



**THE RESULTS OF AN ACOUSTIC TESTING PROGRAM
CAPE BRIDGEWATER WIND FARM
44.5100.R7:MSC**

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ACKNOWLEDGEMENT

The material set out in this report relates to a study conducted at three houses in proximity to the Cape Bridgewater Wind Farm in SW Victoria.

The Study was requested by Pacific Hydro to investigate the noise complaints from the occupants of the three houses, without any restrictions to the investigation. Pacific Hydro identified the objective of the noise and vibration monitoring was to determine whether certain wind conditions or certain sound levels give rise to disturbance experienced by specific local residents at Cape Bridgewater.

The residents involved in the study provided unrestricted access to their properties for nine weeks of monitoring (both internal and external locations) and vacated their properties for a number of nights to permit attended monitoring in their homes.

The residents provided diary observations and comments during the study and made themselves available for consultation and discussions re their observations throughout the study.

Pacific Hydro provided unlimited access to the wind farm to undertake measurements that could assist in the study.

The study appears to be the first of its kind in Australia to be a joint exercise between a wind farm operator and residents, and therefore provides information not normally available in a one sided acoustic assessment of a wind farm. Information, findings and recommendations are provided to assist others involved in the investigation of wind farm “noise”.

Without the assistance of the six residents, the wind farm manager (who provided essential data and assistance on site) and Pacific Hydro (who initiated and funded the study) the study could not have occurred. All of these people need to be acknowledged for their participation in the study.



EXECUTIVE SUMMARY

The Cape Bridgewater Wind Farm is an existing facility located in the south-west corner of Victoria and has been operational for approximately six years.

The wind farm has been the subject of acoustic compliance testing in accordance with the consent conditions imposed on the permit for the wind farm [1] that nominates compliance with the criteria and methodology identified in New Zealand Standard 6808: 1998 *Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators* [2].

Despite the wind farm satisfying the acoustic criteria nominated on the permit [9] the operator of the wind farm (Pacific Hydro) is in receipt of noise complaints from residents in proximity to the wind farm.

To address the issue of complaints from residents Pacific Hydro requested the conduct of an acoustic study at three residential properties to ascertain any identifiable noise impacts of the wind farm operations or certain wind conditions that could relate to the complaints that had been received. The study was to incorporate three houses that are located between 650 m to 1600 m from the nearest turbine.

Following discussions with the residents in late 2013 permission was given by the residents for access to their properties to undertake acoustic testing both inside and external to the dwellings, in addition to Pacific Hydro permitting measurements on the wind farm to investigate noise and vibration emissions from turbines and the substation.

In addition to unrestricted access to the wind farm and to the residential properties, wind farm operating data was provided. The study included a period in which the wind farm was shut down for the purpose of high-voltage cabling that permitted measurements to be obtained of the natural environment (without the operation of the wind farm) for direct comparison of the wind farm under different weather scenarios.

The acoustic investigation was not restricted to the general A-weighted level specified on the permit.

Following consultation with residents, residents were asked to record (using severity rankings) perceived noise impacts, vibration impacts and other disturbances which, for the purposes of this study, have been labelled “sensation.” “Sensation” includes headache, pressure in the head, ears or chest, ringing in the ears, heart racing, or a sensation of heaviness.



A diary format for the study was developed based upon that used by the South Australian EPA in relation to the Waterloo Wind Farm [3], with the modification to include vibration and sensation, and alteration of the severity ranking to be user-friendly for the residents. Following a trial of the diary format amendments were proposed so that as far as possible, the residents were asked to provide diary entries on a one to two hourly basis with a view to the diary entries reflecting a continuous record.

It is noted that the study utilises persons who have lodged complaints concerning the subject wind farm and thereby provides an opportunity to specifically to investigate a possible relationship to the observations and the wind farm that may not be apparent with a larger sample of people around a wind farm, in that it is acknowledged not all people complain about the turbines.

The study found that the diarized resident's observations identified "sensation" as the major form of disturbance from the wind farm.

For one resident sensation, noise and vibration were observed with the wind farm shutdown.

While the study found for the six residents that there was no direct correlation between the power output of the turbines and residents' diary observations with respect to noise, it found a trend between high levels of disturbance (severity of "sensation") and changes in the operating power of the wind farm.

The study found a pattern of high severity of disturbance to be associated with four different operating scenarios of the wind farm being:

- when the turbines were seeking to start (and therefore could drop in and out of generation)
- an increase in power output of the wind farm in the order of 20%
- a decrease in the power output of the wind farm in the order of 20%, and
- the situation when the turbines were operating at maximum power and the wind increased above 12 m/s.

There were at times other instances of high severity of disturbance not fitting the above four scenarios.

Noise data was first examined in terms of dB(A) and then 1/3 octave bands.



When noise data was assessed in terms of 1/3 octave bands for calculation of various acoustic parameters, it was found that the dB(Z), dB(G), 0.8Hz 1/3 octave band and the dB(A) followed the power output of the wind farm. Those curves also followed the increase in the wind speed, there being a direct correlation between the power output of the turbine and the prevailing wind speed.

Use of the shut-down testing identified that the extraction of the noise contribution from the wind farm could not be carried out by way of one third octave band analysis, either by use of an L90/L95 level or an Leq level in view of the significant variation in the ambient noise at high wind speeds, as a result of the fluctuating wind.

Examining the noise data with respect to 1/3 octave band data to obtain generalised acoustic parameters failed to reveal any significant difference between the operation of the wind farm and the natural environment that would support the concept that there is no difference between the natural acoustic environment and that of a wind farm. The analysis of the shutdown testing indicates the permitted noise emission on the permit (as a contribution) cannot be determined.

Examination of the acoustic environment in terms of narrowband analysis however, confirmed the results of previous investigations. It demonstrated that there is a unique signature attributed to wind farms that involves a peak at the blade pass frequency and the first five harmonics of that frequency. This unique infrasound pattern has been labelled by the author in other investigations as the “Wind Turbine Signature”.

The shut-down testing confirmed that the Wind Turbine Signature is present when the turbines are operating but does not occur in the natural environment (i.e. wind farm shut down).

The investigation identified for the turbines used at Cape Bridgewater that when the turbines were operational there is a distinct frequency generated at 31.5 Hz that exhibits side bands on either side of that frequency (at multiples of the blade pass frequency). This pattern confirms the presence of an amplitude modulated signal which is not present in the acoustic environment when the turbines are not operating.

Superimposing narrowband signals onto 1/3 octave band results clearly shows that the natural infrasound environment in proximity to a wind farm when NOT operating is significantly different to that for the same locations with the wind farm operating.



By including narrowband analysis in the description of the acoustic environment, the study confirms that the infrasound obtained in a wind farm affected environment is different to that in a natural acoustic environment.

Clarification as to the mechanism of amplitude modulation and the wording used in some cases to describe that phenomena associated with turbines has been explored with a suggestion for clarification of such wording.

The Danish dB(A) LF method [4] has been used for low-frequency noise annoyance, based on sources other than wind turbines [5] [6]. It was not found to have sufficient correlation to be used for wind farms by reason of the internal noise that can be generated during the presence of high winds.

Using 1/3 octave band information and noise annoyance as a general descriptor, the analysis for the three houses was unable to separate the wind farm contribution from the ambient.

Utilising the wind turbine signature and the aforementioned discrete low-frequency amplitude modulated signal when compared with the severity observations provided by the six residents reveals that as the magnitude of those discrete frequency signatures increase so does the level of severity.

From the resident's subjective observations a wind turbine signature rating curve has been derived that indicates an unacceptable presence of sensation inside a dwelling (for those 6 residents) occurs at an level of 51 dB(WTS) – when assessed as rms values 400 lines for analysis range of 25 Hz. Utilising PSD values (400 line 25 Hz range) the unacceptable level for the 6 residents occurs at 61 dB(WTS).

It is noted that the participants involved in the study have experienced the impact of the wind farm for a period of in excess of six years and would appear to have a heightened sensitivity to such impacts, although the threshold levels of perception generally agrees with similar observations made during measurements undertaken by TAG at residential properties in proximity to the Waterloo Wind Farm (in South Australia), the Waubra Wind Farm (Victoria), the Capital Wind Farm and the Cullerin Wind Farm (both in NSW).

Being the first study to document or to identify “sensation” associated with the wind farm and the wind turbine signature, it is noted that the sample data is small and has persons already affected by the “noise”. The findings must be considered as **preliminary** and warrant further detailed studies of the scientific rigour necessary for the purpose of confirming/verifying the suggestions for the use of the nominated dB(WTS) thresholds.



It is however noted that when placed in the context of a dB(WTS) curve there is agreement with the infrasound components of the turbine perception concept nominated by Kelley in 1982 [7].

The observations from the residents with respect to sleep disturbance indicate that for the rural setting of Cape Bridgewater, where the ambient noise levels at night inside dwellings are typically below 15 dB(A) (in the absence of any activity in the household), then the concept of a 30 dB(A) Leq threshold level identified in the New Zealand Standard (that in the main is based upon road traffic noise [8]), would appear to be an inappropriate threshold for the assessment of internal noise levels associated with wind farms.

Other findings concerning the emission of vibration and the relationship to general acoustic measures identified during the course of the study are summarised in the conclusion.

During the course of the study there were significant issues in terms of instrumentation that requires for other researchers in this area identification of problems and the **essential** need for persons involved in the measurements of noise, and particular infrasound, in proximity to wind farm affected environments to utilise calibrated instrumentation covering the entire signal chain from the microphone (or pressure sensor) through to the read out. Reliance upon manufacturer's data does not always cover the entire spectrum of concern, with an entire section of this study report addressing instrumentation issues that have been identified during this study.

On the basis of a limited number of affected residents for the study, it is suggested that:

- **for these residents the presence of “sensation” is the major impact;**
- **surveys of residents near other wind farms should utilise the Cape Bridgewater Wind Farm survey method so as to include “sensation” in any investigations;**
- **the use of dB(A) or dB(C) for internal measurements of the wind farm does not separate the results from that generated by the wind – for residences that are directly exposed to the wind.**



There is not enough data from this study to justify any change in regulation. However, the following matters are suggested for further investigation:

- **the validity of the dB(WTS) and the appropriate threshold levels be the subject of further studies to provide the necessary scientific rigour for a threshold to protect against adverse impacts;**
- **examination of the use of the dB(WTS) index (both external and internal) to supplement the external dB(A) index currently used for wind farms;**
- **the use of the internal dB(WTS) method can assist in medical studies in that the internal dB(WTS) identifies the presence of energy from the operation of a wind farm. The dB(A) level measured inside dwellings is of no assistance in such studies;**
- **the use of an external dB(WTS) can overcome the limitations of the dB(A) method that can be influenced by extraneous sources (i.e. wind); and**
- **the issues of directivity and identification of the noise emission sources of a turbine relative to sound power testing at ground level be examined. Whilst there are significant costs involved, further investigations are required (by the use of a crane or similar) to measure noise levels at the hub height and the top and bottom of the swept path for say 150 metres from the tower, including directivity testing at those heights around the turbine.**



1.0 INTRODUCTION

In late 2013 Pacific Hydro approached The Acoustic Group to enquire as to the possibility of undertaking an investigation along the lines of what had been proposed some 18 months earlier and not just restricted to dB(A) measurements external to dwellings.

The enquiry was presented as a genuine desire by Pacific Hydro to take a fresh approach to noise from the Cape Bridgewater wind farm.

Pacific Hydro own and operate the Cape Bridgewater Wind Farm located near the town of Portland in south-west Victoria. The Cape Bridgewater Wind Farm consists of twenty-nine (29) REpower MM82 2MW wind turbine generators with a hub height of 69 m. The wind turbines are distributed in three groups, one towards the south end of the cape, one towards the north and the other between the two aforementioned groups. A site layout plan for the wind farm is provided in Appendix A.

The wind farm has been in operation since 2008 pursuant to conditions 13 & 14 of a consent [1] that specified noise emission to be assessed in accordance with the New Zealand Standard NZ 6808:1998 [2]. The assessment procedure is based on a dB(A) averaged level recorded outside a dwelling on the assumption the outside to inside attenuation of an open window is 10 dB(A).

A condition of the Planning Permit for the wind farm required that a monthly post-construction noise monitoring program be undertaken, for a period of twelve months, in accordance with the New Zealand Standard 6808:1998 *Acoustics – The assessment and measurement of sound from wind turbine generators* (NZS6808:1998) [2], which is applicable in Victoria.

Acoustic compliance testing of the operational wind farm has been undertaken by Marshall Day Acoustics who have certified the wind farm is operating in accordance with the permit conditions (reference Marshall Day Acoustics report *Cape Bridgewater Wind Farm Post-Construction Noise Compliance Assessment* ref 002R01 2058370 dated 23rd July, 2013) [9].

The wind farm operator is in receipt of complaints from residents in close proximity to the wind farm identifying that the operation of the wind farm gives rise to disturbance, with the disturbance identified as low frequency noise and at times a pressure sensation detected in various parts of the body.



There have been other complaints in relation to tonal and intermittent noise sources from the wind farm which have been investigated by Pacific Hydro and identified as being related to wear and tear on various plant items requiring maintenance, lack of lubrication or binding brakes associated with servo motors required to orient the turbines into the wind.

The community and the wind farm operator have held a number of community consultative meetings where various issues relating to the operation of the wind farm having been presented by residents.

It is in the context of the above that the subject investigation was requested by Pacific Hydro to investigate and report on noise emitted from the Cape Bridgewater Wind Farm with respect to 3 residential properties in proximity to the wind farm.



2.0 BACKGROUND TO THE INVESTIGATION

Preliminary concepts for undertaking the study were presented in December, 2013, following a site visit to the residential properties and discussions with the residents as to their perceived impacts from the wind farm.

A format for the purpose of the acoustic investigation was presented to the residents and Pacific Hydro, suggesting unattended noise measurements external to the dwellings and inside a bedroom in each dwelling together with a more comprehensive recording system to obtain measurement data covering two nights of operation for the occupied houses and for six weeks at the unoccupied house.

The investigation also involved measurements conducted on the wind farm site proper covering both noise and vibration, and at the residential dwellings the conduct of noise and vibration measurements at various hotspots identified by the residents.

The primary **aim** of the investigation was by the use of the resident's diary observations to ascertain if there was any correlation with the observations versus noise emission levels generated by the wind farm.

During the investigation site visits to download data and meet with residents to ascertain the progress of the investigation occurred on a nominal 2 week basis, in addition to 2 public meetings held at Cape Bridgewater to discuss the progress of the work.

During the course of the monitoring questions as to measurement results from the preliminary findings were raised by both Pacific Hydro and the residents that in some respects involved additional measurements to address those questions.

In view of there being a number of separate issues raised during the course of the investigation, and that measurements are not only restricted to the residential dwellings, the format of this report is divided into a number of chapters to identify and discuss relevant items or components of the investigation.

Whereas the acoustic criteria on the permit for the wind farm [1] relates to only the A-weighted noise level external to dwellings, residents have indicated noise disturbance both external to and inside dwellings that may not be associated with the A-weighted level.



As part of the initial consultative process Pacific Hydro requested TAG's attendance to 3 residential properties to meet with the residents and gain a greater appreciation of the issues raised, together with attendance at one of the consultative committee meetings (open to the public) to discuss the concept of the proposed investigations.

The 3 houses inspected were found to be of different construction and have a different relationship to the wind farm.

As a result of the site visit and meetings with the residents, together with an examination of the acoustic compliance report that has been prepared for the wind farm, the project brief was to present a testing program that could be undertaken to address matters raised by the community [10].

As a result of the consultation process Pacific Hydro gave an undertaking to conduct acoustic testing both inside and outside dwellings so as to identify the full spectrum acoustic signature of the internal and external environment that is not normally assessed by way of the A-weighted level.

Both Pacific Hydro and the community have acknowledged that such testing goes beyond the noise testing requirements on the permit conditions.

Pacific Hydro has indicated that the conduct of the measurements and the preparation of the test plan were to be transparent and independent.

The investigation has utilised 3 houses with 2 of the houses being east of turbines CBW 12 to CBW 29, and 1 house to the north/north-east of turbines CBW 1 to CBW 5.

Appendix A provides a layout of the wind farm on which has been superimposed the location of the 3 houses used in this investigation that are identified as Houses 87, 88 and 89.

The program for the testing was to undertake unattended noise logging for a period of 8 weeks, that included shut-downs over a two week period and to conduct attended measurements on the wind farms and at residential locations during that period.

The original proposal involved monitoring on the wind farm in the early stages of the testing program then followed by attended monitoring at the houses, with a regular two week attendance to download data and meet with residents.



However, the original advice from residents was that nobody other than the Principal of TAG was permitted on their properties. The restriction on man power and the occurrence of adverse weather required alteration to the original testing program. In the end, permission was given for TAG staff to attend to assist in measurements, resulting in the majority of the wind farm measurements being conducted at the end of the testing program.

The measurement program was altered by the requirement to attend community consultative meetings leading to an extension in the monitoring program as shown in the Figure 1, that was completed by the due date in July 2014.

The reporting component of the project was extended past the original intended date of September 2014 by reason of the volume of data that had been collected and issues of instrumentation/calibration discussed in the report.



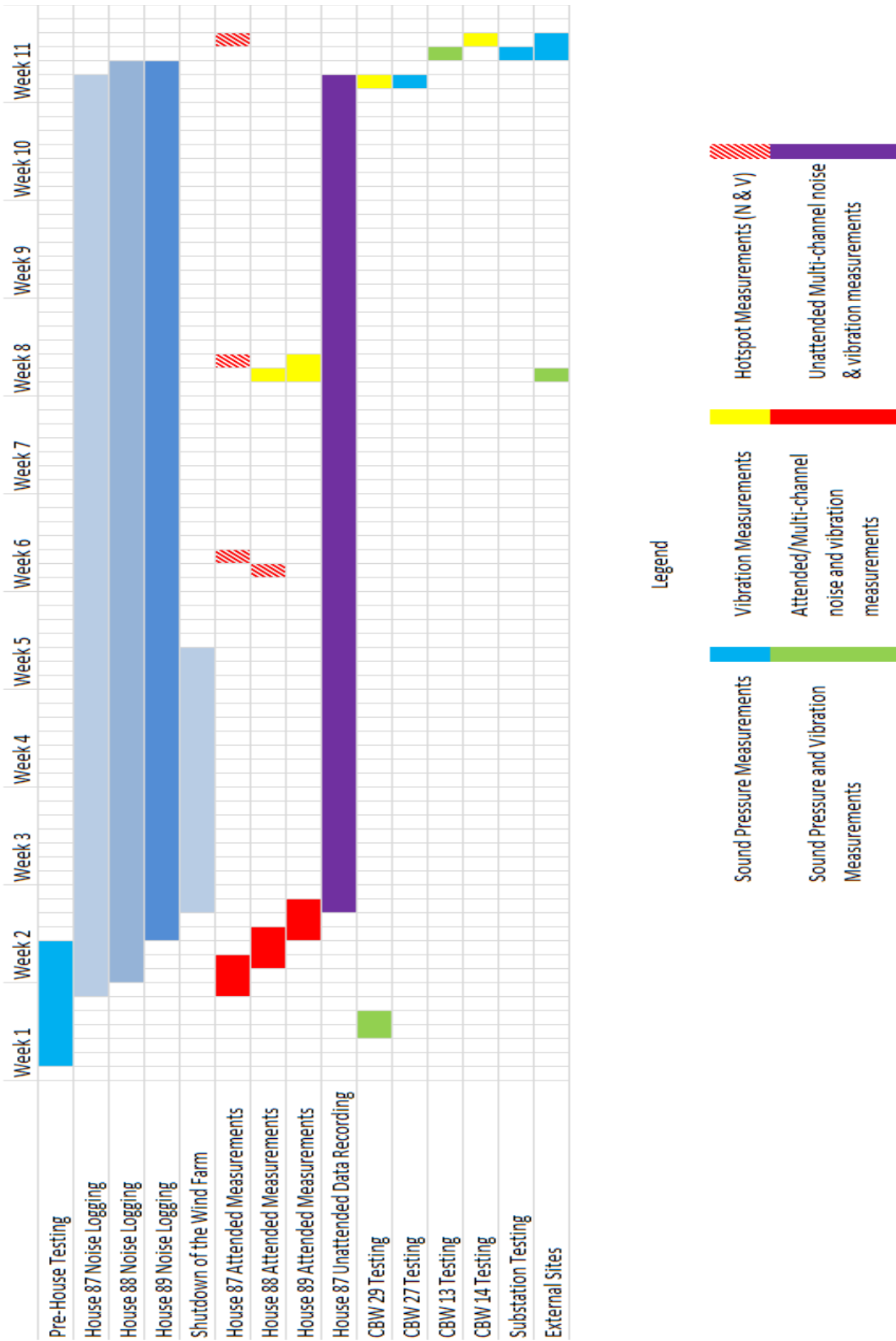


FIGURE 1:



3.0 SITE VISIT PRIOR TO INVESTIGATION

Three residential properties were nominated for inclusion in the testing with two of the properties being less than 900 m from the nearest turbine and one at 1.6 km from the nearest turbine.

Appendix A provides a layout of the wind farm that indicates in simplistic terms there are three separate sections of the wind farm, which for the purpose of this exercise are identified as the southern portion, the middle portion and the northern portion.

In the EIS for the wind farm the three properties that were the subject of this study are identified as Houses 2, 4 and 63. For the purpose of this investigation and to overcome any other numerical identification that may exist in other documents, the three houses have been identified as 88, 87 and 89 respectively.

In late 2013 in the presence of senior representatives of Pacific Hydro a Committee Consultative meeting was held in Cape Bridgewater supplemented by individual meetings with the residents occurred at their houses to discuss the potential project and gain first hand an appreciation of the residents' issues and their environment.

Meetings held at the 3 residential properties involved an external inspection of the dwelling with discussions occurring outside the premises to indicate the resident's areas of concern, and in particularly any noticeable "hotspots" around the house, and discussions as to the perceived impacts as a result of the operation of the turbines.

The impacts described by the residents at each of the houses were slightly different from house-to-house, but also different for each of the 2 individuals that were at each house.

At each of the houses the female adult experienced a different impact to the wind farm to that of the male adult, hence giving rise to different types of complaints on the wind farm database relative to the individual house. It is noted that at the initial phase of the investigation the residents used different terminology (to that of acousticians) to describe the impacts they experience.



At each house both residents advised that when away from their dwelling the impacts attributed to the wind farm were not observed and made particular note that this report is to identify that when staying overnight at locations removed from the wind farm they are able to have undisturbed sleep and did not have headaches or the perception of pressure in their body.

One of the houses is abandoned with the occupants advising they reside elsewhere so as to be removed from the wind farm.

Following discussions in seeking to clarify the individual impacts that have been identified, and the response of the residents to those impacts, an internal inspection of each dwelling was undertaken (in the presence of Pacific Hydro representatives) with various rooms in which adverse effects occur being noted.

In the course of the inspection a simple listening test was undertaken by placing an ear to internal sides of the external walls and internal walls of the dwelling, and revealed noise being detected in some internal walls in the form of low-frequency noise/rumble.

All of the residents indicated that over time their sensitivity to “noise” from the wind farm has increased and that there is regular occurrence of sleep disturbance to the point that their health has been affected (to varying degrees).

A number of the residents indicated that they have hearing problems which can in some respects reduce the audibility of noise via the outer ear, but in some cases can change the relationship/sensitivity of low frequencies and high frequencies by way of such hearing issues.

For example persons over the age of 50 are subject to a slight natural hearing loss identified as presbycusis. Persons that may not be subject to hearing loss can develop tinnitus which is often described as a ringing in the ears.

Where a hearing loss occurs such as the typical case of industrial deafness, irrespective of the frequencies of noise that may be encountered during the workplace, the general trend for a normal hearing loss is to have a reduction in the sensitivity of hearing at the high frequency region around 6 kHz and then as a hearing impairment becomes greater than the bandwidth of hearing loss expands to encompass the middle frequencies and then the low frequencies.



A general trend in terms of hearing loss is for persons to lose the frequency content associated with speech and often describe the sounds that they hear as muffled.

As a result of the discussions with the residents it was requested that for the purpose of the proposed study a diary/log be prepared to identify impacts that were perceived/detected by the residents, together with the notation of weather conditions and wind direction. It was suggested the concept of the sliding scale from 1 to 10 be added to the comments so as to indicate the severity of the impacts.

One of the residents (of House 88) provided a log book that was already in existence to indicate the nature of impacts that has been used in a severity scale of 1 to 7. To be consistent with the log book, which was provided for our review during the meeting and was found to be very extensive, it was suggested at the following meeting a log book of the severity scale being 1 to 7 for the other residents.

It was suggested that in view of each of the residents experiencing a different perception that the log books be individual log books rather than a joint log book for each house.

There is an issue with respect to House 87 being unoccupied in that a current log book would be of no assistance. However the residents indicated that they do have log book in relation to when they occupied the house that could be made available subject to agreement as to the confidentiality between the parties.

The 3 houses inspected were found to be of different construction and have a different relationship to the wind farm.

In view of the differences between the houses and the observations made during the course of the initial meetings the following is noted.

3.1 House 87

Matters identified by the residents of this house were different to the other two houses and indicated that the extent of such disturbance was significant to the point that the dwelling had been abandoned and the occupants reside elsewhere.



The discussions commenced external to the house to indicate various hotspots at which the occupants could detect or readily perceive the wind farm. As in the case of the other two houses the 2 occupants presented different forms of disturbance or perception as a result of the wind farm. The residents advised that when moving away from the wind farm to other areas the impacts did not exist.

The residents indicated that they were experiencing severe discomfort at the time of the meeting whilst some noise could be detected from the wind farm by those in attendance. The two residents were very specific as to a low frequency noise and a distinct pressure that could be detected in the body (different parts of the body for each resident).

The walls of the dwelling are of substantial construction using sandstone blocks for the external walls of the main house and solid rocks for the western extension, with timber or plaster lath ceilings and a metal deck roof.

The residents indicated that the majority of rooms in the dwelling were impacted and that the entire family had been affected in their individual bedrooms.

The residents indicated there were different affects in different rooms and that there was a focusing point in the centre of the kitchen/dining area.

The front living room (towards the wind farm) has a sloping timber ceiling on the underside of the roof joists of which gives rise to a range of room modes for that room.

The master bedroom located on the eastern side of the building is a rectangular room with the internal wall being parallel to the wind farm. On a listening test (for an ear to the wall) the internal wall parallel to the wind farm was subject to low-frequency noise, whereas the walls perpendicular to the wind farm had less of an audible impact.

The occupants indicated that the internal wall to the bedroom extends into the ceiling space. The wall may not continue directly through to the roof and could be the subject of investigation.



Bedrooms used by the children of the family were a different size and construction with one bedroom being at the north-eastern corner of the residence, and another one in a western extension of the residence. Between the kitchen dining area and the western bedroom is a rectangular family room which has a vaulted ceiling and would appear to have a different impact compared to other rooms with a flat ceiling.

The residents had no objection to monitoring conducted inside and outside of the dwelling as there is nobody residing at the premises.

It is noted that this house is the furthest from the turbines (of the 3 houses) but is level with the base of some turbines and therefore could experience a different propagation to other dwellings that are below the bottom of the turbine swept path.

3.2 House 88

Discussions external to the dwelling identified that at times there was a perception of noise from the southern portion of the wind farm whilst at other times, depending upon the prevailing weather conditions, there was a view that a disturbance was associated with the northern portion of the wind farm. House 88 itself is of substantial construction in the form of sandstone blocks with external and internal cladding/render and has a metal deck roof with timber ceilings.

There is a band of trees to the north of the house that provided visual shielding to the northern portion of the wind farm and there are low scrub bushes to the west of the house that filter out views from the house to the southern portion of the wind farm.

Whilst external to the house the issue of a constant low frequency hum was discussed with the possibility of the sub-station being a potential source raised by one of the residents.

An inspection of the premises identified different rooms in the dwelling where problems were perceived. The residents advised that at times vibration in the kitchen could be observed by looking at water in glass bowls or observing a set pendulum balls moving.



On listening to various internal walls in the building a low frequency rumble could be detected in walls that would be described as being parallel to the wind turbines, whereas walls that were perpendicular to the wind farm had less of an audible rumble type characteristic detected in the walls.

The residents were agreeable to monitoring being conducted at the property utilising both internal and external locations.

Discussion as to the practicality of internal monitoring (as the house is occupied) and the presence of equipment inside the dwelling was raised as the results could at times be affected by internal activities. The residents did raise at the outset the privacy issue as to the content of any recording or measurements that would be undertaken.

It was explained to the residents that statistical measurements that utilise the nominal 10 minute period for assessment purposes are just simply numbers and do not have any recording or content of the activity, whereas the more complex measurements using WAVE files will record the content that is used for subsequent analysis. Any monitoring does not mean that persons will listen to days and days of actual monitoring. If the general analysis reveals patterns or frequencies that will require investigation, then the analysis would occur for that period. In undertaking an analysis of the Wave file there is not a requirement to listen to the audible content of the wave file.

The residents have declined to release the internal WAVE files other than for the attended measurements when the house was not occupied.

3.3 House 89

The house is a timber frame and timber clad dwelling located near the northern portion of the wind farm. The residents indicated that there is a perception of a greater impact on the side of the residence towards the wind farm.

There are no large trees or obstacles between the house and the wind farm (with respect to viewing to the south or the west). However, to the south west there are trees between the house and portions of the wind farm.



The residents advised of experiences where distinct audible characteristics (similar to that described for the servomotors) and “whomping” sounds were present and provided a video with a recording of the “squeal” that has been subsequently attributed to binding brakes.

The residents identified a focusing point in the kitchen of the dwelling. It was noted that there are large windows adjacent to that facade and relatively hard surfaces in the kitchen.

Walking through the dwelling indicated that there is a different floor construction in the kitchen versus the main body of the building.

A number of “hot-spots” inside and outside the dwelling were identified that were subsequently identified and found to be related to audible differences in the reverberant nature of the various internal hotspots.

3.4 Resident’s Questions

Prior to the investigation (and during the investigation) a series of questions were raised by the residents in relation to noise emitted from the operation of the wind farm and potential sources of disturbance. Where possible measurements/observations were undertaken to attempt to address a number of the questions that were raised being:

- Different impacts associated with the turbines, noticed under different prevailing weather conditions.
- Seasonal variations observed in impacts.
- Impacts are not related to any specific time, but there is a greater degree of disturbance observed when residents are trying to sleep.
- During periods of extremely high winds there is a noticeable buffeting effect that occurs.
- How can there be a claim of natural environment of Infrasound being the same as that from wind farms?
- Vibration is perceived by residents inside and outside dwellings. Is there a potential increase in vibration as a result of caves under the ground?
- On occasions there is a shockwave type pulsation detected under variable wind conditions that from other wind farm sites has been described as “bolts”.
- Is the substation generating low frequency noise that can be detected at our residence?



- At times there is an audible noise like that of a plane not landing that does not occur when turbines are not operating.
- At times there is a sensation of headache or nausea or dizziness when the turbines are operating. Please explain.
- At different points of the property (both inside and outside) there appears to be focusing of sound or sensation, please investigate.
- At some locations around house 89 the sound of the turbines is entirely different to other locations. Please explain.
- At times there is extreme pressure felt in resident's heads whilst other times a slight degree of pressure. Please explain.
- Why is there disturbed sleep and general lethargy observed when the turbines are operating?
- Why if the wind farm is complying with the noise conditions of consent are we disturbed?

A number of the above questions are outside TAG's area of expertise, but observations and measurements identified in this study may assist others in answering such questions.

3.5 Diary Observations

Prior to the commencement of the study the residents were provided the diary format/instructions used in the SA EPA Waterloo study [3] to trial the format to see if it was workable and easily understood by the residents, before the commencement of the Cape Bridgewater survey and measurements.

Feedback from the residents indicated there was a problem in comprehending a number of classifications/requirements in the SA EPA Waterloo study that would present difficulties for ongoing reporting and did not appear to address the complaints that have been lodged with Pacific Hydro.

Appendix C sets out the SA EPA Waterloo diary methodology which was not found by the residents to be readily understood or practical.



Problems were encountered with respect to the description of the operation of the wind farm which may not be known by persons participating in the study, particularly with respect to night time operations where the turbines could not be observed. One resident indicated there were problems in fulfilling the wind farm operation requirement if he was not there for the entire day.

A major concern with a number the resident's trial run of the diary concept was that the descriptors for setting the severity rating did not necessarily accord with what they experienced and more importantly, the matter of disturbance was not restricted just to noise.

On discussing the impacts that residents experience it became apparent that the classifications of "noise" being separate to "vibration", and in turn separate to "sensation" would appear to address the issue, as from a resident's perspective the major disturbance would not be classified as "noise" disturbance but one of "sensation".

This was considered a major finding by the residents, in that in their opinion in the past complaints lodged with Pacific Hydro was that the operation of the turbines was giving rise to noise disturbance, when in fact the complaints related more to sensation

The residents expressed concerns as to the SA EPA description of severity. A different description of severity used in a UK study [11] was presented and received approval of the residents.

The revised descriptors for severity rating of 1 to 5, and the inclusion of "vibration" and "sensation" as separate categories, addressed the residents' concerns and were considered appropriate for the survey.

As identified above the process for the study was to obtain noise data, wind data, and residents' observations on a fortnightly basis and having reviewed the material to return and discuss the observations/diary comments to provide a further insight into the measurement results.

Examination of the first two weeks of comments when correlated with the A-weighted logger results (both internal and external) did not find agreement with the severity rankings that had been provided. But, when compared with the power output of the wind farm a number of repeatable scenarios were identified in which the high level of sensation became apparent. That is, the preliminary results found that there was a relationship with some of the observations in terms of the power output of the turbines but not directly related to specific noise levels.



This pattern was evident for each of the resident's diaries involved in the survey.

During the second interview after the preliminary analysis it was suggested that the observations that were being made related only to changes in the wind farm and not necessarily the operation of the wind farm. Each of the residents discussed (on an individual basis) this possibility and agreed that the observations were made when changes were observed. This was not the assumption that was expected in relation to the provision of diary comments.

A number of the residents identified that they were subject to continuous impact/effects of the wind farm and as such some of those impacts had in effect been blocked out by the individuals. It was only the changes in operation or effects that they observed that then resulted in providing a diary notation.

It was requested that it would be of benefit to all if the diary observations could be made on a regular basis, not just when changes occurred, and if possible for those at home during the day and evening periods to provide observations on a one-hour or two hourly basis.

It was realised that such a commitment would add additional pressure to the residents but the residents agreed for the benefit of the survey where possible they would conduct such a method of recording observations.

With the benefit of the revised form of observations the changes in the operation of the wind farm became more apparent.

For some residents they expressed distress in terms of making regular observations. It was subsequently suggested that a method could involve sitting at the same position for observations (chair or table), closing the eyes, relaxing for a minute, carrying out the observations with closed eyes and then writing down the particulars. For some residents they welcomed the concept in being able to be more relaxed in making the observations.

Appendix D sets out the amended Cape Bridgewater Wind Farm diary format that was developed in conjunction with and agreed to by the residents.

It is considered the identification of the original diary format **only leading to changes in the wind farm operation to be a significant finding** with respect to addressing issues from wind farms. It would appear the difference between operation and changes in operation was not generally noted.



As a side issue, on contacting a number of residents that were involved in the SA EPA Waterloo study and posing the same question as to the diary observations in all cases it was found that those residents had prepared their diaries on the basis of changes that they perceived in the course of the monitoring and not a regular basis as required for this survey.

A number of the Waterloo residents also advised that they found some of the SA EPA concepts to be confusing and towards the end of the survey were simply too tired and drained by the exercise to continue filling in the diaries.

For the Cape Bridgewater study the residents continued filling in the diaries although there were some holes in the diary comments towards the end of the survey. However after the monitoring equipment has been removed a number of the residents advised they were still using the diary format which was confirming the concept as to severe or high levels of sensation that was observed when the measurements were being conducted.



4.0 MEASUREMENT PROCEDURES

Typical acoustic assessments for wind farms provide a graphical representation as a regression line of fit to the dB(A) noise levels versus the hub height (or 10 metre) wind speed obtained at the wind farm site measured over a typical two week period.

Such a methodology does not identify the change in noise level over time or the influence of wind direction.

The normal wind farm assessment procedure requires noise monitoring at residential receivers (in standard 10 minute intervals) and information from the wind farm as to hub height wind speed (not normally available in the public domain).

Previous wind farm investigations at residential premises revealed that in assessing the variation in noise levels during the day there was benefit in plotting the measured dB(A) noise level versus the power out of the wind farm. This provided an insight into the change in the noise levels versus the operation of the wind farm. The addition of wind speed and direction at the microphone (as normally such information for the wind farm is not available) assists in showing differences as a result of the wind conditions.

The concept for this study was to start from the residents' observations to determine whether there were any patterns of the severity (of the reported observations) with respect to the operation of the wind farm, in terms of the power output of the wind farm versus the wind speed and direction. The next step was to examine the wind farm power output in terms of the measured noise levels.

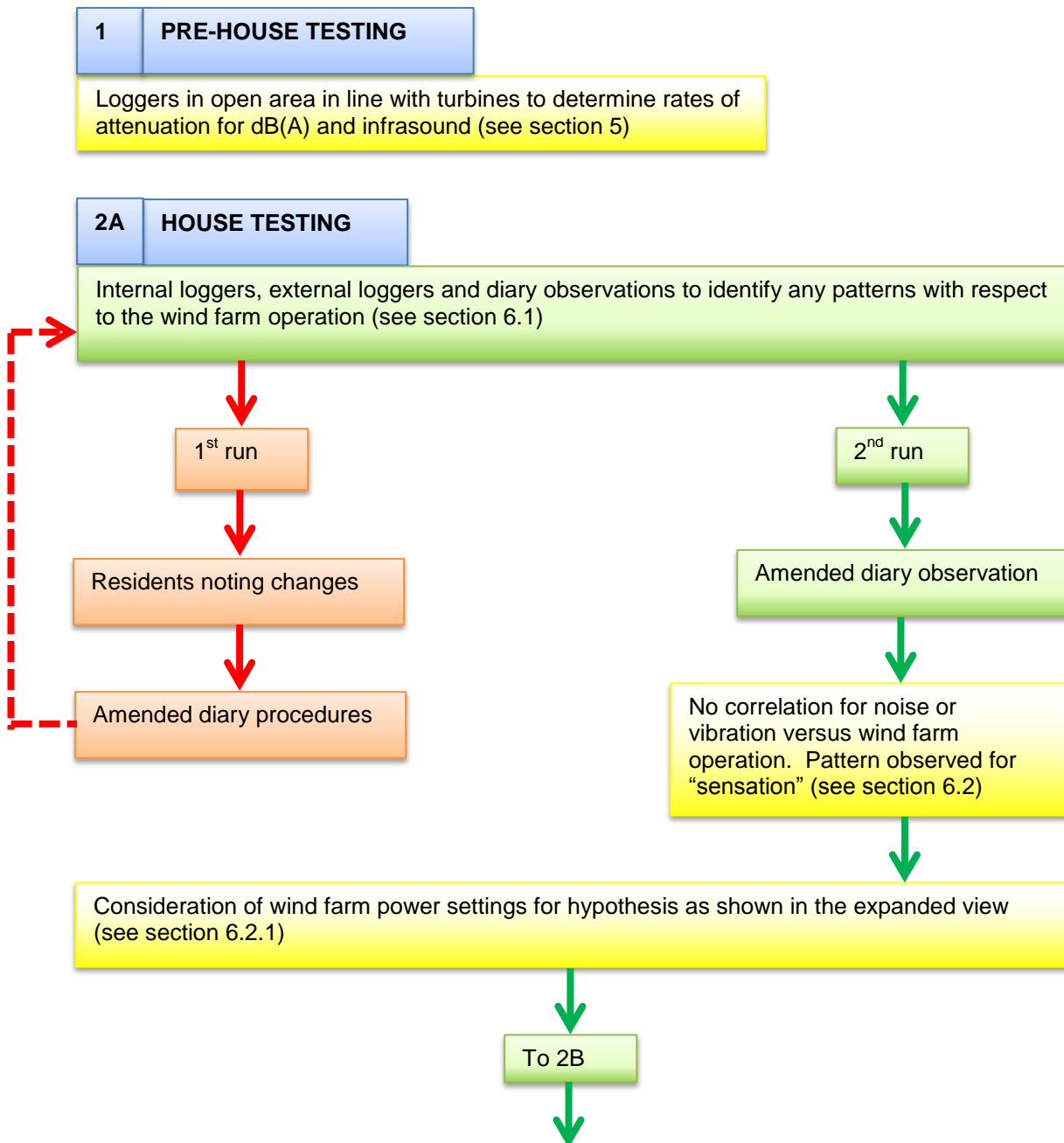
Apart from dealing with the A-weighted noise level, both inside and outside the dwellings, the intent was to obtain spectral information covering both audible and infrasound components utilising where possible standard instrumentation in the form of noise loggers with the reference 10 minute intervals specified as the measurement parameter for the assessment of wind farms.

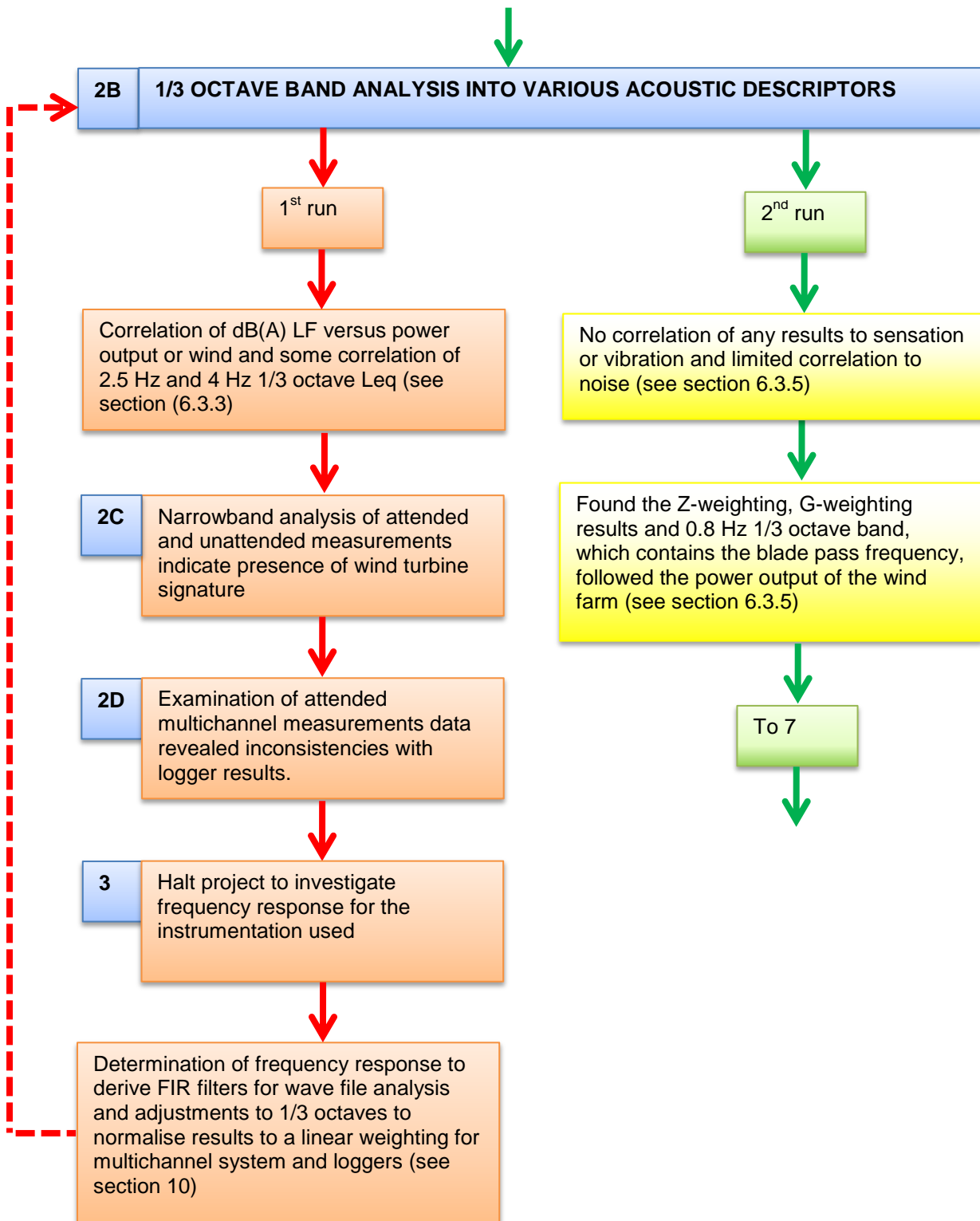
As a consequence of the amended testing program the subsequent analysis of the on-site material required the earlier analysed material to be reviewed.

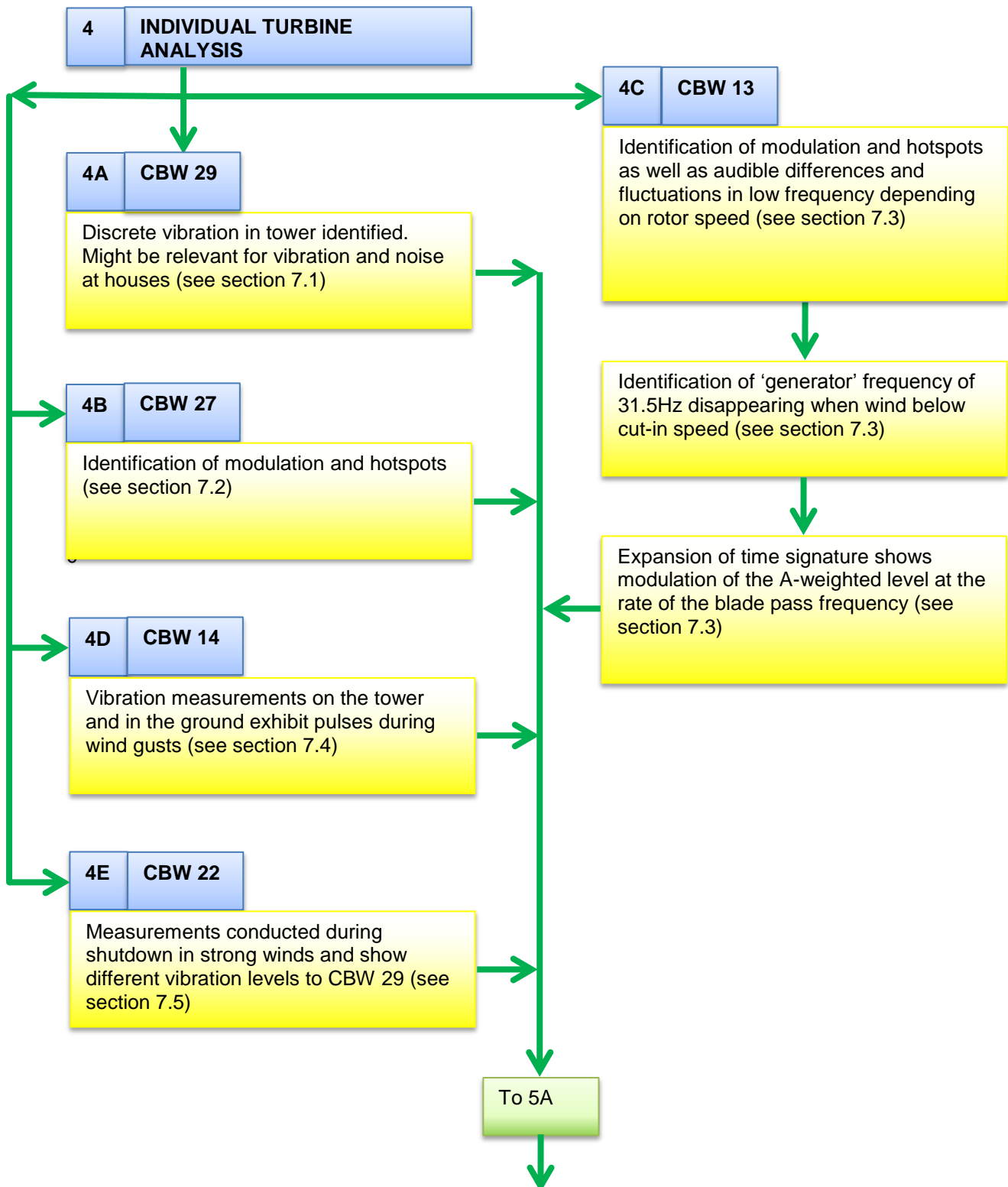
The presentation of the finding of this study are broken up into sections and subsections that follow the linear progress of the investigation that relied upon separate areas of analysis, that in turn required a review of earlier results i.e. the consequence of some analysis required a reanalysis of earlier work.

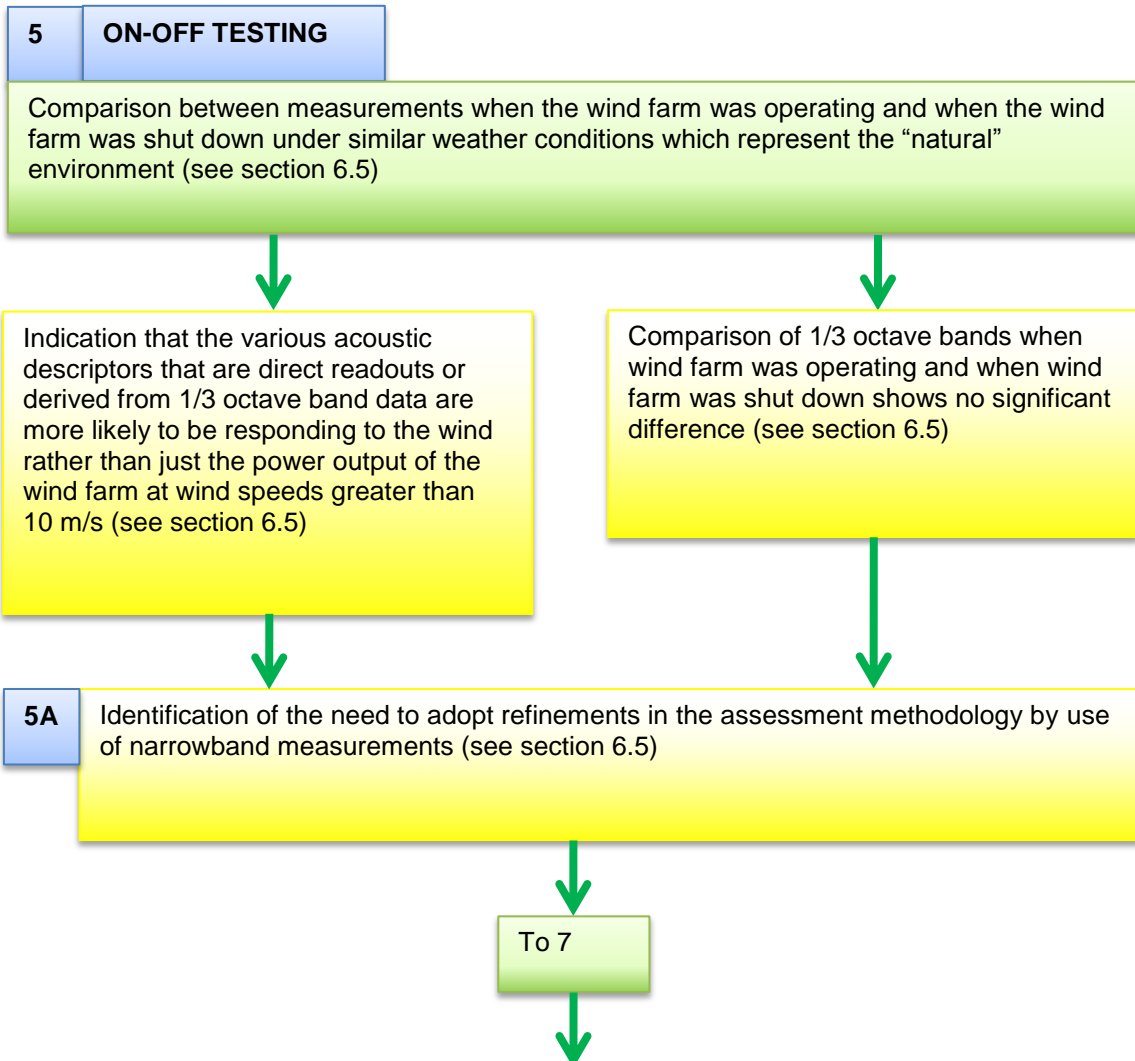


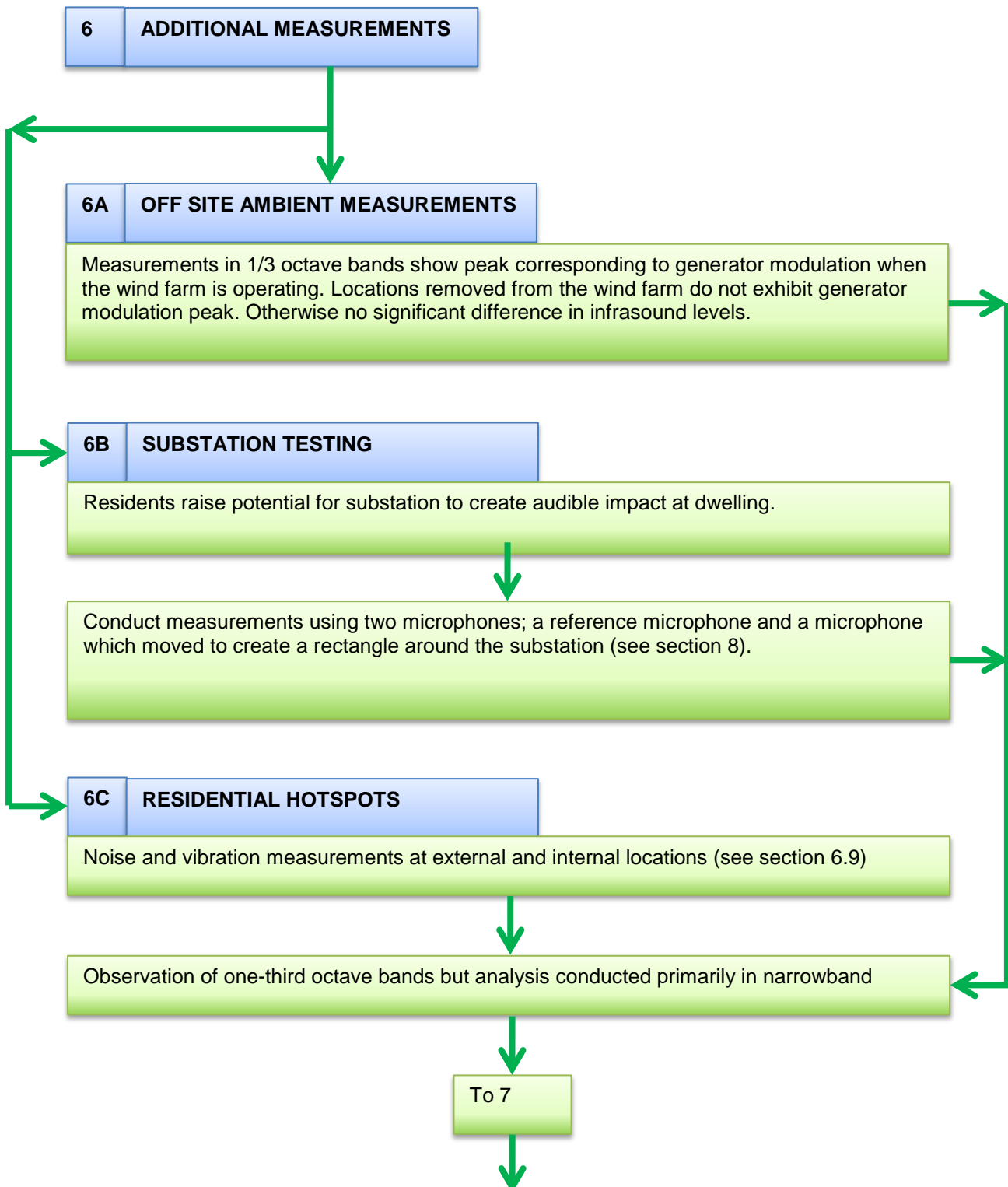
The following flow chart for the investigation (presented in a linear time frame) identifies the relevant aims and outcomes to permit the reader to navigate through the process of examining various aspects of the study, and the sections (of this report) that interact with different components of the investigation.

