36.4	38.7	40.8	42.8	44.5	45.9	47.5	49.8	52.7
Background+5, or 40, L95	40.0	40.0	40.0	41.1	44.5	47.9	51.1	53.8	55.8	56.9
Excess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

No exceedence has occurred.

The report states that the noise emissions "are not considered tonal and therefore an adjustment for tonality has not been included in the assessment." However, it did not state whether any other special characteristics were present such as cyclic variations.

A4-P-816171-07 (monitoring between 19/04/2003 and 19/05/2003)

This report is titled "Results of Toora Wind Farm Noise Monitoring Program and is dated 6 June 2003.

The report states "From the graphs in section four for the period between 19th April and 19th May (for locations L3 and L4) it can be seen that the noise sensitive curves are within the limits."

The polynomial values of the (Turbine + Background) L_{95} levels versus wind speed, and the L_{95} levels of background versus wind speed, for the relevant sites L3 and L4, are given on the following table.

Noise levels, dB(A)

Site L3										
-Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	30.6	31.5	33.4	35.4	37.6	39.7	41.8	43.6	45.1	46.2
Background, L95	31.4	31.6	32.3	33.7	35.0	37.4	39.6	41.7	43.7	45.4
Turbines alone, L95	N.A.	N.A.	26.7	30.6	34.1	35.9	37.7	39.1	39.5	38.4
Background+5, or 40, L95	40.0	40.0	40.0	40.0	40.0	42.4	44.6	46.7	48.7	50.4
Excess	N.A.	N.A.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Site L4										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	36.0	37.3	39.9	42.6	45.3	47.8	50.0	51.8	53.0	53.4
Background, L95	29.1	30.2	33.0	36.1	39.5	42.9	46.1	48.8	50.8	51.9
Turbines alone, L95	35.0	36.3	38.9	41.5	44.0	46.1	47.8	48.7	48.9	48.1
Background+5, or 40, L95	40.0	40.0	40.0	41.1	44.5	47.9	51.1	53.8	55.8	56.9
Excess	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0

It would appear that a small exceedence has occurred at Site L4 at 6m/s wind velocity.

A4-P-816171-08 (monitoring between 19/05/2003 and 19/06/2003)

This report is titled “Results of Toora Wind Farm Noise Monitoring Program” and is dated 11 June 2003.

The report states “for the period between 19 May and 19 June 2003, the calculated wind farm sound pressure levels are below the limits at sensitive receptor L3. However for a band of wind speeds and directions may be audible within the ambient noise spectrum at L4”.

The polynomial values of the (turbine and background) L_{95} levels versus wind speed, and the L_{95} levels of background versus wind speed for the relevant sites L3 and L4 are given on the following table:

Noise levels, dB(A)

Site L3										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	29.5	31.8	35.7	38.9	41.3	43.1	44.2	44.8	45.0	44.7
Background, L95	31.4	31.6	32.3	33.7	35.0	37.4	39.6	41.7	43.7	45.4
Turbines alone, L95	N.A.	17.4	33.1	37.3	40.2	41.7	42.4	41.9	39.0	N.A.
Background+5, or 40, L95	40.0	40.0	40.0	40.0	40.0	42.4	44.6	46.7	48.7	50.4
Excess	N.A.	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	N.A.
Site L4										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	34.9	37.2	41.3	44.9	48.0	50.5	52.5	53.9	54.8	55.1
Background, L95	29.1	30.2	33.0	36.1	39.5	42.9	46.1	48.8	50.8	51.9
Turbines alone, L95	33.6	36.2	40.6	44.3	47.3	49.7	51.4	52.3	52.6	52.3
Background+5, or 40, L95	40.0	40.0	40.0	41.1	44.5	47.9	51.1	53.8	55.8	56.9
Excess	0.0	0.0	0.0	3.2	2.8	1.8	0.3	0.0	0.0	0.0

The above indicates there was a small noise exceedence at Site L3 and a significant exceedence of 3.2dB at Site L4.

The report states that the noise emissions "are not considered tonal and therefore an adjustment for tonality has not been included in the assessment." However, it did not state whether any other special characteristics were present such as cyclic variations.

A4-P816171-09 (monitoring between 19/06/2003 and 19/07/2003)

This report is titled "Results of Toora Wind Farm Noise Monitoring Program" and is dated 24 July 2003.

The report does not include a discussion comparing the noise limits with the measured level.

The polynomial values of the (Turbine + Background) L_{95} level versus wind speed, and the L_{95} levels of background versus wind speed for the relevant Sites L3 and L4 are given in the following table.

Noise levels, dB(A)

Site L3										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	29.5	31.8	35.7	38.9	41.3	43.1	44.2	44.8	45.0	44.7
Background, L95	31.4	31.6	32.3	33.7	35.0	37.4	39.6	41.7	43.7	45.4
Turbines alone, L95	N/A	17.4	33.1	37.3	40.2	41.7	42.4	41.9	39.0	N/A
Background+5, or 40, L95	40.0	40.0	40.0	40.0	40.0	42.4	44.6	46.7	48.7	50.4
Excess	N/A	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	N/A
Site L4										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	33.9	35.7	39.2	42.4	45.3	47.9	50.2	52.0	53.4	54.4
Background, L95	29.1	30.2	33.0	36.1	39.5	42.9	46.1	48.8	50.8	51.9
Turbines alone, L95	32.2	34.3	38.0	41.2	44.0	46.3	48.0	49.2	50.0	50.8
Background+5, or 40, L95	40.0	40.0	40.0	41.1	44.5	47.9	51.1	53.8	55.8	56.9
Excess	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0

The data for Site L3 is probably not correct as the data points and regression polynomials are identical to the data given for Site L3 for the May/June 2003 period.

The above indicates a very small excess at Site L3 and L4 for wind speeds of 7m/s and 6m/s respectively.

The report states that the noise emissions "are not considered tonal and therefore an adjustment for tonality has not been included in the measurement." However it did not state if any other special characteristics were present such as cyclic variations.

A4-P816171-10 (monitoring between 19/07/2003 and 19/08/2003)

This report is titled "Results of Toora Wind Farm Noise Monitoring Program" and is dated 22 August 2003.

The report states "For the period between 19th July and 19th August 2003 the calculated wind farm sound pressure levels are below the limits at sensitive receptor L3. However, considering the uncertainty of the trended lines within the data set, the slight exceedence indicated for L4 does not demonstrate a condition of non compliance with the objectives of the planning permit."

The polynomial values of the (Turbine + Background) L_{95} level versus wind speed, and the L_{95} levels of background versus wind speed for the relevant Sites L3 and L4 are given in the following table.

