Macarthur Wind Farm
Infrasound & Low Frequency Noise
Operational Monitoring Results

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Glossary

A-weighting	A spectrum adaption that is applied to measured noise levels to approximate the frequency response of human hearing at low noise levels. A-weighted levels are used as human hearing does not respond equally at all frequencies.
Decibel	Unit of measurement (expressed as dB) used to express sound level. We typically perceive a 10 dB increase as a doubling of the sound level.
dB	Unit of unweighted (linear) sound pressure levels.
dB(A)	Unit of sound pressure levels that have had the A-weighting function applied to them.
dB(G)	Unit of sound pressure levels that have had the G-weighting function applied to them.
Frequency	The number of times a vibrating object oscillates (moves back and forth) in one second. Fast movements produce high frequency sound (high pitch/tone), but slow movements mean the frequency (pitch/tone) is low.
G-weighting	Spectrum adaptation that is applied to approximate how the human ear responds to infrasound.
Hertz (Hz)	Unit of frequency – one Hz is equivalent to one cycle per second.
Infrasound	Sound or noise whose frequency spectrum lies mainly in the band below 20 Hz.
L_{10}	Noise level exceeded for 10% of the measurement time. The L_{10} level represents the typical upper noise level.
L_{90}	Noise level exceeded for 90% of the measurement time. The L_{90} level is commonly referred to as the background noise level.
$L_{eq,T}$	Equivalent Noise Level—Energy averaged noise level over the measurement time (T).
$L_{pA,LF}$	The A-weighted noise level calculated in third-octave bands from 10 Hz to 160 Hz. Used to quantify low frequency noise levels.
Low frequency noise	Low frequency noise is noise in the frequency range from about 10 Hz to approximately 160 Hz.

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Summary

The Macarthur Wind Farm is located east of Macarthur in Victoria. It is comprised of 140 Vestas V112 3 MW wind turbine generators (WTGs). The site has been fully operational since late January 2013.

Indoor measurements of infrasound and low frequency noise levels have been conducted at residences Y21A (2.7 km from the nearest WTG) and O17A (1.8 km from the nearest WTG) during the following stages:

- pre-operational: no WTGs operating
- interim: approximately 105 out of 140 WTGs operating
- operational: all 140 WTGs operating.

The aim of the assessment was to compare measured infrasound (noise at frequencies lower than 20 Hz) and low frequency noise (noise from frequencies of 10 Hz to 160 Hz) levels between the measurement stages as well as to relevant assessment criteria. This study was undertaken in response to concerns from some community members.

Methodology

Assessment criteria

Measured infrasound and low frequency noise levels were assessed against the following criteria based on relevant international and Australian guidance documents:

- 85 dB(G) residential criterion for infrasound.
- UK Department for Environment, Food and Rural Affairs (DEFRA) criteria for low frequency noise in one-third octave bands from 10 Hz to 160 Hz.

In addition, the infrasound and low frequency noise levels measured during each stage of operation were assessed to determine whether there had been any change between the pre-operational and operational scenarios. This included consideration of unweighted (linear) sound pressure levels from 0.8 Hz to 160 Hz.

Measurements

During each stage of operation, the noise monitoring equipment was setup in the same location within a bedroom in the residence facing towards the wind farm. The equipment stored G-weighted sound pressure levels and linear sound pressure levels in one-third octave bands from 0.8 Hz to 20 kHz.

At least 10 days of data were gathered at each location for each of the monitoring periods, with the exception of the pre-operational period at O17A when 347 10-minute data points (2.4 days) were collected.

It is known that infrasonic and low frequency noise levels within an environment will increase with wind speed (Guldberg, 2012; Howe, McCabe & Ferguson, 2012). Similarly, noise emissions from WTGs also increase with wind speed, with the Macarthur Wind Farm WTGs reaching a maximum sound power output at a hub height wind speed of approximately 10 m/s. Therefore, to allow comparison of results between operational stages all measured noise levels were referenced to the hub height wind speed measured at the wind farm site during the monitoring.

Infrasound assessment

Y21A

There was no change in infrasound levels between the pre-operational, interim and operational monitoring stages at Y21A, with measured levels during both the interim and operational stages being no higher than those measured during the pre-operational stage. Apart from very occasional scattered periods that were clearly affected by extraneous noise, the measured levels remained below the 85 dB(G) assessment criterion for both the interim and operational measurements.

Figure 1 compares the measured night time infrasound levels for both the pre-operational and operational stages at Y21A.

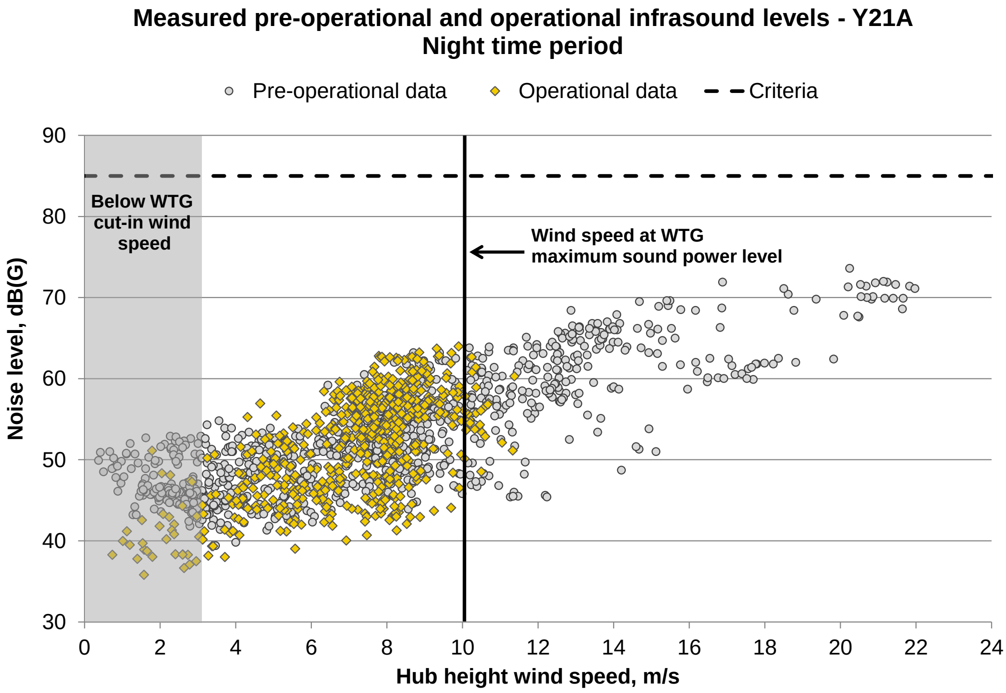

Figure 1 – Measured pre-operational and operational infrasound levels at Y21A, night time period

O17A

The assessment conducted at O17A found that there was no measurable change in infrasound levels between the pre-operational, interim and operational stages, when other variables such as wind direction were considered. The measured infrasound levels at O17A remained compliant with the 85 dB(G) assessment criterion for all periods.

Figure 2 compares the measured infrasound levels for both the pre-operational and operational stages at O17A. A wind direction of 240º through to 10º has been considered as this is limited by the 2.4 days of pre-operational measurements at this residence. Levels during both daytime and night time periods are presented.

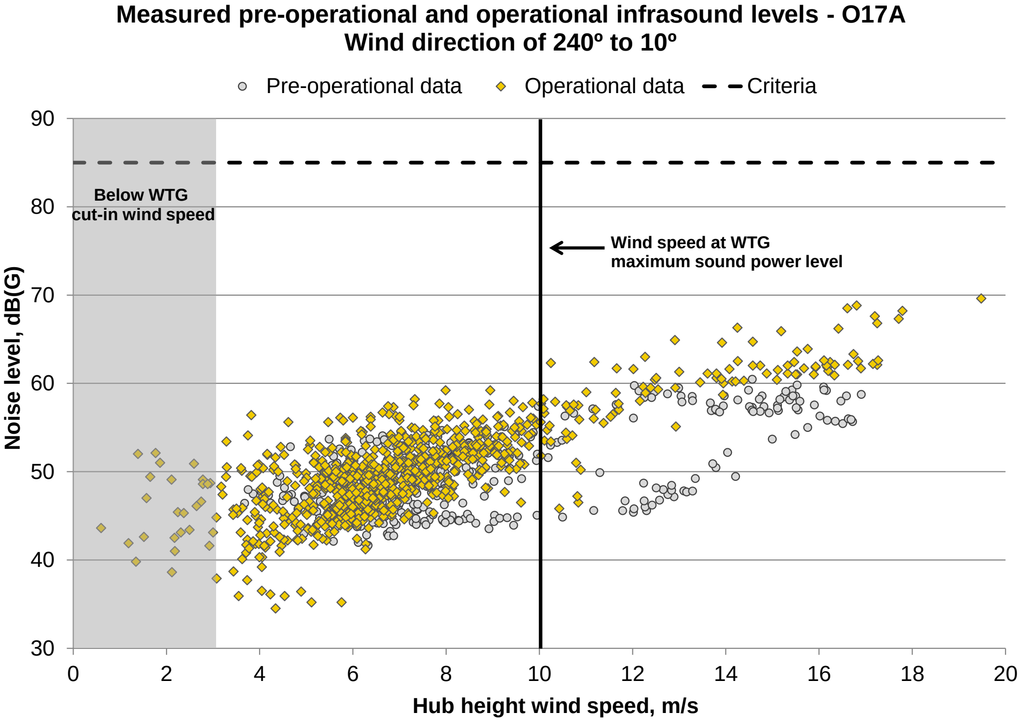

Figure 2 – Measured pre-operational and operational infrasound levels, wind direction of 240º – 10º

While the measured operational infrasound levels at high wind speeds in Figure 2 were marginally higher than those measured during the pre-operational monitoring stage, it is believed that this was due to differing local wind conditions at the residence during these higher wind speed periods.

Low frequency noise assessment

Y21A

There was no change in low frequency noise (10 Hz to 160 Hz) levels between the pre-operational and operational monitoring stages at Y21A, and no exceedances of the relevant DEFRA criteria were detected that were attributable to wind farm noise.

Figure 3 compares the measured night time pre-operational and operational low frequency noise levels at Y21A with hub height wind speed. It can be seen that the same upward trend with wind speed occurred during the pre-operational stage as occurred during the operational stage.

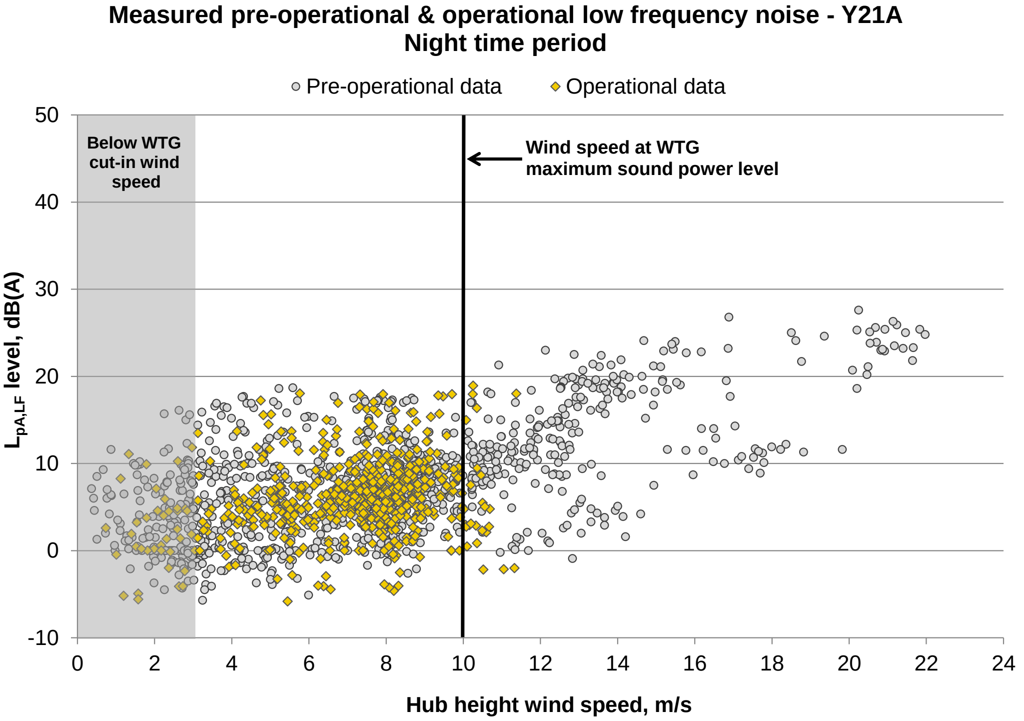

Figure 3 – Measured pre-operational and operational low frequency $L_{pA,LF}$ noise levels at Y21A

During the interim monitoring at Y21A, slightly higher low frequency noise levels were measured during high wind speed periods (10 to 15 m/s at hub height) than were measured during the pre-operational stage. This related to an increase in measured noise levels in the 63 Hz one-third octave band.

It is not clear if this was a result of wind farm operation, as the same increase was not observed for similar conditions at O17A (located approximately 900 metres closer to the Macarthur Wind Farm than Y21A). Regardless, when the higher measured levels at 63 Hz were assessed against the DEFRA low frequency noise criteria they were found to be compliant.

O17A

Figure 4 compares the measured night time pre-operational and operational low frequency noise levels at O17A with hub height wind speed. Daytime periods have been excluded to reduce extraneous results in both datasets. It can be seen that there is no significant change between the two datasets.

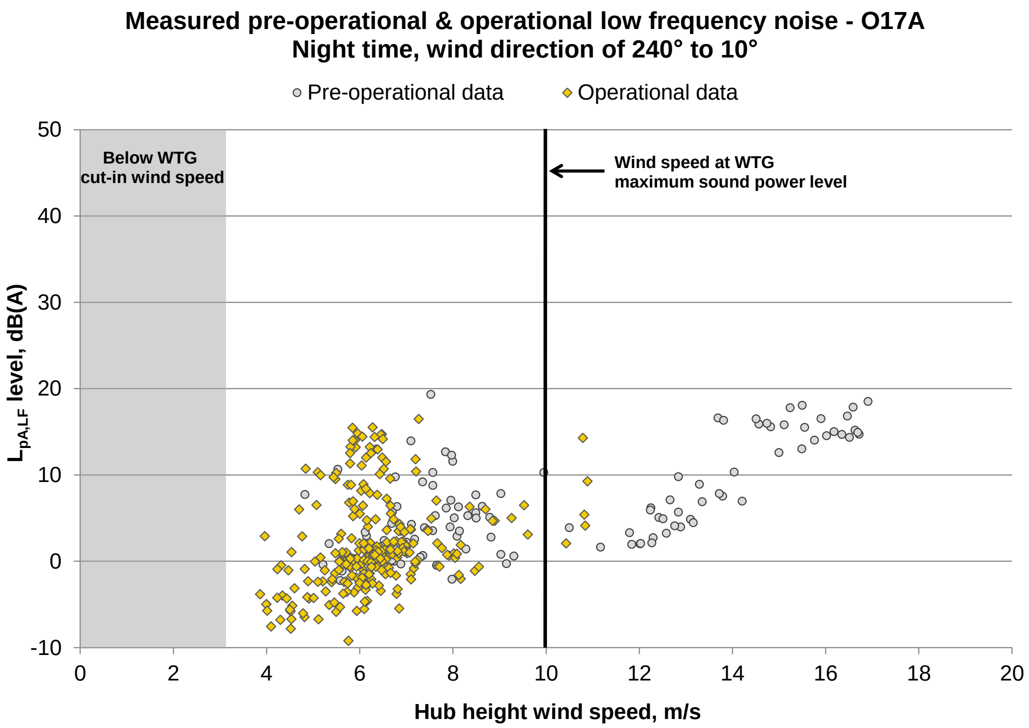

Figure 4 – Measured pre-operational and operational low frequency $L_{pA,LF}$ noise levels at O17A

Assessment of the linear (unweighted) one-third octave band levels at O17A found that operation of the wind farm may have resulted in an increase in noise levels at frequencies of 63 Hz and above at the residence during the operational monitoring stage. However, when the measured levels for each individual 10-minute period were assessed against the relevant low frequency noise criteria, the vast majority of measurements were found to comply.

Low frequency noise levels were found to exceed the criteria for only seven out of a total of 1,242 night time periods (0.6% of the measurement period), and it is thought that these exceedances were all significantly influenced by local wind noise.

Conclusions

The assessment has demonstrated that infrasound and low frequency noise levels from Macarthur Wind Farm are compliant with relevant assessment criteria at the two nearby residences.

No change in infrasound levels was identified relative to the pre-operational monitoring as a result of the wind farm operation. As shown in the graphs above, low frequency noise levels were typically consistent between the pre-operational monitoring and the operational monitoring periods. There was a slight increase in low frequency noise levels at frequencies of 63 Hz and above measured at each of the residences for particular conditions, and may be a result of noise from Macarthur Wind farm, although these levels were compliant with the applicable low frequency noise criteria.

1 Introduction

The Macarthur Wind Farm is located east of Macarthur in Victoria. It is comprised of 140 Vestas V112 3 MW wind turbine generators (WTGs). The site has been fully operational since late January 2013.

AGL Energy Limited (AGL) has engaged Resonate Acoustics to undertake infrasound and low frequency noise monitoring at two residences adjacent to the Macarthur Wind Farm, in order to determine and assess any contribution from the wind farm to infrasound and low frequency noise levels at these residences. Monitoring was undertaken indoors at the two residences to minimise the influence of wind noise across the microphone.

The monitoring was conducted in three stages:

- Pre-operational monitoring was undertaken in September 2012 prior to any WTGs at the site commencing operation.
- Interim monitoring was undertaken in November/December 2012 while the majority of turbines at the site were operational. A total of 105 WTGs were operational midway through the monitoring (1 December).
- Operational monitoring was undertaken in March/April 2013 when the site was fully operational and commissioned.

This report details the results of the infrasound and low frequency measurements, comparing the operational and interim measurements to the pre-operational measurements as well as to relevant assessment criteria.

2 Infrasound and low frequency noise

There is often confusion regarding the separation between low frequency noise and infrasound. There is no physical separation between the two and it could be argued that infrasound is simply very low, low frequency noise. However, they have traditionally been separated by definition such that infrasound refers to noise at frequencies below 20 Hz and low frequency noise refers to noise in the range from approximately 10 to 160 Hz. This results in some overlap between infrasound and low frequency noise, as shown in Figure 5.

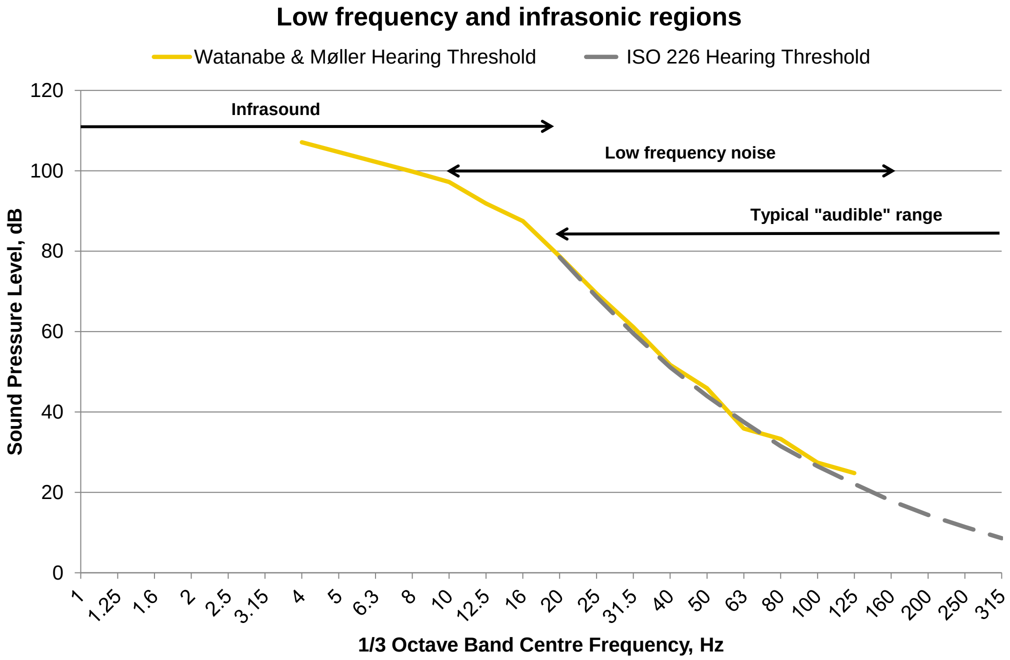

Figure 5 – Low frequency and infrasonic regions

The mean human hearing thresholds as determined by Watanabe and Møller (1990) from 4 Hz to 125 Hz and from ISO 226[1] for frequencies above 20 Hz are also shown on Figure 5. These thresholds demonstrate that human hearing does not stop at frequencies below 20 Hz but that we can still hear noise levels within this range as long as the level is high enough. In this respect, there is no difference between infrasound and low frequency noise.

[1] ISO 226:2003, *Acoustics – Normal equal-loudness-level contours*.

This is supported by recent research into the brain activity of subjects listening to infrasound and to low frequency tones (Dommes et al, 2009). It was found that both low frequency tones and infrasound are perceived through the same auditory pathways as for higher sound frequencies. Infrasound below the threshold of hearing (inaudible) did not result in a response in the brain.

However, considering infrasound and low frequency noise separately does provide some benefits. While infrasound is audible provided the level is high enough (Leventhall, 2006), humans lose tonal perception of noise at frequencies below approximately 16 to 18 Hz with the sound becoming discontinuous in character (Møller & Pedersen, 2004). This represents a key element of the perception of noise (Leventhall, 2003).

For the purposes of this report, infrasound and low frequency noise have been considered separately. This results in noise levels in the range of 10 to 20 Hz being considered as part of both the infrasound and low frequency noise assessments.

2.1 Infrasound

2.1.1 Definition

Infrasound is very low frequency noise, defined by ISO 7196[2] as:

> *Sound or noise whose frequency spectrum lies mainly in the band from 1 Hz to 20 Hz.*

A level of infrasound is always present in the environment, arising from natural sources such as wind and waves, and from air conditioning, industry and traffic. The human body also constantly generates infrasound through breathing and heartbeat, and when walking or running due to pressure changes at the ear (Department of Health, 2013).

2.1.2 G-weighting

IEC 61400-11 Edition 3[3], the Standard used for the measurement of WTG sound power levels, provides guidance on the measurement of infrasound from wind turbines. It states that:

> *If infrasound is thought to be emitted, an appropriate measure is the G-weighted sound pressure level according to ISO 7196.*

The G-weighting function is defined in ISO 7196 and is used to quantify sound that has a significant portion of its energy in the infrasonic range. The function weights noise levels between 0.25 Hz and 315 Hz to reflect the human perception of infrasound within this frequency range. Figure 6 shows the G-weighting function across the considered frequency range between 0.25 Hz and 315 Hz.

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[2] ISO 7196-2:1995, *Acoustics – Frequency-weighting characteristic for infrasound measurements*.

[3] IEC 61400-11 Edition 3, 2012, *Wind turbines – Part 11: Acoustic noise measurement techniques*.

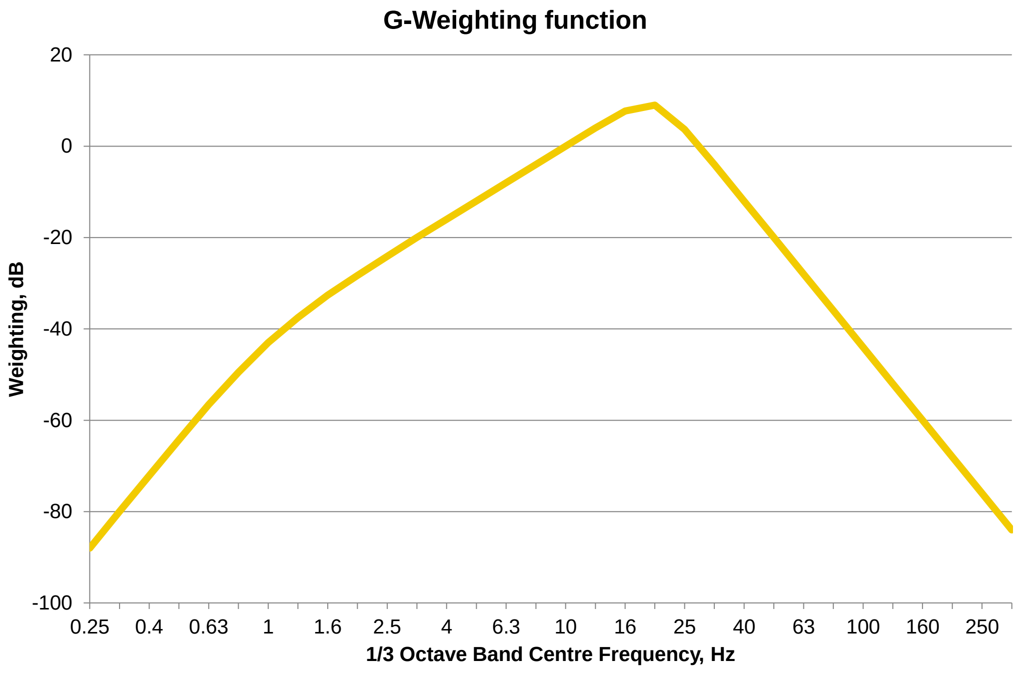

Figure 6 – G-weighting function

The perception of noise in the infrasonic range is greatest at 20 Hz and perception of infrasound reduces as the frequency decreases. Note that the G-weighting negatively weights sounds at frequencies above 20 Hz and noise at these frequencies (up to 160 Hz) is assessed separately in this report as low frequency noise.

Møller (1987) undertook a study into the relationship between G-weighted noise levels and annoyance from infrasound. There was found to be a close relationship between the annoyance rating given to perceptible levels of infrasound and the G-weighted level, indicating that G-weighted noise levels are an appropriate descriptor to use for the assessment of infrasound.

While the G-weighting provides an appropriate method of quantifying infrasound with regards to human perception, the assessment detailed this report has also considered the unweighted (linear) sound pressure levels across the infrasonic range.

2.1.3 Infrasound and annoyance

People can perceive infrasound if the level is high enough. There has been debate about whether very low frequency noise levels are heard or rather felt through the body but current available evidence suggests that infrasound is heard through the ears at the onset of perception (Møller & Pedersen, 2004; Dommes et al, 2009).

