

15 December 2010

There has been recent debate about infrasound from wind farms. In the interests of informing the debate, Pacific Hydro has commissioned a report to measure and compare infrasound levels from wind farms and common environment infrasound sources, both natural and man-made.

The noise measurements were recorded for Pacific Hydro by an independent acoustic consulting firm, Sonus, with the aim of helping us to better understand the levels of infrasound that exist in the environment (both natural and man-made).

For the purposes of the report, infrasound was measured at two of our Australian wind farms, Clements Gap in South Australia and Cape Bridgewater in Victoria (while operating and while off), at a beach, a cliff top along the coastline, in the Adelaide CBD close to two busy roads, in an Adelaide suburb, and near a gas-fired power station. The results are summarised in the table below and the full report is attached.

The results show that infrasound is not unique to wind farms. The levels of infrasound produced by wind turbines is well below established perception thresholds and, importantly, is also below levels produced by other natural and man-made sources. Interestingly one of the highest levels of infrasound that was recorded was at a beach.

Whilst this report is by no means exhaustive it does provide further support to existing overseas data which shows that infrasound emissions from operational wind farms is significantly below recognised perception thresholds of 85dB(G). It also reaffirms that infrasound is not unique to wind farms and is, in fact, produced by many sources, both natural and man-made.

**Summary of report findings:**

Source	Measurement level dB(G)
Adelaide CBD - 70m and 200m from two main roads	76
Cape Bridgewater beach - 25m from high water mark	75
Gas fired power station - 350m	74
Cliff face (Cape Bridgewater) 250m (approx) from the coastline	69
Clements Gap wind farm 185m downwind of the closest operating turbine	67
Cape Bridgewater wind farm 200m downwind of the closest operating turbine	63
Ambient infrasound measurement at Cape Bridgewater wind farm (wind farm not operating). Recording taken 100m downwind from turbine but with turbines not operating.	62
8km inland from the coast - Victoria	57
Adelaide suburb (Blackwood) at 10m with no wind	51

Full report attached.

Sonus Pty Ltd  
17 Ruthven Avenue  
ADELAIDE SA 5000  
Phone: (08) 8231 2100  
Facsimile: (08) 8231 2122  
[www.sonus.com.au](http://www.sonus.com.au)  
ABN: 67 882 843 130



# **INFRASOUND MEASUREMENTS FROM WIND FARMS AND OTHER SOURCES**

**Prepared for:**

**Pacific Hydro Pty Ltd  
Level 11, 474 Flinders Street  
Melbourne VIC 3000**

**November 2010**



## CONTENTS

CONTENTS .....	2
EXECUTIVE SUMMARY .....	3
INTRODUCTION .....	6
INTERNATIONAL DESKTOP RESEARCH.....	7
Mechanical Noise.....	8
Aerodynamic Noise .....	8
<i>Amplitude Modulation</i> .....	9
<i>Low Frequency Noise</i> .....	10
<i>Infrasound</i> .....	11
DETERMINATION OF A MEASUREMENT METHODOLOGY .....	13
Microphone Mounting Method .....	13
Inputs.....	15
MEASUREMENTS .....	17
Controlled Verification .....	17
RESULTS.....	20
Testing at Clements Gap Wind Farm.....	20
Testing at Cape Bridgewater Wind Farm .....	25
Map 1: Cape Bridgewater Wind Farm Measurement Locations .....	29
Testing of other man-made noise sources.....	30
Comparison against International results.....	32
CONCLUSION .....	34
Reference list.....	36

## **EXECUTIVE SUMMARY**

Infrasound is generated by a range of natural sources, including waves on a beach and against the coastline, waterfalls and wind. It is also generated by a wide range of man-made sources such as industrial processes, vehicles, air conditioning and ventilation systems and wind farms.

Specific International studies, which have measured the levels of infrasound in the vicinity of operational wind farms, indicate the levels are significantly below recognised perception thresholds and are therefore not detectable to humans.

The measurement of infrasound at low levels requires a specific methodology, as it is readily affected by wind on the microphone. Such a methodology has been developed for this study to measure infrasound from two Australian wind farms for the purposes of comparison against recognised perception thresholds. This study also measures the levels of infrasound from a range of natural and man made sources using the same methodology for the purposes of comparison against the wind farm results.

The specific methodology is based on measurements being conducted below the ground surface in a test chamber that is approximately 500mm square and 500mm deep to reduce the influence that even light surface breezes can have on the infrasound results.

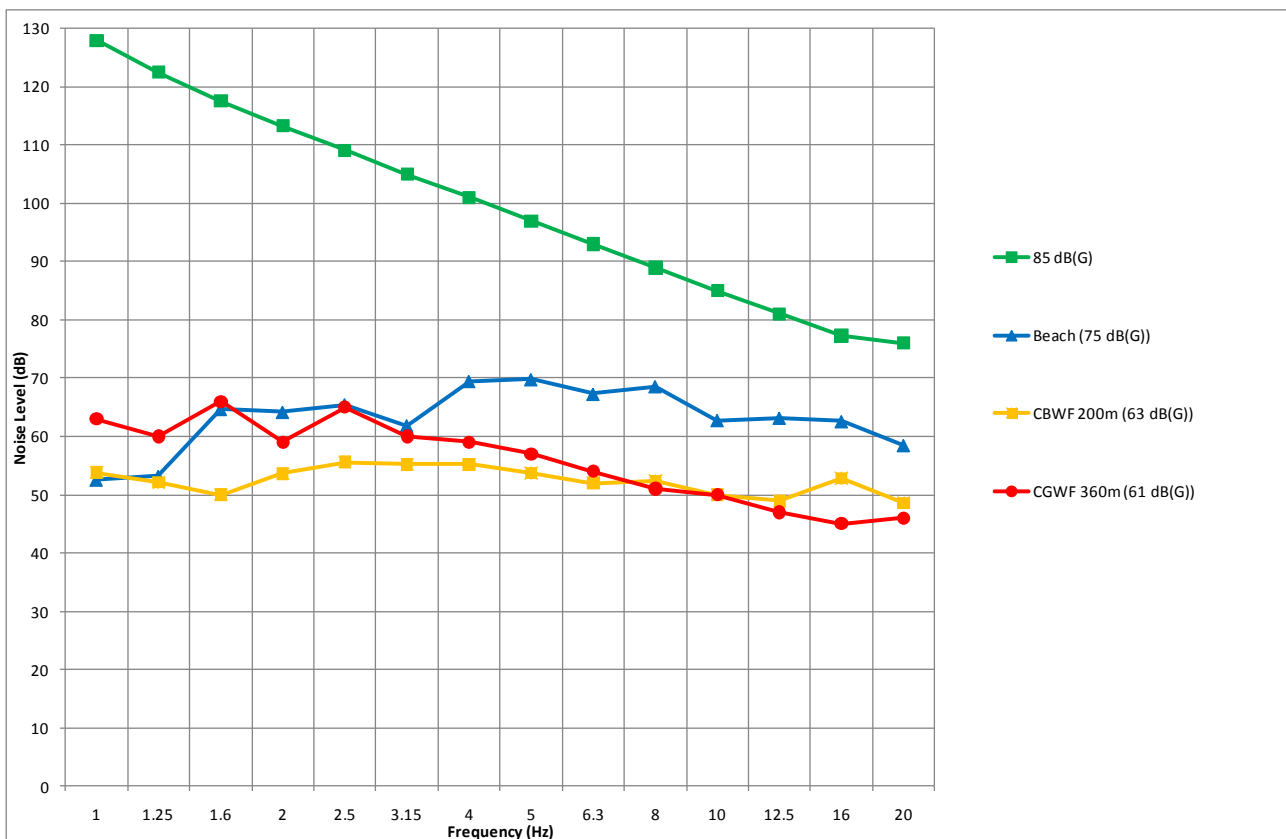
The below ground methodology has been tested as part of this study and it has been confirmed that levels of infrasound above the ground and within the chamber are the same in the absence of surface winds when measuring a known and constant source of infrasound.

The methodology has also been tested on site, and it has been confirmed that the expected theoretical reduction in infrasound of 6 dB per doubling of distance can be measured from a wind turbine. This reduction cannot be measured above the ground surface due to wind on the microphone influencing the results. This result confirms that the below ground methodology is able to reduce the influence of wind on the microphone to identify the level of infrasound from a noise source.



Infrasound was measured at two Australian wind farms, Clements Gap in the mid-North of South Australia (CGWF) and Cape Bridgewater in the coastal region of south-western Victoria (CBWF), using the below ground methodology. Infrasound was also measured in the vicinity of a beach, the coastline, a central business area and a power station using the below ground methodology.

A summary graph of the results of the infrasound measurement results at the wind farms and at a beach are shown below against the perception threshold for infrasound established in international research as 85 dB(G).



**Summary Graph – Infrasound measurement results from two Australian wind farms (Clements Gap at 61 dB(G) and Cape Bridgewater at 63 dB(G)) compared against measurement results at a beach (measured at 75 dB(G)) and the internationally recognised Audibility Threshold (85 dB(G))**



The measurement results indicate that the levels of infrasound in the vicinity of the two Australian wind farms are:

- well below the perception threshold established in International research as 85 dB(G); and
- of the same order as other International infrasound measurement results (a table summarising the results of other measurements is provided in this study); and
- of the same order as that measured from a range of sources including the beach, the Adelaide Central Business District and a power station.

This Australian study therefore reinforces several international studies by government organisations that infrasound emissions from wind farms are well below the hearing threshold and are therefore not detectable to humans.

This study goes beyond the international studies by providing comparative measurements of natural and other human made sources. These sources, including waves on a beach and motor vehicles, have been found to generate infrasound of a similar order to that measured in close proximity to wind farms.

In addition, measurements of the transfer of infrasound from outside to inside a dwelling have been made in this study, to confirm that the levels of infrasound inside a dwelling will be lower than the levels of infrasound outside a dwelling for an external noise source. This information is important because there is limited research available on this transfer.

## INTRODUCTION

Noise is often the most important factor in determining the separation distance between wind turbines and sensitive receivers. The assessment of noise therefore plays a significant role in determining the viability of and the size of wind farms.

Australian States presently assess the noise from wind farms under a range of Standards and Guidelines. These Standards and Guidelines do not provide prescriptive requirements for infrasound from wind farms due to the absence of evidence that infrasound should be assessed.

Notwithstanding, there have been concerns raised by the community regarding infrasound levels from wind farms.