Noise levels, dB(A)

Site L3										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	32.8	33.8	35.9	38.2	40.4	42.6	44.5	46.1	47.3	48.0
Background, L95	31.4	31.6	32.3	33.7	35.0	37.4	39.6	41.7	43.7	45.4
Turbines alone, L95	27.3	29.8	33.5	36.3	39.0	41.0	42.8	44.2	44.8	44.5
Background+5, or 40, L95	40.0	40.0	40.0	40.0	40.0	42.4	44.6	46.7	48.7	50.4
Excess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Site L4										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	33.7	35.8	39.7	43.3	46.5	49.3	51.6	53.5	54.8	55.5
Background, L95	29.1	30.2	33.0	36.1	39.5	42.9	46.1	48.8	50.8	51.9
Turbines alone, L95	31.9	34.4	38.6	42.3	45.5	48.2	50.2	51.7	52.6	52.9
Background+5, or 40, L95	40.0	40.0	40.0	41.1	44.5	47.9	51.1	53.8	55.8	56.9
Excess	0.0	0.0	0.0	1.2	1.0	0.3	0.0	0.0	0.0	0.0

The results show no excess at Site L3, and also show a maximum excess of 1.2dB at 6m/s wind speed at Site L4.

The report states that the noise emissions "are not considered tonal and therefore an adjustment for tonality has not been included in the measurement." However it did not state if any other special characteristics were present such as cyclic variations.

A4-P816171-11 (monitoring between 19/08/2003 and 19/09/2003)

This report is titled "Results of Toora Wind Farm Noise Monitoring Program" and is dated 26 September 2003.

The report states "For the period between 19th August and 19th September 2003 the calculated wind farm sound pressure levels are below the limits at sensitive receptor L3. However, considering the uncertainty in determination of wind speeds, sound pressure levels and the uncertainty of the trended lines within the data set, the slight exceedence indicated for L4 does not demonstrate a condition of non compliance with the objectives of the planning permit."

The polynomial values of the (Turbine + Background) L_{95} level versus wind speed, and the L_{95} levels of background versus wind speed for the relevant Sites L3 and L4 are given in the following table.

Noise levels, dB(A)

Site L3										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	32.5	33.7	36.1	38.4	40.6	42.7	44.5	46.1	47.4	48.3
Background, L95	31.4	31.6	32.3	33.7	35.0	37.4	39.6	41.7	43.7	45.4
Turbines alone, L95	26.2	29.6	33.7	36.6	39.2	41.1	42.8	44.1	45.0	45.2
Background+5, or 40, L95	40.0	40.0	40.0	40.0	40.0	42.4	44.6	46.7	48.7	50.4
Excess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Site L4										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	35.2	37.2	40.9	44.0	46.8	49.2	51.3	53.1	54.8	56.3
Background, L95	29.1	30.2	33.0	36.1	39.5	42.9	46.1	48.8	50.8	51.9
Turbines alone, L95	34.0	36.3	40.1	43.3	45.9	48.0	49.7	51.1	52.5	54.3
Background+5, or 40, L95	40.0	40.0	40.0	41.1	44.5	47.9	51.1	53.8	55.8	56.9
Excess	0.0	0.0	0.1	2.2	1.4	0.1	0.0	0.0	0.0	0.0

The results show no excess at Site L3, and also show a maximum excess of 2.2dB at 6m/s wind speed at Site L4.

The report states that the noise emissions "are not considered tonal and therefore an adjustment for tonality has not been included in the measurement." However it did not state if any other special characteristics were present such as cyclic variations.

A4-P816171-10 (monitoring between 19/09/2003 and 19/10/2003)

This report is titled "Results of Toora Wind Farm Noise Monitoring Program" and is dated 30 October 2003.

The report states "For the period between 19th September and 19th October 2003 the calculated wind farm sound pressure levels are below the limits at sensitive receptor L3. However, considering the uncertainty in determination of wind speeds, sound pressure level and the uncertainty of the trended lines within the data set, the slight exceedence indicated for L4 does not demonstrate a condition of non compliance with the objectives of the planning scheme."

The polynomial values of the (Turbine + Background) L_{95} level versus wind speed, and the L_{95} levels of background versus wind speed for the relevant Sites L3 and L4 are given in the following table.

Noise levels, dB(A)

Site L3										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	32.0	33.1	35.5	38.1	40.7	43.3	45.5	47.3	48.6	49.0
Background, L95	31.4	31.6	32.3	33.7	35.0	37.4	39.6	41.7	43.7	45.4
Turbines alone, L95	23.0	27.6	32.6	36.1	39.4	42.0	44.3	46.0	46.8	46.5
Background+5, or 40, L95	40.0	40.0	40.0	40.0	40.0	42.4	44.6	46.7	48.7	50.4
Excess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Site L4										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	35.7	37.6	41.2	44.4	47.3	50.0	52.3	54.3	56.0	57.4
Background, L95	29.1	30.2	33.0	36.1	39.5	42.9	46.1	48.8	50.8	51.9
Turbines alone, L95	34.7	36.7	40.4	43.7	46.6	49.0	51.1	52.9	54.5	56.0
Background+5, or 40, L95	40.0	40.0	40.0	41.1	44.5	47.9	51.1	53.8	55.8	56.9
Excess	0.0	0.0	0.4	2.6	2.1	1.1	0.0	0.0	0.0	0.0

The results show no excess at Site L3, and also show a maximum excess of 2.6dB at 6m/s wind speed at Site L4.

The report states that the noise emissions "are not considered tonal and therefore an adjustment for tonality has not been included in the measurement." However it did not state if any other special characteristics were present such as cyclic variations.

A4-P816171-13 (measured between 11/05/2004 and 01/06/2004)

This report is titled "Results of Toora Wind Farm Noise Monitoring Program" and is dated 09 June 2003 (sic).

This test was a result of condition 16 of Planning Permit 125, which requires Stanwell Corporation Limited to conduct a follow up monitoring program.

The report states "For the period between 11th May and 18th May 2004 the calculated wind farm sound pressure levels are below the limits at sensitive receptor L3 and L4.

The polynomial values of the (Turbine + Background) L_{95} level versus wind speed, and the L_{95} levels of background versus wind speed for the relevant Sites L3 and L4 are given in the following table.