A study conducted by Møller (1984) analysed the performance of sixteen subjects as they undertook various tasks while exposed to inaudible infrasound, audible infrasound, traffic noise and a relatively quiet level (as a control condition):

> *The most conspicuous effect of infrasound was a high rating of annoyance and a feeling of pressure on the ear at less than 20 dB above the threshold of hearing. No influence on the cardiovascular system was seen and the performance only deteriorated in one of nine tasks. Infrasound below the hearing threshold had no effect.*

These findings are consistent with those of Landström and Byström (1984), who found that infrasound levels above the hearing threshold could be correlated to a reduction in wakefulness but that no clear effect was observed at pressure levels below the hearing threshold. Landström, Lundström and Byström (1983) linked this reduction in wakefulness to levels above the hearing threshold by studying the reaction of hearing and deaf subjects to a level of 115 dB at 6 Hz (equivalent to approximately 107 dB(G)). It was observed that "reduced wakefulness was noticed among the hearing subjects but not among the deaf subjects".

While infrasound only becomes annoying when levels exceed the hearing thresholds, it is important to note that the degree of annoyance can increase markedly for only relatively small changes in the infrasonic noise level above the hearing threshold (Andresen and Møller, 1984). Therefore, increases in infrasound levels above the perceptibility limit need to be considered differently to similar increases above perceptibility in broadband noise.

2.2 Low frequency noise

2.2.1 Definition

Low frequency noise refers to unwanted sound occurring within the lower region of the frequency range. As identified in Figure 5, the term low frequency noise is used to describe noise in the frequency range from approximately 10 Hz to 20 Hz that overlaps with infrasound, but also includes frequencies above 20 Hz.

People are often exposed to low frequency noise in the environment, as it is produced by transportation (aircraft, cars and locomotives), industrial (pumps, compressors, turbines) and natural (wind, waves) sources. Two sources of noise, which are dominated by low frequency noise and that will be familiar to almost everyone are truck exhausts and bass music.

The definition of low frequency noise varies to some degree between different standards and guidelines used for its assessment. A frequency range of 10 Hz to 160 Hz is used to define low frequency noise in both the UK (DEFRA, 2005) and Denmark (Poulsen & Mortensen, 2002), and this range has been adopted within this report.

2.2.2 Low frequency noise and annoyance

The primary effect of low frequency noise, and that most frequently reported, is annoyance (Broner, 1978). In a similar manner to infrasound, low frequency noise annoyance occurs when the level of low frequency noise is a sufficient amount above the hearing threshold. However, as low frequency noise considers a wider frequency range than infrasound, the margin above audibility required to result in annoyance will vary. For example, only a small margin above audibility can result in annoyance at frequencies lower than 20 Hz, whereas people are generally more accepting of audible noise (in terms of the difference between the noise level and the audibility threshold) at frequencies above 100 Hz as it is relatively common in the environment.

Direct effects of low frequency noise on other parts of the human body only start to occur at a level well above that at which low frequency noise is first heard through the ears. Experiments conducted with normally hearing and profoundly deaf subjects found that the threshold of sensation of the deaf subjects was approximately 40 to 50 dB above the hearing threshold of the normally hearing subjects at a frequency of 63 Hz, and the margin was even greater at higher frequencies (Yamada et al, 1983). When the profoundly deaf subjects were able to sense the noise at the much higher noise level, it was felt mainly within the chest.

3 Assessment criteria

3.1 Planning Permit

The Planning Permit for the Macarthur Wind Farm states that:

15. The operation of the wind energy facility must comply with the New Zealand Standard 'Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators' (NZS 6808:1998) (the 'Standard'), at any dwelling existing in the vicinity of the wind energy facility as at 7 February 2006. In determining compliance with the Standard, the following shall apply:

a. The sound level from the operating wind energy facility, measured outdoors within 10 metres of a dwelling at any relevant nominated wind speed, shall not exceed the background noise level (L_{95}) by more than 5dBA or a level of 40dBA L_{95}, whichever is the greater. This 'background sound level' shall be determined by the method specified in NZS 6808:1998. Compliance shall be determined separately for all time data and for night time data. Night time is defined as 10pm to 7am.

b. If sound has a special audible characteristic the measured sound level of the source shall have a 5 dB penalty applied. The EMP must provide detail on how special audible characteristics are to be determined and the penalty is to be applied.

None of NZS 6808:1998, its successor (NZS 6808:2010), or the EMP define infrasound or low frequency noise as special audible characteristics of wind turbine noise that needs to be assessed. With regard to infrasound, NZS 6808:1998 states:

Reference to overseas studies on infrasound reveals that:

(a) Sound spectra for modern WTGS indicate that compliance with the limits in this Standard … will ensure that infrasound pressure levels will be well below the threshold of perception.

(b) Any potential adverse effect of infrasound would occur at levels greater than the threshold of perception.

NZS 6808:2010 also states the following with regard to infrasound and low frequency noise:

5.5.1 Although wind turbines may produce some sound at (ultrasound and infrasound) frequencies considered to be outside the normal range of human hearing these components will be well below the threshold of human perception.

5.5.2 *Claims have been made that low frequency sound and vibration from wind turbines have caused illness and other adverse physiological effects among a very few people worldwide living near wind farms. The paucity of evidence does not justify at this stage, any attempt to set a precautionary limit more stringent than those recommended* (in this Standard).

Therefore, to undertake this assessment, reference has been made to assessment criteria for infrasound and low frequency noise from other standards and guidelines.

3.2 Infrasound

There are no widely accepted assessment criteria for infrasound. Normally, assessment criteria that do exist have been proposed for infrasound and very low frequency noise based on the threshold of perception. For example, ISO 7196 states that sound pressure levels below 90 dB(G) will "not normally be significant for human perception". Andresen and Møller (1984) proposed a criterion of 95 dB(G) based on the onset of annoyance from perceptible infrasound.

In Australia, the Queensland Department of Environment and Resource Management's (DERM) Draft *ECOACCESS Guideline – Assessment of Low Frequency Noise* recommends an internal noise limit of 85 dB(G) for dwellings, consistent with that recommended in Denmark (Jakobsen, 2001). This Guideline was released in draft form in 2004 and no final version has been released.

The proposed 85 dB(G) and 95 dB(G) limits are compared to the low frequency hearing threshold from Watanabe & Møller (1990), and other low frequency noise assessment criteria between 0.5 Hz and 20 Hz in Figure 7. It can be seen that an infrasound criterion of 85 dB(G) is reflective of the typical lowest assessment criteria applied to very low frequency noise, and lower than the mean hearing threshold up to a frequency of 20 Hz.

It is important to note that the 85 dB(G) criterion would typically be more conservative than the line plotted on Figure 7. Figure 7 would only reflect the applicable 85 dB(G) criterion where the infrasound is concentrated at one particular frequency (i.e. highly tonal). An 85 dB(G) criterion would be more stringent than shown on the graph where the infrasound is more broadband in nature, or is composed of tones at multiple frequencies.

The standard deviation between the hearing threshold of individuals at very low frequencies is approximately 5 dB (Møller and Pedersen, 2004). Given that an 85 dB(G) criterion is at least 5 to 10 dB lower than the mean hearing threshold, it can be considered a conservative criterion that takes into account expected variations in individual hearing thresholds to very low frequency noise. Therefore, a criterion of 85 dB(G) has been adopted for this assessment.

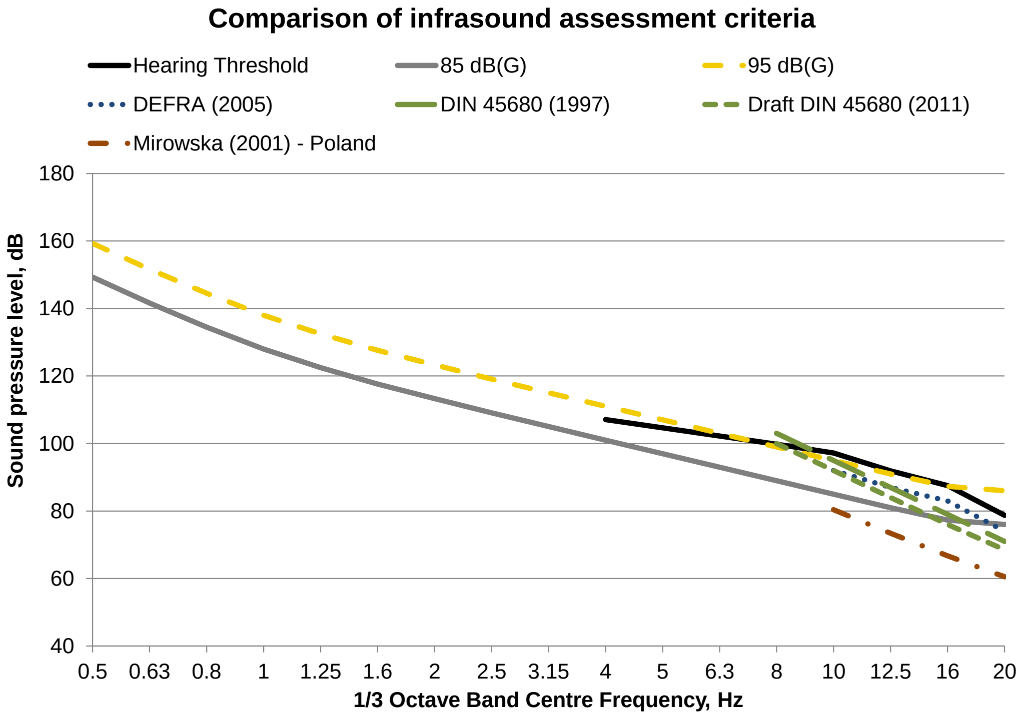

Figure 7 – Infrasound assessment criteria

While the G-weighted levels are appropriate as they relate measured infrasound levels to human perception, consideration has also been given to a comparison between unweighted (linear) sound pressure levels across the pre-operational, interim and operational stages. This will identify whether operation of the Macarthur Wind Farm is producing noise in the frequency range of 0.8 Hz to 20 Hz and whether any such noise is excessive.

3.3 Low frequency noise

3.3.1 DEFRA criteria

There are no specific assessment criteria for low frequency noise published in Victoria or in NZS 6808:1998. Consequently, assessment criteria have been taken from the UK Department for Environment, Food and Rural Affairs (DEFRA) *Proposed criteria for the assessment of low frequency noise disturbance* (DEFRA, 2005). We understand that the Environment Protection Authority Victoria (EPA Victoria) would currently suggest that these criteria should be applied for any low frequency noise assessment of wind farms.

The DEFRA proposed criteria for the assessment of low frequency noise disturbance are presented in Table 1, and are to apply to low frequency noise levels measured in unoccupied rooms indoors. Where the criteria are exceeded, the DEFRA report states that it may indicate a source of low frequency noise that could cause disturbance.

Table 1 – DEFRA proposed criteria for the assessment of low frequency noise disturbance

Proposed limit in dB(Lin) at 1/3 octave band centre frequency (Hz)												
10	**12.5**	**16**	**20**	**25**	**31.5**	**40**	**50**	**63**	**80**	**100**	**125**	**160**
92	87	83	74	64	56	49	43	42	40	38	36	34

Note that the criteria presented in Table 1 are the minimum criteria for the assessment of steady low frequency noise at night time. A 5 dB relaxation of the limits may be applied for either of the cases outlined below:

- the noise occurs only during the daytime
- the noise is steady, i.e. (L_{10} – L_{90}) < 5 dB in the dominant one-third octave band.

The criteria apply to measured L_{eq} noise levels over the time period for which a complainant says that the noise is present. As these measurements are being undertaken at residences near a wind farm operating continuously at an output determined by the wind speed at the site, 10-minute assessment periods have been considered for consistency with the wind speed data obtained for the site. This means that each individual 10-minute period within the monitoring stages has been assessed separately.

The proposed DEFRA night time criteria are presented in Figure 8, and are compared to the mean low frequency hearing threshold from Watanabe & Møller (1990).

It can be seen that the low frequency noise criteria remain below the mean hearing threshold up to a frequency of 50 Hz, as they account for typical variations in hearing thresholds between individuals. Above 50 Hz, the criteria are marginally higher than the hearing threshold in recognition that background noise levels at these frequencies are often audible within the environment and that people are more accepting of low audibility noise levels at these frequencies.

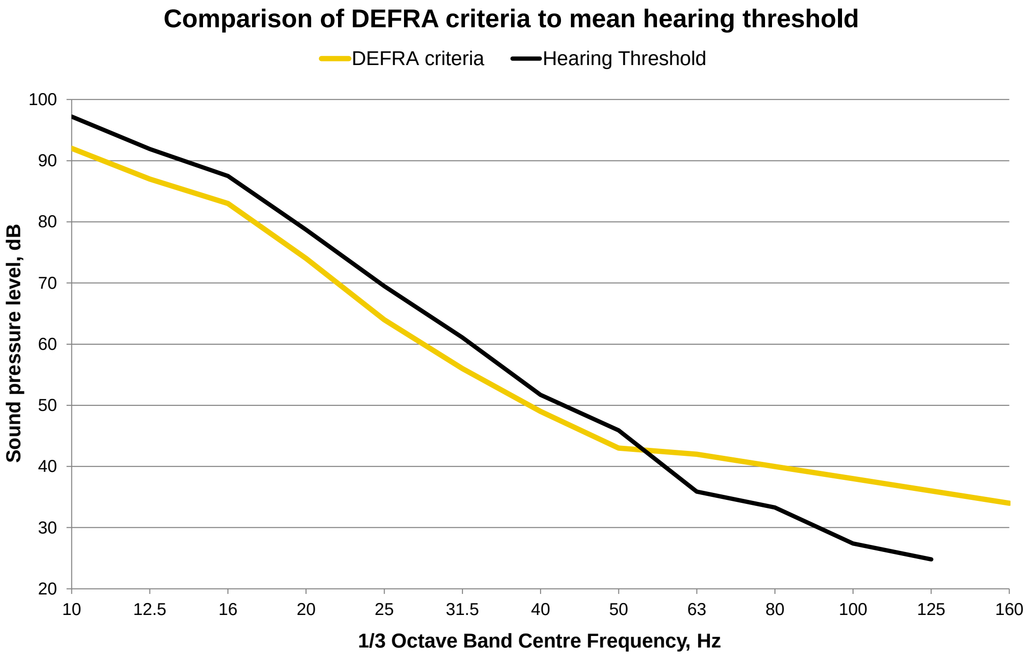

Figure 8 – Low frequency noise assessment criteria

3.3.2 $L_{pA,LF}$ levels

While the DEFRA criteria presented in Table 1 provide low frequency noise assessment criteria for the measurements gathered at each residence, it is difficult to present the measured levels for each of the thousands of 10-minute periods in a clear manner. Therefore, the measured $L_{pA,LF}$ levels over each 10-minute period at each residence have also been considered and analysed against wind speed.

The $L_{pA,LF}$ noise level is determined as the A-weighted $L_{eq,10min}$ noise level considering only the one-third octave bands from 10 Hz to 160 Hz. It is used as a metric to assess low frequency noise in Denmark (Poulsen & Mortensen, 2002). As it provides a single value for low frequency noise for each 10-minute period, the $L_{pA,LF}$ metric makes it simpler to visualise any change in levels given the considerable amount of data collected at each residence. The $L_{pA,LF}$ has been previously shown to correlate well with subjective response to low frequency noise (Poulsen & Mortensen, 2002).

We note that the $L_{pA,LF}$ level is used to assess low frequency noise in Denmark, with a night time level of 20 dB(A) recommended for residences at night time (Jakobsen, 2001). This has not been explicitly considered in this report, as we understand the EPA Victoria would recommend compliance with the DEFRA criteria rather than the Danish criteria. Additionally, the measurement locations within each room were not necessarily in accordance with the Danish procedure meaning that direct comparison cannot be made.

3.4 Summary

The criteria used for this infrasound and low frequency noise assessment are summarised in Table 2.

Table 2 – Summary of assessment criteria

Type of noise	Assessment criteria
Infrasound	85 dB(G) $L_{eq,10min}$
Low frequency noise	DEFRA proposed criteria (refer Table 1)

As part of this assessment, the low frequency noise criteria have been assessed as $L_{eq,10min}$ noise levels, as a 10-minute assessment period provides consistency with the intended application of the criteria as well as matching the wind speed and direction data available for the Macarthur Wind Farm site. The measured $L_{Geq,10min}$ infrasound levels have also been assessed against the 85 dB(G) infrasound criterion to provide consistency with the wind speed and direction data.

While the criteria listed in Table 2 have been used to assess the final infrasound and low frequency noise levels once the Macarthur Wind Farm is fully operational, pre-operational monitoring has also been undertaken to allow a comparison of the measured levels prior to and during operation of the site. This has been undertaken on the basis of G-weighted levels, A-weighted $L_{pA,LF}$ levels, and unweighted (linear) levels.

4 Measurement methodology

4.1 Monitoring locations

Infrasound and low frequency noise monitoring was undertaken at two residences adjacent to the Macarthur Wind Farm:

- Y21A – approximately 2.7 km from the nearest turbine (WTG 80)
- O17A – approximately 1.8 km from the nearest turbine (WTG 52).

Figure 9 presents the noise monitoring locations, along with the WTGs and meteorological mast locations at Macarthur Wind Farm.

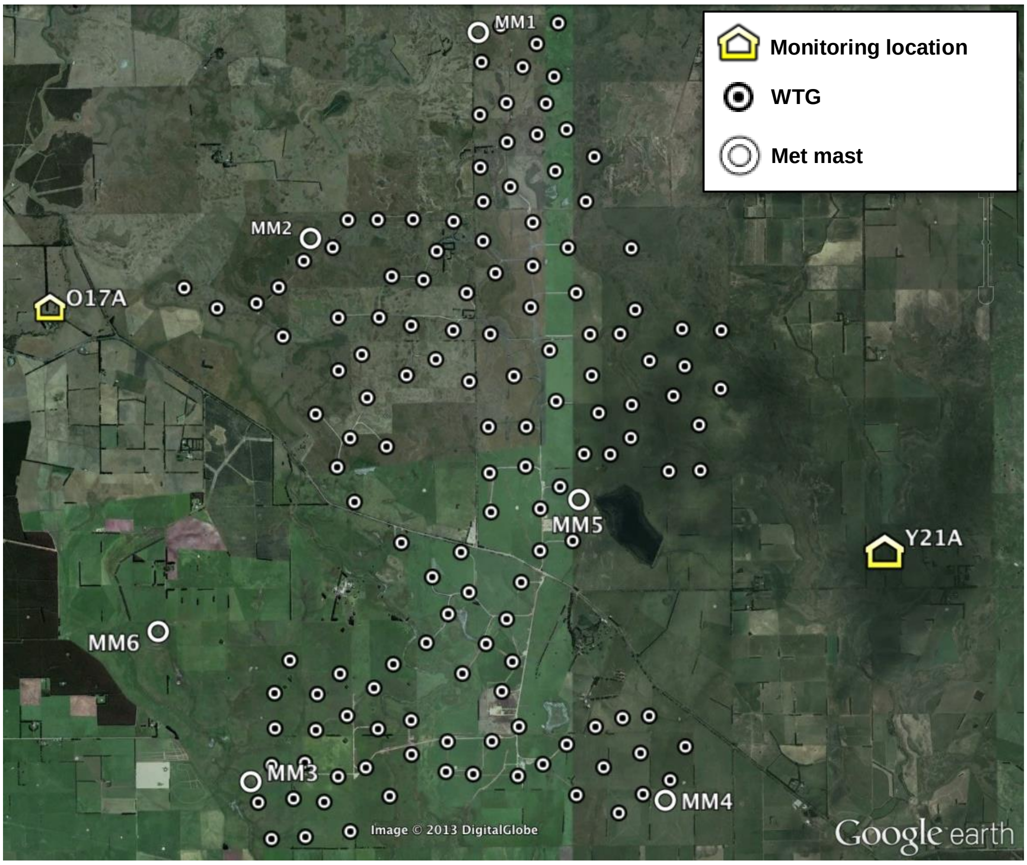

Figure 9 – Macarthur Wind Farm WTGs, meteorological masts and noise monitoring locations

During the interim monitoring stage (22 November to 7 December 2012), the majority of the WTGs at the site were operational as they underwent commissioning and reliability testing. AGL advised that 105 WTGs were operational as at 1 December (midway through the interim monitoring) and these are identified in Figure 10. All 140 WTGs were operating during the operational monitoring stage in March and April 2013.

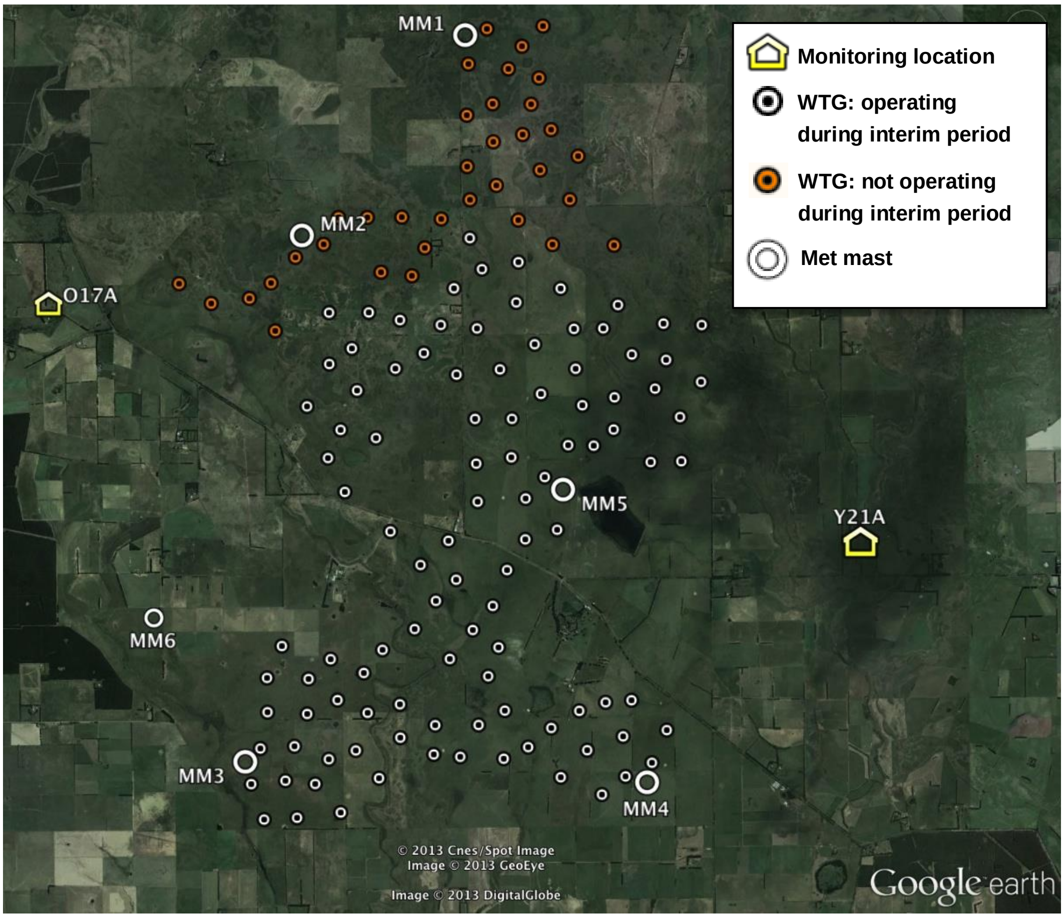

Figure 10 – Macarthur Wind Farm WTGs operating during interim stage

The WTGs operating during the interim monitoring stage include the nearest WTGs to Y21A but not the nearest WTGs to O17A. The nearest operational WTG to O17A for the interim monitoring was WTG 68, located 3.6 km from the monitoring location.

The sound level meters were located indoors at each of the measurement locations, with the following rooms selected:

- Y21A – occupied bedroom on the western facade of the house facing towards the Macarthur Wind Farm
- O17A – unoccupied bedroom on the northeast facade of the house facing towards the Macarthur Wind Farm.

Photographs of the installed noise monitoring equipment are included in Appendix A.

4.2 Equipment

All measurements were carried out using the equipment listed in Table 3.

Table 3 – Measurement equipment

Analyser	Microphone	Frequency range[1]	Location
SVANTEK SVAN 945A (S/N 8603)	GRAS 40AN (S/N 54371)	0.8 Hz – 20 kHz	Pre-operational: Y21A Interim: O17A Operational: Y21A
SVANTEK SVAN 979 (S/N 21094)	GRAS 40AN (S/N 7348)	0.8 Hz – 20 kHz	Pre-operational: O17A Interim: Y21A Operational: O17A

1. Frequency range shows frequency range of the analyser. The Grass 40AN microphone has specified accuracy of +/- 2 dB at 0.5 Hz - 20 kHz, and +/- 1 dB at 1 Hz – 10 kHz.

The calibration of the analysers and microphones was checked both prior to and following each set of measurements, and no drift in calibration was observed. All noise measurement equipment used holds current calibration certificates from a National Association of Testing Authorities (NATA) certified laboratory (refer Appendix B).

4.3 Measurement procedure

4.3.1 Location

A study conducted by DELTA (2008) showed the measurement position within a room has minimal effect on noise levels at frequencies of 50 Hz and below, which will control the measured infrasound and low frequency noise levels at the bottom of the frequency range. However, it should be noted that low frequency noise levels at approximately 50 Hz and above can noticeably change with position within the room.

There are a variety of measurement positions suggested by different low frequency noise measurement standards. Oliva (2012) questioned a number of experts on the appropriate position within a room for the measurement of low frequency noise and found that there was no agreement between experts in the field of low frequency noise as to the best location. However, the majority of experts questioned by Oliva suggested that locations representative of normal use of the room were desirable, rather than a location in the very corner of the room where low frequency noise levels above approximately 50 Hz may be higher.

At each residence near the Macarthur Wind Farm, the sound level meters and microphones were installed at a location agreed with the resident, which was near the windows of the room. The measurement position at Y21A was approximately 0.8 metres from the corner of the room, which measured approximately 3 metres x 4 metres x 2.7 meters high. The measurement position at O17A was approximately 1.5 meters from the corner of the room, with room measuring approximately 3 meters x 5 metres and having a raked ceiling of about 1.8 metres to 3 metres height. The measurement height in both residences was approximately 1.5 metres above the floor. Microphones were fitted with 90 mm diameter windshields, and the windows of the rooms were closed when the equipment was installed and recovered from site.