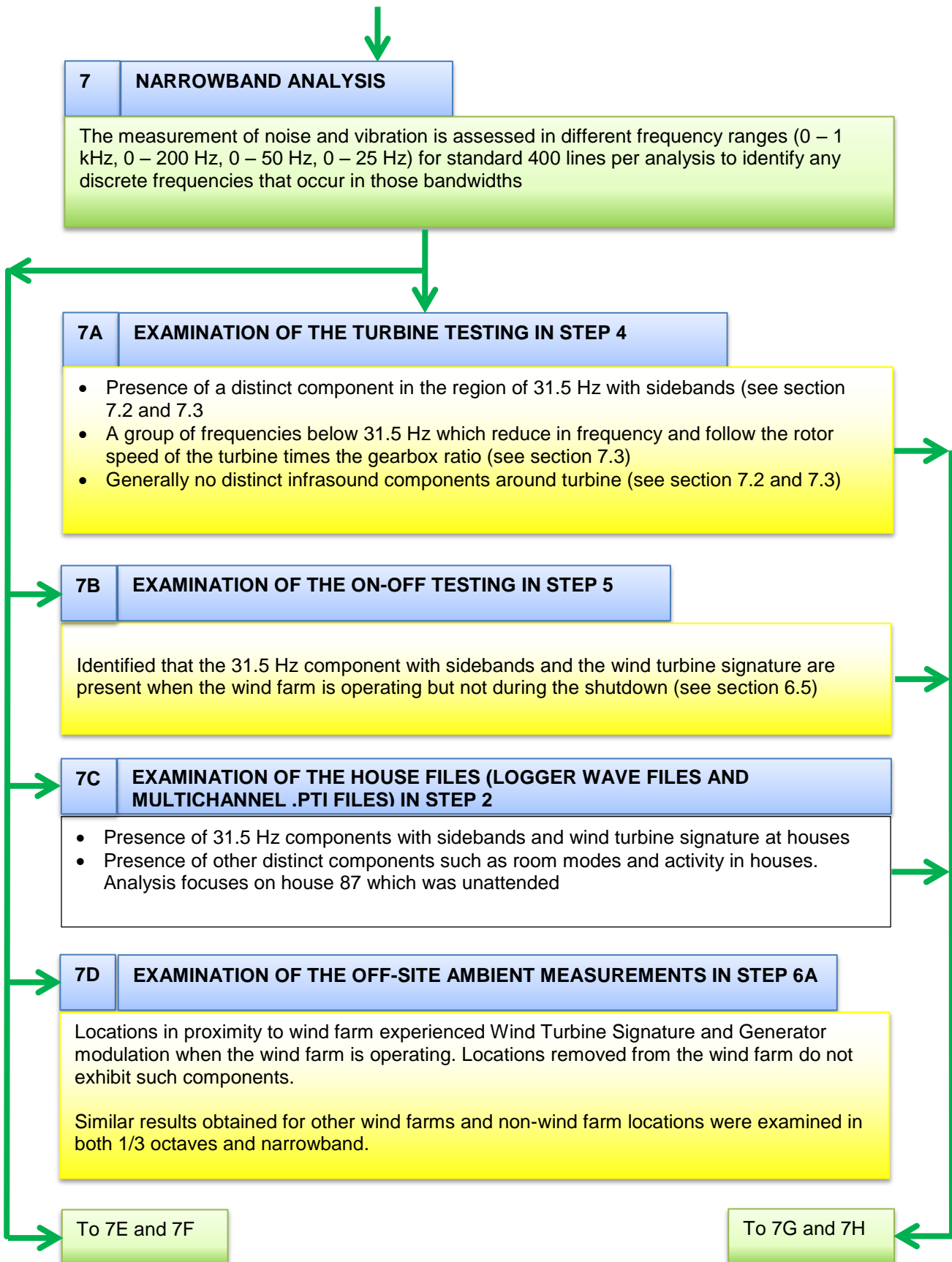


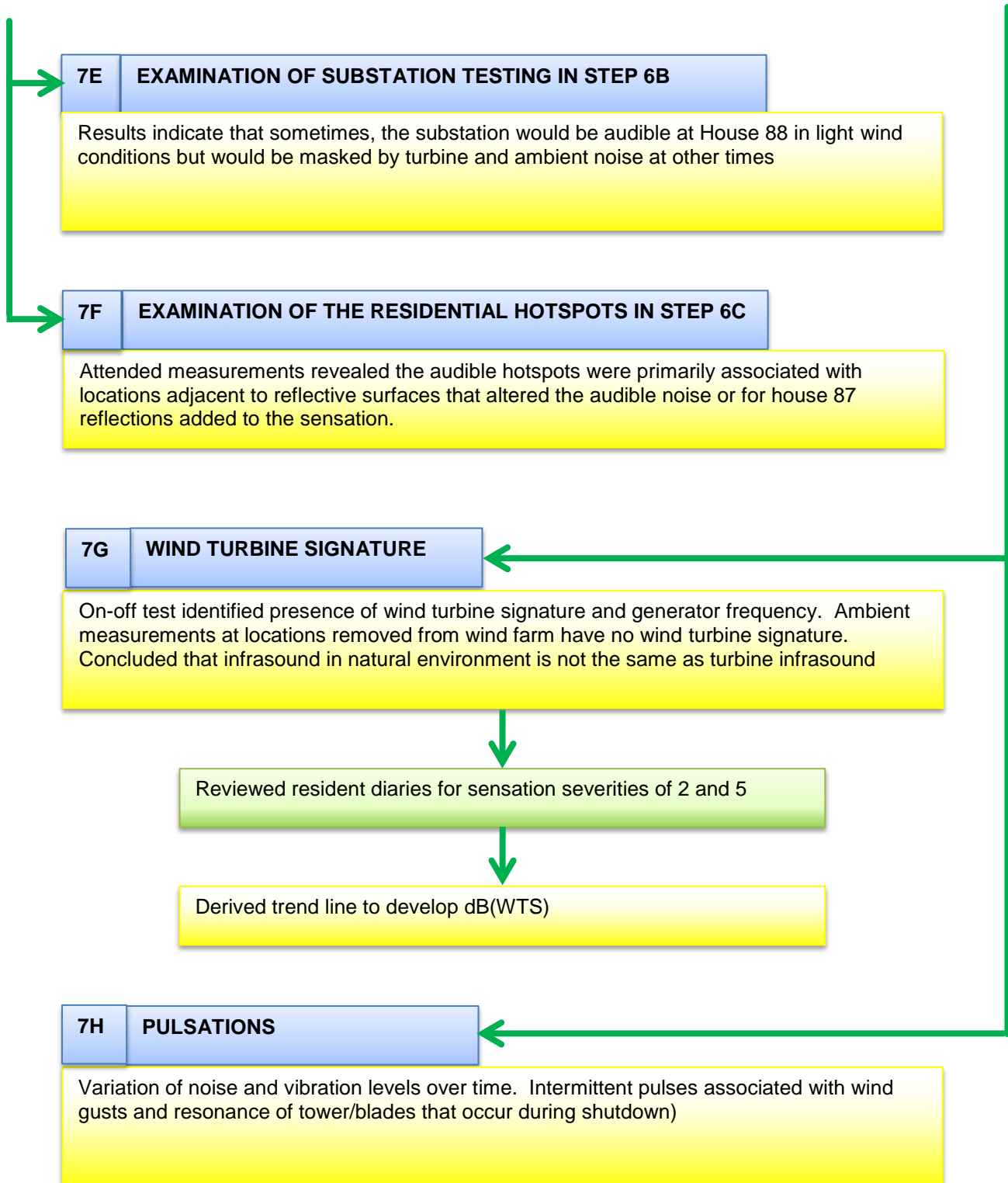












4.1 Instrumentation

For the attended measurements at the houses a multi-channel Bruel & Kjaer Pulse System Type 3650D and a Bruel & Kjaer LANXI Pulse System Type 3050 was used to record both noise and vibration data inside and outside the dwelling, all based on 10 minute samples.

For the unattended logger measurements at the houses the instrumentation used was a combination of SVAN 957 and SVAN 979 sound level meters.

The assessment of wind farms under New Zealand Standard NZS 6808:1998 [2] refers to the wind farm noise expressed in terms of a Leq parameter. The compliance method utilises the background level (identified as an L95 level) with a correction to obtain the Leq. The 2010 version of the NZ Standard [12] utilises the L90 level for the background level. The permit conditions for the Cape Bridgewater Wind Farm [1] are expressed in terms of the 1998 NZ Standard and therefore the measurements are reported as L95 and Leq levels.

As the Standard refers to the wind farm noise assessment in 10 minute intervals the meters for recording both internal and external noise levels were set for a 10 minute sample periods, with the field checks of the reference calibration level checked prior to, during, and after measurements using a Bruel & Kjaer Sound Level Calibrator Type 4321 or 4320.

In addition to standard noise logger measurements covering the full spectrum, the SVAN 979 meters have the capability of recording 10 minute wave files of which a number of the meters recorded those results until it was ascertained there were some issues with recording such large amounts of data on external USBs.

Problems occurred at house 88 with a number of USB memory sticks (and an external hard disk) being corrupted and becoming unreadable. The external sound level meter at house 88 was found to have failed after a period of time and on returning the meter to the manufacturer it was ascertained that coils on the USB circuitry had burnt out. Attempts to recover data from the “fried” USBs have been unsuccessful. As a result of the loss of data the wave file recordings for the external monitoring units were discontinued midway during the survey.

In view of the amount of data that was obtained, both in terms of the normal noise loggers and the multi-channel system described below, the monitoring involved a site visit every two weeks for the purpose of extracting the data from various recording systems, as well as reviewing the observations with the residents and discussions of results to date and any impacts that had been observed.



The standard noise loggers can have their data extracted and placed into an excel spreadsheet for the purpose of plotting the A-weighted level. Utilising the 1/3 octave band information (commencing at 0.8 Hz) different analysis of the recorded data can be undertaken using various acoustic descriptors.

In addition to the standard noise logging units a separate multi-channel system was used to provide additional measurement data for post-processing looking at a finer resolution in the frequency domain.

The multi-channel system that was utilised at houses for attended measurements (commencing at house 87 for three days, then to house 88 for two nights, and house 89 for two nights and then back to house 87 for the remainder of the monitoring period) was based around a Bruel & Kjaer Pulse 18 channel system (type 3560D) to record both noise and vibration. The Pulse unit utilised a B & K Multichannel Data Recorder program Type 7708 to a dedicated computer to record the PTI files in 10 minute intervals throughout the monitoring period.

The set-up of the multi-channel system for the attended measurements at houses is described in Appendix E.

A secondary Pulse system using a LAN VXI Type 3050 unit into a portable computer was used to ascertain individual components of the monitoring directly using the Pulse software or the Data Recorder software.

Consistent with the requirement for noise monitoring the reference calibration of each channel was checked with either a Bruel & Kjaer Sound Level Calibrator Type 4320 (or a Bruel & Kjaer Vibration Calibrator Type 4294 for vibration measurements) prior to and after various measurement scenarios.

The multi-channel system that continued in operation at house 87 for the next 6 weeks of testing utilised the same system with some different sensors into the data recorder.

For noise and vibration monitoring conducted on the wind farm, and at locations external to the wind farm, for the purpose of ascertaining ambient noise and vibration levels such monitoring utilised the Bruel & Kjaer LANXI Pulse unit with various combinations of microphones, DC response accelerometers Types 4573 and 4575, and also conventional Bruel & Kjaer accelerometers Types 4370 and 4371.

At each of the houses there was a Rainwise wind logger set to record the wind speed and direction at a position approximately 3 - 5 m from the logger microphone and at a height of 2 m above ground to identify the wind speed (and direction) at the microphone.



At house 87 an additional Rainwise wind logger was positioned on a weather mast to have the anemometer at a height of 10 m above the ground level surrounding house 87. That wind logger remained in operation for the entire survey period and recorded a maximum wind speed on one occasion of 121 km/h.

In the living room of house 87 an Infiltec infrasound pressure detector was set up to record on a continuous basis on a Toughbook CF28 laptop for the purpose of identifying infrasound below 20 Hz.

During the course of the monitoring power fluctuations and surges caused at times the Infiltec program to cease operating thereby providing limited data. It is noted that the pressure detector system was not originally intended to be part of the survey but was added as part of the investigation.

Post processing of the recorded data has been undertaken with SVAN PC++ software, B & K Reflex and proprietary software developed by TAG. Issues in relation to instrumentation and subsequent analysis are discussed in Section 10.



5.0 PRE HOUSE TESTING

(step 1 in Figure 2)

The original intent of the program was to carry out measurements in the first week by use of unattended loggers, not on residential properties that were to be the subject of investigation, and permit the coordinated logger measurements to occur for different operating scenarios of the wind farm whilst undertaking measurements on the wind farm site.

However the requirement involved in sorting out the diary methodology and inclement weather during that period prohibited the on-site testing that was planned.

Originally the testing program was to involve a number of persons setting up the monitoring stations. However, prior to the commencement of the study advice was received that the residents were prohibiting other persons from attending the site which was taken as limiting the attendance of TAG staff. Therefore the fieldwork in the early stages was limited to only the Principal of TAG that consequently presented issues in terms of timing/installation of equipment, and the original program.

During the study it was clarified that the residents had no objection to the principal of TAG or TAG staff being on-site, in that the restriction was a prohibition of any representatives from the wind farm operator or their consultants entering any of the residential sites. This permitted additional TAG staff at the end of the study to undertake multiple measurements.

For the first week of the initial testing three unattended noise loggers were located in a line east of turbine CBW 15 representing a distance of approximately 500 m, 1000 m and 2000 m from that turbine. Similarly, with respect to turbine CBW 3, two unattended noise loggers were set out in a northerly direction one being at approximately 1 km (to coincide with monitoring being undertaken by the wind farm's acoustic consultants) and a monitor a further 500m to the north.

The location of the first three loggers is identified as locations A, B and C in Appendix A with the two northern loggers identified as locations D and E.

Over a sample period of few days, the intent was to ascertain whether an attenuation rate could be determined on a dB(A) basis and to indicate in the first instance any changes with respect to wind conditions and/or any relationship between the noise level and the wind farm with respect to the subject environment.



Appendix G sets out the results of the unattended noise loggers A to E presenting the concept of the variation in the L_{95} , L_{eq} and L_{10} 10 minute parameters throughout the day to which has been added the wind speed, wind direction and power output of the wind farm.

The meteorological masts available on the wind farm cover the southern portion of the wind farm may not necessarily apply to the northern section.

For the purpose of wind identification, in relation to all of the measurement results associated with the study for loggers A, B and C, house 87 and house 88, the approach adopted was to take the wind data for all turbines CBW 12 to CBW 29 (both in terms of wind speed and wind direction) and provide an arithmetic average of the wind speed and direction.

For noise loggers D and E, and house 89, the same approach was taken with respect to wind speed direction and power output but related only to turbines CBW 1 to CBW 5.

For the three houses that have been used in the study the wind speed and power output for turbines CBW 6 to CBW 11 are not significant with respect to the test sites. This approach has been applied for the study for simplicity, although on a logarithmic basis the summation of noise output the additional turbines not included in the assessment is considered to be insignificant with respect to their overall noise impact at the three houses.

The outcome of the unattended noise monitoring for logger locations A to C, and D to E, show the obvious concept that on moving further away from the wind farm the turbine noise levels are reduced. The results reveal that in a general sense different wind directions impact upon the noise levels at the receiver locations and, as expected different wind strengths alter the measured noise levels.

The results for logger C highlight that for the use of a dB(A) measurement the noise generated by the wind farms starts to merge with the background level.

For loggers D and E the measurement results reveal that under a westerly wind condition the ambient background level does not closely follow the power generation of the wind farm to the same extent that occurs under a southerly condition.



Attendance to northern loggers and house 89 during the day, evening and night time periods revealed that there can be an audible impact from the surf to the west of the wind farm that provides masking of the wind farm noise. Under a southeast condition there is a similar masking at house 89 from the waves on the inner bay of Cape Bridgewater, although to a lower extent than that from the ocean with respect to a westerly wind condition.

This finding is considered significant in that unless adjustments are made for the ambient noise under different wind conditions any regression analysis with respect to house 89 would lead to an overestimate of the noise contribution from the wind farm.

From the pre-house measurement results a series of regression line analyses were determined for the different wind directions (as well as the average) and also considered the attenuation rate that may be applicable for those results.

Appendix H sets out a series of regression lines of the pre-test logger results where in the first instance there is consideration of all the data superimposed on the three sets of results for loggers A, B and C on one graph to show the similarity with the results. For logger location C there starts to be an issue of distance attenuation from the turbines and/or the influence of the ambient noise.



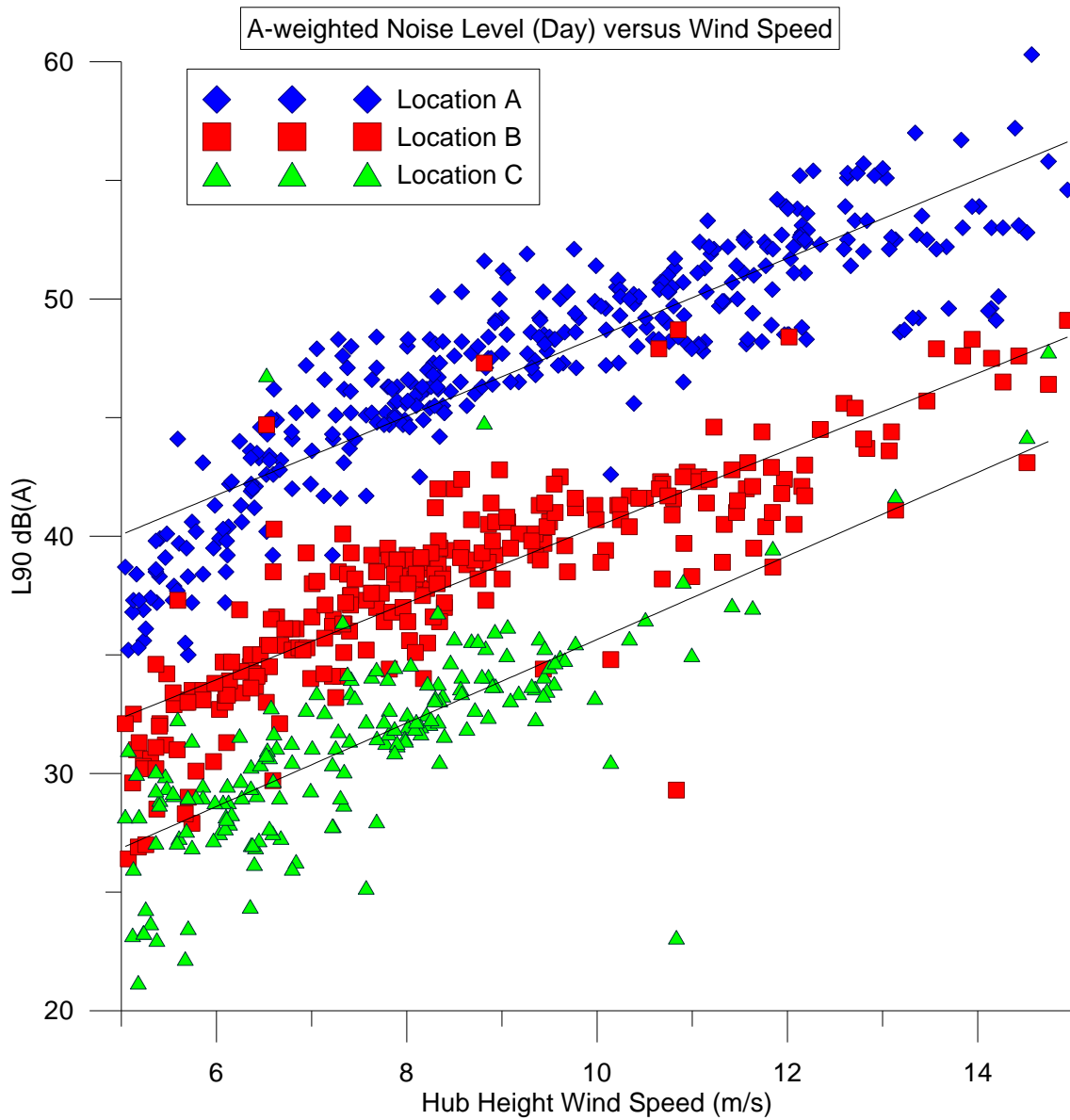


FIGURE 3: Regression for Pre Test Measurements Loggers A, B & C – Day time

On reviewing the data (limited as it is) different wind directions give rise to a slightly different regression line analysis curves.



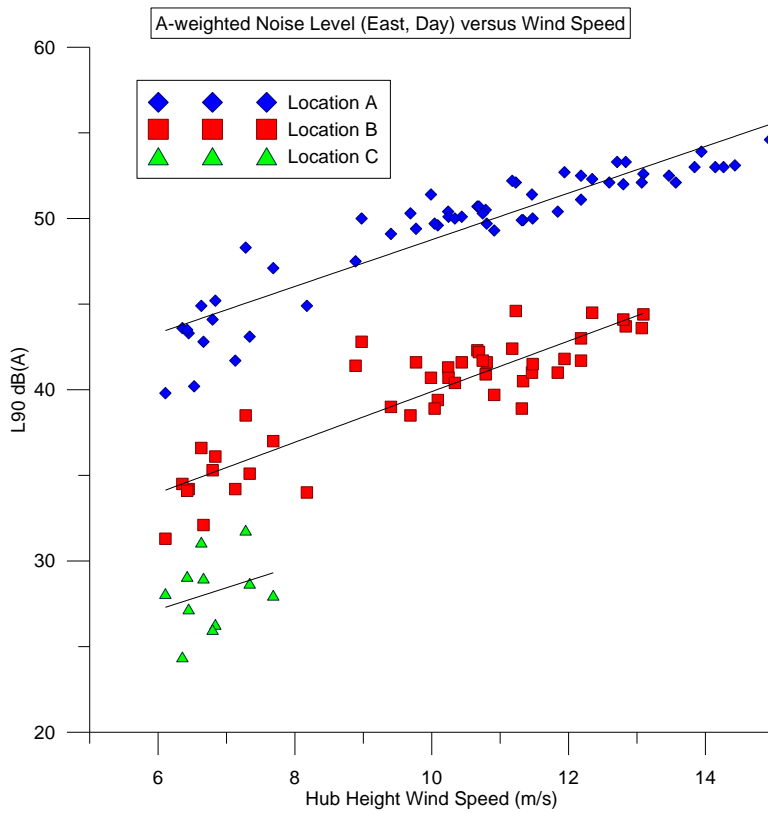
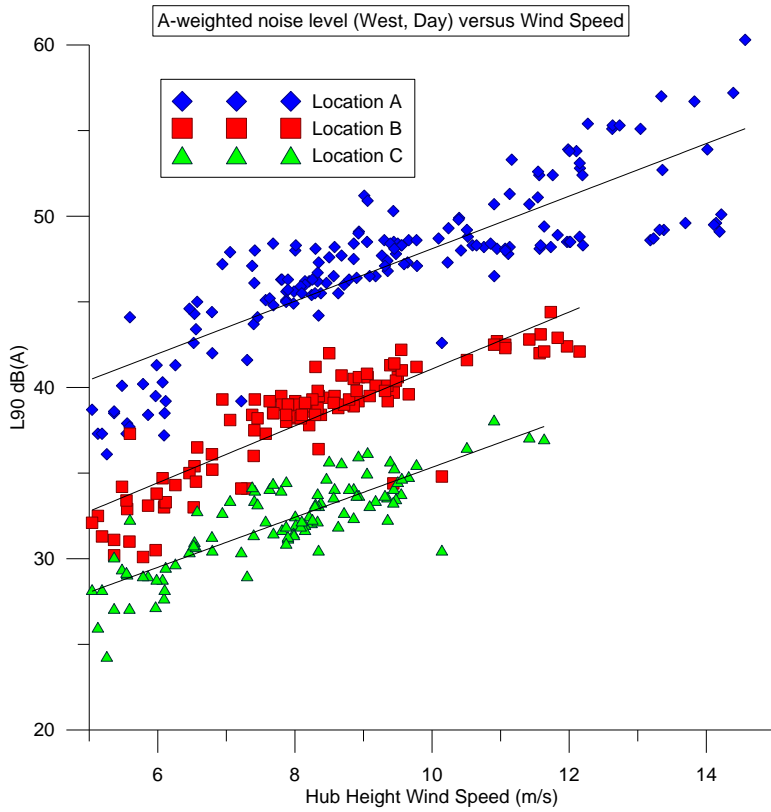


FIGURE 4: Regression Analysis Day time – East Wind versus West Wind

In seeking to determine attenuation rates over distance as a result of the different levels associated with wind speeds there was no clear or consistent result available from the regression analysis method. However by taking the regression lines and considering the range of results at individual wind speeds a rate of decay can be determined.

The influence of the wind at these sites affects the Leq levels. Plotting the A-weighted L90 results (being used in the current NZ Standard and the SA EPA Guidelines) with respect to the closest turbine (turbine CBW 15) to loggers A, B & C did not provide a linear response. The provision of two lines at 6 dB per doubling on the graphs is to provide a reference for the attenuation normally applied to audible noise.

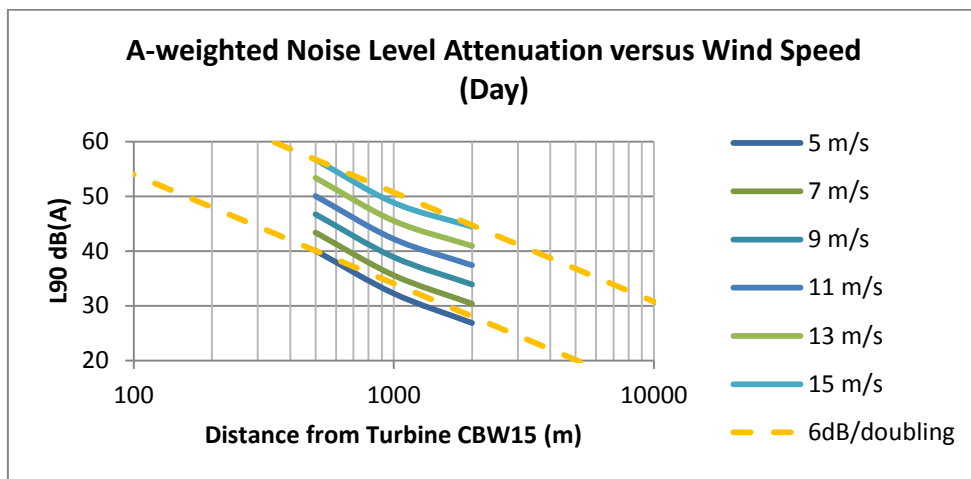


FIGURE 5: Pre Test Attenuation Loggers A, B & C - Day

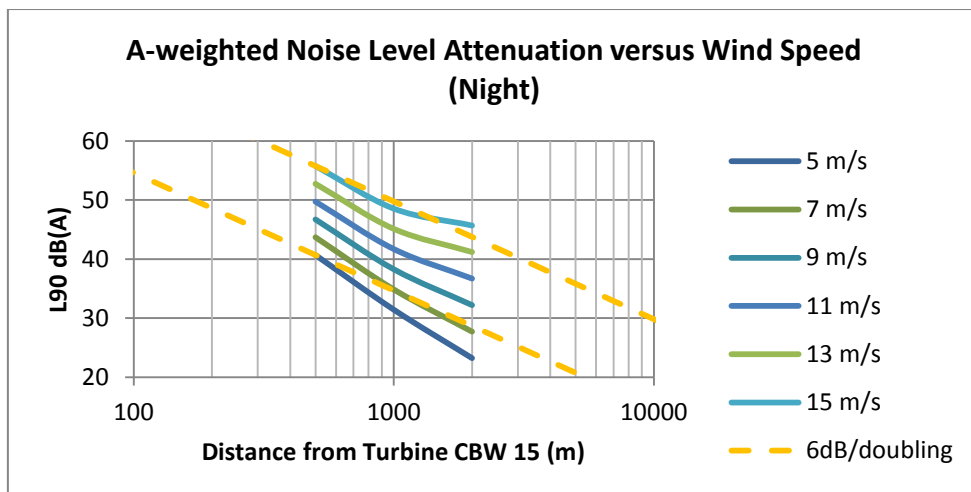


FIGURE 6: Pre Test Attenuation Loggers A, B & C - Night



If one considers logger A to be dominated by turbine CBW 15, that scenario cannot be applied to loggers B & C where the influence of turbines CBW 21, CBW 22 and CBW 27 (see Appendix A) would be expected to impact upon Logger B, with Logger C affected by additional turbines.

Utilising the diagram of the variation in the direction of the wind at each turbine (Figure 27) it would appear that the houses are dominated by a smaller number of turbines (say 4 or 5) with the remainder giving rise to a lower contribution if one considers the turbines as point sources. Considering 4 turbines to influence the pre-test loggers at the southern end of the wind farm moves the centre of the apparent noise source back 200 metres.

Considering a mean distance of the four turbines to Logger B suggested an increase of 200 metres for the source to receiver distance at Loggers B & C (“Modified Distances”) that provides on a dB(A) basis general agreement with the 6dB per doubling of distance although it is apparent that the influence of the wind for both an up wind and downwind situation can alter the shape of the propagation curves as one moves further out from the turbines.

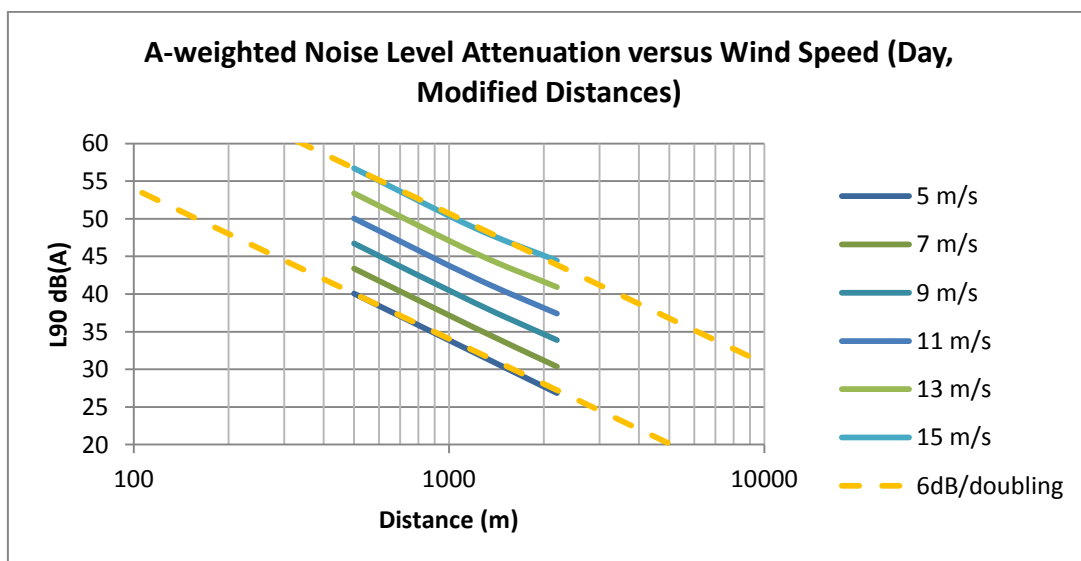


FIGURE 7: Pre Test Attenuation Loggers A, B & C - Day (modified distances)



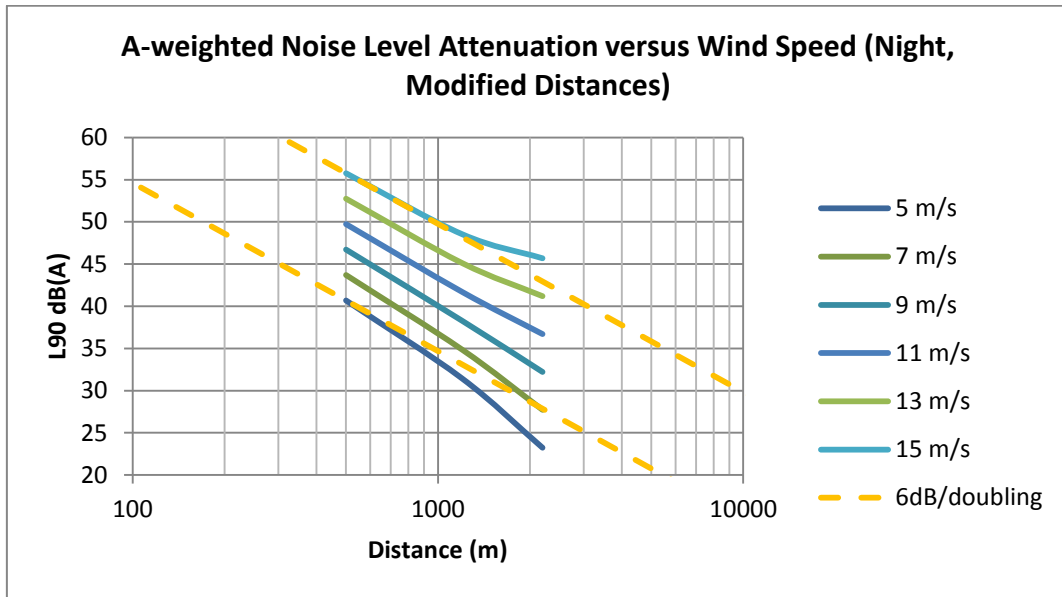


FIGURE 8: Pre Test Attenuation Loggers A, B & C – Night (Modified distances)

Such a variation in terms of propagation is typical for normal industrial noise assessments.

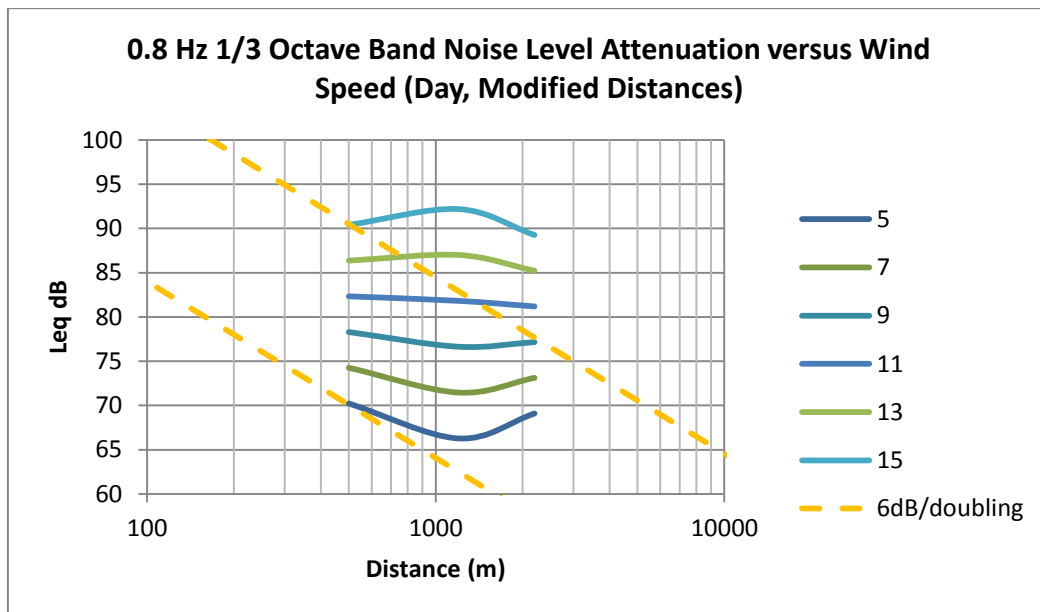


FIGURE 9: Pre Test Attenuation @ 0.8Hz, Loggers A, B & C – Day (modified distances)



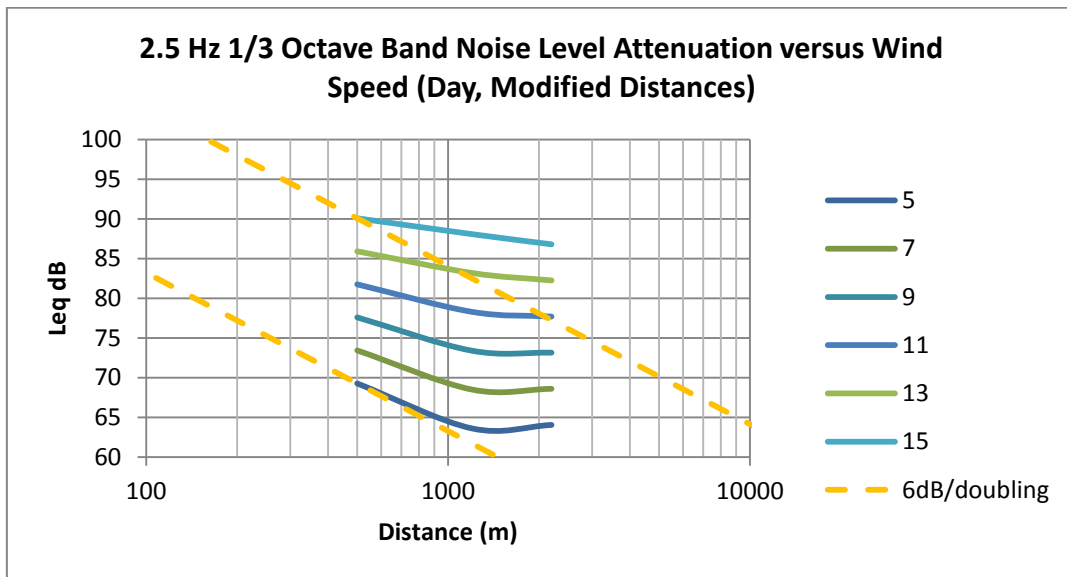


FIGURE 10: Pre Test Attenuation @ 2.5Hz, Loggers A, B & C – Day (modified distances)

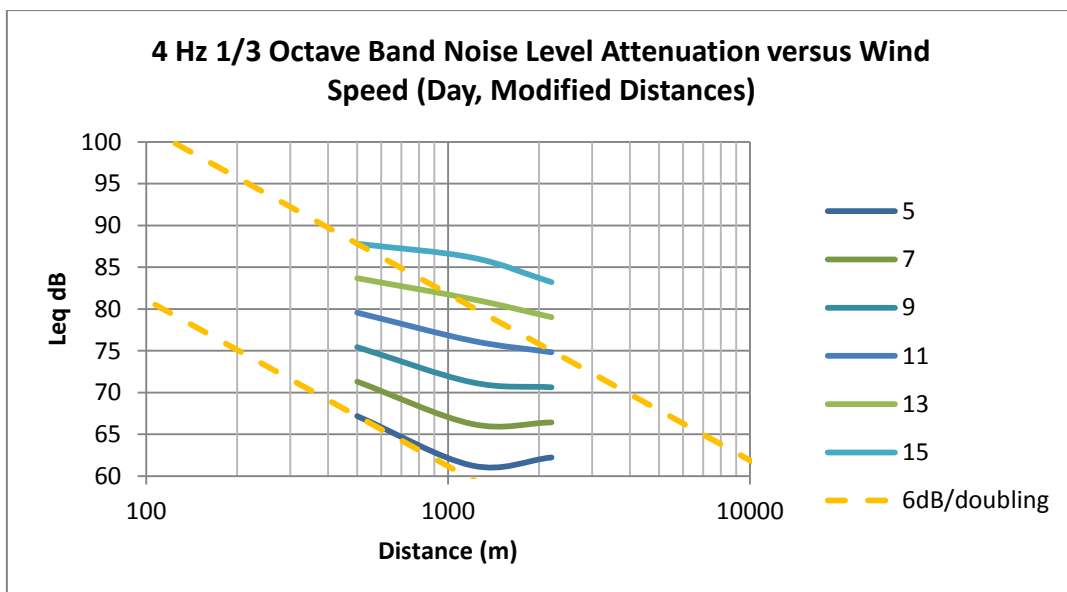


FIGURE 11: Pre Test Attenuation @ 4Hz, Loggers A, B & C – Day (modified distances)

With respect to the rate of decay for infrasound components a similar assessment shows a lower rate of attenuation. This is similar to work undertaken by NASA on a single turbine identified as MOD 2 [13].



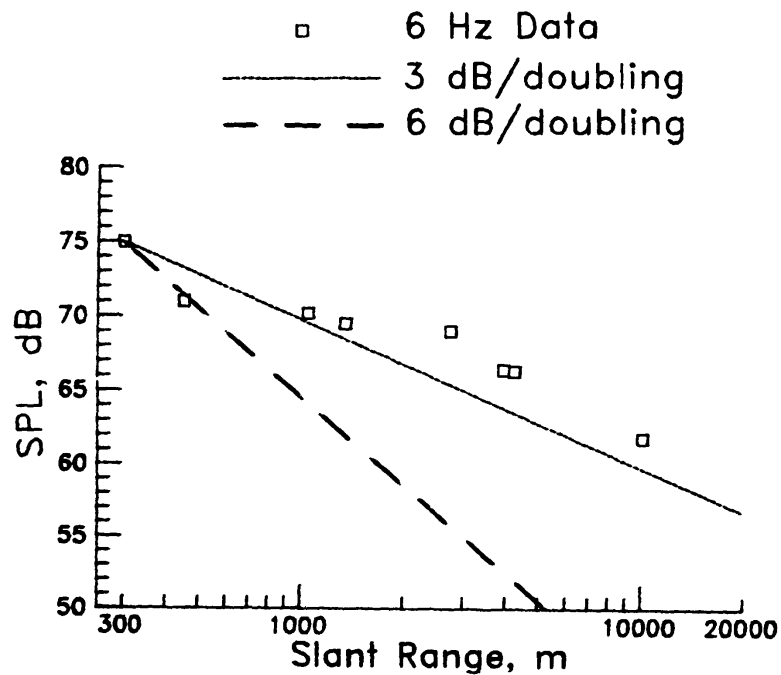


FIGURE 12: NASA Attenuation @ 6.Hz

The above results identify that the rate of attenuation for infrasound is lower than the nominal 6 dB/doubling of distance assigned to audible noise.

It would therefore appear, as has been conducted for other studies, that any attenuation assessment in relation to turbines (if carrying out a similar exercise to that described above) **should if possible be undertaken on an individual turbine** rather than that of a wind farm in that the propagation from multiple turbines will be different to that from a single turbine by way of different configuration in terms of noise source and/or interaction (both combination and cancellation) that may occur from multiple turbines.

If one is using a wind farm to determine low frequency propagation then the monitoring locations must be significantly removed to provide an assessment in the far field that is not influenced by the interaction of different turbines.

The monitoring for logger D and E was continued for a longer period of time than that for the three loggers at the southern end of the wind farm, by reason of access across the paddock was difficult after a number of days of heavy rain.



The pre-house testing conducted at the two logger locations D and E are to the north of the wind farm and found generally a similar degree of attenuation from the grouping of the five turbines in the northern section of the wind farm.

Utilising the methodology of plotting the variation in the A-weighted noise level (10 minute samples) throughout the day versus the power output of the turbines at the northern end of the wind farm, together with the wind speed and direction, generally identifies a change in the background level as the wind farm power increases.

As identified above, with respect to the monitoring for logger D and E the results show that this is not necessarily the case, particularly when there is a prevailing westerly wind,

The comparison of the ambient background level with the turbines operating and not operating for the same wind strength, reveals that at times when the turbines are not operating the ambient background level is higher than when operating. This indicates that the measurements of the northern end of the site are influenced by another source that is affecting the results independent of the turbines.

For example Appendix G30 provides the results for logger location E being the most northern location for Thursday 1st May and Appendix G31 for the same location on Friday 2nd May 2014 (reproduced below).



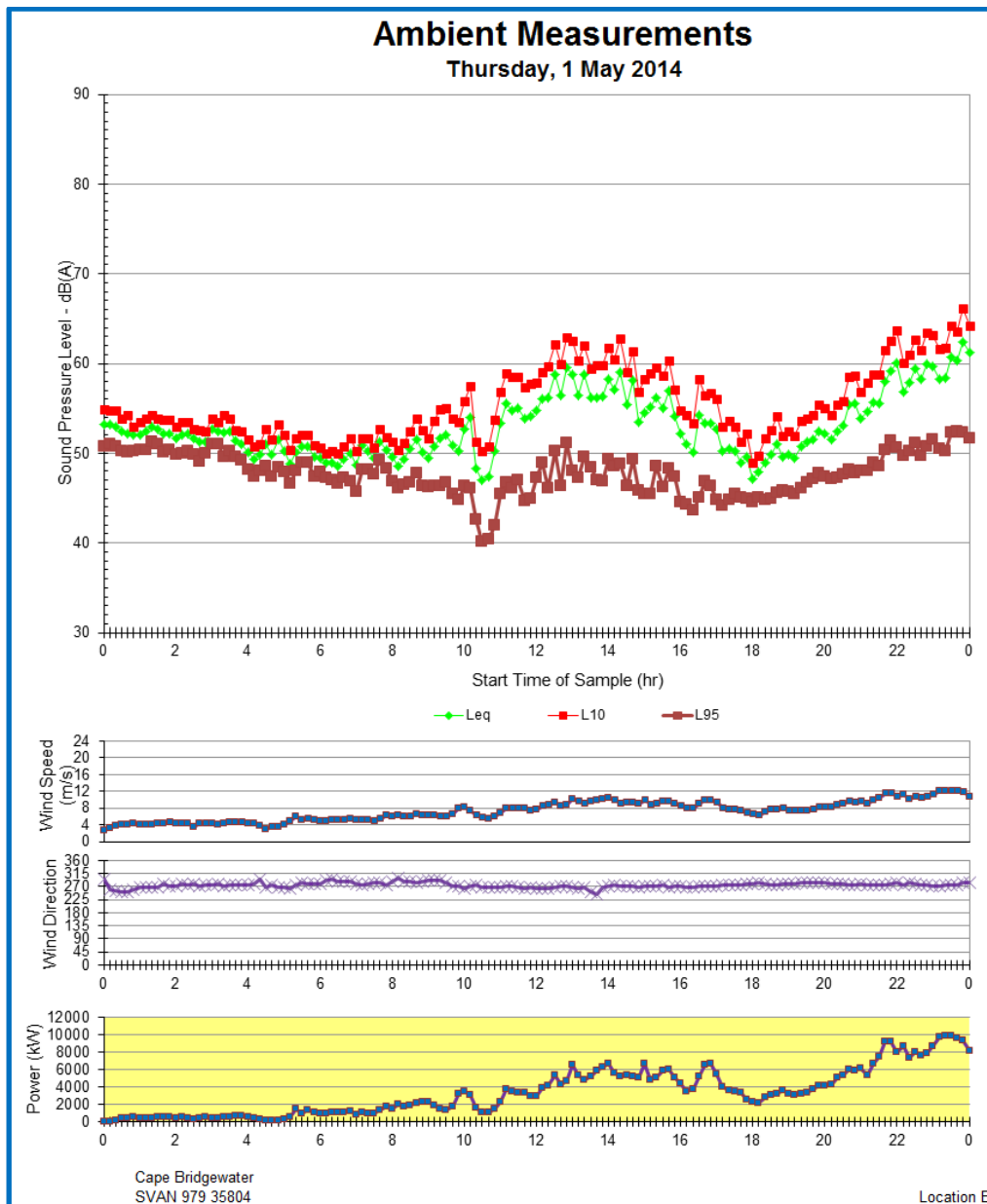


FIGURE 13: External A-weighted levels Pre Test Logger E

In the early hours of 1st May the turbines do not have sufficient wind to produce electricity, if one uses 5 m/s as the cut-in speed. However under a light westerly wind the background level is around 50 dB(A). After 4am the wind increases slightly and the background level decreases. In the day the wind increased slightly and the background starts to increase but remains generally below 50 dB(A). It is in the evening/night period that the power increases as does the background level.



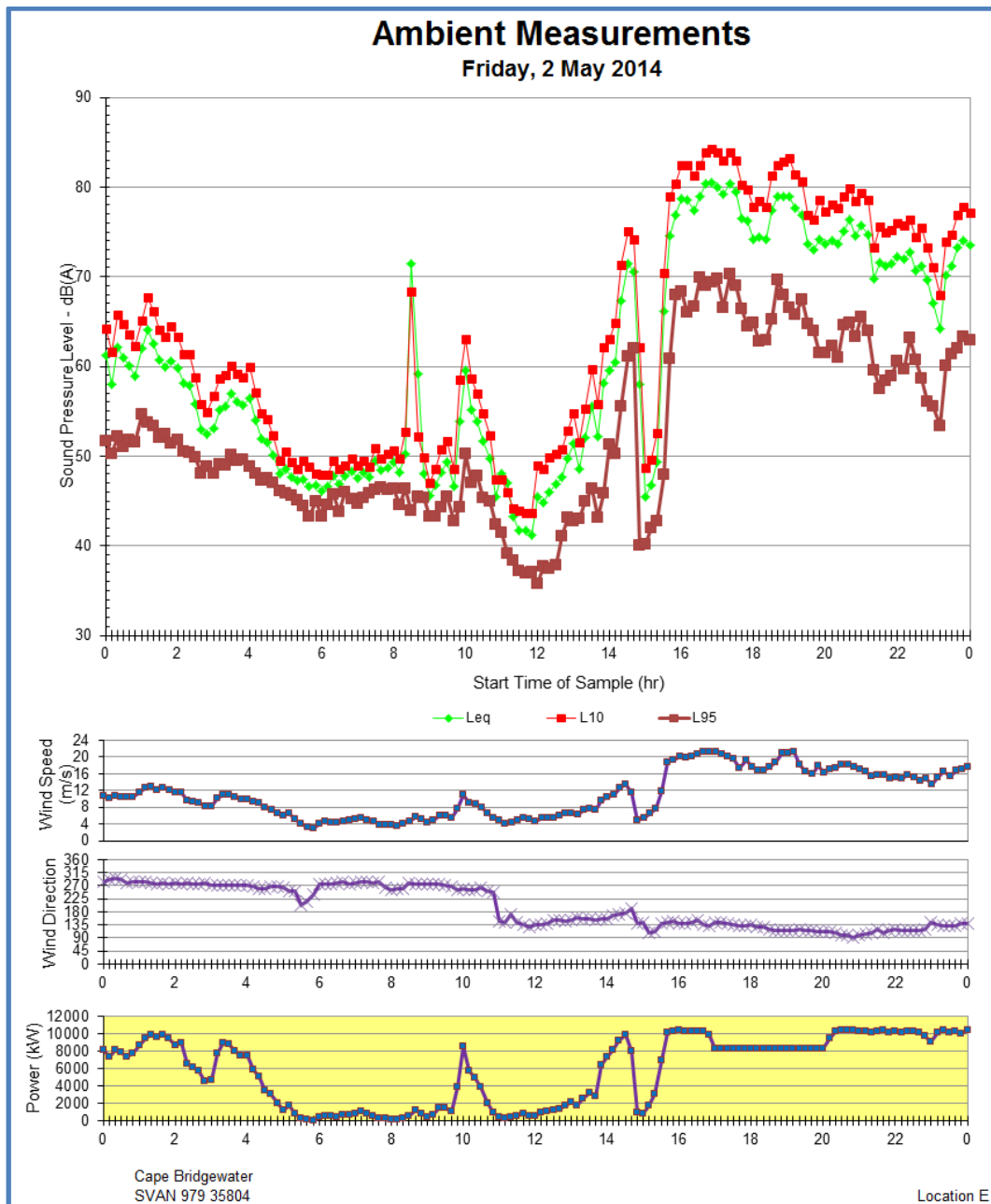


FIGURE 14: External A-weighted levels – Pre Test Logger E

In the early hours of the morning for 2nd May the turbines are operating at a moderate output under a westerly wind and the background being above 50 dB(A) follows the power output. At 6am the wind drops (still from the west) and the ambient background falls to below 46 dB(A). In the afternoon the high background levels are not from the wind but the heavy rain storms that prevailed for the rest of the day.



The pattern that occurs under a westerly wind also occurs under a south-easterly wind which was confirmed by attended site visits to the loggers to be noise coming from the ocean to the west (under a westerly wind condition) and from Cape Bridgewater Bay (for a south-easterly wind) that was verified by TAG on numerous occasions when attending house 89.

The most important aspect from the pre-house testing at the northern section of the wind farm was identification that for the monitoring at house 89 it was necessary during the attended monitoring to take note of what was causing the ambient noise level so as to place such noise levels in the correct context.



6.0 HOUSE NOISE TESTING

(Steps 2-3 in Figure 2)

The majority of the data associated with the study utilised unattended noise loggers at the residential dwellings (both inside and outside) to be correlated with the diary observations during the monitoring period.

Following the pre-house tests, noise loggers were located externally to each of the three dwellings with locations varying between 7m and 25 m that is shown in the photos set out in Appendix F.

The internal noise logger in each house was set up in a bedroom. At the commencement of the monitoring an additional logger was located in the living room of house 87.

As noted in this report a number of issues occurred with respect to instrumentation such that the living room logger at house 88 was removed from that location and substituted for the external noise logger at house 88, after it had been found that the logger had ceased to function.

In general terms for the compliance testing of wind farms the emphasis has been on locations external to the dwelling, on the assumption that there is a 10 dB(A) attenuation from outside and inside to utilise an external measurement for assessment of sleep disturbance being the nominated 30 dB(A) internal level.

Due to building elements having an attenuation at low-frequencies much lower than that of high frequencies, the external spectra from outside a dwelling changes in its spectral shape when measured inside a dwelling, such that where there is a broadband noise outside then inside the dwelling the noise becomes predominantly a low-frequency noise by the elimination of mid and high frequency components.

The relevance of the difference of a dB(A) level outside versus a dB(A) level inside for wind farm assessments is questioned because of the nature of the change in the spectrum and the resultant internal spectrum. The internal spectra as a result of wind farms, is not the same as road traffic noise, that would appear to be the source of the majority of the investigations leading to the WHO internal noise level guideline [8], upon which the NZ wind farm Standard [2] was based.



As the majority of complaints relate to noise disturbance that occurs inside the houses then the use of an external noise monitoring location (as recommended in the NZ Standard) for assessment purposes must take into account the above matters (concerning differences in the attenuation across frequency bands) rather than a reduction of 10 dB(A). To resolve the complaints required noise loggers to be located inside the dwellings.

With the availability of simultaneous external and internal measurements one can evaluate the attenuation of the building over a long-term statistical basis and also examine whether the typical concept of 10 dB(A) attenuation is valid as an A-weighted level across a frequency spectrum.

Dickinson [14] carried out a similar exercise and indicated the attenuation in the low-frequency sound region is lower than 10 dB for an open window situation.

With the intent of the study to ascertain where possible if standard instrumentation can be used for such an exercise, the analysis in the first instance looked at the A-weighted level on a statistical basis using 10 minute samples, where the L95, the Leq and the L10 levels were extracted directly from the logger results.

After the A-weighted assessment the next step is to consider the 1/3 octave band results from the loggers. The purpose of obtaining the 1/3 octave band results was to apply different frequency adjustments to obtain the various weighting curves that are available in environmental acoustics and ascertain if there was a correlation with the residents observations. As the assessment is related to noise emission from the turbines, the parameter obtained by the logging method in 1/3 octave bands is a Leq level.

As discussed in Chapter 10 “Measurement Uncertainty” it was after the monitoring and the analysis was underway that it was established the newer loggers (SVAN 979) used for the internal monitoring had their 1/3 octave band spectra set on Z-weighting that provided a non-linear result, whereas the external loggers (SVAN 957) provided Linear results, contrary to the manufacturer’s manual [15] [16].

The preliminary results presented to the Cape Bridgewater Community Consultative Committee was on the basis of the results obtained from the loggers which did not have the correct weighting for the critical infrasound components.



Using the TAG methodology adopted for wind farm assessments involves plotting the 10 minute variation in the A-weighted results throughout a 24 hour period but at the same time providing the wind speed, wind direction and power output of the turbine. This method provides a mechanism to identify the correlation between the operation of the wind farm and the noise levels measured under different power outputs and different wind speeds and directions.