Noise levels, dB(A)

Site L3										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	29.8	31.1	33.6	36.0	38.2	40.2	41.8	43.1	43.9	44.2
Background, L95	31.4	31.6	32.3	33.7	35.0	37.4	39.6	41.7	43.7	45.4
Turbines alone, L95	N.A.	N.A.	27.7	32.1	35.3	36.9	37.8	37.4	30.0	N.A.
Background+5, or 40, L95	40.0	40.0	40.0	40.0	40.0	42.4	44.6	46.7	48.7	50.4
Excess	N.A.	N.A.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N.A.
Site L4										
Wind velocity, m/s	3.5	4	5	6	7	8	9	10	11	12
Turbines plus background, L95	32.6	33.8	36.7	40.3	44.0	47.4	50.3	52.1	52.5	51.1
Background, L95	29.1	30.2	33.0	36.1	39.5	42.9	46.1	48.8	50.8	51.9
Turbines alone, L95	30.1	31.3	34.3	38.2	42.0	45.5	48.2	49.3	47.6	N.A.
Background+5, or 40, L95	40.0	40.0	40.0	41.1	44.5	47.9	51.1	53.8	55.8	56.9
Excess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N.A.

The report states that measurements were made from 11 May 2004 to 01 June 2004. Based on this it would be expected there would be about 3,000 data points to analyse.

On the graphs of (Turbine + Background) sound pressure levels versus wind speed, it states that data was only analysed for the period May 11-18. Based on this there would be about 1,000 data points to analyse, however the results state only 442 data points were used in the analysis. No explanation is given why less than 7% of the total data points were used in the analysis.

It is noted that the Planning Permit only requires 7 days of monitoring for this measurement, but this is inadequate. Under 5.2.3 it is stated "If typically 1440 data points were collected over the required wind range, it would be possible to repeat the regression analysis.

In any case, only 442 data points is considered insufficient to provide an accurate assessment of the noise from the wind farm.

The report makes no mention of special audible characteristics.

DISCUSSION

Background Levels

As discussed earlier, the acceptable limits under NZS 6808 are determined from

- the average background sound level (L_{95}) +5dB for any given wind speed, or
- 40dB(A)

whichever is the greater.

The background noise level for a given wind speed can be dependant on the wind direction. Thus, where there is a variation in background level with wind direction the average background level determined over a week or month will depend on the prevailing wind at that time of the year.

Further, it can be shown that the background level depends on the time of day. Background levels are normally quieter at night than during the day. In country areas this can be due to bird noise, etc. but it can also be shown to be due to different wind profiles (which are a result of atmospheric stability).

For a noise limit to be useful, it must be robust. That is to say the calculated values should be repeatable and not dependent on time of year (prevailing wind) etc.

NZS 6808 is quite clear on this matter. Under 4.5.5 it states:

> "It may be necessary to separately correlate background sound levels with wind speed for different wind directions and/or time of day."

The first background noise level measurements were carried out by Pacific Air and Environment for Stanwell and provided in a report dated May 2000.

As part of the report, the background noise levels were calculated out for Day (0700h – 0600h), Evening (0600h – 1000h) and Night (1000h – 0700h). This report showed for the critical wind speeds of 6m/s and 8m/s the background noise levels were 5.5dB and 3.6dB lower during the night time than the day time. It also showed that the background levels for Evening were generally between the Night and Day background levels. Although the sample was small it is clear that Stanwell Corporation Limited should have been aware that it may be necessary to separately correlate background sound levels with time of day.

The pre-construction background noise monitoring was made in the July to September period for sites L1, L2 and L3 and in December 2001 to January 2002 period for Site L4.

The pre-operation monitoring was made in the July to August period of 2002. The monitoring period was slightly less than for the pre-construction period (22 days versus 20 to 44 days). The results showed for all sites the background levels had increased on an average of 5.1dB. This is a very large difference from an acoustician's view.

This matter was raised with Stanwell Corporation Limited by the EPA. Stanwell's response (May 2003) that the difference "may be due to seasonal changes, environmental changes (including vegetation) and climatic conditions". Also in an earlier letter Stanwell Corporation Limited response (October 2002) "We have found that a degree of difference in noise levels may be attributed to the difference in wind direction between the two assessments.

From the above it would appear that Stanwell Corporation Limited was aware of both importance of time of day and wind direction on background levels, but the procedures suggested by NZS 6808 to separately correlate background levels under these conditions were not followed.

It is worth noting at this point that by dividing data into day and night, for example, the data size is halved. Thus in order to obtain the same level of confidence in the data monitoring needs to be carried our for twice the period. Further, if data is also broken down into wind direction (say into 4 quadrants) then 4 times as much data is required. For background monitoring data to be analysed for Day/Night and wind direction, then about 80 days of data is required.

There is now a precedent for dividing data into Day/Night. In the Bald Hills hearing the panel concluded "NZS 6808 itself contemplates that data disaggregation can be justified. The Panels approach is that this would be a reasonable precautionary step to take". "However if the van den Berg effect does eventuate to a significant extent a clearly defined night period for data averaging will prevent the dilution of night data into day data". Night period was suggested to be from 2200-0700h.

More recently, in the Dollar Wind Farm report (Reference 7) background noise was analysed for both the 24 hour period, and night period. This showed that typically the night time results were about 1.7dB quieter for the important 6-8m/s wind speed range compared to the 24h (aggregated) data. However, the background data was not correlated with wind direction.

A best practice approach would require that data for background sound levels should be disaggregated in to Day/Night and also into wind direction. This is particularly relevant where studies have indicated this was occurring and is also noted by NZS 6808.

Post Installation Compliance Testing

Measurements of the noise from the wind turbines were initially made between September 2002 and October 2002. The turbines were not fully operational, thus the noise levels are probably not typical. A further short period of noise monitoring was carried out in May 2004. It is understood that for the latter test the turbines may have been in "noise optimised" mode, but there was no documentation to the council available to confirm this.

The majority of the noise monitoring occurred between 19/10/2002 and the 19/10/2003. Results in the reports show the turbine noise emissions generally conformed to the acceptable limits calculated by Stanwell Corporation Limited from the background levels at Site L3, however several periods of noise excess at Site L4.

As discussed earlier, the assessment of noise depends critically on the "robustness" of the background levels which are the basis of the noise limits.

Stanwell Corporation Limited did not disaggregate the data for Day/Night, nor for wind direction. However, as mentioned above recent work reported in the Dollar Wind Farm showed that night time backgrounds are about 1.7dB lower than aggregated (all data) backgrounds. In order to determine the affect of disaggregation of background levels as suggested by NZS 6808, a factor of 1.7dB has therefore been applied to the aggregated 24h background levels in order to estimate the Night background noise levels at Toora. This is shown in the table that follows.