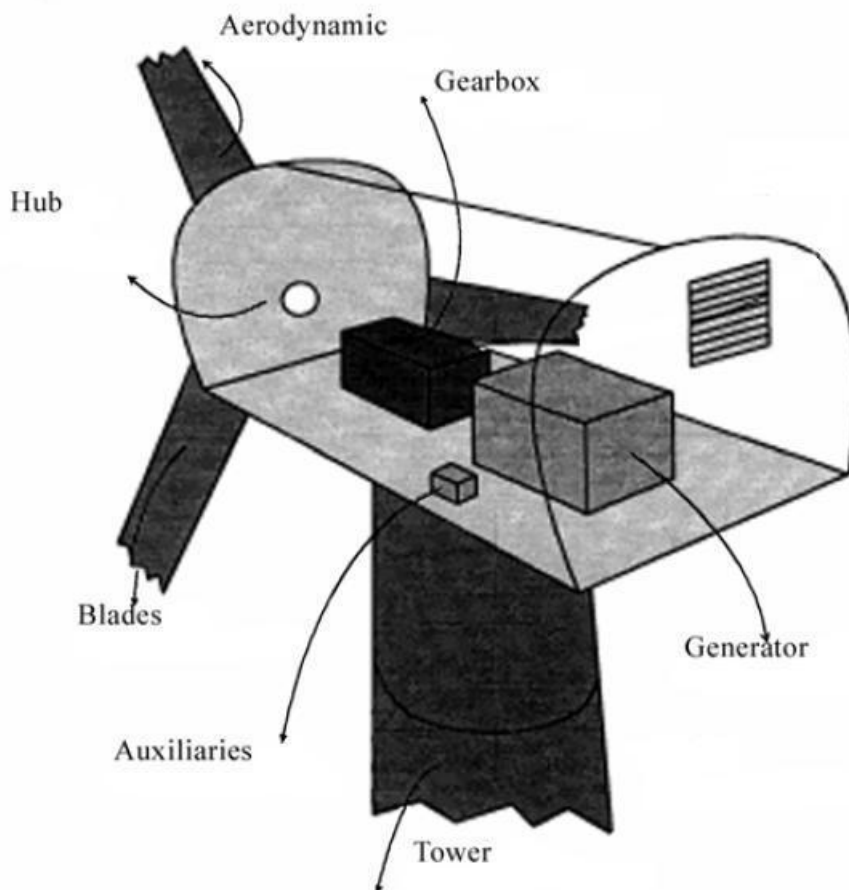
Pacific Hydro has therefore engaged Sonus to make an independent assessment of the infrasound produced by wind farms.

To further investigate infrasound in the vicinity of Australian wind farms, this study:

- Develops a methodology to measure infrasound that minimises the influence of wind on the microphone;
- Measures the levels of infrasound at a range of distances from two wind farms;
- Compares the results against recognised audibility thresholds;
- Compares the results with previous wind farm infrasound measurements made in a range of other studies; and
- Compares the results with infrasound measurements made of natural sources, such as beaches, and man-made sources, such as a power station and general activity within the Central Business District of Adelaide.

## INTERNATIONAL DESKTOP RESEARCH

Noise is inherently produced by movement. There are two main moving parts that generate the environmental noise from a wind turbine, being the external rotating blades and the internal mechanical components such as the gearbox and generator.



**Figure 1 - (Modified from Wagner 1996)**

The noise from the blades and the internal machinery are commonly categorised as mechanical and aerodynamic noise respectively.



## **Mechanical Noise**

Mechanical noise sources are primarily associated with the electrical generation components of the turbine, typically emanating from the gear box and the generator. Mechanical noise was audible from early turbine designs, however, on modern designs, mechanical noise has been significantly reduced (Moorhouse et al., 2007).

## **Aerodynamic Noise**

Aerodynamic noise typically dominates the noise emission of a wind turbine and is produced by the rotation of the turbine blades through the air.

Turbine blades employ an airfoil shape to generate a turning force. The shape of an airfoil causes air to travel more rapidly over the top of the airfoil than below it, producing a lift force as air passes over it. The nature of this air interaction produces noise through a variety of mechanisms (Brooks et al., 1989).

Aerodynamic noise is broadband in nature and includes acoustic energy in the infrasound, low, mid and high frequency ranges.

Whilst the aerodynamic noise from a rotating turbine blade produces energy in the infrasound range, there are natural sources of infrasound including wind and breaking waves, and a wide range of man-made sources such as industrial processes, vehicles and air conditioning and ventilation systems that make infrasound prevalent in the natural and urban environment (Howe, 2006).

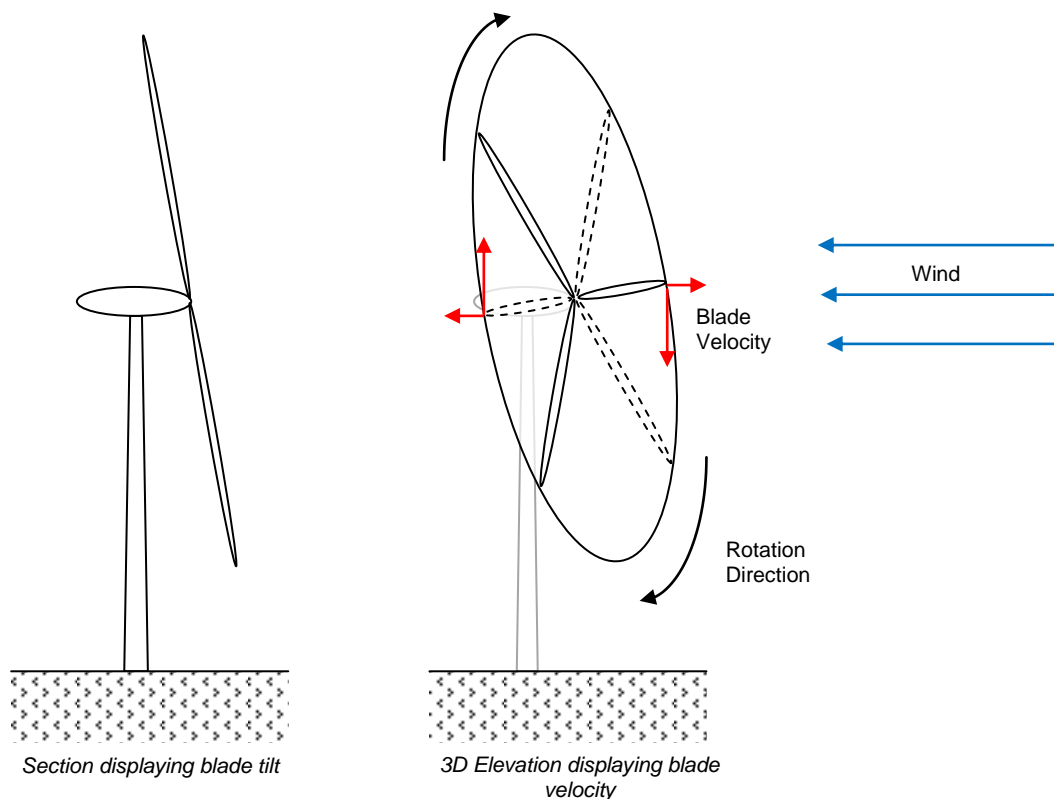
Aerodynamic noise can be further separated into the following categories which are relevant to the infrasound study:

### Amplitude Modulation

Amplitude modulation is most commonly described as a “swish” (Pedersen, 2005). “Swish” is a result of a rise and fall in the noise level from the moving blades. The noise level from a turbine rises during the downward motion of the blade. The effect of this is a rise in level of approximately once per second for a typical three-bladed turbine as each blade passes through its downward stroke.

It was previously thought that “swish” occurred as the blade passed the tower, travelling through disturbed airflow, however, a recent study indicates it is related to the difference in wind speed over the swept area of a blade (Oerlemans and Schepers, 2009).

Other explanations for the rise in noise level that occurs on the downward stroke relate to the slight tilt of the rotor-plane on most modern wind turbines to ensure that the blades do not hit the tower. An effect of the tilt is that when the blades are moving downwards they are moving against the wind. Conversely, when moving upwards they are moving in the same direction as the wind. Therefore, with the effective wind speed being higher on the downward stroke, it is suggested that a higher noise level is produced.



**Figure 2 - Blade Velocity due to Tilt**

### Low Frequency Noise

Noise sources that produce low frequency content, such as a freight train locomotive or diesel engine have dominant noise content in the frequency range between 20 and 200 Hz (O'Neal et al, 2009). Low frequency noise is often described as a "rumble".

Aerodynamic noise from a wind turbine is not dominant in the low frequency range. The main content of aerodynamic noise generated by a wind turbine is often in the area known generically as the mid-frequencies, being between 200 and 1000Hz.

Noise reduces over distance due to a range of factors including atmospheric absorption. The mid and high frequencies are subject to a greater rate of atmospheric absorption compared to the low frequencies and therefore over large distances, whilst the absolute level of noise in all frequencies reduces, the relative level of low frequency noise compared to the mid and high frequency content increases. For example, when standing alongside a road corridor, the mid and high frequency noise from the tyre and road interaction is dominant, particularly if the road surface is wet. However, at large distances from a road corridor in a rural environment, the remaining audible content is the low frequency noise of the engine and exhaust.

This effect will be more prevalent in an environment that includes masking noise in the mid and high frequencies, such as that produced by wind in the trees.

Separation distances between wind farms and dwellings can be of the order of 800 to 1200m. At these distances, in an ambient environment where wind in the trees is present, it is possible that only low frequencies remain audible and detectable from a noise source that produces content across the full frequency range. This effect will become more prevalent for larger wind farms because the separation distances need to be greater in order to achieve the relevant noise standards. A greater separation distance changes the dominant frequency range from the mid frequencies at locations close to the wind farm to the low frequencies further away, due to the effects described above.

Low frequency sound produced by wind farms is not unique in overall level or content. Low frequency noise from other sources that is well in excess of that in the vicinity of a wind farm can be measured and heard at a range of suburban and rural locations.

The low frequency content of noise from a wind farm is inherently considered as part of its environmental noise assessment against relevant standards and guidelines.

## Infrasound

Infrasound is generally considered to be noise at frequencies less than 20 Hz (O'Neal et al., 2009). The generation of infrasound was detected on early turbine designs, which incorporated the blades 'downwind' of the tower structure (Hubbard and Shepherd, 1990). The mechanism for the generation was that the blade passed through the wake caused by the presence of the tower.

Audible levels of infrasound have been measured from downwind blade wind turbines (Jakobsen, J., 2005). Modern turbines locate the blades upwind of the tower and it is found that turbines of contemporary design now produce much lower levels of infrasound (Jakobsen, J., 2005), (Hubbard and Shepherd 1990).