We note that, regardless of disagreement between experts on the best location for low frequency noise measurements, the measurement location used for this assessment was consistent during the three stages of measurements at each location. By comparing pre-operational and operational measurements of low frequency noise, any change in the low frequency noise within the room can be observed.

4.3.2 Measurement period

The measured noise levels in this report are generally presented as 10-minute average levels to provide an average over a reasonable duration of time, but to also provide consistency with the wind speed and direction data available for the site. To determine the 10-minute average levels, either 10-second or 1-minute measurement periods were used as discussed below.

The SVAN 979 sound level meter was configured to continuously store the G-weighted $L_{Geq,10s}$ noise level and unweighted (linear) $L_{eq,10s}$ noise level in each one-third octave frequency band from 0.8 Hz to 20 kHz. A 10 second measurement period was selected as Annex A of ISO 7196 states that:

> *The integrating time constant chosen should be sufficiently long for the observed value to be representative of the noise being measured. Usually, this will be the case for an integration time/time constant of 10 s.*

Due to the storage limitations of the SVAN 945A sound level meter, 10 second measurement periods could not be implemented and this meter was configured to store unweighted (linear) $L_{eq,1min}$ noise levels in each one-third octave frequency band from 0.8 Hz to 20 kHz.

As the G-weighting function is not implemented correctly on the SVAN 945A sound level meter, G-weighted $L_{Geq,1min}$ noise levels have been calculated based on the measured unweighted one-third octave band levels. This is in accordance with Annex A of ISO 7196, which states that:

> *An approximate determination of the G-weighted sound pressure level may be made by band analysis of the signal using bandwidths no greater than one-third octave.*

To determine any potential errors arising from using the one-third octave band G-weighting corrections, the $L_{Geq,10min}$ levels measured using the G-weighting function on the SVAN 979 were compared to the $L_{Geq,10min}$ levels calculated from the one-third octave band values for the same period. It was found that the maximum difference between the two values was 1 dB(G), with an average difference of 0.3 dB(G). The $L_{Geq,10min}$ data calculated from the one-third octave band values was found to be higher than that measured using the G-weighting function on the SVAN 979. Therefore, it is considered that the use of the one-third octave band data to calculate $L_{Geq,10min}$ noise levels provides a sufficient level of accuracy for this assessment.

4.4 Measurement stages

Table 4 summarises the measurement times at both locations for each measurement stage. The number of 10-minute data points available for analysis is also summarised in the table. During the pre-operational measurements at O17A, the SVAN 979 unit was located on site from 11 September to 25 September but failed to store any data after 0:20 on 14 September. This limited the pre-operational data available for analysis at O17A, with the wind directions during this stage being primarily from the North, Northwest and West.

The cause of this equipment problem was unable to be conclusively determined but the equipment manufacturer suggested it may have been a result of the equipment being setup to store a large amount of data every 10 seconds. The setup of the equipment was subsequently modified such that a smaller amount of data was stored every 10 seconds, with the data collected still meeting the requirements listed in Section 4.3.

Table 4 – Measurement times

Location	Equipment	Measurement times		Number of 10-minute data points
		Start	End	
Pre-operational measurements				
Y21A	SVAN 945A	31/8/12 13:30	25/9/12 12:20	3594
O17A[1]	SVAN 979	11/9/12 14:40	14/9/12 0:20	347
Interim measurements				
Y21A	SVAN 979	22/11/12 12:10	7/12/12 8:20	2102[2]
O17A	SVAN 945A	22/11/12 15:20	4/12/12 12:50	1714
Operational measurements				
Y21A	SVAN 945A	19/2/13 12:50	5/3/13 13:30	2022
O17A[3]	SVAN 979	19/2/13 15:40	5/3/13 12:10	3176[2]
		25/3/13 13:40	3/4/13 13:10	

1. The SVAN 979 unit was located on site until 25 September but failed to store data after 14 September.
2. A small number of data points (~100) could not be used during these stages due to the relevant meteorological mast not operating for the whole time period.
3. The SVAN 979 unit was also located at O17A from 5 March until 15 March 2013 but failed due to external power cable disconnecting from the meter.

Overall, a large number of data points were obtained for the pre-operational measurement stage at Y21A and for the interim and operational measurement stages at both locations.

4.5 Wind speed and direction data

Wind speed and direction data at WTG hub height (84 metres above ground) was sourced in 10-minute average values from the meteorological masts at the site.

Once the WTGs are operational, wind speed measurements at the meteorological masts on site are potentially wake-affected under some wind directions. Therefore, the wind speed data for each residence was sourced according to the nearest wake-free mast for the particular wind direction. Table 5 summarises the wake-free wind speed and wind direction sources for each residence, as advised by wind analysts GL Garrad Hassan.

Table 5 – Wake-free wind speed and direction sources

Residence	Wind direction source	Wind speed source	
		Mast	Wind direction range
Y21A	MM4	MM4	70º – 218º
		MM3	218º – 340º
		MM6	340º – 70º
O17A	MM6	MM4	70º – 175º
		MM6	175º – 70º

Where wind speed was taken from a mast other than MM6 for O17A and MM4 for Y21A, the wind speed was scaled based on directional correlation (speedup) ratios between the two masts. Table 6 presents the speedup ratios for the masts provided by GL Garrad Hassan.

Table 6 – Directional correlation (speedup) ratios

Wind direction	Directional correlation (speedup) ratios		
Bin centre (º)	MM3 to MM4	MM6 to MM4	MM4 to MM6
0	1.026274	1.064022	0.932446
30	0.961163	0.983088	1.002183
60	0.975658	0.999326	1.000303
90	0.971357	0.991799	1.00651
120	0.978159	1.023324	0.97507
150	1.013695	0.976371	1.028481
180	1.022938	1.037683	0.987351
210	1.056454	1.145282	0.88845
240	1.023231	1.185487	0.839709
270	1.054981	1.213244	0.826959
300	1.085166	1.139725	0.864311
330	0.993236	1.015667	0.971517

5 Infrasound assessment

This section presents the results of the infrasound measurements conducted at Y21A and O17A, including a comparison between pre-operational, interim and operational measurements.

The results are presented as $L_{Geq,10min}$ noise levels and, as a comparison can be made between the pre-operational and operational scenarios, this provides sufficient indication of any change in infrasound levels within the environment. Additional consideration has also been given to the linear (unweighted) sound pressure levels in Section 7.

The complete datasets of G-weighted noise levels with wind speed for each measurement stage are provided in Appendix C.

5.1 Y21A

5.1.1 Pre-operational

The measured pre-operational infrasound levels ($L_{Geq,10min}$) at Y21A with the hub height wind speed at Macarthur Wind Farm are presented as Figure C1 in Appendix C.

The pre-operational data indicates that measured infrasound levels at Y21A typically range from 45 dB(G) to 70 dB(G), with some isolated data points between 75 and 90 dB(G) that are believed to be the result of human activity (including use of vehicles) within or outside the house. While there is a general upward trend with wind speed, there is also considerable spread in the dataset.

As the room in which the measurement equipment was located was occupied during the pre-operation monitoring stage, data collected at Y21A during the day and night time periods was analysed separately. A review of the pre-operation data indicated that noise levels often decreased considerably between 22:00 and 23:00, and increased noticeably after 6:00, suggesting that a night time period of 23:00 to 6:00 represented the time when the residents would be expected to be asleep (and any activities would not be generating significant infrasound). Therefore, a night time period of 23:00 to 6:00 was selected for this analysis. Unlike the activities of the occupants of the house, there will be no change in wind turbine operation between the day and night time periods for a given wind speed.

Figure 11 presents the measured pre-operational infrasound levels at Y21A for both the day and night time periods. It is clear that the night time infrasound levels are significantly less influenced by human activity, and are influenced more by wind speed than the daytime dataset. The measured night time infrasound levels increase from approximately 45 dB(G) to 70 dB(G) as the hub height wind speed increases from 1 m/s to 22 m/s. This observation of an increase in the infrasound level in the natural environment with increasing wind speed matches previous observations at locations away from wind farms (Howe et al, 2012; Evans et al, 2013).

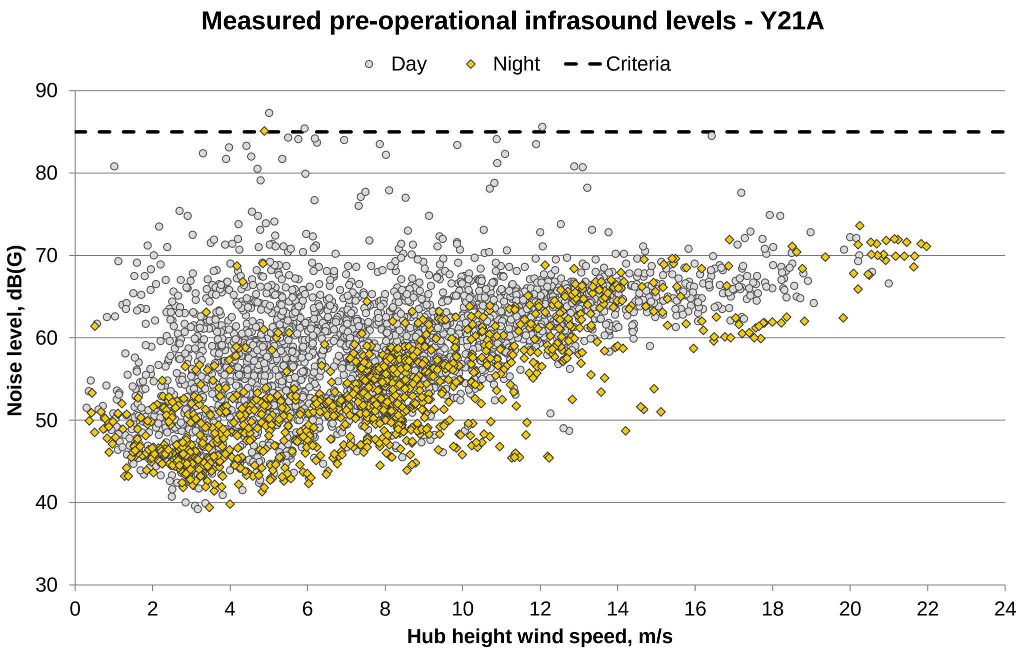

Figure 11 – Measured pre-operational infrasound levels at Y21A

The daytime dataset appears to have been considerably affected by human activity, with infrasound levels of 60 to 70 dB(G) regularly occurring across the entire wind speed range. We note that there is also likely to be lower wind shear during the day, meaning that the wind speed at the house is likely to be closer to the wind speed at hub height than it would be at night. This may have also affected the daytime dataset, resulting in higher levels of infrasound at the house for lower hub height wind speeds at the wind farm.

5.1.2 Interim

During the interim monitoring stage at Y21A, the nearest WTGs to the residence were operational. Therefore, there would not be expected to be any change in the contribution of Macarthur Wind Farm to noise levels at the residence between the interim and operational stages.

The complete dataset of measured infrasound levels at Y21A during the interim monitoring stage is included as Figure C2 in Appendix C. As for the pre-operational dataset, there is significant spread in the interim dataset with time of day found to be a key factor.

Figure 12 and Figure 13 compare the measured pre-operation and interim $L_{eq,10min}$ infrasound levels at Y21A for the daytime and night time periods respectively.

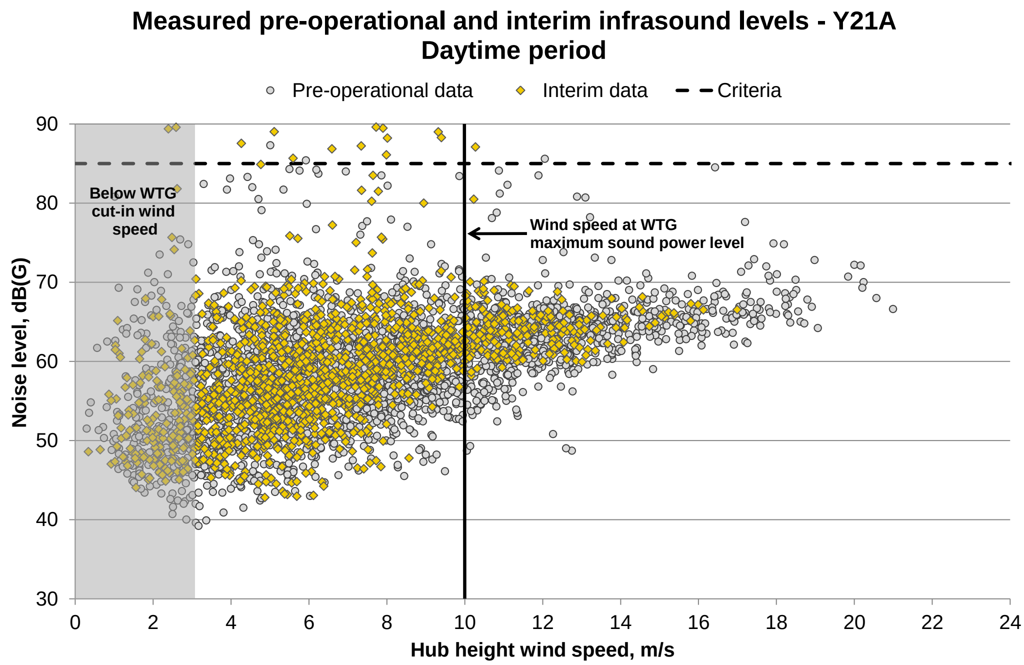

Figure 12 – Measured pre-operational and interim infrasound levels at Y21, daytime period

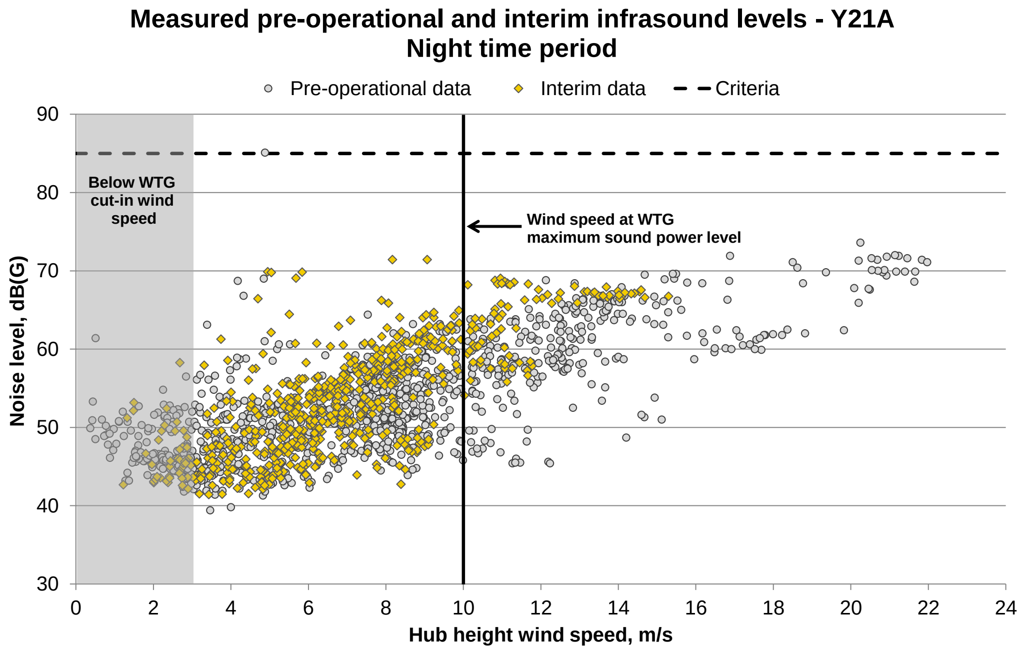

Figure 13 – Measured pre-operational and interim infrasound levels at Y21, night time period

The cut-in wind speed of the V112 WTGs is 3 m/s at hub height, and the maximum A-weighted sound power level is reached at 10 m/s as identified on Figure 12 and Figure 13. Note that sound power measurement data available for the V112 WTG indicates that there is no noticeable change in unweighted (linear) sound power levels in the frequency range from 10 Hz to 160 Hz for wind speeds above 10 m/s. This is to be expected as noise levels in this frequency range are typically associated with mechanical noise from the WTGs, which would not increase at wind speeds above 10 m/s due to constant power output. Therefore 10 m/s can reasonably be taken as the wind speed at which the maximum low frequency sound power output of the WTGs is also reached, making it relevant for this infrasound assessment.

From Figure 12, it is clear that there is no significant change between measured daytime pre-operation and interim infrasound levels at Y21A. The range of infrasound levels measured during the interim stage matches that measured during the pre-operational stage, with a similar trend in wind speed. This indicates that the Macarthur Wind Farm had no noticeable influence on the daytime infrasound levels at Y21A across the interim measurement stage.

It can be seen that, as for the pre-operational dataset, the measured interim infrasound levels at night time are influenced by hub height wind speed, with measured levels of between approximately 41 and 69 dB(G). There is more spread in the daytime dataset, suggesting that human activity within and possibly outside the house has contributed to both the measured interim and the pre-operation infrasound levels.

There are occasional periods where the measured $L_{Geq,10min}$ infrasound levels are between 80 and 91 dB(G). However, the distribution of these points relative to the main day and night time data sets, the occurrence at wind speeds below turbine cut-in, and the occurrence of similar data during the pre-operation measurements indicates these points are the result of localised short term sources rather than operation of the turbines.

A similar result is evident in the night time infrasound measurements (Figure 13), where the range of measured infrasound levels during the interim monitoring stage fall within those measured during the pre-operation stage.

Overall, the interim monitoring results indicate that there has been no noticeable increase in G-weighted infrasound levels at Y21A during the interim monitoring stage.

5.1.3 Operational

The complete dataset of measured infrasound levels at Y21A during the operational monitoring stage is included as Figure C3 in Appendix C. Time of day was again found to be a controlling factor for the measured infrasound levels at the residence.

Figure 14 and Figure 15 compare the measured pre-operational and operational $L_{eq,10min}$ infrasound levels at Y21A for the daytime and night time periods respectively. As for the interim monitoring stage, the measured operational infrasound levels at Y21A fall within the range of those measured during the pre-operational monitoring.

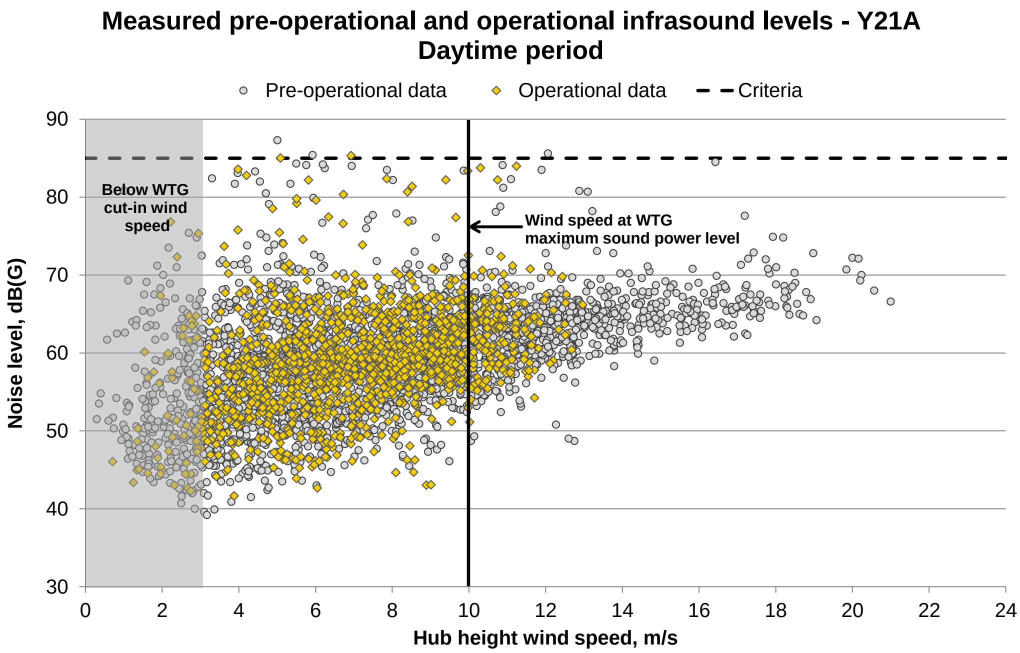

Figure 14 – Measured pre-operational and operational infrasound levels at Y21A, daytime period

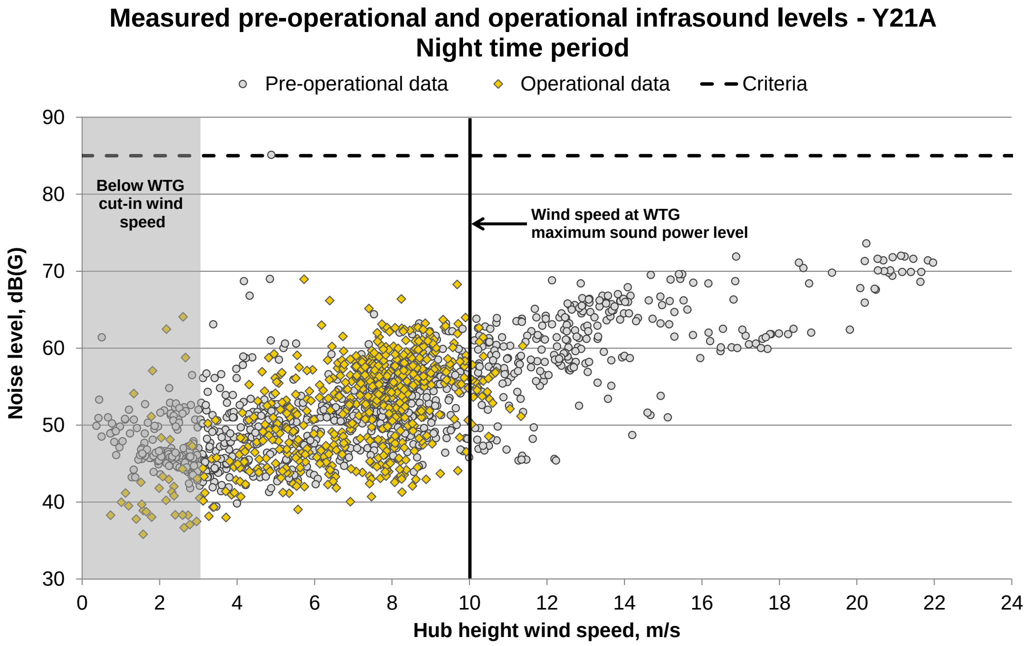

Figure 15 – Measured pre-operational and operational infrasound levels at Y21A, night time period

While there are occasional scattered periods with higher measured infrasound levels, particularly during the daytime, these also occurred during the pre-operational stage. Given that these do not occur with any consistency and bear no relationship to wind speed, they are believed to be the result of extraneous events in and around the residence. Note that periods affected by these clearly extraneous events have been removed from Figure 1 in the Summary.

Overall, the pre-operational, interim and operational monitoring results at Y21A demonstrate that there has been no change in $L_{Geq,10min}$ infrasound levels at the residence due to the operation of Macarthur Wind Farm.

5.2 O17A

5.2.1 Pre-operational

Figure 16 presents the measured pre-operational infrasound levels ($L_{Geq,10min}$) at O17A with the hub height wind speed at Macarthur Wind Farm.

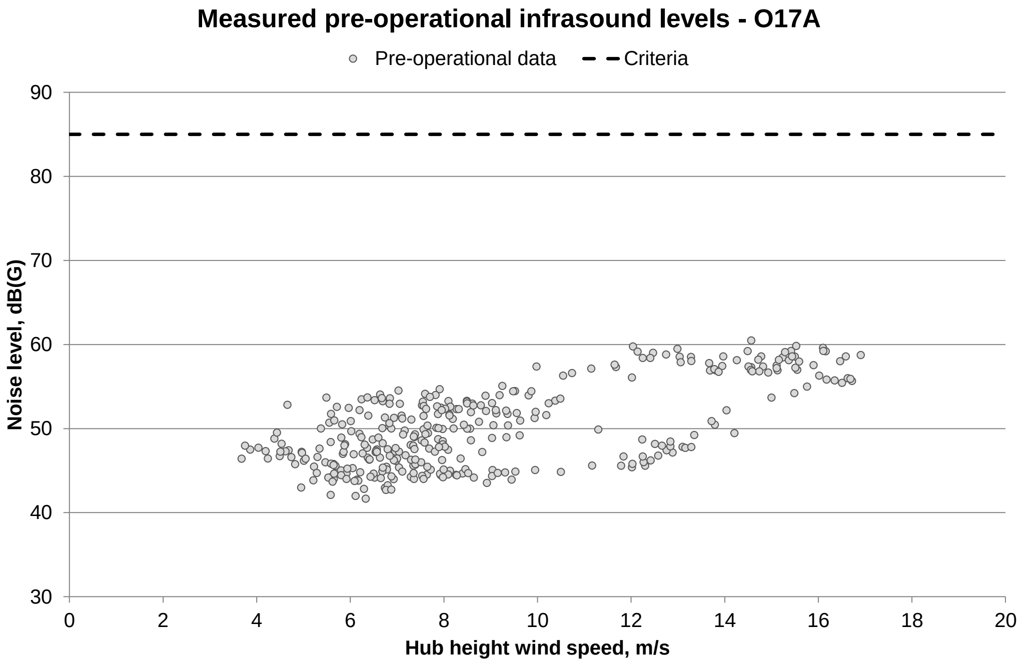

Figure 16 – Measured pre-operational infrasound levels at O17A

It can be seen that the measured pre-operational infrasound levels at O17A typically range from 45 to 60 dB(G). As expected, the measured infrasound levels generally increase as the hub height wind speed at the wind farm site increases, although there is still a considerable variance in the measured levels for each particular wind speed.

It is important to note that the dataset available for the pre-operational stage at O17A was captured for wind directions between 240º and 10º, corresponding to upwind and crosswind conditions relative to the nearest WTGs to the house. Any apparent change in the operational measurements relative to the pre-operational measurements should be interpreted with care as a change in wind direction can result in a change in measured infrasound levels at a location, regardless of whether the location is near to a wind farm (Evans et al, 2013).

5.2.2 Interim

The complete dataset of measured G-weighted noise levels at O17A during the interim monitoring stage is included as Figure C5 in Appendix C.