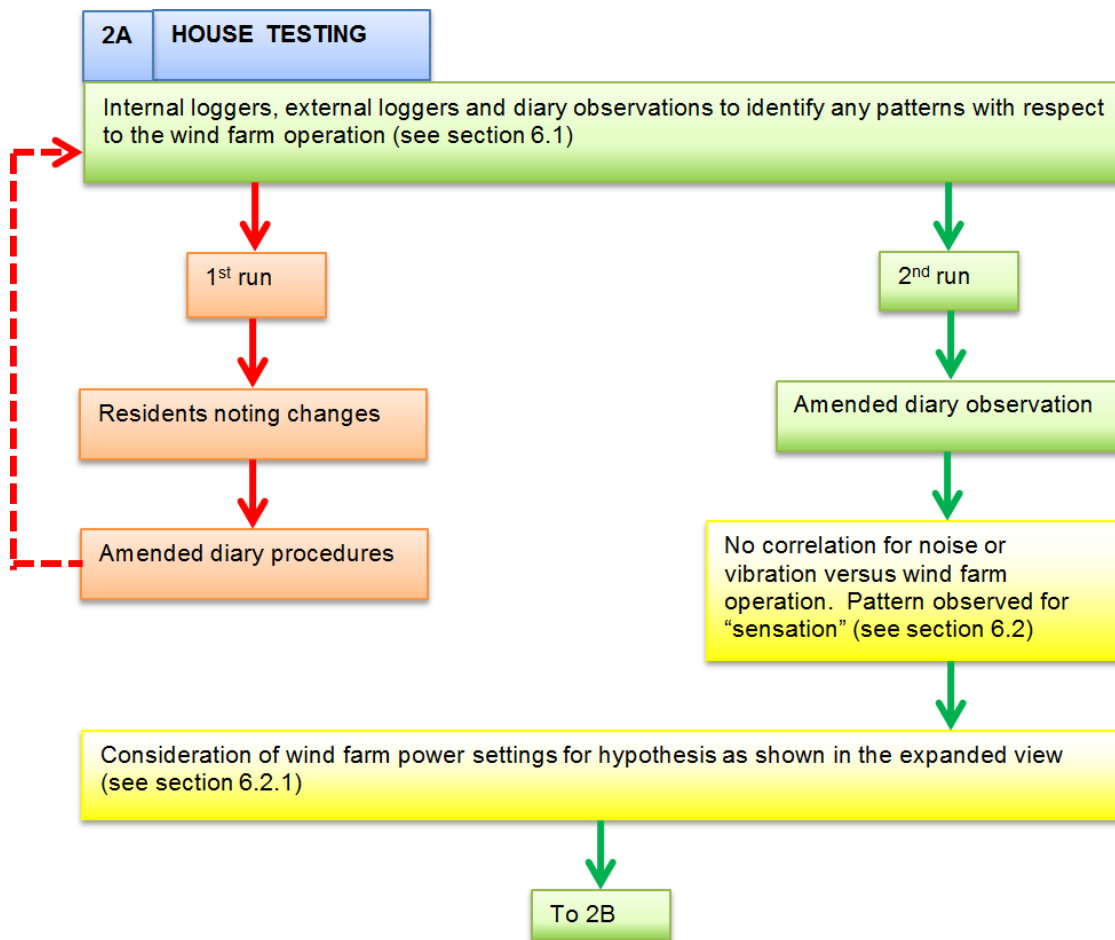
The TAG methodology has been used to identify the variation in wind farm noise (see Figures 14 & 15) and is of assistance in understanding the variation in noise throughout the day which cannot be obtained by use of the regression analysis method.

The monitoring commenced with loggers inside and outside the three houses. During the course of the monitoring there were a number of instrumentation issues. There were both instrumentation and USB problems leading to a loss of data. An issue of microphones unscrewing themselves inside enclosures occurred, as a result of the high levels of wind that continuously vibrated the supporting structure, which has never been observed on any other monitoring that the principal of TAG has conducted over 35 years of testing. That in itself is a unique phenomenon attributed to the study.

6.1 Preliminary Analysis and Observations

Step 2A shown below (of figure 2) relates to the first phase of the House Noise Testing as discussed in Sections 6.1 and 6.2.





The first analysis looked at the A-weighted level versus the power output information for the wind farm and then reviewed those results with respect to the resident's observations.

Utilising the severity scaling method and the classifications of noise, vibration and sensation (as described earlier) from the diaries required the development of a tool that would show the results of those observations versus the measurement results.

After a trial of different presentations the concept of using coloured arrows was derived (where blue is noise, green is vibration, red is sensation) that could be superimposed on the measurement charts with the level of sensation placed inside the arrow. The transfer of the data to provide such a visual representation is time-consuming because the arrows should not obscure the measured levels.



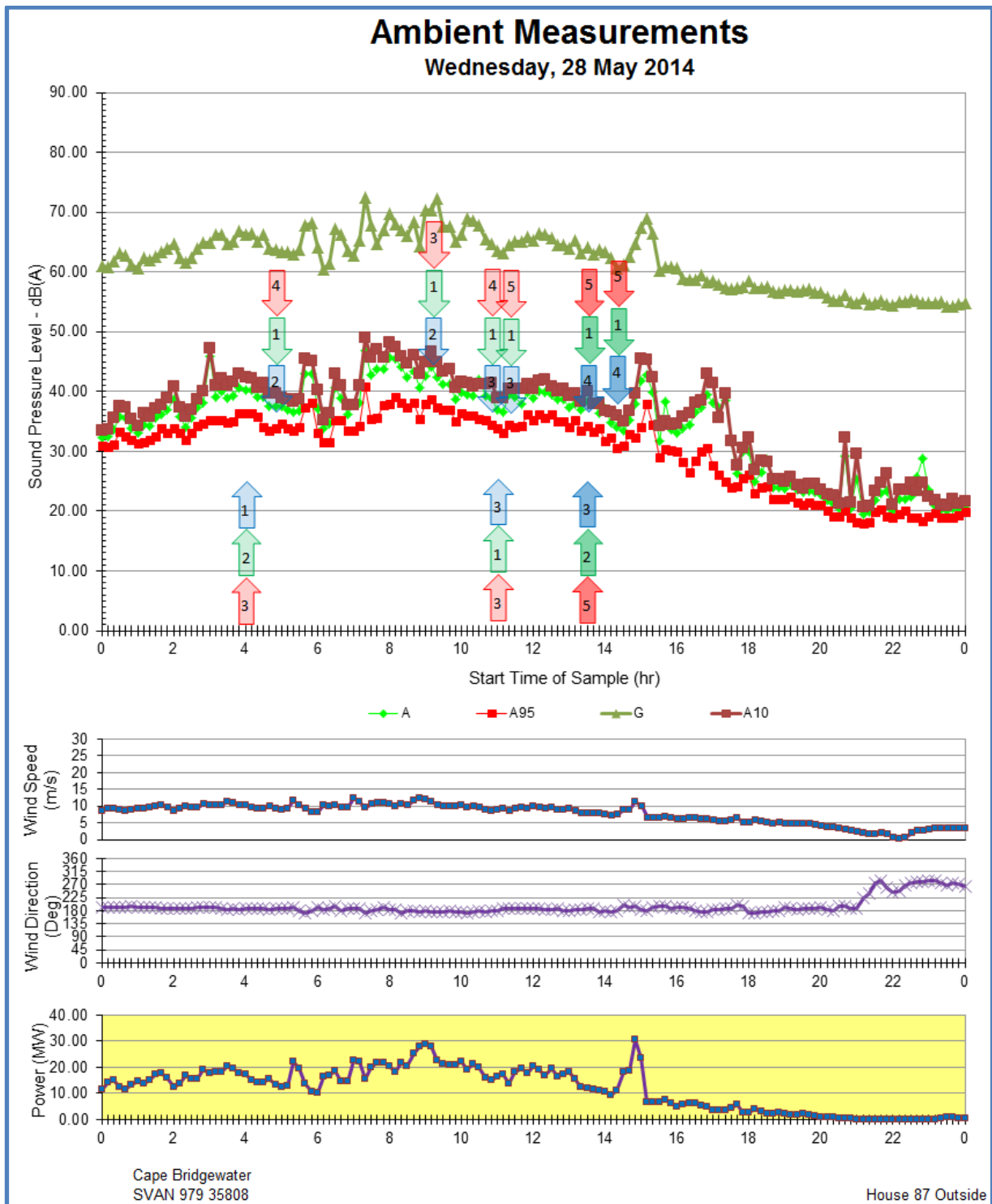


FIGURE 15: House 87 External Measurements: blue – noise, green – vibration and red - sensation



In viewing the diary observations and the relevant noise levels the procedure is to compare those results with the wind farm power output curve (highlighted by yellow background above) to identify any patterns.

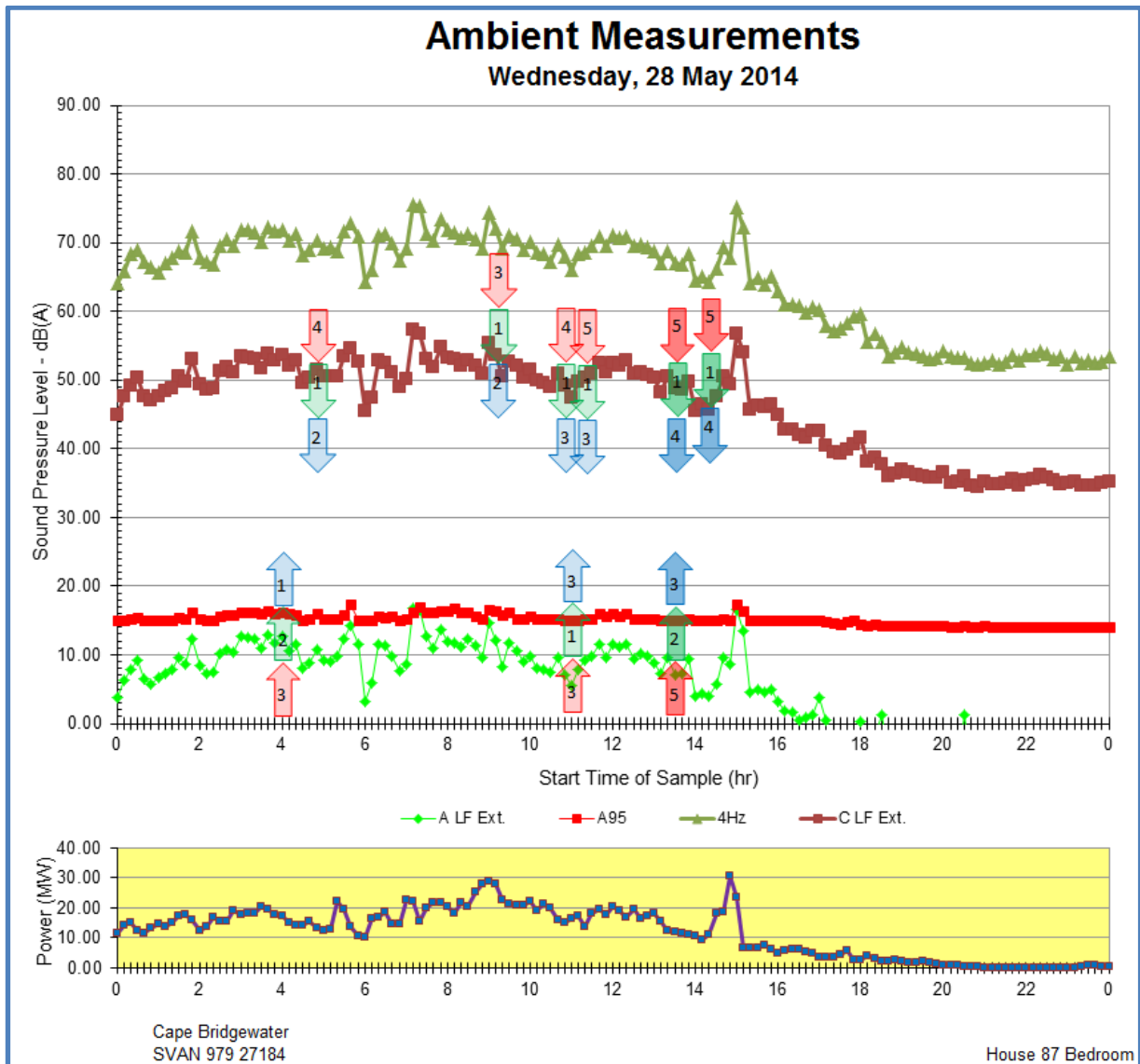


FIGURE 16: House 87 Internal Measurements: blue - noise, green - vibration and red - sensation



The initial analysis found that inside houses the measured levels were typically hitting the noise floor of the sound level meter. On an A-weighted basis the internal environments of those houses are very quiet, which is to be expected from the nature of the external noise levels that are relatively low.

6.1.1 Residents' diary observations

Utilising the initial results for plotting the sensation versus the operation of the wind farm over the first two weeks revealed patterns that showed changes in the wind farm power level had no obvious correlation in terms of noise or vibration.

Examination of the residents' observations in terms of the A-weighted measurements and the power output of the wind farm found that the diary observations appeared to be related to changes in the wind farm.

It was considered the reporting by the residents was only of changes and not what was occurring on a regular (or continuous basis) whilst carrying out their daily duties.

On the first attendance to download data and review the material with the residents (on an individual basis) it became apparent that the residents were unaware that their reporting was only due to changes that they perceived as a result of the turbine operations. This reporting was an unconscious methodology in that the residents indicated they were used to experiencing unpleasant symptoms or impacts from the turbine that in the filling out of the diary it was only the changes that they noted.

On explaining to the residents that the purpose of the diary was to provide regular reporting of the impacts (not necessarily just changes), so as to identify the status of their environment which could then identify any changes in the severity versus the operation of the wind farm based upon the diary observations.

On discussing the issue with each of the residents it was found that they had been documenting changes. As a result the diary methodology was modified so as to have regular observations (throughout the period of observations where possible).



The use of the diary observation is relevant in that the concept from the outset was **not to take** the noise levels and then provide a correlation of the noise levels with the diary observations. The approach was to **start with the diary observations** and then look to see if there was any correlation with the measurement data.

Hence the use of the visual concept of arrows and sensations overlaid on the data, rather than a statistical analysis of the severity ranking and the data, particularly as it was unknown as to what parameters would be applicable, which is why in the first instance the analysis started with the dB(A) level being the parameter used in the wind farm guidelines.

6.1.2 Shutdowns

At the end of the second week of the test program the wind farm commenced a shutdown for extended periods of time on a daily basis that was associated with high voltage cabling occurring at another site requiring isolation of the high-voltage network that in turn resulted in a total shutdown of both the Cape Bridgewater Wind Farm and the Cape Nelson Wind Farm.

Monitoring during the shutdown period was considered of significant benefit to the study in that it permitted the opportunity to obtain noise data of the natural environment under various wind conditions, which would not be available during normal operations because of the operation of the turbines.

The shutdown occurred on a daily basis for 10 to 12 hours and involved the physical disconnection of all power to the turbines so that not even the ventilation equipment, internal computers, or the turbine anemometers were operating. It was subsequently found that, the turbine instrumentation was powered by a UPS and therefore would record some data after the shutdown.

For the purpose of the evaluation of the noise levels at the residential dwellings, the absence of wind information for the turbines or even the wind masts (due to there being been no power) presented a challenge in utilising the noise data during the shutdown for the intended purpose of evaluating the ambient background under different wind conditions.



Wind data that is available from the wind loggers that were stationed at each microphone and the 10 metre high wind logger at house 87, provided wind speed and direction during the shutdown at those locations. It is noted that those locations are at a significantly different elevation to that of the hub height of the turbines, upon which the general regression analysis is based.

6.1.3 Wind data during shutdown

For the periods when the wind farm was shut down weather data was obtained from the Bureau of Meteorology weather stations at Portland Airport and Cape Nelson. Whilst the two meteorology sites are not at the Cape Bridgewater Wind Farm, they are in relatively close proximity to the wind farm to provide an indication to the weather at the time. During the shutdown period the noise logger charts, show the different wind data by a change in colour.

In seeking to use the external meteorological data, it was ascertained that there are problems with the wind direction at Cape Nelson Lighthouse, particularly when compared with the wind data that is available for the Cape Nelson Wind Farm, which has shown to provide on a consistent basis a steady wind value whilst the Lighthouse data is questionable.

The difference in wind strength is also influenced by the location of the Lighthouse on the eastern side of Bridgewater Bay which is exposed to wind directly off the sea in comparison to the location of the subject turbines located on the western side of Bridgewater Bay and set back from the ocean leading to ground effects and topography.

It is noted that the Bureau of Meteorology wind anemometer is located at 10m above ground whereas the turbine anemometers are above the turbine that has a nominal hub height in the order of 70 metres above ground.

On conducting a regression analysis to compare the wind speed data from the anemometers of CBW 1 – 5 to the wind speed at the meteorology stations, it is observed that the wind speed data from the Cape Nelson Lighthouse is more similar to the wind turbine anemometers than Portland Airport.

Figure 17 reveals a linear relationship can be established for the Cape Nelson wind speed to the hub height wind speed.



Utilising the data for Portland Airport (which is further inland) was found to be inconsistent with that recorded on the wind farm. That data has not been used.

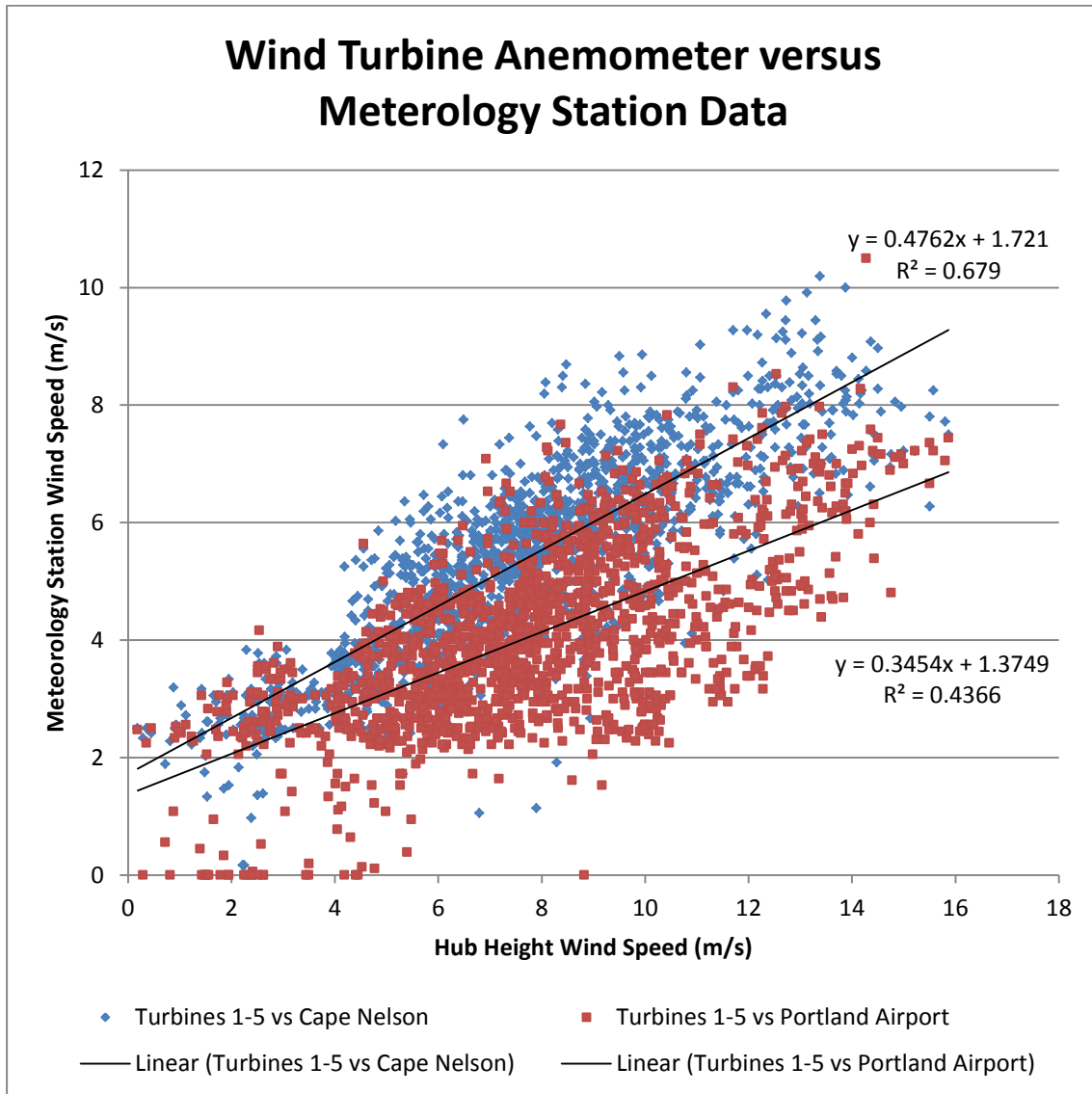


Figure 17: Regression to compare wind turbine data to Bureau of Meteorology data

By utilising the elevated wind anemometer outside house 87 and comparing those results with the turbine wind strength for the southern group of turbines revealed a general factor of 1.76 times the house 87 value approximated the wind level of the turbine at the beginning and end of each shutdown.



On the logger graphs the Cape Nelson wind strength (in blue) and the adjusted house 87 elevated wind anemometer (in red) are shown for the missing turbine wind data.

6.2 A-weighted Level Versus the Wind Farm Data

The resident's observations during the shutdown periods identify there was no appreciable impact in terms of noise, vibration or sensation inside the dwellings or the external yard area. However, it is noted that one of the residents who has a heightened sensitivity, due to a hearing impairment, could still identify disturbance issues in the dwelling during shutdown periods. The nature of the diary observations from that resident indicates the character of the disturbance is different but there are still issues of pulsations in vibration through the building and presence of other noises in the dwelling that occurred during the shutdown period (see Section 6.5).

Attendance to the dwelling (by TAG) during the shutdown period experienced vibration in the kitchen floor of house 88 that could be described as a travelling wave or a pulse. Turning off the refrigerator in the kitchen caused a change in some noise levels and vibration in the dwelling. The shaking of the building and the travelling pulse were issues that were identified by the resident as occurring at the time. The resident expressed concern about the level of heightened sensitivity that was experienced even during a shutdown.

The issue of the intermittent vibration through the ground was later the subject of a vibration measurements external to the dwelling (and on the wind farm) and would be appear to be subject to wind gusts that were evident at the turbines by way of a significant intermittent increase in vibration measured in the ground and on the tower.

As the permit conditions [1] are expressed in an A-weighted level, in the first instance plots were derived for each of the individual houses on a daily basis showing the resident's observations versus the external level of noise, observations versus the internal level of noise, with the wind speed/direction and the wind farm output.



As there have been two formats for the diary observations the graphical presentations have been separated with Appendix I providing the observations versus the A-weighted levels when the residents were just noticing changes. The analysis of the data in the first pass involved comparing the A-weighted levels versus the observations AND at the same time versus the wind farm power output, by visually viewing the graphs, i.e. the method of visually examining the various plots is to view the resident's observations (the coloured arrows superimposed on the graphs) in terms of the different noise levels and also in terms of the wind data and the power output of the relevant section of the wind farm at the same time.

Commencing with house 87 the results in Appendices I1 – I22 show the external location, the living room, the bedroom with the power output for turbines CBW 12 – CBW 29.

Appendices I23 – I36 show the external location, the bedroom for house 88 with the power output for turbines CBW 12 – CBW 29.

Appendices I37 – I48 show the external location, the bedroom with the power output for turbines CBW 1 – CBW 5.

In the first form of diary observations (i.e. of changes rather than regular observations) it can be seen from the graphs that the difference between the outside and inside is significant in terms of the A-weighted level. For the majority of time the internal locations, on an A-weighted basis, are sitting on the noise floor of the meter.

The diary observations relate to the occupation of the internal areas of the house and do not have any relevance to the external measurements upon which the normal method of wind farm compliance is undertaken.

The amended diary observations in Appendices J, K & L, that covered the majority of the monitoring period, show observations in terms of the internal locations with the wind speed, wind direction and power. There is a corresponding material (for the majority the time) for the external locations that have not been presented due to the amount of available data.

Appendices J, K & L provide the results for houses 87, 88 & 89 respectively.



On an A-weighted basis and taking into account the observations of the residents the major component that is attributed to the observations that have a high severity rating is that of sensation. The perception of noise and vibration occurs significantly less than that of sensation.

One of the residents at house 88 is more sensitive than the other people in that that individual (who has a hearing impairment) has a greater tactile sensitivity and appears to have a greater degree of sensitivity to noise and vibration. The perception of noise to a hearing-impaired person that uses hearing aids involves a different frequency spectrum to that of normal hearing. The acute perception of vibration by this occupant has presented a number of challenges in the investigations at that dwelling.

Similarly, one of the residents at house 87 has a hearing impairment and during the instrumentation setup was found to have a high sensitivity to the detection of the hum from a power supply that could be detected in another room. This required the power supply to be installed in a road case to attenuate the hum and indicates a greater bias to low frequency noise to that for normal hearing.

6.2.1 High Sensation Sensitivity

On reviewing the data based upon the residents observations, and the wind data and the power data provided from the turbines using the same methodology as described for the pre-testing found that the high rankings of sensation were related to four operating scenarios of the wind farm identified as:

- when the wind farm is seeking to start, which as a general concept is around a wind speed of 5 m/s (identified as the cut-in speed) which include turbines turning but not generating power and turbines not turning.
- where the wind farm exhibits a change in its power level in the order of 20%. This would occur when the wind is increasing its speed and as a consequence so will be output of the wind farm.
- a change in the 20% concept of power, on a decreasing wind speed.
- at a wind speed that is above the maximum rating for the turbines where the turbine blades are oriented so as to de-power the turbine.



The hypothesis derived from looking at those four scenarios, being based on just the power output of the wind farm and the diary observations (i.e. not the noise results) from the perspective of acoustic engineers not wind turbine engineers, suggested on the basis of first principles the possibility of instability across the blades in that they were not aligned to have the most efficient air flow across the blade.

When this concept was discussed with the wind farm manager it was identified that for different wind speeds the turbine blades are able to adjust the pitch of the blade (angle to the wind) so as to maintain the most efficient air flow across the blades for the purpose of generating power. When the wind strength is greater than the maximum capacity of the turbine the blades are angled so as to de-power the turbine and therefore would not be positioned at an efficient angle of attack to the wind. The concept of turbulence being generated by the blades not being aligned at their most efficient manner was considered as a method of describing the possible generation of an adverse sensation.

On that same basis it was considered that when the turbine is seeking to start then the blades would not be in the most efficient angle (pitch) for airflow across a blade. Similarly, where the wind is changing in speed then the blades could also be in a similar inefficient operation. If the turbine was starting to turn but did not have a steady wind the force to turn the blades would alter. A possible layman's explanation is that the blades had not overcome their inertia to have sufficient momentum to keep operating.

Crude as the above scenario may be for persons trained in blade analysis the hypothesis was considered to be a possible description of the problem experienced by the residents.

Figure 18 provides the results for house 88 when the residents were present and indicated high sensation for both noise and sensation. The wind farm power output graph is highlighted to identify the hypothesis that has been proposed. The small graph at the bottom of Figure 17 is an exploded view of the wind and power variation between 11am and midday.

Figure 19 provides a graph for house 88 where the resident identified high sensations for an upwind situation and very low power. The two small graphs below the figure are exploded views of the wind speed and power out between 5 AM and 7AM, and between 8AM and 11AM that reveal substantial variation but at low power outputs.



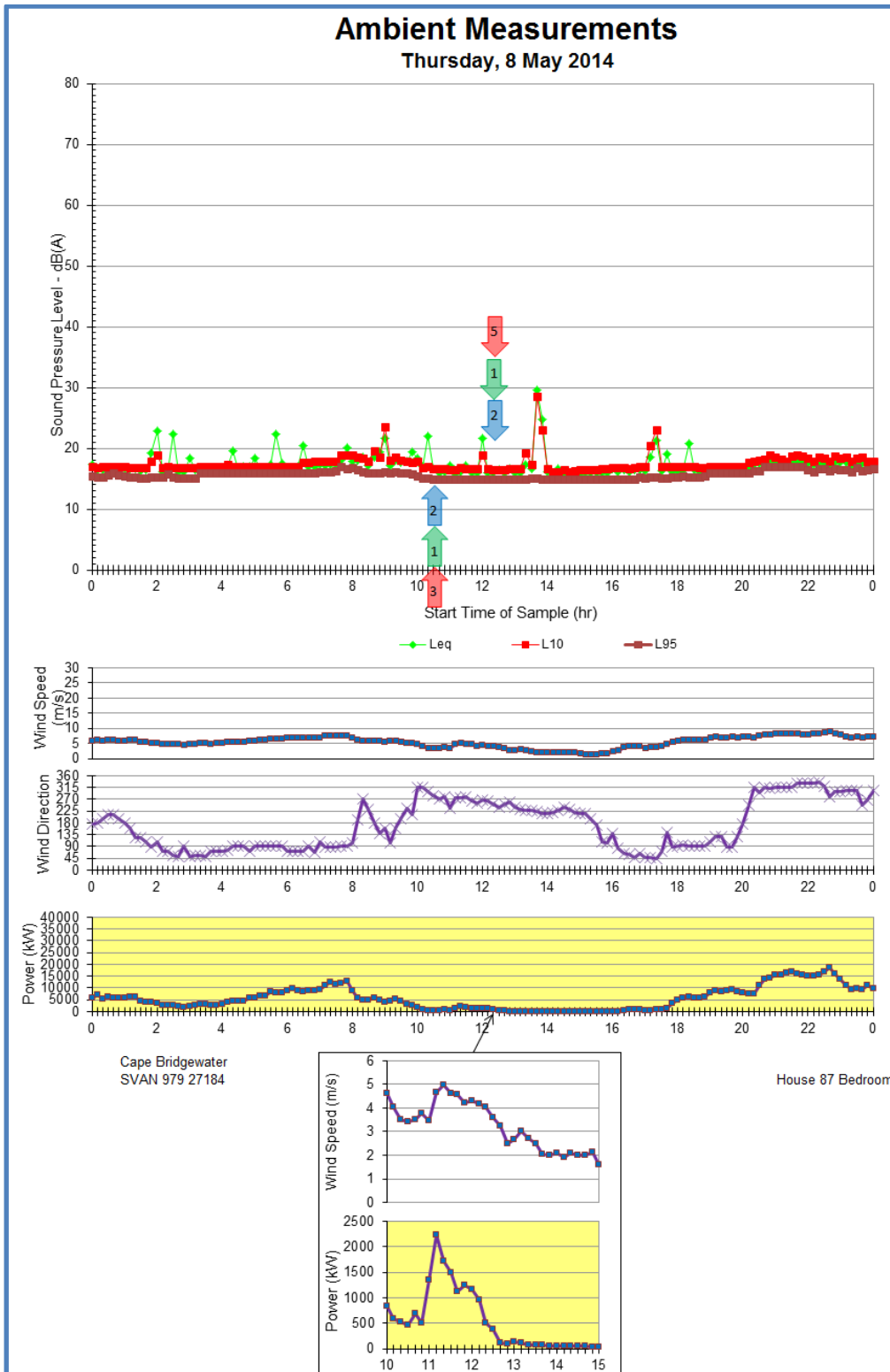


FIGURE 18: Internal Measurements (House 87): blue - noise, green - vibration and red - sensation



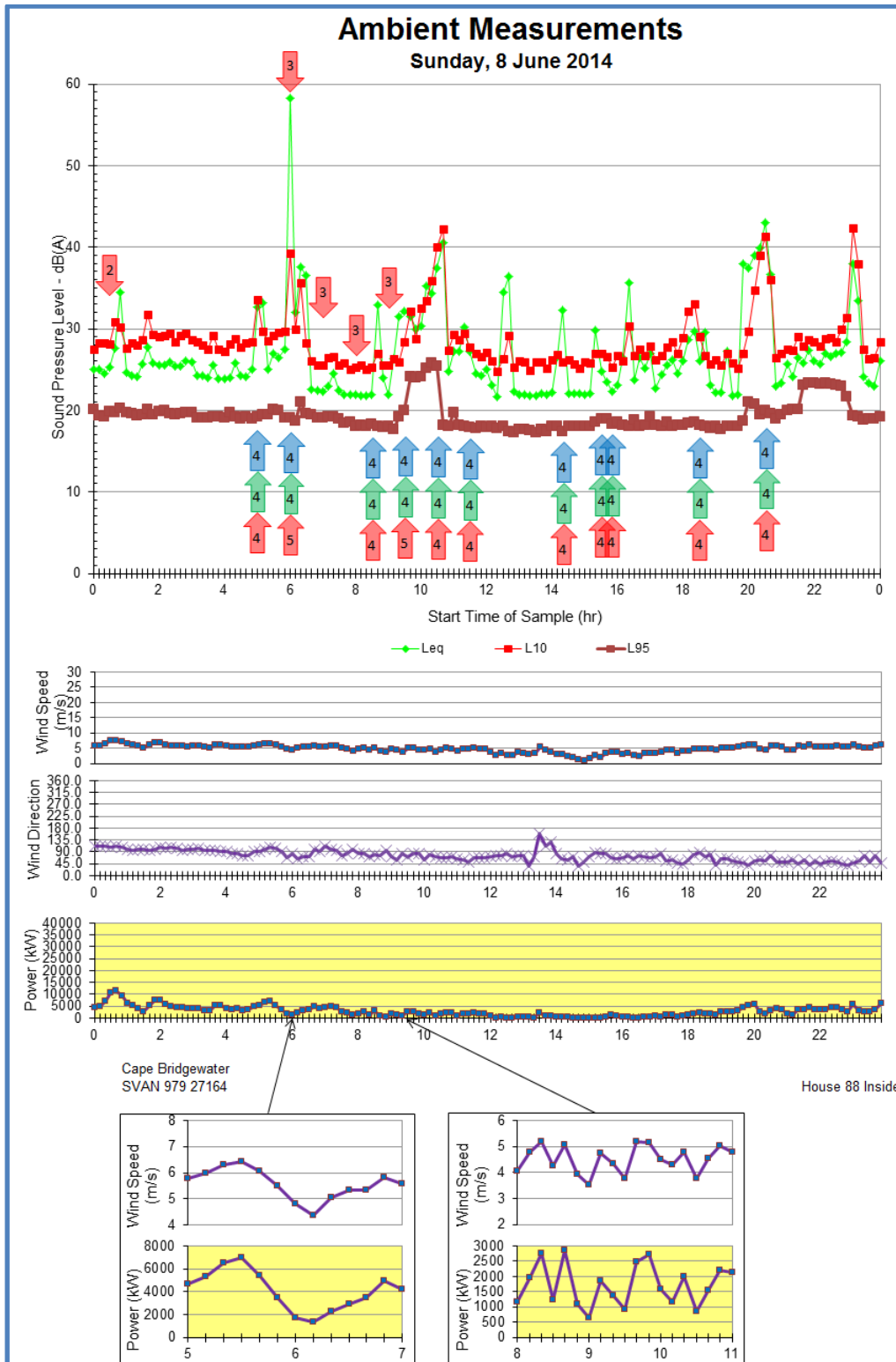


FIGURE 19: Internal Measurements (House 88): blue – noise, green – vibration and red - sensation



When the above graphs were presented as a generalised concept in the public meetings the residents (in the study) confirmed their own observations of the operations when viewing a website that provides the power information (<http://windfarmperformance.info/?date=2014-08-29>) and supported the hypothesis. Whether a 20% change of the wind farm power is the appropriate percentage change was purely speculative at the preliminary stages as discussed in the next section. Further analysis of the wind farm data gave rise to a number of possible scenarios to support the hypothesis and even reduce the percentage of individual turbines down to 10%.

The concept of sensation being the major impact during this survey is supported by viewing the graphs with the red sensation arrows versus the power output of the wind farm. Figure 19 with an expanded view of the variation in the power output of the wind farm was obtained directly from the wind farm's computer system. This concept provides a mechanism for further investigation of the cause of the sensation.

On the basis of the hypothesis identified above for the four scenarios, presented at preliminary meetings to the community, an examination of the diary observations in terms of the reporting of the higher classification of severity (being 4 & 5) found that 63% of those high sensitivity ratings related to sensation.

It is noted that the hypothesis for sensation derived from the observations is based on the wind and power farm data and at the initial stages had nothing to do with noise.

The challenge that was posed in looking at a large amount of data was to see how the sensations at the adverse level could be related to noise.

6.3 Acoustic Parameters

As the high sensations identified by the residents are related to inside their dwellings, in looking at the A-weighted charts there are a number of issues that are of concern in any analysis, the primary one being whether activities inside the dwelling gave rise to noise in itself that would mask the observations.



In the case of monitoring undertaken by Adelaide University with respect to the Waterloo Wind Farm [17] in their analysis of the data (where they were not looking for any correlation of sensation or impacts versus the noise, but just noise) the procedure was to only look at the data between midnight and 5 AM, and ignore the daytime results that might be affected by other extraneous noise sources.

The study for Cape Bridgewater was endeavouring to correlate the resident's complaints with respect to the operation of the wind farm and therefore relies upon the observations in terms of looking first at the wind farm data, being a different approach to that used by Adelaide University for the Waterloo study.

It must be acknowledged that some of the data will be contaminated by activities occurring in the occupied house throughout the survey that may affect the results. With one house being vacant there was an expectation of unaffected results leading to the multi-channel system remaining at the unattended house for the majority of the study.

The analysis of the results found in some cases problems inside dwellings by reason of the noise floor of the instrumentation and the bias in the A-weighting value towards high-frequency noise which is significantly reduced when inside the dwelling.

In considering noise impacts from wind farms a number of different acoustic parameters have been proposed by various researchers/agencies etc. to relate to the perceived impact.

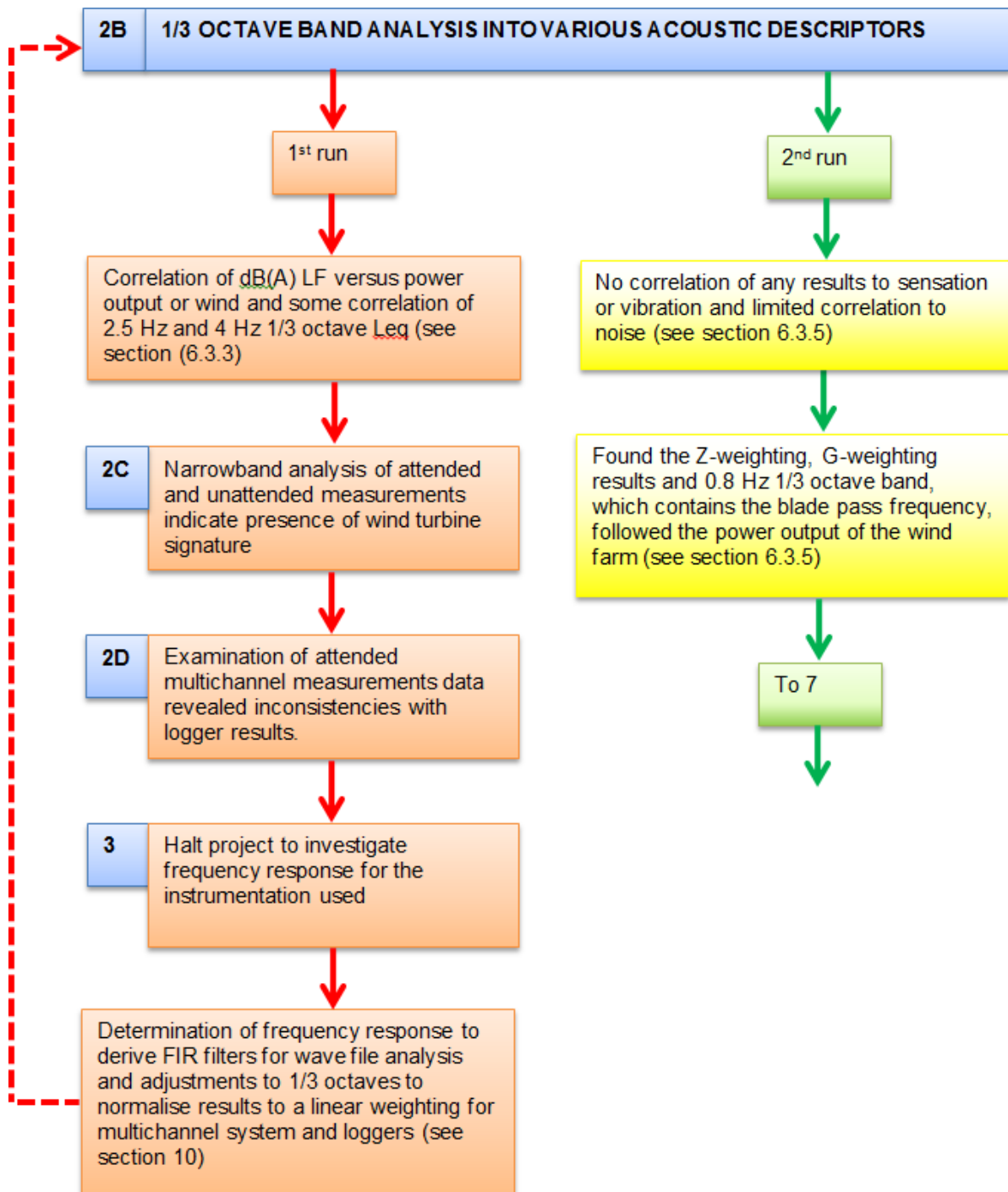
A number of the different acoustic descriptors are directly read from instrumentation incorporating the appropriate weighting curves or filters, whilst other instrumentation requires derivation of the descriptor based upon an analysis of 1/3 octave band material.

In anticipation of undertaking an assessment for the various different functions there was a requirement from the outset that the 1/3 octave band material from the unattended loggers would be used for analysis.

Because of the issue raised as to the presence of infrasound and low frequency noise potentially being a source of complaint it was essential to ensure that the instrumentation used for measurements could provide data down to the 1/3 octave band of 0.8 Hz which contains the blade pass frequency.

Parts 2B – 3 of Figure 2 relate to the investigation of the different acoustic parameters discussed in the following sub-sections.





Various concepts discussed below were presented in the public meetings as **preliminary findings** from the study, **with the qualification that all the material presented in the public forums was subject to change as the analysis proceeded.**

As discussed in the following sections the subsequent analysis utilising corrected noise data gave rise to different outcomes to that identified to the community meetings as preliminary findings.

6.3.1 The blade pass frequency

The blade pass frequency is a description used in the evaluation of ventilation fans to describe the number of times a blade will pass a fixed point per second. The blade pass frequency is a product of the rotating speed of the shaft times the number of blades.

A general concept for these turbines, which have three blades, is a nominal speed of 17 revolutions per minute. At a single position on the rotation of the turbine there will be $3 \times 17 = 51$ passes in a minute. Dividing 51 by 60 to obtain the number of passes per second gives 0.85 Hz. This is the frequency that it is described as the blade pass frequency for the nominal rotation speed of the turbine.

At the outset of the project there was an assumption that the blade pass frequency would be 0.85 Hz.

During the course of monitoring at turbine CBW 29 discussions with a maintenance team revealed that the turbines do not operate at a fixed rotor speed but can vary between 8.5 to 17.1 RPM. The turbines utilise a gearbox with the turbine shaft being the input that increases the speed by a ratio of 1:105.4 to drive the generation system to produce an electrical voltage supplied to a transformer at the base of the tower for ultimate distribution to the grid from the substation.

From the possible operational speeds the blade pass frequency could vary between 0.425 Hz and 0.855 Hz.

There can be a variation in the speed of the turbines (by observing individual turbines on the wind farm that are not rotating at the same speed) which can lead to a spread of the results when dealing with narrowband analysis. However, it would appear that the operating speed of the turbines is near the nominal 17 RPM for maximum power output and wind speeds above 10 m/s.



The 1/3 octave band at 0.8 Hz covers the frequencies of 0.7 Hz – 0.88 Hz (14 RPM – 17.6 RPM). That 1/3 octave band should cover the majority of the turbine operating speeds.

However in dealing with narrow band measurements the variation in turbine speed could give rise to a range of peaks for individual blade pass frequencies that does not necessarily show up in Leq (energy average) measurements

Based upon the logger data (in 1/3 octave bands) the application of different weighting curves can be viewed with respect to the resident's diarised observations.

6.3.2 Different weightings to the 1/3 octave band results

Twenty two different weighting curves were applied to the 1/3 octave bands for examination of different acoustic/infrasound/vibration parameters, with respect to the wind farm power data and the diary results.

For the basic dB(A), dB(C) and dB(Z) levels the general response curves for environmental acoustics do not extend below 10 Hz. To cover the entire infrasound region available from the loggers the curves have been extended down to 0.8 Hz.

The dB(A) LF parameter adopted by the Danish EPA [4] [6] for addressing low frequency noise annoyance (not infrasound) has an upper limit of 160 Hz. For the purpose of the analysis of the data and comparison of the resident's observations, a similar bandwidth of 10 Hz – 160 Hz was applied to the C-weighting and Z-weighting curves in addition to an extended bandwidth of 0.8 Hz to 160 Hz for the A-weighting, C-weighting and Z-weighting curves.



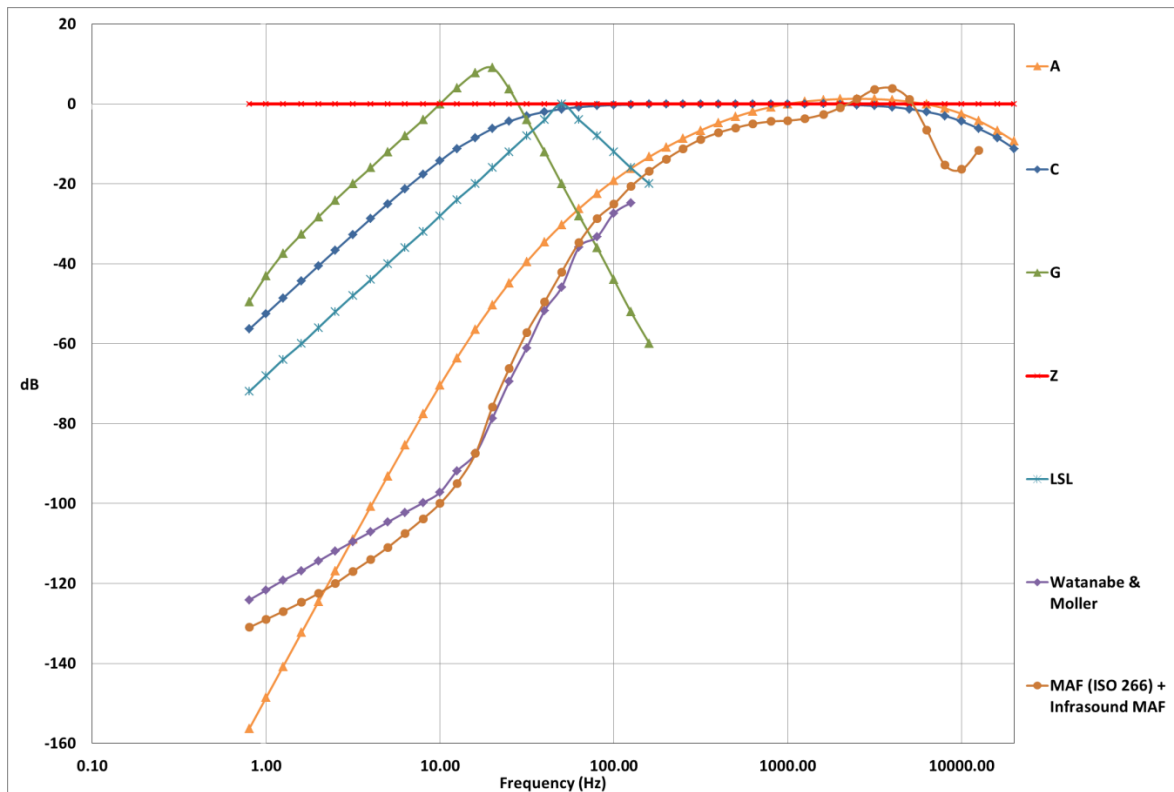


FIGURE 20: Weighting Curves

By applying the weighting curves from Figure 20 to the Leq 1/3 octave band results (in 10 minute intervals) an analysis has considered full and limited bandwidths of:

- dB(A) LF covering 10 Hz – 160 Hz
- dB(A) LF (ext) covering 0.8 Hz – 160 Hz
- dB(C)
- dB(C) LF covering 10 Hz – 160 Hz
- dB(C) LF (ext) covering 0.8 Hz – 160 Hz
- dB(Z)
- dB(Z) LF covering 10 Hz – 160 Hz
- dB(Z) LF (ext) covering 0.8 Hz – 160 Hz
- dB(Z) Infra covering 0.8 Hz – 5 Hz
- dB(G)
- LSL (Kelley curve)
- 0.8Hz 1/3 octave band



- 2.5Hz 1/3 octave band
- 4 Hz 1/3 octave band
- Leq (A) – L95 dB(A)
- Leq (C) – Leq (A)
- Watanabe & Moller (extrapolated to 0.8Hz)
- Minimum Audible Field (ISO 266 for audible range) + proposed Infrasound MAF
- Minimum Audible Field (ISO 266 for audible range)
- Proposed Infrasound MAF

In dealing with the audibility in the infrasound region reference is usually made to testing by Watanabe & Moller [18] to assess the audibility threshold in the infrasound region that has been established using pure tones down to 4 Hz. International Standard ISO 266 [19] documents reference sound pressure levels for different loudness levels with the Minimum Audible Field identified as the threshold of hearing in the audio range [20].

Figure 21 provides the audible sound pressure level in terms of the nominated thresholds for audibility and the 95 dB(G) curve. On the assumption the individual hearing threshold may be 10 dB lower than the average threshold [6], the general concept for inaudibility for environmental infrasound has been nominated as 85 dB(G).

Subtraction of the following curves from the measured data provides an indication of audibility of the internal noise levels.



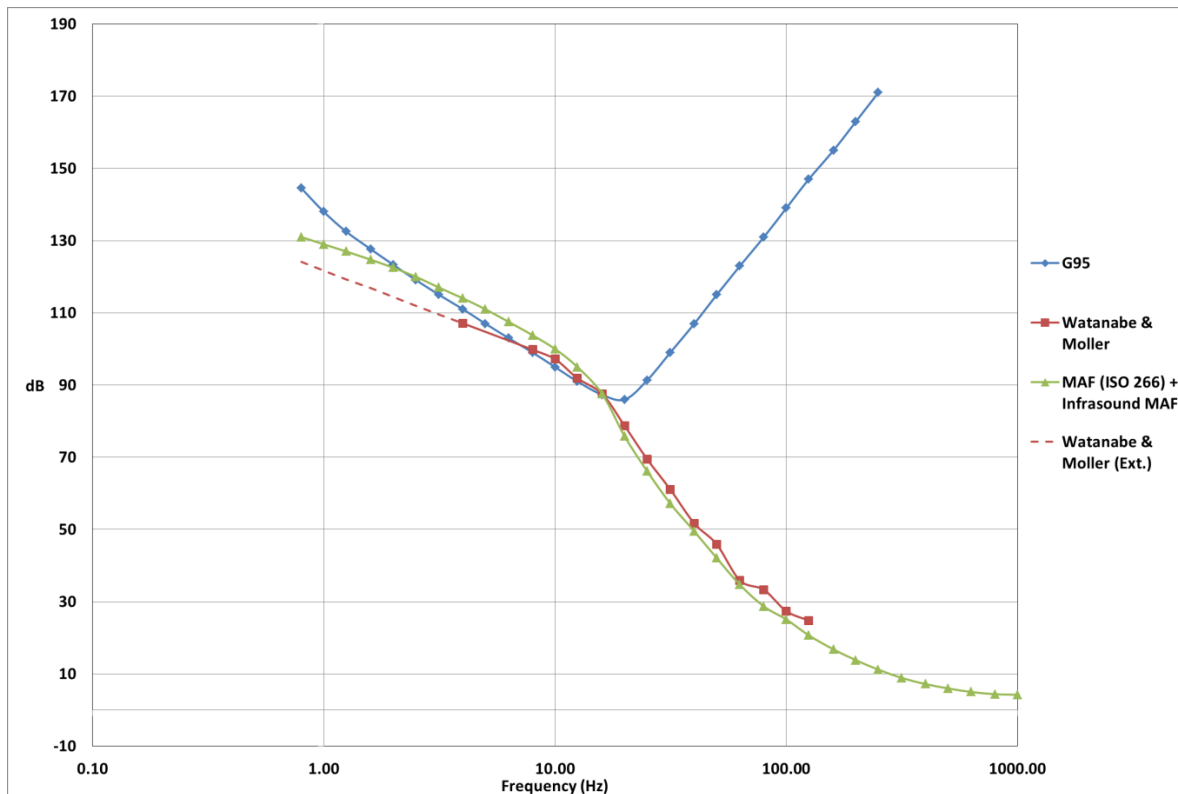


FIGURE 21: Audible Response Curves

Other than the LSL (Kelley) curve [21] none of the acoustic curves address vibration as an impact.

However Australian Standard AS 2670.1-2001 “Evaluation of human exposure to whole-body vibration, Part 1: General Requirements” [22] provides a weighting curve for acceleration in the vertical axis (W_v) (that has a sensitivity peak at 0.16 Hz) to be used for evaluating motion sickness, and a weighting curve for perception in the horizontal axis (W_d) that has a sensitivity peak at 1 Hz. The acceleration levels can be converted to radiating sound pressure levels for comparison with the equivalent sound pressure levels in terms of:

- Whole Body Vibration curve W_D
- Whole Body Vibration curve W_F

Alternatively if vibration measurements are available one can use the vibration curves in AS 2670.1 or the corresponding ISO 2631-2 [23] recommended by Jakobsen [6] for a weighted acceleration a_w of 5.6 mm/s^2 (addressed later in this report).



In dealing with the A-weighted value the Leq, L10 and L95 (the background) levels can be extracted directly from the logger data but no correlation could be established with the operation of the wind farm in terms of power output (see Appendices J – L inclusive).

6.3.3 dB(A) LF

With respect to the dB(A) parameter the Danish EPA dB(A) LF (restricted to between 10 Hz and 160 Hz) is identified as based upon an annoyance level for low frequency [6]. The recommended limit for dwellings in the day is 25 dB(A) LF and reducing to 20 dB(A) LF at night. The levels are not restricted to bedrooms which appears to be an interpretation applied by some environmental authorities in considering the dB(A) LF parameter.

Jakobsen [6] does not identify the basis of how dB(A) LF was derived as the low frequency annoyance limit and whether the limit is applicable to wind farms.

Poulsen and Mortensen [5] identify a study that was carried out for the Danish EPA to compare objective results for a number of methods of low frequency noise and found the Danish EPA dB(A) LF method gave the best relation to the subjective assessments made by the test persons. The sources of noise tested were traffic, drop forge, gas turbine, fast ferry, steel factory, generator, cooling compressor and a discotheque. Wind farm noise was not a source of noise investigated.

The dB(A) LF parameter was considered in the South Australian EPA Waterloo study [3] but was ignored in the analysis even though there were a significant number of occurrences when the noise level in the dwellings is above 20 dB(A) LF and correlated with the resident's diaries. The basis of ignoring the parameter was due to excessive wind external to the dwelling impacting internal levels.

The dB(A) LF is not a function that is available on a standard sound level meter and requires the numerical analysis of the 1/3 octave band data. The 1/3 octave band data is required to be Linear (unweighted) values. If the meter provides an A-weighted result the data can fall into the noise floor and be invalid.

With the opportunity to extend the frequency down to 0.8 Hz an additional parameter dB(A) LF (ext) was derived. Due to the A-weighting filter curve the result of the investigation found there is no difference in the plotted dB(A) LF versus the dB(A) LF (ext).



For the dynamic range of the noise loggers and the noise floor that is available the derived dB(A) LF values were found to be valid above 5 dB. In terms of the Danish EPA internal criterion of 20 dB(A) LF there were no issues with the validity of the derived levels.

Plotting the internal noise levels of dB(A) LF versus the power output of the wind farm found a corresponding relationship with the dB(A) LF determined in the bedrooms of the dwellings.

In evaluating the data with respect to the diaries utilising the Z-weighting curve (as a flat response) dB(Z) for 10 Hz to 160 Hz, and dB(Z) (ext) covering 0.8 Hz to 160 Hz were considered. As a result of the analysis an additional concept of Linear (Z) weighting over the bandwidth of 0.8 Hz – 5 Hz was derived.

Similarly the dB(G) and the LSL curves were applied together with assessment of the audibility curves described above.

In the initial stage of the investigation of the data the use of the dB(A) LF was found to follow the power output of the wind farm and that at times the level recorded inside the dwellings exceeded the nominated threshold criteria of 20 dB(A) LF. Examination of the spectral characteristics indicated that the frequency of concern was in the 100 – 160 Hz region that is evident by way of the threshold of audibility curves. The response of the A-weighted curve is such that the influence of infrasound on the dB(A) LF value would be relatively insignificant.

In the initial stage of analysis the dB(A) LF, the 2.5 Hz and the 4 Hz 1/3 octave band all followed the power output of the wind farm. However as discussed in section 6.5 the on-off testing found that such results can be influenced by the ambient noise levels (as a result of the wind) that affect the Leq levels. **With wind speeds above 10m/s the dB(A) LF method (as an Leq level) appears to be masked by wind noise.**

As a result of the ON – OFF testing an analysis was undertaken and established that on a dB(A) LF basis, and a dB(A) basis, where there is a consistent wind there was no significant difference between prior to the wind farm shutting down and after the wind farm had shut down.

The dB(A) LF not only follows the power output of the turbines but also follows the wind speed because the output of the wind farm and the wind speed are directly related to one another (provided there is no intended or unintended shutdown of wind farm).



On reviewing the dB(A) LF results with respect to the ON-OFF tests it was established that for a wind speed above 10 m/s the dB(A) LF concept is no longer valid, as suggested in the Waterloo Wind Farm acoustic investigation report issued the SA EPA.