Infrasound is often described as inaudible, however, sound below 20 Hz remains audible provided that the sound level is sufficiently high (O'Neal et al., 2009). The thresholds of hearing for infrasound have been determined in a range of studies (Leventhall, 2003). These thresholds are depicted in graphical form below for frequencies less than 20 Hz (Figure 3).

Non-audible perception of infrasound through felt vibrations in various parts of the body is also possible, however, this is found to only occur at levels well above the audible threshold (Moeller and Pedersen, 2004).

Weighting networks are applied to measured sound pressure levels to adjust for certain characteristics. The A-weighting network (dB(A)) is the most common, and it is applied to simulate the human response for sound in the most common frequency range. The G-weighting has been standardised to determine the human perception and annoyance due to noise that lies within the infrasound frequency range (ISO 7196, 1995).

A common audibility threshold from the range of studies is an infrasound noise level of 85 dB(G) or greater. This is used by the Queensland Department of Environment and Resource Management's (DERM's) draft Guideline for the assessment of low frequency noise as the acceptable level of infrasound in the environment from a noise source to protect against the potential onset of annoyance.



The audibility threshold limit of 85 dB(G) is consistent with other European standards and studies, including the UK Department for Environment, Food and Rural Affairs threshold developed in 2003 (DEFRA., Leventhall, 2003), the UK Department of Trade and Industry study (DTI, Hayes McKenzie, 2006), the German Standard DIN 45680, the Denmark National Standard and independent research conducted by Watanabe and Moeller (Watanabe and Moeller, 1990).

The 85 dB(G) audibility threshold limit is shown in Figure 3 below. Other audibility thresholds have also been overlaid to provide a comparison.

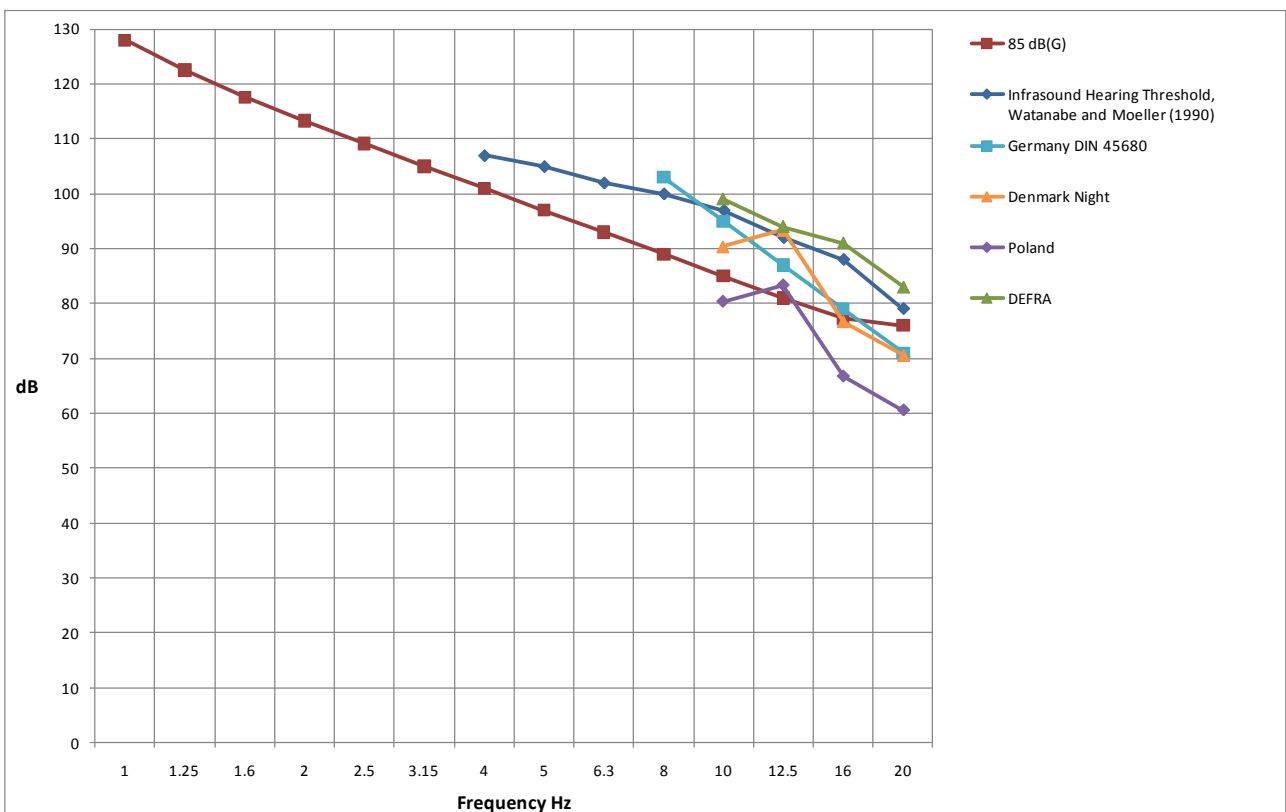
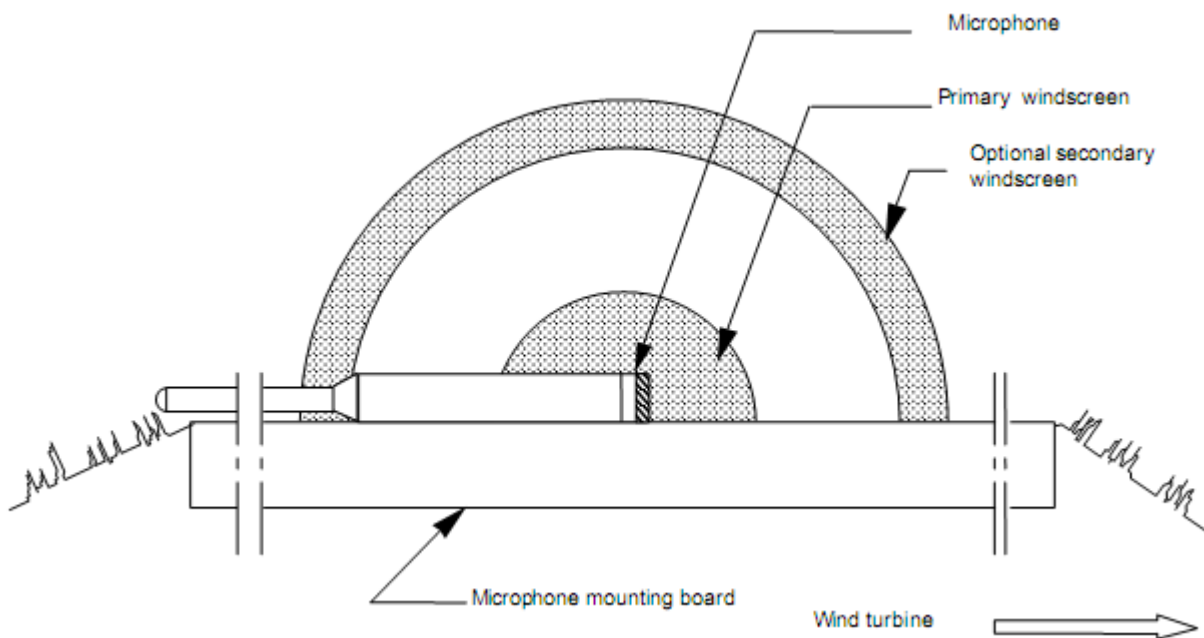


Figure 3 - Audibility Threshold Curves from the Listed Sources

## DETERMINATION OF A MEASUREMENT METHODOLOGY

### Microphone Mounting Method

A microphone mounting method is provided in IEC 61400-11 (IEC, 2002), as shown in Figure 4 below. The method was developed to minimise the influence of wind on the microphone for the measurement of noise in frequencies higher than those associated with infrasound. This is achieved by mounting the microphone at ground level on a reflecting surface and by protecting the microphone with two windshields constructed from open cell foam.



**Figure 4 - Mounting of the microphone – vertical cross-section  
(Reproduced from Figure 1b, IEC 61400-11)**

The above method was not developed specifically for the measurement of infrasound, and wind gusts can be clearly detected when measuring in the infrasound frequency range using the above method.

Therefore, this study has developed an alternative method to reduce the influence of wind on the microphone that would otherwise mask the infrasound from the turbine.



A below ground surface method was developed based on a similar methodology (Betke et al, 2002). This method has been adapted for this study, and includes a dual windshield arrangement, with a foam layer mounted over a test chamber, and a primary windshield used around the microphone.

The microphone mounting arrangement is depicted in the following schematic:

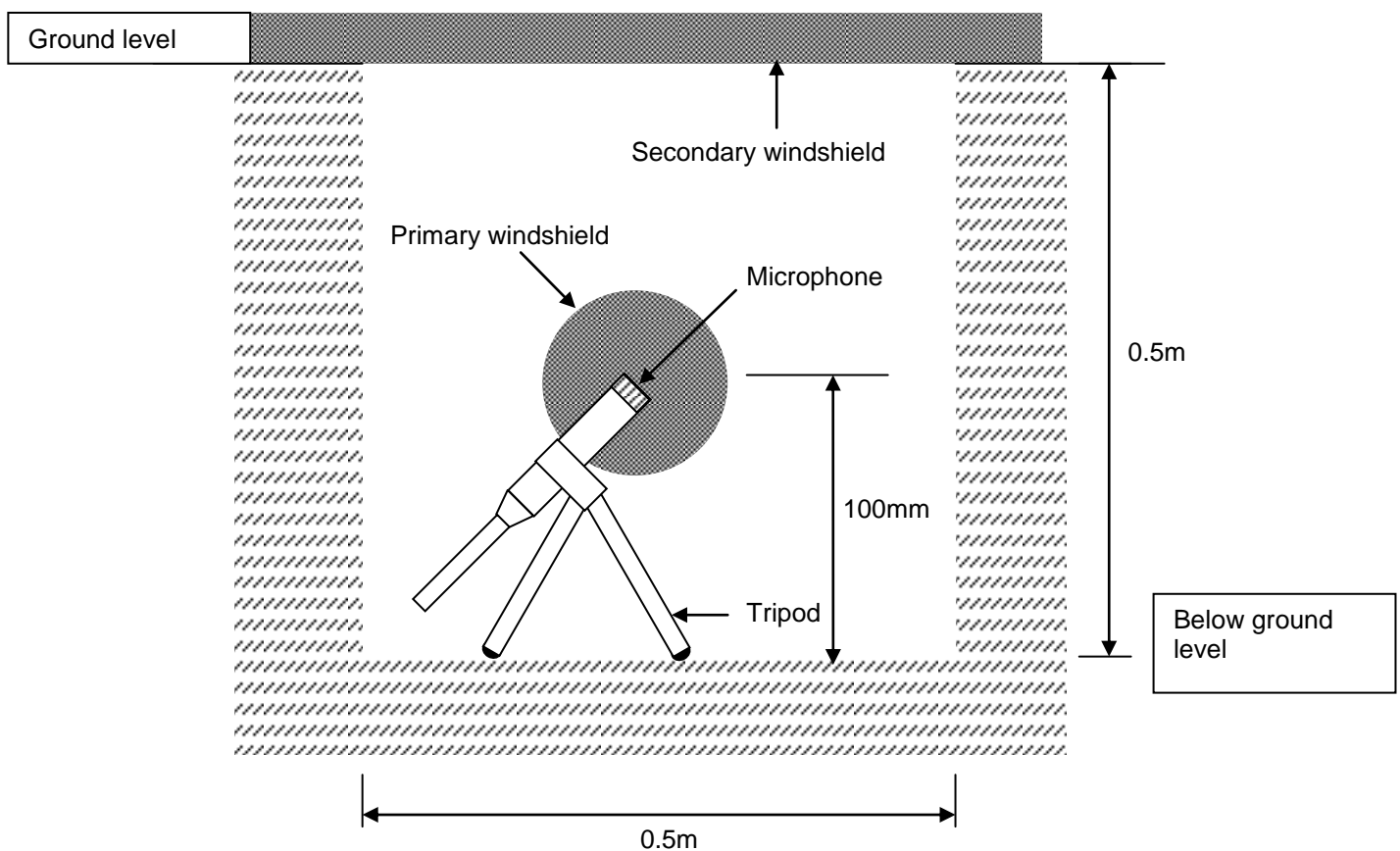


Figure 5 - Schematic of Microphone Position



## Inputs

The measurement methodology was developed with the following inputs:

- Literature review related to wind turbine infrasound research;
- Measurements to determine the influence of wind on the microphone using different measurement techniques, including the IEC 61400-11 measurement procedure, placing the microphone in an enclosure above the ground, and placing the microphone in a 500mmx500mmx500mm deep (approximate) test chamber with an open cell foam (acoustically transparent) lid, based on the Betke et al method. The measurements were initially made at locations without any appreciable man made noise sources;
- Measurements to determine the level of transfer of infrasound at a range of different frequencies between 8Hz and 20Hz, from immediately outside a chamber to inside a chamber, under conditions of negligible wind and ambient noise influence. The infrasound noise source (bass speaker and tone signal generator) was placed 10m away from the chamber and 1m above the ground;
- Measurements to determine the level of transfer of infrasound at a range of different frequencies between 8Hz and 20Hz, from immediately outside a lightweight elevated dwelling with windows open, to inside a room within that dwelling, under conditions of negligible wind and ambient noise influence, comprising use of an infrasound noise source (bass speaker and tone signal generator) placed 10m from the dwelling and 1m above the ground;
- Discussions with Mr Andrew Roberts of REPower Australia Pty Ltd regarding the test measurement procedure and the preliminary results.





Based on the above, the important factors for an infrasound measurement methodology comprise:

- The ability to reduce the influence of wind on the microphone;
- Turning the noise source on and off to confirm infrasound from the source can be identified within the ambient environment;
- Measurement conditions that minimise the influence of the ambient environment whilst enabling the operation of a wind farm. This is expected to comprise a light breeze (similar to a Beaufort Scale 2 breeze of between 2 and 3 m/s at ground level) occurring on a night or early morning with a clear sky.



## **MEASUREMENTS**

### **Equipment**

All measurements were made with the SVANTEK 957 Type 1 NATA calibrated sound and vibration analyser. The SVANTEK 957 Type 1 meter has a measured frequency response to 0.5 Hz. A GRAS 40AZ ½" free field microphone with a frequency response of  $\pm 1$ dB to 1 Hz was also used. The meter and microphone arrangement is therefore suitable for measurement of noise levels in the infrasound range.

### **Controlled Verification**

The below ground technique was analysed at a remote site away from a wind farm, transport corridor or other appreciable noise source and in very still conditions. The location was a suburban property in Blackwood, a suburb of the Adelaide Hills.

The aim of the analysis was to determine the level of transfer of infrasound from outside to inside the chamber. The following procedure was used:

- Generation of a constant level of infrasound using a tone signal generator and sub-woofer speaker, mounted 1m above the ground at a distance of 10m horizontally from the chamber. The infrasound was generated at a number of discrete frequencies between 8 and 20 Hz;
- Measurement of the infrasound using the IEC 61400-11 above ground technique;
- Measurement of the infrasound using the below ground technique;
- Measurement of the infrasound without the tone signal generator operating (ambient infrasound).

In addition, to provide additional information regarding the noise level reduction of infrasound from outside to inside a dwelling, a measurement of infrasound inside a lightweight dwelling with the windows open was also made at a number of discrete frequencies.

The testing was conducted between approximately 9pm and 11pm on two occasions in Blackwood under conditions of negligible breeze and no appreciable ambient noise sources.



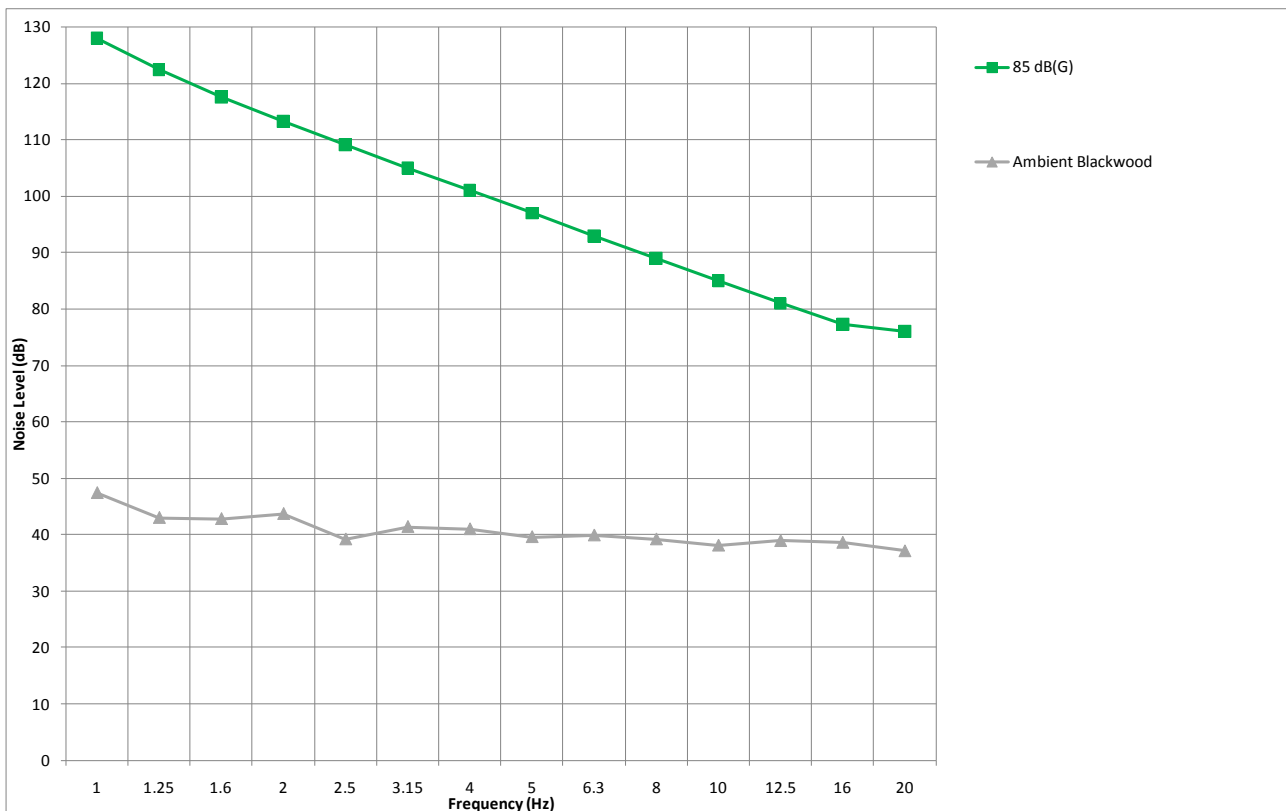
The measurement results are summarised in the following tables and the ambient noise level is shown in Figure 6.

**Table 1 - Measurement approximately 10m from controlled source with no wind**

Frequency (Hz)		8.00	10.0	12.5	16.0	20.0
Noise Level (dB)	Inside chamber	47	50	54	60	63
	Outside chamber	47	50	54	60	63

**Table 2 - Measurement of ambient conditions in test location (controlled source turned off)<sup>1</sup>**

Frequency (Hz)	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	39	38	39	39	37	51



**Figure 6 - Ambient infrasound noise level measured without any appreciable noise sources or wind**

<sup>1</sup> Measurements of the ambient levels of infrasound were also made at frequencies lower than 8 Hz. These results are shown in Figure 8. The sub-woofer arrangement was not able to generate infrasound below 8 Hz. Table 7 shows the results from 8 Hz to 20 Hz for the purposes of comparison with Table 6.



The results of the testing of the effect of a lightweight facade (with the windows open) on the transfer of infrasound are presented in the following tables:

**Table 3 - Measurement of facade transfer with controlled source**

Frequency (Hz)		10.0	16.0	20.0
Noise Level (dB)	Inside house	47	61	54
	Outside house	54	63	56

**Table 4 - Measurement of ambient conditions in house locations**

Frequency (Hz)		10.0	16.0	20.0
Noise Level (dB)	Inside house	37	41	34
	Outside house	42	43	41

The above conclusions can be made from the above results and on site observations:

- The measurement of a constant source of infrasound in still conditions is the same above the ground as in the chamber using the technique described above. Therefore, the below ground technique can be used to measure the infrasound from a source;
- The results are consistent at a number of discrete frequencies between 8 Hz and 20 Hz;
- The levels of infrasound inside a dwelling will be lower than the levels of infrasound outside a dwelling for an external noise source. This information is important because there is limited research available on this transfer. These results are consistent with Jakobsen, J., 2005, who found that “the outdoor to indoor correction may be quite small in a part of the infrasound range, but it is unlikely to become negative, which would imply a higher level indoors than out of doors”.