The measured infrasound levels during the interim monitoring stage typically ranged from 40 to 65 dB(G). As for the pre-operational stage, measured infrasound levels generally increased as the wind speed at the site increased. All measured infrasound levels during the interim stage remained below the assessment criterion of 85 dB(G).

While measured interim infrasound levels were higher on average than the measured pre-operational levels, it is important to recognise that different wind directions were observed during the monitoring stages. During the pre-operational monitoring, the wind was confined to the North, Northwest and West directions. As the monitoring location was on the eastern side of the residence, it is probable that natural wind-controlled infrasound levels would be lower under these conditions in that particular room of the house. Therefore, to directly compare the measured interim infrasound levels to the measured pre-operational infrasound levels, the measured interim levels were filtered to consider only those measurements gathered when the wind direction was between 240º and 10º. This allows direct comparison of the pre-operational and interim datasets.

Figure 17 compares the measured pre-operational and interim infrasound levels ($L_{Geq,10min}$) at O17A for wind directions of 240º and 10º.

From Figure 17, there is no noticeable change between the majority of the pre-operation and interim datasets for the matching wind conditions. While there are occasional isolated periods where measured infrasound levels were between 60 and 75 dB(G), these periods occurred:

- only during the daytime hours when extraneous noise sources (e.g. people within the house, vehicles outside) were more likely to influence the measurement results
- most frequently at very low wind speeds when the Macarthur Wind Farm WTGs would not be operational or would be operating at a low power output.

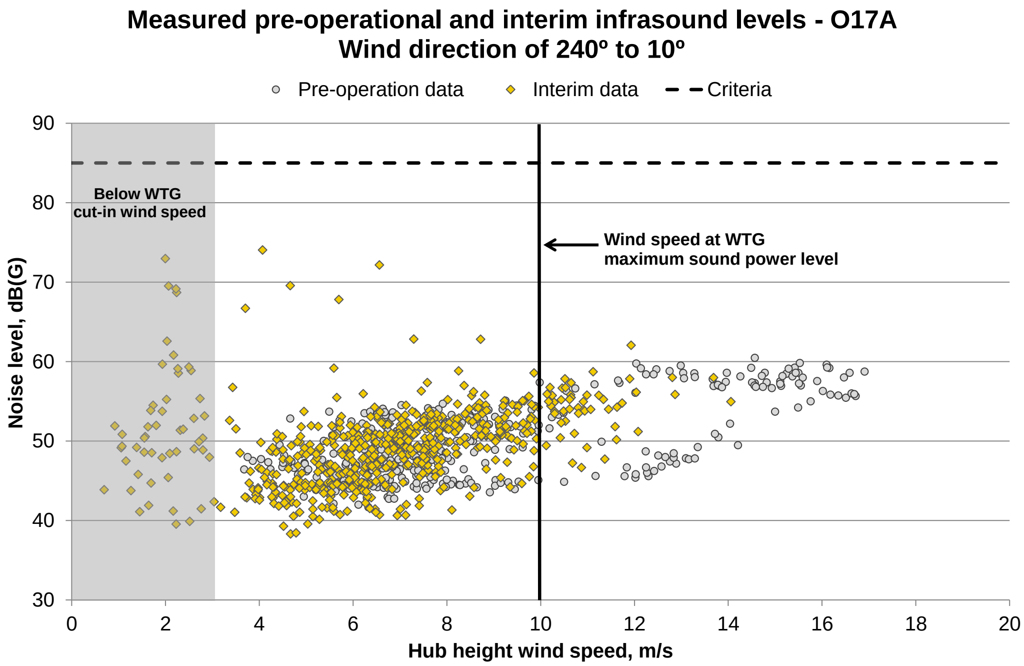

Figure 17 – Measured pre-operational and interim infrasound levels, wind direction of 240º to 10º

5.2.3 Operational

The complete dataset of measured G-weighted noise levels at O17A during the operational monitoring stage is included as Figure C6 in Appendix C.

The measured infrasound levels during the operational monitoring stage typically ranged from 40 to 70 dB(G), increasing as the wind speed at the site increased (as was observed during the pre-operational and interim stages). All measured infrasound levels during the operational stage remained below the assessment criterion of 85 dB(G), with the vast majority of data points significantly lower than the criterion.

The range of measured infrasound levels at O17A during the operational stage was larger than that measured during the pre-operational stage, with more data points in the 60 to 70 dB(G) range. However, it is important to recognise that different wind directions were observed during the pre-operational and operational monitoring stages, and to make a more direct comparison it is important to consider similar wind conditions. Therefore, the measured operational levels were filtered to consider only those measurements gathered when the wind direction was between 240º and 10º, as was observed during the pre-operational stage.

Figure 18 compares the measured pre-operational and operational infrasound levels ($L_{Geq,10min}$) at O17A for wind directions of 240º and 10º.

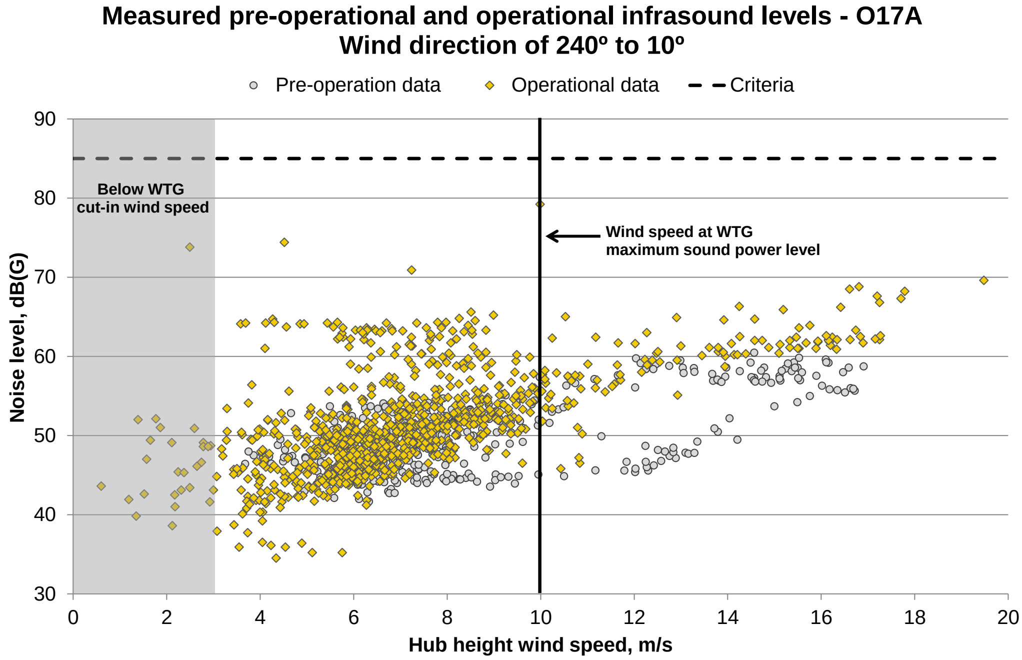

Figure 18 – Measured pre-operational and operational infrasound levels, wind direction of 240º – 10º

It can be seen that the measured operational infrasound levels at O17A were generally within the range of those measured during the pre-operational stage for wind speeds below 10 m/s.

There is a cluster of data points at approximately 60 to 65 dB(G) that exhibits a constant level regardless of wind speed. These higher levels at relatively low wind speeds occurred from 19:00 to 22:00 on 26 March and again from 19:00 to 00:30 on 27 March. They were characterised by a sudden increase in infrasound levels with no corresponding change in wind speed and direction, with a sudden decrease at the end of the period. Given they did not correlate with any change in wind conditions at the wind farm site, it is believed that these increased levels resulted from an extraneous source within or outside the house. Note that these periods, and other periods obviously affected by extraneous noise, have been removed from Figure 2 in the Summary.

At wind speeds above 10 m/s, the measured operational infrasound levels are approximately 2 to 5 dB(G) above the levels measured at the same wind speeds during the pre-operational measurements. During the pre-operational measurements data points were collected at these higher wind speeds primarily during the night time period, whereas during the operational monitoring they occurred in the daytime. It is therefore likely that a lower wind shear for the daytime meant that the actual wind speed at the house would be higher during the operational measurements than the pre-operational measurements for a given hub height wind speed, resulting in an increase in infrasound levels. It is also possible that there was a contribution from extraneous sources during the daytime operational measurements that was not present during the pre-operational stage.

However, regardless of the cause of the increase, the measured operational levels during these higher winds were well below the 85 dB(G) assessment criterion and were also lower than the pre-operational infrasound levels measured at Y21A, indicating that infrasound levels post operation are no greater than levels that occurred naturally in the local environment pre-operation of the wind farm.

Overall, measured pre-operational and operational infrasound levels at O17A do not exhibit any significant difference and levels remain well below the 85 dB(G) assessment criterion.

The resident at O17A expressed a concern about noise levels from Macarthur Wind Farm on the days and nights of 2 March to 3 March while the operational monitoring was being conducted. It was noted by the resident that during this period the site sounded a bit like a distant semi-trailer which never arrived. On these days the hub height wind speed at the wind farm varied from 2 to 13 m/s and the wind direction varied from easterly through to north-easterly, meaning the residence was approximately downwind of the nearest turbines (±60°).

Figure 19 presents measured operational infrasound levels at O17A from 7 am on 2 March to 7 am on 4 March compared against measurements gathered during other operational periods.

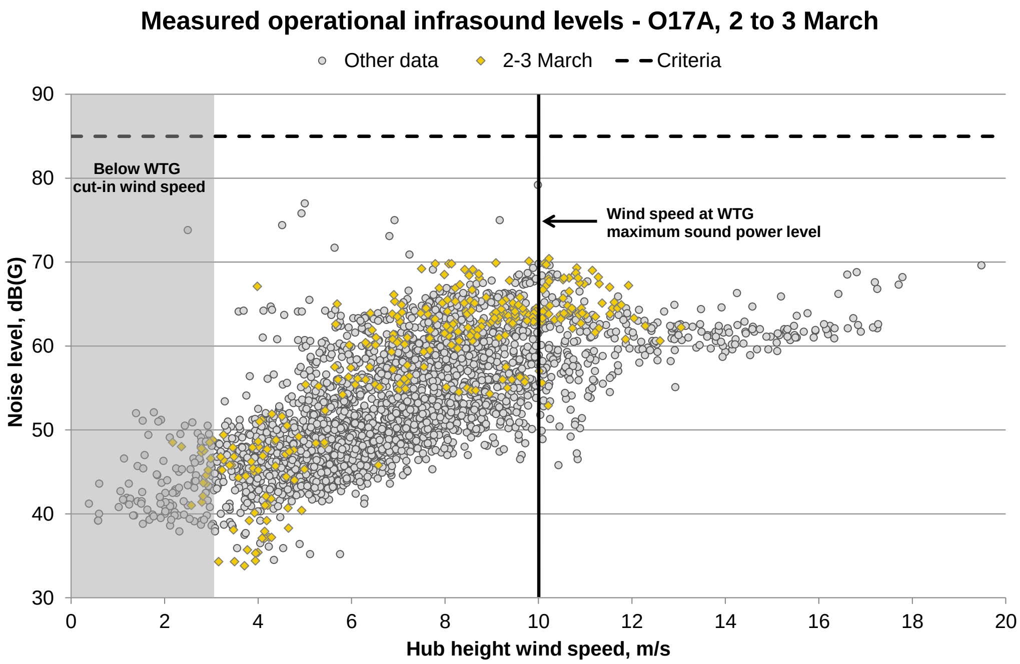

Figure 19 – Measured operational infrasound levels at Y21A on 2 March and 3 March

While the measured infrasound levels on 2 March and 3 March at wind speeds of approximately 7 to 11 m/s are some of the higher measurements, this is to be expected even without the wind farm given that the wind would have been blowing against the facade of the room where the measurements were taken. Measured infrasound levels during this period were all well below 85 dB(G) and would not have been perceptible.

It should also be noted that similar infrasound levels were also measured on other nights when the resident did not express a concern, indicating that the resident's concern would have been regarding audible noise from the wind farm and unrelated to infrasound.

5.3 Short-term infrasound levels

The assessments conducted at Y21A and O17A have considered 10-minute average infrasound levels and shown that they were well below the 85 dB(G) criterion for all stages. Given the significant margin between the measured levels and the criterion, it is not considered that potential short-term variations in infrasound levels would result in levels above 85 dB(G).

To check whether there is significant variation in infrasound levels over periods shorter than 10 minutes, the measured 10-second infrasound levels (L_{Geq10s}) for typical periods were reviewed. The 10-second measurements were undertaken using the SVAN 979 sound level meter, which was used at O17A during the pre-operational and operational stages, and at Y21A during the interim stage. Note that 10 seconds is considered the minimum applicable integration time as ISO 7196 states:

> *The integrating time constant chosen should be sufficiently long for the observed value to be representative of the noise being measured. Usually, this will be the case for an integration time/time constant of 10 s.*

A shorter integration time would not result in a representative measurement of the infrasound level.

Figure 20 shows the measured $L_{Geq,10s}$ infrasound levels over typical 10-minute periods during the pre-operational and operational stages at O17A, and the interim stage at Y21A. The periods have been selected such that they are representative of night time infrasound levels with a hub height wind speed of 10 m/s when the WTGs would be operating at or near rated power. The period at Y21A is also when the measurement location is downwind of the nearest WTGs.

It can be seen from Figure 20 that short-term variations in these infrasound levels are no greater during the interim and operational stages than during the pre-operational stage. A review of other periods at matching wind speeds indicated similar results. This suggests that short-term variations in the infrasound level will not result in an exceedance of the 85 dB(G) criterion at either location, unless they were significantly influenced by an extraneous noise source.

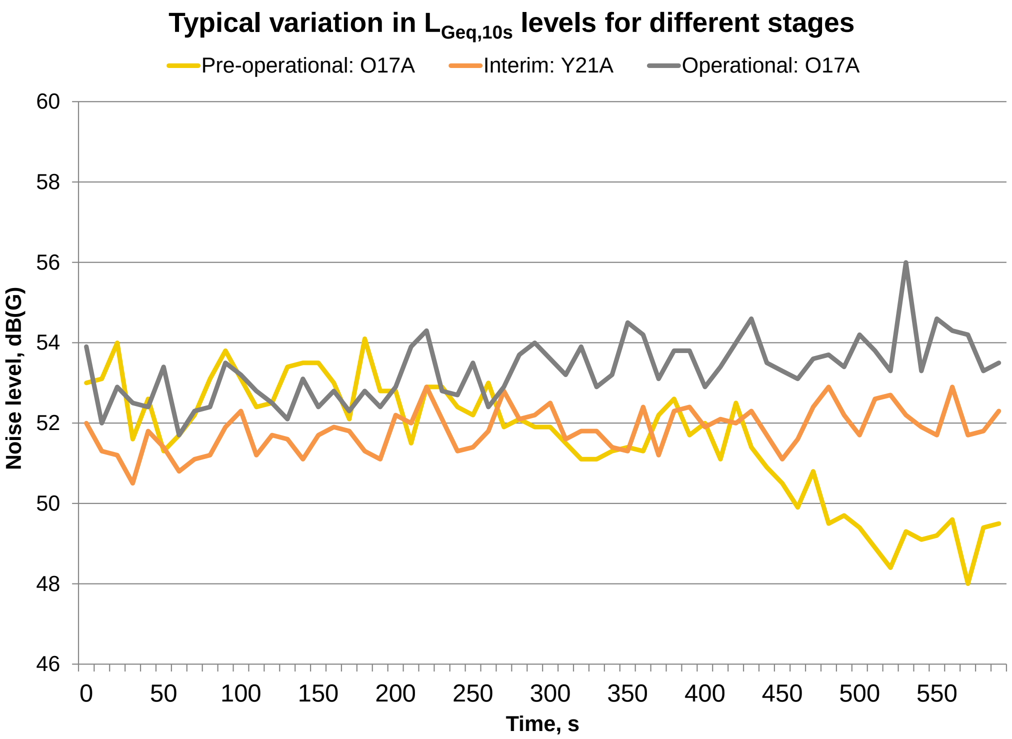

Figure 20 – Measured $L_{Geq,10s}$ over typical 10-minute periods (with average wind speed of 10 m/s)

Note that a review of the wind speed data for the pre-operational measurements at O17A indicates a reduction in wind speed is the likely cause of the reduction in measured infrasound level during the last 2-minutes of the measurement shown on Figure 20. Natural wind-generated infrasound often controls infrasound levels at rural locations (Howe et al, 2012; Evans et al, 2013), such that any fluctuation of wind speed results in a corresponding fluctuation in the infrasound level.

6 Low frequency noise assessment

This section presents the results of the low frequency noise measurements conducted at Y21A and O17A. A comparison is made between the pre-operational, interim and operational measurement results for both locations based on the measured $L_{pA,LF}$ levels. The aim of this comparison is to determine whether operation of the Macarthur Wind Farm has resulted in a change in low frequency noise levels at the residences.

The measured levels for each measurement stage are also compared against the relevant DEFRA assessment criteria for both Y21A and O17A. It is expected that the DEFRA criteria will be adopted for use in wind farm low frequency noise assessments, in future guidance to be released by the EPA Victoria.

Consideration has also been given to the low frequency content of the measured levels, including analysis of the linear levels from 0.8 Hz to 160 Hz (Section 7).

6.1 Y21A

6.1.1 Measured $L_{pA,LF}$ levels

Pre-operational

Figure 21 presents the measured A-weighted low frequency $L_{pA,LF}$ noise levels at O17A during the pre-operational stage. The measured levels during the daytime (6:00 to 23:00) and night time (23:00 to 6:00) periods are presented separately as for the infrasound assessment.

From Figure 21, it is clear that the pre-operational low frequency noise levels at O17A were significantly influenced by extraneous noise sources during the daytime period. The measured low frequency $L_{pA,LF}$ noise levels regularly ranged from 20 to 45 dB(A). This is expected to be a result of human activity within and around the house during the daytime hours.

At night time, the measured pre-operational low frequency noise levels at Y21A are typically lower and exhibit a general upward trend with wind speed. At hub height wind speeds of 12 m/s and above, the measured low frequency $L_{pA,LF}$ noise levels ranged from 10 to 28 dB(A), indicating a wide spread of low frequency noise levels most likely controlled by wind in the immediate environment.

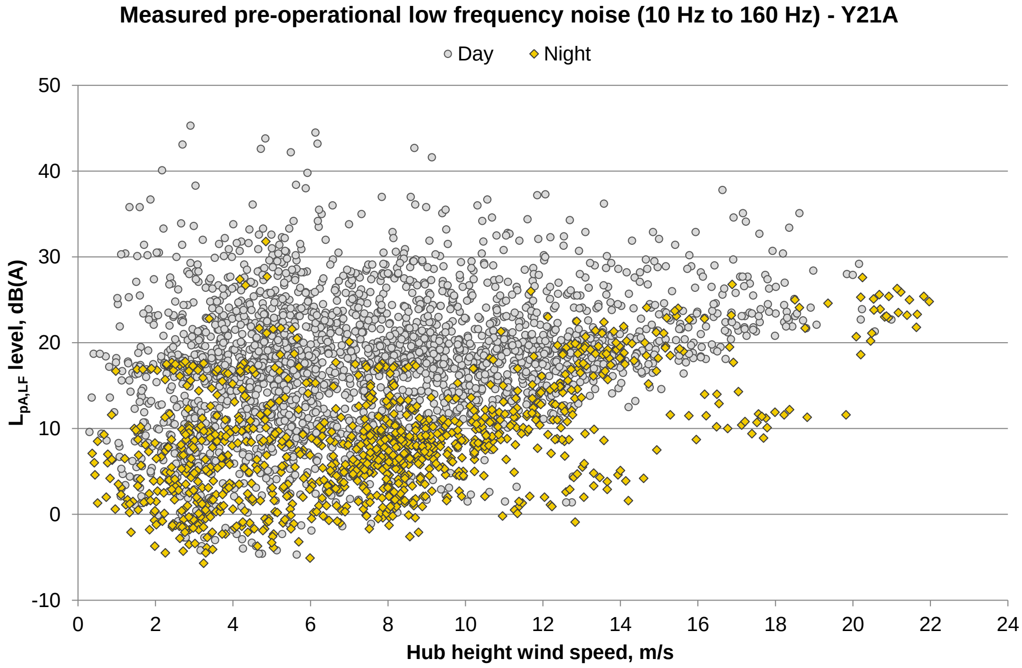

Figure 21 – Measured pre-operational low frequency $L_{pA,LF}$ noise levels at Y21A

Interim

The complete dataset of measured low frequency $L_{pA,LF}$ noise levels at Y21A during the interim monitoring stage is included as Figure D2 in Appendix D. As for the pre-operational dataset, there is significant spread in the interim dataset with time of day found to be a key factor. To exclude some of the more extraneous noise affected measurements only measured night time levels have been considered further here.

Figure 22 presents the measured interim low frequency $L_{pA,LF}$ noise levels during the night time period at Y21A with the hub height wind speed at Macarthur Wind Farm. The wind speed at which the maximum sound power level of the WTGs is reached (10 m/s) is also shown. As discussed previously in Section 5.1.2, sound power measurement data available for the V112 WTG indicates that there is no noticeable change in unweighted (linear) sound power levels in the frequency range from 10 Hz to 160 Hz for wind speeds above 10 m/s.

The measured interim low frequency noise levels at show a general upward trend with wind speed, as was the case for the pre-operational stage. The measured levels are generally below 20 dB(A) at wind speeds below 10 m/s. At higher winds speeds, there are measured levels in the range of 20 to 24 dB(A), although this also occurred during the pre-operational measurements. There are also scattered measurements in the range of 20 to 35 dB(A) at lower wind speeds that do not exhibit any clear trend with wind speed and are expected to the result of extraneous noise sources.

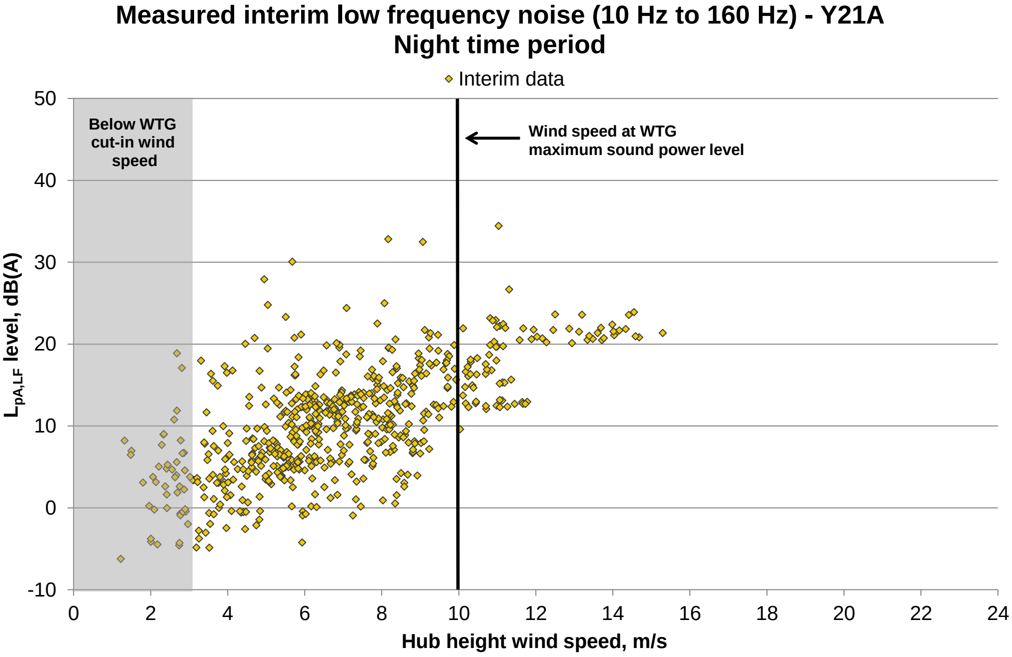

Figure 22 – Measured night time interim low frequency $L_{pA,LF}$ noise levels at Y21A

Figure 23 compares the measured pre-operational and interim low frequency $L_{pA,LF}$ noise levels at Y21A for the night time period. It indicates that the interim night time $L_{pA,LF}$ noise levels at Y21A are within the range of those measured during the pre-operational monitoring. However, it does appear that there has been an increase in the measured low frequency noise levels for hub height wind speeds between 9 and 14 m/s, with low frequency levels measured in the range from 20 to 24 dB(A).

The night time periods during which these low frequency noise levels were measured were reviewed and were found to all occur between 11 pm on 4 December and 6 am on 5 December 2012. During this period, the hub height wind speeds ranged from 10 to 15 m/s, and the wind direction was 250º to 300º, approximately corresponding to downwind conditions at Y21A. Given these wind conditions it was considered that these increased $L_{pA,LF}$ levels could potentially be the result of noise from the Macarthur Wind Farm. Further analysis of these periods was undertaken as part of the relevant DEFRA low frequency noise assessment for Y21A (Section 6.1.2) and it was found that these levels were compliant with the relevant low frequency noise criteria.

A comparison of low frequency noise levels measured during the daytime was also undertaken for Y21A but no change in level was observed due to the significant influence of extraneous noise sources on the daytime results.

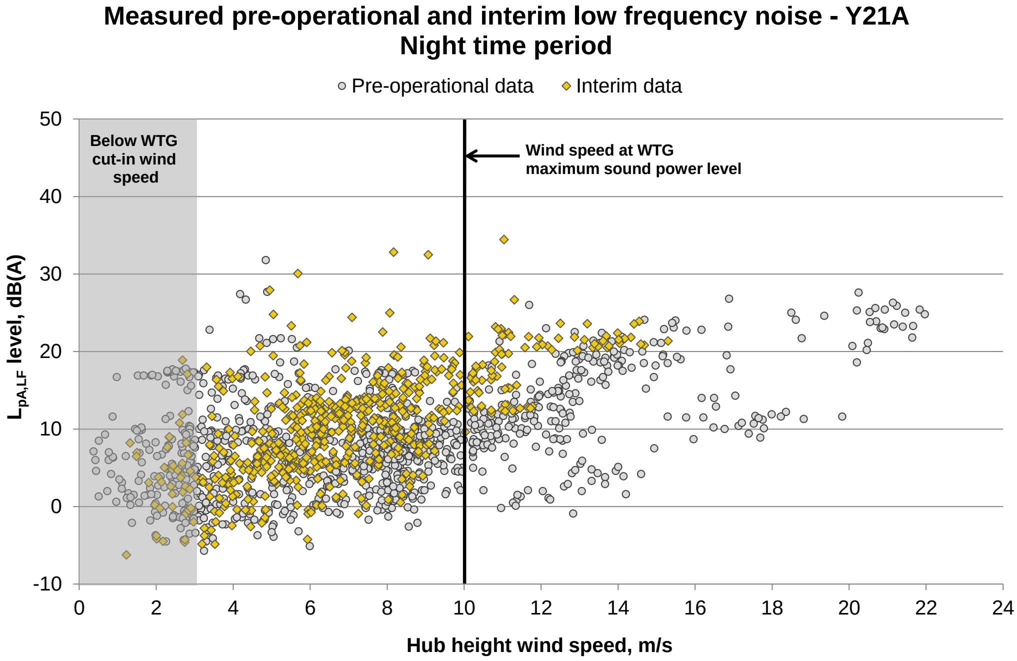

Figure 23 – Measured pre-operational and interim low frequency $L_{pA,LF}$ noise levels at Y21A

Operational

The complete dataset of measured low frequency $L_{pA,LF}$ noise levels at Y21A during the operational monitoring stage is included as Figure D3 in Appendix D.