For the occasions when the hub height wind speed is below 10 m/s and the residents report disturbance the dB(A) LF value would appear to be well below 20. A review of the report by Poulsen [5] into the investigation for the Danish EPA indicates that in terms of the spectral characteristics and the noise sources used there were no frequencies as low as that attributed to wind turbines, and that those studies were specific in terms of being an investigation into low frequency annoyance.

The appropriateness of the dB(A) LF criteria in the application of an assessment of a wind farm is questioned, as is the apparent threshold limit either in terms of the dB(A) LF or just dB(A) that has been attributed to a level that gives rise to annoyance or sleep disturbance respectively.

6.3.4 dB(C) – dB(A)

In general environmental acoustics the identification of a low frequency noise has been to consider the dB(C) minus dB(A). When the difference is greater than 15 dB then an adjustment is provided to account for low frequency noise.

With respect to the monitoring conducted at Cape Bridgewater for the external application of dB(C) minus dB(A) in general the difference is about 15 dB but of course there is an influence of the wind in the external environment that can affect the low-frequency levels that are dominant in the dB(C) measurement. Figure 22 provides an example of the dB(C) minus dB(A) level/dB(A) Leq – L95) pattern that was observed for the external logger at House 87 on 12th June, 2014.



Ambient Measurements

Thursday, 12 June 2014

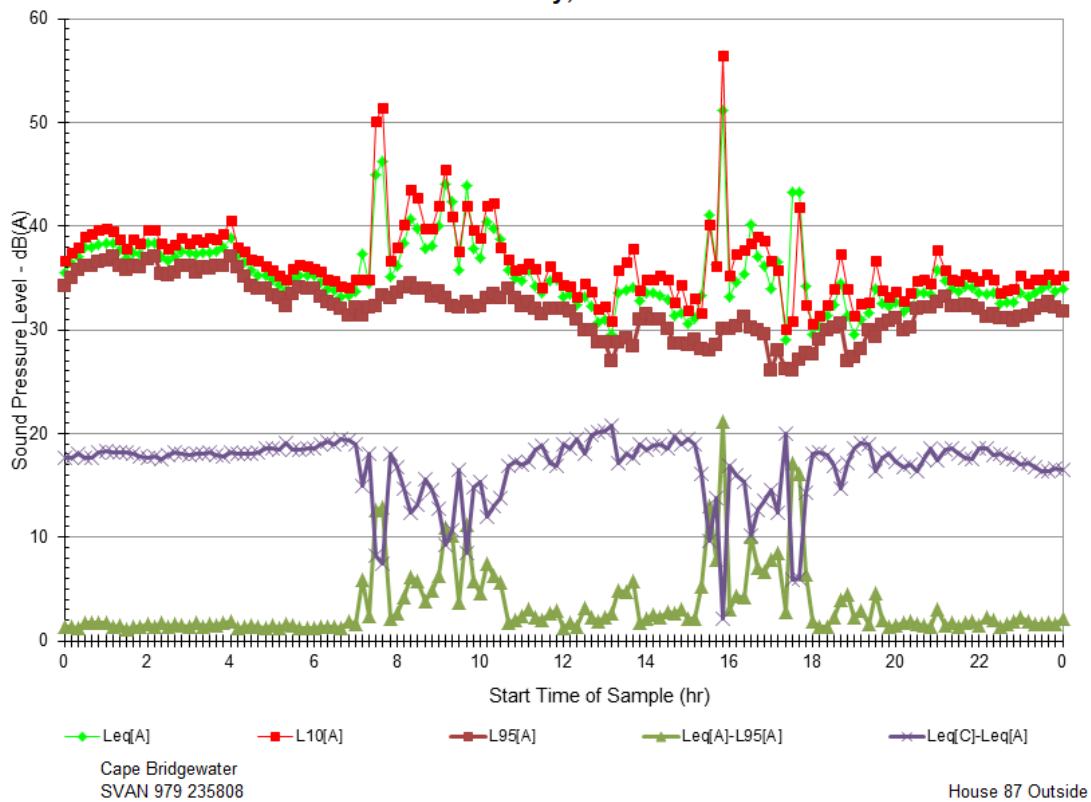


Figure 22: Logger results external to House 87

For the monitoring locations inside dwellings the dB(C) minus dB(A) for most of the time is well above 15 dB as a result of the substantial degree of attenuation of high frequency noise from outside when compared to a lesser degree of attenuation for the low-frequency such that on a proportional basis the internal dB(A) inside are significantly lower than the dB(C) levels, leading to a greater differentiation between dB(C) minus dB(A). Figure 23 illustrates the internal dB(C) minus dB(A) levels and the dB(A) Leq-L95 pattern recorded inside House 87 for 12th June, 2014.

The analysis of the 1/3 octave band results revealed the occurrence of the above patterns was not an isolated case requiring further investigation.



Ambient Measurements

Thursday, 12 June 2014

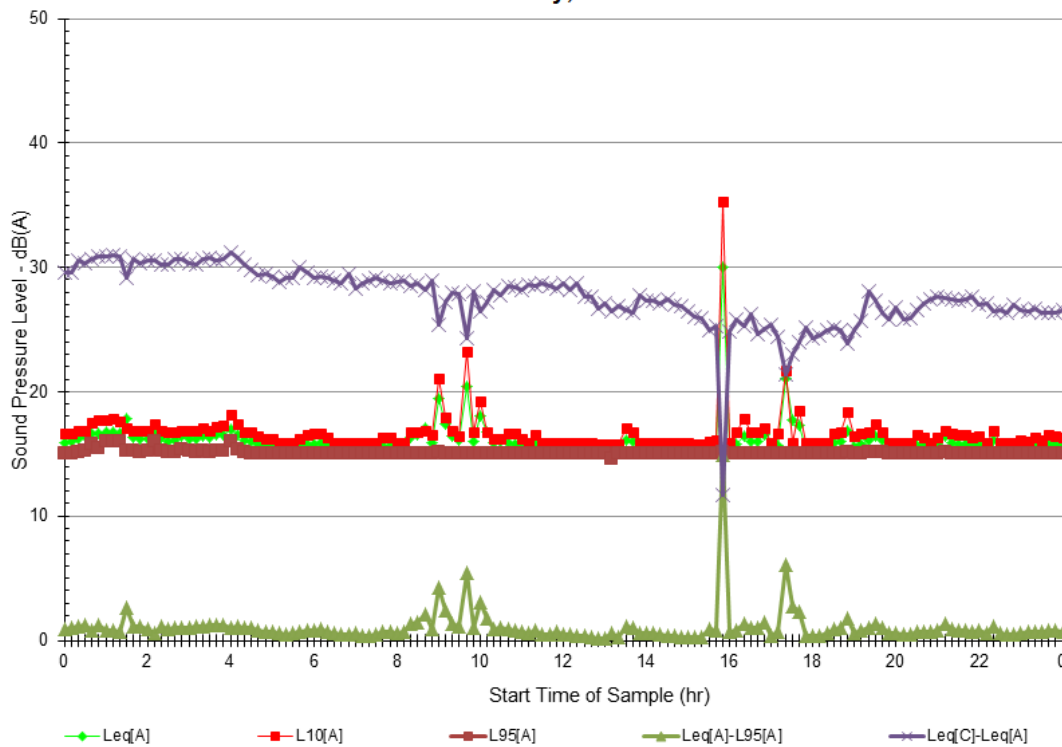


Figure 23: Logger results inside House 87

On some occasions (such as 3:50 PM in the above graphs) there is a pattern that shows a substantial drop in the dB(C) minus dB(A) Leq level and at the same time gave rise to a substantial increase in the dB(A) Leq minus dB(A) L95.

The logger results do not identify the source of the noticeable change. However the benefit of having wave files permits the analysis of the time periods of concern.

Figure 24 presents a sonogram of a 1/3 octave band measurement from inside House 87 at 3:50PM on 12th June, 2014. It illustrates the short duration, high frequency noise which simultaneously dropped the dB(C) minus dB(A) level and increased the dB(A) Leq minus dB(A) L95 in the logger results.



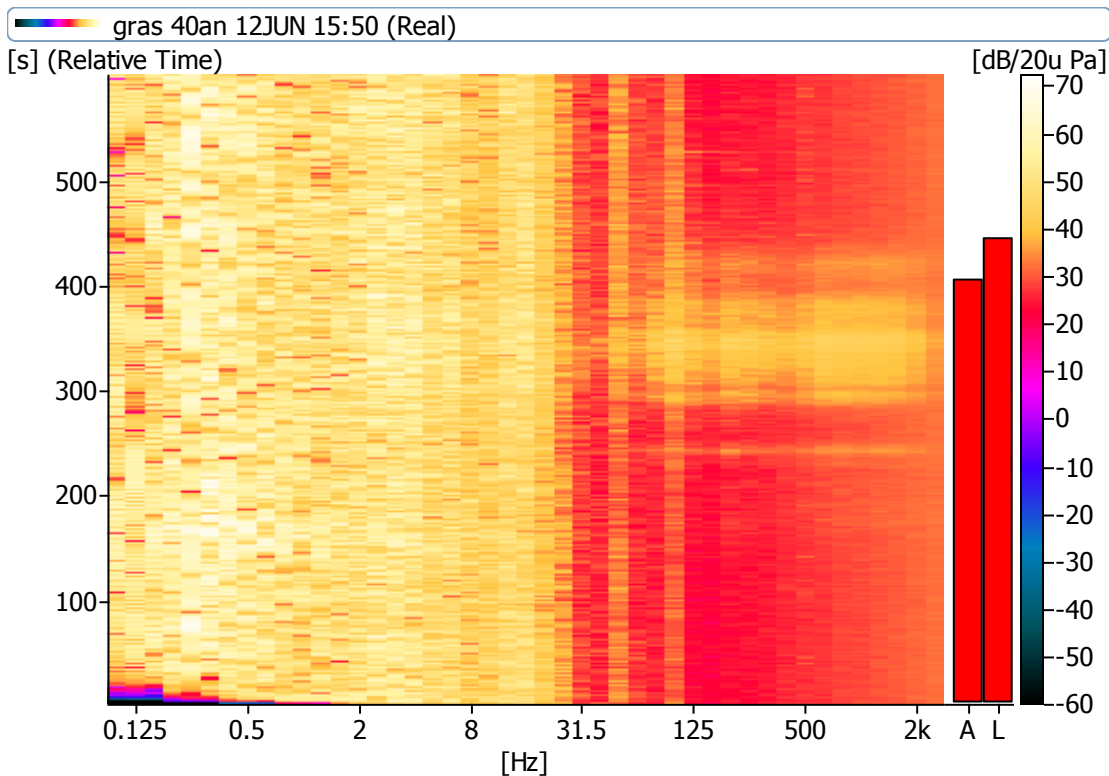


Figure 24: 1/3 octave band sonogram inside House 87

Subsequent listening of the wave files (external and internal) found that this pattern had nothing to do with the operation of the wind turbines but found a significant increase in high frequency noise external to the premises that reduced the dB(C) minus dB(A) and also increased the dB(A) Leq minus dB(A) L95 level by reason of a short rainstorm.

Patterns that produced a significant difference in the dB(C) minus dB(A) level and at the same time produced a significant increase in the dB(A) Leq minus dB(A) L95 level are not associated with the wind farm but are due to extraneous noise.

In terms of a dB(C) threshold suggested for wind farms, the analysis of the results found there was no correlation with the dB(C) level and the resident's observations to either noise, vibration or sensation.



6.3.5 Instrumentation issues

As described in the section on Measurement Uncertainty, an analysis of some of the wave files was unable to obtain results that agreed with the measured values. Further investigation found that the wave files determined by the SVAN loggers were subject to a filter that is associated with one of the three profile channels and that some of the spectrum information also incorporated a Z-filter such that the results were non-linear.

This became an interesting exercise in that using the SVAN 957 meter for the exact same settings (Z-weighting) to agree with the manufacturer's manual [15] the 1/3 octave band logger results were in actual fact a linear result, whereas the Svan 979 meters [16] gave a Z-weighted logger result.

As a result of this finding the analysis process of the project was placed on hold whilst calibration differences in frequency response for the instrumentation used were investigated.

In the calibration of sound level meters the lowest frequency that is tested for an acoustic input to the microphone is the 31.5 Hz octave band, i.e. the acoustic performance of the entire system below 31.5 Hz is not undertaken. The investigation was undertaken primarily by use of the low-frequency GRAS calibrator (Type 42AE) which is able to generate signals for microphones in the range of 0.1 Hz up to 100 Hz and is used as a specific calibration device to determine the infrasound and low frequency response of microphones in addition to the standard microphone/instrumentation calibration using a Bruel & Kjaer Multi-Function Calibrator Type 4226 (NATA Calibrated by the National Measurements Laboratory).

It became apparent that the calibration is not just the microphone, but is a combination of the microphone, sound level meter or recording device, and the settings on the meter. It was established that the filtering on the SVAN meters (that was expected to be a flat response) had a significant roll off below 5 Hz which would underestimate the measurement results.

Section 10 on Measurement Uncertainty provides details of the calibration exercise that was undertaken and also the fact that the IEC Standard for sound level meter [41] has as a very wide-range in the permitted tolerance at 10 Hz and has no specified tolerance or specification for frequencies below 10 Hz. This contradicts the assumption of a 0 dB weighting curve.



For the different combinations of meters/analysers/microphones used in the study the individual frequency response curves were determined to derive adjustments to the one third octave curves recorded by different meters to normalise the results to a Linear weighting. It was necessary to determine FIR filters for the processing of the narrowband analysis.

As a consequence of clarifying or correcting the results to obtain a flat response, changes to the outcomes identified in the preliminary findings presented to the community were required. What this means is that when the linear (corrected) results from the noise loggers were obtained, the data for frequencies below 5 Hz increase significantly and as such changed the preliminary outcomes.

With the normalised (corrected) results it is found that the power output of the wind farm follows the blade pass frequency in the 0.8 Hz 1/3 octave band as well as the Z-weighting and the G-weighting results. The variations in those levels exhibit significant differences that accord with the hypothesis as to the power settings obtained by examining the power data and the resident's observations.

Due to the variation in noise that can occur in a single 10 minute sample the use of an Leq parameter is questioned when there can be large variations – particularly as a result of the wind. The use of plots showing the variation in level over time provides a visual format to highlight such variations. Such visualisations are not restricted to just the overall value (dB(A), dB(G), dB(Z), LSL etc.) but have benefit when considering the frequency content that also changes in time.

Section 7 discusses the results of testing of both noise and vibration for individual turbines. That testing found discrete frequencies associated with the turbines in the infrasound region and the low frequency region. The presence of narrow band peaks at the blade pass frequency and harmonics of that frequency that are evident at residential locations is not that obvious on the wind farm. However, the presence of a distinct frequency of 31.5 Hz, with sidebands of multiples of the blade pass frequency, were identified on the wind farm when the turbines were operating above the cut-in speed.

The source and the relationship of that frequency to the operation of the turbine is unknown, although at this stage considered to be associated with the generator, and may be clarified by the turbine manufacturer.

The 31.5 Hz plus sideband frequencies are present at the residential locations when using a narrow band assessment.



On comparing the variations in the blade pass frequency over time there is agreement with the higher sensation levels when looking at narrow band results in the infrasound region as discussed in see Section 6.6.

In examining the resultant (derived) levels there was no correlation of any of the results versus the sensation, or vibration, and limited correlation in relation to the noise. The relationship of the observed increase in the various acoustic parameters with the power output of the wind farms is evident. However one needs to address the potential for such an increase to be related to the increase in the wind rather than directly attributed to the wind farm. It is this concept to obtain a finer resolution of the measured levels that leads to the use of narrow band analysis where discrete signatures in the frequency domain become apparent.

Subsequent on-site testing of individual turbines identified the use of 1/3 octave band data at residential locations was of limited value, whereas the use of narrowband analysis provided distinct differences in noise emission characteristics.

6.4 Fluctuations in the Blade Pass Frequency and Power Output

Utilising the results for house 88 for Tuesday, 10th June 2014, where there was a relatively low output from the wind farm and plotting the 10 minute results through the day in terms of the 0.8 Hz, the dB(G) and the audibility curve reveals that in terms of noise in the house, theoretically there should be no audible noise attributed to the wind farm, although the dB(A) LF suggest there could be some annoyance.



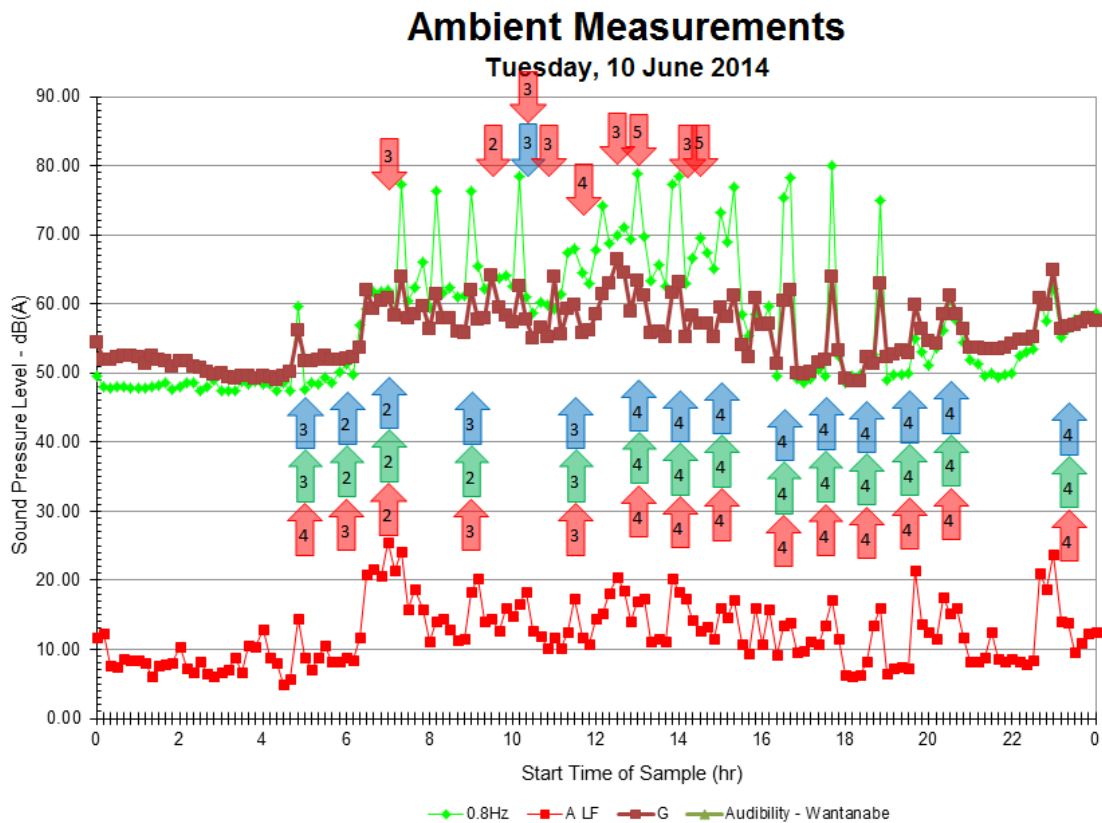


FIGURE 25: Occurrence of high sensitivity inside house 88

The dB(G) curve, which has been proposed by some authorities for addressing infrasound, shows variations in the peak levels but of a lesser magnitude in terms of the differences for the blade pass frequency, but is deemed to be inaudible by reason of the dB(G) level being significantly below 85 dB(G).

In looking at the dB(A) LF value it can be seen that there are fluctuations in the day, but as identified above such fluctuations could be influenced by activities in the house.

Figure 25, in terms of the A-weighted values and the wind/power data, appears as Appendix J24.



Comparison of the overall dB(A) noise levels versus the power output of the wind farm indicates that there was a nominal westerly wind during the middle of the day with the occupants of that dwelling observing sensations with sensitivity of 3 and 4 throughout the day, with a significant number of the peaks for the 1/3 octave band containing the blade pass frequency coinciding with the identification of sensation.

On utilising the blade pass frequency one third octave band (0.8 Hz) it is unlikely that there are any activities occurring in house that would generate that frequency, noting that the above graph shows significant fluctuations during the day. However, subsequent measurements inside the dwelling found the floor to be “live” in that it responded to movement in other parts of the dwelling that as such could have generated the significant increases in Leq levels for the 0.8 Hz 1/3 octave band.

The power output of the wind farm during the early hours of the morning is low until around 7am, then there is an increase in wind and the power output during the day, a decrease in the evening and then a gradual increase at night. On disregarding the large intermittent fluctuations in the 0.8 Hz 1/3 octave band in Figure 25 the general trend in the dB(G) and the 0.8 Hz 1/3 octave band follow the power output of the wind farm. The operation of the wind farm on that day includes three components of the hypothesis of instability.

To evaluate the hypothesis that was proposed from an examination of the diary observations and the wind farm power output data in terms of noise, the power output data and wind strength and direction for individual turbines reveals not all turbines were operating under the same scenario.

Figure 26 repeats the previous graph time span when applied to the bedroom of house 87 (empty house) with a graph of the power output of three turbines being CBW 15 (purple), CBW 27 (blue), and CBW 29 (red) which are the three closest turbines to house 87. It can be seen that the power output of those three turbines is not the same.

Examining turbine CBW 27 on its own (being the closest turbine to house 87) and taking the differential of the power change in 10 minute intervals versus a capacity of 2 MW indicates the rate of change as nominated in the hypothesis for the up-and-down change would appear to agree with some of the peaks identified in the blade pass frequency 1/3 octave band in the upper graph.



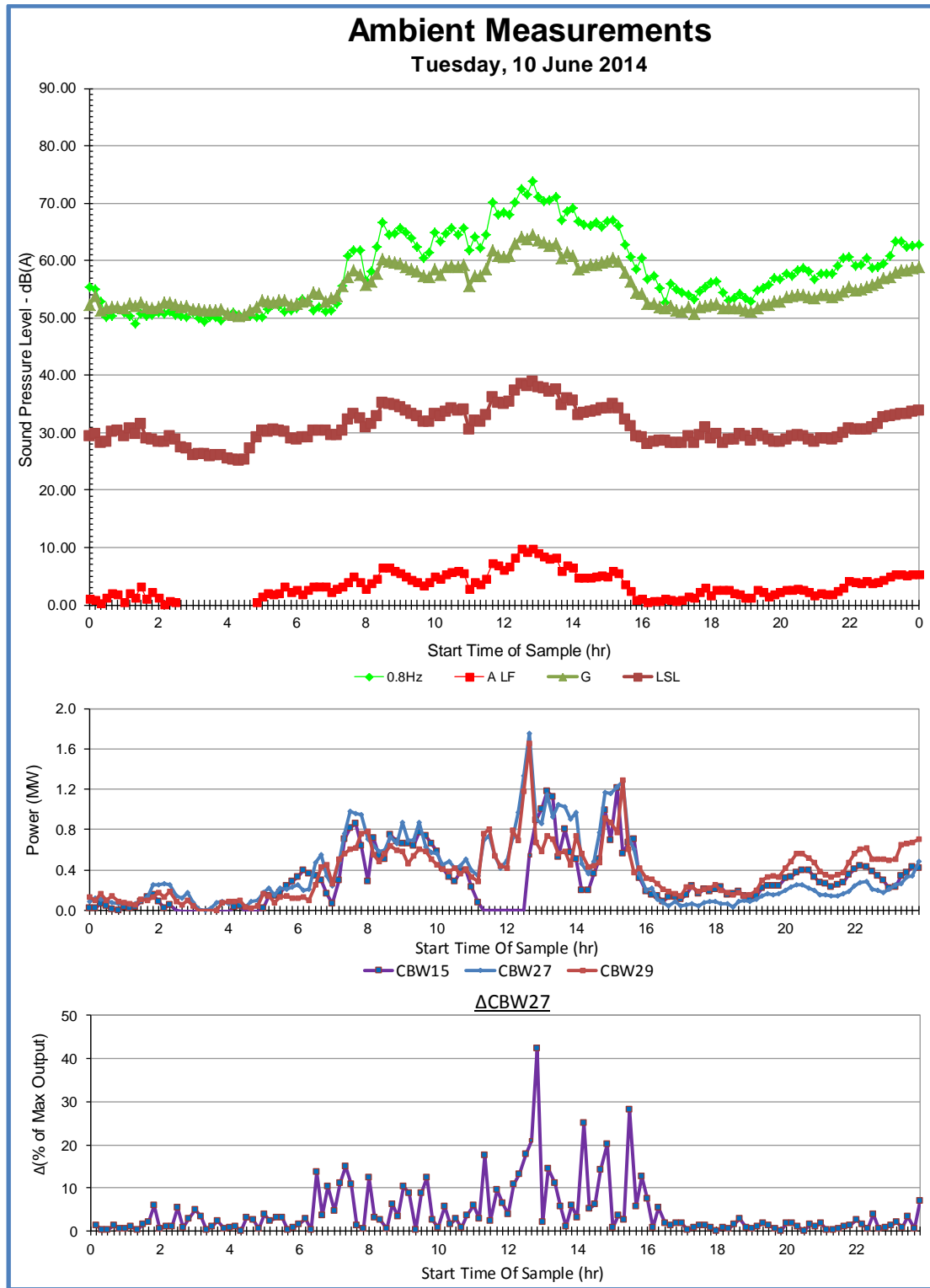


FIGURE 26: House 87 bedroom and operation of three nearest turbines



Taking the change in the power output of the entire wind farm (bottom graph) it can be seen that from a more detailed analysis the hypothesis of 20% for a power increase may for that scenario be reduced to 10%.

The degree of fluctuation in the blade pass frequency in the 1/3 octave band is significant and could be used as a possible method for the concept of sensation. However the question arises as to what gives rise to such a difference in the level of the blade pass frequency 1/3 octave band?

The graph for Tuesday, 10th June (Figure 26) shows in the early hours of the morning that there are fluctuations in terms of the dB(A) LF which was measured in the master bedroom of the house. The upper graph reveals in the early hours of the morning there is a reduction in the dB(G) level and a relatively steady level for the 0.8 Hz 1/3 octave band.

Looking at the individual power output for the three turbines set out in Figure 26 it can be seen that there are some minor fluctuations in the early hours the morning where there is a slight degree of power being generated by the turbines. The different power outputs indicate the presence of wind at varying strengths. From the differential power graph for turbine CBW 27 (the closest turbine to house 87) or the differential power for the entire wind farm there were some turbines turning at times during the night and generating power. This indicates that the turbines were coming in and out of operation and as such would fall into the first category in the hypothesis.

Figure 27 provides the period of midnight to 4 AM of Figure 26 showing the power output, wind speed and the wind direction for turbines CBW 15, CBW 27 and CBW 29. Examining the power data graph indicates a variation in the three turbines.

If one utilises the wind speed information versus the power output for the three turbines it would appear that there is actually a cut-in speed slightly above 3 m/s at which power may be generated by the turbine that is lower than the nominal 5 m/s assumed earlier in the assessment.

Looking at the wind direction and speed over the same time period it can be seen that on this occasion for the same wind speeds the turbine output was not the same.

Figure 28 considers the three closest turbines to house 88.



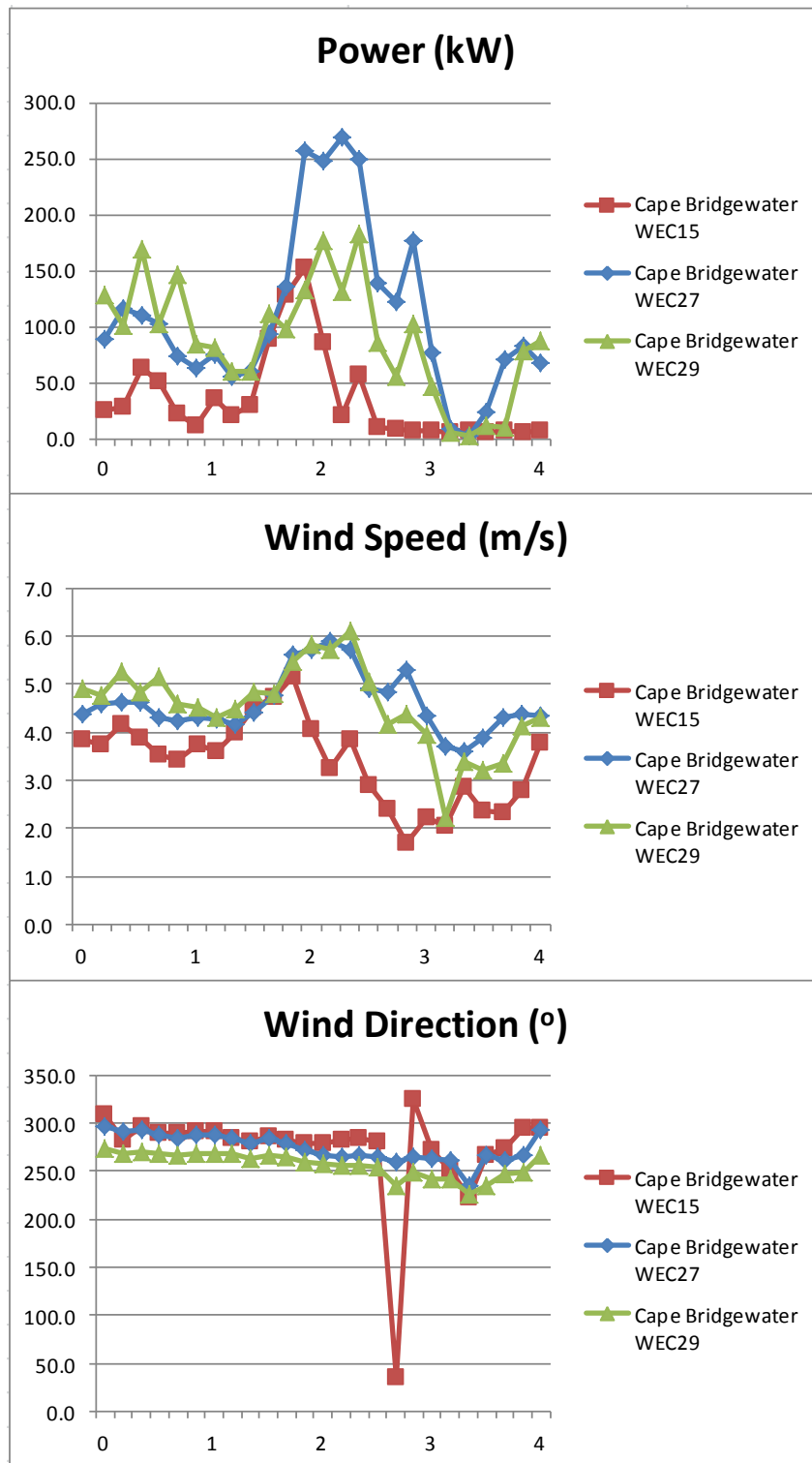


FIGURE 27: Operation of three nearest turbines to house 87 (midnight to 4AM)



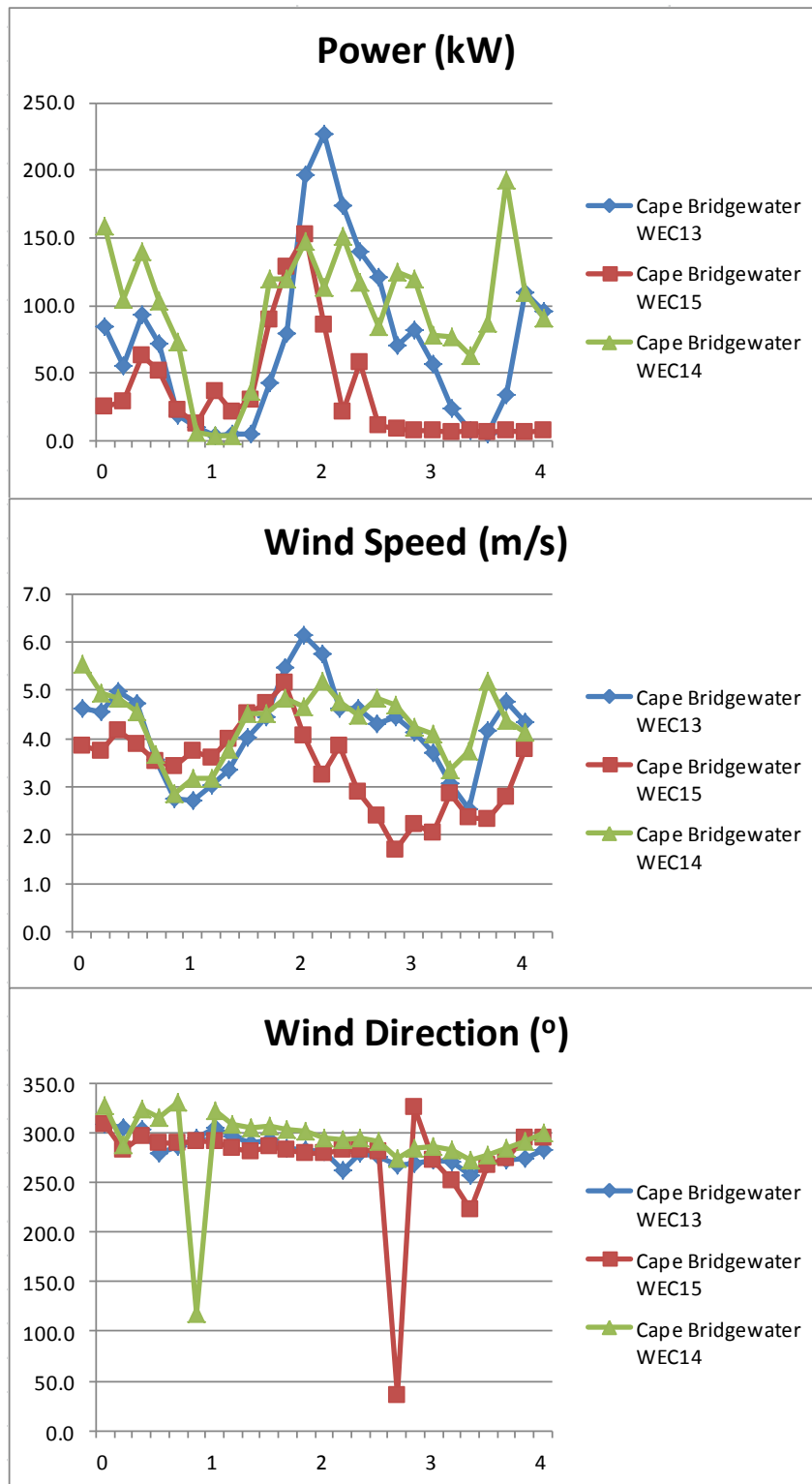


FIGURE 28: Operation of three nearest turbines to house 88 (midnight to 4AM)



Not being wind engineers or designers of wind farms TAG is unable to provide an explanation for those significant differences. The situation of a dramatic shift in wind direction at individual turbine raises questions about the flow of wind across the wind farm and the efficiency of individual turbines being downwind of other turbines.

As to the hypothesis concerning the instability of the blades, the variability of the wind direction and the strength shown above in the early hours of morning could be a contributing factor.

To gain a further insight into the variation of individual turbines when power was being generated, and the fluctuations in the blade pass frequency for the period of 7 AM to 11 AM, carrying out the same analysis for other turbines at the southern end of the wind farm reveals noticeable differences in the power output and the wind at individual turbines.

As shown in Figures 29 – 32 a noticeable difference in the wind direction between individual turbines is observed, For example between turbine CBW 13 and turbine CBW 15 there is a difference in wind direction of around 20°, a similar difference between turbine CBW 12 and CBW 20, but about 60° difference between turbine CBW 18 and turbine CBW 17.



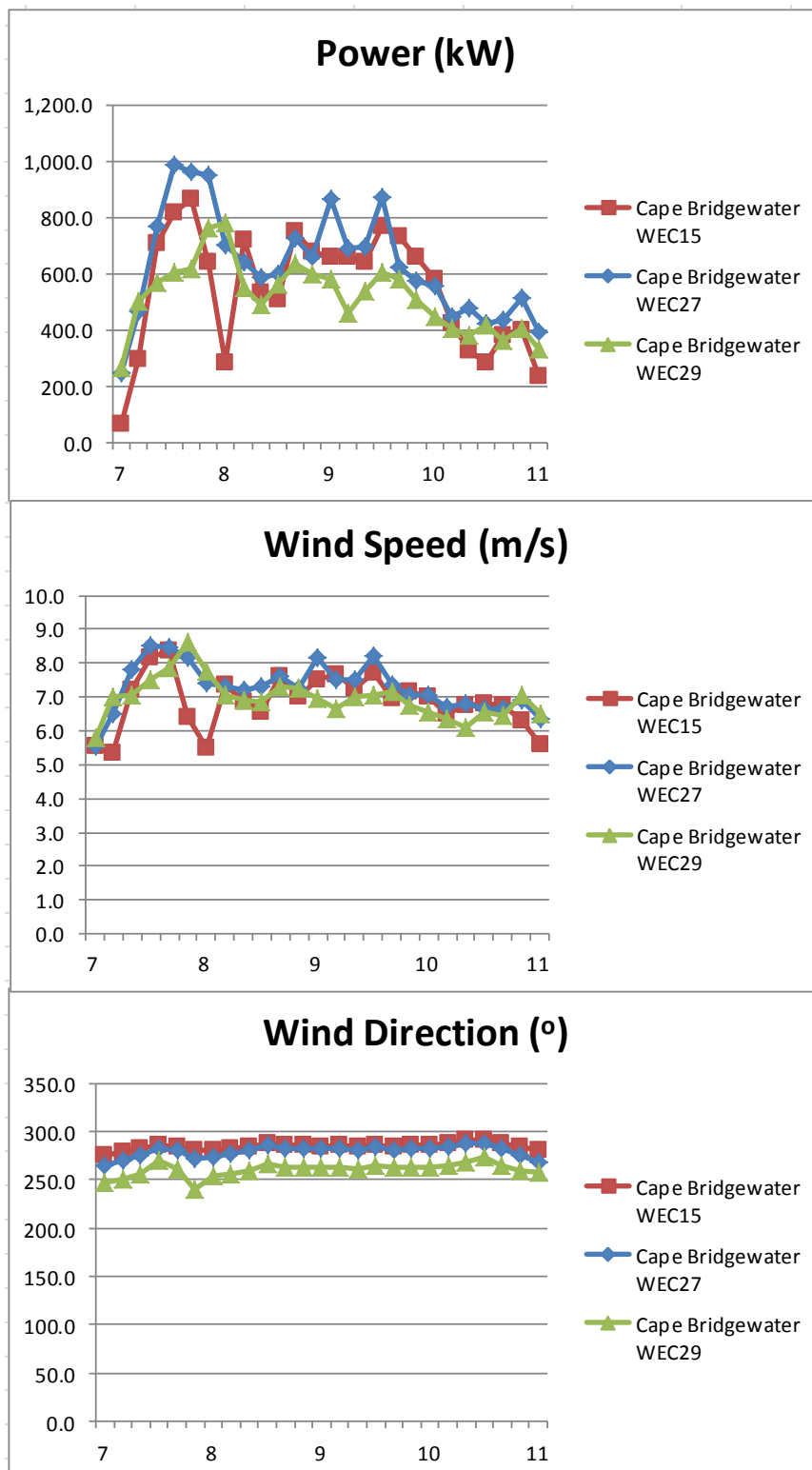


FIGURE 29: Operation of turbines 15, 27 & 29 (7AM to 11AM)



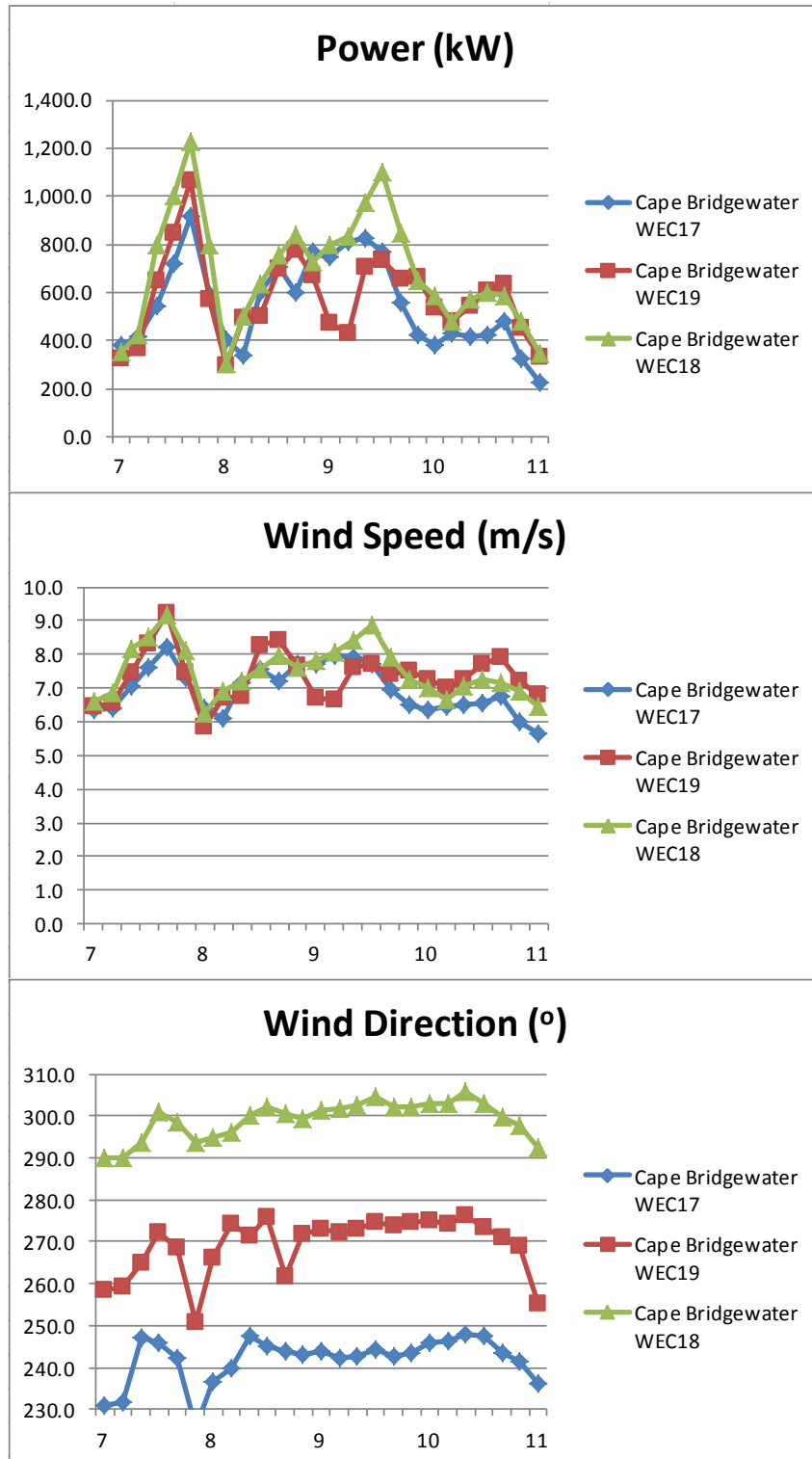


FIGURE 30: Operation of turbines 17, 10 & 18 (7AM to 11AM)



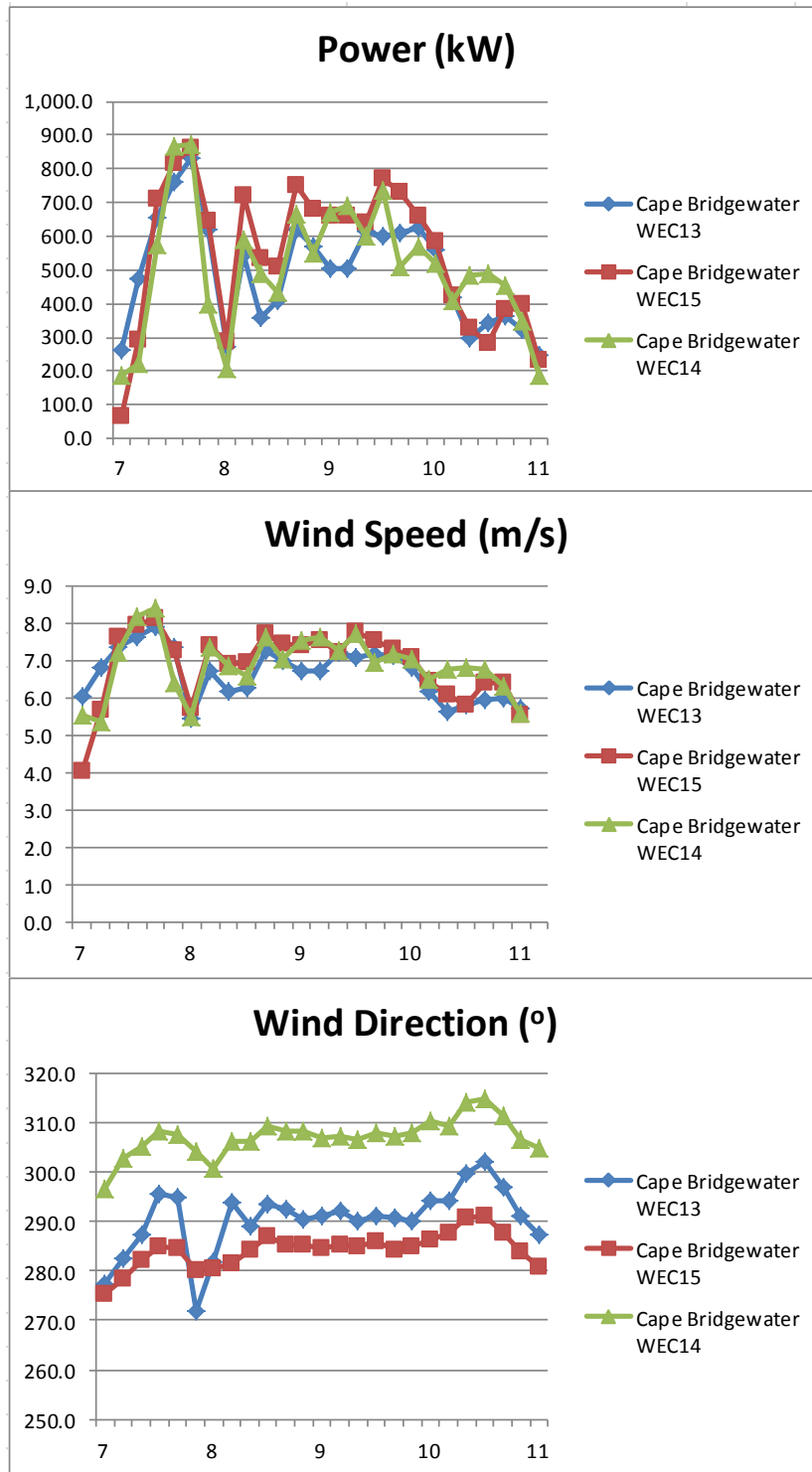


FIGURE 31: Operation of turbines 13, 14 & 15 (7AM to 11AM)



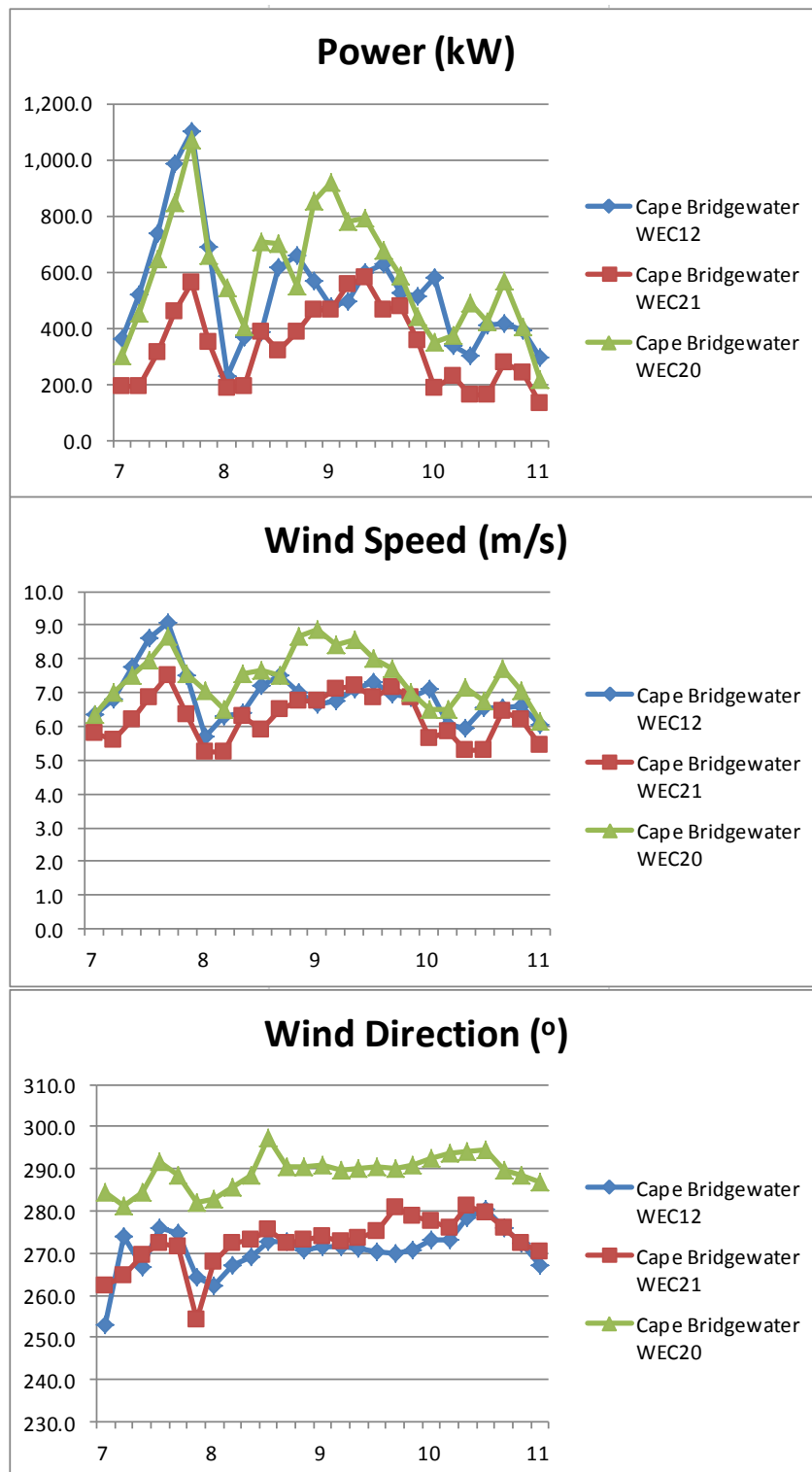


FIGURE 32: Operation of turbines 12, 20 & 21 (7AM to 11AM)



If the turbines are orientated at different angles from one another then the propagation of noise from the turbines would not be considered as a uniform emission. This situation has the potential for interaction between individual turbines. Does this contribute to the significant difference in the blade pass frequency that has been identified?

A classical picture in terms of wake behind turbines is for the Horns Rev Offshore Wind Farm in Denmark. The turbine layout is identified as a rectangular grid at 560 m spacing. The turbine wake shows an expanding cone of turbulence which impacts upon each following turbine and creates a dramatic representation of the wake behind a group of turbines.



FIGURE 33: Horns Rev Offshore Wind Farm

It should be noted that the above photograph is a perspective view, although the turbines are parallel to one another, the picture being taken from a distance suggests an angle.

To comprehend Figures 27 – 32 for Cape Bridgewater in terms of wind direction, Figure 34 is a plot of the wind direction for each turbine at 9 AM on 10th June 2014 to show that for some turbines there is a significant difference in the direction.



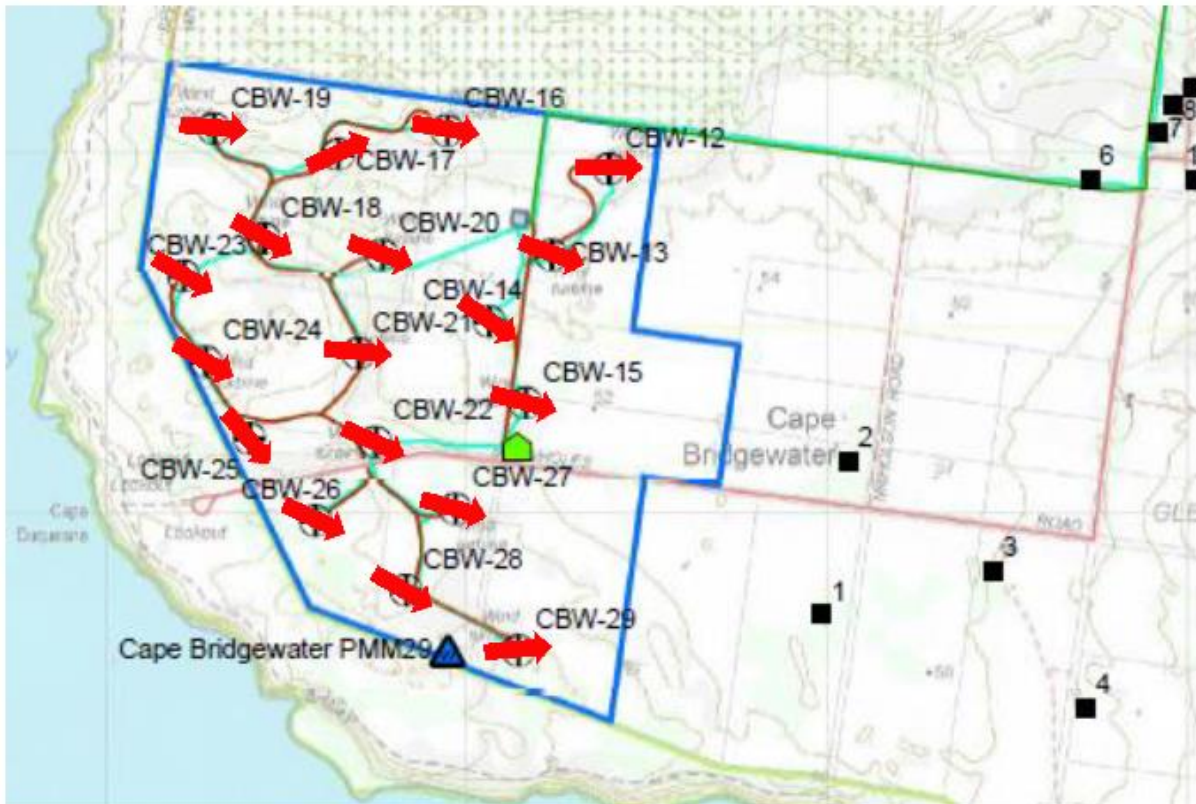


FIGURE 34: Average wind direction 9.00 AM - 9.10AM on 10th June 2014

If one considers the propagation of the turbine at the blade pass frequency to be occurring in the form of a cylinder or a cone (rather than a hemispherical radiation) then extrapolation of the direction of the turbines would suggest that at house 88 the impact at that time is generated by a few turbines rather than the entire wind farm. Similarly, with respect to house 87 that impact may be attributed to a few turbines south of Blowholes Road.

This concept would appear to agree with the suggestion in the pre-test attenuation that whilst turbine CBW 15 may be the major source with respect to house 88, the influence of the other turbines giving a slightly lower amplitude would artificially move the centre of the noise source for the turbines approximately 200 m to the west of turbine CBW 15.



Whilst TAG has not undertaken any numerical analysis in terms of this concept, looking at the data and changing the distances to have the curve fit into a more linear approach in the pre-house testing may be an entirely incorrect method. However, utilising the graphical representation of the relative direction of the turbines at a particular point in time when the measurements were undertaken is not something that can be lightly dismissed.

The consequences of the propagation of wind from turbines that can impact upon other turbines leads potentially to a change of the inflow for the next turbine and reduces the efficiency or the power output of the turbine must affect the propagation of noise from the wind farm.

What this exercise demonstrates is that the evaluation of the wind farm and the noise produced by the wind farm, if one is investigating sensation complaints, will be extremely more complex than consideration of a point source located on a map with an equal propagation at 6 dB per doubling of distance, disregarding any interference effects between the noise propagated from individual turbines and/or the direction of propagation from turbines.