5.1.1 of NZS 6808 states "This section outlines a precise method for the post installation compliance testing of sound from WTGs in the far field, i.e. at distances where the cyclic variations in sound due to blade rotation are no longer discernible. The procedure is based upon the method outlined in 4.5 with the exception that the WTGs will now be operational."

The important point is that if the cyclic variations are discernible, then by definition, either NZS 6808 does not apply, or the sound from the wind farm has special audible characteristics. NZS 6808 also states "At present, there is no simple objective procedure available to quantify special audible characteristics, and subjective assessment is therefore necessary, supported by objective evidence (e.g. frequency analysis) where appropriate.

NZS 6808 states that "an assessment of any special characteristics should be undertaken".

Stanwell Corporation Limited has in several of the reports, reported that the noise from the wind farms was not tonal, however at no time was an assessment recorded that the noise from the wind farm had "cyclic variations in sound due to blade rotation".

It is understood that the main complaint by residents near the wind farm is in fact the rhythmic sound of the turbines. It would appear therefore that an adjustment for this characteristic is required if it can be shown this characteristic occurs regularly.

Recent work by Frits van den Berg (Reference 6) has shown that wind farms can sound impulsive, particularly at night under stable atmospheric conditions. This phenomenon is unlikely to occur during the day. To investigate this effect Stanwell Corporation would need to have inspected the wind farm at night. There is no evidence that Stanwell has made investigations at night. Under 5.3.2 of NZS 6808 states that "when a sound has a special audible characteristic, the measured sound level of the source shall have a 5dB penalty applied."

The following summary assumes two scenarios. These are:

- No penalty for special audible characteristics, and
- a penalty of +5dB. While the 5dB penalty may be too "harsh", the following table provides the possible range of levels.

Excess Noise Levels, dB
Assessment based on 24h Aggregate Background Data

Date of Measurement	Site L3		Site L4	
	NP(*1)	P(*2)	NP	P
09/09/2002 to 17/09/2002	Prel. (*3)	Prel.	Prel.	Prel.
19/10/2002 to 19/11/2002	Est. 0 (*4)	Est. 3	Est. 1.5	Est. 6.5
19/11/2002 to 19/12/2002	0	4.8	0.5	5.5
19/12/2002 to 19/01/2003	Est. 0	Est. 5	Est. 0	Est. 1
19/01/2003 to 19/02/2003	Est. 0	Est. 2	Est. 0	Est. 4
19/02/2003 to 19/03/2003	0	3.9	1.1	6.1
19/03/2003 to 19/04/2003	0	0	0	4.7
19/04/2003 to 19/05/2003	0	0	0.4	5.4
19/05/2003 to 19/06/2003	0.2 (*5)	5.2 (*5)	3.2	8.2
19/06/2003 to 19/07/2003	0.2	5.2	0.1	5.1
19/07/2003 to 19/08/2003	0	4.0	1.2	6.2
19/08/2003 to 19/09/2003	0	4.2	2.2	7.2
19/09/2003 to 19/10/2003	0	4.7	2.6	7.6
11/05/2004 to 01/06/2004	0	0.3	0	2.6

Excess Noise Levels, dB
Assessment based on Night Background Data

Date of Measurement	Site L3		Site L4	
	NP	P	NP	P
09/09/2002 to 17/09/2002	Prel.	Prel.	Prel.	Prel.
19/10/2002 to 19/11/2002	Est. 0	Est. 4	Est. 3	Est. 8
19/11/2002 to 19/12/2002	0.2	5.2	2.0	7.0
19/12/2002 to 19/01/2003	Est. 1.5	Est. 6	0	Est. 3
19/01/2003 to 19/02/2003	0	Est. 3	Est. 1	Est. 6
19/02/2003 to 19/03/2003	0	4.5	2.5	7.5
19/03/2003 to 19/04/2003	0	0.9	1.3	6.3
19/04/2003 to 19/05/2003	0	1.9	1.9	6.9
19/05/2003 to 19/06/2003	1.5 (*5)	6.5 (*5)	4.8	9.8
19/06/2003 to 19/07/2003	1.5	6.5	1.7	6.7
19/07/2003 to 19/08/2003	0.9	5.9	3.0	8.0
19/08/2003 to 19/09/2003	1.0	6.0	3.5	8.5
19/09/2003 to 19/10/2003	1.7	6.7	4.0	9.0
11/05/2004 to 01/06/2004	0	2.5	0	5.0

Notes:

*1 NP stands for No Penalty
*2 P stands for Penalty applied, that is blade rotation is discernible. +5 has been applied but this correction may be excessive.
*3 Preliminary
*4 Estimated
*5 Data for Site L3 for the period 19/07/2003 to 19/08/2003 is identical to data for the period 19/06/2003 to 19/07/2003 and appears to have been copied. This data appears to be an error.

From the above results the following can be concluded (excluding the preliminary measurements and last measurements).

Using aggregated background data (24 hours) and assuming no penalty for special audible characteristics

- At Site L3, wind turbine noise was excessive for 2 measurement periods (17%) with excesses up to 0.2dB.
- At Site L4, wind turbine noise was excessive on 9 measurement periods (75%) with excesses up to 3.2dB.

For night period background data (estimated) and assuming no penalty for special audible characteristics

- At Site L3, wind turbine noise was excessive for 7 measurement periods (58%) with excesses up to 1.7dB.
- At Site L4, wind turbine noise was excessive for 11 measurement periods (92%) with excesses up to 4.8dB.

Using aggregated background data (24 hours) and assuming "discernible rotation" with +5dB penalty

- At Site L3, wind turbine noise could be excessive for up to 10 measurement periods (83%) with excesses up to 5.2dB.
- At Site L4, wind turbine noise could be excessive for up to 12 measurement periods (100%) with excesses up to 8.2dB.

For night period background data (estimated) and assuming "discernible rotation" with +5dB penalty

- At Site L3, wind turbine noise could be excessive for up to 12 measurement periods (100%) with excesses up to 6.7dB.
- At Site L4, wind turbine noise could be excessive for up to 12 measurement periods (100%) with excesses up to 9.8dB.

It should be noted that the existence of "discernible rotation" was not assessed by Stanwell Corporation Limited at Sites L3 or L4, therefore the above of +5dB may not be appropriate. Further "impulsiveness" is most likely to occur at night, under stable weather conditions. There is no comment in the reports that inspections were made at night at times when "impulsiveness" was most likely to occur.

Further, NZS 6808 does not advise what correction should be applied if "discernible rotation" or other special audible characteristics are only audible for 10%, or 90% of the time, for example. 5.3.2 of NZS 6808 requires a maximum penalty of +5dB which in practice may, for many instances, be too "harsh" a penalty, however no clause is available for latitude in this area.