Figure 24 presents the measured night time low frequency $L_{pA,LF}$ noise levels at Y21A with hub height wind speed during the operational monitoring stage. It can be seen that the measured levels remained below 20 dB(A) at all times with the exception of a handful of scattered periods. These scattered periods are believed to be the result of extraneous noise sources in and around the residence as they also occurred during the pre-operational monitoring.

Figure 25 compares the measured pre-operational and operational low frequency $L_{pA,LF}$ noise levels at Y21A. The measured levels during the operational monitoring indicate that there has been no observable change in low frequency $L_{pA,LF}$ noise levels at the residence between the two monitoring stages. Note that periods that were obviously affected by extraneous noise during both the pre-operational and operational stages have been removed from Figure 3 in the Summary of this report.

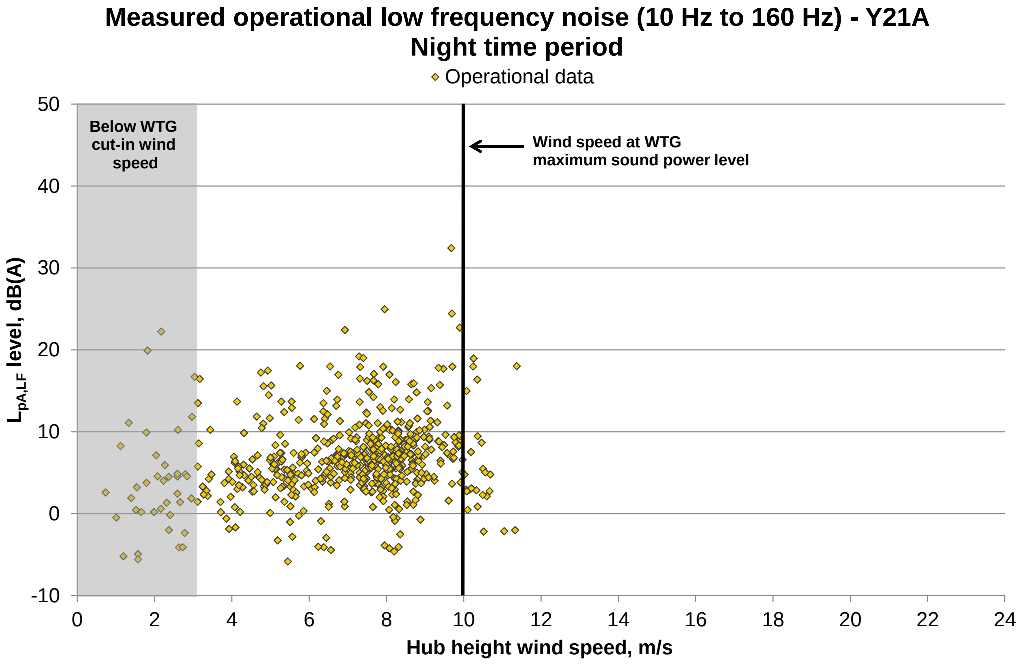

Figure 24 – Measured night time operational low frequency $L_{pA,LF}$ noise levels at Y21A

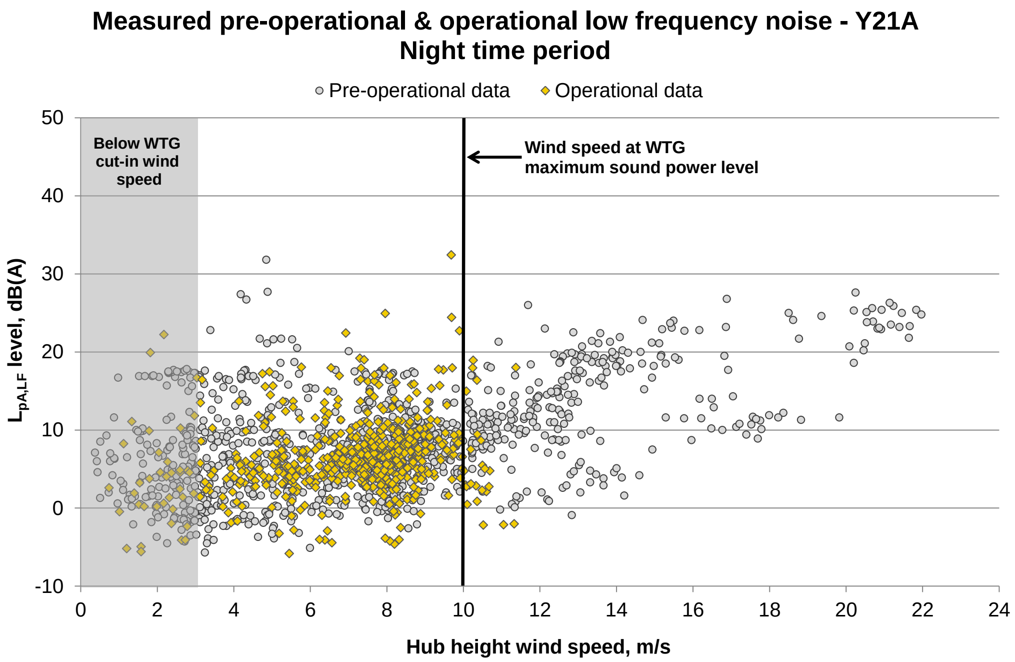

Figure 25 – Measured pre-operational and operational low frequency $L_{pA,LF}$ noise levels at Y21A

Overall, the operational monitoring at Y21A indicates that Macarthur Wind Farm did not noticeably contribute to the measured $L_{pA,LF}$ noise levels at the residence during the stage. It is important to note that the operational monitoring at Y21A did not gather the same data at wind speeds of 10 to 14 m/s as was gathered during the interim monitoring stage when a relatively small increase in low frequency noise levels was observed. However, the interim monitoring stage at Y21A can be considered representative of operational conditions at the site as the nearest WTGs were operating at the time.

6.1.2 Assessment against DEFRA criteria

The assessment of the measured low frequency noise levels at Y21A against the relevant DEFRA criteria has been undertaken for the measured night time levels only. As the DEFRA criteria are more stringent at night time, this will provide a more conservative assessment as the Macarthur Wind Farm can operate 24 hours a day depending on wind speed.

Table 7 summarises the number of 10-minute periods for which a potential exceedance of the DEFRA low frequency noise criteria was detected in each one-third octave band during the pre-operational, interim and operational monitoring stages at Y21A. These are referred to as "potential exceedances" as the minimum DEFRA criteria have been used for this preliminary screening assessment, and the criteria would be increased by 5 dB should the noise be found to be steady in nature.

Table 7 – Potential exceedances of DEFRA criteria detected at Y21A

Frequency	Minimum night time criteria[1]	Pre-operational stage		Interim stage		Operational stage	
Hz	$L_{eq,10min}$, dB	No.	Range, dB	No.	Range, dB	No.	Range, dB
10	92	0	–	0	–	0	–
12.5	87	0	–	0	–	0	–
16	83	0	–	0	–	0	–
20	74	1	76	0	–	0	–
25	64	0	–	0	–	0	–
31.5	56	0	–	0	–	0	–
40	49	1	53	0	–	1	51
50	43	31	44 – 53	7	44 – 49	1	53
63	42	8	43 – 51	50	43 – 53	1	50
80	40	3	41 – 46	5	43 – 50	1	42
100	38	5	39 – 40	2	39 – 41	0	–
125	36	4	37 – 41	5	37 – 43	1	40
160	34	5	35 – 39	4	37 – 46	3	35 – 42
Potential exceedances	**–**	**36**	**–**	**50**	**–**	**3**	**–**

1. If noise is found to be steady then criteria need to be increased by 5 dB.

It can be seen that a similar number of potential exceedances of the low frequency noise criteria were found in all but the 50 Hz and 63 Hz one-third octave bands during both the pre-operational and interim monitoring stages. This suggests that extraneous noise sources are typically the cause of the exceedances in these one-third octave bands, rather than noise from the Macarthur Wind Farm.

The decrease in potential exceedances of the criterion in the 50 Hz one-third octave band between the pre-operational and interim stages is not suggestive of an issue with compliance due to the operation of the wind farm, so is not investigated further. In the 63 Hz one-third octave band, there is an increase in the number of potential exceedances from the pre-operation monitoring stage to the interim monitoring stage. However, it should be noted that the absolute levels of the potential exceedances were not noticeably higher than those detected during the pre-operational stage.

The significantly lower number of potential exceedances at Y21A during the operational stage relative to the pre-operational stage suggests that noise from the Macarthur Wind Farm did not result in exceedances of the DEFRA criteria during the operational monitoring. The occasional potential exceedances are at the same frequencies and less regular than during the pre-operational stage, indicating extraneous noise sources are the most likely cause.

The potential exceedances in the 63 Hz one-third octave band during the interim monitoring stage were reviewed and it was found that 35 of the potential exceedances appeared to occur at a similar wind speed and direction, all occurring between 23:00 on 4 December and 6:00 on 5 December 2012. This period matches the period where A-weighted low frequency $L_{pA,LF}$ noise levels between 20 and 24 dB(A) were measured. Given these conditions, it is considered that these potential exceedances could potentially be the result of noise from the Macarthur Wind Farm. However, it is important to note that these wind conditions only occurred across one night and it is possible that another source was present for that period.

The other 15 periods at Y21A where a potential exceedance of the DEFRA criteria in the 63 Hz one-third octave band was detected are believed to be the result of extraneous noise as they occurred infrequently and showed no trend against wind speed and direction.

The measured interim $L_{90,10min}$ and $L_{10,10min}$ noise levels in the 63 Hz one-third octave band during the 35 periods where a potential exceedance of the DEFRA criteria occurred were analysed to determine whether the measured low frequency noise is steady. If the noise is steady (i.e. if the $L_{10,10min}$ is less than 5 dB above the $L_{90,10min}$) then the DEFRA criteria require that the criterion at that particular one-third octave band be relaxed by 5 dB.

Table 8 presents the 10-minute measurements in the 63 Hz one-third octave band during these potential exceedance periods, including the difference between the $L_{90,10min}$ and $L_{10,10min}$ noise levels.

Table 8 – Potential exceedances of DEFRA criteria at Y21A for 63 Hz one-third octave band

Date & time	Hub height wind conditions		Noise level in 63 Hz one-third octave band, dB			
	Wind speed, m/s	Direction	$L_{10} - L_{90}$	Steady	Criterion	Measured L_{eq}
4/12 23:00	10.8	294º	2	✓	47	45
4/12 23:20	11	289º	2	✓	47	45
4/12 23:30	11.1	290º	1	✓	47	45
4/12 23:40	10.9	290º	2	✓	47	44
4/12 23:50	10.1	283º	3	✓	47	45
5/12 00:00	11.2	279º	2	✓	47	45
5/12 00:10	11.2	281º	2	✓	47	45
5/12 00:20	11.7	284º	2	✓	47	45
5/12 00:30	12.9	279º	2	✓	47	44
5/12 00:40	13.1	274º	2	✓	47	44
5/12 00:50	11.9	271º	2	✓	47	45
5/12 01:00	11	275º	2	✓	47	45
5/12 01:10	13.7	273º	2	✓	47	44
5/12 01:20	15.3	265º	3	✓	47	43
5/12 01:30	14.1	256º	2	✓	47	43
5/12 01:40	12.5	256º	3	✓	47	44
5/12 01:50	13.2	249º	2	✓	47	43
5/12 02:00	14.6	251º	2	✓	47	43
5/12 02:10	14.4	250º	2	✓	47	43
5/12 02:50	14.6	258º	3	✓	47	44
5/12 03:00	13.3	259º	2	✓	47	43
5/12 03:10	13.8	258º	3	✓	47	43
5/12 03:20	13.4	258º	2	✓	47	44
5/12 03:30	12.2	260º	3	✓	47	43
5/12 03:50	14.3	252º	2	✓	47	43
5/12 04:00	14.2	249º	2	✓	47	43
5/12 04:10	14	252º	2	✓	47	43
5/12 04:20	14	252º	2	✓	47	43
5/12 04:30	14	251º	2	✓	47	43
5/12 04:40	13.6	251º	2	✓	47	43
5/12 04:50	12	251º	3	✓	47	43
5/12 05:00	11.6	251º	2	✓	47	43
5/12 05:10	12.3	255º	3	✓	47	43
5/12 05:30	11	253º	2	✓	47	43
5/12 05:40	11.9	255º	3	✓	47	43
5/12 05:50	10.8	294º	2	✓	47	45

It can be seen that the noise levels in the 63 Hz one-third octave band during periods of potential exceedance were steady in nature (L_{10} – L_{90} < 5 dB) and are therefore subject to a night time criterion of 47 dB. As the measured noise levels at 63 Hz were between 43 and 45 dB, they were compliant with the DEFRA criteria.

The interim exceedances in the 63 Hz one-third octave band presented in Table 8 did not reoccur during the operational monitoring at Y21A. However, this may have been due to a lack of similar wind directions and wind speeds. Regardless, the interim monitoring stage at Y21A can be considered representative of an operational monitoring period as all the nearest WTGs were operating.

Furthermore, during the operational measurements at O17A, similar wind conditions were observed to those at Y21A during the interim stage. However, the potential exceedances in the 63 Hz one-third octave band were not identified in the operational measurements conducted at O17A, which is located closer to the nearest WTG. Therefore, it is possible that the measurement results at Y21A analysed in Table 8 were the result of an extraneous source rather than the operation of the wind farm.

6.2 O17A

6.2.1 $L_{pA,LF}$ levels

Pre-operational

Figure 26 presents the measured A-weighted low frequency noise levels ($L_{pA,LF}$) at O17A during the pre-operational stage. The measured low frequency noise levels are presented for both the daytime and night time periods in Figure 26.

The results shown in Figure 26 demonstrate that, as for the measured infrasound levels at O17A, low frequency noise levels increased with wind speed during the pre-operational stage. This indicates that increases in the local wind speed will result in increases in low frequency noise levels in the absence of any contribution from Macarthur Wind Farm.

It is also clear that the existing $L_{pA,LF}$ noise levels within the residence at O17A regularly exceed 10 dB(A) at wind speeds of 7 m/s and above, and occasionally exceed 20 dB(A) . Therefore, any measured low frequency noise levels of this order during the interim and operational stages will not necessarily be a result of low frequency noise from the WTGs at Macarthur Wind Farm.

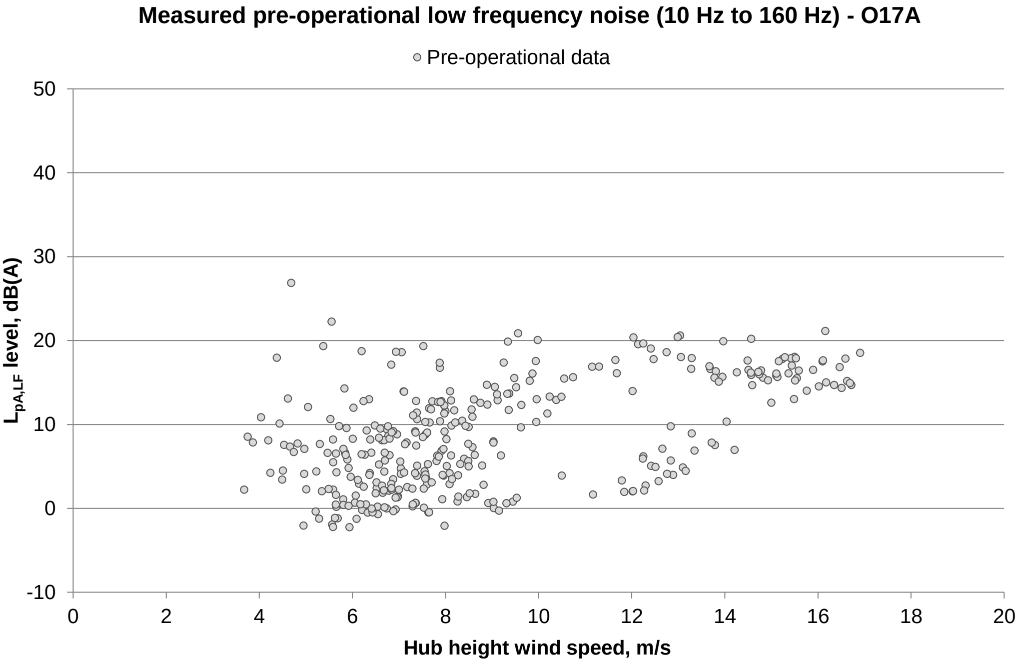

Figure 26 – Measured pre-operational low frequency $L_{pA,LF}$ noise levels at O17A

Interim

The complete dataset of measured $L_{pA,LF}$ noise levels at O17A during the interim monitoring period is included as Figure D5 in Appendix D.

It can be seen that the majority of measured low frequency $L_{pA,LF}$ noise levels at O17A were below approximately 15 dB(A) during the interim period when most of the WTGs at Macarthur Wind Farm were operating. While there are occasional periods during which the measured levels were in the range from 15 to 47 dB(A), these measurements are scattered and also occur when the wind speed at Macarthur Wind Farm is below cut-in (3 m/s). Therefore, these isolated measurements above 15 dB(A) are considered to be the result of extraneous noise sources.

The measured low frequency noise levels during the interim period were reviewed and it was found that the vast majority of these measured levels above 20 dB(A) $L_{pA,LF}$ were isolated occurrences between the hours of 7:00 and 22:00, suggesting that human activity within and around the house was a likely cause of the occasional higher measured low frequency noise levels.

Figure 27 presents the measured interim low frequency noise levels at O17A for the night time period from 22:00 to 7:00. The measured night time $L_{pA,LF}$ noise levels typically range from -5 to 13 dB(A). The occasional scattered periods of higher levels above 15 dB(A) occur regardless of wind speed and are the result of single extraneous source in or around the residence.

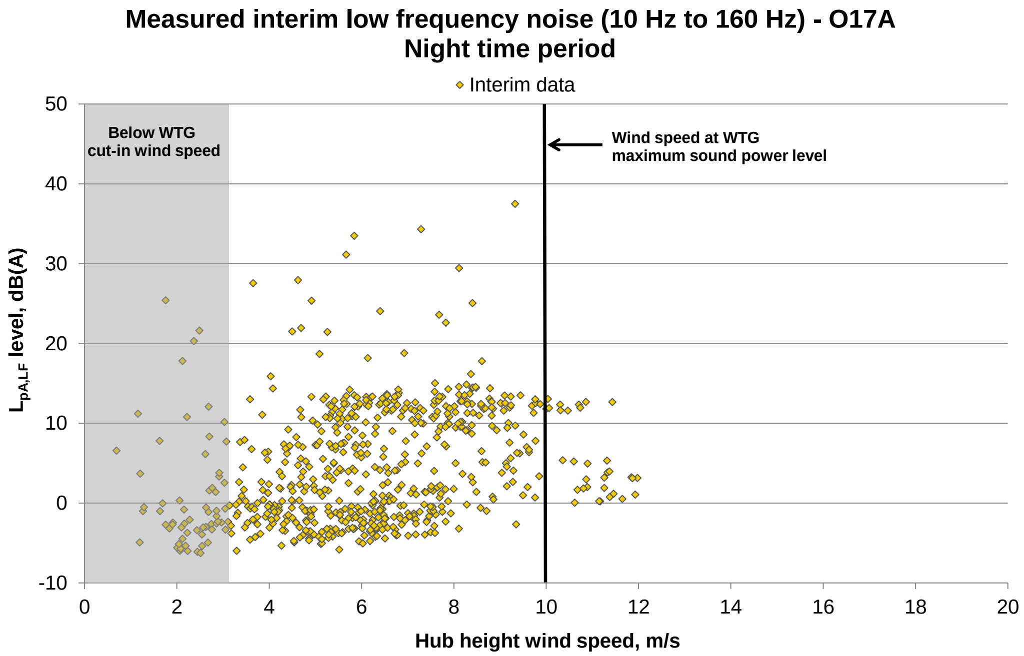

Figure 27 – Measured night time interim low frequency $L_{pA,LF}$ noise levels at O17A

The two groupings of measured $L_{pA,LF}$ noise levels evident in O17A appear to correspond to two different wind directions with respect to Macarthur Wind Farm. The lower levels of between 0 and -5 dB(A) were typically measured during upwind conditions, with the higher levels of 10 to 13 dB(A) measured during downwind conditions. This increased contribution during downwind periods may be a result of noise from Macarthur Wind Farm but it is important to note that similar $L_{pA,LF}$ noise levels were measured during the pre-operational monitoring so they may also result from another noise source unrelated to the wind farm.

Figure 28 compares the measured $L_{pA,LF}$ noise levels at O17A for the pre-operational and interim stages. In order to provide a clear comparison of noise levels, only night time periods and those with a wind direction of between 240° to 10° (through 0°) have been considered. This wind direction range is limited by the data gathered during the pre-operational monitoring stage.

The measurement results indicate that there was no change in measured low frequency $L_{pA,LF}$ noise levels at O17A for comparable wind directions during the interim monitoring stage, when the nearest WTG was 3.6 km from the residence.

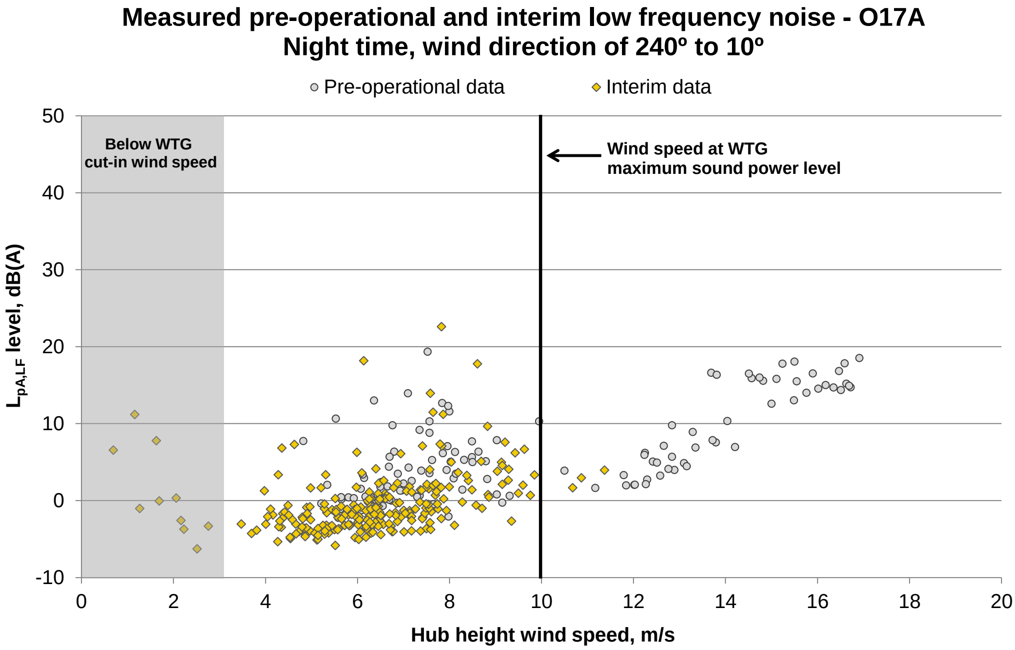

Figure 28 – Measured pre-operational and interim low frequency $L_{pA,LF}$ noise levels at O17A

Operational

The complete dataset of measured $L_{pA,LF}$ noise levels at O17A during the operational monitoring stage is included as Figure D6 in Appendix D. It can be seen that the majority of measured $L_{pA,LF}$ levels are below 20 dB(A) but there are a number of scattered data points above 20 dB(A), including some at higher wind speeds.

Figure 29 presents the measured operational low frequency noise levels at O17A for the night time period from 22:00 to 7:00. It can be seen that the majority of measured night time $L_{pA,LF}$ noise levels are below 20 dB(A) up to a wind speed of 10 m/s. The scattered periods above 20 dB(A) for these lower wind speeds are considered to be the result of extraneous noise sources in or around the residence. For the limited number of periods at wind speeds above 10 m/s, the majority of the data points range from 13 to 28 dB(A) $L_{pA,LF}$.

Figure 30 compares the measured $L_{pA,LF}$ noise levels at O17A for the pre-operational and operational stages. As for the interim stage, only night time periods and those with a wind direction of between 240° to 10° (through 0°) have been considered to provide a direct comparison between the pre-operational and operational measurement stages. This wind direction range is limited by the data gathered during the pre-operational monitoring stage.