## RESULTS

Infrasound was measured at Clements Gap in the mid-North of South Australia (CGWF) and Cape Bridgewater in the coastal region of south-western Victoria (CBWF), using the verified below ground methodology. At Clements Gap, measurements were also made concurrently using the above ground technique provided by IEC 61400-11.

The following sections summarise the results of the measurements at the wind farms and in the vicinity of other sources of infrasound including a beach, the coastline, a central business area and a power station.

### Testing at Clements Gap Wind Farm

Testing at the Clements Gap wind farm was conducted using the following procedure:

- Measurement of infrasound using the IEC 61400-11 above ground technique at distances of 85, 185 and 360m from the base of the turbine in a downwind direction; and
- Measurement of infrasound using the below ground technique at distances of 85, 185 and 360m from the base of the turbine in a downwind direction.

The testing was conducted between approximately 7pm and 11pm on Tuesday the 11<sup>th</sup> of May under a clear night sky with a light breeze. Operational data indicates the turbines were subject to hub height wind speeds of the order of 6 to 8m/s during the period of the testing.

The measurement results in close proximity to the wind turbine are summarised in the following tables and shown in the following figure. The tables provide the measured noise level at each 1/3 octave band between 1 and 20 Hz and also sum the results to provide an overall dB(G) noise level. The figure includes the 85 dB(G) audibility threshold.

Twenty (20) continuous 1 minute measurements were made at each location. The presented results are typical of those during the measurement period, excluding those at the start and end of the period, where movements adjacent the measurement equipment might influence the results. The number of continuous measurements is based on the on site observations regarding the repeatability of the results.



**Table 5 - Measurement approximately 85m downwind from closest operational turbine (No. 25)**

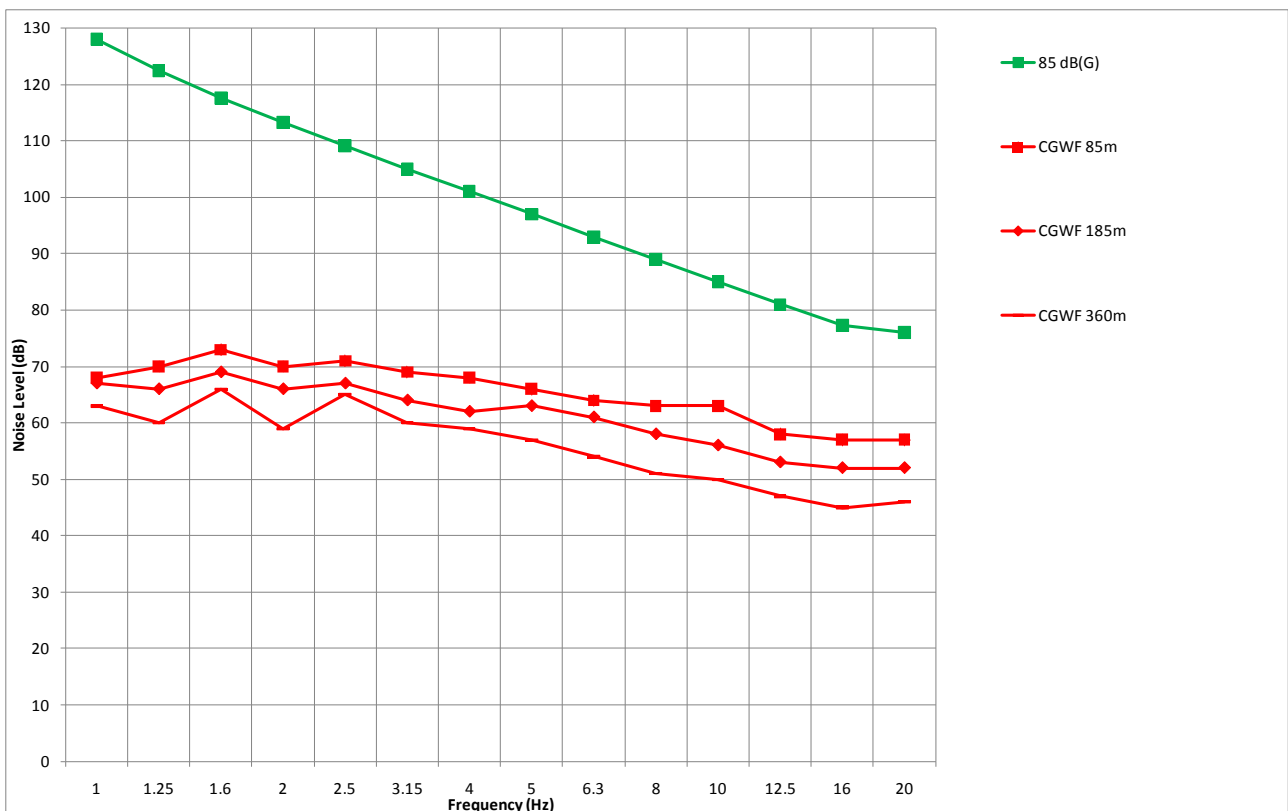
Frequency (Hz)		1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	Inside chamber	68	70	73	70	71	69	68	66	64	63	63	58	57	57	72
	Outside chamber	70	71	72	70	69	69	68	67	66	63	60	57	57	56	71

**Table 6 - Measurement approximately 185m downwind from closest operational turbine (No. 25)**

Frequency (Hz)		1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	Inside chamber	67	66	69	66	67	64	62	63	61	58	56	53	52	52	67
	Outside chamber	80	79	79	77	77	77	75	75	73	72	71	69	66	64	80

**Table 7 - Measurement approximately 360m downwind from closest operational turbine (No. 25)**

Frequency (Hz)		1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	Inside chamber	63	60	66	59	65	60	59	57	54	51	50	47	45	46	61
	Outside chamber	71	69	72	72	72	68	69	65	64	61	59	55	53	50	67



**Figure 7 - Infrasound measurements below the ground at Clements Gap wind farm**



The theoretical reduction in noise level from a noise source is 6dB for every doubling of the distance from that source due to the “hemispherical spreading” of the sound wave. This reduction theoretically applies to noise at all frequencies, including below 20 Hz. Tables 5, 6 and 7 indicate that a reduction in the order of 6 dB is achieved using the below ground technique, but not for the above ground technique. This is due to the above ground measurements being influenced by surface wind on the microphone.

The following conclusions can be made from the results and on site observations:

- The wind turbines generate infrasound;
- The level of infrasound is well below the audibility threshold of 85 dB(G);
- The distances at which the measurements of the operational wind farm were made are significantly less than separation distances expected between a wind farm and a dwelling, where the levels of infrasound will be correspondingly lower;
- A noise level reduction of approximately 6 dB was measured inside the chambers when doubling the distance from turbine 25. This indicates the level of infrasound measured below the ground was directly associated with turbine 25;
- The measurements above the ground surface did not reduce by 6 dB due to the presence of surface winds and their influence on the results. This indicates the IEC 61400-11 based test does not enable the infrasound from the turbines to be separated from infrasound due to the wind.

In addition to the above testing in close proximity to an individual turbine, the “Byarlea” residence was visited, which is approximately 1200m to the east of the nearest turbines in the Clements Gap wind farm.

An infrasound measurement was made within a room of the dwelling. The refrigerator was operating in the dwelling at the time of the measurement but a full survey of other operating equipment was not made. A level of the order of 51 dB(G) was measured.



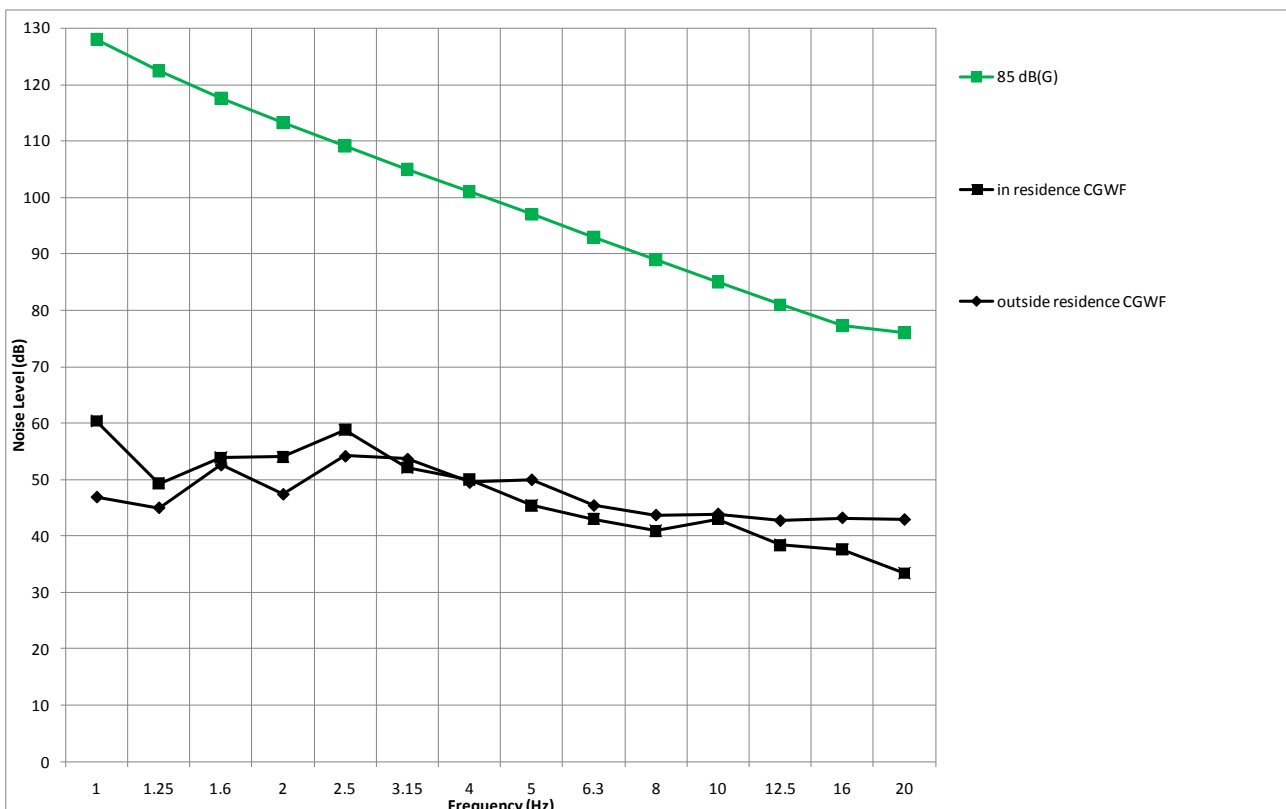
Given the still conditions at the dwelling at the time of inspection, a local above ground infrasound measurement outside the dwelling was able to be made. A level of the order of 58 dB(G) was measured. The results of the measurements are presented in Tables 8 and 9 and Figure 8 below:

**Table 8 - Measurement inside a room of a dwelling**

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	60	49	54	54	59	52	50	45	43	41	43	38	38	33	51

**Table 9 - Measurement outside of dwelling**

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	47	45	53	47	54	54	50	50	45	44	44	43	43	43	58



**Figure 8 - Measurements of infrasound inside and outside a dwelling in the vicinity of the Clements Gap wind farm**

The above conclusions can be made from the above results and on site observations:





- The levels of infrasound inside a dwelling in the vicinity of a number of turbines associated with the Clements Gap wind farm is well below the audibility threshold of 85 dB(G);
- The levels of infrasound outside a dwelling in the vicinity of a number of turbines associated with the Clements Gap wind farm is well below the audibility threshold of 85 dB(G).