CONCLUSIONS AND RECOMMENDATIONS

- NZS 6808 states that "it may be necessary to separately correlate background sound levels with wind speeds for different directions and/or time of day".

  Stanwell Corporation Limited has assessed the background sound levels versus wind speed by aggregating all data.

  The initial noise survey carried out for Stanwell Corporation Limited by Pacific Air & Environment indicated that background sound levels were dependent on time of day. Recent work by Marshall Day Acoustics for Dollar Wind Farm has confirmed that background noise levels can be dependent on time of day in a rural environment, with lower background noise levels being recorded at night. Lower background levels result in lower noise limits and more accurately represent the lowered masking effect the background noise has on the turbine noise at night.

  Stanwell Corporation Limited has also noted that the background noise level may also be dependent on wind direction "while the regression for the entirety of the combined data exhibits a low co-efficient of regression, partitioning and separate correlation of the data within 45 degree wind-direction segments results in markedly higher correlation coefficients." (Letter dated 25 October 2002).

  In view of the above, it is considered that a best practice analysis of the background noise data should have adopted, using the recommendation given in NZS 6808. Background sound levels should have been separated into:

  - Time of day (say Day/Night (2200h to 0700h)
  - Wind direction (say 45 or 60 degree wind-direction segments)

  It is recognised that to obtain sufficient confidence in the data, background sound level monitoring would need to be taken over a longer period than carried out by Stanwell Corporation Limited.

  Recommendation 1

  That a best practice approach is adopted, and that the background sound level monitoring data is reanalysed using the recommendation given in NZS 6808, that is "it may be necessary to separately correlate background sound levels with wind speeds for different directions and/or time of day".

  It is suggested that the time of day analyses should be based on a Night period of 2200h to 0700h.

  It is suggested that wind direction analysis should be based on 45˚ or 60˚ segments.

- In a similar manner to above Stanwell Corporation Limited has aggregated all the post installation sound compliance testing results and has not disaggregated data for time of day or wind direction.

  By not disaggregating data results then high levels of wind turbine noise (for example, when the wind blows from the turbine farm to the residential premises) will be averaged with lower levels of noise from the wind farm when the wind blows in all other directions thereby "diluting" the sound level measured from the wind farm.

  Further NZS 6808 states under 5.2.2

"Compliance level testing shall take place at the same positions and across a similar range of wind conditions for which background sound level data has been previously collected."

If background sound data is required to be disaggregated, then post compliance testing results will also need to be disaggregated.

Recommendation 2

That a best practice approach is adopted, and that the measured sound levels of the wind farm are reanalysed using the same procedures as given in Recommendation 1.

- NZS 6808 states that the post installation sound compliance testing is to be used in the far field, "ie at distances where the cyclic variations due to blade rotation are no longer discernible".

  If the blade rotation is discernible then it would seem the correct interpretation of the Standard is that cyclic variations due to blade rotation are a "special audible characteristic", and a penalty is to be applied to the measured level. (The alternative interpretation of the NZS 6808 is that it is not to be used where cyclic variations are discernible).

  It is understood that residents living very near to Toora Wind Farm complain of noise from the farm having a rhythmic quality, particularly at night.

  Recent work by Frits van den Berg has also shown that wind farms can produce "impulsive" like noise, particularly at night (Reference 6).

  It is not known if Stanwell Corporation Limited has assessed the noise from the wind farm at times when cyclic variations due to blade rotation or "impulsiveness" are most likely to be noticed, that is at night.

  If the noise from the wind turbines is judged to have a noise character which is more annoying than a steady source then it would seem a "special audible characteristic" penalty is appropriate. NZS 6808 suggests a +5dB penalty, however this may be too harsh if the character is not present all the time. However NZS 6808 does not provide guidance on how to assess a penalty if "special audible characteristic" is not present at all times.

  Recommendation 3

  That a study is made into special audible characteristics from the Toora Wind Farm.

  The study should include:

  - the presence, or otherwise, of audible tonal components, both inside and outside residential houses, and the percentage of time the effect is audible, particularly at night.

  - the presence or otherwise, of discernible blade rotation, at residential houses, and the percentage of time the effect is audible, particularly at night.

  - the presence, or otherwise, of "impulsive" noise as described by Dr Frits van den Berg, at residential houses, and the percentage of time the effect is audible, particularly at night.

- Calculations have been made of the number of times the monthly measured noise levels of the Toora wind farm were excessive between 19 October 2002 and 19 October 2003.

  A summary follows:

  Acceptable Limits based on background levels based on 24 hour data

Site	% of monthly periods excessive	Maximum excess
L3	17%	0.2dB
L4	75%	3.2dB

  Acceptable Limits based on estimated Night (2200h to 0700h) background levels

Site	% of monthly periods excessive	Maximum excess
L3	58%	1.7dB
L4	92%	4.8dB

  The estimated Night background levels are based on information from the Dollar Wind Farm with a 24 hour/Night adjustment of – 1.7dB. This adjustment may not be correct for Toora Wind Farm.

  If special audible characteristics such as discernible blade rotations occur, then the percentage of percentage of monthly periods that are excessive, and the maximum excess in dB, may both increase.

  NZS 6808 does not provide guidance as to a breach of the standard. For example, is a small excess once in 12 months a breach? This is a matter that may require legal advice.

- Monitoring of the wind farm was also carried out between 11 May and 01 June 2004 as required by Condition 16 of the Planning Permit. Thus monitoring showed levels conformed to the limits. The permit only required 7 days monitoring.

  It is understood that the turbines may have been in "noise minimised" mode, which would reduce noise output. However, insufficient results are available to confirm that the Toora Wind Farm was and continues to be operating within the requirements of NZS 6808.

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GRAEME E HARDING & ASSOCIATES PTY LTD

Graeme E Harding & Associates Pty Ltd is a member company of the Association of Australian Acoustical Consultants and the work herein reported has been performed in accordance with the terms of membership.