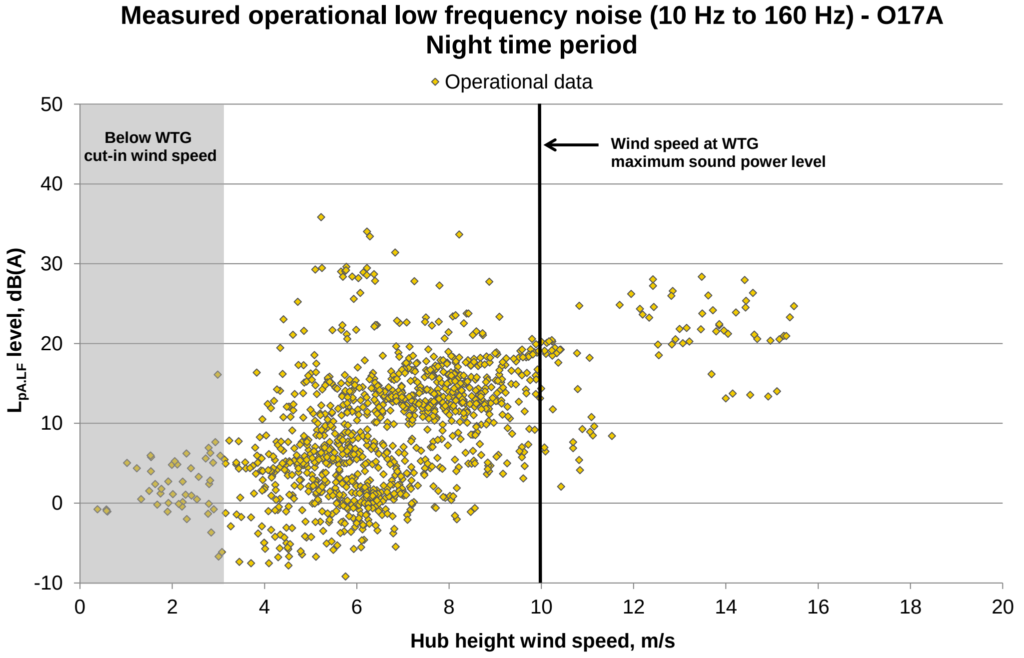

Figure 29 – Measured night time operational low frequency $L_{pA,LF}$ noise levels at O17A

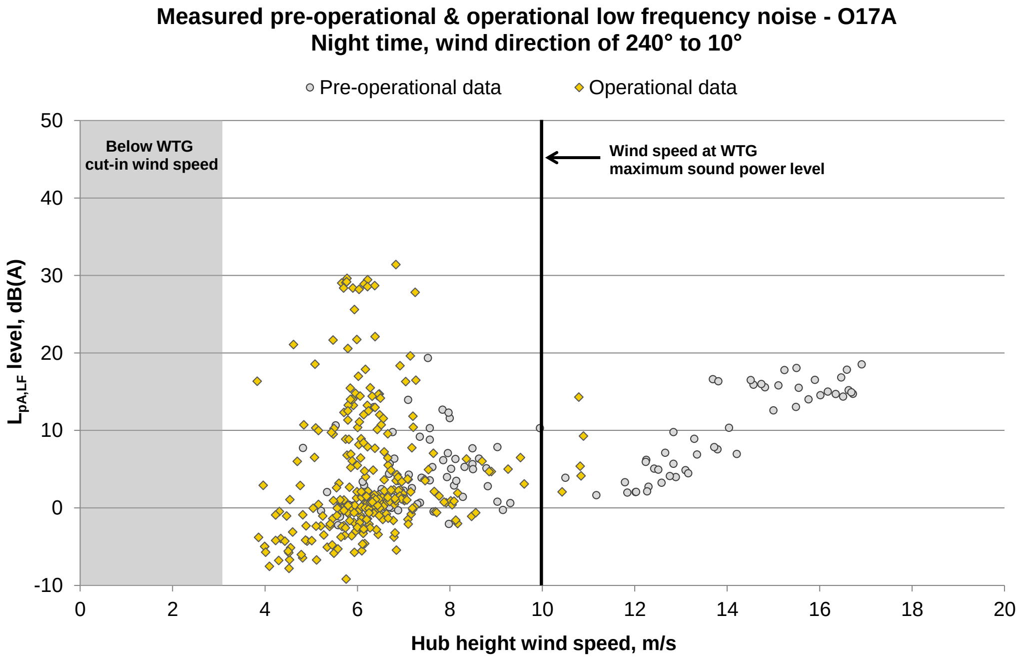

Figure 30 – Measured pre-operational and operational low frequency $L_{pA,LF}$ noise levels at O17A

From Figure 30, there appears to have been an increase in low frequency $L_{pA,LF}$ noise levels for some of the measurement periods at wind speeds of approximately 5 to 7 m/s, resulting in $L_{pA,LF}$ noise levels of 10 to 15 dB(A). However, this change is not consistent, and the majority of measured operational low frequency noise levels show no noticeable change relative to the pre-operational levels. Note that the periods of increased low frequency $L_{pA,LF}$ noise levels at 28 to 29 dB(A) at approximately 6 m/s are believed to be the result of an extraneous noise source in or around the residence given the significant increase in noise level and the small number of data points.

As identified in Section 5.2, the resident at O17A expressed a concern about noise levels from Macarthur Wind Farm on the days and nights of 2 March to 3 March while the operational monitoring was being conducted. Figure 31 presents the measured operational low frequency $L_{pA,LF}$ noise levels at O17A from 7 am on 2 March to 7 am on 4 March compared against the measurements gathered during other operational stages.

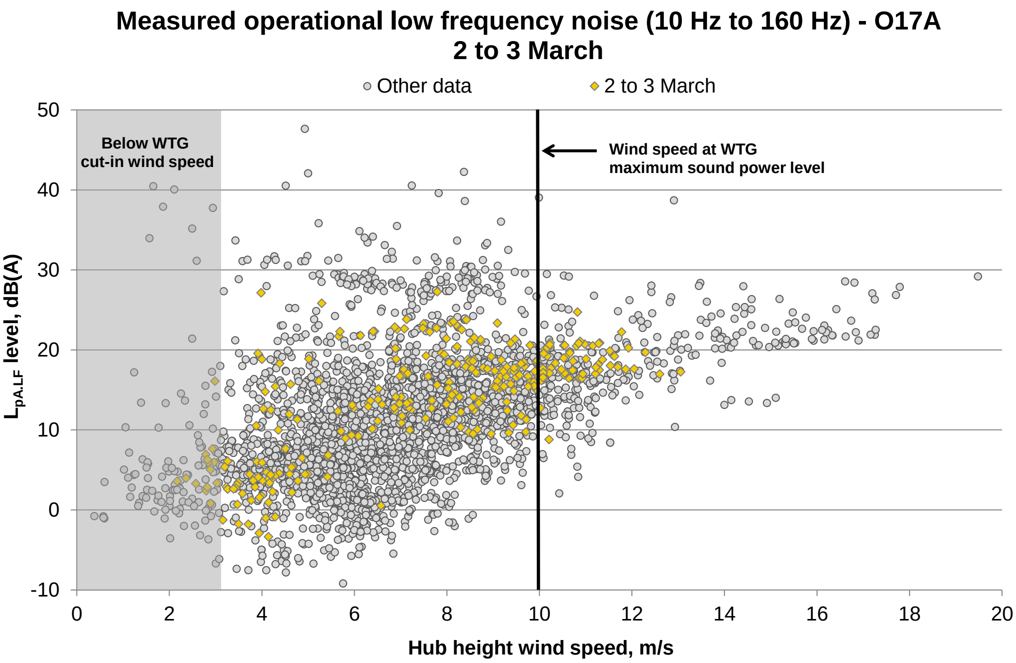

Figure 31 – Measured operational low frequency $L_{pA,LF}$ noise levels at O17A, 2 March to 3 March

The measurement results indicate that low frequency noise levels on 2 March and 3 March were not markedly higher than those measured during other operational stages. However, the wind during this period was downwind and it is possible that low frequency noise from Macarthur Wind Farm was more audible during this period than others and perhaps more distinct amongst the background low frequency noise.

Overall, the operational low frequency $L_{pA,LF}$ noise monitoring results at O17A indicate higher levels than during the interim stage. During the interim stage, the nearest WTG was 3.6 km from the residence as compared to 1.8 km during the operational monitoring stage. Therefore, the Macarthur Wind Farm may be the source of this increased low frequency noise.

It is important to note that a level of audible low frequency noise is relatively common from traffic, aircraft and industry, including primary production industry (sources such as harvesters, tractors and the like), mining and quarrying. An assessment against the relevant DEFRA low frequency noise criteria is required to assess whether the low frequency noise levels measured at O17A may increase annoyance. This assessment is presented in the following section.

6.2.2 Assessment against DEFRA criteria

The assessment of the measured low frequency noise levels at O17A against the relevant DEFRA criteria has been undertaken for the measured night time levels in order to remove extraneous events that occurred more regularly during the daytime. As the DEFRA criteria are more stringent at night time, this will provide a more conservative assessment as the Macarthur Wind Farm can operate 24 hours a day depending on wind speed.

No exceedances of the DEFRA night time low frequency noise criteria were detected during the pre-operational monitoring stage at O17A. However, this may be a result of the shorter pre-operational monitoring stage at O17A, with only 122 night time 10-minute periods available for analysis.

There were 12 potential exceedances of the DEFRA night time low frequency noise criteria detected during the interim monitoring stage at O17A, from a total of 648 10-minute periods. There were also 32 potential exceedances of the DEFRA night time criteria detected during the operational monitoring stage from a total of 1242 10-minute periods. Note that these are referred to as “potential exceedances” as the minimum DEFRA criteria have been used for this preliminary screening assessment, and the criteria would be increased by 5 dB should the noise be found to be steady in nature.

Table 9 summarises the number of 10-minute periods for which a potential exceedance of the DEFRA criteria was detected in each one-third octave band during the interim and operational monitoring stages at O17A.

During the interim monitoring, the potential exceedances of the DEFRA criteria occurred in the frequency range from 40 Hz to 160 Hz. The wind speeds and directions of the potential exceedances for the interim monitoring stage were reviewed and it was found that two occurred at wind speeds lower than the cut-in wind speed of the WTGs. The other potential exceedances during the interim monitoring stage at O17A did not show any clear correlation with wind speed (as per Figure 27) and direction, and are therefore all believed to be the result of extraneous noise sources.

Table 9 – Potential exceedances of DEFRA criteria detected at O17A

Frequency	Minimum night time criteria[1]	Interim stage		Operational stage	
Hz	$L_{eq,10min}$, dB	No.	Range, dB	No.	Range, dB
10	92	0	–	0	–
12.5	87	0	–	0	–
16	83	0	–	0	–
20	74	0	–	0	–
25	64	0	–	0	–
31.5	56	0	–	0	–
40	49	2	53 – 58	0	–
50	43	6	45 – 55	13	44 – 48
63	42	3	43 – 49	12	43 – 52
80	40	4	41 – 52	18	41 – 49
100	38	3	40 – 44	22	39 – 48
125	36	10	37 – 51	29	37 – 47
160	34	8	35 – 45	31	35 – 48
Total exceedance periods	**–**	**12**	**–**	**32**	**–**

1. If noise is found to be steady then criteria need to be increased by 5 dB.

During the operational monitoring stage, potential exceedances were detected over a similar frequency range as for the interim monitoring stage (50 Hz to 160 Hz). The wind speeds and directions of the potential exceedances for the operational monitoring stage were reviewed and it was found that a large number were isolated events with no corresponding change in wind speed or wind direction. Given the continuous operation of Macarthur Wind Farm when the wind speed is sufficiently high, it is considered most likely that these events were the result of extraneous events particularly as many occurred from 6:00 to 7:00 when the residents may have been awake.

In addition to these isolated events, the following potential exceedances were also noted:

- One potential 2 dB exceedance at 160 Hz at 23:40 on 2 March during a period when the resident noted concern with noise from the wind farm.
- Eight potential exceedances between 1 to 3 dB at 160 Hz from 23:20 on 26 March to 3:50 on 27 March. For some of these periods, potential exceedances also occurred in the one-third octave bands from 50 to 125 Hz. However, the potential exceedance was greatest at 160 Hz.

Table 10 presents the 10-minute measurements in the 160 Hz one-third octave band during these exceedance periods, including the difference between the $L_{90,10min}$ and $L_{10,10min}$ noise levels to determine whether a 5 dB relaxation of the criteria should be applied for steady noise.

Table 10 – Potential exceedances of DEFRA criteria at O17A for 160 Hz one-third octave band

Date & time	Hub height wind conditions		Noise level in 160 Hz one-third octave band, dB			
	Wind speed, m/s	Direction	$L_{10} - L_{90}$	Steady	Criterion	Measured L_{eq}
2/3 23:40	7.8	94°	15	×	34	36
26/3 23:20	12	26°	4	✓	39	36
27/3 0:10	12.4	25°	17	×	34	37
27/3 0:20	12.4	25°	7	×	34	37
27/3 0:30	12.9	25°	7	×	34	36
27/3 1:10	13.5	24°	21	×	34	37
27/3 2:10	14.6	26°	15	×	34	35
27/3 3:00	14.4	26°	24	×	34	37
27/3 3:50	13.6	27°	3	✓	39	36

From the results presented in Table 10, it can be seen that there were a small number of periods where the measured noise levels at 160 Hz would not be characterised as steady. There is no consistency in the differences between the measured L_{10} and L_{90} levels, with a difference of 24 dB in one period indicating the source was highly variable in nature. Based on a review of audio and 100 ms one-third octave band data previously stored at night near the Macarthur wind farm it appears plausible that periods with the smaller differences (3 – 4 dB, but maybe also 7 dB) were wind turbine noise controlled. However, it does not appear plausible that periods with differences of 15 dB and above were controlled by turbine noise, with those periods most likely being controlled or significantly influenced by wind noise.

Additionally, given the irregular occurrences of exceedance of the criteria during these measurements, it is not clear whether the source of the low frequency noise is Macarthur Wind Farm. Low frequency noise levels were found to exceed the criteria for only seven out of a total of 1,242 night time periods (0.6% of the measurement period) indicating that, regardless of the source, the exceedances are infrequent.

7 Linear sound pressure levels

In addition to the assessments against relevant criteria for infrasound and low frequency noise, the measured unweighted (linear) sound pressure levels from 0.8 Hz to 160 Hz were considered between the pre-operational, interim and operational monitoring stages.

As there was found to be a correlation between wind speed and the measured infrasound and low frequency noise levels, the average measured sound pressure levels from 0.8 Hz to 160 Hz have been determined for the following wind speed ranges:

- Low wind speeds – 0 to 2 m/s at hub height: these wind speeds are below the cut-in wind speed of the V112 WTGs (3 m/s) and Macarthur Wind Farm would not be operating.
- Medium wind speeds – 5 to 7 m/s at hub height: at these wind speeds, the V112 WTGs are operating but at lower noise levels. Background noise levels at residences are also typically lower at these wind speeds.
- High wind speeds – 10 to 14 m/s at hub height: at these wind speeds, the V112 WTGs are operating at or close to the maximum power output and sound power level. However, background noise levels at residences are also typically higher at these wind speeds.

7.1 Y21A

The median measured interim and operational noise levels at Y21A for low, medium and high wind speeds across the one-third octave band centre frequencies from 0.8 Hz to 160 Hz are shown in Figure 32 and Figure 33 respectively. Only measured noise levels for the night time period (23:00 to 6:00) were considered for this analysis as this period was found to be considerably less affected by extraneous sources. The spectra are based on the median 10-minute average level in each one-third octave band for the specified conditions.

The values for both the all wind direction and worst case (±45°) wind direction datasets are presented on Figure 32 and Figure 33. However, night time downwind data points at medium and high wind speeds were not available for the operational period at Y21A. The DEFRA criteria and 85 dB(G) criterion are also presented. Note that the DEFRA criteria have been increased by 5 dB as the measured noise levels under high wind speeds were found to steady in the 63 Hz one-third octave band (the closest to the criterion), as stipulated in the DEFRA document (DEFRA, 2005).

Overall, it is clear that, while low frequency noise levels increase as the wind speed increases, the median measured levels remain below the DEFRA criteria and 85 dB(G) criterion. While there is an increase in levels in the worst case wind directions, this also occurs at low wind speeds (when the WTGs are not operating) suggesting this is due to the exposure of the room to wind from these directions.

Median interim night noise levels for wind speed ranges - Y21A

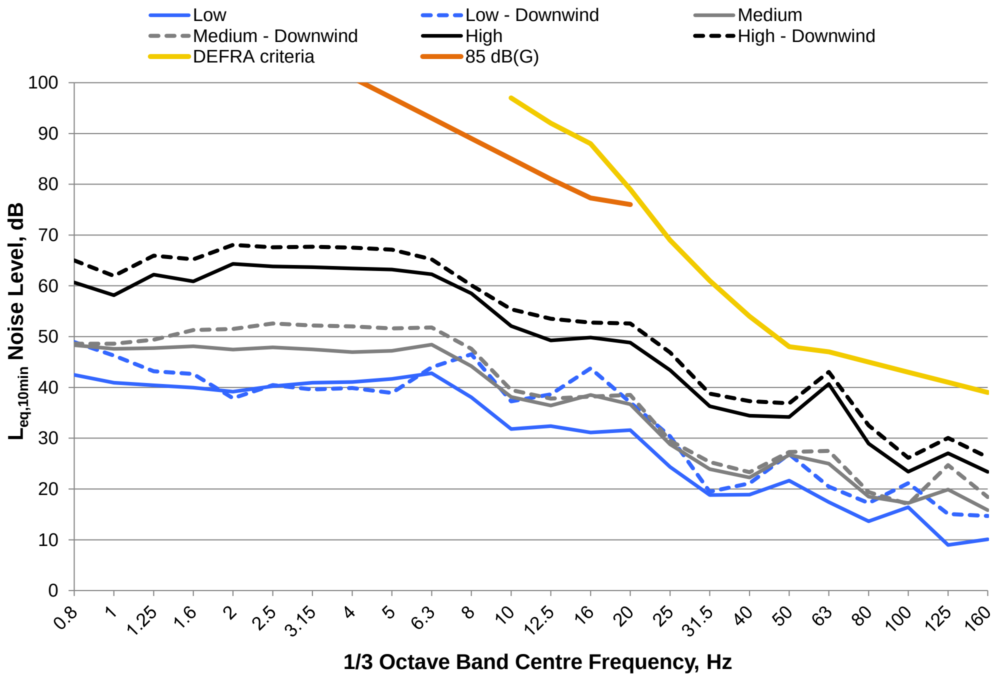

Figure 32 – Median measured interim night noise levels at Y21A for different wind speeds

Median operational night noise levels for wind speed ranges - Y21A

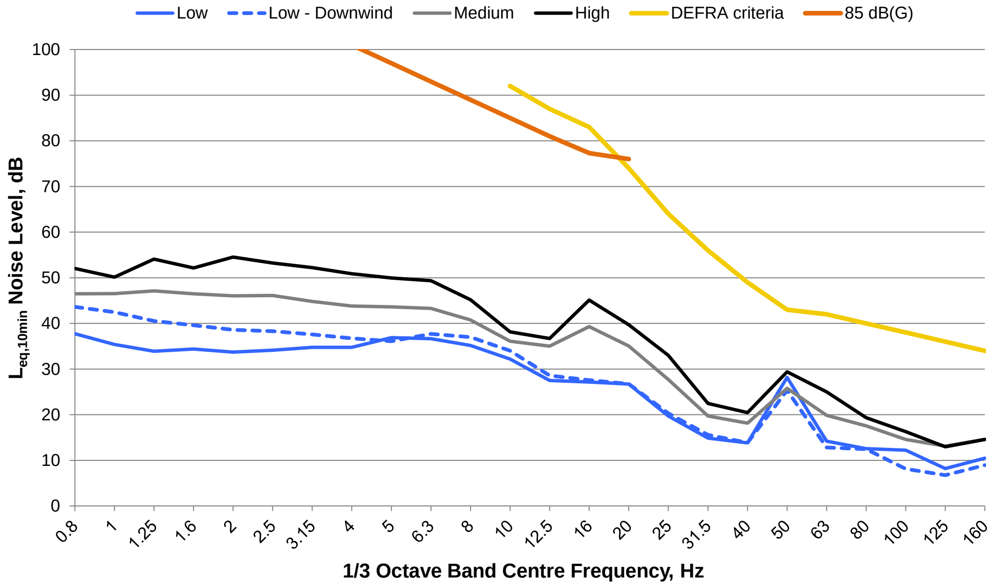

Figure 33 – Median measured operational night noise levels at Y21A for different wind speeds

Figure 34, Figure 35 and Figure 36 compare the measured pre-operational, interim and operational noise levels from 0.8 to 160 Hz at Y21A for low, medium and high wind speeds respectively. Only the night time period (23:00 to 6:00) has been considered for the different monitoring periods. Note that, in Figure 36, the DEFRA criteria have been increased by 5 dB in accordance with the stipulated procedure to reflect the fact that the higher low frequency noise levels measured during the interim period were steady in nature.

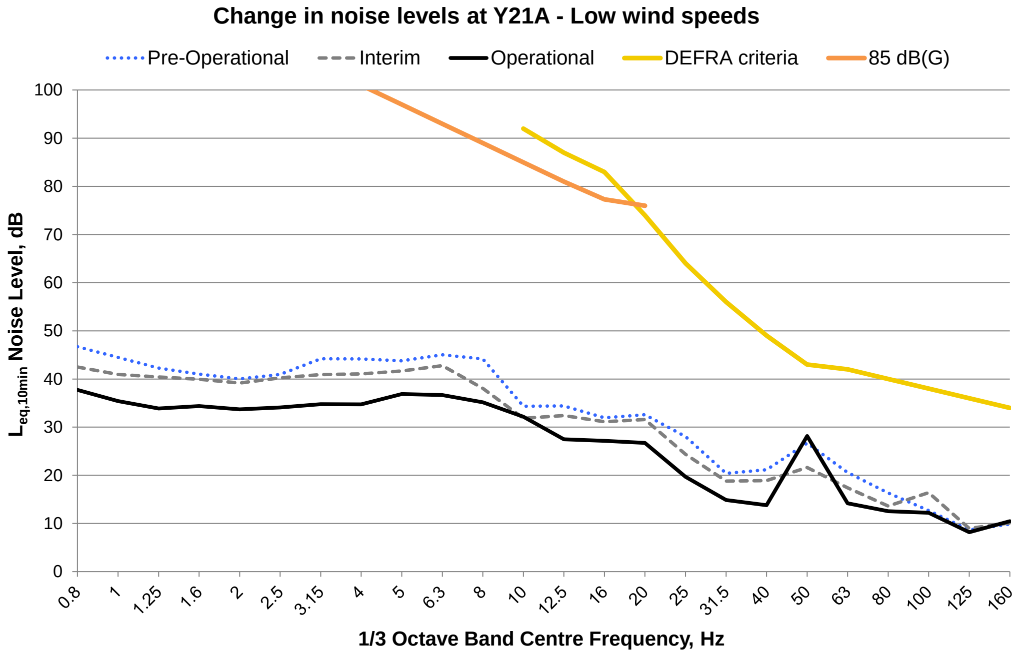

Figure 34 – Change in noise levels at Y21A for low wind speeds

As the WTGs at Macarthur Wind Farm would not be operating at low wind speeds, Figure 34 illustrates that there is variability in the low frequency noise levels at Y21A. Note that the peak that occurs at 50 Hz during the pre-operational and operational monitoring stages is likely to be a result of noise from electrical equipment at the house.

During medium wind speeds (Figure 35), it can be seen that there is no noticeable increase in the interim and operational low frequency noise levels relative to the pre-operational low frequency noise levels for frequencies of 80 Hz and below. It is possible that the increase at frequencies of 100 Hz and above is a result of operation of the Macarthur Wind Farm but measured levels at these frequencies remained well below the minimum DEFRA criteria.

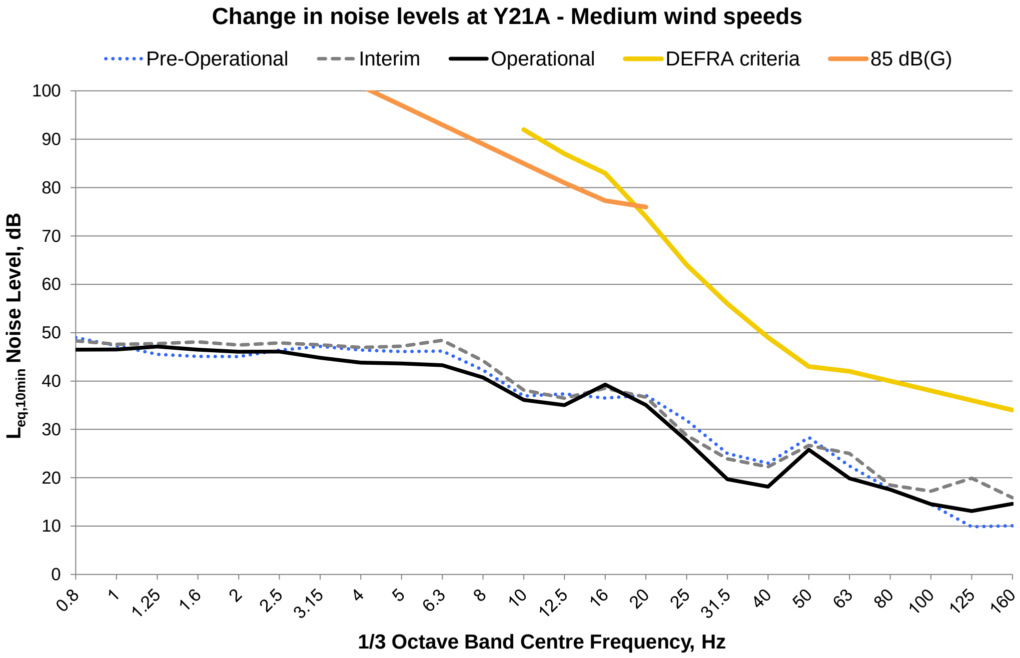

Figure 35 – Change in noise levels at Y21A for medium wind speeds

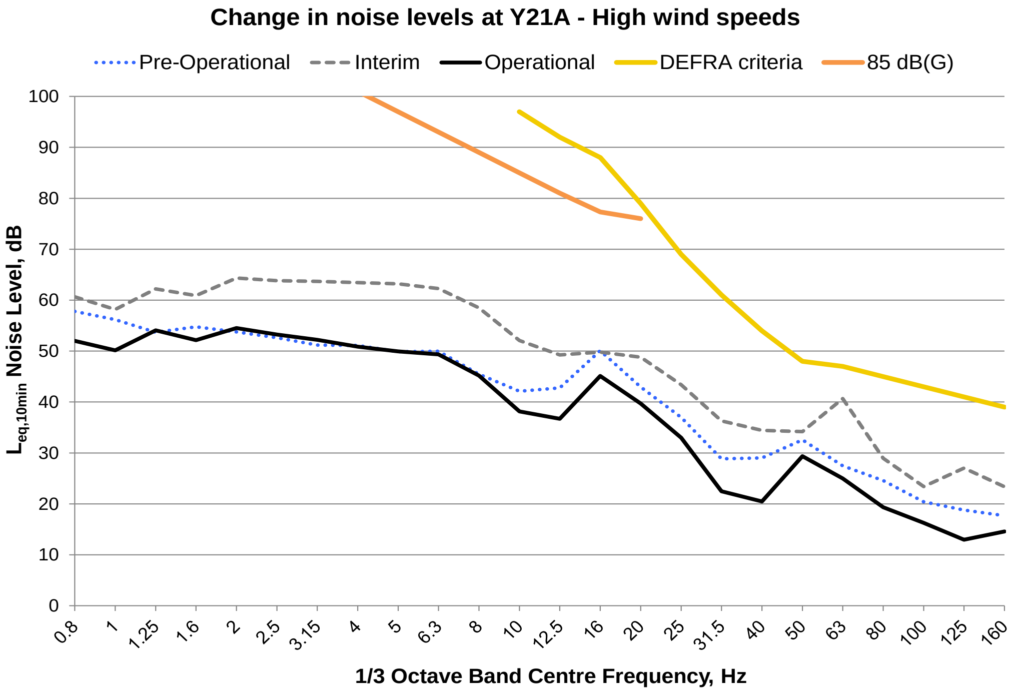

Figure 36 – Change in noise levels at Y21A for high wind speeds

From Figure 36, it can be seen the average measured interim noise levels during high wind speeds at Y21A are noticeably higher than the measured pre-operation noise levels across the frequency range from 1 Hz to 12.5 Hz, and also higher across the frequency range from 20 Hz to 160 Hz. However, the measured levels during the operational stage were actually lower than during the pre-operational stage.