## Testing at Cape Bridgewater Wind Farm

The controlled verification testing and the Clements Gap Wind Farm test confirmed that the use of the below ground technique was able to reduce the influence of wind on the microphone and identify the level of infrasound associated with a wind turbine and/or a wind farm.

Therefore, testing at the Cape Bridgewater wind farm was conducted using the following trialed and analysed procedure based around the below ground technique:

- Measurement of infrasound using the below ground technique in close proximity to an operating wind turbine at distances of 100 and 200m from the base of the turbine in a downwind direction;
- Measurement of infrasound with the wind farm not operating;
- Measurement of infrasound at the beach to the east of Cape Bridgewater;
- Measurement of infrasound in the vicinity of the coastline to the west of Cape Bridgewater;
- Measurement of infrasound in a designated forest area approximately 8km inland from the coast, under conditions of negligible wind.

The testing at the wind farm site was conducted between approximately 4am and 6am on Wednesday the 2<sup>nd</sup> of June under a clear night sky with a light breeze. During the testing, the operational status of the turbines was constantly observed and confirmed. The results in Tables 10 and 11 were taken at distances of 100m and 200m respectively from the closest operational turbine. The results in Table 12 were taken with the wind farm stationary at the 100m measurement location.

The measurement results in close proximity to the wind turbine are summarised in the following tables and shown in the following figure. The tables provide the measured noise level at each 1/3 octave band between 1 and 20 Hz and also sum the results to provide an overall dB(G) noise level. The figure includes the 85 dB(G) audibility threshold and the ambient noise result from the Adelaide Hills.

Twenty (20) continuous 1 minute measurements were made at each location. The presented results are typical of those during the measurement period, excluding those at the start and end of the period, where movements adjacent the measurement equipment might influence the results.



**Table 10 - Measurement approximately 100m downwind from closest operational turbine**

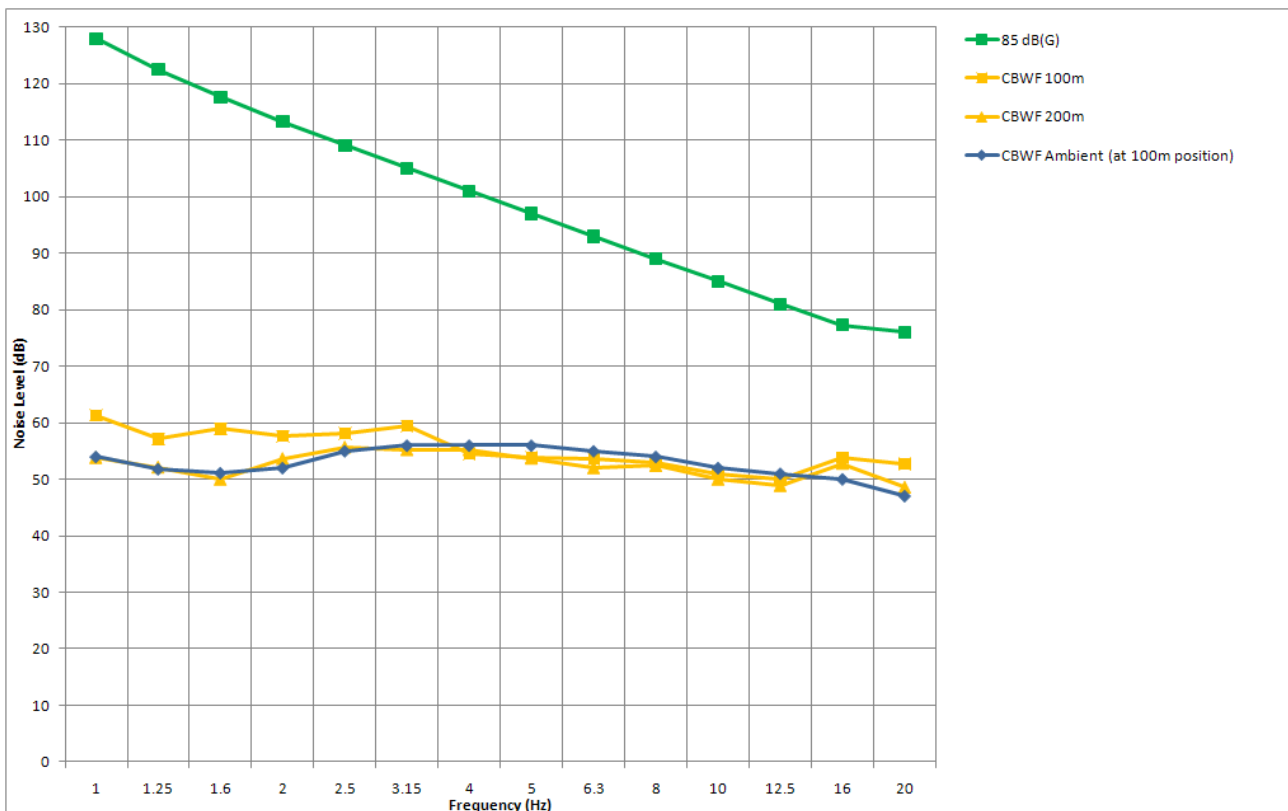
Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	61	57	59	58	58	59	55	54	54	53	51	50	54	53	66

**Table 11 - Measurement approximately 200m downwind from closest operational turbine**

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	54	52	50	54	56	55	55	54	52	52	50	49	53	49	63

**Table 12 - Ambient infrasound measurement (with the wind farm not operating)**

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	54	52	51	52	55	56	56	56	55	54	52	51	50	47	62



**Figure 9 - Infrasound measurements below the ground at Cape Bridgewater wind farm**



The above conclusions can be made from the above results and on site observations:

- The wind turbines generate infrasound;
- The level of infrasound is well below the audibility threshold of 85 dB(G);
- The distances at which the measurements of the operational wind farm were made are significantly less than separation distances between a wind farm and a dwelling, where the levels of infrasound will be correspondingly lower;
- A high level of ambient infrasound exists (infrasound in the absence of noise from the wind farm) which influences the results for the wind turbines.

Measurements were made in the vicinity of the adjacent beach and the coastline to confirm the source of the high ambient infrasound levels. In addition, a measurement was made inland to determine the extent of influence of the high ambient infrasound levels.

The results of the measurements are presented in Figure 10 below:

**Table 13 – Beach at approximately 25m from the high water mark**

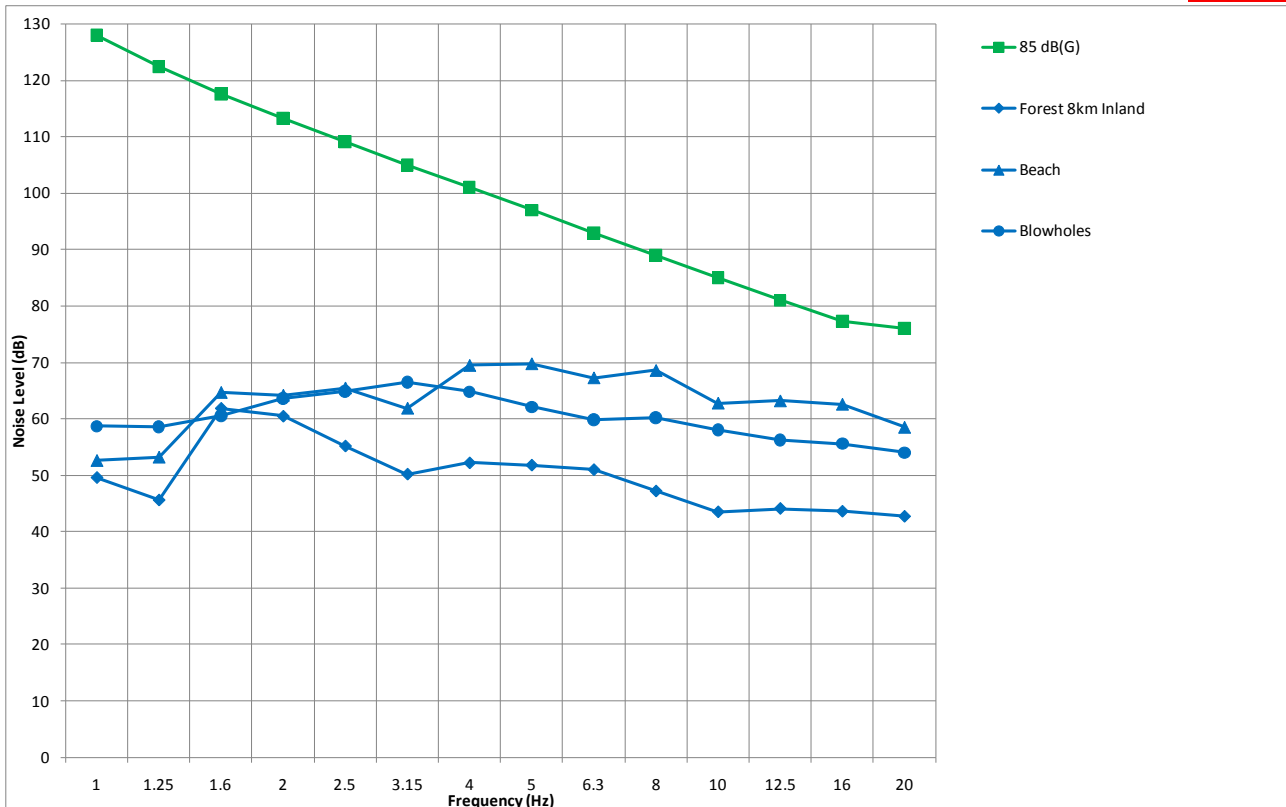
Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	53	53	65	64	66	62	70	70	67	69	63	63	63	59	75

**Table 14 –On the cliff face at approximately 250m from the coastline**

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	59	59	61	64	65	67	65	62	60	60	58	56	56	54	69

**Table 15 – Inland at approximately 8km from the coast**

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	50	46	62	61	55	50	52	52	51	47	44	44	44	43	57



**Figure 10 - Ambient noise measurements in the vicinity of Cape Bridgewater**

The following conclusions can be made from the above results and on site observations:

- Natural sources generate infrasound;
- The levels of infrasound from natural sources are of the same order as those measured within 100m of a wind turbine;
- Measurable levels of infrasound that are of a similar order to that measured in close proximity to a wind farm are prevalent in the natural environment over a large area due to sources other than wind farms.