END OF REPORT

List of Reports of Monitoring Results prepared by/for Stanwell Corporation Limited

Doc. No.	Rev.	Date	Revision Date	Description	Period Start	Period Finish	Revision
1	-	May 2000	-	Toora Wind Farm Noise Modelling - Pacific Air and Enviroment	15/02/2000	25/02/2000	
2	1	12/10/01	-	Toora Wind Farm - Pre-Construction Noise Monitoring Assessment	25/07/2001	29/08/2001	A4-P-816014-01 (Original)
3	2	12/10/01	08/02/02	Toora Wind Farm - Pre-Construction Noise Monitoring Assessment	25/07/2001	31/01/2002	Addition of L4
4	2	12/10/01	18/09/02	Toora Wind Farm - Background (Pre-Operation) Noise Monitoring Assessment	29/07/2002	19/08/2002	A4-P-816014-02 (2002 Update)
5	3	12/10/01	23/05/03	Toora Wind Farm - Background (Pre-Operation) Noise Monitoring Assessment	29/07/2002	19/08/2002	A4-P-816014-03
6	1	19/09/02	-	Assessment of Noise from the Toora Wind Farm	09/09/2002	17/09/2002	A4-P-816172-01
7	1	12/12/02	-	Assessment of Noise from the Toora Wind Farm	19/10/2002	19/11/2002	A4-P-816122-01
8	1	12/12/02	-	Results of the Toora Wind Farm Noise Monitoring Program	19/10/2002	19/11/2002	A4-P-816171-01
9	2	12/12/02	11/04/03	Results of the Toora Wind Farm Noise Monitoring Program	19/10/2002	19/11/2002	A4-P-816171-01 B
10	1	15/01/03	-	Assessment of Noise from the Toora Wind Farm	19/11/2002	19/12/2002	A4-P-816172-02
11	2	15/01/03	11/04/03	Results of the Toora Wind Farm Noise Monitoring Program	19/11/2002	19/12/2002	A4-P-816172-02 -B
12	1	05/02/03	-	Results of the Toora Wind Farm Noise Monitoring Program	19/12/2002	19/01/2003	A4-P-816171-03
13	2	05/02/03	11/04/03	Results of the Toora Wind Farm Noise Monitoring Program	19/12/2002	19/01/2003	A4-P-816171-03 -B
14	1	06/03/03	-	Results of the Toora Wind Farm Noise Monitoring Program	19/01/2003	19/02/2003	A4-P-816171-04
15	2	06/03/03	11/04/03	Results of the Toora Wind Farm Noise Monitoring Program	19/01/2003	19/02/2003	A4-P-816171-04 -B
16	1	11/04/04	-	Results of the Toora Wind Farm Noise Monitoring Program	19/02/2003	19/03/2003	A4-P-816171-05
17	1	06/05/03	-	Results of the Toora Wind Farm Noise Monitoring Program	19/03/2003	19/04/2003	A4-P-816171-06
18	1	06/06/03	-	Results of the Toora Wind Farm Noise Monitoring Program	19/04/2003	19/05/2003	A4-P-816171-07
19	1	11/06/03	-	Results of the Toora Wind Farm Noise Monitoring Program	19/05/2003	19/06/2003	A4-P-816171-08
20	1	24/07/03	-	Results of the Toora Wind Farm Noise Monitoring Program	19/06/2003	19/07/2003	A4-P-816171-09
21	1	22/08/03		Results of the Toora Wind Farm Noise Monitoring Program	19/07/2003	19/08/2003	A4-P-816171-10
22	1	26/09/03	-	Results of the Toora Wind Farm Noise Monitoring Program	19/08/2003	19/09/2003	A4-P-816171-11
23	1	30/10/03	-	Results of the Toora Wind Farm Noise Monitoring Program	19/09/2003	19/10/2003	A4-P-816171-12
24	1	09/06/03	-	Results of the Toora Wind Farm Noise Monitoring Program	11/05/2004	01/06/2004	A4-P-816171-13

List of Correspondence

Doc. No.	Rev.	Date	Revision Date	Description	From	To
25	-	18/05/2000	-	Planning Permit Application - Toora Wind Farm	PPK Environment & Infrastructure	South Gippsland Shire Council
26	-	06/06/2000	-	Planning Permit Application - Toora Wind Farm	PPK Environment & Infrastructure	South Gippsland Shire Council
27	-	09/06/2000	-	Planning Permit Application - Toora Wind Farm	PPK Environment & Infrastructure	South Gippsland Shire Council
28	-	22/06/2000	-	Corrections to Toora Wind Farm Report	Pacific Air & Enviroment	PPK Environment & Infrastructure
29	-	27/11/2001	-	Toora Wind Farm - About monitoring conditions	Stanwell Corporation Limited	South Gippsland Shire Council
30	-	2/10/2002	-	Noise complaint procedures and noise monitoring at Toora Wind	EPA	South Gippsland Shire Council
34	-	25/10/2002	-	Noise monitoring at Toora Wind Farm	Stanwell Corporation Limited	South Gippsland Shire Council
31	-	23/04/2003	-	Noise monitoring at Toora Wind Farm	EPA	South Gippsland Shire Council
32	-	30/06/2003	-	Comments on Noise Reports	EPA	South Gippsland Shire Council
33	-	28/07/2003	-	Toora Wind Farm monitoring results Reports 1-8 - Addendum	Stanwell Corporation Limited	South Gippsland Shire Council

REFERENCES

Reference 1 International Standard IEC61400-11, Wind Turbine generator systems – Part 11: Acoustic noise measurement techniques.

Reference 2 The Assessment & Rating of Noise from Wind Farms, ETSU-R-97, September 1996.

Reference 3 Physical Characteristic and Perception of Low Frequency Noise from Wind Turbines, K P Shepherd and H H Hubbard, N.C.E.J., Jan-Feb 1991.

Reference 4 The Propagation of Noise from Petroleum and Petrochemical Complexes to Neighbouring Communities – CONCAWE Report No. 4/81, May 1981.

Reference 5 NZS 6808 : 1998, Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators.

Reference 6 Effects of the Wind Profile at Night on Wind Turbine Sound, Frits G P van den Berg, J.S.V.

Reference 7 Dollar Wind Farm – Noise Impact Assessment. Report no. 03.544-3, Final.

Reference 8 State Environment Protection Policy (Control of Noise from Commerce, Industry and Trade) No. N-1, Victorian Government Gazette No. S31 – Special.

Technical Issues with the Application of 4.5.5 of NZS6808

Background Noise Levels – Wind direction

4.5.5. of the Standard states that background sound level measurements at the residential premises are to be correlated with the wind speeds measured at the wind farm site. It also goes on to say that "It may be necessary to correlate background sound levels with wind speed for different wind directions and/or time of day".

The Standard does not provide further guidance on how or why this should be done.

For limits provided by the Standard to be technically correct, then the average background levels for a given wind speed, which is the basis of the limits, must be robust. That is to say, it should not matter if the background levels are measured in summer, winter, spring or autumn. The average background levels, and hence the noise limits, must be the same (within a reasonable level of confidence, say ±2dB).