6.5 ON – OFF Testing

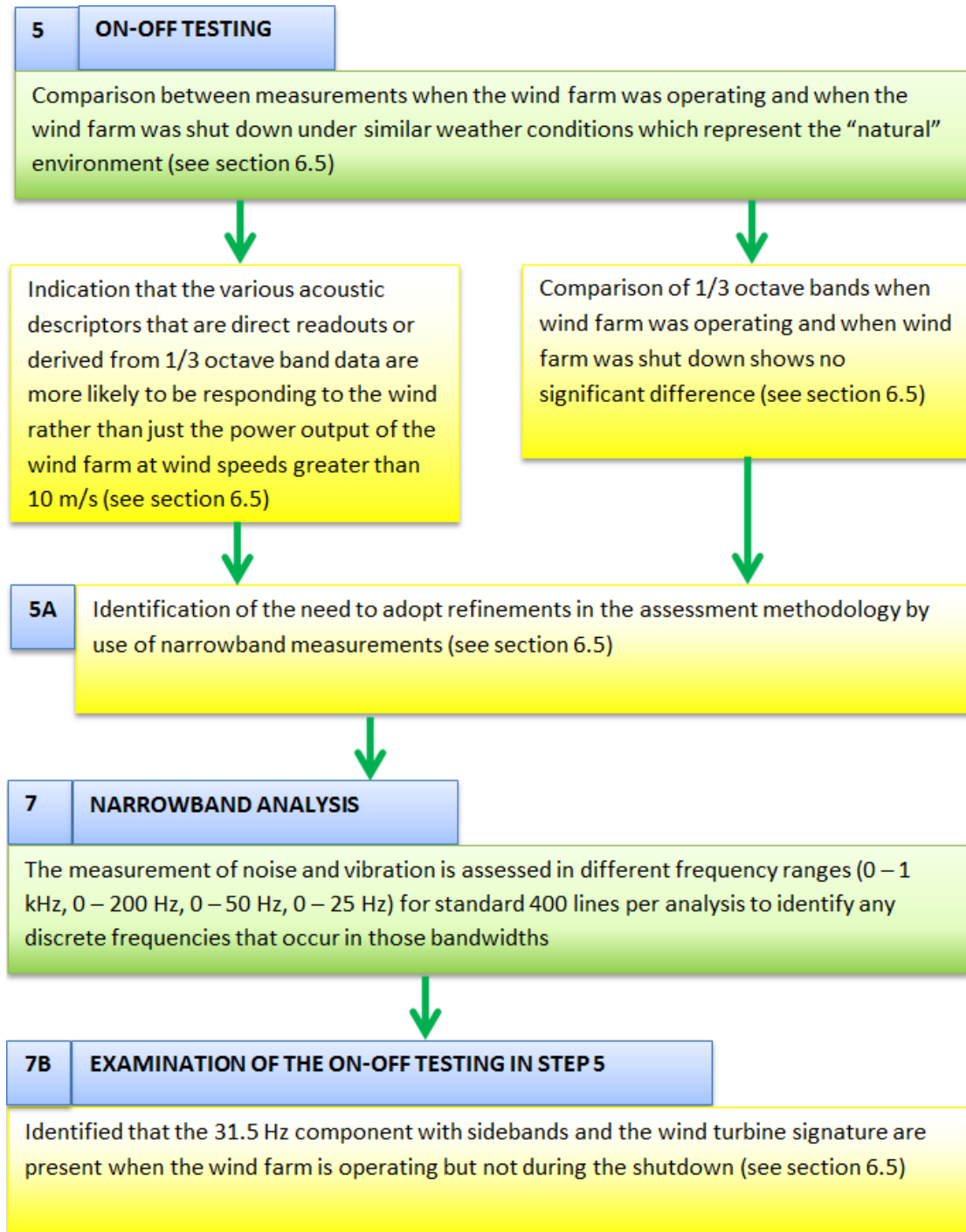
With the requirement for the wind farm to be shut down over a nominal 10 day period for the purpose of high-voltage cabling work, the opportunity to compare measurements between the wind farm operating and the natural environment was considered to be of significant importance to the study, both in terms of the impact assessment undertaken by the residents and examination of acoustic data during that period.

The majority of high-voltage cabling work would appear to be related to the daytime period with the shutdown of the wind farm occurring around 6.30 AM and the reactivation of the wind farm in the late afternoon/early period.

During the course of the monitoring the residents advised that there were a number of days where there was a complete shutdown of the turbines that included the night time period.



Parts 5 and 7B of Figure 2 relate to the investigation of the on-off testing.



As shown in Figure 35, the turbines incorporate a UPS that permits the recording of wind data for a period of approximately 30 to 40 minutes after the power to the turbines had been disconnected and therefore provides accurate material in relation to the wind speed and direction prior to and after the shutdown.

Having identified that there is a relationship between the power output of the wind farm and the 1/3 octave band covering the blade pass frequency, that shows a substantial increase when the wind farm is operating, examination of noise data prior to and after a shutdown for different wind conditions allows examination of the differences under relatively stable weather conditions. The total shutdown of the wind farm overcomes the testing for a temporary cessation of a turbine that can still have ventilation equipment for each turbine operating and possibly remote turbines operating on another wind farm such as found at Waterloo.

Utilising house 87 (the empty house) with no internal activities to contaminate the data permits examination of the ON-OFF situations both external to and inside the dwelling from the recordings obtained by the multichannel system.

Figure 35 shows the internal noise levels (0.8 Hz 1/3 octave band, dBA LF, dBG and LSL) in 10 minute intervals over a shutdown period for Thursday 15th May 2014 (corresponding to Appendix N1) with the power output highlighted to show the shut-down of the entire wind farm at 6.30 AM and start up at 7 PM.

Due to the UPS system in the individual turbines, the anemometers continued recording wind data for a short period after the turbines have been shut down. It was observed on the days chosen (i.e. 15/05/14 and 27/05/14) that the wind conditions remained relatively constant after the turbines had been shut down.

This provided the opportunity to analyse an ON versus the OFF situation where it can be assumed that the noise levels due to the wind are relatively similar in both cases. This includes both the overall external level and internal levels due the excitation of any room modes.

Appendix N provides the results of the ON-OFF analysis including overall averages of the 10 minute samples prior to and after the shutdown including different averaging and scanning windows.



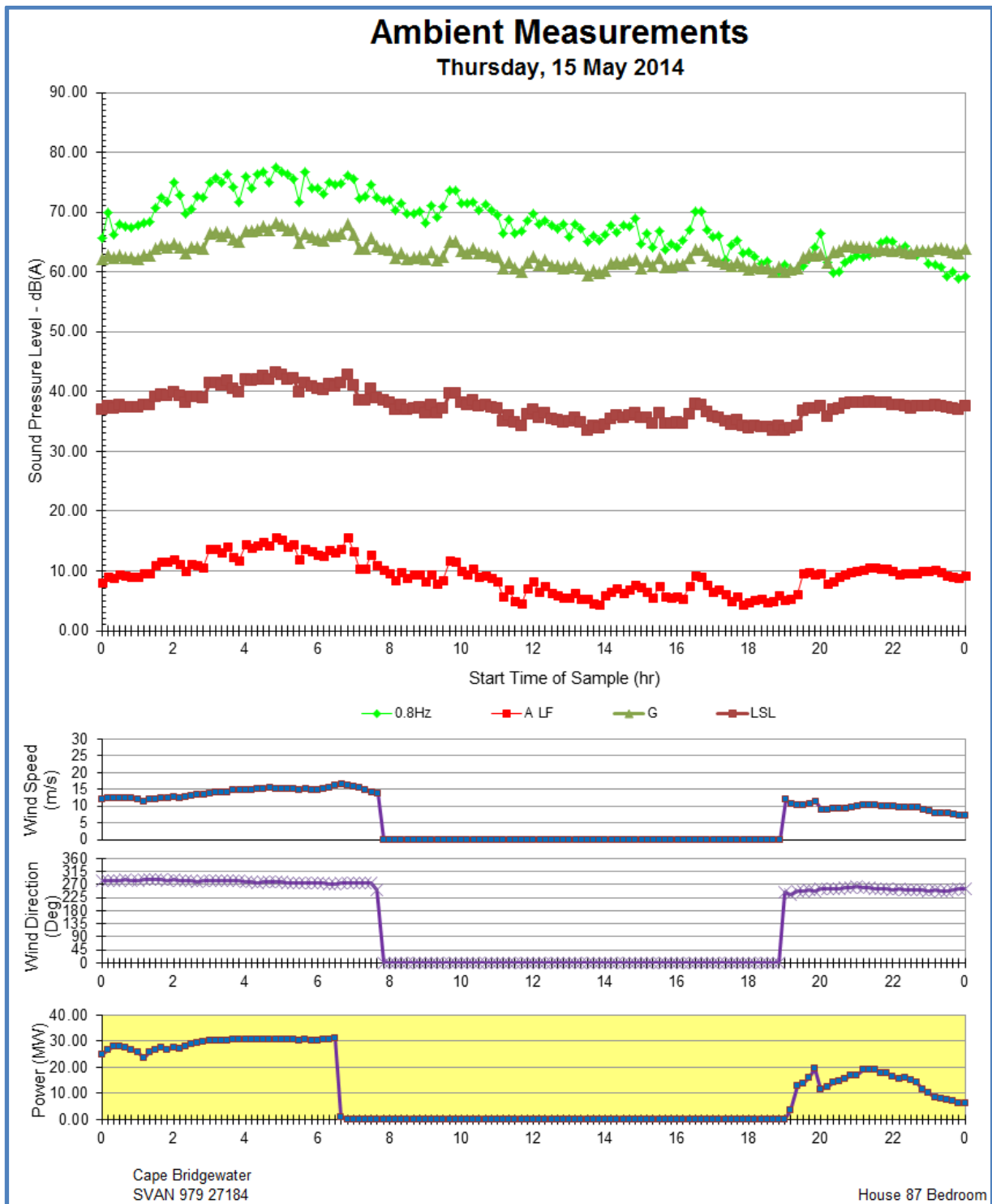


FIGURE 35: House 87 Results during a shutdown



Figure 35 shows the wind prior to and after the shutdown to be from the west at or near the speed for maximum power output. Being a 10 minute average of multiple turbines it is expected that the wind will vary about this nominal level. Nevertheless the average power output for the 10 minute period is 30MW which is, for the 17 x 2MW turbines, approximately the combined rated maximum output for the turbines.

The following table sets out times of the 10 minute samples used in the following analysis and the corresponding turbine data. The wind power, wind speed and wind direction were 10 minute averages of the hub height anemometer results from turbines CBW 12-27.

Date	Turbine Status	Time	Power Out (MW)	Wind Speed (m/s)	Wind Direction (°)
15/05/2014	Operating	600	30	15	275
	Shutdown	700	0	16	278
27/05/2014	Operating	600	8	9	262
	Shutdown	730	0	11	270
28/05/2014	Operating	1750	3	5	187
	Shutdown	1720	0	5	250

For evaluating the ON-OFF situation the procedure that has been adopted is to consider a 10 minute sample recorded at 6 AM when the wind farm is operating and at 7:00 – 7:30 AM when the wind farm has been shut down for an average wind speed of 15 m/s, 10 m/s, and a nominal 3 to 5 m/s (that from the previous section is a scenario that could have some turbines operating and other turbines not operating). Appendix N provides the results of the various scenarios assessed.

The 15th May scenario corresponds to a high wind situation where the turbines are at or near their maximum power output when operating, with house 87 in a downwind situation. The 27th May scenario corresponds to a moderate wind situation resulting at a moderate-low turbine power output also with house 87 in a downwind situation.

The third scenario assessed was for a moderate wind at house 87 in an upwind situation, with the fourth scenario for an upwind situation but low power output.

The current assessment procedure for the evaluation of noise emission from wind farms relies upon measurements external to the dwelling, although from the Standard there is identification that the Standard is based on an internal noise level to protect against sleep disturbance.



From Appendix N, commencing at Appendix N4, the 1/3 octave band results for the 15 m/s wind reveals little variation in the A-weighted level between ON and OFF although the ground plane microphone and the elevated microphone reveal differences in the 31.5 Hz 1/3 octave band and in the 63 Hz 1/3 octave band.

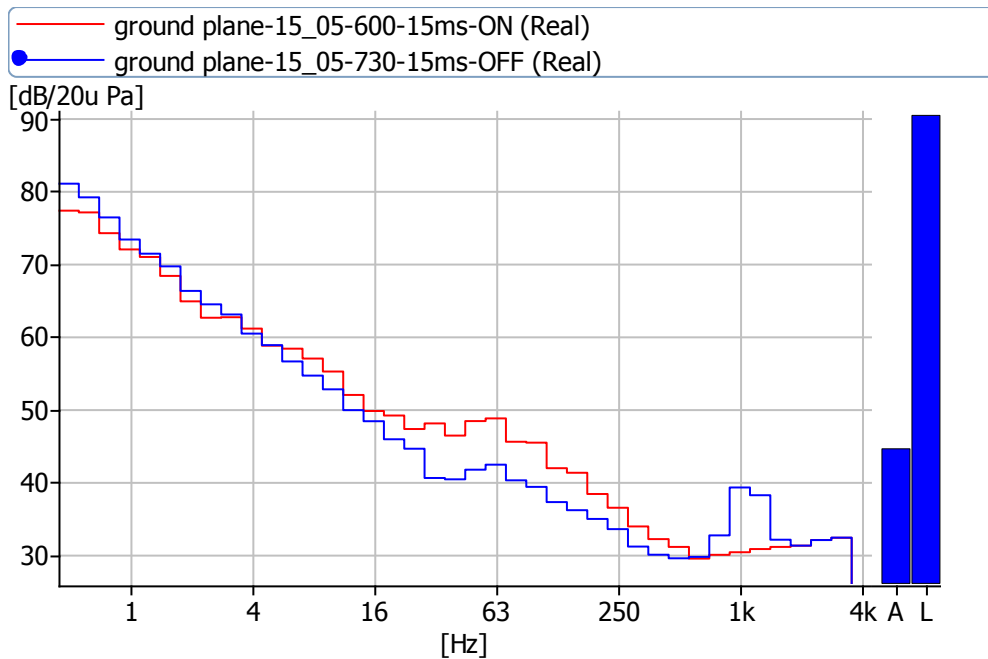


Figure 36: House 87 Results Wind Farm ON and OFF (1/3 octaves)

The noticeable differences relate to low-frequency noise whilst in terms of the infrasound components there are no significant differences when using 1/3 octave bands leading to agreement with the concept there is no difference between a natural environment and a wind farm affected environment if only dealing with 1/3 octave band results.

However, as noted elsewhere in this report the above results being an Leq (energy average) will be biased towards the higher levels that occur. The wind strength that has been recorded as a 10 minute average suggests that for a fluctuating wind there can be a significant variation in the overall level. This is entirely consistent with the general concept used for regression analysis that indicates as the wind increases in strength so does ambient background, and therefore so will the Leq level (although at potentially a greater rate).



In considering the narrowband analysis with respect to the low-frequency region (below 200 Hz) there is a difference between ON and OFF where there is generally a higher average noise level for the ON situation that reveals slight peaks in the region of 31.5 Hz, and no significant peak at 63 Hz (that was suggested in the 1/3 octave band) and a slight peak in the order of the 150Hz.

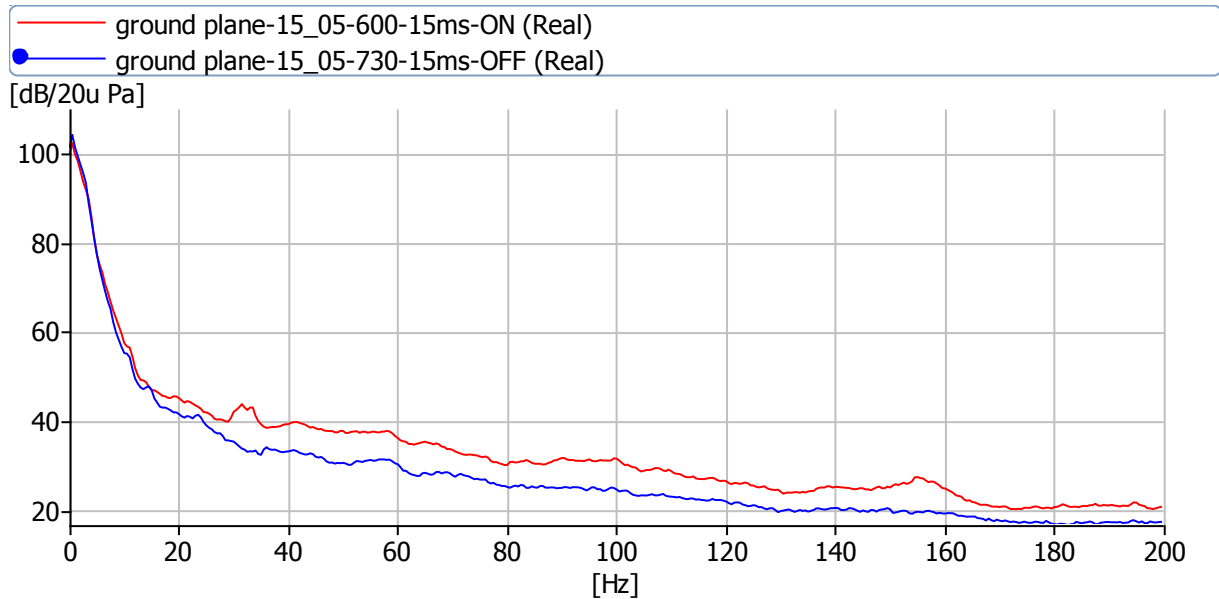


Figure 37: House 87 Results Wind Farm ON and OFF (0 – 200 Hz) – HIGH WIND

The corresponding sonograms for the range of 0 to 200 Hz in Appendix N5 show the vertical line corresponding to the 31.5 Hz component and shows horizontal lines across the graph being the impact of individual pulses which are attributed to the fluctuations in the wind. These fluctuations generate a higher level than the constant 31.5 Hz and contribute to the Leq level that has a bias to the higher levels. By reason of the frequency span used in the analysis, the fluctuations only show slight differences in the Leq between the ON and the OFF situation.



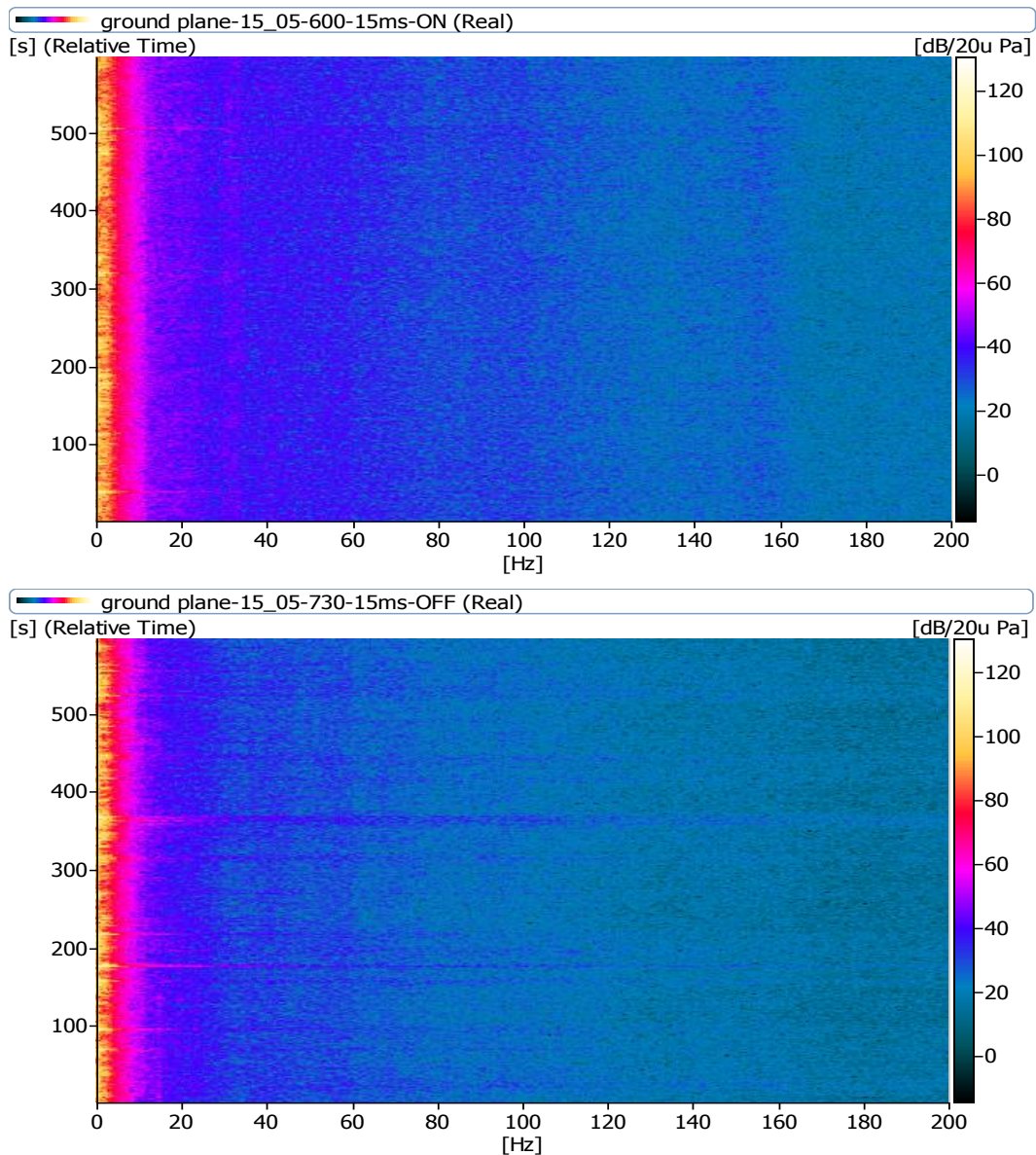


Figure 38: House 87 Results Wind Farm ON and OFF (0 – 200 Hz) – HIGH WIND

The narrow band data when presented on a logarithmic frequency scale (to accord with the 1/3 octave bands) indicates some discrete frequencies although not significant when compared to the general background level, which by the analysis technique are Leq levels.

Use of a linear frequency axis for the narrow band results provides a different perspective and reveals the following Leq spectra outside the dwelling.



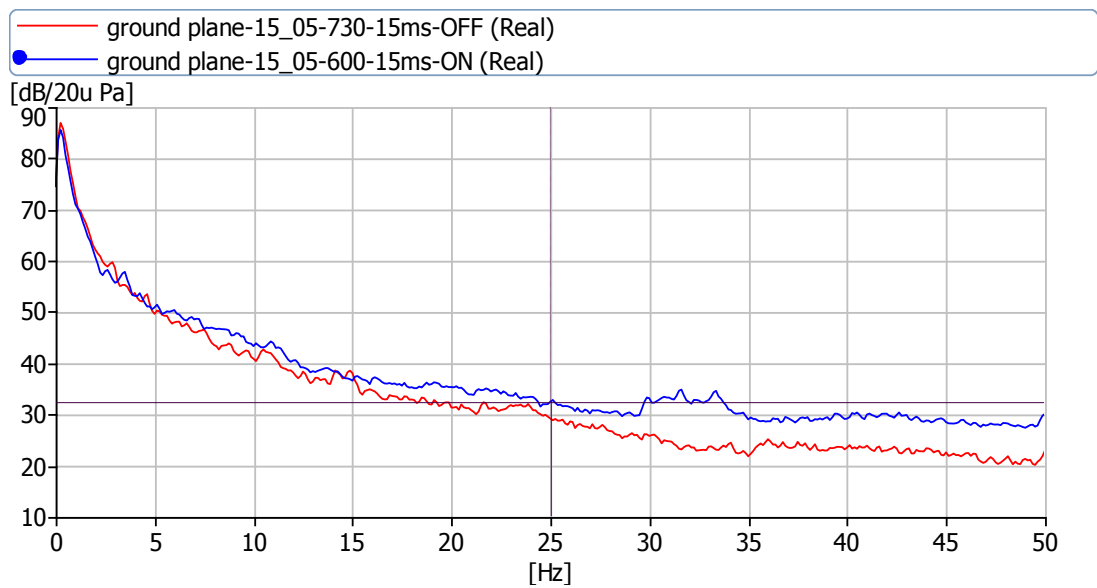


FIGURE 39: House 87 Results Wind Farm ON and OFF (0 – 50 Hz) – HIGH WIND

The spectra in Figure 39 show minor differences in the blade pass frequency (and harmonics) and the 31.5 Hz peak (with sidebands), with an elevated base levels above 30 Hz. However the use of an Leq level (supplied by most analysers as a Linear average) will be affected by the fluctuations in the wind during the measurements.

Appendix N provides a series of spectra obtained for the ON-OFF tests and includes sonograms that show the variation in the sound pressure level (by different colours) for individual frequencies at each 1/10th of a second. The use of a sonogram provides a tool for exploring the differences in the various spectra over a 10 minute sample.

Figure 40 is the sonogram for the high wind measurements with the wind farm ON (prior to the shut-down), for the frequency range of 0 – 50 Hz. The wind peaks are of a lower intensity than obtained 90 minutes later. The presence of a vertical band at 31.5 Hz in the sonogram identifies a particular frequency throughout the sample – although at times the wind tends to mask the line.



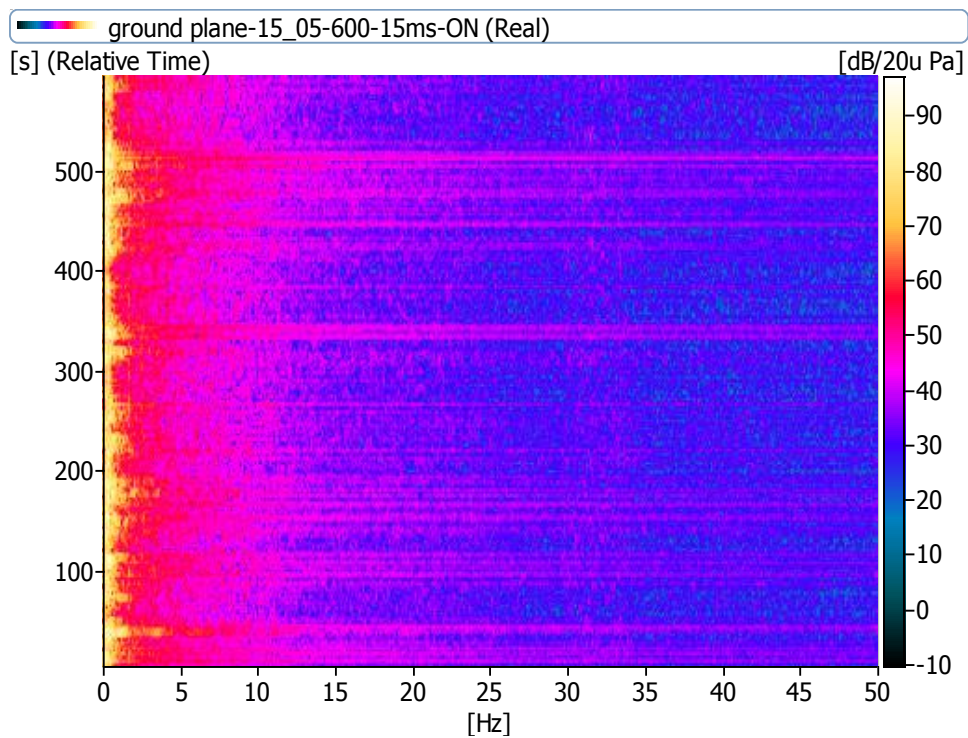


FIGURE 40: House 87 Results Wind Farm ON (0 - 50 Hz) - HIGH WIND

Reducing the bandwidth of Figure 38 in the narrow band analysis to a limit of 50 Hz exposes the difference in the ON-OFF scenarios.

Comparing the 10 m/s wind average wind speed for the ON-OFF tests reveals a more distinct characteristic for the 31.5 Hz component and the distinct frequencies being harmonics of the blade pass frequency as shown in Figure 41.



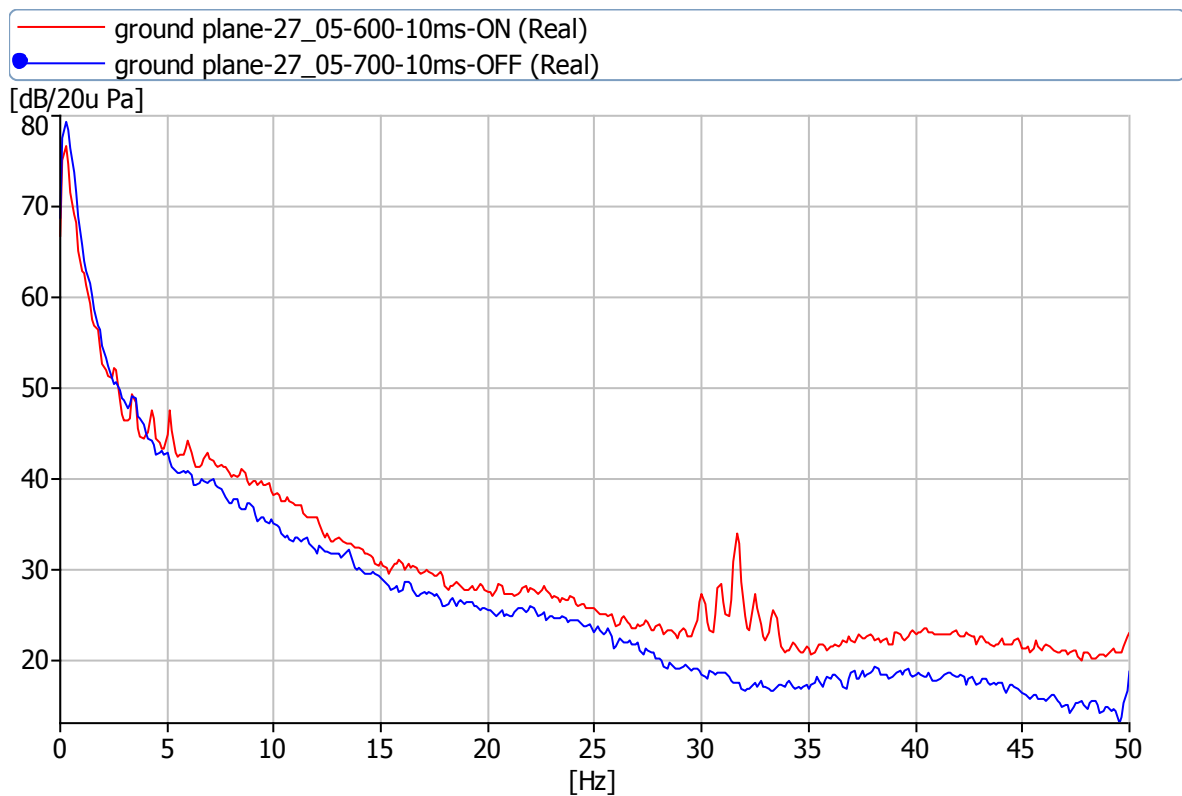


Figure 41: House 87 Results Wind Farm ON and OFF (0 - 50 Hz) - MODERATE WIND

If one superimposes the narrowband FFT results onto the 1/3 octave band spectra, by restricting the frequency range to 50 Hz, as shown in Figure 42, it becomes apparent that with respect to the infrasound region there is clearly a difference between ON and OFF that is not apparent by restricting the analysis exclusively to 1/3 octave bands.



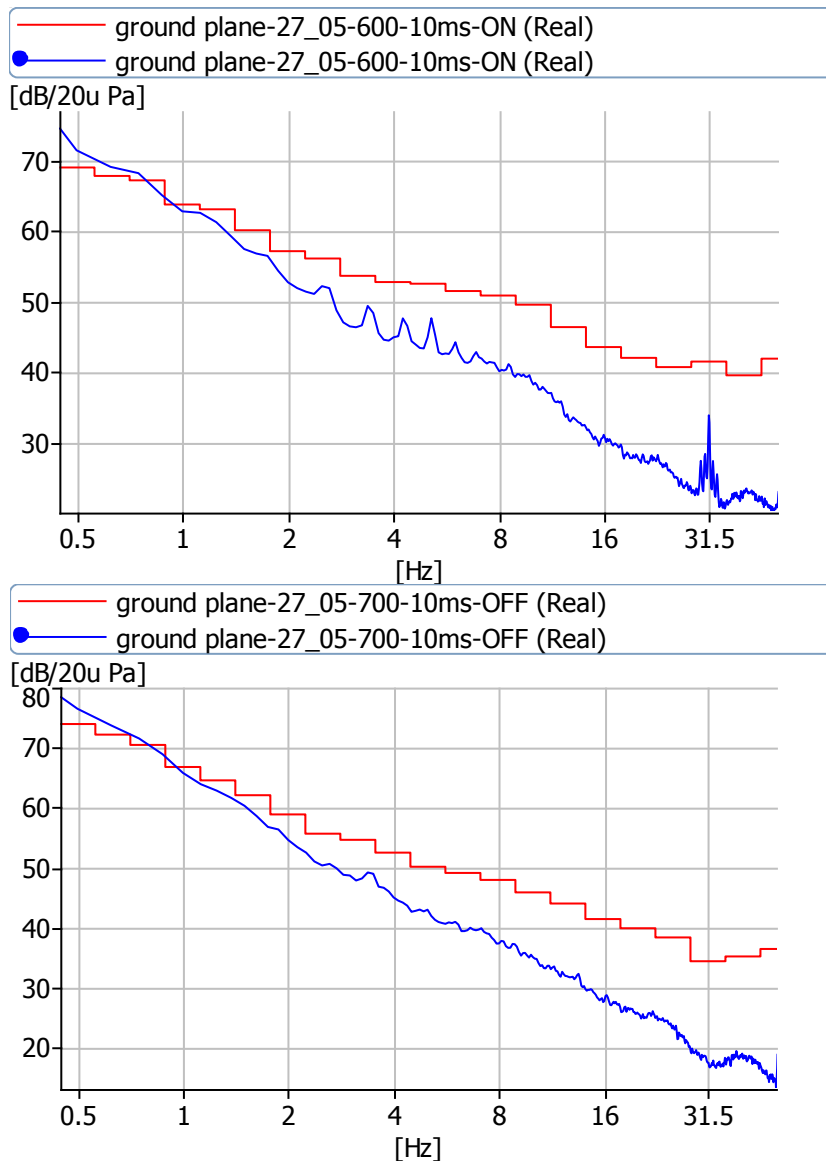


FIGURE 42: House 87 Results Wind Farm ON and OFF - MODERATE WIND

Reducing the analysis to a bandwidth limit of 10 Hz over 400 lines will realise a line spacing of 10/400 (a resolution of 0.025 Hz) so that the presence of harmonics of the blade pass frequency for the ON situation versus the OFF situation is readily apparent in Figure 43 (Appendix N10), as is the influence of pulses associated with wind.



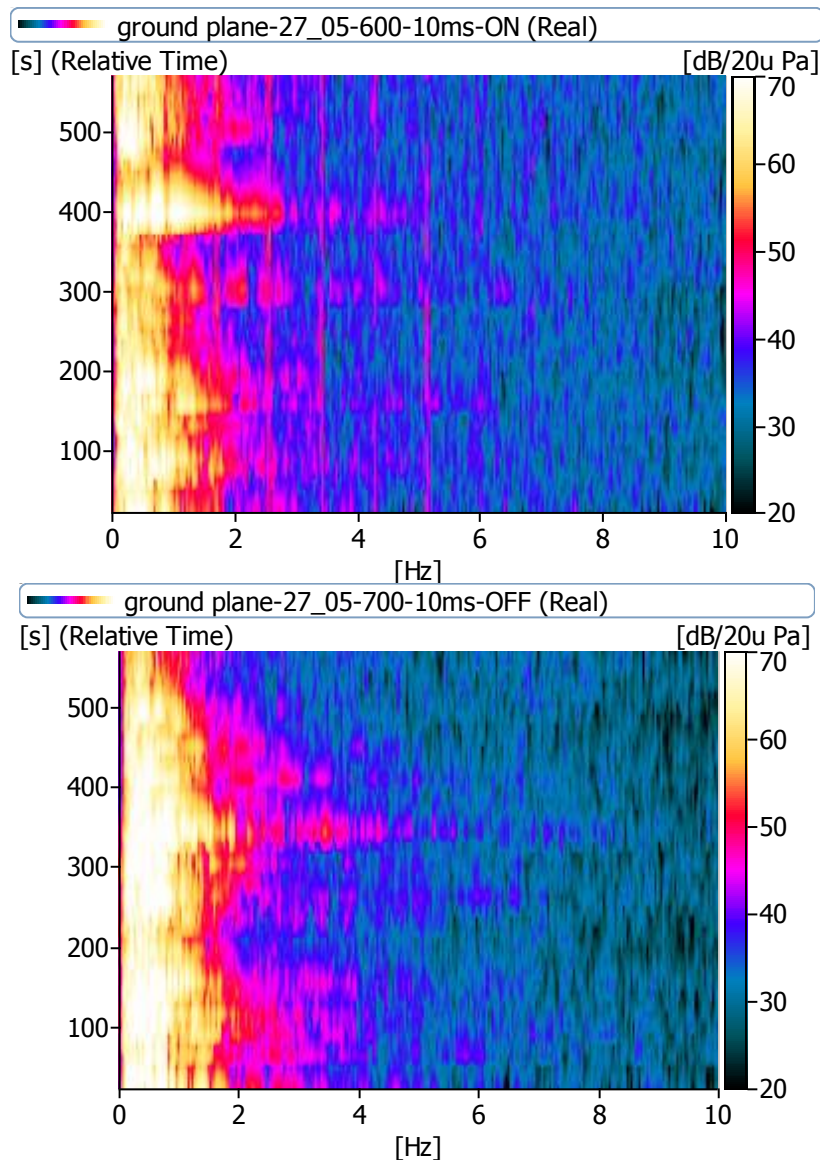


FIGURE 43: House 87 Results Wind Farm ON and OFF – MODERATE WIND

Appendix N12 provides sonograms for the light wind condition identified as an average of 5 m/s. The spectra do not indicate discrete frequencies in the infrasound region. By reference to Figures 27, 28 29 and 31 it is apparent that at that speed there can be turbines operating but not producing power. As the speed of the turbines is unknown a question arises as to the nominal blade pass frequency at start up. Testing on CBW 13 (discussed in the following sections) addresses the low wind speed operations.



As the complaints from residents primarily relate to inside their dwellings a similar exercise for the internal microphones at house 87 was carried out.

Figure 44 provides a comparison of the internal levels (in the living room) for the high wind scenario with a direct comparison of ON and OFF using 1/3 octave bands to reveal no significant differences.

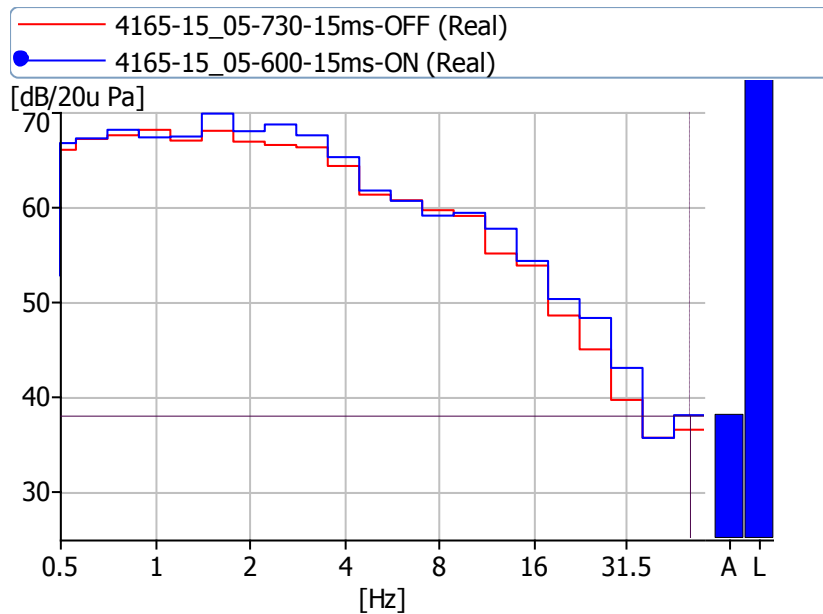


FIGURE 44: House 87 Results Wind Farm ON and OFF

Figure 45 provides the 1/3 octave band results for the wind farm ON with high wind and superimposes the narrow band FFT rms results.



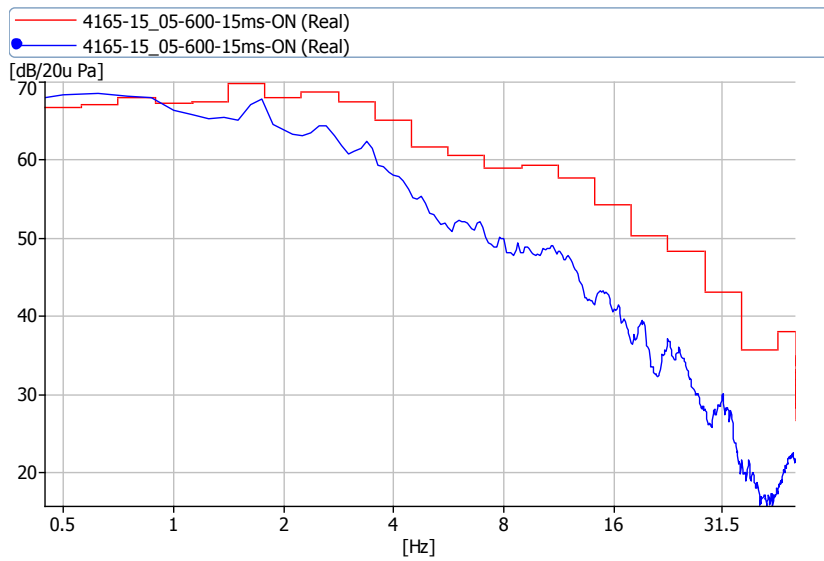


FIGURE 45: House 87 Results Wind Farm ON - HIGH WIND

Similarly Figure 46 considers the moderate wind scenario for the wind farm ON. As the above results are provided for comparison purposes all the results are presented as rms levels read by the analyser without any conversion to power spectral density.

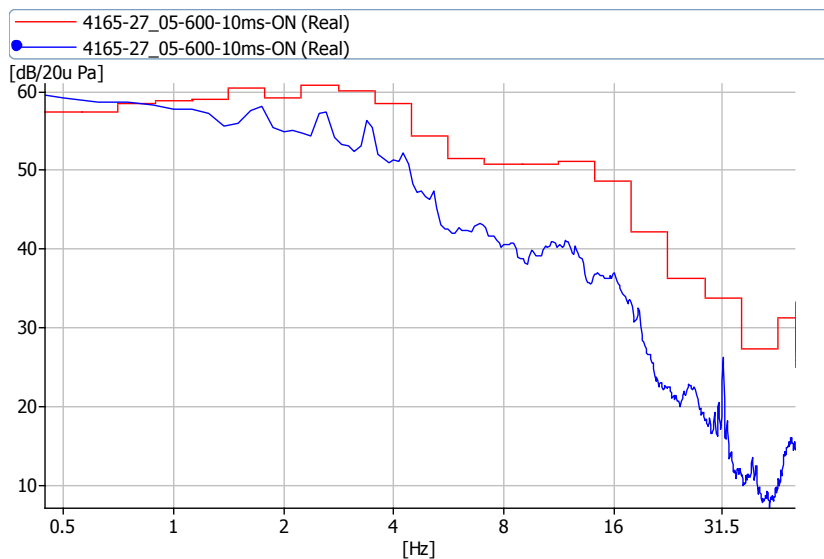


FIGURE 46: House 87 Results Wind Farm ON - MODERATE WIND

Appendix N includes similar analysis for different frequency ranges for the other ON-OFF tests for the external locations and inside the living room and bedroom of house 87.



Appendices N22 & N23 reveals a number of discrete frequencies in the bedroom with the wind farm not operating. These frequencies are found to be resonant frequencies in the bedroom (room modes), noting that there was no equipment or household items operating in the bedroom.

Following the results of the testing with respect to house 87 Appendix N includes a similar exercise for the internal location in house 89 and exhibits similar outcomes to house 87 but having different magnitudes with respect to the multiples of a blade pass frequency and the 31.5 Hz tone that has been associated with the turbines at Cape Bridgewater.

In addition to the issue of averaging of the data, in typical narrow band analysis the default window for the filtering is the Hanning window. Different windows have different response times. For accuracy of the amplitude of transients the Uniform window provides slightly better results as shown in Appendix N29.

As discussed in the previous section there is an issue as to whether the general acoustic parameters will accurately identify the noise from the wind farm separately from the wind. Comparison of the ON and OFF results revealed the general noise levels to be influenced by the wind (both inside and outside the dwelling).

Appendix N30 compares the variation of the overall (Linear) level over time for each sample to show no significant differences for either outside or inside. If the wind farm was contributing to the overall levels one would expect a significant difference.

A similar exercise for the A-weighted levels is shown in Appendix N37 and indicates on an Leq basis no difference between ON and OFF, although there is a slightly smaller dynamic range for the OFF situation but not sufficient to identify any difference in the A-weighted levels to identify the operation of the wind farm.

Repeating the exercise of examining the ON-OFF testing with the dB(A) LF parameter reveals a slight reduction for the outside measurements but no reduction inside the dwelling.

Considering the individual 1/3 octave band levels for the ON situation versus the OFF situation indicates the derivation of the A-weighted contribution from the wind farm (being only the wind farm after excluding the ambient noise) at residential properties is unlikely to be obtained, i.e. it would appear difficult to actually derive a level of noise emitted from a wind farm at residential locations to indicate compliance or non-compliance with the permit conditions.



Appendix N also includes spectra during the shut-downs where the number of lines in the narrowband spectra is increased and highlights the presence of discrete frequencies that are related to or resonant modes of the tower and/or the blades that occur at the residential locations even with the wind farm fully shutdown. By reason of the presence of the turbines the ambient measurements at the house locations in the shut-down period are still not an environment free of infrasound components from the wind farm and strictly still not a “natural” environment.

The ON-OFF testing indicates the need for monitoring closer to the wind farm and calculation of the predicted level at residential receivers to establish compliance/non-compliance on a dB(A) basis, due to the noise generated by the wind.

The ON-OFF assessment indicates that the use of dB(A) LF can show a relationship with the power output of the wind farm but is more likely to be a response to the wind rather than just the wind farm when the hub height wind speed is at or above 10m/s. A similar conclusion can be found for the use of the broad based acoustic parameters that are direct readouts or derived from 1/3 octave band data.

However, the use of narrow band measurements for the infrasound region and the 31.5 Hz component identified from the measurements near the turbines are indicators of the operation of the turbines (as discussed in Section 6.6).

The concept of using micro barometers to monitor the infrasound region only (or as a result of this study with an extension to 40 Hz) to overcome microphone issues is a measurement system that has been used for wind farms to identify the signature of turbines.

Comparison of a shutdown on 22nd May 2013 is provided in Appendix N where an analysis of the ON-OFF noise measurements is compared with the results from the Infiltec pressure detector.



The concept of using micro barometers to monitor the infrasound region only (or as a result of this study with an extension to 40 Hz) to overcome microphone issues is a measurement system that has been used for wind farms to identify the signature of turbines. It is recommended that further work be carried out in this area as a mechanism for correlating complaints with the operation of the wind farm.

6.6 Narrowband Measurement Results

As set out above the use of the A-weighted level or any of the combinations of acoustic parameters determined from the 1/3 octave band results did not find any strong relationship with respect to the noise observations provided by the residents.

Whilst at the present point in time the permit conditions are expressed in terms of an L95 level (assessed by a regression method from the NZ Standard) the Standard seeks a noise contribution in Leq. The analysis of narrow band (and 1/3 octave band) are conducted using Leq.

The Leq level for the dB(A) value the ON-OFF testing as a result of the planned shutdowns did not reveal any significant difference in the A-weighted Leq value and on that basis would suggest there is some difficulty in determining the contribution from the wind farm separately to the Leq level determined by the wind.

As such the regression line method that does not take into account the wind direction or different seasons and assumes the comparison of before and after the construction of the wind farm identifies the contribution is questionable.

One possibility to determine the contribution is where there is a modulation of the A-weighted value one could look to the minimum level of that value as an indication of the background level and the maximum level of the value as to the ambient background plus the wind farm, so as then derive a contribution of the maximum value. However this would require further computation to determine the Leq value over 10 minutes from the maximum level of modulation.

Where there is no significant modulation of the A-weighted level then there would be difficulty in determining the sound level contribution of the wind farm.



If one looks to spectral analysis, i.e. 1/3 octave bands, to derive a spectrum then there is a computational issue in that the Leq level includes the presence of wind. Similarly the background level must include the presence of a steady component of the wind but not necessarily the fluctuations.

On looking at 1/3 octaves, or a dB(A) or dB(G) basis, that is no difference in the acoustic environment at the residential locations with the wind farm operating versus the wind farm shutdown (relative to a corresponding wind strength and direction).

However, testing in proximity to wind farms by other researchers by the use of narrow band analysis has identified the presence of discrete components that in a general concept may be expressed as tones.

The determination of these narrowband components is generally obtained by the utilisation of the Fast Fourier Transform (“FFT”) that takes the time signal and determines periodic patterns (that occur in the time signal) as discrete frequencies in the frequency domain.

Typically the narrowband analysis expresses the frequency output in a linear domain and not the logarithmic presentation that occurs with 1/3 octave bands.

In general the default situation for narrowband analysis is to consider the nominated bandwidth in terms of 400 lines that are spaced in increments of equal frequency width across the total bandwidth that is being analysed. For example, if one is considering a 400 line narrowband analysis over the bandwidth of 0 - 400 Hz it then follows that each line in the analysis will occur at 1 Hz spacing.

Similarly 400 lines over 0 - 800 Hz range represent a 2 Hz bandwidth for each line and for 0 - 1600 Hz, each line would represent a 4 Hz bandwidth and so on.

It follows that if the narrowband analysis by the FFT method utilises a greater number of bands then the bandwidth will be smaller.

As a consequence of reducing the bandwidth in such analysis, to maintain the standard formula of $BT = 1$ requires the time of the analysis to be increased which as a result changes the number of averages that may be obtained from a 10 minute sample available to have statistical validity.



The graphs that have been provided in the previous sections shown narrowband analysis over different frequency ranges so as to highlight various characteristics in the mid and high frequency bands, separately to audible characteristics that occur in the frequency band of 0 – 200 Hz, that is then separate to the spectral information that occurs in the infrasound region which as already noted is inaudible in all cases of assessing the subject wind farm.

In seeking to compare the 1/3 octave band material with the narrowband data the graphs superimposed both sets of data onto the one graph where the levels are expressed as an RMS level being the standard default condition generally used in acoustic analysis. As discussed in Section 10.7.1 the correct method for narrowband analysis of wind turbines is to use Power Spectral Density which normalises the measured level in the narrowband output to a reference frequency of 1 Hz.

Where the FFT analysis has a bandwidth greater than 1 Hz per line the PSD level will be lower than the rms level, whereas where the bandwidth is less than 1 Hz the PSD level will be higher than the rms level.

This alters the absolute levels (of the FFT spectra) that are measured but not the graphical pattern of the spectra that are obtained.

As identified in Section 6.5 in relation to the ON-OFF testing, the narrowband analysis revealed the presence of a discrete frequency at 31.5 Hz together with side bands (on either side) that are spaced at multiples of the blade pass frequency.

The testing has also revealed in the infrasound region (below 20 Hz) there is a periodic pattern that shows discrete frequencies at the blade pass frequency and multiples of that frequency.

The pattern of the blade pass frequency and the first six or seven harmonics of that frequency have been described by TAG on previous occasions [24] as the “Wind Turbine Signature”.

As discussed in Appendix V, the wind turbine signature is the same as that mathematically derived by an FFT analysis of a pulse. The actual shape of the pulse, whether it is a square wave, a triangular wave or trapezoidal wave influences the relationship of the amplitudes of the harmonics of the fundamental frequency of the pulse. This accounts for in the majority of the examples the amplitude of the blade pass frequency (normally around 0.85 Hz) being lower than the second or third harmonic of that frequency.



Depending upon the bandwidth of the FFT used for the analysis of the infrasound components, the resolution available for identifying the wind turbine signature will vary.

For example, in the Shirley Wind Farm report [25] the primary narrowband analysis contained in the body of the report compared an outdoor measurement to an indoor measurement over the frequency range of 0.1 Hz to 1000 Hz with the frequency (horizontal) axis presented in a logarithmic format. For the frequency range in the lower frequencies of concern there is a limited set of data compared to the higher frequencies as discussed above.

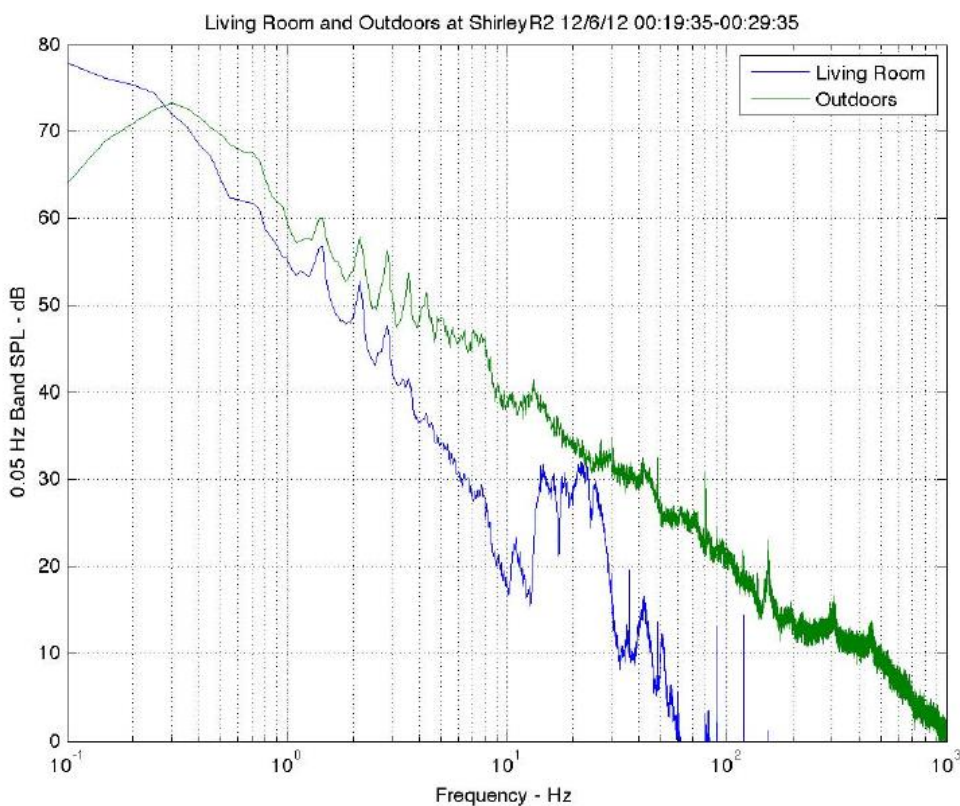


FIGURE 47: Extract from Shirley Wind Farm Main Report

As identified above for this study in seeking to differentiate the frequency components for the different regions of concern has considered combinations of 0-4 kHz, 0 - 1000 Hz, 0 - 200 Hz, 0 - 50 Hz, and 0 -10 Hz in analysing the emissions from the Cape Bridgewater Wind Farm.



When comparing that 1/3 octave and narrowband results in a graphical presentation using an RMS level and 400 lines per frequency per FFT the analysis has identified the presence of discrete frequencies that are not apparent in the 1/3 octave bands and as such highlights the benefit on refining the analysis to include narrowband results, i.e. restricting analysis to 1/3 octave bands will not identify characteristics that have been attributed to the noise generated from wind farms.

In a strict sense, the narrowband results should be expressed as power spectral density as per the Shirley Wind Farm results. If one seeks to compare directly with the 1/3 octave material then that material should also be expressed as power spectral density.

However, in general acoustics, the expression of 1/3 octave bands is in terms of RMS levels as the presentation of PSD levels in 1/3 octave bands will result in a different concept than what is normally encountered.

When one expresses both the 1/3 octave bands and narrowband analysis in PSD levels, then the relationship of the two signals becomes obvious in that they fall in line and clearly shows the relationship between the two levels. However, expressing the 1/3 octaves as an RMS level and the narrowband results as an RMS level provides an easier graphical interpretation of the capability for narrowband analysis to identify tones.

Whilst the sensation results obtained from the residents' observations were found to relate to specific power situations for the wind farm there was no correlation of the power output by reason of steady state operations giving rise to a lower sensation.

Figure 48 compares the same analysis for 10 m/s wind with the turbines operating with respect to the 1/3 octave band and FFT for RMS/RMS, RMS/PSD and PSD/PSD.

The PSD/PSD graph shows in a simple format the averaging of the narrow band frequencies across and individual 1/3 octave band (e.g. the 3.15Hz, 4Hz and 5Hz 1/3 octave bands) that can be considered as an Leq average across the frequency instead of in amplitude.