The following map depicts measurement locations relative to the turbine:



**Map 1: Cape Bridgewater Wind Farm Measurement Locations**



**Testing of other man-made noise sources**

Testing has been conducted using the below ground technique in the vicinity of other man-made noise sources using the following procedure:

- Measurement of infrasound using the below ground technique at a distance of approximately 350m from a gas fired power station;
- Measurement of infrasound using the below ground technique within the Adelaide Central Business District at approximately 70m and 200m from two major road corridors;

The measurement results are summarised in the following tables and shown in the following figure. The tables provide the measured noise level at each 1/3 octave band between 1 and 20 Hz and also sum the results to provide an overall dB(G) noise level. The figure includes the 85 dB(G) audibility threshold and the ambient noise result from the Adelaide Hills.

The results presented are typical of those during the measurement period, excluding those at the start and end of the period, where movements adjacent the measurement equipment might influence the results.

**Table 16 – Power Station**

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	63	57	57	54	53	50	50	49	54	55	57	62	61	61	<b>74</b>

**Table 17 - CBD**

Frequency (Hz)	1.00	1.25	1.60	2.00	2.50	3.15	4.00	5.00	6.30	8.00	10.0	12.5	16.0	20.0	Total (dB(G))
Noise Level (dB)	63	60	61	62	61	58	59	56	56	53	55	60	65	63	<b>76</b>

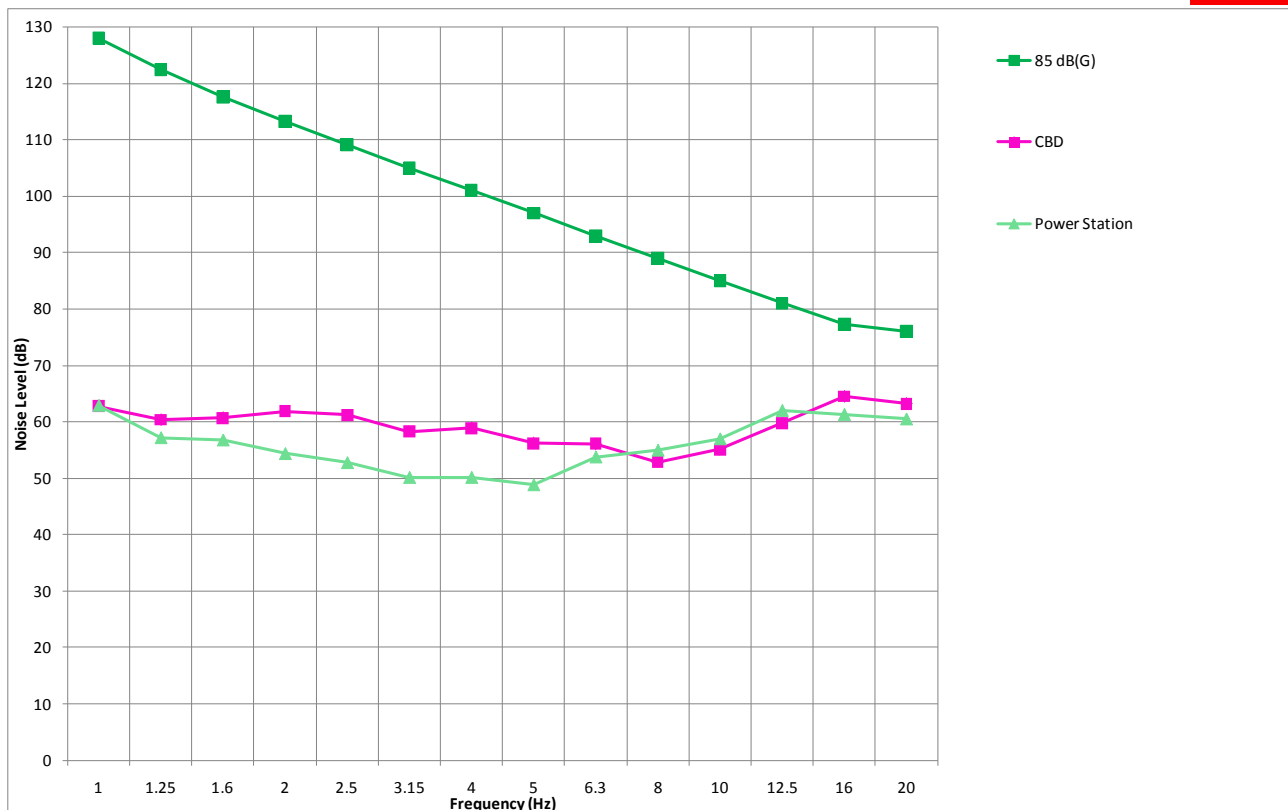


Figure 11 - Infrasound from man-made noise sources

The following conclusions can be made from the above results and on site observations:

- Man made sources generate infrasound;
- The levels of infrasound from man made sources are of the same order at those measured within close proximity of a wind turbine;
- Measurable levels of infrasound that are of a similar order to that measured in close proximity to a wind farm are prevalent in the urban environment over a large area due to sources other than wind farms.





### Comparison against International results

The Canadian Wind Energy Association (Howe, 2006) and Jakobsen, J., 2005, provide a summary of results of infrasound testing at a range of sites. The data is presented as an overall dB(G) level. The methodology used to measure these data is not known and therefore the results might be influenced by wind or other sources. These data and the measured levels as part of this study are summarised in the following table:

**Table 18 - Summary of Infrasound Levels**

Noise source	Distance (m)	Infrasound level dB(G)	Comments
General Electric MOD-1	105	107	Downwind turbines, known to generate higher levels of infrasound compared to a modern upwind turbine
General Electric MOD-1	1000	75	Downwind turbine
Hamilton Standard WTS-4	150	92	Downwind turbine
Hamilton Standard WTS-4	250	85	Downwind turbine
Boeing MOD-5B	68	71	Upwind two bladed turbine at a limited separation distance – this shows the significant reduction between downwind and upwind turbines
US Wind Power USWP-50	500	67-79	14 downwind turbines influencing the results
WTS-3	750	68	Downwind turbine
WTS-3	2100	60	Downwind turbine
Enercon E-40	200	64	Modern upwind turbine
Vestas V66	100	70	Modern upwind turbine
Vestas V80	60	79	Influenced by wave action from the Atlantic Ocean (HGC Engineering, 2006)
GE 1.5MW	300	67	Modern upwind turbine
Nordex N-80	200	60 (7m/s)	Measurements were made downwind from 5m/s to 12m/s. The level increases by approximately 1 dB(G) for each 1m/s increase in wind speed from 5m/s
DTI Wind Farm	1000	65	Details of the turbine type were not provided in the DTI study. The wind farm included seven turbines (DTI, Hayes McKenzie, 2006)
Siemens SWT 2.3-93	300	73	Measured as part of the "Epsilon" study (O'Neal, 2009)
GE 1.5sle	300	70	Measured as part of the "Epsilon" study (O'Neal, 2009)
Clements Gap	85	72	Modern upwind turbine
Clements Gap	180	67	Modern upwind turbine
Clements Gap	360	61	Modern upwind turbine
Cape Bridgewater	100	66	Modern upwind turbine, influenced by the ambient noise environment
Cape Bridgewater	200	63	Modern upwind turbine, influenced by the ambient noise environment

The main source of uncertainty associated with the measurement of infrasound is the influence of wind on the microphone. The methodology used by the international studies is not explicitly nominated, and therefore the contribution of wind on the microphone in the above results is not known. However, the infrasound associated with the turbines will be at most the same and more likely less than the results in the above table.

This study employs a specific methodology that aims to reduce the influence of wind on the microphone and therefore the extent of the uncertainty in the infrasound attributable to the turbines. However, the influence of wind and the presence of infrasound in the ambient environment when measuring in the vicinity of the coast, as is the case at Cape Bridgewater, are still expected to influence the results. Therefore, as for the international studies, the uncertainty predominantly relates to the extent that the infrasound from the turbines is below the results presented in this report.

Jakobsen, J. 2005 notes the following with respect to review of the data available for the 2005 works:

*...the level from an upwind turbine of contemporary design at 100m distance would be about 70 dB(G) or lower, while the level from a downwind machine can be 10 to 30 dB higher.*

The results of this study show infrasound noise levels of the order of 60 to 70 dB(G) in close proximity to wind turbines. Based on the above table, these levels show consistency with other International measurements of modern upwind turbines. In addition, the measured noise levels in this study are provided by a detailed methodology that reduces the influence of the wind and therefore the uncertainty for the results.



## CONCLUSION

The following conclusions can be made from the results of the study:

- Wind turbines generate infrasound, however, measurements made both outside and inside and at a variety of distances significantly less than separation distances between wind farms and dwellings, indicate the infrasound produced by wind turbines is well below established guideline perception thresholds;
- The level of infrasound that has been measured in both a rural coastal and an urban environment is of the same order as that measured within 100m of a wind turbine.