However, consider a situation where in summer southerly winds are common, while northerly winds are common in winter. Further consider a situation where wind turbines are to be located on a ridge of hills running east-west and a residential premises is located to the south on a plain. If the background measurements are made in summer the winds will tend to be from the south. Under these conditions the residence and nearby trees will be relatively unshielded from the wind and for specific wind speeds at the proposed wind turbine locations relatively high background levels will result at the residence.

Now consider that the background measurements are made in winter. In winter the wind will tend to blow from the north. Under these circumstances it is quite probable that the atmosphere at low levels will be decoupled from the atmosphere at higher levels, with the results that winds at this residence, relative to the winds at the proposed turbine location will be lower. Consequently if the wind speeds near the residence is lower then the background noise due to the foliage is lower.

It is clear that under these situations the background noise levels, and hence the noise limits, are dependent on wind direction. Aggregating and averaging the background levels without considering wind direction results in a high limit if measurements are made in summer and a low limit if measurements are made in winter. The acceptable limits depend on the time of year that the measurements are made.

Background Noise Levels – Atmospheric stability

Consider turbines and residential premises on a flat plain. During the day the wind is "unstable", During "unstable" conditions the velocity profile increases rapidly with height up to a certain point, then increases only a small amount with increasing height. Consequently with wind being measured at 10m height at the wind farm, the background noise due to tree foliage will be relatively high.

However, when "stable" conditions occur at night the wind profile changes significantly. Near the ground the wind velocity profile increases slowly with height but continues to increase with height (Appendix D, page 1). At night, when a "stable" condition occurs ("stable" conditions do not occur every night), the background noise due to the foliage will be lower for a particular wind speed (measured at 10m above ground level (agl)).

In summary, for the same wind speed at 10m agl, the background sound level with "unstable" conditions during the day will be relatively high, but during those nights under "stable" conditions the background level will be quieter.

At certain times of the year there may be only a few nights of "stable" conditions, while other times of the year many nights of "stable" conditions would occur.

Thus the background sound level due to foliage noise at the residence is not just dependent on the wind speed at 10m agl but also the wind speed profile. Recent measurements by Marshall Day Acoustics have shown that lower "average" background levels occur at night than during the day (Reference 7).

Under NZS 6808, applying 4.5.5 it would now seem appropriate that in all cases that background noise data should be disaggregated into Day and Night.

However, at some times of the year there will be a high percentage of stable wind conditions at night, while at other times of the year there will be fewer stable conditions.

From this it can be seen that the background level for the Night period could be seasonal, and therefore not robust. If in one season a high percentage of stable atmospheric conditions low backgrounds will result. A season that has a low percentage of stable conditions at night will result in higher backgrounds.

An appropriate method of establishing a reliable background level for Night, would be to further disaggregate data into Stable and Not Stable.

At this time, this approach is not considered under NZS 6808, however to obtain a technically correct and robust background noise level for the night period, this form analysis is required.

Measured Levels – Wind direction

A similar problem arises with post installation compliance testing.

For the example described earlier with the turbine located on a ridge of hills running east-west and a residential premises located to the south on a plain, then the noise levels from the turbines will be lower in summer when the wind generally is from the south, and higher in winter when the wind is generally from the north.

Clearly in order to really determine whether noise emissions from a wind turbine comply, or don't comply with a noise limit, the "measured level" obtained should be repeatable, no matter what time of the year the measurements are made.

Measured levels – Time of day and wind profile

A recent study by Frits G P van den Berg has shown that under certain meteorological conditions, the noise level from wind turbines can be significantly higher than predicted (Reference 6).

At the residential location 400m from the turbines, the turbine was dominant (by the author's definition) for 72% at night, and hardly audible during daytime (4%). At a second location 1500m from the nearest turbine, the turbines were dominant for 38% at night.

The study showed that at night the expected noise level for the nearest location for a specified low wind speed of 3 and 4 m/s (at 10m reference height) was about 15dB more than expected by calculations. The location at 1500m from the turbines at low wind speeds of 2 to 4 m/s (at 10m reference height) the actual sound level is up to 18dB higher than expected.

Wind turbines are certified for noise and a fixed relationship is assumed between the wind speed υ_h at height h and the wind speed υ_{ref} at a reference height h_{ref} (usually 10m). This wind profile is used in

international recommendations for wind turbine noise emission measurements, for example, IEC International Standard 61400-11 Wind turbine generator systems - Part II - Acoustic Measurement Techniques.

For a height h the wind speed υ_h is calculated as follows:

$$\upsilon_h = \upsilon_{ref} \log(h/z)/\log(h_{ref}/z)$$

The equation is an approximation of the wind profile in the turbulent boundary layer of a neutral atmosphere, when the air is mixed by turbulence due to wind shear with the ground. During daytime thermal turbulence is added, especially when the heating of the earth surface by the sun is significant. A neutral atmosphere, characterised by the adiabatic temperature gradient, occurs at night-time under heavy cloud and/or at relatively high wind speeds. However, when there is some clear sky, and in the absence of strong winds, the atmosphere becomes stable because of radiative cooling of the surface. The wind profile changes and can no longer be adequately described by the above equation.

Noise measurements of wind turbines are based on wind speed measurements normally made or corrected for a height of 10m above ground.

During the day the "daytime" wind profile will occur resulting in the velocity of the wind at hub height will be only slightly higher than the wind at 10m, and

During the evening and night under stable conditions the "night-time" wind profile will occur resulting in the velocity of the wind at hub height will be significantly higher than at 10m height, therefore the noise will be much higher, and

In summary, during the day the noise levels from the turbines are low for a given 10m wind speed. While at night with a different wind profile the turbines are noisier for a given 10m wind speed. Thus, the noise from wind turbines are not just related to windspeed at 10m, but are also correlated with atmospheric stability.

The major part of this problem can be reduced if wind speed measurements are made hub height and not at 10m height, however this introduces a problem that background noise levels will no longer be reliably correlated with wind speed.

The alternative approach, which is recommended, is that the measured noise levels are further disaggregated with atmospheric stability (wind profile) being a parameter.

This will ensure that the low turbine noise levels which occur at night under unstable conditions are not aggregated with the higher noise levels which occur at night under stable conditions.

More "impulsiveness" from Wind Turbines than expected

The work of Frits van den Berg noted earlier, not only showed higher noise levels from wind farms at night than expected, but also showed higher levels of "impulsiveness", as noise character that "resembles distant pile driving" or "an endless train".

"On a summer's day in moderate or even strong wind, the turbines may only be heard within a few hundred meters, and one might wonder why residents should complain about noise by the wind park. However, on quiet nights the wind park can be heard at distances up to several kilometres when the turbines rotate at high speed. On these nights, certainly at distances between 500m and 1000m from the wind park, one can hear a low pitched thumping noise with a repetition rate of once a second (coinciding

with the frequency of blades passing a turbine mast) not unlike pile driving, superimposed on constant broadband 'noisy' sound."