The measured interim levels for high wind speeds at Y21A were largely limited to one night time period. It is possible that these levels were affected by an extraneous source and/or higher wind speeds at the house, particularly as the measured levels were markedly lower during the operational measurements.

Regardless of the source of the higher measured levels during the interim stage, the measured noise levels at Y21A remain well below the 85 dB(G) infrasound assessment criterion and are compliant with the proposed DEFRA criteria for low frequency noise.

7.2 O17A

The median measured interim and operational noise levels at O17A for low, medium and high wind speeds across the one-third octave band centre frequencies from 0.8 Hz to 160 Hz are shown in Figure 37 and Figure 38 respectively. The values for both the all wind direction and worst case (±45°) wind direction datasets are presented. Only measured noise levels for the night time period (22:00 to 7:00) were considered for this analysis as this period was found to be considerably less affected by extraneous sources. As for Y21A, the spectra are based on the median 10-minute average level in each one-third octave band for the specified conditions.

The median value is presented as it is not exceeded by 50% of the measured $L_{eq,10min}$ noise levels and is therefore considered to provide a better representation of potential noise generated by the Macarthur Wind Farm (which operates constantly at a given wind speed). The 85 dB(G) level and minimum proposed DEFRA criteria (for non-steady low frequency noise) for the night time period are also presented. Note that 85 dB(G) is only visible for a limited frequency range as it is equivalent to a level of over 100 dB at frequencies of 4 Hz and lower.

The median measured levels remained below the DEFRA criteria and 85 dB(G) criterion for all wind speed ranges during both the interim and operational stages. Higher levels were measured in the worst case wind direction, but this is to be expected as the room in which the measurements were conducted was more exposed to wind in this direction. This can be seen as higher levels were also observed for the worst case wind direction under low winds (speeds that the WTGs do not operate at) during the operational monitoring stage. As the wind farm would not have been operating during these periods, this indicates that the increase across the entire frequency range is likely due to a change in wind direction rather than significant increases in noise from the wind farm.

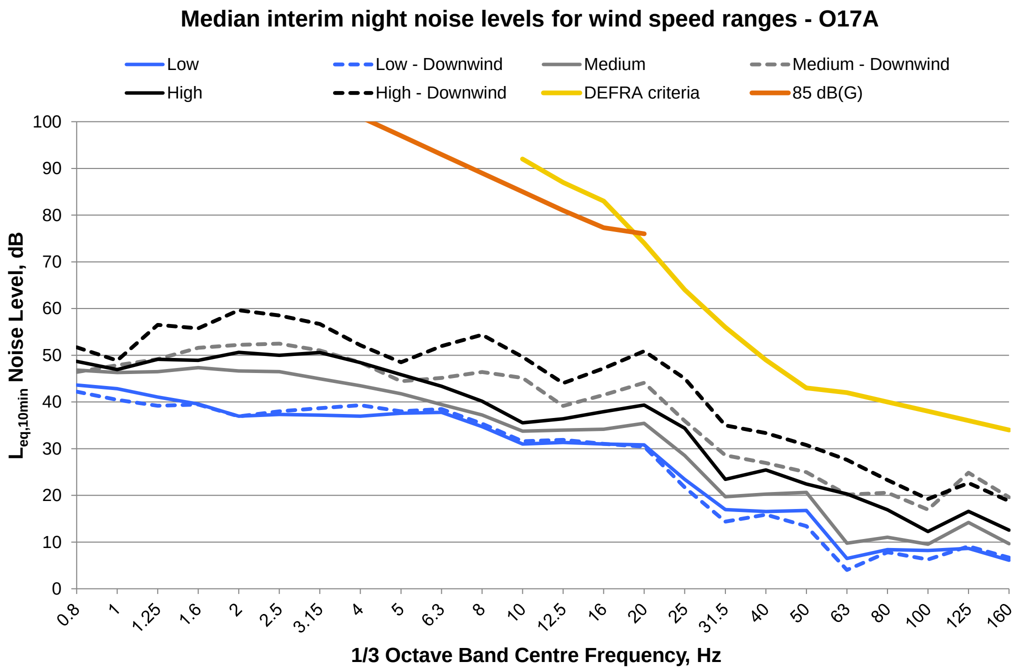

Figure 37 – Median measured interim night noise levels at O17A for different wind speeds

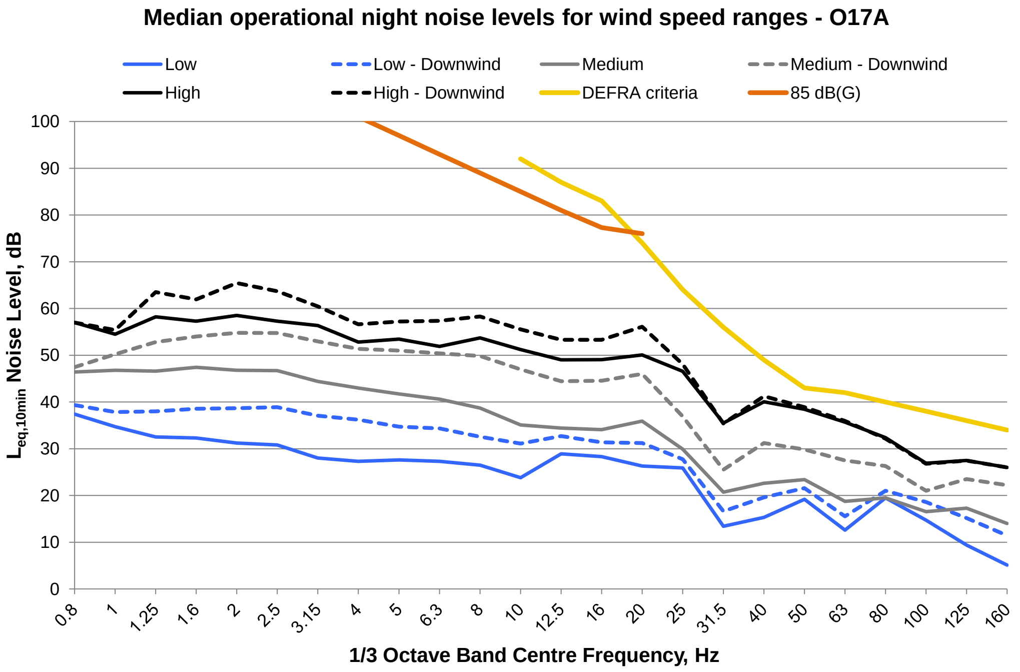

Figure 38 – Median measured operational night noise levels at O17A for different wind speeds

Figure 39 and Figure 40 compare the measured pre-operational, interim and operational noise levels from 0.8 to 160 Hz at O17A for medium and high wind speeds respectively. In order to enable comparison with the measured interim noise levels, the interim noise levels have been calculated from those levels measured when the wind direction was between 240° and 10°. To reduce the influence of extraneous noise, only night time data points have been considered for the medium wind speed comparison (Figure 39). However, due to a lack of night time data points for high wind speed periods, both daytime and night time data has been considered for the high wind speed comparison (Figure 40).

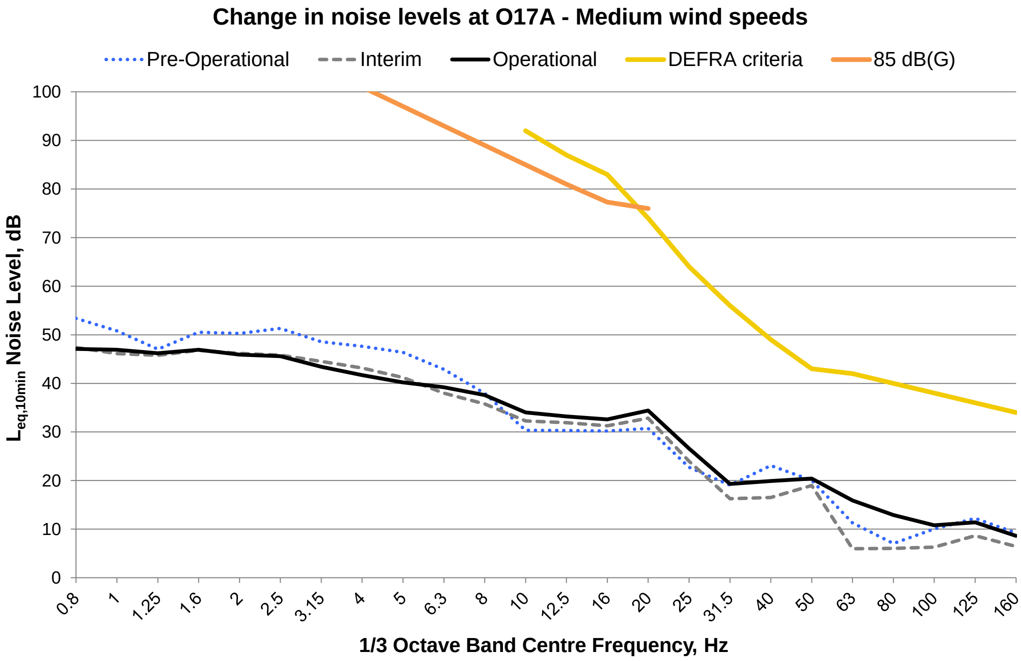

Figure 39 – Change in noise levels at O17A for medium wind speeds

Comparing the measured pre-operational noise levels to the interim and operational noise levels, it can be seen that there is no significant increase in the measure levels at frequencies below 50 Hz. Under medium wind speeds, the pre-operational measurements are approximately 5 dB higher at frequencies below 10 Hz, whereas the reverse is true for high wind speeds. This suggests that changes in measurements are indicative of the variance in ambient environmental noise and is not necessarily a result of wind farm operation.

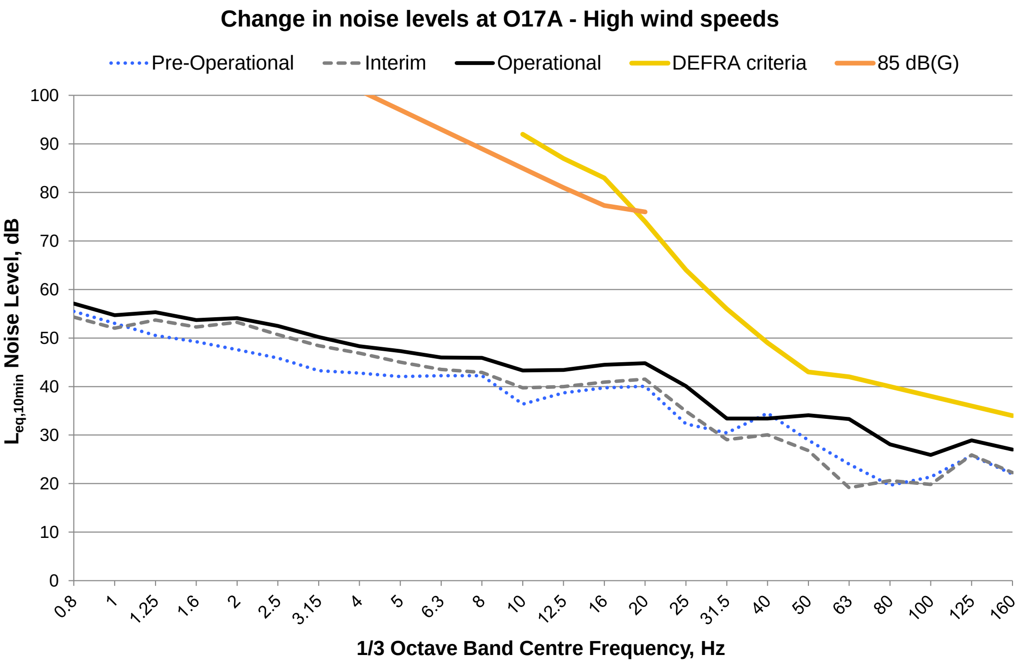

Figure 40 – Change in noise levels at O17A for high wind speeds

For higher wind speeds (Figure 40), the difference between the pre-operational and operational levels increases at frequencies above 63 Hz. A review of audio data that had been collected as part of a different noise assessment at one of the closest non-involved residences to the wind farm (approximately 1.6 kilometres from the nearest turbine) suggested that this increase in noise at these frequencies might be due to noise generated by Macarthur Wind Farm. However, the median levels are well below the applicable DEFRA night time criteria for these wind directions.

Overall, the measurement results at O17A indicate that the operation of Macarthur Wind Farm may have resulted in an increase in noise levels at frequencies of 63 Hz and above but there is no clear change at frequencies lower than approximately 10 Hz. Note that the increased noise levels at frequencies of 63 Hz and above have been assessed against the applicable low frequency noise criteria in Section 6.2, with consideration given to each individual 10-minute measurement.

8 Conclusion

An infrasound and low frequency noise assessment has been undertaken at two residential locations adjacent to the Macarthur Wind Farm. Indoor measurements of infrasound and low frequency noise levels at residences O17A (1.8 km from the nearest WTG) and Y21A (2.7 km from the nearest WTG) have been conducted during pre-operational, interim and operational stages of Macarthur Wind Farm.

The measured infrasound levels at both residences remained compliant with the 85 dB(G) assessment criterion for both the interim and operational measurements. The measurements at O17A showed that there was no clear change in infrasound levels. While the measured operational $L_{Geq,10min}$ levels at high wind speeds were marginally higher than those measured during the pre-operational monitoring, this was most likely due to differing local wind conditions at the residence. There was no significant change in infrasound levels at residence Y21A, with the measured operational levels no different to the measured pre-operational levels.

The low frequency noise (10 Hz to 160 Hz) assessment at O17A found that operation of the Macarthur Wind Farm may have resulted in an increase in noise levels at frequencies of 63 Hz and above at the residence during the operational monitoring stage. However, when the measured levels for each individual 10-minute period were assessed against the relevant low frequency noise criteria, the vast majority of measurements were found to comply. Only seven 10-minute periods out of a total of 23 nights of monitoring were found to exceed the criteria, and it is thought that these exceedances were all significantly influenced by local wind noise.

Low frequency noise levels at Y21A during the interim and operational monitoring stages were also found to comply with the relevant criteria. During the interim monitoring at Y21A, it was found that there was an increase in low frequency noise levels during high wind speed periods (10 to 15 m/s at hub height). However, there was no change in low frequency noise levels between the pre-operational and operational monitoring stages.

Overall, this assessment has demonstrated that infrasound and low frequency noise levels from Macarthur Wind Farm are compliant with relevant assessment criteria at the two nearby residences. No change in infrasound levels was identified relative to the pre-operational monitoring. An increase in low frequency noise levels at frequencies of 63 Hz and above was measured at each of the residences for particular conditions, and may be a result of noise from Macarthur Wind Farm.

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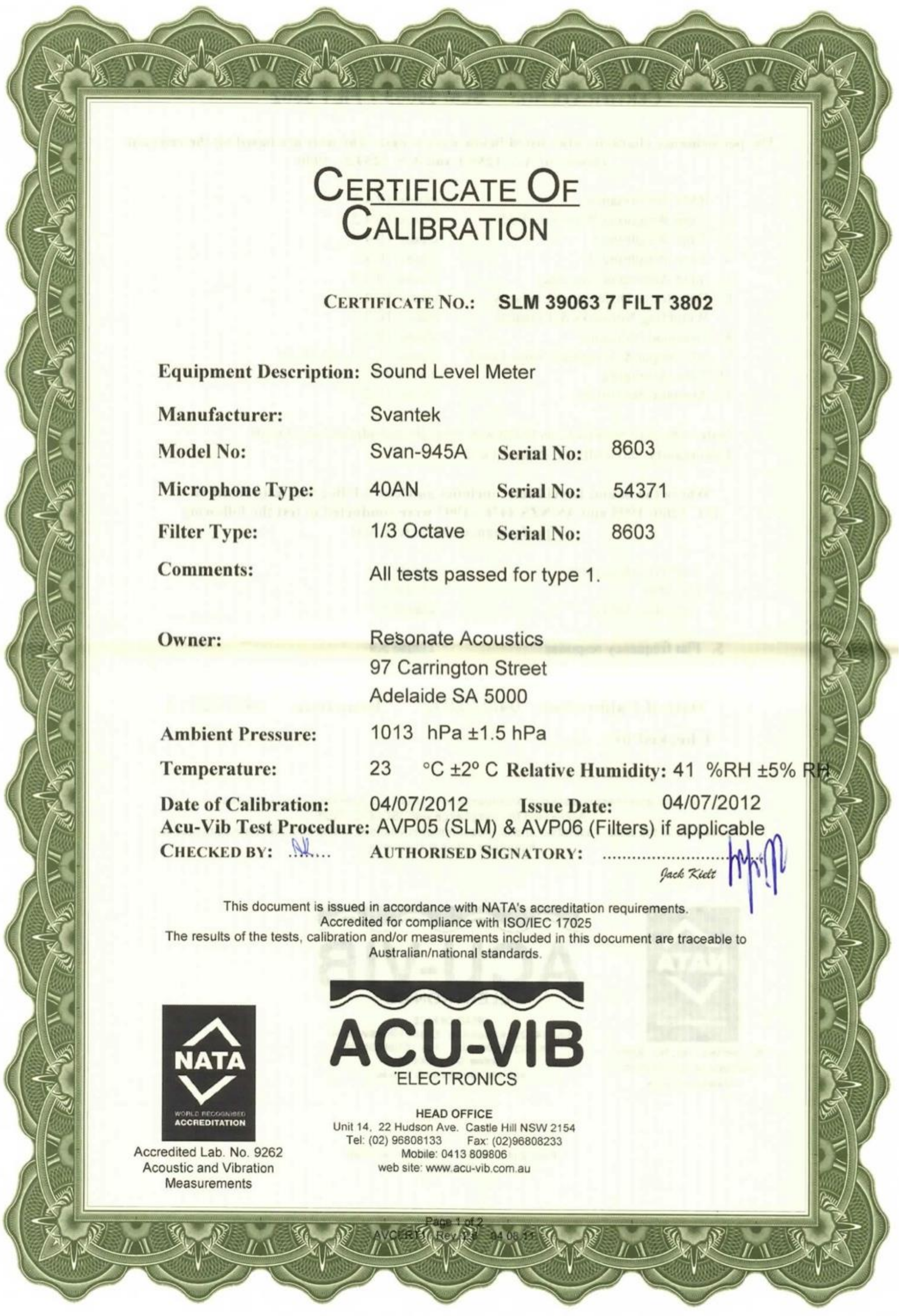
Appendix A—Photographs

Figure A1 – Noise monitor installed in spare bedroom at O17A

Figure A2 – Noise monitor installed in bedroom at Y21A

Appendix B—Calibration Certificates



CERTIFICATE OF CALIBRATION

CERTIFICATE NO.: **SLM 39063 7 FILT 3802**

Equipment Description: Sound Level Meter
Manufacturer: Svantek
Model No: Svan-945A **Serial No:** 8603
Microphone Type: 40AN **Serial No:** 54371
Filter Type: 1/3 Octave **Serial No:** 8603
Comments: All tests passed for type 1.

Owner: Resonate Acoustics
97 Carrington Street
Adelaide SA 5000

Ambient Pressure: 1013 hPa ±1.5 hPa
Temperature: 23 °C ±2° C **Relative Humidity:** 41 %RH ±5% RH
Date of Calibration: 04/07/2012 **Issue Date:** 04/07/2012
Acu-Vib Test Procedure: AVP05 (SLM) & AVP06 (Filters) if applicable
CHECKED BY: .... **AUTHORISED SIGNATORY:** ....
Jack Kielt

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The results of the tests, calibration and/or measurements included in this document are traceable to Australian/national standards.

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Mobile: 0413 809806
web site: www.acu-vib.com.au

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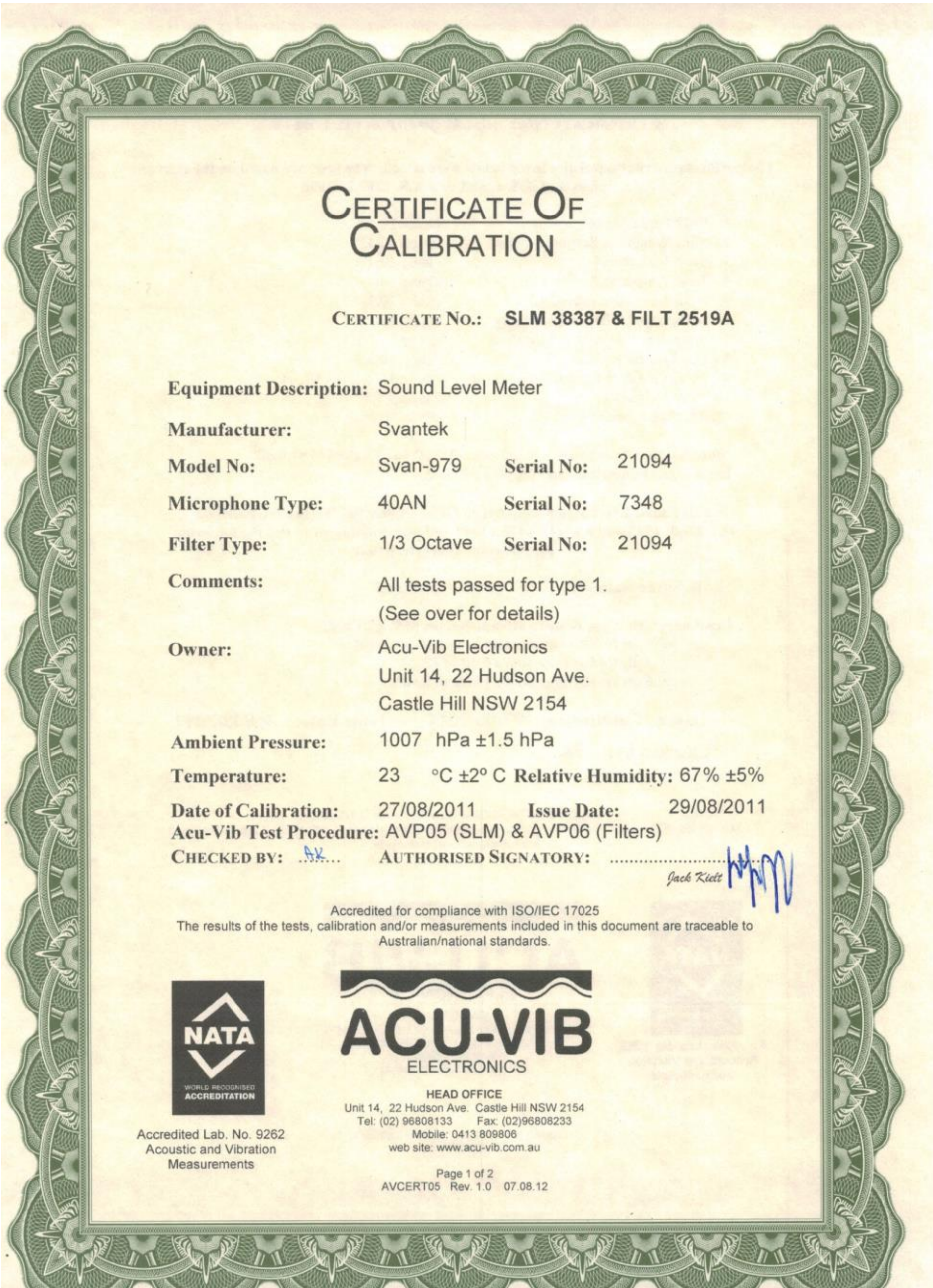
Figure B1 – Calibration certificate for SVAN 945A sound level meter



CERTIFICATE OF CALIBRATION

CERTIFICATE NO.: **SLM 38387 & FILT 2519A**

Equipment Description:	Sound Level Meter		
Manufacturer:	Svantek		
Model No:	Svan-979	**Serial No:**	21094
Microphone Type:	40AN	**Serial No:**	7348
Filter Type:	1/3 Octave	**Serial No:**	21094
Comments:	All tests passed for type 1. (See over for details)		
Owner:	Acu-Vib Electronics Unit 14, 22 Hudson Ave. Castle Hill NSW 2154		
Ambient Pressure:	1007 hPa ±1.5 hPa		
Temperature:	23 °C ±2° C	**Relative Humidity:**	67% ±5%
Date of Calibration:	27/08/2011	**Issue Date:**	29/08/2011
Acu-Vib Test Procedure:	AVP05 (SLM) & AVP06 (Filters)		
CHECKED BY:	AK	**AUTHORISED SIGNATORY:**	Jack Kielt