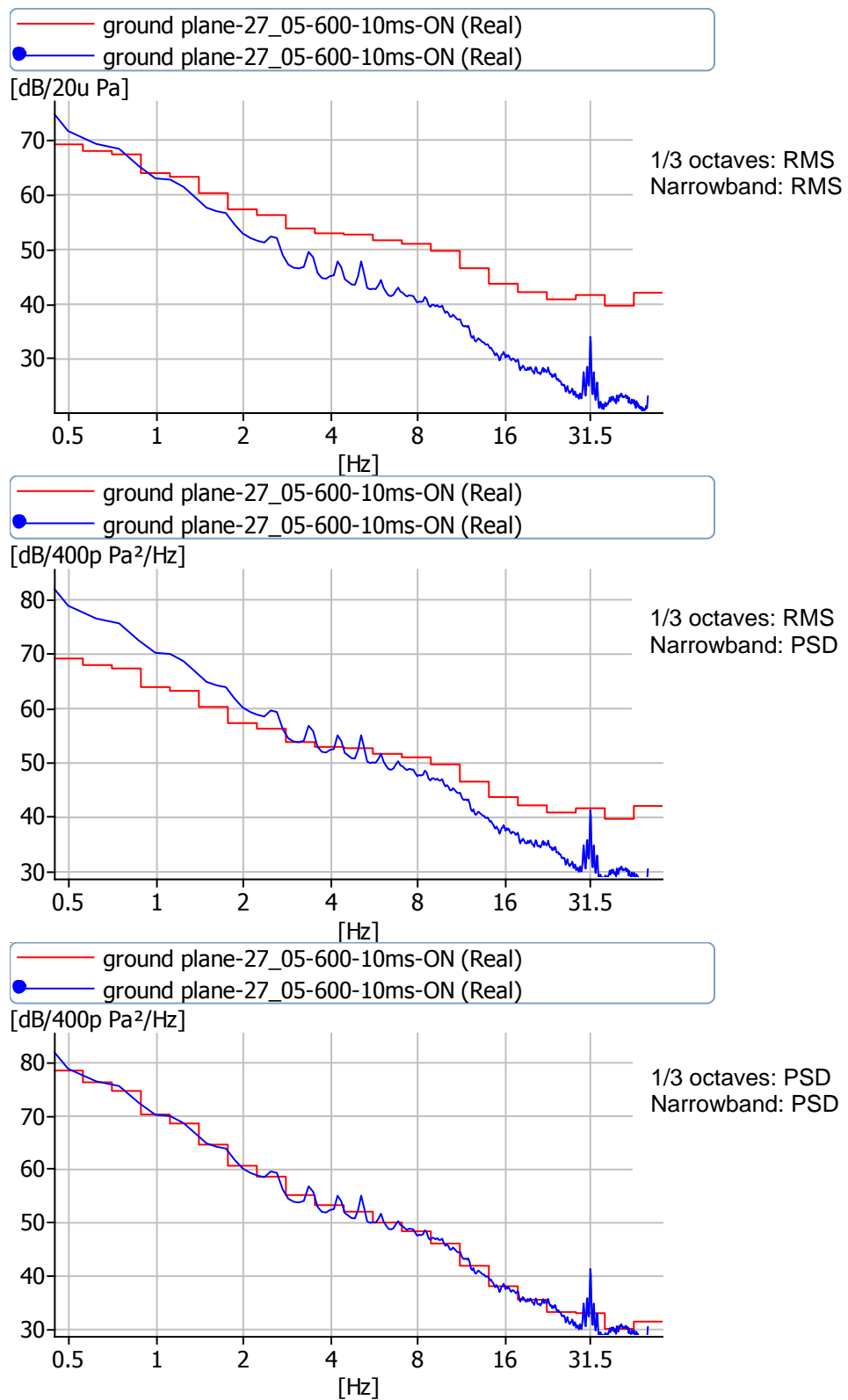


Figure 48: Comparison of RMS/RMS, RMS/PSD and PSD/PSD



Use of the narrowband analysis for the low frequency and the infrasound components attributed to the operation of the wind farm (specifically identified as a result of the ON-OFF tests) was re-examined in terms of the resident's sensation observations. In view of the time involved in analysis of the 10 minute samples a random selection of 166 of those observations were reanalysed so as to determine the WTS components and the 31.5 Hz component for sensation 5 and sensation 2, i.e. not all of the sensation 2 or sensation 5 results were reanalysed simply because of the time that would be involved in such analysis and the limits of this study.

6.6.1 Wind Turbine Signature

The conduct of narrow band measurements (FFT) in the infrasound region identifies the unique characteristic of the operation of wind turbines. The pattern shows a discrete peak at the blade pass frequency and multiple harmonics of that frequency.

In some case the harmonics can be up to the 10th harmonic but generally above the 5th harmonic the signal is masked by ambient noise.

In quiet rural environments the same pattern can be detected external to the dwelling and at some frequencies gives rise to lower levels externally to that recorded in the dwelling.

The author has previously identified this pattern of discrete frequencies related to the blade pass frequency as the Wind Turbine Signature ("WTS") and notes that other researchers have also shown the same pattern [17] [26] [27] [28].

In the recent release of preliminary findings on the Canadian Wind Turbine Noise and Health Study [29] reference is made to the Health Canada "Primer on Noise" (<http://www.hc-sc.gc.ca/ewh-smmt/noise-bruit/turbine-eoliennes/noise-bruit-eng.php>),[30] where the WTS is identified as:

*The frequency of rotation of a source can be used to help identify the source that is producing the sound. For example, a wind turbine with 3 blades, spinning at 16 revolutions (full rotations) per minute (RPM) will have a **fundamental frequency** that corresponds to 0.8 Hz (i.e. (3 blades X 16 RPM) divided by 60 seconds). Therefore, in this example, one can isolate the wind turbine sound from background noise if in the measured sound at a given distance, the sound level due to the wind turbine is high enough to show frequency peaks at the fundamental frequency and at multiples of the fundamental frequency. These multiples are called **harmonics** and for a source with a 0.8Hz fundamental frequency, they would be 1.6 Hz, 2.4 Hz, 3.2 Hz, 4.0 Hz, 4.8 Hz, and so on.*



Figure 2: Wind Turbine infrasound Measurements

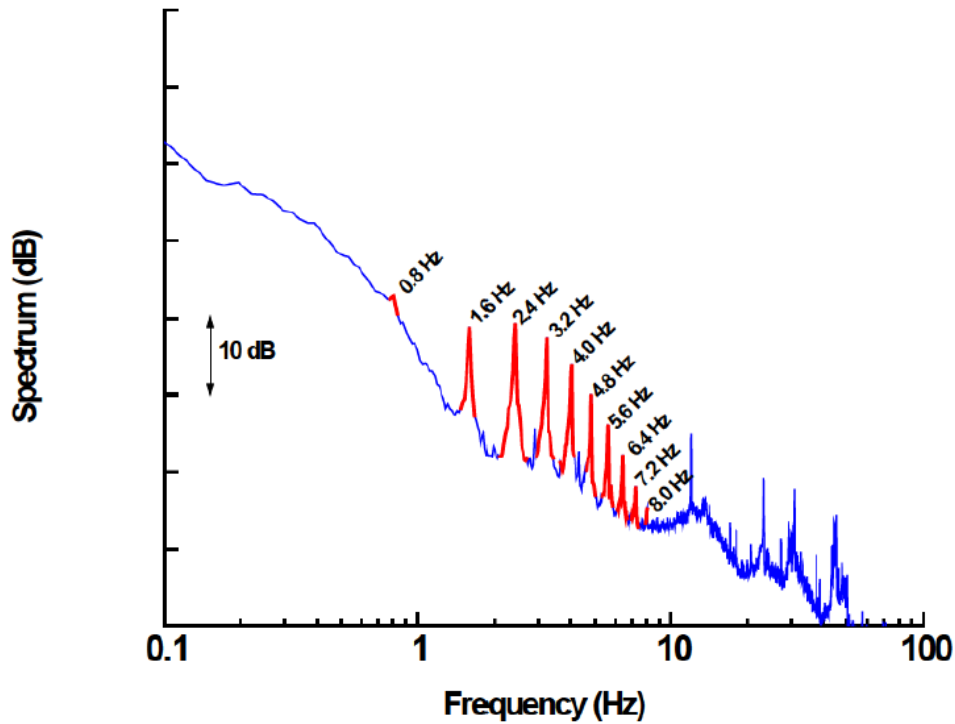


Figure 47 (from the Shirley Wind Farm report) provides a direct comparison of the WTS inside and outside a dwelling. In general the fundamental frequency (the blade pass frequency) is found to have a lower amplitude than the 2nd – 5th harmonics of that frequency).

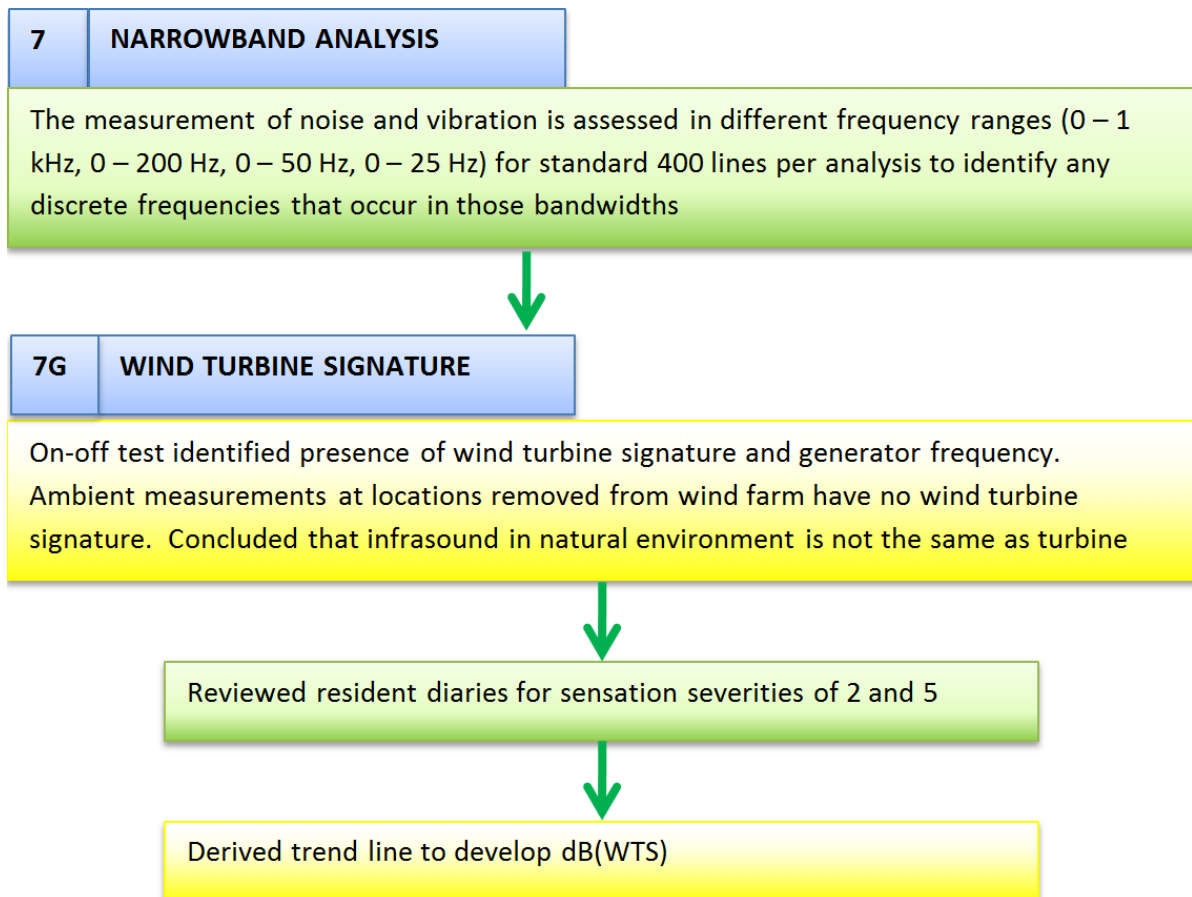
In looking at the WTS it is necessary to have the appropriate instrumentation that can accurately record the WTS in that many microphones/sound level meters have dynamic and frequency limitations/roll offs below 10 Hz (or lower) that affect the accuracy of the reported results (see Section 10 on Measurement Uncertainty).

The presence of the WTS occurs when the wind farm is operating but not when the wind farm is shutdown, or alternatively in the “natural environment”. As identified in the above extract from Health Canada the WTS has the ability to isolate the operation of a turbine/wind farm in an environment. The WTS has been recorded by the author and Hansen [31] out to 10 km from an operating wind farm and is readily apparent at the three houses used in the subject study



As the WTS can be extracted even in the presence of wind that overpowers/masks the dB(A) level it has relevance to the identification of the operation of a wind farm and benefit in addressing the fundamental aim of this study to relate the complaints/resident's observations to the subject wind farm.

Taking into account the above discussion Part 7G of Figure 2 relates to the investigation of the wind turbine signature.



The dB(A) charts of the logger results have coloured arrows (blue noise, green vibration and red sensation) with a number to identify the resident's severity ranking.



From the resident's diaries there are 441 Sensations classified as severity ranking 4, and 81 as severity ranking 5. A total of 323 Sensation 4 and 5 observations were examined in terms of the wind farm power output to find 194 of the observations fell into the wind farm operation sensation hypothesis proposed in this report (turbine start up, increase in power output of 20%, decrease in power output of 20% and maximum power output). The remainder of the Sensation 4 & 5 events would be either steady moderate winds or changes less than 20%.

Whilst sensations 4 & 5 would normally be grouped for analysis, as sensation 5 is of a level that would make the specific residents in the study want to leave their premises to obtain respite, the following analysis is based on sensation severity 5 and being the absolute worst case scenario. Noting that the degree of time involved in analysing the data for sensation 4 would be significant.

Of the 81 Sensation 5 observations the noise data is missing data for 30 of those results.

In considering the WTS material in relation to Sensation 5, of the 51 remaining wave files, 7 results were not used because when the hub height wind speed was in the order of 18 m/s (or more) the ambient Leq as a result of the wind masked the WTS thereby leading to those samples removed from the analysis.

Similarly for the start/low power sensation 5 the analysis found the blade pass frequency to be much lower than 0.85 Hz and as such did not give the same harmonic frequencies as for higher wind speeds. For the analysis 13 (all) start up sensation 5 results were excluded.

Figure 49 provides a plot of the WTS and 31.5 Hz RMS components from a 400 line analysis for 0 – 50 Hz range for the sampled sensation 5 and a similar sample for sensation 2. Figure 50 are the same results but using PSD as the amplitude of the measured values.



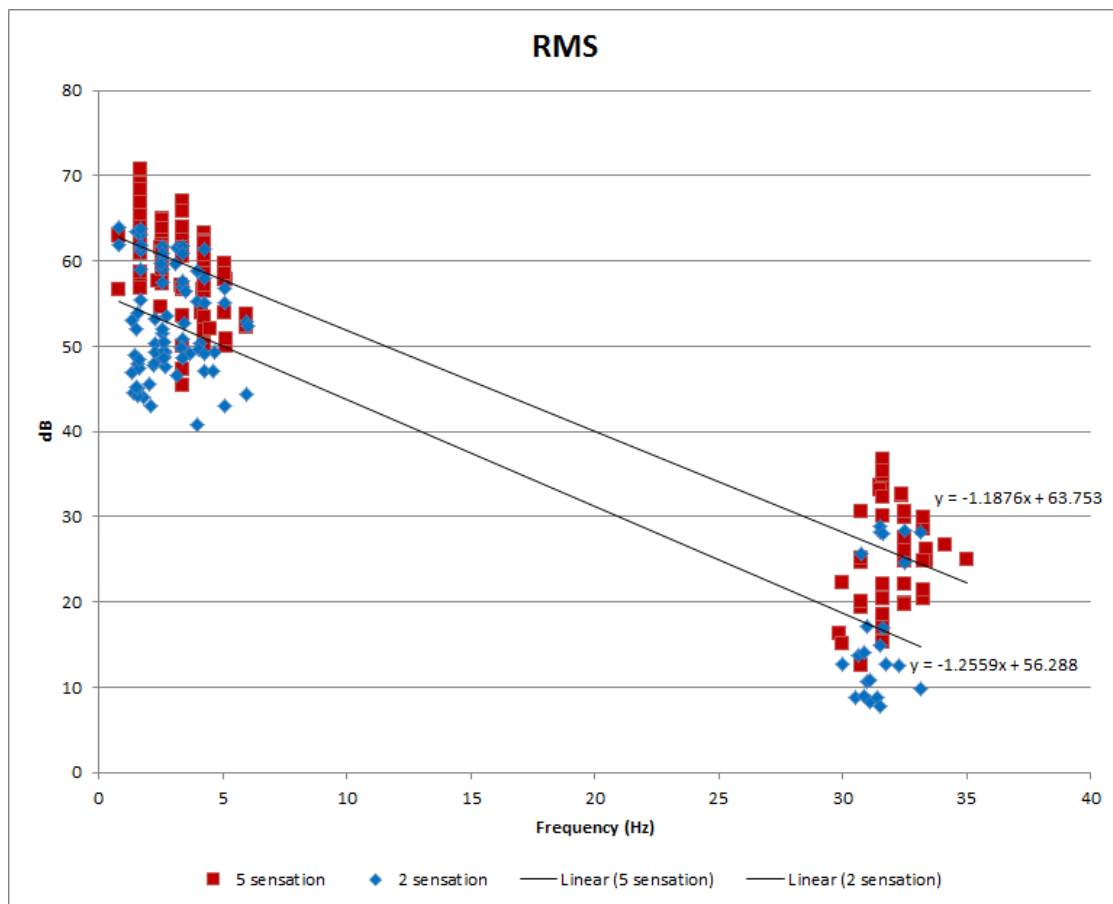


FIGURE 49: WTS and 31.5 Hz RMS components

The trend lines obtained from the limited set of data indicates an increase in the WTS and the amplitude at 31.5 Hz occurs when there is an increase in sensation.

As the WTS components in the infrasound are below 85 dB(G) then such infrasound levels are considered to be inaudible.

Figures 49 and 50 indicate a mechanism to identify the operation of the wind farm in terms of the perception of a sensation. The application of a mechanism based upon the trend line would satisfy the Pacific Hydro brief to ascertain any relationship between the complaints and the turbines.

The ON–OFF testing (shutdowns) shows the WTS and the modulated generator frequency to be absent when the wind farm is not operating (for both external and internal locations), whereas the dB(A) parameter for the monitoring locations used in this study did not show a difference (due to the wind).



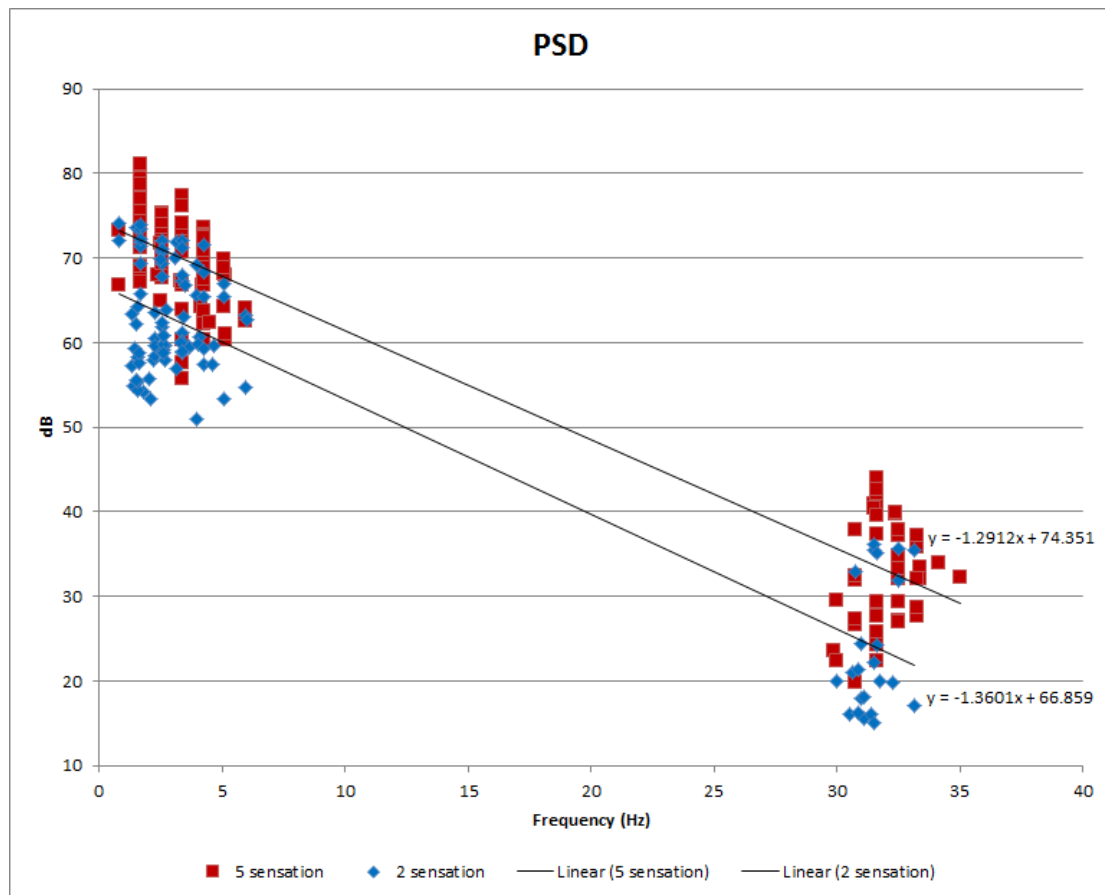


FIGURE 50: WTS and 31.5 Hz PSD components

The three houses being the subject of this study are exposed to the turbines and the surrounding environment. The measurement results could not determine an A-weighted contribution of the turbines.

However, that is not to say that all locations could not determine an A-weighted level of a turbine. For example, if a residential location was in a position that was shielded from the wind and as such had no wind noise on the microphone then there can be a difference in the dB(A) level for the wind farm operating versus shutdown and similarly a change in the WTS [32].

The above two graphs with the ON-OFF testing results indicate a mechanism to identify the operation of the wind farm that appear to be a tool to assist in other studies investigating the operation of a wind farm.



The above two graphs suggest that it is possible to determine an infrasound contribution from the turbines (even in the presence of wind) that from this limited study could suggest an acceptable and an unacceptable threshold by just looking at these components (even in the presence of fluctuating wind) by reason of the FFT analysis that looks for discrete periodic components.

A proposal for using the summation of the infrasound narrowband components (bpf to 10Hz) in Ontario [44] has suggested a limit of 50 dB Leq (1 hour), but has no identification of the measurement parameter.

In Figures 49 & 50 the trend line is extended out to 31.5 Hz and it is a frequency that has been found at Cape Bridgewater to be associated with the operation of the turbines that is not present when the turbines are shutdown.

The 31.5 Hz component is not part of the WTS by reason of it being in the close to the 37th harmonic of the blade pass frequency. Because the signature does not clearly show harmonics between the 6th and the 35th harmonic it is unlikely the 31.5 Hz is related to a mechanical operation of the rotor as the multiple of the rotor speed times the gear box ratio is less than 30 Hz.

Using the above trend lines and restricting the data to 0 – 10 Hz (shown in Figure 51) it is proposed that the point on the trend line at 10 Hz become the reference point for 0 dB weighting from which the correction factors for equal intensity are derived.

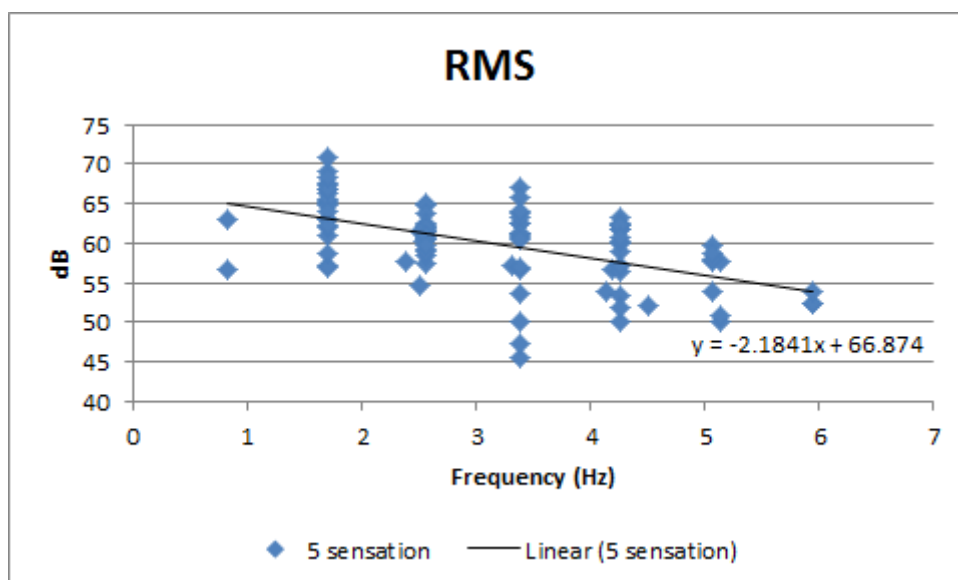


FIGURE 51: WTS RMS components



On the basis of the above rms graph it is suggested that for the sensation 5 trend line ($y = -2.1841x + 66.874$) the following weighting is applied to the discrete frequency components making up the WTS (derived using 400 lines, 0 – 25 Hz) to which then the logarithmic addition of those individual components becomes the dB(WTS).

Harmonic	Blade pass frequency	2 nd	3 rd	4 th	5 th	6 th	7 th	8 th	9 th	10 th	11 th
Frequency Hz	0.855	1.71	2.57	3.42	4.28	5.13	5.99	6.84	7.70	8.55	9.41
weighting	-19.97	-18.11	-16.23	-14.37	-12.49	-10.64	-8.76	-6.90	-5.02	-3.17	-1.29

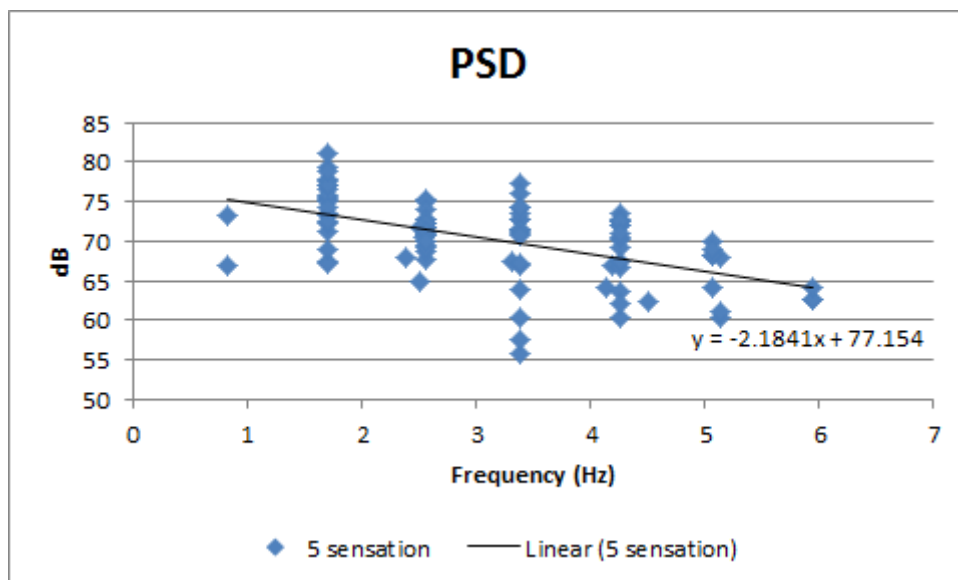


FIGURE 52: WTS PSD components

Similarly, on the basis of the above PSD graphs (using 400 lines) for 0 – 25 Hz analysis it is suggested that for the sensation 5 trend line ($y = -2.1841x + 77.154$) the following weighting is applied to the discrete frequency components making up the WTS to which then the logarithmic addition of those individual components becomes the dB(WTS).



Harmonic	Blade pass frequency	2 nd	3 rd	4 th	5 th	6 th	7 th	8 th	9 th	10 th	11 th
Frequency Hz	0.855	1.71	2.57	3.42	4.28	5.13	5.99	6.84	7.70	8.55	9.41
weighting	-19.97	-18.11	-16.23	-14.37	-12.49	-10.64	-8.76	-6.90	-5.02	-3.17	-1.29

By changing the resolution of the FFT analysis (either in the number of lines or expressed as a sample rate) can provide a finer degree of resolution but also a different amplitude.

The above corrections for the derivation of the dB(W TS) are based upon using 400 lines in an FFT analysis over the frequency range of 0 to 25 Hz.

If one was subject to a sine wave signal which is continuous in nature, then altering the resolution of the analysis would on an RMS basis give slight differences that should under power spectral density give the same result.

However the noise signature generated from a wind farm that has multiple turbines is subject to differences in amplitude due to the interaction of the signals generated by individual turbines that can result in addition and cancellation of the signal, and also the fact as identified by measurements on turbine CBW 13 that there can be variations in the speed of the turbine during a single 10 minute sample.

It therefore follows that if an individual turbine or multiple turbines are subject to different speeds during a 10 minute sample then there can be a spread of discrete frequencies if the blade pass frequency is not the same in all cases.

If however one assumes that there is a general similarity in terms of the speed of the turbines then the degree of difference between individual frequencies should not be that great. On that basis the residential location may be dominated by a few turbines by reason of the remainder of the turbines being significantly removed and therefore subject to a greater degree of distance attenuation.



If one assumes that turbines are operating at the same speed (which does not occur) but there are interference patterns that result in a variation of amplitude at the discrete frequencies the consequence of changing the number of lines for the same overall frequency span whilst providing a finer resolution of the discrete frequencies will give rise to a different averaging time for the analysis that can give rise to differences in levels for the same 10 minute sample.

Figures 53, 54 and 55 utilise a 10 minute sample recorded inside the bedroom of house 87 that correspond to the resident's observation of a five severity in sensation.

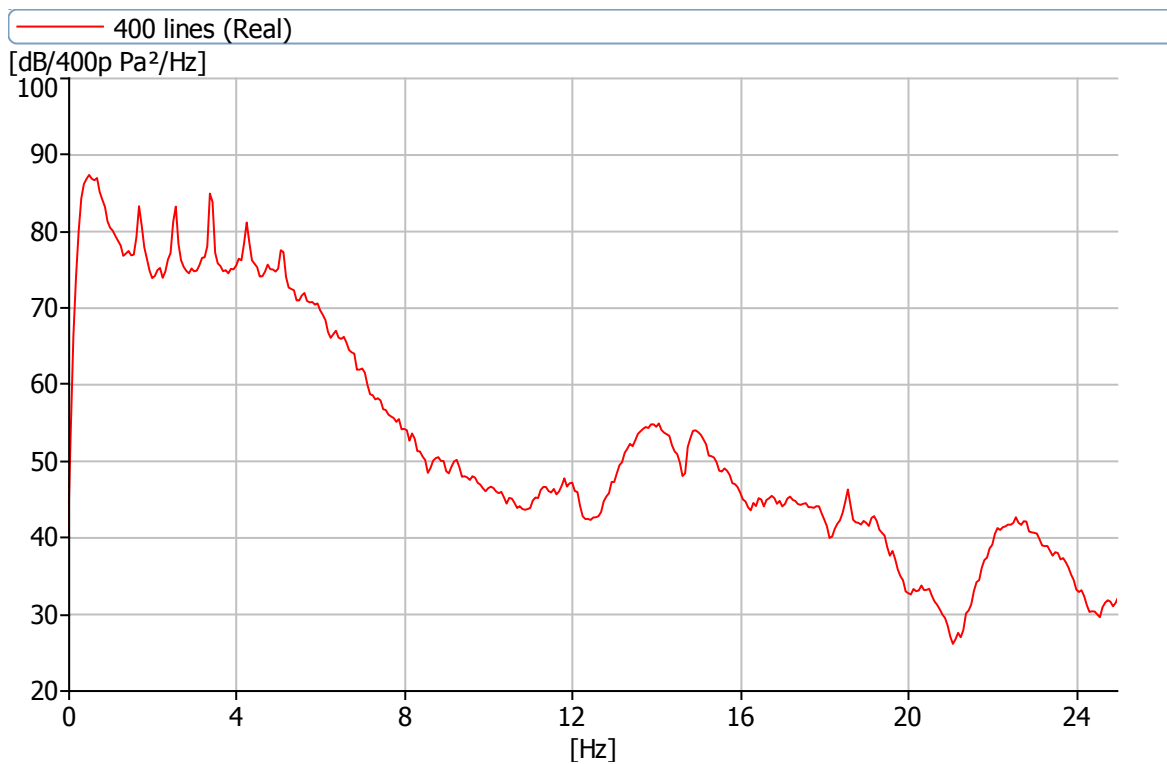


Figure 53: 400 lines, 0 - 25 Hz FFT analysis



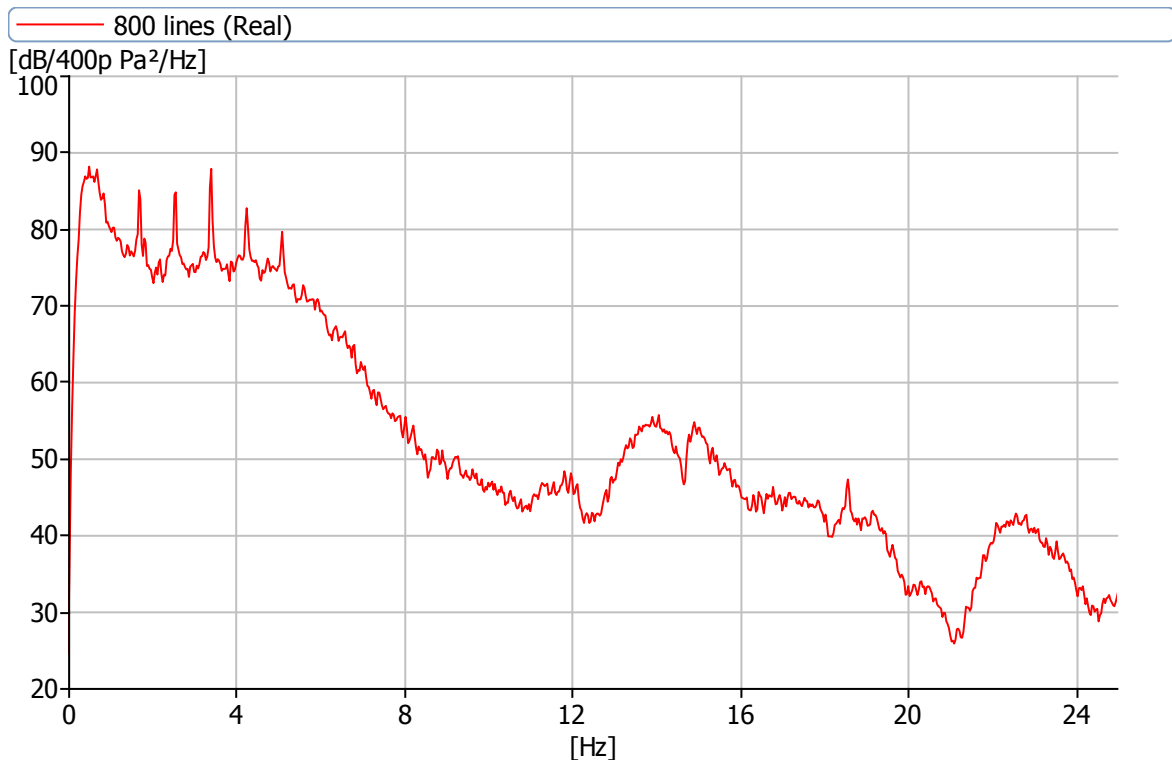


Figure 54: 800 lines, 0 – 25 Hz FFT analysis

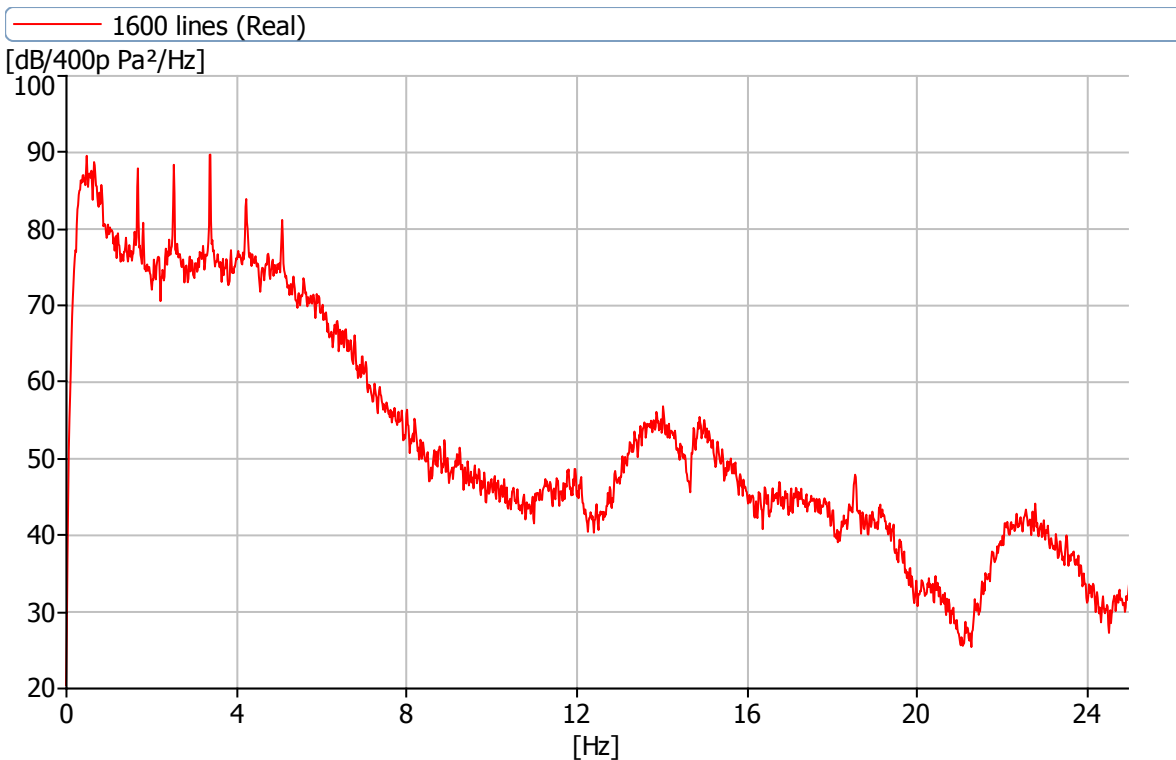


Figure 55: 1600 lines, 0 – 25 Hz FFT analysis



Figure 53 presents the results as power spectral density levels using 400 lines over the analysis range of 0 to 25 Hz. The blade pass frequency and its multiple harmonics are identified as being above 80 dB and being significantly greater than the broadband frequencies around 14, 15, 18 and 23 Hz.

Figure 54 is the same time signal but utilising 800 lines for the 0 to 25 Hz analysis that identifies a finer resolution of the frequency components to that in figure 50 but also indicate under a PSD slightly higher levels associated with the blade pass frequency and its multiple harmonics. The 800 line resolution identifies for the fifth and sixth harmonics of the blade pass frequency a distinct frequency that is not apparent in the 400 line analysis.

Figure 55 considers the same signal but utilising 1600 lines over 0 to 25 Hz bandwidth and shows a greater degree of resolution with distinct narrowband frequencies being more identifiable than in the 400 line analysis.

Examination of the charts show the general WTS but that as the number of lines are increase the trace shows more variation. The higher resolution reveals that there were some variations of the rotor speeds (more the one turbine) during the sample. The finer resolution is relevant for determining exact frequencies. However for the dB (WTS) the lower resolution is considered to be sufficient.

The following table presents the PSD levels for the nominated harmonics of the blade pass frequency utilising the frequencies derived in the 400 line analysis. It is noted that as the resolution is improved (i.e. more lines) the identification of discrete frequencies alter with the general concept that the maximum levels at the “nominated” harmonic increase in level. For this example of the turbine the blade pass frequency would appear to be in the order of 0.85 Hz.

Harmonic	2 nd	3 rd	4 th	5 th	6 th
400 lines	83.19 dB	83.141 dB	84.833 dB	81.059 dB	77.435 dB
800 lines	84.998 dB	84.721 dB	87.789 dB	82.694 dB	79.562 dB
160 lines	87.779 dB	88.266 dB	89.585 dB	83.801 dB	81.066 dB



The inclusion of narrowband analysis highlights the spectral characteristics of wind turbines that is not evidence in the 1/3 octave band assessment.

The WTS identifies the operation of the turbines. The generator modulated frequency identifies when the turbine(s) are generating power.

The use of narrowband analysis of the WTS and the generator frequency recorded inside dwellings provides a mechanism to identify the operation of a wind farm, whereas the use of dB(A), dB(C), dB(G) and individual 1/3 octaves in this study could not be separated from the wind.

It is suggested that the use of the WTS and the generator frequency are the key components for monitoring of a wind farm/turbine for coordination with any further studies/observations in relation to the impact of wind turbines.

Using the shutdown of 22nd May 2014 the different number of lines is shown for both scenarios using the 4193 microphone inside house 88.

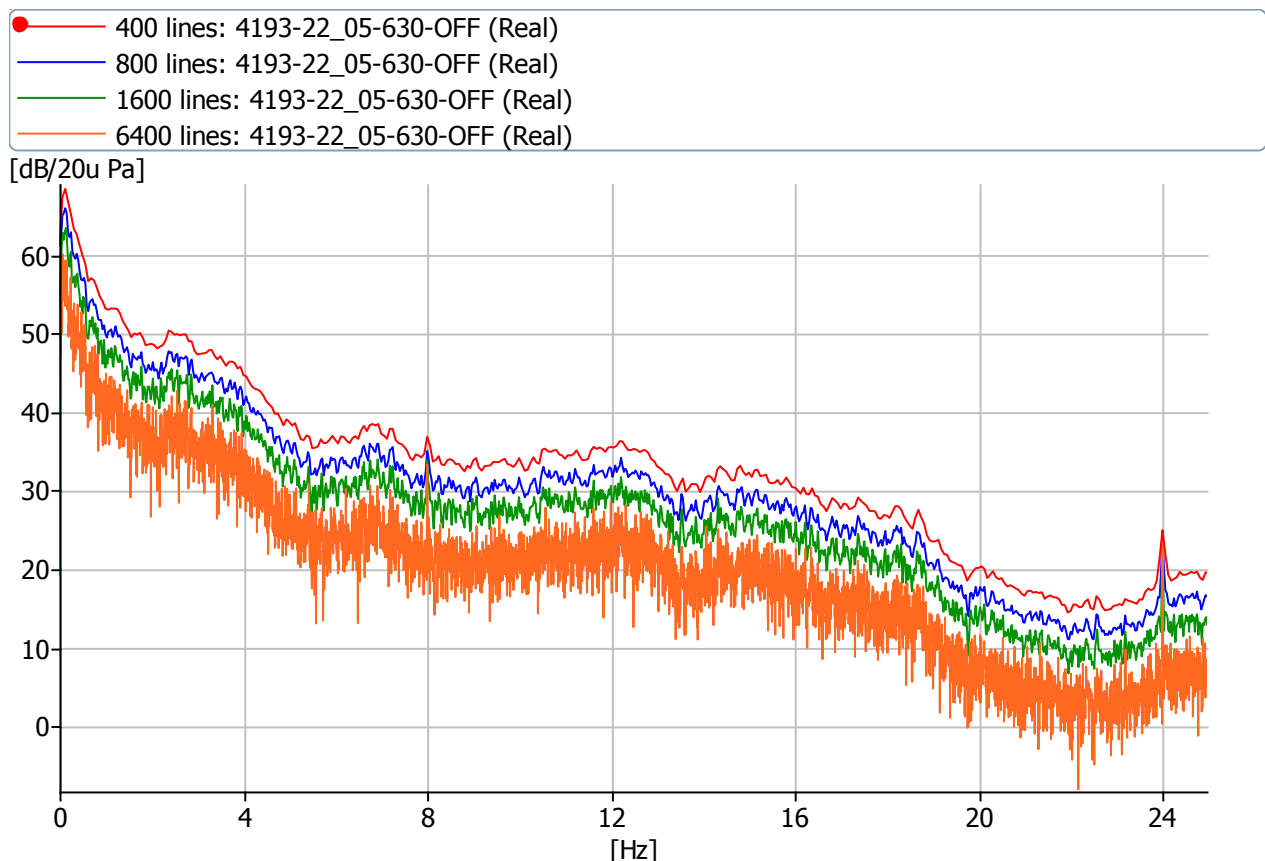


FIGURE 56: RMS Noise - OFF



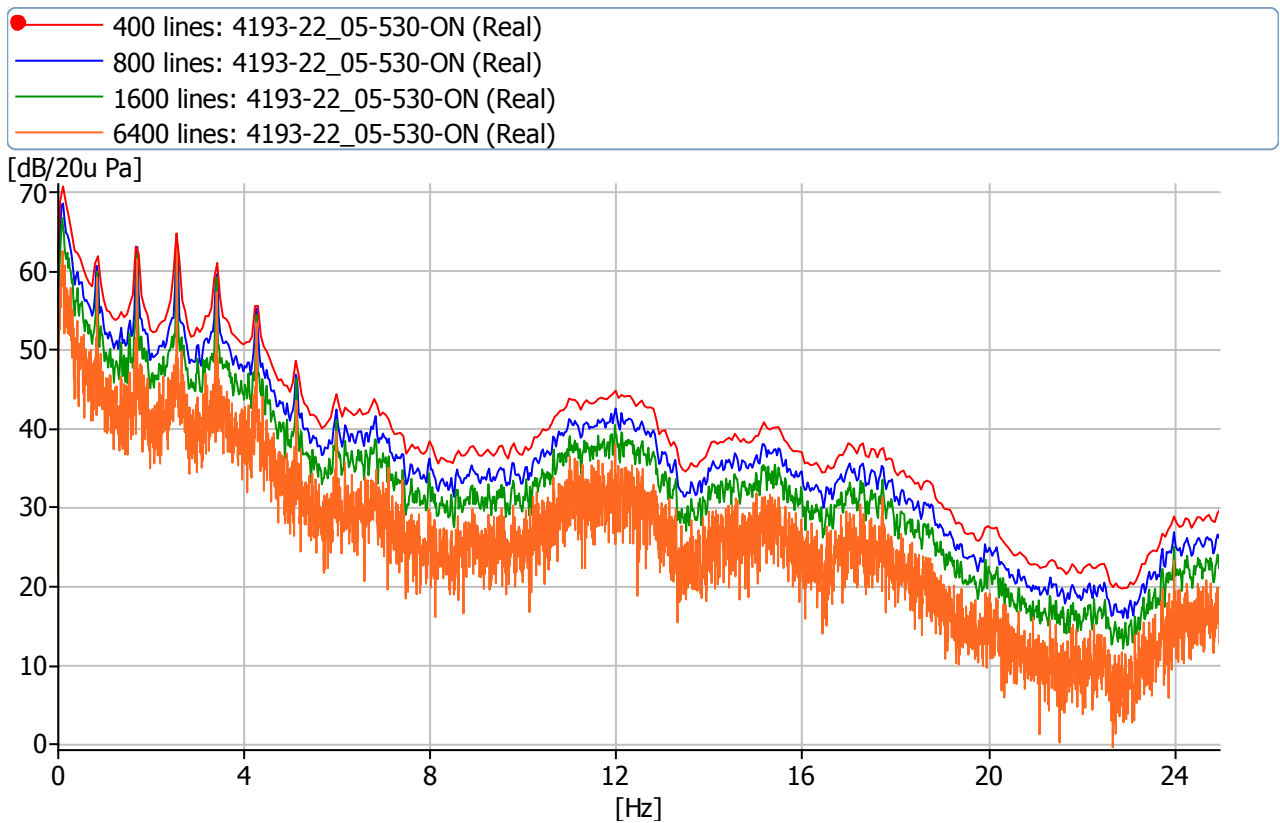


FIGURE 57: RMS Noise - ON

The above graphs show that as the resolution is increase whilst the peaks are similar the noise floor is lowered and therefore identifies the peaks for the same sample. However if one is to maintain a similar number of averages then as the number of lines is increase so must the time period for the sample.

Figure 58 shows the expanded view of Figure 57 covering the frequency of 0 – 5 Hz.



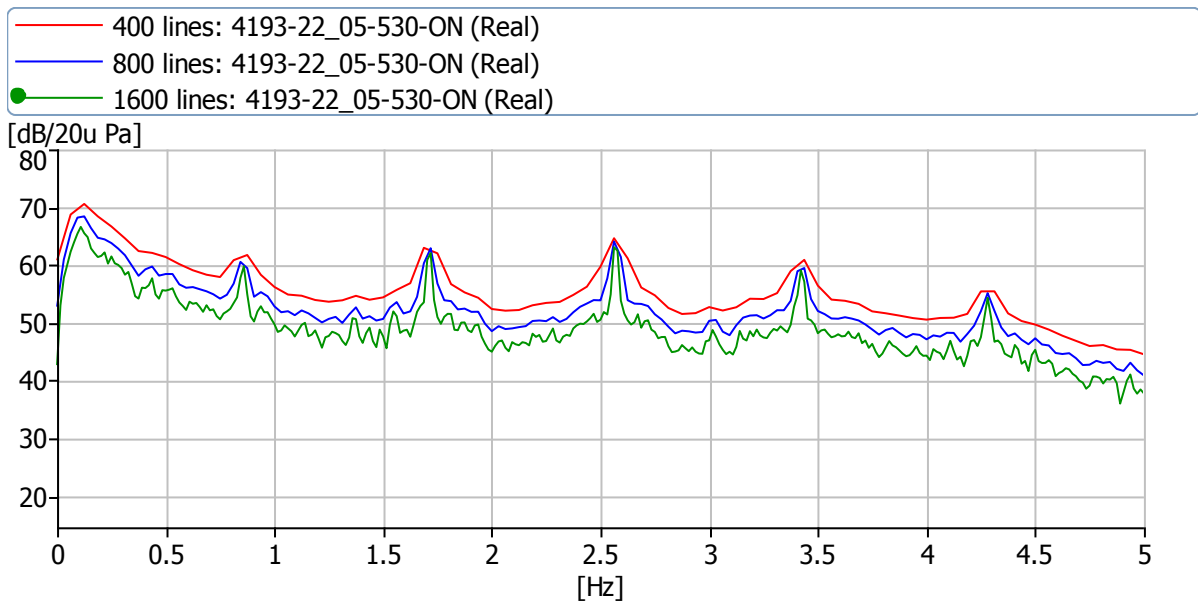


FIGURE 58: RMS Noise – 0 – 5 Hz

By comparison the PSD results for the same scenarios shows a consistent result with the higher resolution masking the other levels.

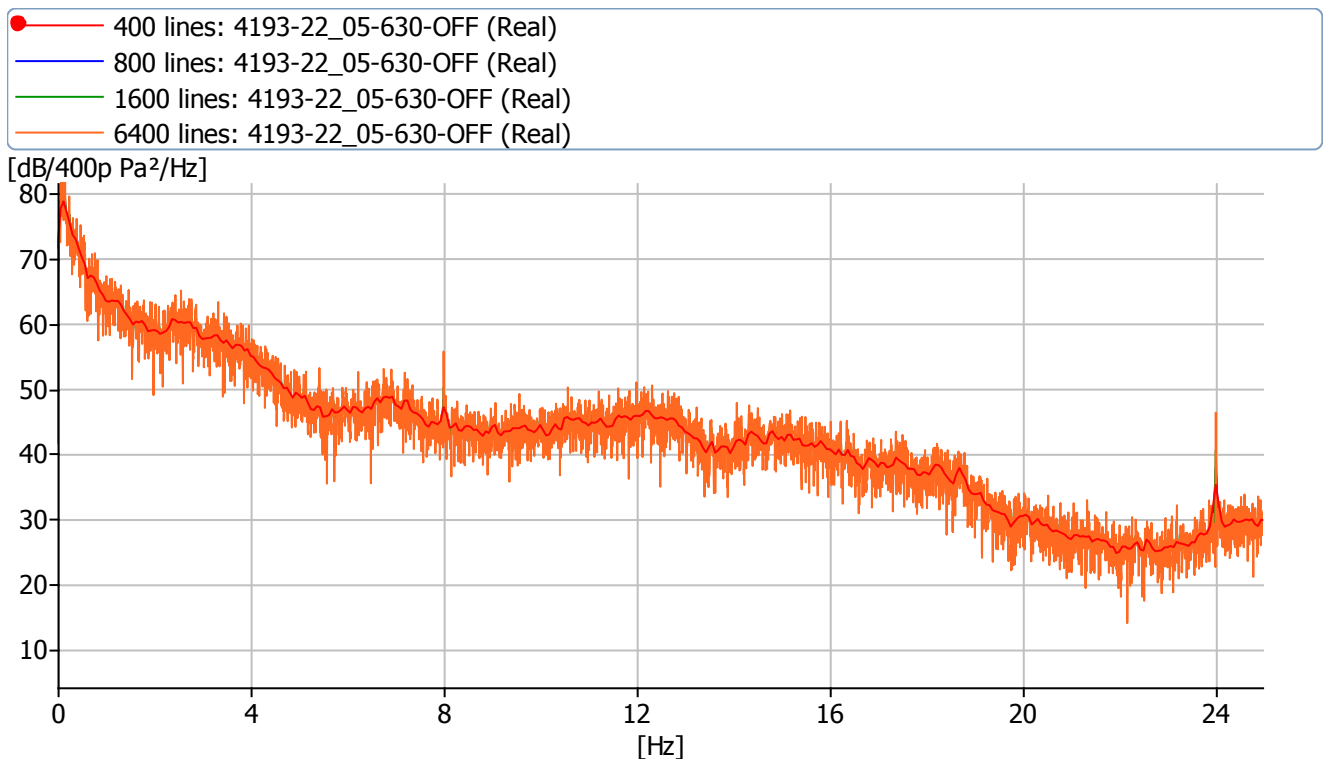


FIGURE 59: PSD Noise - OFF



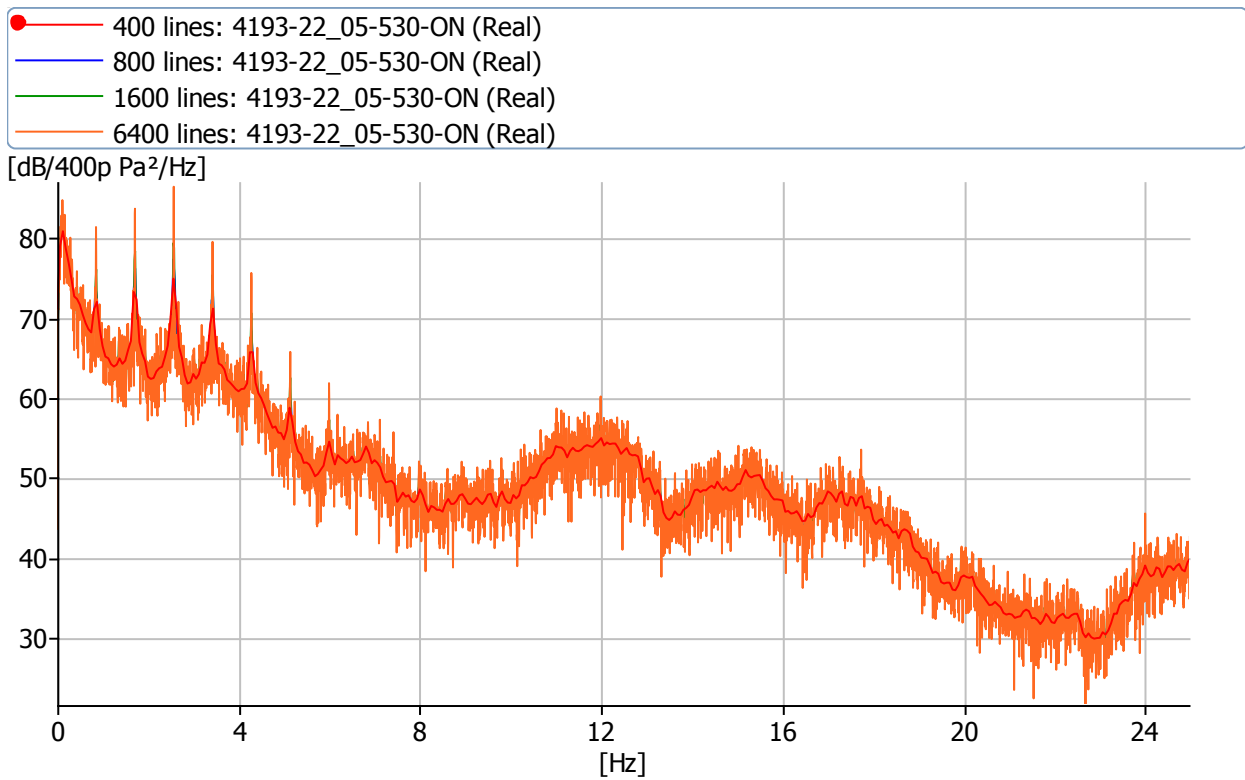


FIGURE 60: PSD Noise - ON

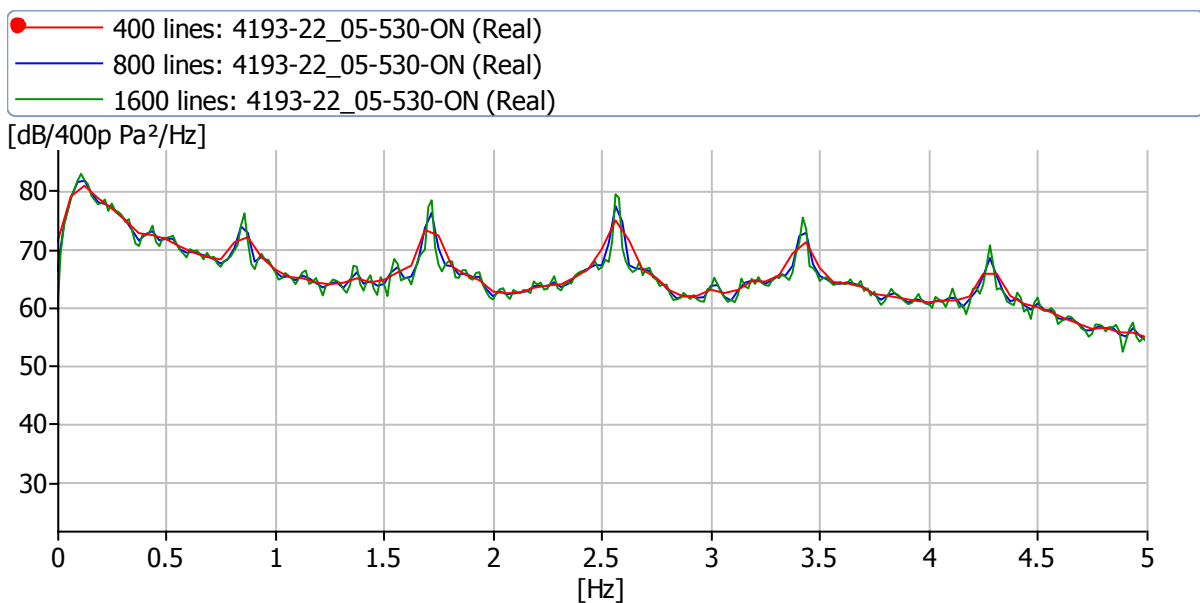


FIGURE 61: PSD Noise – 0 – 5 Hz

The same exercise for the pressure detector (See Appendix N) reveals similar results although it is noted the pressure detector was on the floor and the 4193 microphone was near the ceiling.