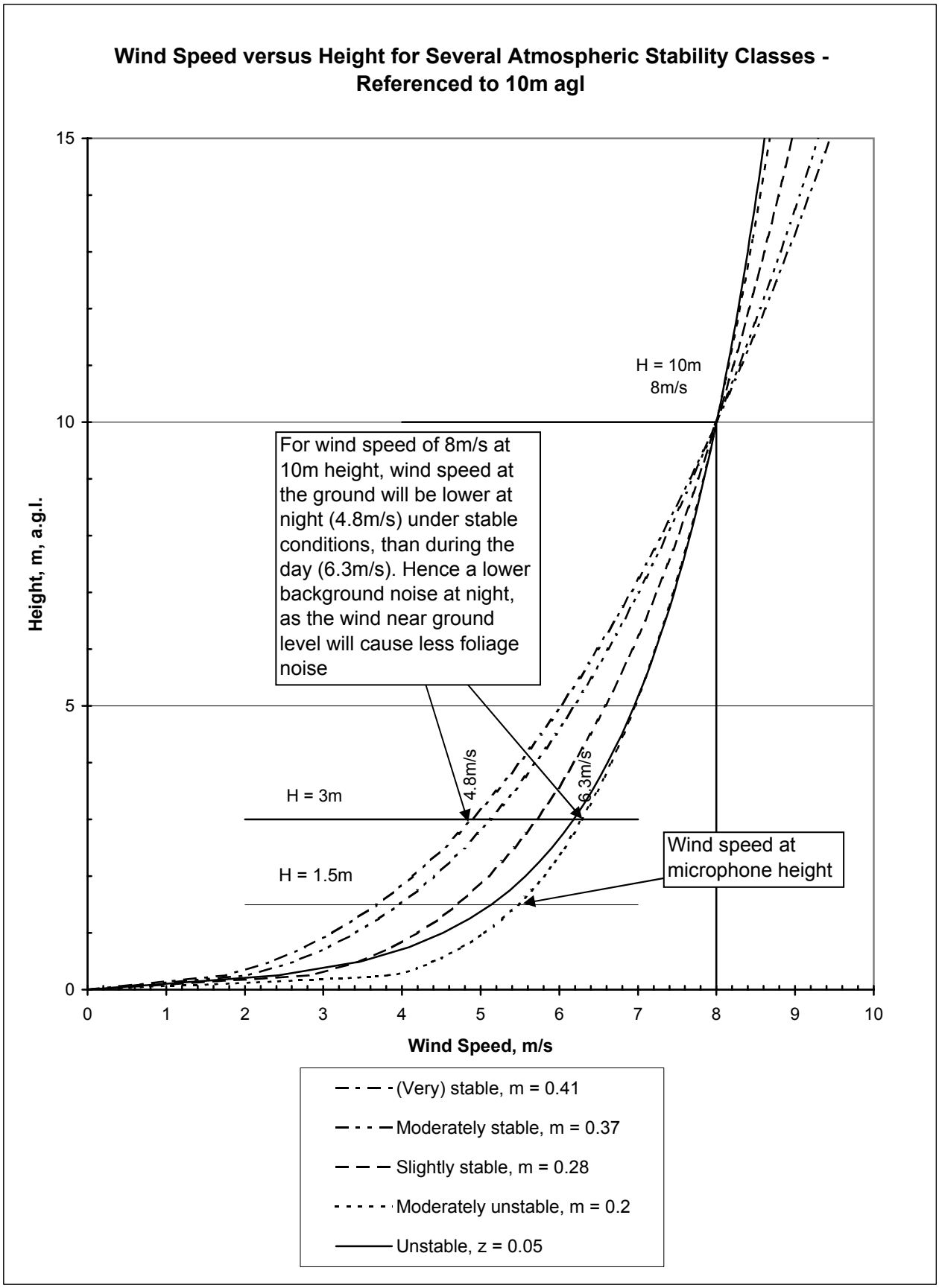
He states on the noise character "The primary factor for this is the well known swishing sound caused by the pressure fluctuation when a wing passes the turbine mast. For a single turbine these 1-2dB broad band sound pressure fluctuation would not classify as impulsive. When several turbines operate nearly synchronously the pulses however may occur in phase: two equal pulses give a doubling in pulse height (+3dB), three a tripling (+5dB). Several low magnitude pulse trains thus cause sound with an unexpected, relatively strong impulsive character whenever they synchronise. *The sound then resembles distant pile driving or, as a resident said: "an endless train".*(My emphasis) Synchronisation here refers to the sound that the wind turbines contribute at the emission point. In the wind park we never heard the impulsiveness".

Clearly, the noise of individual modern turbines operating under clear airflow conditions is not "impulsive"; however, the phasing of the noise of multiple turbines can cause strong "impulsiveness".

Verbal evidence given by Mr G P van den Berg at The Bald Hills Wind Farm Project Hearings (March, April 2004) was that the layout of the turbines was not important. Whether the turbines were in rows or randomly laid out, the phasing effects resulting in the "impulsiveness" would occur. Based upon this, whether a 2 bladed or 3 bladed turbine was used would also not change the likelihood of "impulsiveness" occurring.

It is important to note that this "impulsiveness" seems to be more likely to occur during the night than during day time hours. Consequently, to determine if this "impulsiveness" occurs, the assessments must be made during the night under stable atmospheric conditions.

NZS 6808 does not give guidance on how to apply a penalty if "impulsiveness" only occurs occasionally. If "impulsiveness" only occurs on 10% of nights, should a full +5dB apply, or should a lesser adjustment be considered? This issue was raised at the Bald Hills Hearing, and certain recommendations were given by the Panel.


Wind Speed versus Height for Several Atmospheric Stability Classes - Referenced to 10m agl
Height, m, a.g.l.
Wind Speed, m/s
H = 10m
8m/s
H = 3m
H = 1.5m
For wind speed of 8m/s at 10m height, wind speed at the ground will be lower at night (4.8m/s) under stable conditions, than during the day (6.3m/s). Hence a lower background noise at night, as the wind near ground level will cause less foliage noise
4.8m/s
6.3m/s
Wind speed at microphone height
(Very) stable, m = 0.41
Moderately stable, m = 0.37
Slightly stable, m = 0.28
Moderately unstable, m = 0.2
Unstable, z = 0.05

Noise assessment under NZS6808 - Typical windfarm