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AVCERT05 Rev. 1.0 07.08.12

Figure B2 – Calibration certificate for SVAN 979 sound level meter

Appendix C—Measured infrasound levels

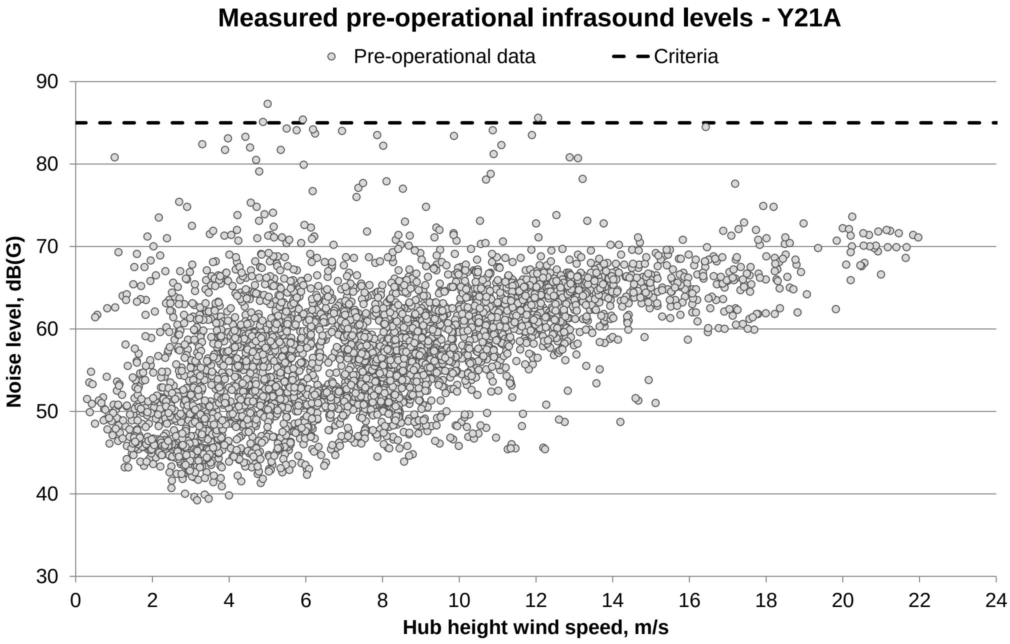

Figure C1 – Measured pre-operational infrasound levels at Y21A

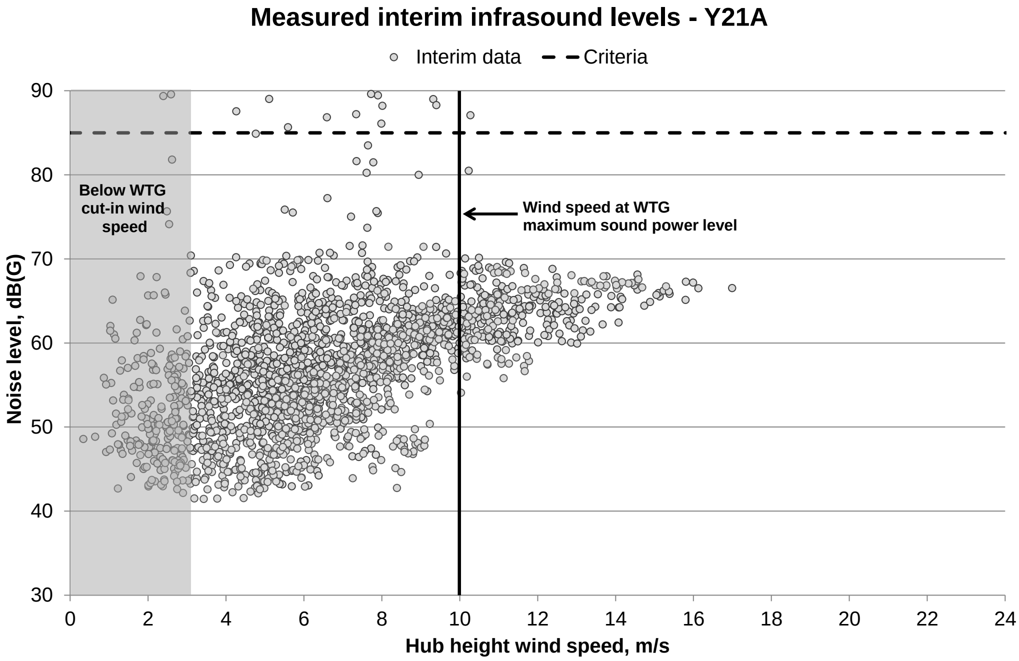

Figure C2 – Measured interim infrasound levels at Y21A

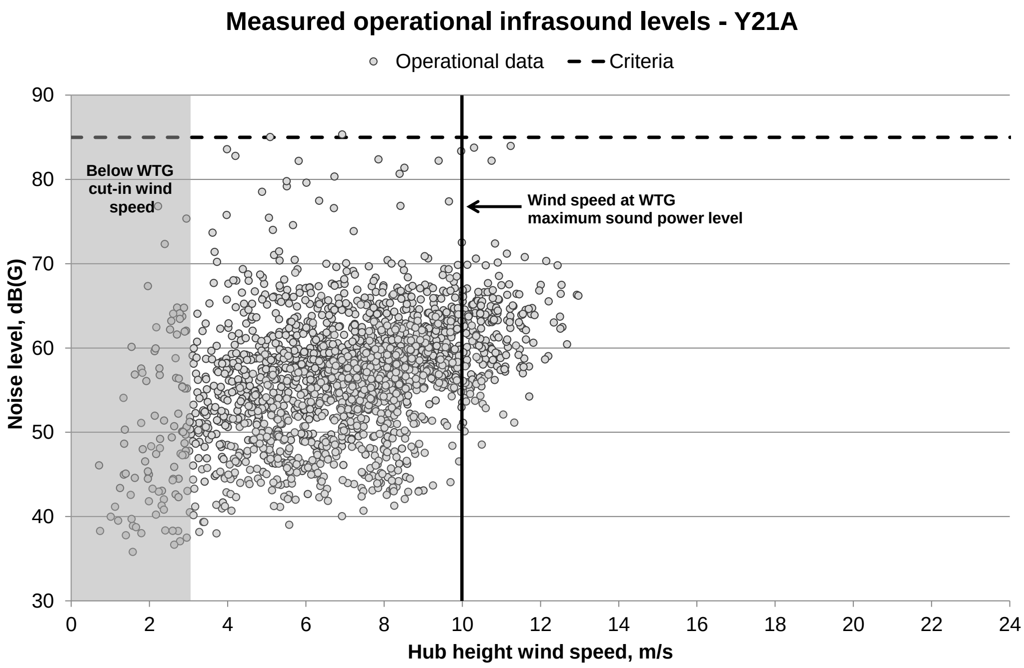

Figure C3 – Measured operational infrasound levels at Y21A

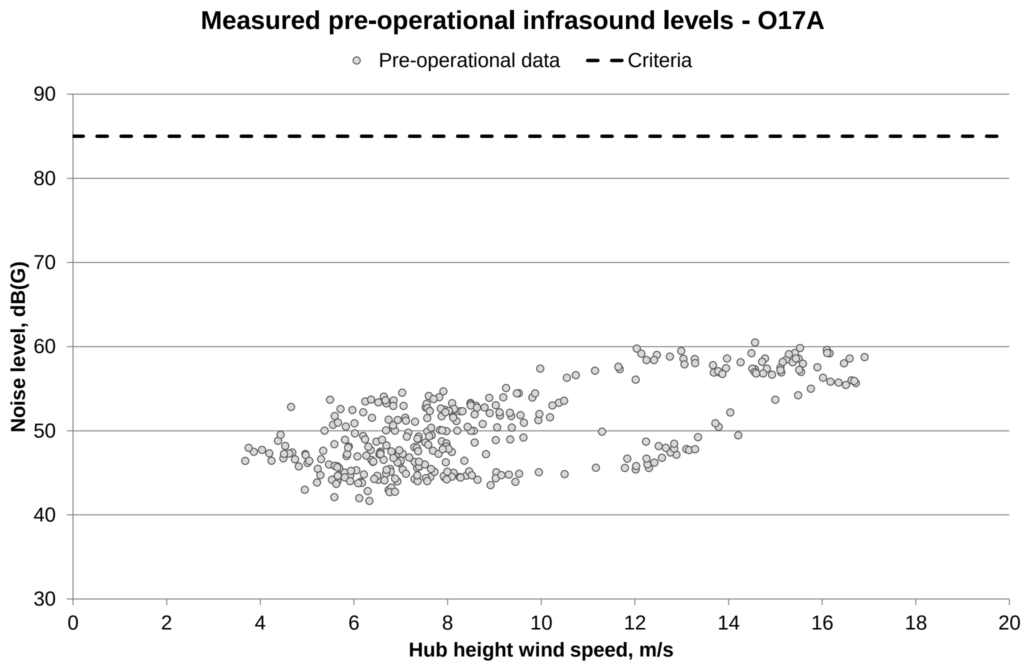

Figure C4 – Measured pre-operational infrasound levels at O17A

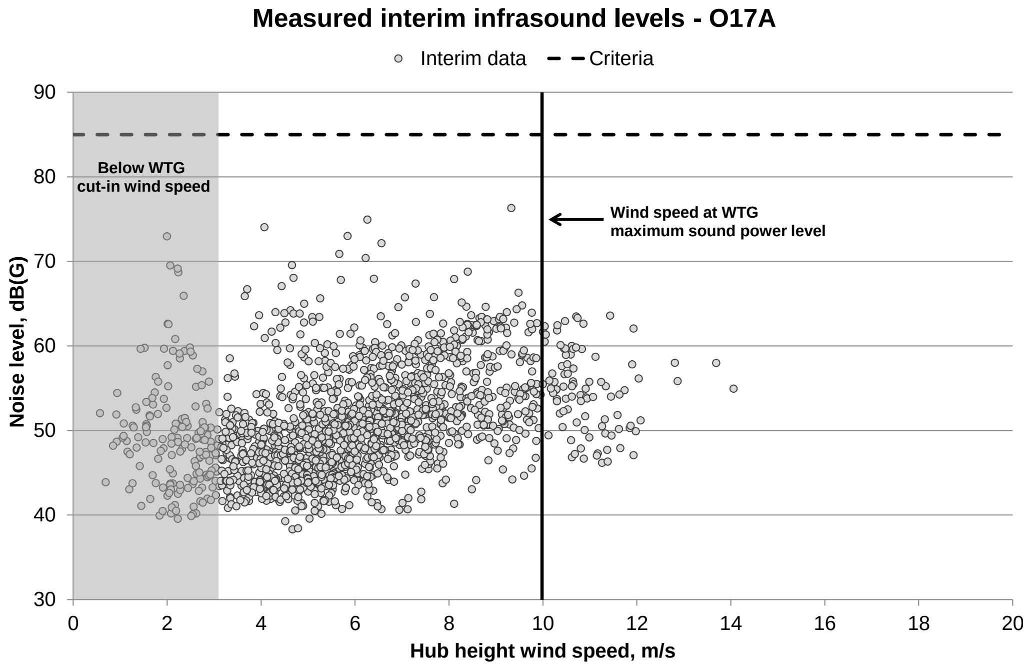

Figure C5 – Measured interim infrasound levels at O17A

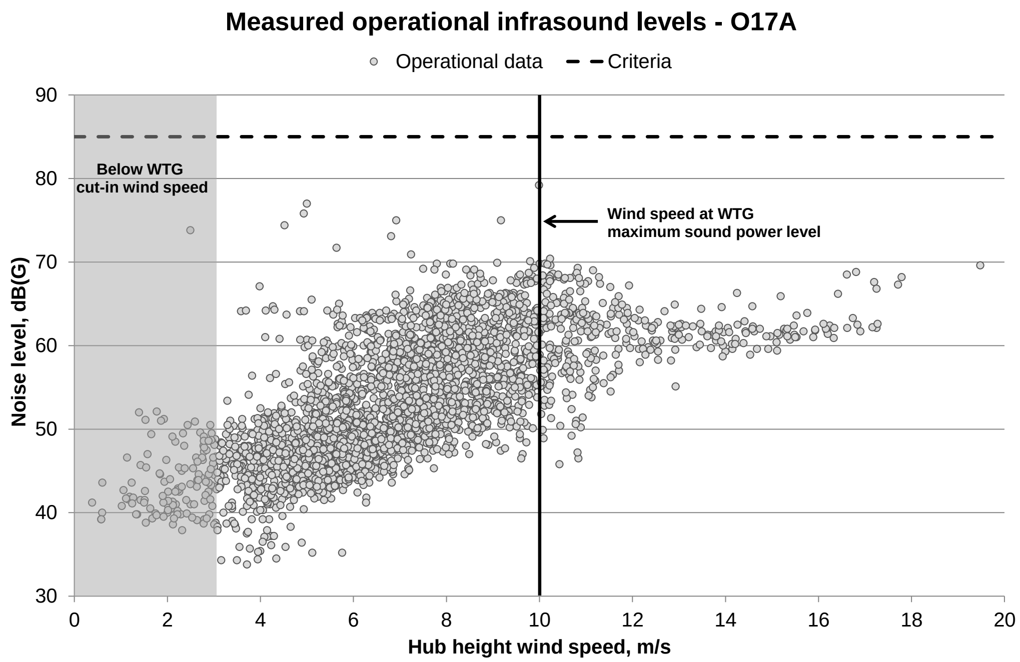

Figure C6 – Measured operational infrasound levels at O17A

Appendix D—Measured low frequency noise levels

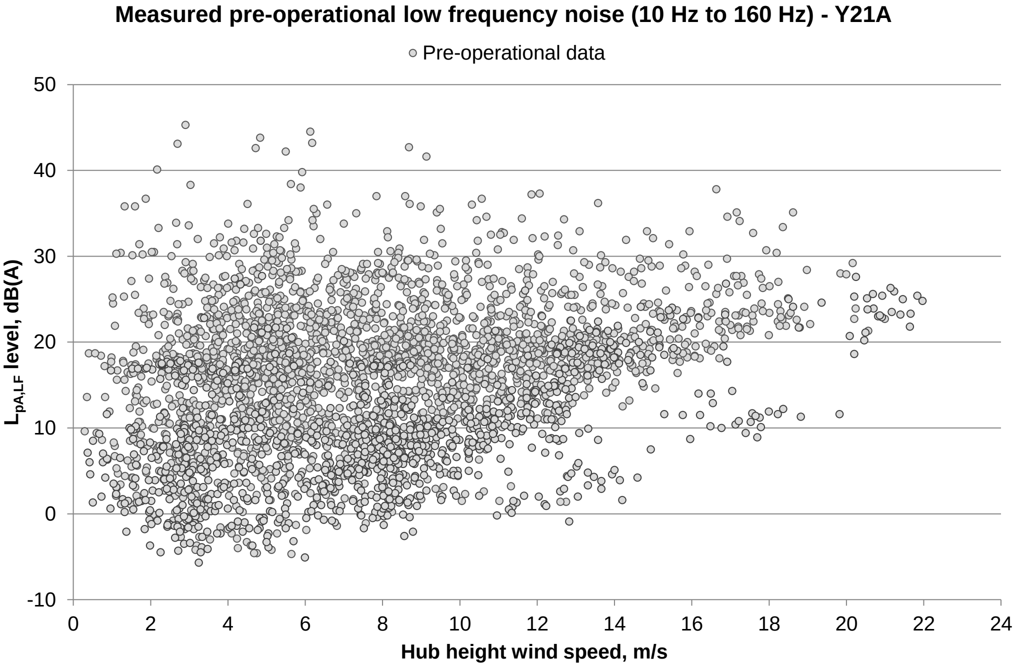

Figure D1 – Measured pre-operational low frequency noise levels at Y21A

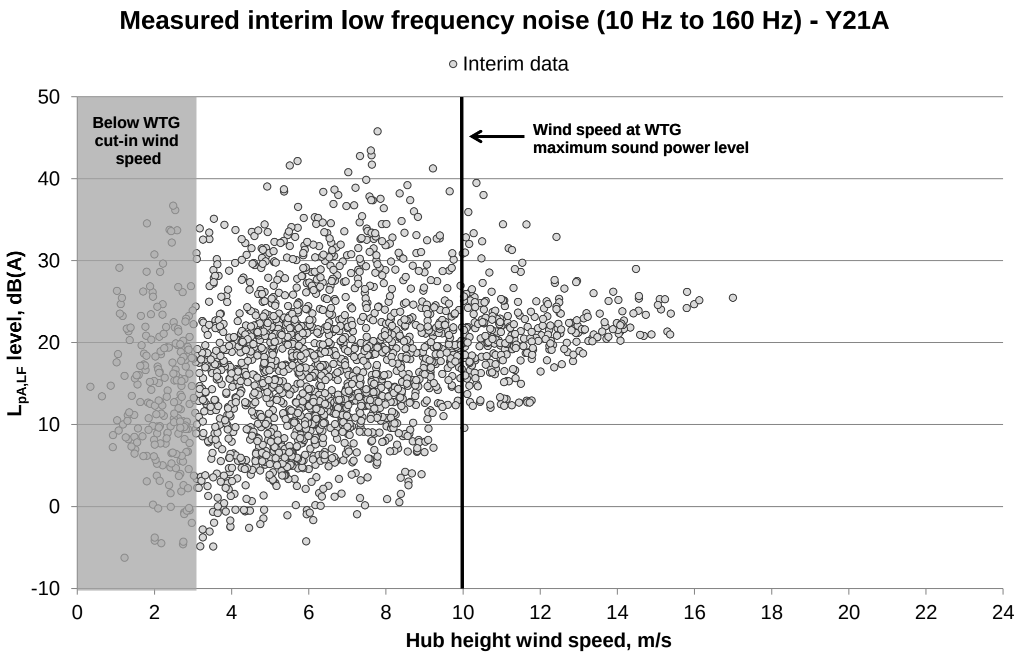

Figure D2 – Measured interim low frequency noise levels at Y21A

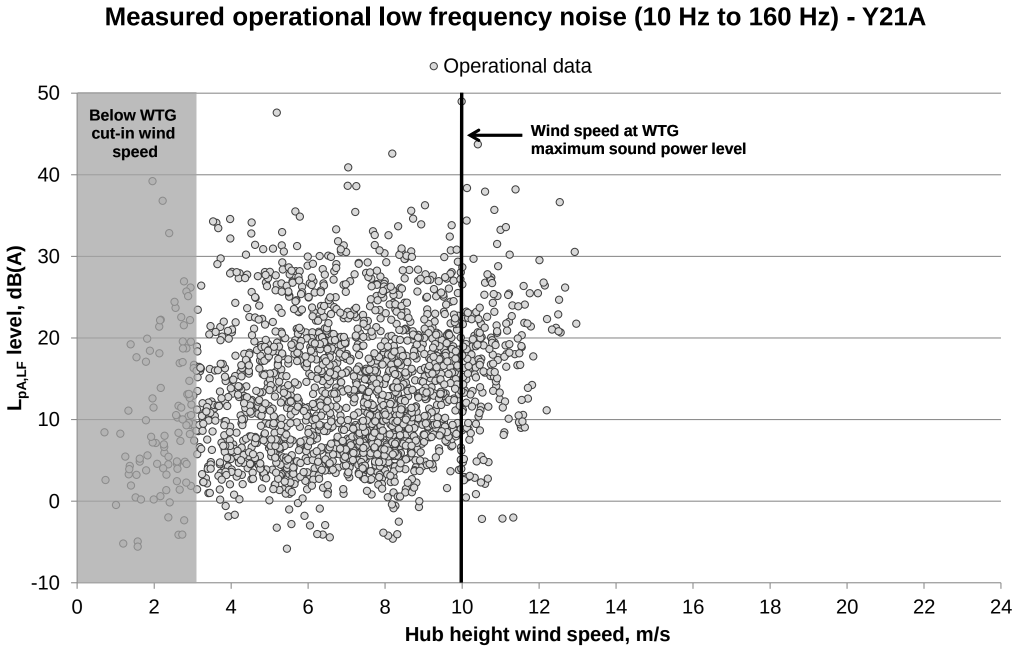

Figure D3 – Measured operational low frequency noise levels at Y21A

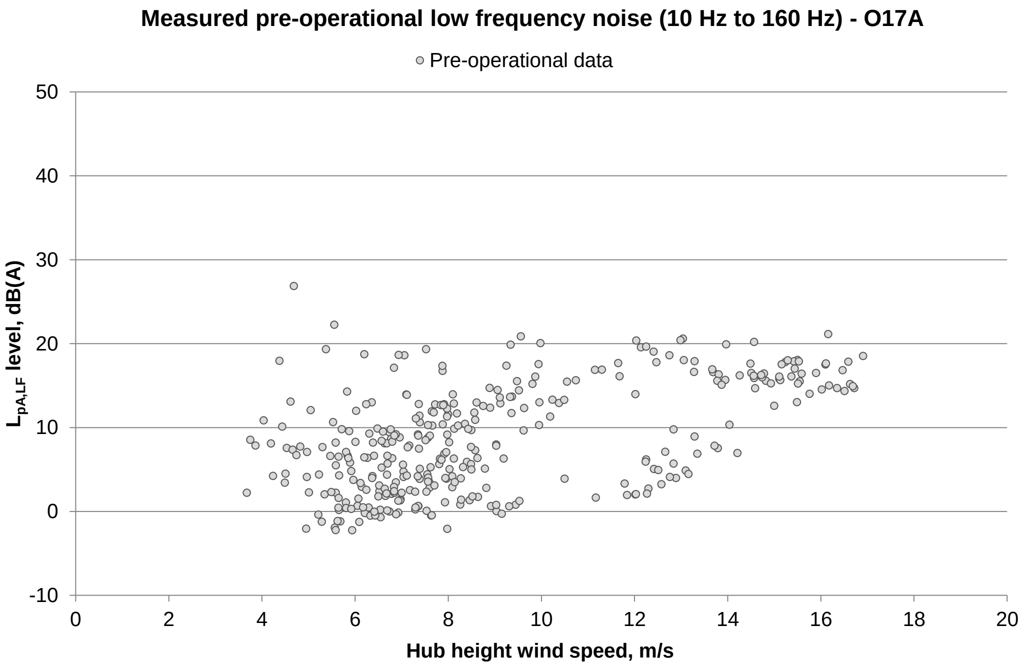

Figure D4 – Measured pre-operational low frequency noise levels at O17A

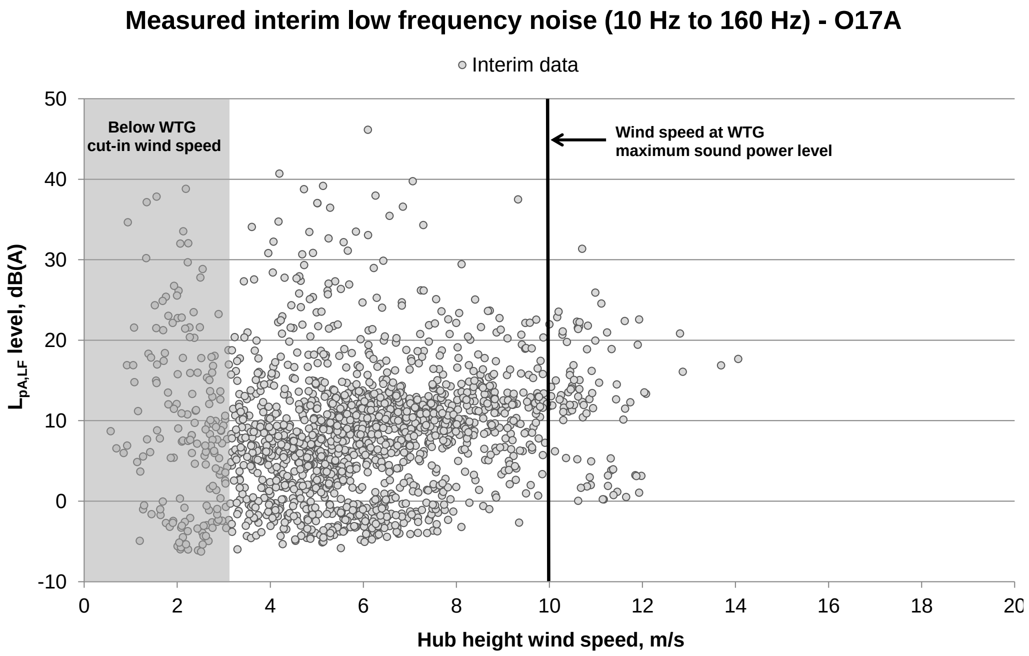

Figure D5 – Measured interim low frequency noise levels at O17A

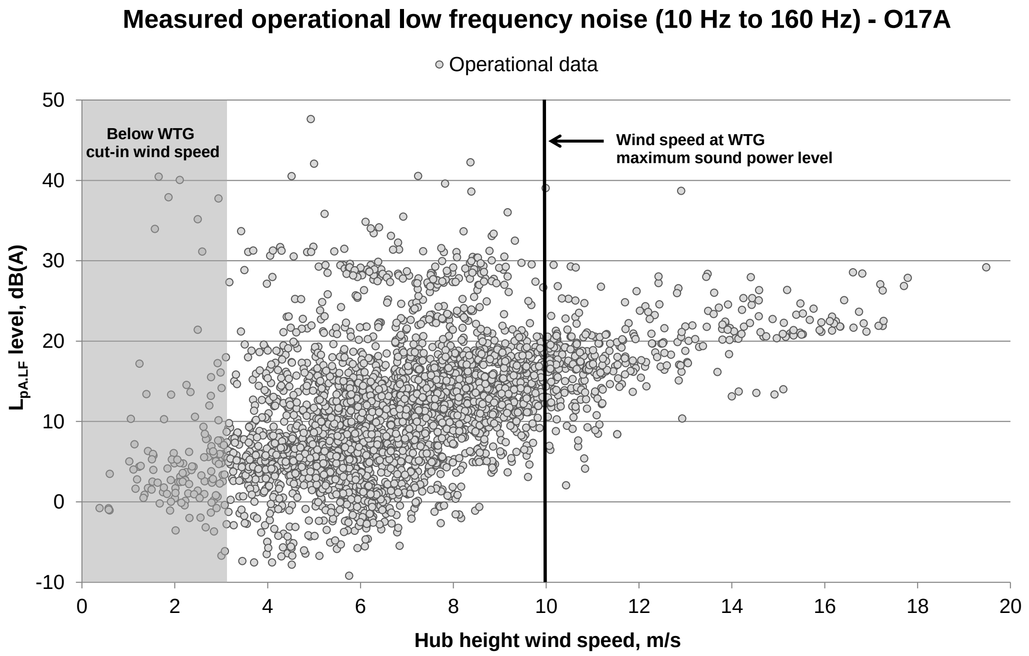

Figure D6 – Measured operational low frequency noise levels at O17A