The logarithmic addition of the WTS components would appear to be biased towards the lower harmonics and does not cover the different operating scenarios derived from the resident's observations for high level of sensations.

The use of narrowband analysis for the region below 10 Hz permits the derivation of a weighted curve that may be appropriate for determining an acceptable and unacceptable threshold for such levels recorded inside dwellings.

Due to the variability in the speed of individual turbines it is suggested that the discrete frequency components forming the WTS are based upon the default analysis of 400 lines over a 0 – 25 Hz analysis range, using a default Hanning window.

Use of a finer resolution with a Uniform (or Flat Top) window would be the subject of more testing.

6.6.2 Changes in power levels/frequency

As noted above the sensation results in Figures 49 & 50 excluded the start-up results due to the blade pass frequency of the turbines being significantly lower than the generally used figure of 0.85 Hz.

Plotting all the different sensation 5 scenarios considered in the hypothesis by assigning the results for above 10 m/s in the high power group, the results for below 5 m/s in the low power group and the remainder assigned as change in power reveals different frequency patterns for the various scenarios as shown in Figures 62 & 63.



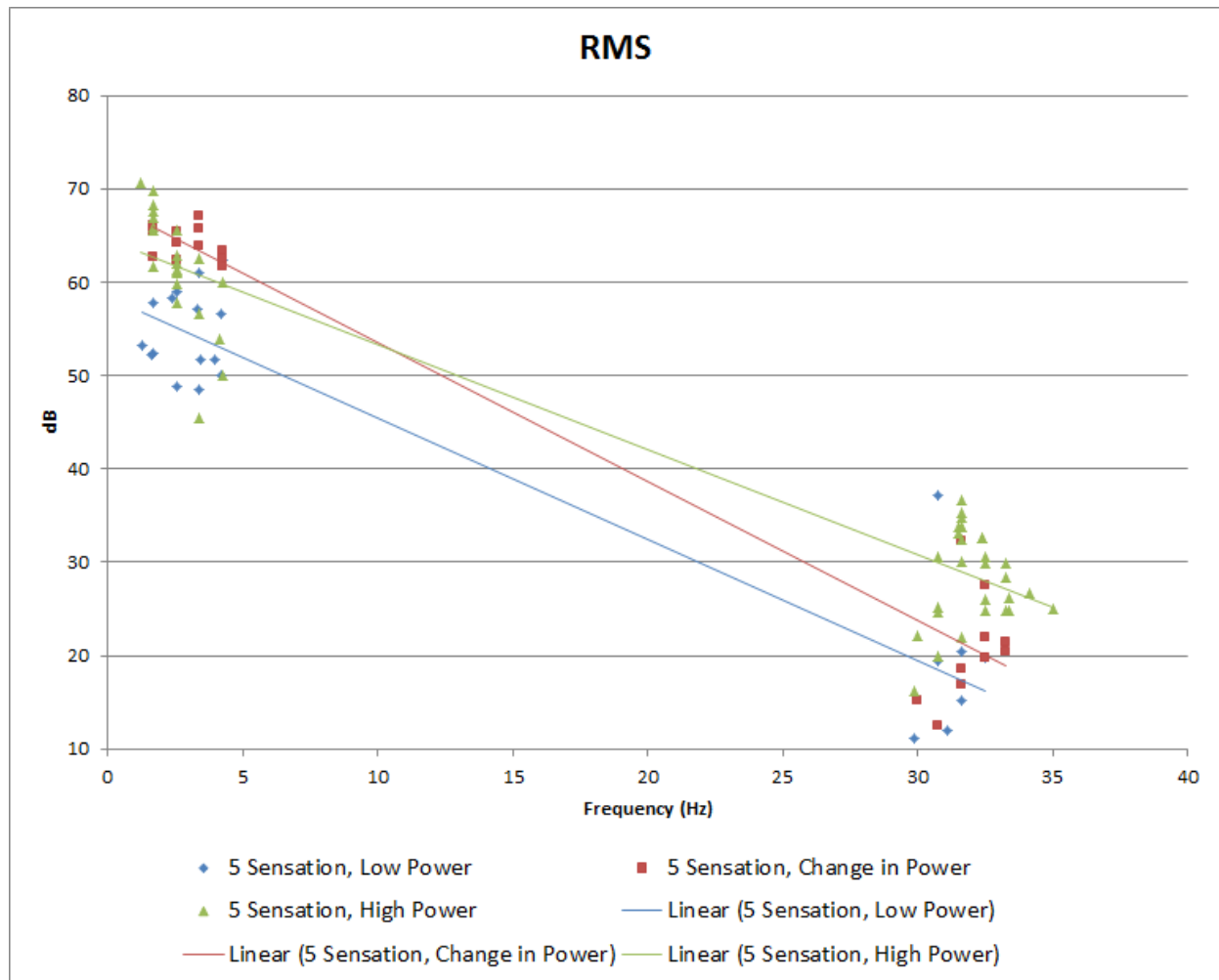


FIGURE 62: WTS and 31.5 Hz RMS components with separation of different scenarios



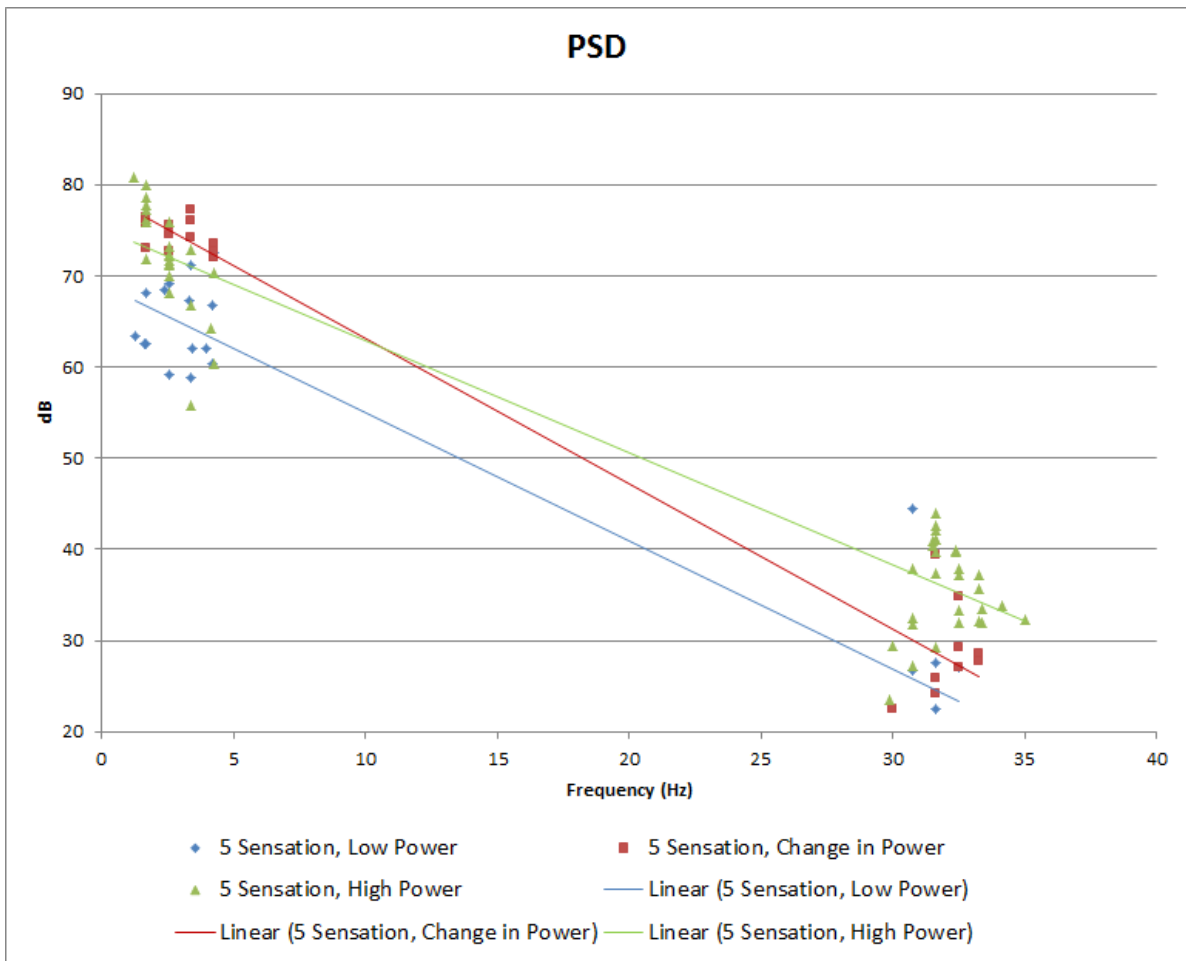


FIGURE 63: WTS and 31.5 Hz PSD components with separation of different scenarios

An examination of different sensation 5 results is shown in Figure 63.

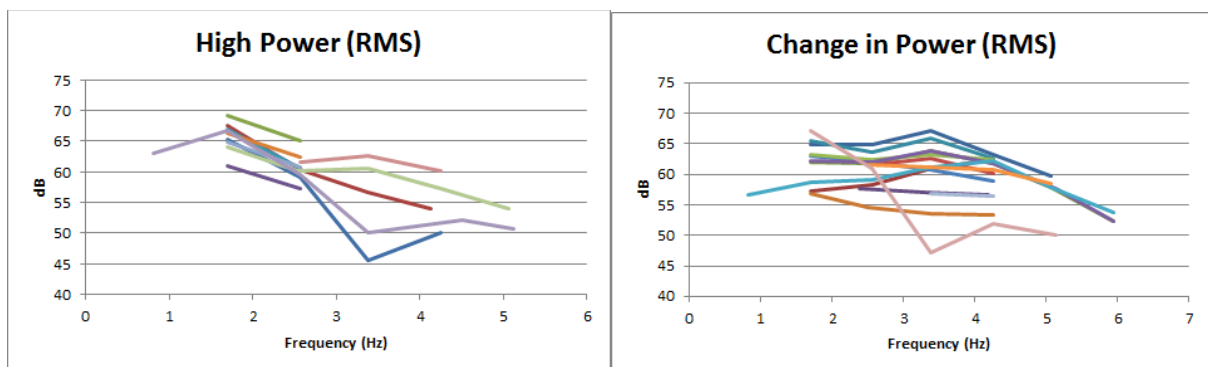


FIGURE 64: Comparisons of WTS signature for different power settings re sensation 5



In general terms for acoustic assessments the turbines are normally identified with respect to a set rotating speed when in fact the speed varies.

As a result of the review of the start-up scenario and the identification of different turbines that can be subject to different wind speed (and in some cases direction) shown in Section 6.4, a review of turbine data for on-site testing of turbine CBW 13 provides a greater insight in to the extent of the variability.

As part of near field testing around turbine CBW13 measurements were undertaken at various locations to examine noise signatures at ground level around the turbine (see Section 7.3 and Appendix Q).

The operating parameters specifically provided for that testing included the rotor speed and the wind speed at 1 minute intervals.

The upper graph is a plot of the wind speed (in blue) and the rotor speed (in maroon). There is not direct relationship between the two speeds in that the graphs cross over. At some instances the wind drops below 5 m/s and the rotor speed approaches 10 rpm.

From the hub height wind speed one cannot determine the speed of the rotor, yet in noise assessment there it is indicated the sound power of a turbine is related to the wind speed.

The lower graph compares the rotor speed and the blade pass frequency (being 3 times the rotor speed). The left hand vertical axis presents the speed in Hz and the right hand vertical axis in rpm.

The upper traces in the lower graph (the blade pass frequency) show a greater variation by reason of the scaling.

At the beginning of the 2 ½ hour sample the blade pass frequency is at the nominal value of 0.85 Hz for a wind speed above 8 m/s. However for the majority of the sample the blade pass frequency is below 0.8 Hz.

The blue band across the lower graph indicates the extent of the 0.8 Hz 1/3 octave band, the light red band the 0.63 Hz, and the light green band the 0.5 Hz 1/3 octave band.



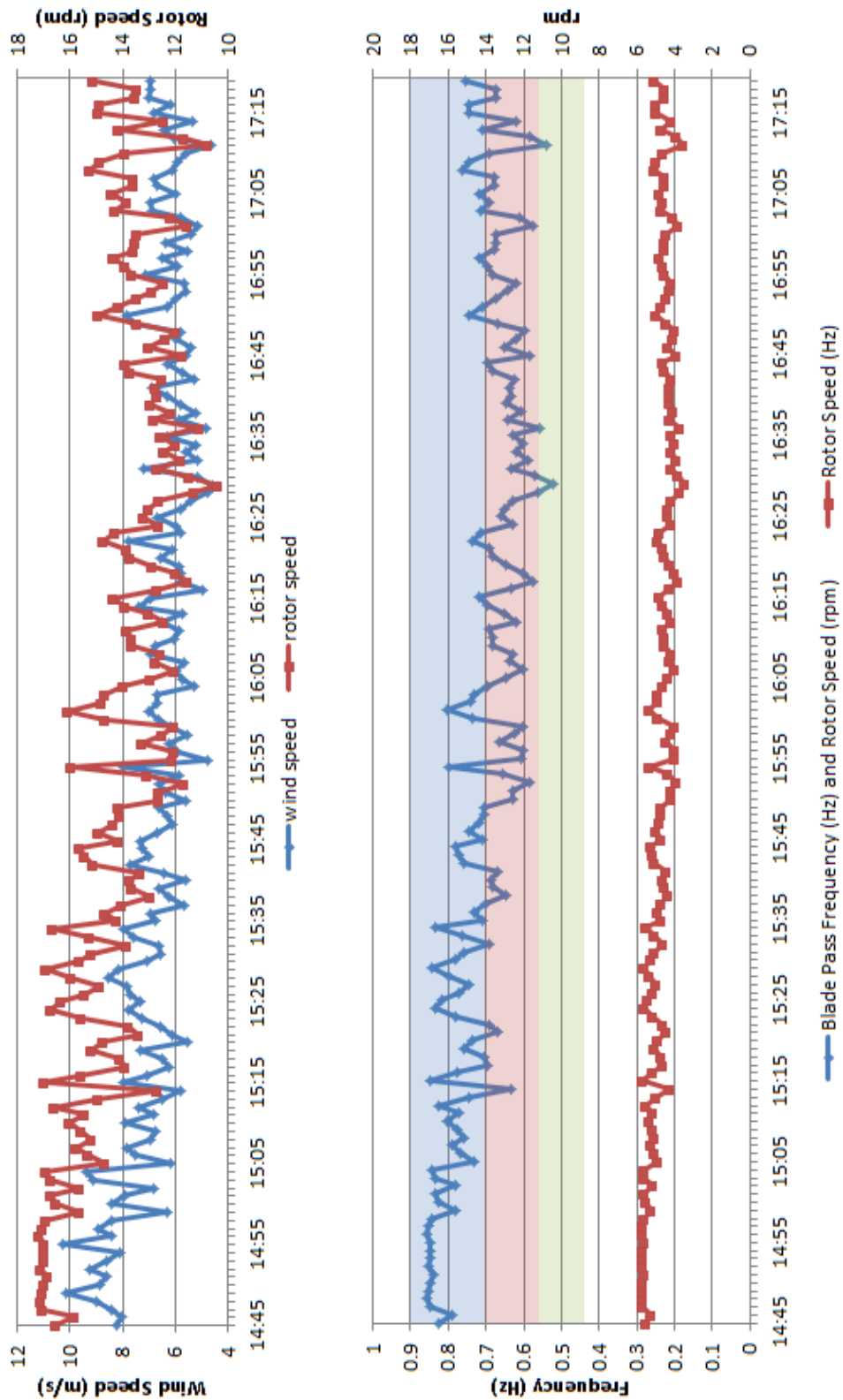


FIGURE 65: Turbine CBW13 Speed Variations



Examination of the blade pass frequency trace shows that the use of 0.8Hz 1/3 octave band for tracking the blade pass frequency of a turbine has limited value. For some wind conditions the normal concept of 0.8 Hz 1/3 octave band as the blade pass frequency becomes incorrect. Similarly the trace reveals limitations of having loggers with a lower 1.3 octave band of 0.8 Hz.

The trace also shows the use of the WTS as an Leq level would underestimate the true WTS if one could track the blade pass frequency. Alternatively if dB(WTS) was to be used for assessment of unacceptability it may require a restriction for use above 8 m/s hub height wind speed that in any event would appear to be the regions of highest WTS levels.

However, vibration testing the following day for turbine CBW 14 revealed a relatively constant rotor speed (Figure 66) even though there is a similar variation in wind speed to that for the previous example. The basis of the difference is unknown.

Figure 66 identifies the angle of the nacelle does not instantaneously follow the wind direction.



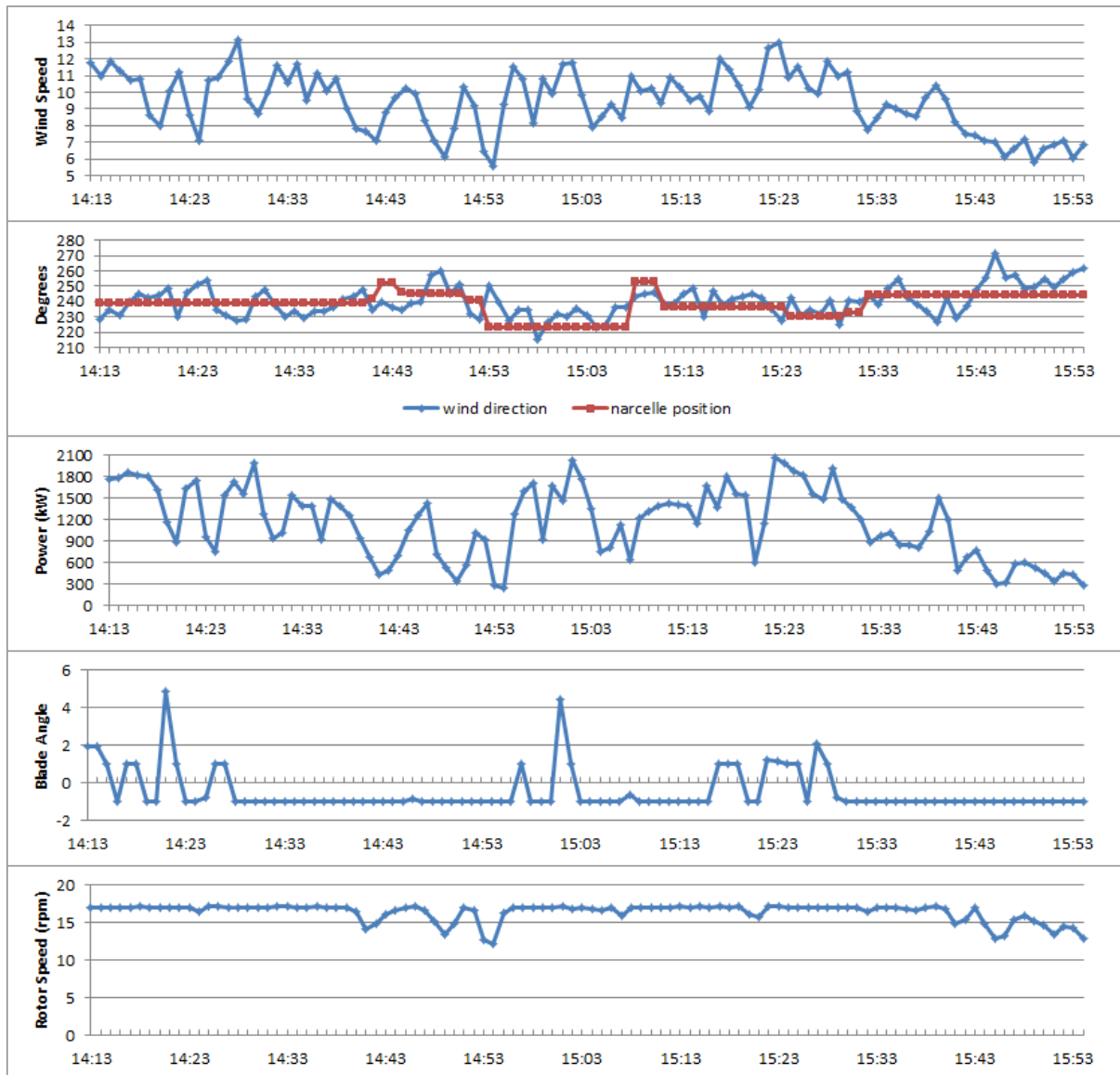


FIGURE 66: Turbine CBW14 Speed Variations

6.7 Amplitude Modulation

In examining various Standards and guidelines concerning wind turbines there is often an identification of amplitude modulation as a special audible characteristic that requires an adjustment to the measured level to account for the subjective effect of that component.



The wording of amplitude modulation varies from guideline to guideline, and standard to standard that in some cases refers to simply the modulation of the signal whilst in other cases expresses it as modulation of the A-weighted value.

In an electrical sense amplitude modulation is normally attributed to the addition of an audio signal to a carrier signal in which the carrier signal level then varies at the rate of the audio signal with the resultant change in the carrier signal graphically presented as amplitude modulation.

In some cases the turbine measurements found that the A-weighted level is subject to modulation which by definition is not a discrete frequency and as such may not under some interpretations be described as amplitude modulation.

Testing in the near field of individual turbines revealed the presence of modulation of the amplitude of the signal dependent upon the location relative to the turbine (upwind, downwind, or upward sweep or downward sweep) and with the material in Appendix Q utilising measurements conducted at turbine CBW 13 to examine such levels.

As a result of the measurements at the various turbines a frequency of 31.5 Hz with multiple side bands (on either side of that frequency) being multiples of the blade pass frequency has been established and specifically identified as being present when the turbines are operating but not present when the turbines are shut down.

This frequency is slightly above the maximum speed of the rotor multiplied by the gearbox ratio and would appear to be associated with the operation of the generator.

The mathematical analysis of the nonlinear multiplication of a pulse at the blade pass frequency and 31.5 Hz is set out in Appendix V to identify this component that is in an electrical theory concept “amplitude modulation”.

Measurements on turbine CBW 13 also indicated that at various locations there is a modulation of the broadband noise generated by the blades which also occurred at the periodic rate of the blade pass frequency. The amplitude of mid frequencies varied up and down at the blade pass frequency rate. If one restricts an analysis to a band of frequencies, i.e. such as one third octaves, the modulation theory applies.



Similarly if one takes the A-weighted detector output of the acoustic signal from turbines and implies that as a “frequency” then the variation in the amplitude of the A-weighted value is described as amplitude modulation and can be seen to occur at certain locations but not all locations.

The nature of the modulation of white noise should also theoretically reveal a modulated output. However the broadband noise generated by the turbines is limited to the mid-frequency range and therefore the ambient noise that is associated with pressure from the wind or frequencies below 200 Hz would not be modulated thereby not showing a modulation of the linear (Z-weighted) time signal.

To overcome confusion in terminology it is suggested that “amplitude modulation” represents modulation of the amplitude of the noise generated by the turbine. In its simplest form it can be examined by use of the A-weighted value where one looks to the variation in the A-weighted level where that variation occurs at the blade pass frequency.

Appendix V also describes the application of the FFT analysis to a pulse to show the derivation of the discrete frequency components of the WTS.

Combining both assessment procedures thereby indicates that the operation of the turbine produces both a wind turbine signature (as a result of the pulse) and amplitude modulation being the generation of the pulse at the blade pass frequency with other signals generated by the turbine.

It is considered that for further studies into the impacts on individuals as a result of the operation of the wind farm requires consideration of both the pulse (WTS obtained by FFT analysis) and the modulation.

6.8 Vibration Measurements

For the attended/unattended measurements using the multi-channel data recorder system over a number of days at the residential dwellings vibration measurements were included in the assessment by use of high sensitive accelerometers (Brüel & Kjær 8306) in a triaxial configuration located primarily in the room of concern.



The resident's diaries indicate on an intermittent basis the presence of vibration with a small percentage of the observations obtaining severity level 5. Residents described the presence of a pulsation from time to time, including for one resident during the scheduled shutdown.

In addition to the multi-channel recorder system supplementary measurements were recorded during the course of the study both inside and external to the buildings as part of the assessment of the hotspots discussed in the following section. However, budget and time constraints limited the conduct of vibration measurements to the status of a preliminary investigation.

The vibration results recorded in the houses reveal relatively low levels when assessed in terms of the standard wind farm procedure of an Leq level of 10 minutes.

Whilst the majority of the hotspots were associated with acoustic issues a number of them were examined in terms of vibration issues, in view of the residents identifying vibration effects that could be perceived.

It is noted that in all cases the nature of the timber floors in the subject houses were found to vibrate and whilst walking across the floor, and in the relatively quiet environment of the dwellings, from acoustic perspective could be found to "boom".

As discussed in the following sub-sections (for each house) the frequency of vibration detected in the dwellings and areas external to the dwellings was not in the infrasound region. The vibration monitoring at houses 87 and 88 led to vibration measurements being conducted on the wind farm at the end of the study that indicated pulses associated with wind gusts recorded on the towers and in the ground.

The vibration levels recorded at Cape Bridgewater are relatively low in amplitude. On the basis of the limited number of measurements the results suggest the generation of Rayleigh waves, being waves that travel near the surface in both longitudinal and transverse motions.

6.8.1 House 87

During the multichannel measurements the vibration levels in the floor of the dwelling were found to be low in amplitude. Walking around the dwelling produced different audible responses in the timber floor for different parts of the dwelling.



Pressure pulses were observed in the vibration traces but were significantly lower than that generated by walking around the room. The excitation of the floor generated broad band peaks between 60 Hz and 180Hz with Leq (10 minute) levels less than 0.5 mm/s^2 .

Ambient vibration levels and pressure pulses measured at the floor junction of the living room with the master bedroom wall (being parallel to the wave front from the wind farm) were marginally higher than at the junction of the floor and the perpendicular wall to the wind farm, on the northern side of the living room with peak levels less than 10 mm/s^2 . Whilst walking in the room produced levels up to 50 mm/s^2 .

Vibration measurements on the northern concrete footing of the eastern verandah (a resident's hotspot) were found to have different frequencies of vibration than for the timber floors inside the dwelling.

Positioning the accelerometers (mounted on an aluminium block) in the ground 2 metres from the building obtained a totally different vibration signature (to that obtained for the verandah) including pulsations but of lower magnitudes.

None of the vibration measurements on the floor of the verandah found the discrete infrasound components that appears in the infrasound noise signature in the rooms.

Overall the vibration recorded in and around the dwelling is considered to be insignificant with respect to the measured levels and perception of vibration.

It is noted that during gusty wind conditions the building itself can shake and generate vibration levels significantly higher than that obtained under moderate or no wind.



6.8.2 House 88

During the multichannel attended measurements in the earlier phase of the study, vibration detected in the master bedroom floor found peaks at 8 Hz and 24 Hz that were at relatively low levels. Simultaneous noise measurements found the turbine signature present in the room with some infrasound component in the signature of a very small magnitude. The resultant level of vibration recorded in the floor of the building is significantly below the comfort level criteria derived from Australian Standard AS 2670.2 and below the threshold level for low frequency noise disturbance of 5.86 mm/s^2 identified by Jacobsen.

Supplementary measurements conducted in the bedroom also included noise measurements where discrete peaks in the vibration signature were attributed to the operation of the refrigerator in the kitchen (45 Hz and multiples thereof) although the major difference between the refrigerator being on was recorded in the noise signature by use of a high sensitive microphone (Brüel & Kjær 4179 microphone).

With the refrigerator off the vibration signature revealed constant vibration at 25 Hz, 50Hz and 100 Hz frequencies. The 50 Hz and 100 Hz were considered to be interference from the 240 volt mains and significantly above the remaining frequencies that make up the ambient.

One resident at house 88 was found to have a heightened sensitivity to noise and vibration when compared to the other residents involved in the study. It is noted that whilst being present in house 88 for the purpose of attended measurements, and also discussions concerning the results, that at times a vibration could be detected in the soles of the feet and that would be best described as a travelling pulse passing through the building from the direction of the wind farm.

The use of a series of balls on a stand to act as a pendulum could at times be seen to vibrate and is an aid used by the residents to express the impacts that they receive.

During one of the measurements (with the refrigerator on) the resident noted a pulse being felt in the floor. The highest level of vibration was in the east west orientation as shown in Figures 67 & 68.



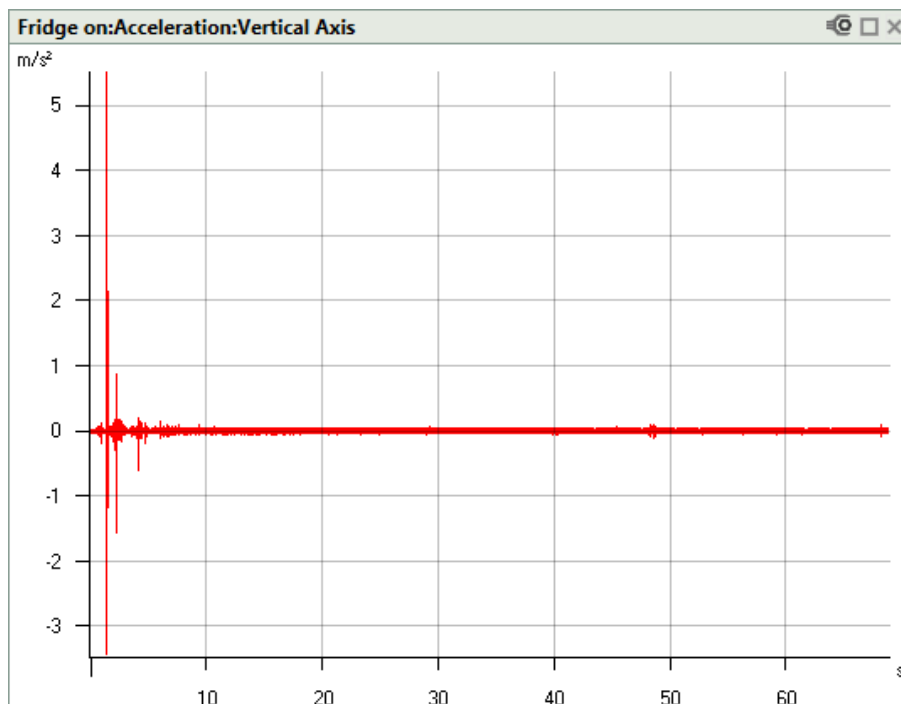


FIGURE 67: Bedroom Floor Pulse – house 88

A series of vibration measurements conducted on different surfaces of the bedroom were limited in the noise floor of the accelerometers. The results suggest that low-frequency energy being produced in the bedroom is one from the roof and not by the floor, although by way of the spectral information provided from the limited measurements are a number of natural frequencies occurring the building of which the source is unknown.

Movement of people around the dwelling was found to result in measureable increases in the vibration recorded on the bedroom floor that were higher in amplitude and different in frequency spectra to that obtained for the pulse.



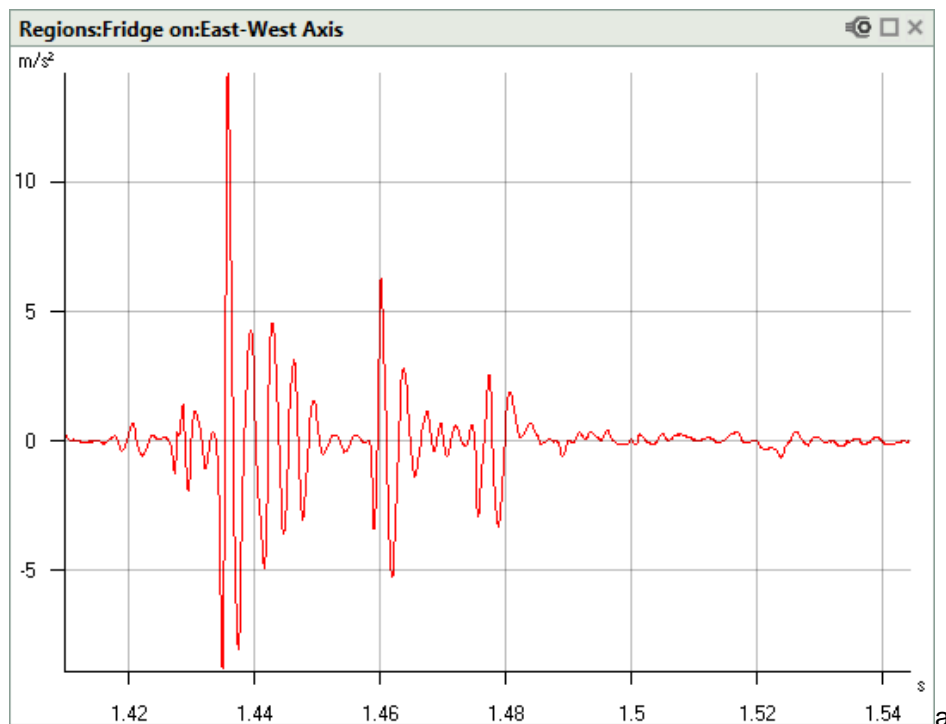


FIGURE 68: Expanded view of Pulse in Figure 67

External monitoring to house 88 was conducted during gusty wind conditions where three Brüel & Kjær accelerometers (type 4370/4381) were attached to an aluminium inertia block that was buried in the ground at a position approximately 10 m to the north of the entry verandah and directly in line with the front door of the residence.

In terms of overall vibration levels the accelerometer oriented in an east-west direction produced noticeably higher vibration levels during the presence of intermittent pulses than for the north-south axis or the vertical axis.

Figure 69 below presents the time signal of the vibration recorded over the 10 minute sample to indicate a significant variation in the vibration level with Figure 70 showing an expanded view of the primary pulse to indicate a high peak with a rapid decay. An expanded view of the time decay is provided.



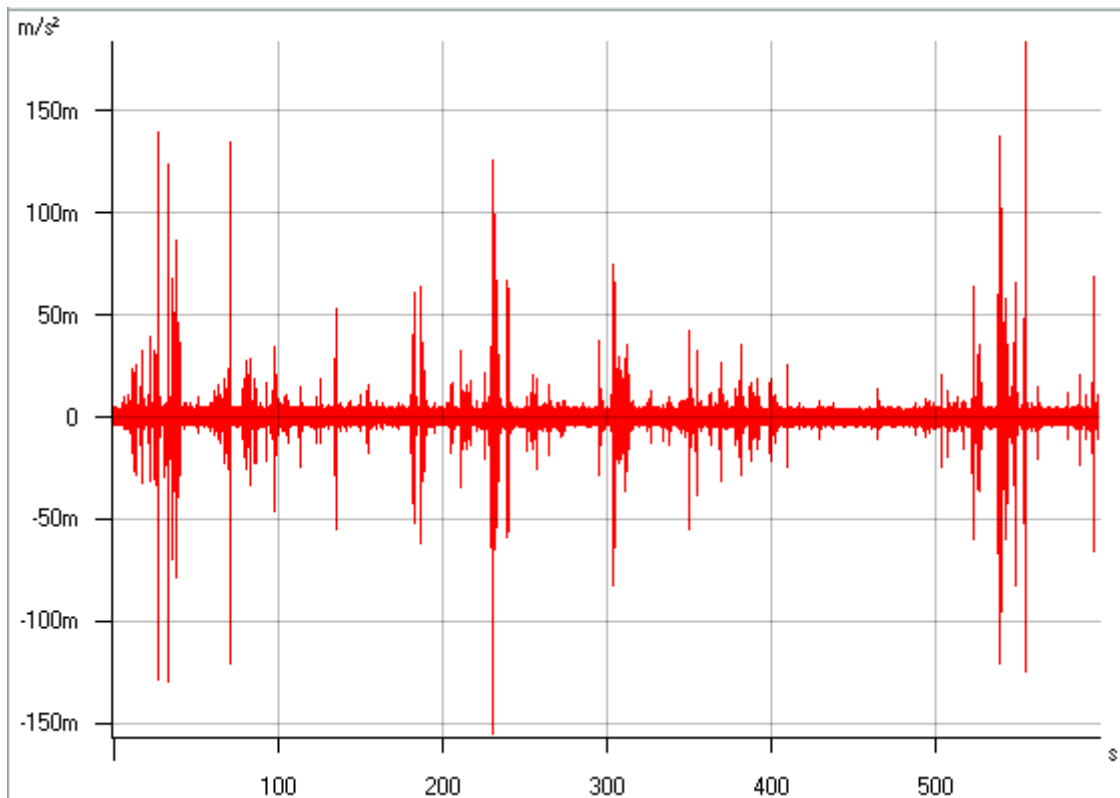


FIGURE 69: Time pulses external to house 88

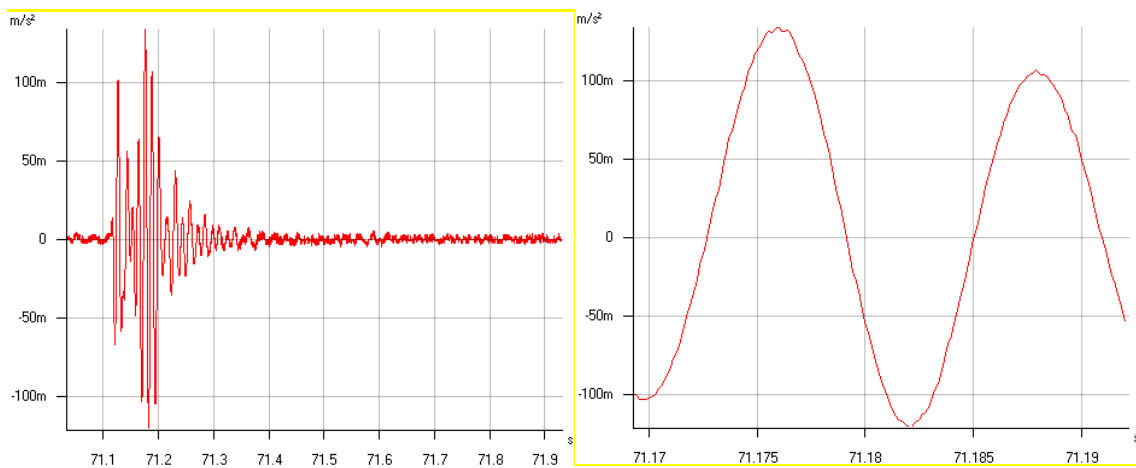


FIGURE 70: Time pulses external to house 88

Under Australian Standard AS2670.2 the assessment of whole-body vibration is related to the axis of vibration and the Leq level in 1/3 octave bands below 100 Hz. Considering 1 minute Leq samples that include the pulses.



AS 2670-2 specifies vibration levels recorded inside the dwelling at a position that represents the vibration input to person (standing, lying or seated) relative to the three orthogonal axes of the individual.

There were insufficient pulses obtained during the attended measurements inside the dwelling under the prevailing conditions at the time. As part of the external hot spot investigation at house 88 measurements were taken in the ground and for the preliminary assessment have been used for comparison of the recommended limits in AS 2670-2 noting that any amplification (or attenuation) of building elements is not applicable to the following results.

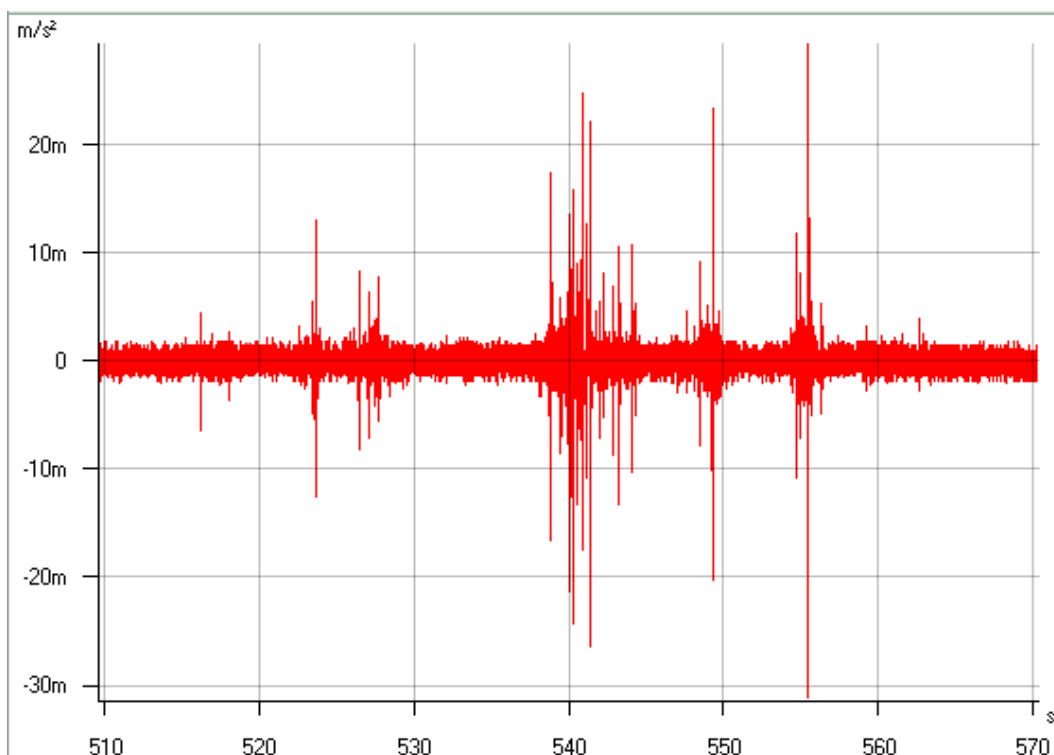


FIGURE 71: 1 minute time pulses external to house 88 – vertical axis



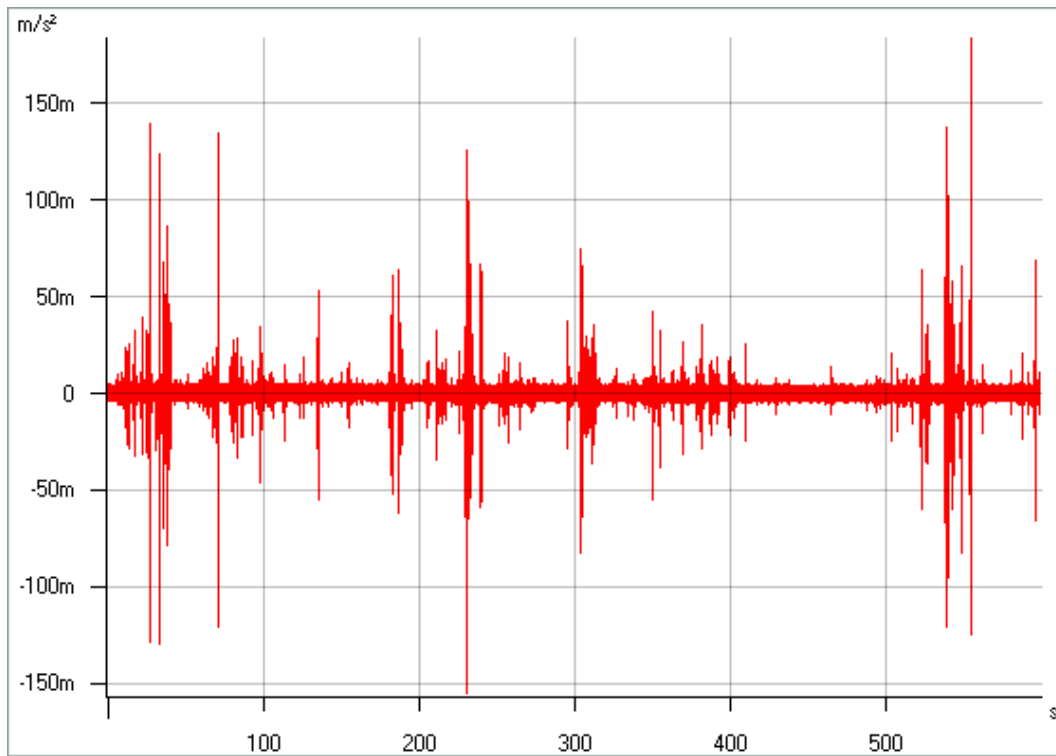


FIGURE 72: 1 minute time pulses external to house 88 - east/west axis

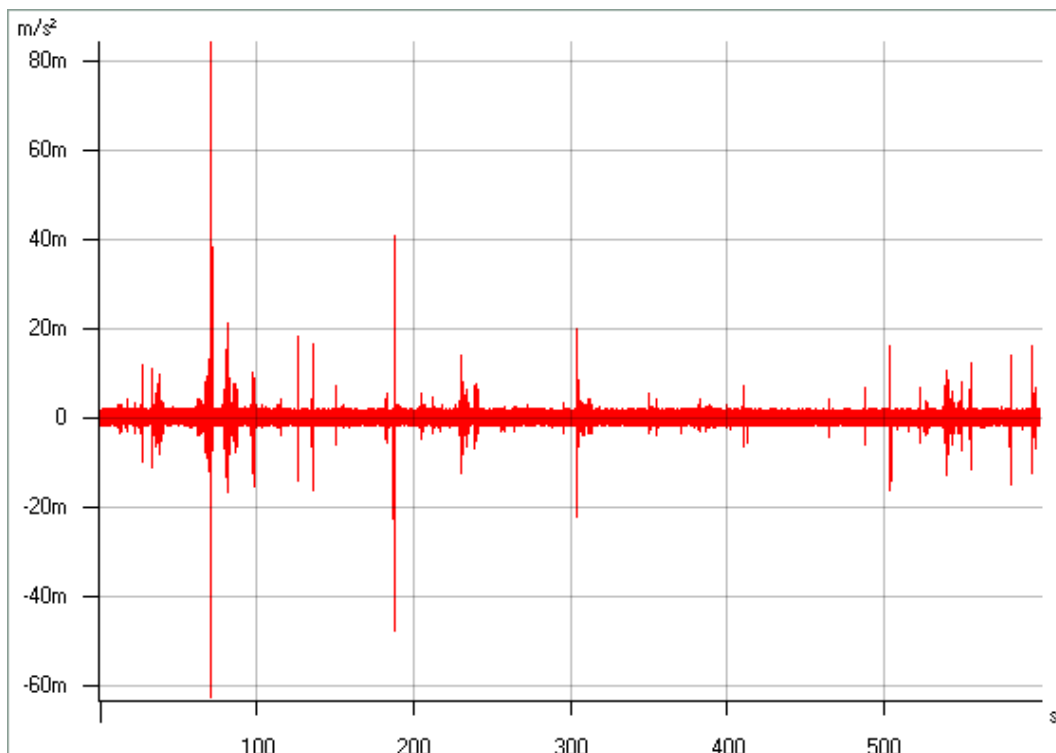


FIGURE 73: 1 minute time pulses external to house 88 - north/south axis



The corresponding Leq 1/3 octave band and FFT results for the above three figures have been derived and show the propagation away from the turbines (east/west direction) has the highest amplitudes.

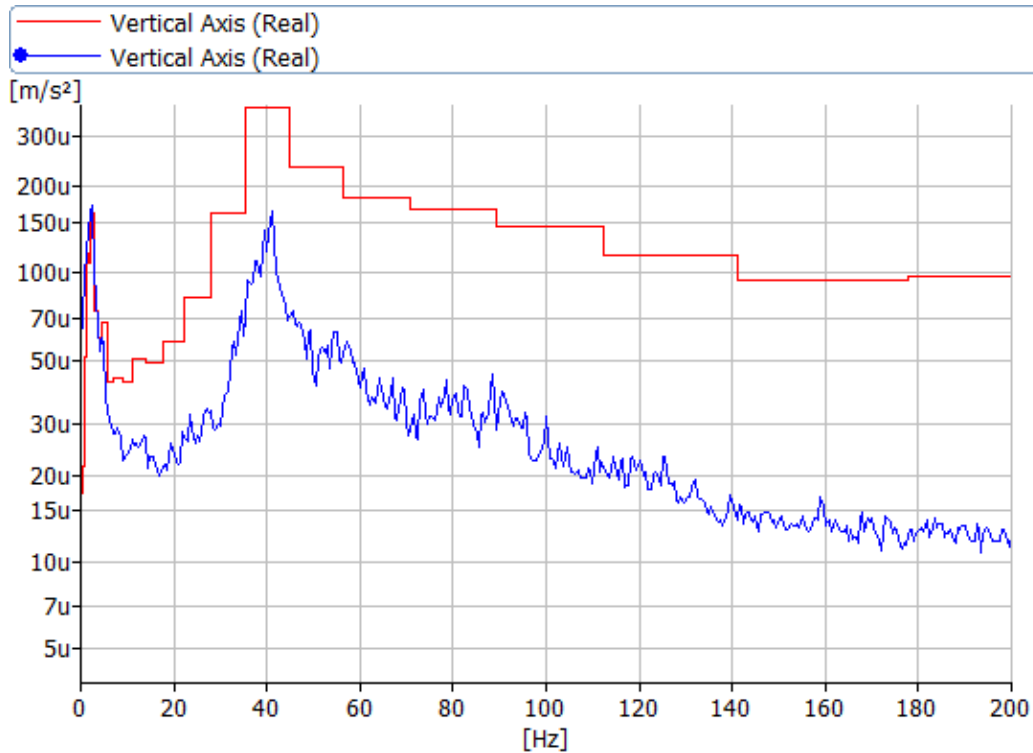


FIGURE 74: 1 minute, 0 - 200 Hz FFT external to house 88 - vertical axis



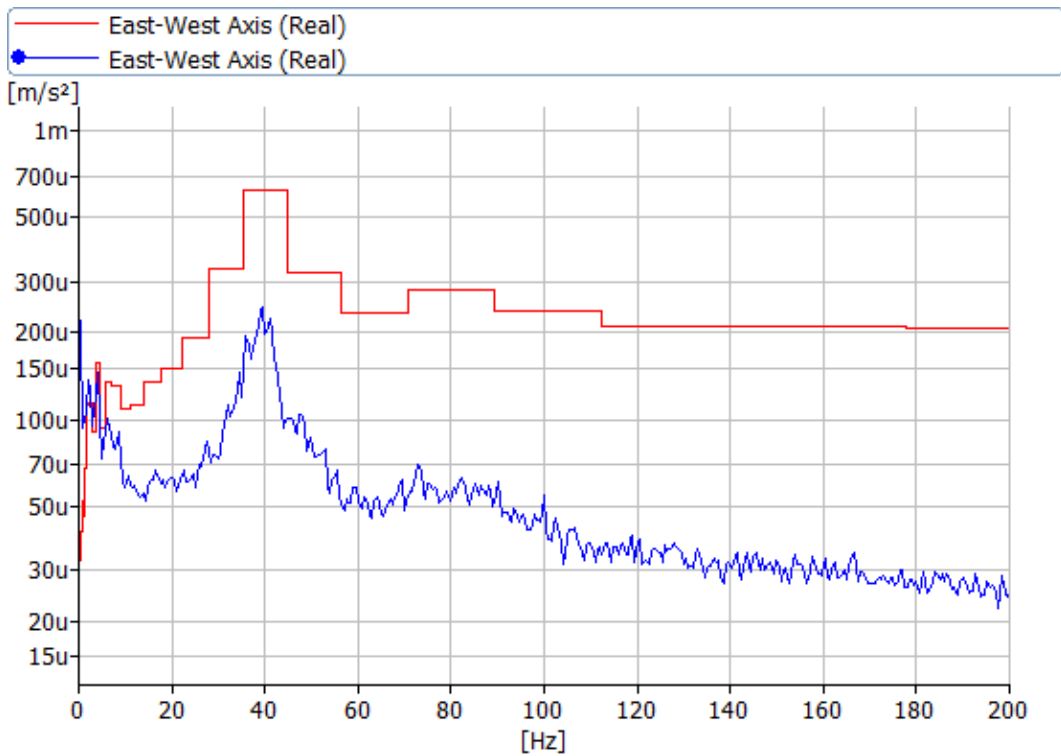


FIGURE 75: 1 minute, 0 - 200 Hz FFT external to house 88 - east/west axis

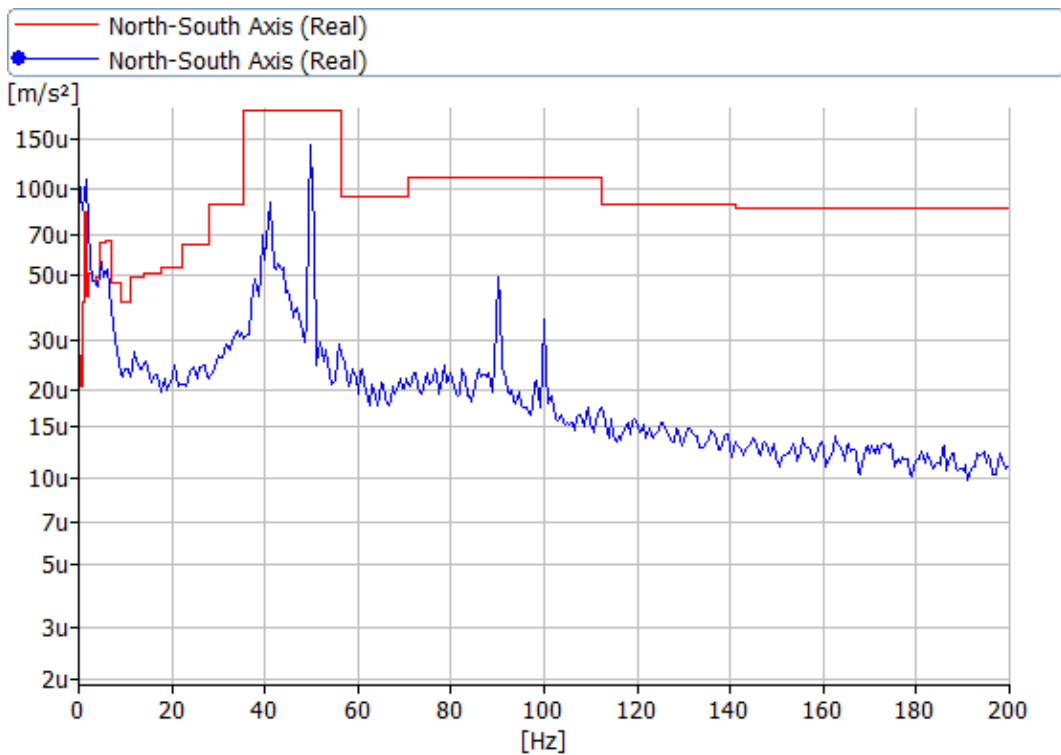


FIGURE 76: 1 minute, 0 - 200 Hz FFT external to house 88 - north/south axis



The following two graphs identify the nature of the vibration recorded external to the dwelling with respect to the base criteria in AS 2670-2 applied for the vertical axis and the horizontal axis. The results reveal vibration levels below the recommended criteria.