The following figure overlays the compiled results of the study:

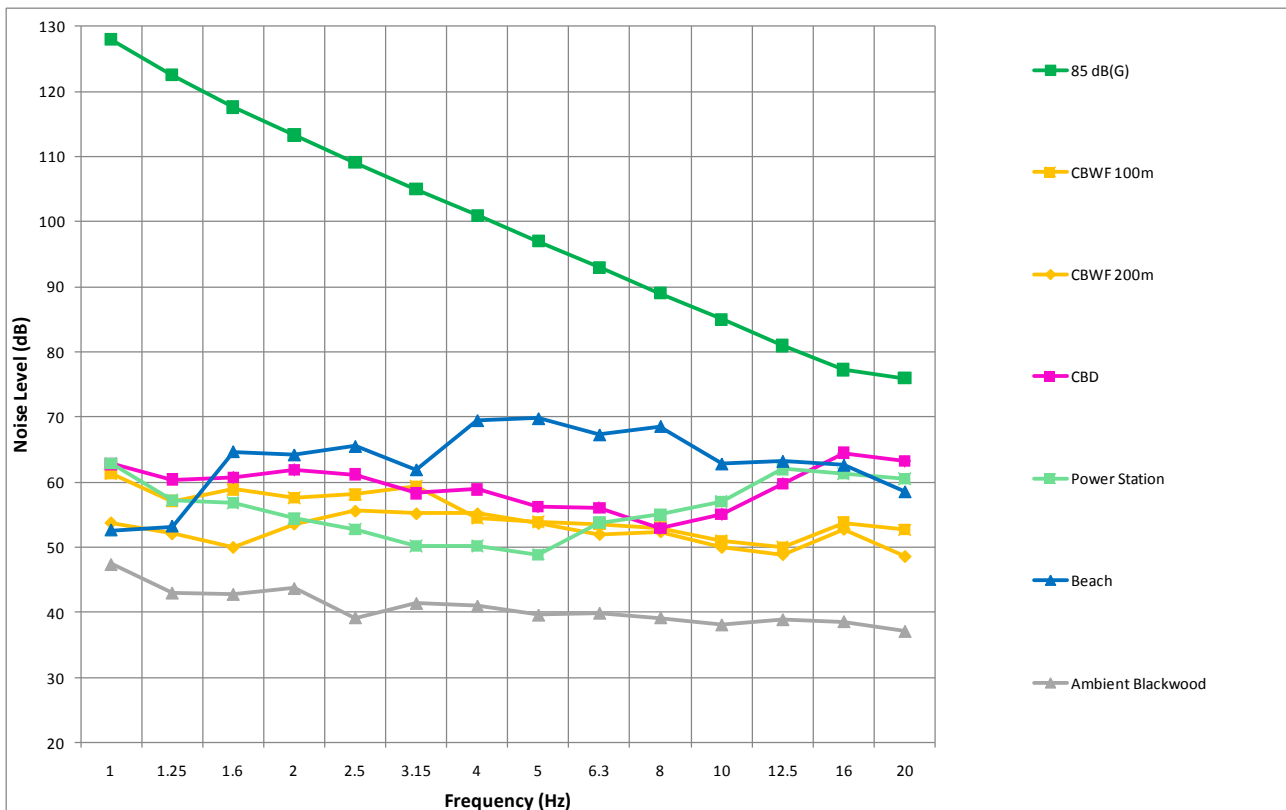


Figure 12 - Summary of Measurements Cape Bridgewater Wind Farm (CBWF)

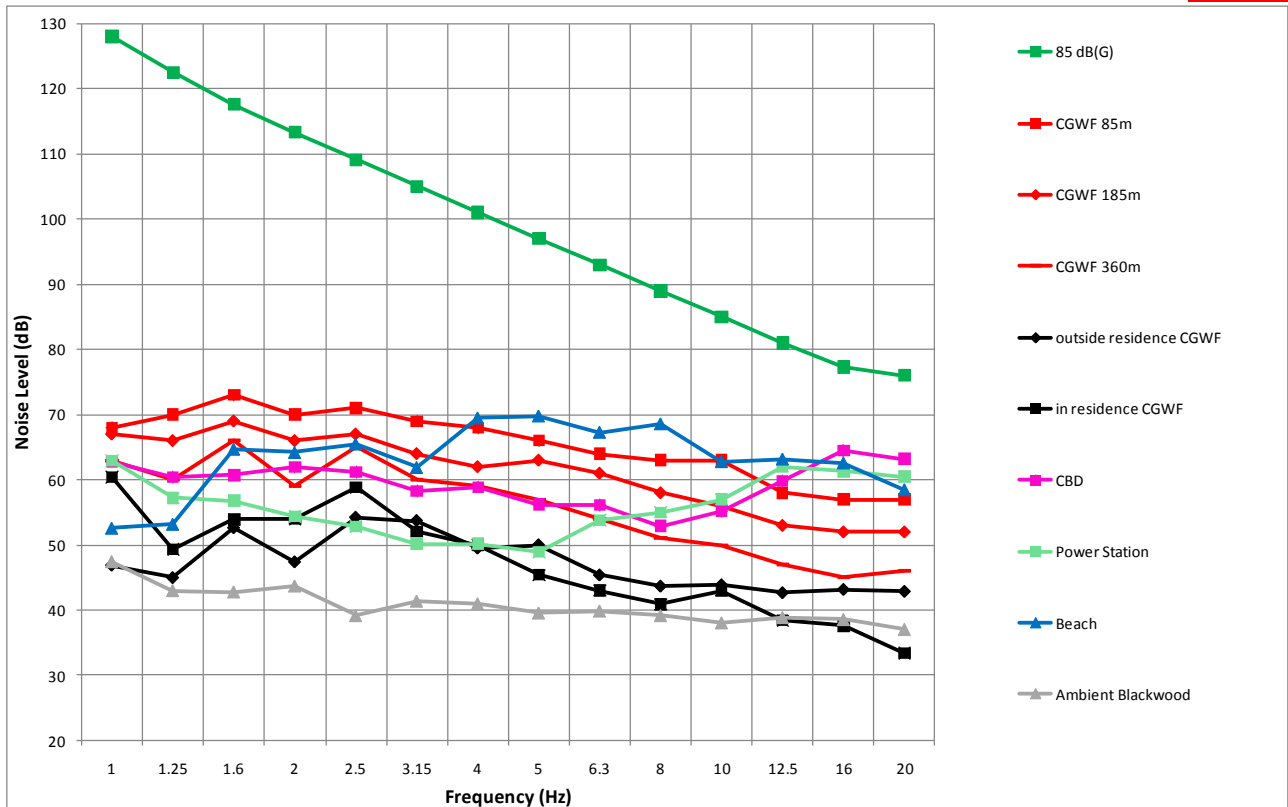


Figure 13 - Summary of Measurements Clements Gap Wind Farm (CGWF)



## REFERENCE LIST

Betke, K., Schults von Glahn, M., Goos, O.: Messung der Infraschallabstrahlung von windkraftanlagen" Proc DEWEK 1996, p 207-210 (In German)

Brooks, Thomas F., D. Stuart Pope, and Michael A. Marcolini. 1989. Airfoil self-noise and prediction. L-16528; NAS 1.61:1218; NASA-RP-1218.

[http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19890016302\\_1989016302.pdf](http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19890016302_1989016302.pdf)

Colby, W. D., Dobie, R., Leventhall, G., Lipscomb, D., McCunney, R., Seilo, M. and Sondergaard, B., (2009). Wind Turbine Sound and Health Effects An Expert Panel Review. American Wind Energy Association, Canadian Wind Energy Association.

Council of Standards Australia, 2010, "AS 4959-2010 Acoustics – Measurement, prediction and assessment of noise from wind turbine generators", Standards Australia, Sydney.

Environment Protection Heritage Council (EPHC), 2009, "National Wind Farm Development Guidelines – Public Consultation Draft", Adelaide.

Hayes McKenzie Partnership., 2006. "The Measurement of Low Frequency Noise at Three UK Wind Farms", UK Department of Trade and Industry (DTI)

Howe, B., November 2006. "Wind Turbines and Infrasound". Howe Gastmeier Chapnik Limited.

Hubbard, H. H., Shepherd, K. P., 1990, "Wind Turbine Acoustics", NASA

IEC 61400-11:2002 "Wind turbine generator systems – Part 11: Acoustic noise measurement techniques" IEC 2002

ISO 7196:1995 "Acoustics – Frequency weighting characteristics for infrasound measurements"

Jakobsen, J., (2005). "Infrasound Emission from Wind Turbines", Journal of Low Frequency Noise, Vibration and Active Control, Vol. 24, No. 3, Copenhagen

Leventhall, G., 2003 "A review of Published Research on Low Frequency Noise and its Effects" Department for Environment, Food and Rural Affairs (DEFRA), May 2003

Moeller, H, and C. S. Pedersen. "Hearing at Low and Infrasonic Frequencies", Noise and Health 2004, v6 issue 23, 37-57, 2004

Moorhouse, A., M. Hayes, S. von Hunerbein, B. Piper, and M. Adams. 2007. "Research into Aerodynamic Modulation of Wind Turbine Noise". Report: Department of Business, Enterprise and Regulatory Reform. [www.berr.gov.uk/files/file40570.pdf](http://www.berr.gov.uk/files/file40570.pdf)

Oerlemans, S. and G. Schepers. 2009. Prediction of wind turbine noise directivity and swish. Proceedings of the 3rd International Conference on Wind Turbine Noise. Aalborg, Denmark. June 17-19, 2009. INCE/Europe.

O'Neal, R., Hellweg, R. D. Jr, Lampeter, R. M., 2009, "A Study of Low Frequency Noise and Infrasound from Wind Turbines", Epsilon Associates Inc, Maynard.

Pedersen, E and Waye, K. P., (2005). "Human response to wind turbine noise – annoyance and moderating factors", in Proceedings of the First International Meeting on Wind Turbine Noise: Perspectives for Control, Department of Environmental Medicine, Goteborg University.

Pierpont, N., March 2009. "Wind Turbine Syndrome – A report on a natural experiment". Pre-publication draft.

Queensland EPA, "Guideline: Assessment of Low Frequency Noise"

South Australian Environment Protection Authority, 2003, "Wind farms environmental noise guidelines"

South Australian Environment Protection Authority, 2009, "Wind farms environmental noise guidelines"

Spiegel, H., 1997 "Nocebo: The Power of Suggestibility" Preventative Medicine, 26, 616-621 1997

Standards Council New Zealand, 1998, "NZS 6808:1998 Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators", Standards New Zealand, Wellington.

Standards Council New Zealand, 2010, "NZS 6808:2010 Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators", Standards New Zealand, Wellington.

Sydney Morning Herald, 2010 "Wind farm approval blows town apart" 5<sup>th</sup> April 2010

Wagner, S., Bareiss, R., Guidati, G., 1996 "Wind Turbine Noise", Springer Verlag.

Watanabe, T. and Moller, H.: Low frequency hearing thresholds in pressuere field and free field. Jnl Low Freq. Noise Vibn 9, 106-115

Worksafe Victoria, 10 February 2010, "Berrybank Wind Energy Facility" correspondence.