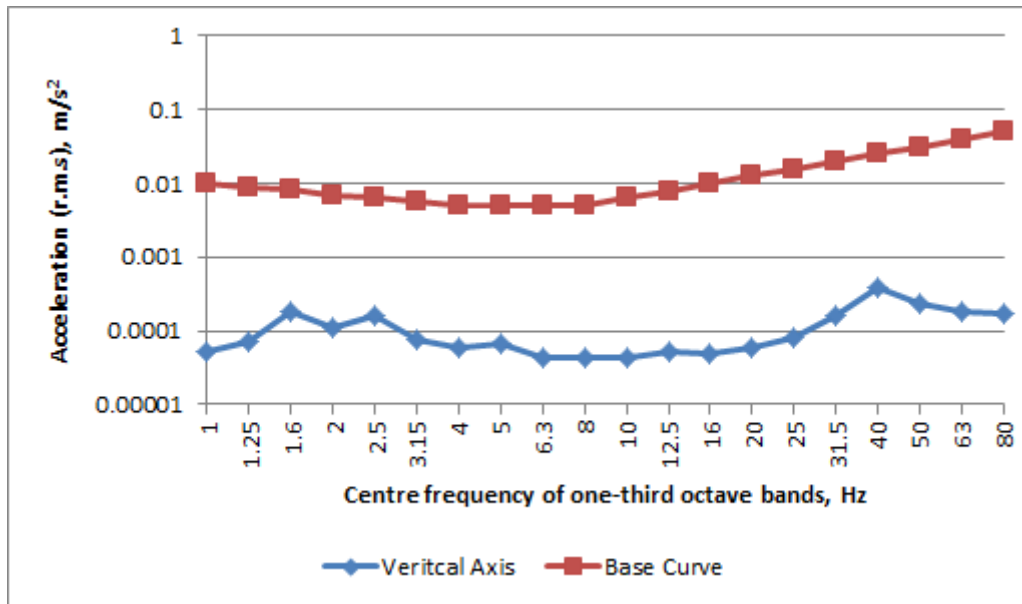


FIGURE 77: Vibration external to house 88 and AS 2670-2 base criteria - vertical axis

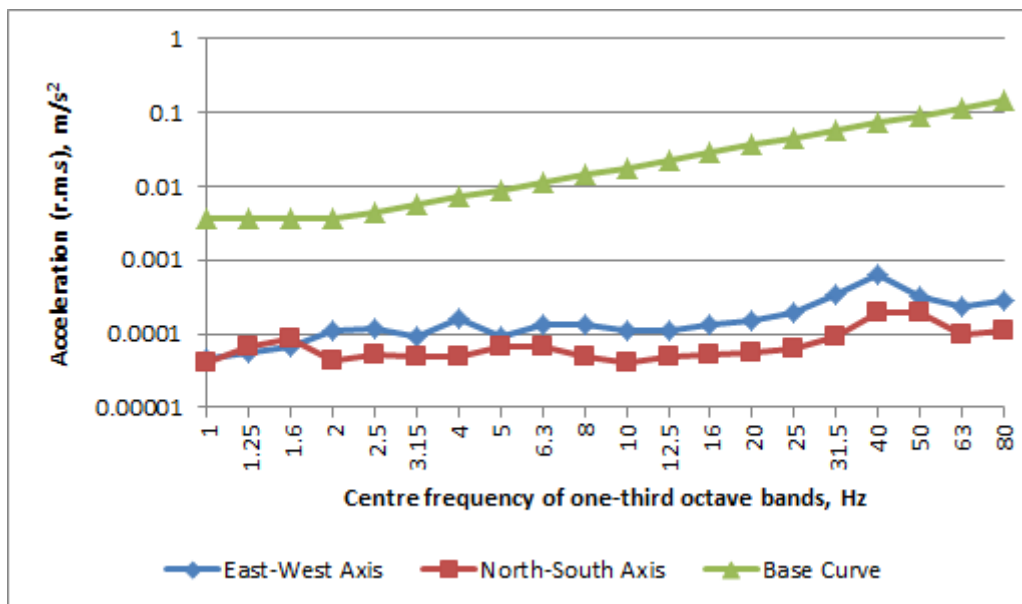


FIGURE 78: Vibration external to house 88 and AS 2670-2 base criteria -horizontal axes



The external vibration measurements for house 88 are presented in Appendices U7 to U13. The variation in the overall acceleration level for each of the three orthogonal axes are followed by an Leq analysis of the results over a 1 kHz bandwidth that indicate the generation of frequencies below 100 Hz.

Considering the vibration in terms of the low frequency noise region (i.e. below 200 Hz) the following graph indicates slight differences in the individual vibration axes being measured with the maximum level for the first sample between 35 and 40 Hz then followed by a secondary peak around 75 Hz. The graphs in Appendices U8 to U12 include the infrasound region and do not exhibit any discrete frequencies of vibration that were considered to be an issue of concern.

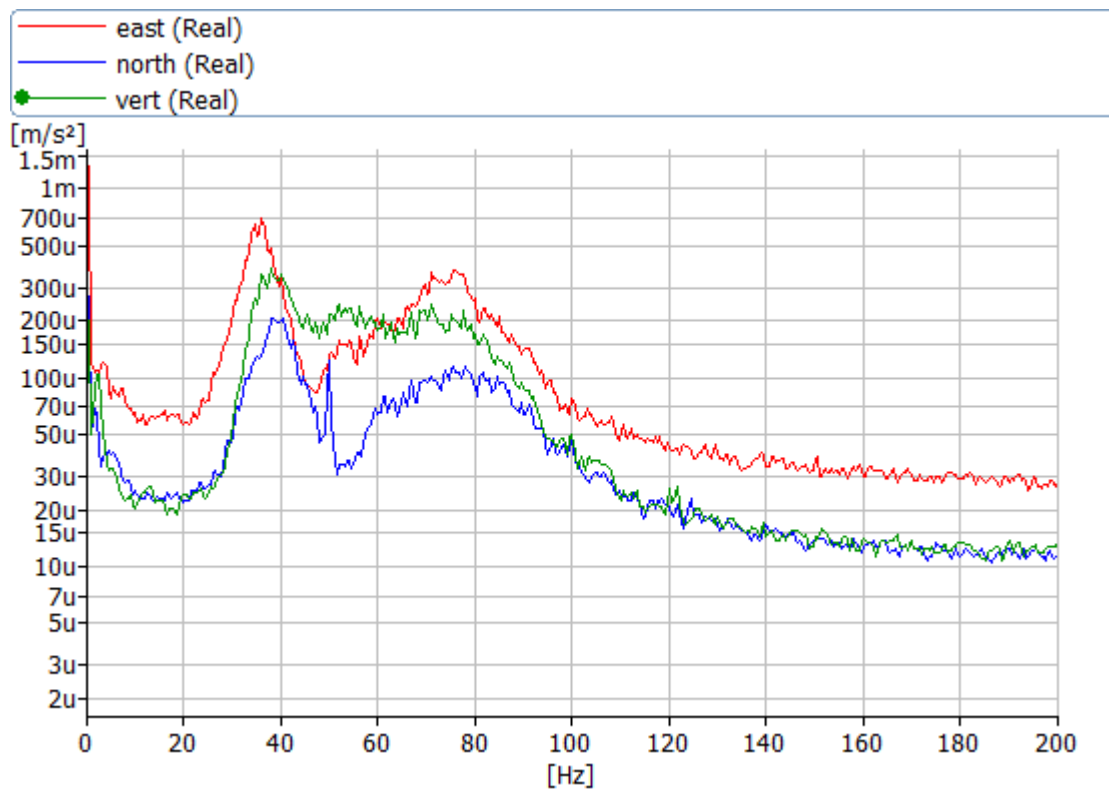


FIGURE 79: Leq of Time pulses in Figure 70 - external to house 88

Similar 10 minute samples show peaks throughout the period with the time averaged Leq levels showing similar frequencies over the entire sample but at a lower amplitude by reason of the averaging period over an entire 10 minutes.



6.8.3 House 89

A similar exercise was carried out at a location on the northern side of house 89 where there was a general steady vibration part with some peaks in the spectra observed over multiple samples. The ground vibration measurements were recorded on the northern side of the rear entrance of the dwelling approximately 10 m from the entry door with some of the spectra identifying vibration in the ground similar to that obtained for the operation of fans on the turbines which had also be detected during the attended measurements inside the dwelling.

A FFT analysis of the signal reveals a peak in the region of 30 to 40 Hz for the different axes and a broadband peak in the region of 70 to 80 Hz which were found to be consistent for the number of samples.

The measurements at the three houses led to the conduct of additional measurements on the wind farm in relation to vibration at the base of turbines and extending out from those turbines (discussed in Section 7) indicating the conversations about vibration detected at house 88 were originating from the turbines.

Measurements conducted on turbines revealed vibration in the tower structure associated with the operation of ventilation fans serving equipment inside the tower, vibration as a result of the rotation of the turbine itself, and at times pulses or significant increases in vibration generated on an intermittent basis that would be related to wind gusts.

Measurements of a stationary turbine under high wind loads (CBW 22) showed discrete frequencies as a result of wind gusts that are suggested to be associated with natural modes of the tower and the individual blades flexing with the wind.

Measurements at the base of turbine CBW14 revealed intermittent vibration as discussed in Section 7.4. The intermittent vibrations are similar to that recorded external to house 88.

6.9 Residential Hotspots

During the preliminary discussions with the residents each of the residents indicated various locations in their dwellings/around the dwellings at which there was particularly a perceptible impact/experience that occurred for which the concept of a hotspot defined those positions.



The majority of the hotspots were associated with an audible difference in the wind farm noise with some residents reporting a change in sensation.

In all houses the resident's identified internal hotspots as bedrooms, living areas, kitchen and dining areas as hotspots for noise and sensation. In house 88 the kitchen and the master bedroom were also identified as a vibration hotspot.

The attended measurements at the three houses using the multi-channel system undertook measurements in the bedrooms and some living areas that are addressed in other sections of this report.

A subsequent investigation of residential external hotspots during the course of the study revealed that in the majority of the occasions the hotspots identified by the residents were positions where there was an enhancement of the audible sound of the turbines. This enhancement was primarily as a result of reflections of the various building elements that gave rise to a noticeable increase in noise for the residents at the locations.

Attendance to the various hotspots with the residents resulted in the provision of explanations (as to the change in audible sound) where the external hotspots were adjacent reflecting surfaces. As such it was considered it was not necessary to undertake extensive measurements at the hotspots to identify the audible change in wind farm noise.

This situation has been observed at other wind farm locations where residents have noticed a significant difference in the noise of the turbines by reason of reflections off buildings.

The residents requested the provision of the subjective observations at the hotspots be included in the report.

Other than the hotspot at the NE external corner of house 87, the majority of the external hotspots were assessed on a subjective basis in the presence of residents as described below.

6.9.1 House 87

At house 87 the external hotspots around the house were located adjacent to the verandah on the northern side of the dwelling (NE corner) being a point that that was identified as a focusing of sound from the turbines, and similarly a point diagonally opposite (SW corner).



Additional focusing points were identified as occurring in the eastern boundary of the home paddock (being elevated above the dwelling) and also at the large shed approximately halfway between the eastern boundary of the property and the dwelling.

Noise measurements conducted external to the dwelling at the various hotspots (except the east paddock) found that the locations were subject to a reflection of low frequency from the building structure and that on moving away from the hot spot there was a reduction observed both in terms of subjective assessment and objective measurements.

Identification of a hotspot at the most eastern end of the property did not have a reflection from a building (as there is no building at the boundary) but there is a slight reflection of sound by reason of the hill behind this boundary and the elevation of the position with respect to the turbines, being position at approximately at the bottom of this blade swept path.

6.9.2 House 88

The master bedroom was identified by the residents as experiencing a major level of disturbance with measurements concentrated in that position.

An internal hotspot identified by the residents for this property related to the kitchen of which the main issue identified by the residents was perception of vibration through the floor. This was detected during an attended site visit and recorded during supplementary hotspot measurements in the bedroom.

An external hotspot was identified as on the wind farm side of the dwelling being a position where the logger was located and one could notice an audible difference moving across the external yard so that there was a slight increase in low-frequency noise in front of the building out to a distance of approximately 3 m. The external logger was located a distance of approximately 7 m to overcome the low frequency reflection.

On the eastern side of the building between the main dwelling and the external therapy room a hotspot was identified which was between a number of reflecting walls and as such would give rise to a reverberant effect, that was readily identified.



6.9.3 House 89

One of the occupants of this house identified a number of hotspots located external to the dwelling and inside the dwelling.

On attending each of the hotspots (external studio covered area, and rear entry to the dwelling, the kitchen and south western corner of the external verandah) all locations were observed to experience a noticeable difference in the audible sound of the wind farm by reason of reflecting surfaces and/or reverberant conditions of the internal spaces. The degree of difference in the low frequency component of the wind farm noise was easily identified and permitted a series of demonstrations to show the subjective effect.

On moving from an external environment removed from the building (wind farm side) and approaching the dwelling there was a noticeable increase in low-frequency energy due to reflections from the building. This became more apparent when one moves from the external environment to the enclosed area behind the building that has been identified as the former art studio.

This large space (when compared with normal room dimensions) has hard surfaces that leads to an increase in the reverberation time in the low-frequency and as such changes the audible characteristics of the noise leading to an emphasis on low-frequency noise.

Similarly on moving into the rear garage it can be demonstrated the nature of the different acoustic environments in a lightweight structure by going to a number of locations and observing different sound fields.

Similarly the rear entrance to the dwelling tone moves from the studio into a small alcove and then into the kitchen. Due to the significant difference in volume of the studio space to the rear alcove there is a discernible difference in the low-frequency of the turbines.

With respect to the verandah position (identified as a hotspot) there is a perception by the residents of a noticeable increase in noise (also identified as vibration at that position). This is the result of the location being in a corner and therefore subject to multiple reflections.



Inside the dwelling the noise/infrasound levels from the wind farm are affected by the different volumes and furnishing. A hotspot in the kitchen is as a result of the change in the reverberant characteristics of the space being in fact a smaller area than other rooms in the building. With hard reflective surfaces gives rise to a difference in noise from the wind farm.

6.9.4 Bending Over Exercise

During the progress of the study and attendance to the hotspots it was noticed that there is a different sensitivity/perception of the wind farm at different locations primarily close to reflections off building elements or adjacent surfaces the changes subjective characteristic of the sound as described for house 89.

In the assessment of room acoustics the issue of reflections can be quite noticeable and for site-specific spaces can give rise to significant differences.

The nature of the presence of constant sound can give rise to different standing waves that may affect individuals.

Observations at a number of hotspots with residents indicated a different perception of the “noise” or “sensation” dependent upon the orientation of the individual with respect to the ground and the location of the wind farm.

An experiment with a number of the residents found that standing in a hotspot and then bending over produced an entirely different sensation to that in a standing position and that there would be different effects by orienting the body towards, away or side-on to the wind farm.

For the purpose of assisting others in terms of the investigation of balance mechanisms for individuals that are sensitised to the wind farm there was a request to undertake a separate exercise in the hotspots, open areas and in the dwelling where the resident would first stand towards the wind farm close their eyes and observe the perception at that position.

The resident was then requested to turn through 90° repeat the exercise, turn through another 90° (so as to be facing away from the wind farm) repeat the exercise, and then continue another 90° (to be side on, opposite to the second orientation) and repeat the exercise.



Residents were then requested to repeat the same exercise at each of the four reference points, bend over and ascertain if there was any difference.

The residents were requested if possible to undertake same exercise but being at a position lying on the ground in terms of the four orientations with respect to the wind farm and conduct the same exercise whilst sitting up.

For the residents who indicated being affected by the wind farm they reported significant differences of which at certain positions standing up and then bending over produced a noticeable increase in their headache and pressure in their head to the extent that some of the residents could not undertake the exercise that was requested.

As noted above the bending exercise is not part of the acoustic study but arose from observations and discussions with the residents during the course of the study when in one instance a resident bending over to open a gate experienced an immediate and noticeable increase in sensation in the head. This information is provided at the request of the residents for the benefit of other researchers.

The residents requested they be permitted to provide input to the study as to their perception of the testing and effort required to undertake the survey (see Appendix M).



7.0 INDIVIDUAL TUBINE TESTING

For the on-site testing, the original concept proposed testing on the wind farm to obtain data in proximity to a number of turbines to evaluate noise levels and/or derive noise spectra from the turbines for correlation with the measurements that occurred at residential properties.

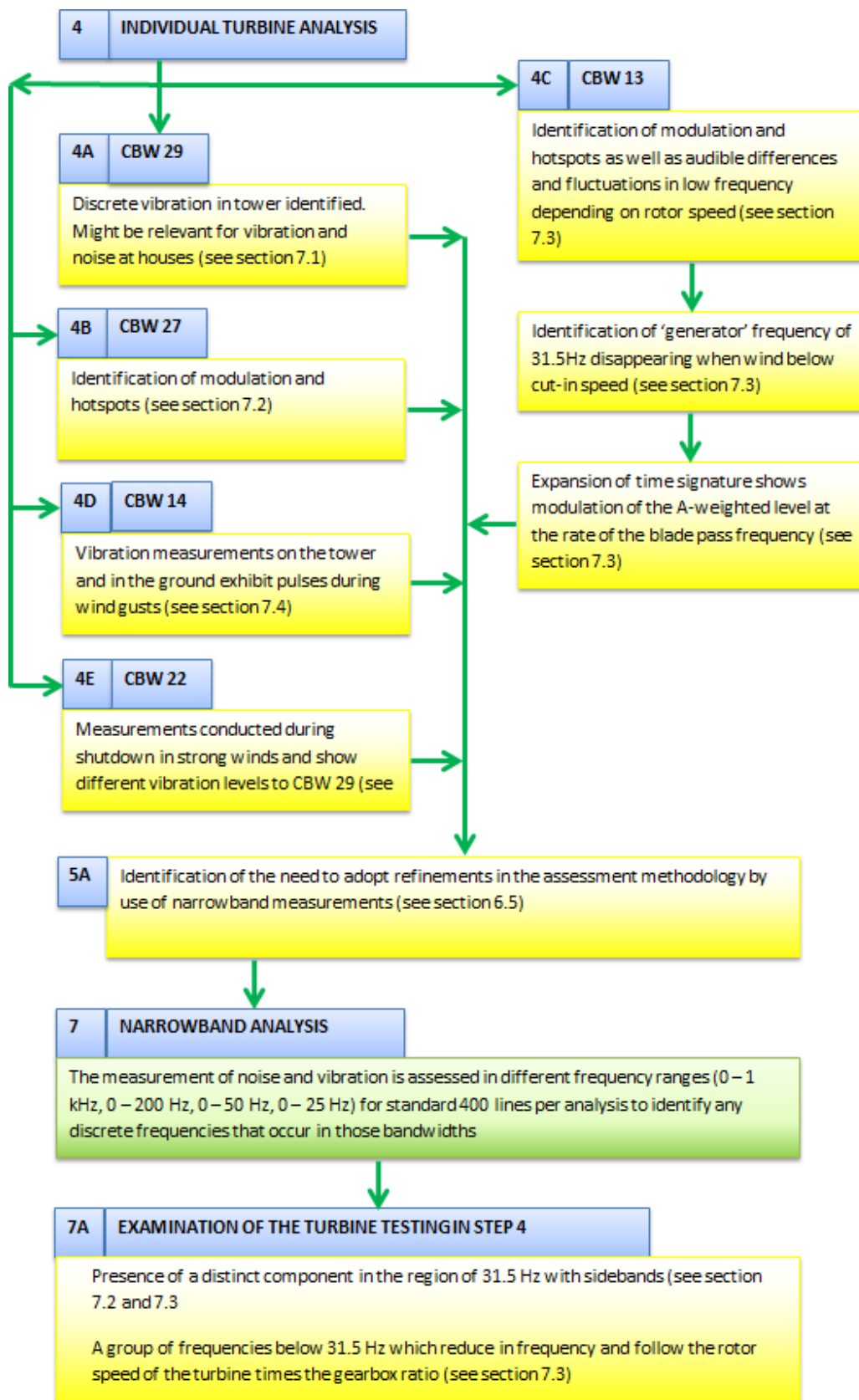
Originally the proposal was to conduct measurements at different distances from a turbine at a corner of the wind farm where there would be less of an impact from other turbines and also to conduct measurements in a group of turbines to ascertain any interference effects that may occur.

The nature of the weather at Cape Bridgewater during the survey period and the restriction on personnel (that had been imposed at the outset) did not result in the desired set of measurements that were nominated at the outset.

During the course of the study measurements were conducted on the wind farm in proximity to a number of turbines. Following the initial analysis of the first set of turbine measurements the methodology and the concept for further investigations on the wind farm changed as a result of those findings.

Parts 4, 5A and 7A of Figure 2 relate to the investigation of the turbine testing.





7.1 CBW 29

Turbine CBW 29 is located in the south-eastern corner of the wind farm and represents a turbine that is removed from other turbines. It was envisaged conducting measurements to the south and east of the turbine could provide data without the influence of other turbines.

Attendance to turbine CBW 29 found that the topography of the area limits the extent of the distance one could obtain for a downwind situation by reason of the cliff line to the south and that the land to the east and south of the turbine drops-off in elevation.

Measurements were initially conducted around the turbine in that on attendance to the turbine it was observed that the tower structure was radiating noise. Measurements conducted on the cardinal points of the turbine found slightly different noise levels with those on the eastern side being influenced by an air inlet serving an internal fan. In terms of the total noise emitted from the wind farm the noise from the inlet would be insignificant.

Appendix O2 provides the A-weighted level over time to reveal a number of discrete peaks, but of relatively low level. As with the majority of the frequency graphs the levels are Leq levels and will not identify any variation over time.

The sonogram below the first two graphs in Appendix O2 shows the variation in individual frequencies during the measurements. The A-weighted time graph commences on the left hand side and progresses in time across the graph (moving from left to right). In viewing the sonogram the left hand vertical axis is the relative time from the start of the measurement with the end of the measurement at the top of the sonogram.



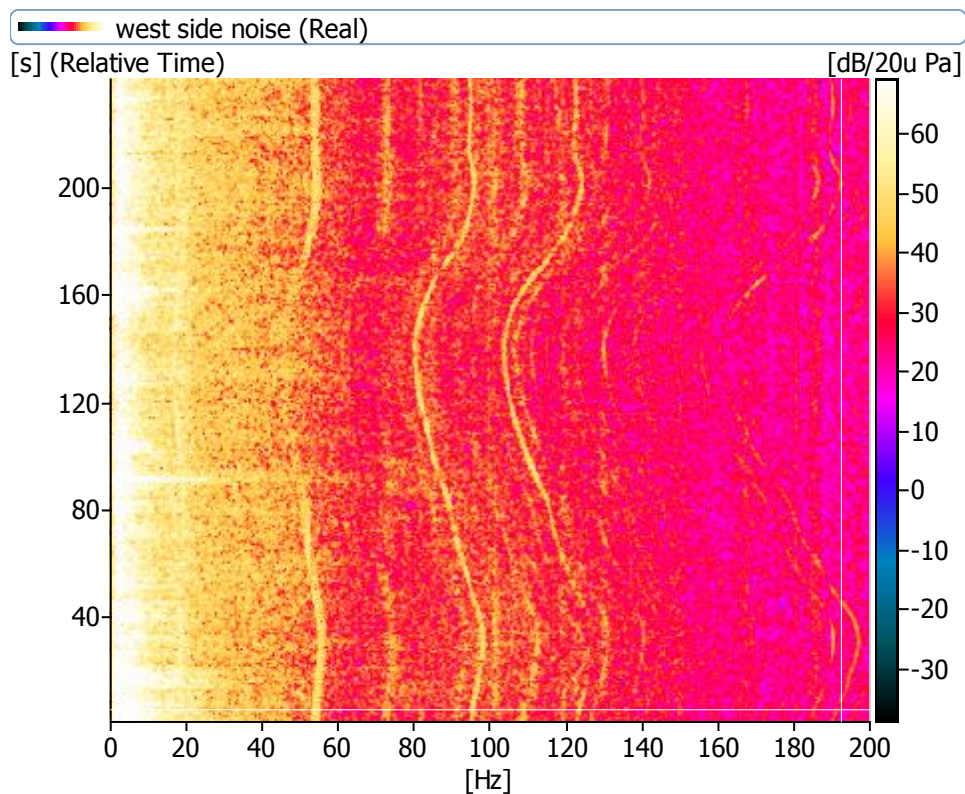


Figure 80: CBW 29 Tower Radial Vibration

The sonogram shows discrete frequencies starting at 52 Hz, 94 Hz and 122 Hz but varying in frequency in a pattern similar to the A-weighted time signal with a constant level just occurring below 20 Hz.

Measurements conducted on the other three sides of the tower (aligned at 90 degree positions) revealed a similar pattern in the sonogram.

The placement of a tri-axial accelerometer on the turbine tower found that there were distinct frequencies induced into the tower itself. Depending upon which of the orthogonal axes being viewed (vertical, radial and tangential) the frequency was slightly different with frequencies of 23.75 Hz, 23.75 Hz and 24.5 Hz respectively being observed. The vibration levels were relatively low but the nature of the discrete frequencies warranted further investigation.

The consequence of vibration in the tower being of a clearly distinct frequency was interesting in that a similar frequency had been detected for the external sound level measurements at house 89 and also for some vibration measurements in that house.



Noise measurements conducted directly under the swept path of the blades and 50 m upwind did not exhibit any narrowband components normally associated with the infrasound signature found to be emitted from wind farms.

On the following day when attending the wind farm to undertake measurements of the substation it was observed that turbine CBW 29 was stationary with a line hanging out of the nacelle that indicated a maintenance crew was in attendance.

With permission from the wind farm manager, measurements were taken at turbine CBW 29 to reveal similar frequencies as on the previous day although the turbine was stationary.

Noise levels in the vicinity of that turbine operating are similar to that with the turbine being stationary but lower than that recorded on the previous day. There were no discrete infrasound frequencies, although the 31.5 Hz frequency observed was considered to be originating from other turbines (CBW 28 and CBW 27 approximately 350 and 500 m away respectively).

In light of the measurements on turbine CBW 29 arrangements were made with the wind farm manager to conduct testing (on another day) on turbine CBW 29 having the turbine stopped and then started which involved a maintenance crew being in attendance to facilitate that exercise.

The maintenance crew explained different operating components in the tower and identified the noise source when the turbine is stationary that gave rise to the vibration level measured were various ventilation fans, with the major fan being the Tower Ventilation Fan that provides cooling/ventilation. The maintenance crew explained that the ventilation fans required for cooling purposes are not fixed speed fans but are variable speed, depending on the heat load.

If a turbine is stationary for the purpose of maintenance then the cooling fans will remain in operation which was the situation on the second visit to turbine CBW 29.

It is only when there is complete loss of power to the turbine, as in the shutdowns experienced in the second and third week of the testing, that the towers would be completely dormant with respect to any mechanical plant or similar that may be operating at other times.



The maintenance crew explained that the turbines do not have to operate at a set speed for the purpose of generating the electrical power or for synchronisation with the mains because they utilise a gearbox to increase the speed from the rotating shaft to a generator that has a rotating field with voltage generated by the alternator electronically converted to a higher voltage at the mains frequency for transmission to the substation.

Appendix O9 provides results of vibration measurements conducted on the tower for the radial vibration where the main ventilation fan was turned on for a period of 1.5 minutes and then off.

Whilst the vibration levels are relatively low, the vibration when assessed as a linear acceleration component is in the order of 6 mm/s^2 that increases to 42 mm/s^2 with the fan operating. The frequency spectrum shown in the lower figure in Appendix O9 indicates that frequency with the ventilation fan in operation to have a maximum in the 400 Hz 1/3 octave band. This becomes relevant in relation to testing on other turbines later in the study.

Appendix O10 provides a sonogram to show the broad band increase in vibration for the period that the fan was operational, with the lower figure providing the same result but in a waterfall plot that indicates a noticeable increase when the fan became operational.

Appendix O11 provides the vibration levels on the tower, for the radial component, involving the start-up of the turbine with the corresponding sonogram that identifies discrete frequencies of vibration that are generated in the tower when the turbine is operating, utilising a frequency range of 0 to 1000 Hz, with the results in Appendix O12 restricted to 0 to 200 Hz.

The waterfall diagram shown in Appendix O13 indicates the run-up of the turbine and the generation of the frequencies in the region of 0 to 200 Hz that corresponds with the sonogram shown in Appendix O12.

7.2 CBW 27

A series of measurements were undertaken downwind of turbine CBW 27 that are shown in Appendix P. This turbine was the subject of testing in the Sonus Infrasound report [33] that only considered 1/3 octave band data but did not clearly identify the operation of the turbine.

Noise measurements were conducted at turbine CBW 27 under a moderate westerly wind.



A microphone was positioned 100 m, 50 m and 25 m downwind of the turbine directly in line with the tower. The topography of the land to the east of the tower drops leading to the elevation of the microphone decreasing on moving in an easterly direction (referenced to the ground level of the base).

Measurements conducted at the 100m downwind position revealed the absence of specific infrasound components identified at residential dwellings. The narrowband spectra of the downwind measurements revealed a distinct component in the region of 31.5 Hz with sidebands to that signal.

The 1/3 octave band spectrum at 100m identifies the peak in the 31.5Hz 1/3 octave band and no significant peaks in the infrasound region. Superimposing the narrow band results with the 1/3 octave band results for the frequencies below 200 Hz (Appendix P1) whilst identifying the 31.5 Hz peak does not reveal any infrasound components attributed to the wind turbine signature.

The A-weighted level of 35 dB(A) is relatively low (when compared to other turbine measurements) but is important if one considers the directivity of the turbine noise is similar to a cylinder (on its side) such that the ground positions would be in an acoustic shadow. Having the 100m downwind position approximately 15 – 20m below the base of the turbine enhanced the acoustic shadow effect.

At 25 metres behind the tower (on level ground) the frequency of 31.5 Hz is clearly apparent with the presence of sidebands being displaced at the multiples of the blade pass frequency either side of the peak. There are no significant infrasound frequencies.

The A-weighted time signal at 25 metres shows a modulation with the expanded view on Appendix P4 identifying the modulation to be at the rate of the blade pass frequency.

In proximity to the turbine, it became obvious that there were two focal points of higher noise levels at about 10 m behind the tower and 45° to either side of the axis of the wind direction. The maxima locations were on the northern side (upward sweep) versus a similar position on the southern side (downwards sweep).

The location 10 metres behind the tower under the downward sweep of the blade, shows the sidebands around the 31.5 Hz peak to be greater than the other locations.



The time signature when expanded shows clearly that the A-weighted level is modulated at the rate of the blade pass frequency of the turbine, approaching the classic modulation concept for amplitude modulation, although the modulating frequency would appear to be lower than the blade pass frequency.

7.3 CBW 13

Measurements conducted at residential dwellings during the course of the study revealed the narrowband infrasound components normally associated with the operation of a wind farm and also low-frequency components depending upon the strength and orientation of the wind with respect to the residential receivers.

Observations of the operation of the wind farm (from Blowholes Road) during the day and night-time periods revealed in terms of a subjective appraisal a periodic increase in the noise level that coincided with the position of a turbine blade at 2 o'clock when looking from the upwind side of the turbine. This maxima has been identified by the use of acoustic cameras [35] and represents the downward sweep of the blades. A secondary hotspot has been identified on the upward movement of the blade at around the 8 o'clock position.

As a result of these observations testing at CBW 13 occurred on the afternoon of 9th July, 2014, and continued for 2 hours at various locations around a rectangle 12m x 80 m.

The concept was to conduct a series of controlled measurements in proximity to the turbine to examine the hotspots identified from the testing on CBW 27 and to examine the spectral content at different positions around the turbine.

A reference microphone was located on the upward side of the turbine 4 metres from the external base of the tower and under the swept path of the turbines. Whilst maintaining the reference location for all subsequent measurements a second microphone was positioned around the turbine using a rectangular grid maintaining the 4m metre distance upwind, then followed by a 4m separation distance from the rear of the tower downwind of the turbine utilising locations 10 m, 20 m and 40 m on either side of the turbine tower as shown in the diagram in Appendix Q1.



A supplementary measurement location, being 40 m behind the turbine and 10 m to the north of the turbine (on the upward sweep of the blades), was found to relate to an audible maxima (by walking around the turbine) leading to a series of measurements being conducted at that location.

At each location a sample measurement for 300 seconds (five minutes) was recorded to provide the 1/3 octave band with the narrowband FFT (both RMS levels) shown in Appendix Q. Also shown is the A-weighted level that occurred during the monitoring period with an expanded view of the A-weighted level to identify the time signature over a 20 second section of the recording.

The results of the monitoring around the turbine reveal a difference in the acoustic signature on the northern side (upward sweep) versus the southern side (downward sweep) both in terms of the A-weighted level and the spectral components.

During the measurements at CBW 13 there were noticeable audible differences as a result of changes in the wind and the speed of the turbines. Appendices Q2 and Q3 reveal the change in Wind Speed, Rotor Speed, Turbine Power Output and Wind Direction during the measurements based upon 1 minute data supplied for the turbine.

Not all the measurements are directly comparable. Hence the use of a reference location for all the measurements at different locations.

If one observes the results for the reference location on the upwind side of the turbine it can be seen during the course of the monitoring that whilst the A-weighted level at that position would be in the order of 52 dB(A) as an average there is in fact a variation in the noise level at that position on the upwind side of the tower between 48 and 60 dB(A).

The provision of the narrow band analysis in the 1/3 octave band graphs for the frequencies below 200Hz permits the identification of audible low frequency components that are not obvious by just looking to 1/3 octave band graphs.

The upwind reference location (left hand side of Appendices Q4 – Q19) reveals the presence of the 31.5Hz peak (found for turbine CBW 27) with the second harmonic of that peak, and at times a very narrow band peak just above 100 Hz. The expanded time signal for the reference location at the upwind side of the turbine does not clearly show any obvious characteristics.



The right-hand side of the Appendices Q4 – Q19 relate to the locations around the turbine that identify a significantly different acoustic spectrum to that of the reference location.

For some of the locations (6, 7, 8 and 9) the A-weighted level experiences a significant variation that becomes most obvious in the expanded timescale to indicate the presence of a periodic pattern which in all cases is the A-weighted level modulated at the blade pass frequency.

On the downwind side of the turbine there is of interest a pure tone at some locations of 100 Hz with its second harmonic being a very discrete sound that for other wind farms has been associated with the operating speed of a shaft in the gearbox.

The downwind side measurements at some locations reveal a similar 31.5 Hz 1/3 octave band to the upwind side and a similar characteristic to that observed at turbine CBW 27.

The measurements in proximity to the turbine show there are no distinct infrasound components in terms of a periodic pattern for any position around the turbine including that 40 m away.

Observations at distances removed from the turbine highlighted the focus point on the downward swept path at approximately 2 o'clock and identified a different audible characteristic for that component versus the upward blade component at about 8 o'clock.

As the 31.5 Hz signal had been identified at residential properties (whilst the turbines were operating) an analysis of the narrowband signature over the frequency range of 0 to 50 Hz for the locations around turbine CBW 13 are set out in Appendices Q22 to Q34 and reveal at some locations (primarily the downwind side) the 31.5 Hz signal is subject to side bands that are spaced at multiples of the blade pass frequency.

In a classical sense this pattern indicates the presence of amplitude modulation with similar patterns being observed for different turbines at other wind farms, although centred on a different frequency.

However the presence of the 31.5 Hz at different magnitudes is evident around the turbine, that only with the provision of data for the operation of that turbine can one look to a basis for such variations.

Commencing at Appendix Q35 and continuing through to Appendix Q48 are sonogram plots to show the variation in the noise level for each of the measurements around CBW 13.



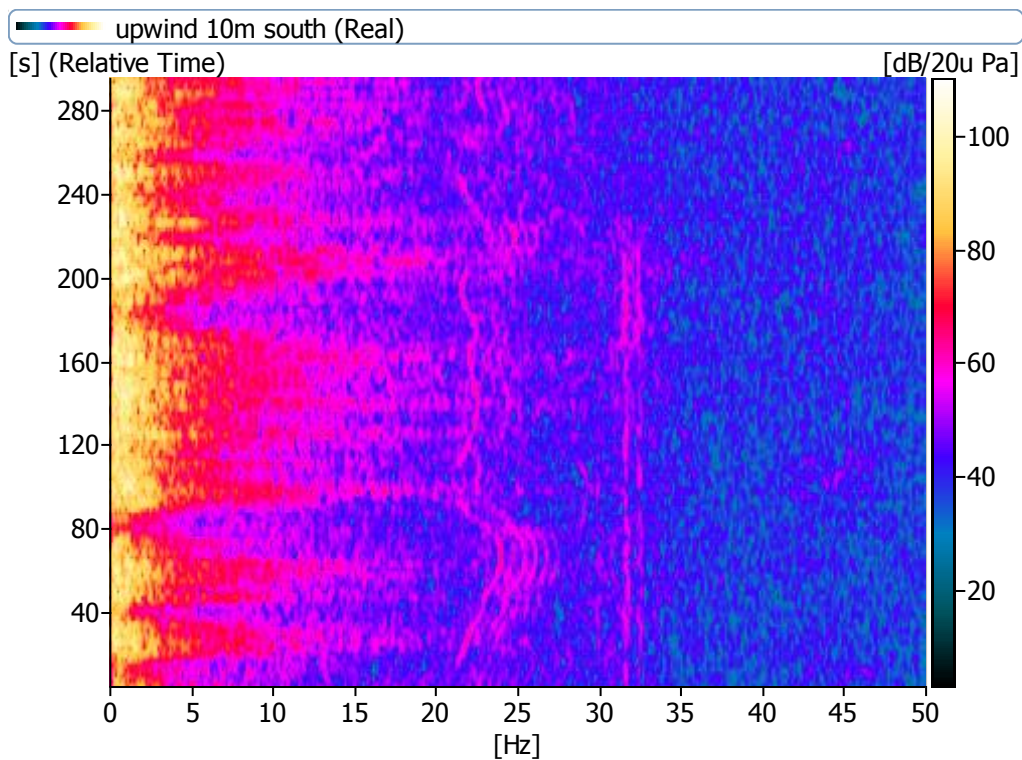


FIGURE 81: 0 – 50 Hz sonogram

Generally throughout the sonograms (for CBW 13) there is a constant vertical line associated with the 31.5 Hz frequency identified in the narrowband results, although on some occasions the line disappears entirely. An examination of the turbine data that appears in Appendix Q2 & Q3 provides a corresponding situation where the power output drops below 200 kW coincides with a wind speed below the cut-in speed therefore would indicate a proportion of the 10 minute period would have no power generated. The occurrence of that pattern suggests the 31.5 Hz signal disappears when the turbine is not generating any power.

On examining the turbine data it would appear that where there is a wind speed change there is also a change in the rotor speed that appears to give rise to a relatively steady power output. The issue of what generates the 31.5 Hz component is unknown at the present time but is a question that has been raised for similar frequencies in proximity to other wind farms that exhibit a steady frequency with modulated side bands.



It would appear the 31.5Hz component is associated with the frequency controlled speed of the rotating fields of the generator rather than structural resonances of the gearbox/nacelle that would be expected to change slightly from turbine to turbine.

The sonograms also reveal a group of frequencies that would appear below or near 31.5 Hz and reduces to a lower frequency during the sample that follows the tracking of the rotor speed identified for the turbine. This frequency is the speed of the rotor speed multiplied by the gearbox ratio and indicates this noise component is associated with the output shaft of the gear box.

Examination of the sonograms also reveal the presence of broad band pulses being an extension from left-hand side of the graph through to the right that, following other sonograms indicates fluctuations in the wind.

During the course of monitoring the noticeable changes in the character of noise generated in proximity to the turbine was observed where noise was found to be radiating from the tower and also from the nacelle. The occurrence of a distinct frequency in the region of 450-500 Hz is apparent in the narrowband analysis set out for the monitoring locations in Appendices Q50 to Q57 which would not be described as low frequency noise but a mid-band noise.

The expanded A-weighted time scale graphs for a number of locations exhibit a distinct modulation of the A-weighted level that as such does not identify any audible characteristics on the basis of a single A-weighted value. Observations in proximity of the turbine found that the audible characteristic of the 2 o'clock position (viewed from the upwind side) versus the 8 o'clock position were different.

On using the sonogram approach for 1/3 octave bands for location 4 on the upward sweep of the turbine the sonogram identifies the periodic pattern that occurs in the A-weighted value that highlights the nature of an increasing frequency that occurs at the beginning of the pulse then followed by a rapid decay of the high-frequency with mid bands being evident.

As one moves in a southerly direction the character of the pulse exhibits a signal that is equal on either side of the peak, indicating the presence of a mid-band noise increasing in frequency and then decreasing identified as an equal pattern on either side of the peak. The upward sweep is more like one side of a triangle describing the above audible characteristic.



A different view of the noise signature appears in Appendix Q81 being the upward sweep recorded at location 4, where the upper graph on Appendix Q81 is the A-weighted level to indicate a slight peak followed by reduction and then a gradual increase to a maximum level and then dropping off.

The A-weighted time signal for location 9, shown in Appendix Q82 being the downward sweep of the rotor, shows a balanced curve on either side of the maximum level.

By use of the waterfall representation of the two events, where the horizontal axis is the relative time corresponding to the upper graph and the sloping axis to the right is the frequency, the results for location 4 indicate a relatively steep approach in frequencies in time to a maximum and a broadband falling off in time. A similar waterfall for the downward sweep of the rotor indicates a more balanced frequency spectrum on either side of the maximum (Appendix Q82). Audibly there is a difference in the signal characteristics of the two locations with the graphical presentation as a means to quantify that difference.

Vibration measurements were conducted in proximity to the base of the turbine where due to the fluctuations in the wind there is a noticeable increase in vibration during the course of sample monitoring and also the generation of noise from the tower being similar to that described as a “plane that never lands”. The vibration measurements indicate the presence of discrete components which do not necessarily appear in the noise signature with the vertical component of vibration being greater in the vicinity of the tower than the other radial components.

With the benefit of measurements conducted at other turbines to indicate variations in the acoustic signature associated with the rotation speed and multiple harmonics the sonograms of the vibration measurements at Turbine CBW 13 show significant differences.

The measurements found some pressure pulses similar to that detected external to house 88.

In terms of the level of vibration that is generated, the levels are relatively low but indicated further investigation should be undertaken of which multiple measurements were conducted for turbine CBW 14 as discussed in the following section.



7.4 CBW 14

Following the noise measurement at CBW 13 vibration measurements were conducted on the tower of CBW 14. Triaxial vibration measurements were conducted on the tower, on the concrete base, and 10 m & 40 m from tower base moving in an easterly direction where the results are vibration measurements indicated in addition to general vibration there were intermittent increases in the level of vibration attributed to the concept of a pulse from the towers similar to that obtained at residential dwellings.

Appendix R provides the results of vibration measurements conducted with respect to the turbine CBW 14 where measurements were conducted in proximity to the turbine and at distances removed from the turbine as shown in the figure Appendix R2.

With the assistance of the wind farm manager the one-minute data in relation to turbine CBW 14 is attached to indicate a change in wind speed and power output during the course of the monitoring. For this turbine the wind speed for the majority of the time was at or near the maximum level.

The base of CBW 14 is 10 metres above the base of CBW 13 and therefore would be expected to have the turbine blades subject to a greater wind speed than that for turbine CBW 13 being the subject of primarily noise investigations and some vibration levels, described in the previous section.

The wind speed data for the turbines relate to average levels and does not give the peak wind speeds at the time. During the course of monitoring, the presence of wind gusts was observed both in terms of a subjective assessment and also feeling vibrations in the tower that were associated with wind gusts.

The measurement results set out in Appendix R identify the presence of intermittent vibration pulses of which during the course of monitoring turbines CBW 14 and CBW 15 were operating with initially turbine CBW 13 stationary.

During the course of monitoring turbine CBW 13 started and as a result, additional pulses were identified in the monitoring although the nature of the monitoring without having a tacho signal to the individual turbines the contribution of each turbine cannot be detected.



7.5 CBW 22

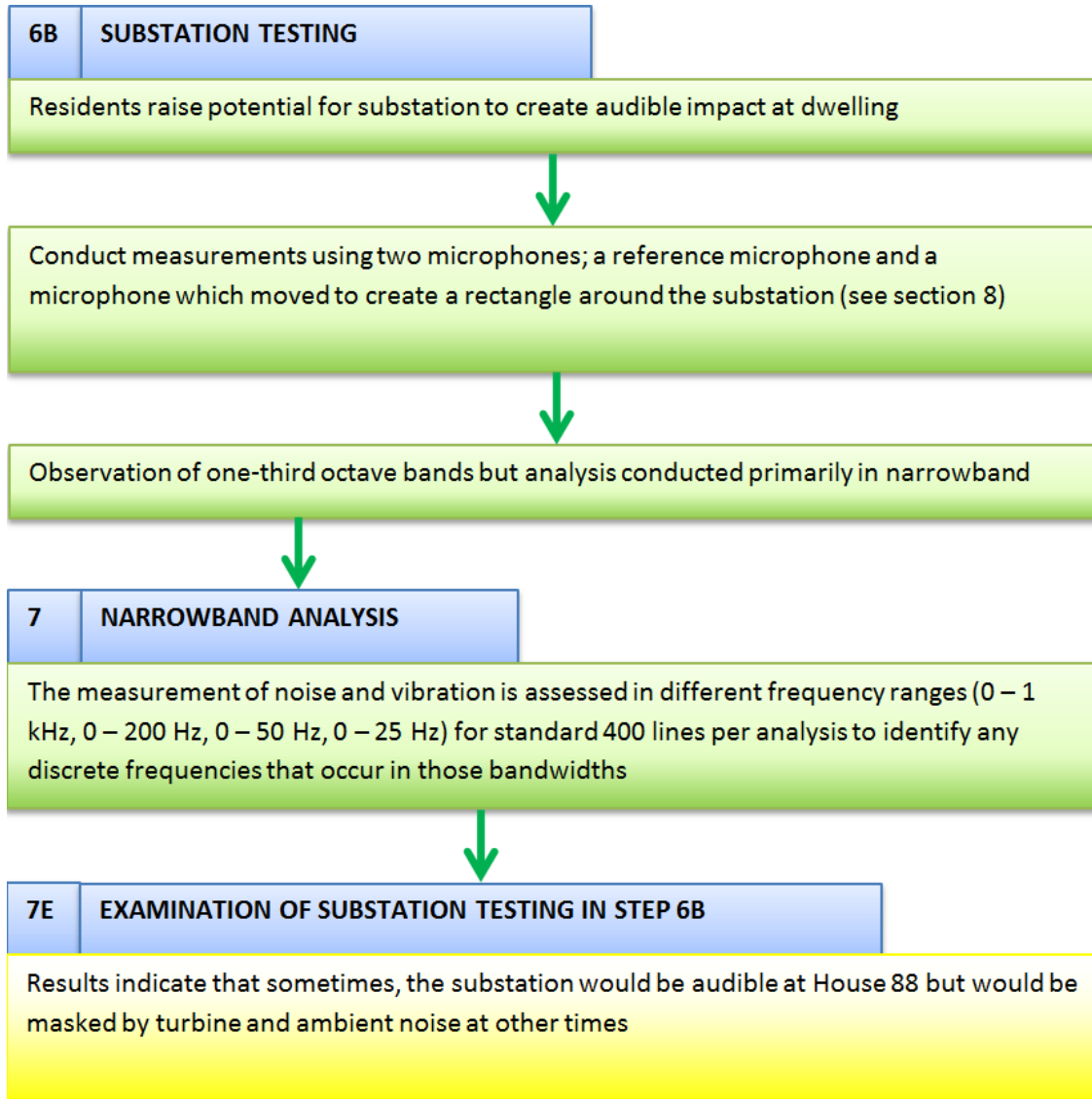
On one site visit to the wind farm it was observed that CBW 22 was stationary whilst at the time when there was a relatively strong wind occurring at the site. The opportunity to undertake vibration measurements on the turbine tower (with the turbine stationary) revealed fluctuations in the vibration level coinciding with wind gusts easily detected at ground level.

However problems with keeping the tri-axial accelerometer on the tower in the strong winds was a challenge such that the data is not considered reliable.



8.0 SUBSTATION TESTING

Part 6B and 7E of Figure 2 relate to the investigation of the substation testing.



Residents of house 88 raised during the pre-investigation discussions, and during the survey, the potential for the substation to create an audible impact at the dwelling. The impact that was described was a low-frequency hum and with the resident's experience in working around electrical substations there was an association with the audible noise attributed to a substation.



It is noted that the generation of 100 Hz from the substation with the multiple harmonics of that frequency are generally described as a low-frequency noise but in some instances is not dissimilar to the hum described by residents for “the propeller plane that never lands” and therefore that noise may not necessarily be associated with the substation but could (as discussed elsewhere) be associated with noise radiation from the towers under certain conditions.

The substation itself is an open area to the west of turbine CBW 13 and north of turbine CBW 14 at a ground level similar to that nominated for turbine CBW 13 in Appendix A3.

The substation is enclosed by a wire fence and has the primary transformer located towards the northern side of the compound at approximately midway along that boundary. There are structures to support the distribution cables and a number of buildings on the southern side of the compound.

Appendix S identifies the monitoring locations around the substation and includes a number of photos of the substation relative to those monitoring positions.

With respect to the substation, measurements were carried out by utilising a fixed microphone on the northern side and to the east of the main open-air transformer, with the creation of a rectangle outside the perimeter of the substation with measurement locations set at eight metre intervals.

The monitoring utilised two microphones where a reference microphone was at the aforementioned position on the northern side of the substation and a second microphone was moved to the reference positions external to the perimeter of the substation site, so if required at a later stage cross correlation of the measurements could be undertaken as part of post processing analysis.

On the southern side of the substation is a metal clad building that provides acoustic shielding to the monitoring positions 1.5 m above ground and will provide some degree of shielding to noise radiating from the transformers if one was conducting assessment on Blowholes Road to the south of the substation.

On the western side of the substation there is another shed for approximately half the width of the enclosed substation that would provide shielding to any remote locations in a south-westerly direction. As there is no issue of high-frequency noise from the substation the graphical presentation of the results are expressed in terms of the 1/3 octave bands over the range of 0 to 1 kHz, and a second set of 1/3 octave bands from 0 to 200 Hz (being the region covering low-frequency noise).



Superimposed onto the one third octaves are the narrowband (FFT) spectrums for the same frequency spans with an allocation of 400 lines for each of the spans.

Because the two plots are superimposed, the results are in RMS dB levels and not spectral density so as to permit our general noise concepts to apply for any assessment.

The FFT spectra highlight the typical narrowband tones emitted from transformers been based on 100 Hz (twice the 50 Hz mains frequency) and multiple harmonics of 100 Hz being lines at regular steps across the frequency spectra.

The results indicate that the dominant frequency from the substation is 100 Hz. If one takes the average noise level of that frequency around the substation and allocates a surface area inside the measuring points to determine a sound power level. In turn the resultant contribution at that frequency at house 88 would be 29-30 dB that is below the background level of 33-35 dB for the 100Hz 1/3 octave band for light wind conditions. The narrow band noise at 100Hz could be audible in light wind conditions.

The calculated 100Hz tonal component would reveal an A-weighted contribution of 24 dB(A) in a background level of 29 dB(A). Because the noise is one of a low-frequency characteristic and highly tonal in nature any assessment of the substation noise would add a 5 dB penalty giving rise to an adjusted contribution linear contribution of 29 dB(A) and under the general noise target of background + 5 dB(A).

However, the external ambient background level at the nearest dwelling (house 88) can at times be below 20 dB(A). These results indicate that sometimes, if the substation was generating a levels similar to that recorded with the wind farm operating would be audible but at other times, would be masked by the noise from the turbines as well as the ambient noise.

If the substation generates similar frequencies when the turbines are at low-power (not investigated in this study) then it could be said that the substation would be more audible during those occasions. Noise from the substation would be under the permitted limits contain on the permit and under the general environmental assessment adopted by the Victorian EPA.

The results of the measurements indicate that at times, there is potential for noise from the substation to be detected at house 88 but due to additional distance would not be audible or detected at house 87 or house 89.



9.0 NATURAL INFRASOUND VERSUS TURBINE INFRASOUND

People respond differently to different types of audible noise producing the same level. This indicates the measurement of a noise in its absolute level is not necessarily an appropriate basis of assessment.

For example if individuals are exposed to 3 different types of music, e.g. heavy rock music, opera, and 1970s music of the Beatles, all played at a level of 100 dB(A) at the individual's ear there will be a wide range of responses depending upon the personal tastes and age of the listeners.

In the above example there is a difference in the content of the music, a difference in the frequency balance across the spectrum, and a variation in the level (dynamics) of the music. The same concept could be applied in the generation of infrasound by various sources.

In general environmental acoustics modifying factors are added to the measured level to take account of the special audible characteristics.

In relation to noise emission from wind farms, where the residents in proximity to the wind farm may complain about the "noise", acousticians in looking to describe the noise have sought to expand upon the basic noise target of a dB(A) level to provide additional criteria to be used for assessment purposes.

Environmental Authorities have suggested the use of a dB(G) level to consider the infrasound component, to be added to the dB(A) level that looks at the audible component of the noise.

One methodology has been to compare the G-weighted values in different natural (external) environments, inside offices and dwellings and then examine those levels for wind farm affected localities for both external locations and internal locations [33] [34].

The SA EPA concentrated on Leq,10 min dB(G) levels and then went one step further to consider the noise in 1/3 octave bands and also compare the 1/3 octaves band results for the natural environment versus similar spectrum characteristics obtained in a wind farm affected environment The conclusion did not provide any summary of the 1/3 octave band material but only discussed the G-weighted infrasound levels so identify that there is no difference [34].



However, other researchers looking at wind farm noise [17] [31] (including TAG [24] [32]) have identified by adopting a further refinement in the assessment methodology that there are narrow band components associated with both the infrasound region and the audible region that exist in wind farm affected environments that do not exist in natural environments. To date that methodology has been ignored by environmental agencies in Australia.

In looking at the introduction of further refinements in describing wind farm noise, the following example of considering the difference between a Holden and a Ferrari (considering both vehicles as being a car), can depending, upon the qualification/restriction of the assessment parameters, give different results as follows:

- If one defines a vehicle by having an enclosure with a motor, wheels, steering and seats such that one could convey people or goods from position X to position Y, then both the Holden and the Ferrari would satisfy the classification of a vehicle. A car fits into this description as does a truck or a bus.
- If one then provided a subset to say that the vehicle for propulsion requires only four wheels to be on the ground, then the Holden and the Ferrari would have the same classification in that subset. A bus would be excluded as would most trucks.
- If the next subset was the top speed of the “car” as a different classification it would then follow that the Holden would be different to the Ferrari.
- Using another classification of the time it took to get from 0 to 200 km an hour from a standing start (as the basis of the subset) then the Holden would be in a different category to that of the Ferrari.
- Using another classification as to the price of the vehicle then the Holden would be a car but the Ferrari could be classified as a very expensive car.

It is in the above context of subsets or refinement that it is suggested utilising dB(A) to describe acoustic environments with and without wind farms will show no difference. Similarly it would appear that no apparent differences exist for dB(G) and in some circumstances comparison of 1/3 octaves show no difference between a natural environment and a wind farm affected environment.



However, residents that are affected by wind farms differ with the general SA EPA approach to say that there is no difference in their acoustic environment to that of a natural environment and that a well maintained wind farm does not produce infrasound.

The first question to be resolved is whether infrasound is generated by a wind farm as some researchers [26] [27] dispute the SA EPA claim that a “well maintained” wind farm DOES NOT generate infrasound [36], [37].

9.1 ON-OFF Tests

The logger charts in Appendix N during the shutdown period provide material with and without the operation of the wind farm.

On the assumption that the acoustic environment at the residential locations without the wind farm operating results in a “natural” environment it would appear the ON-OFF tests (being the total shut down of the wind farm) separated by a short period of time would be an appropriate method to ascertain the difference. This is different to a temporary stopping of the turbines, when the ventilation fans in the tower and nacelle can still be operating and potentially generate audible noise from those elements.

On the morning of 15th May 2014 a shutdown occurred at around 6.30 AM with the turbine UPS continuing to operate after the shutdown that provided wind information. It can be seen that the wind was at or above the required speed for maximum power. As discussed in Section 6.5 there are issues as to wind gusts influencing the Leq levels.

The following 1/3 octave band spectra compare the ON-OFF situation for the outside microphones and the inside microphones at house 87 (Appendix N33).



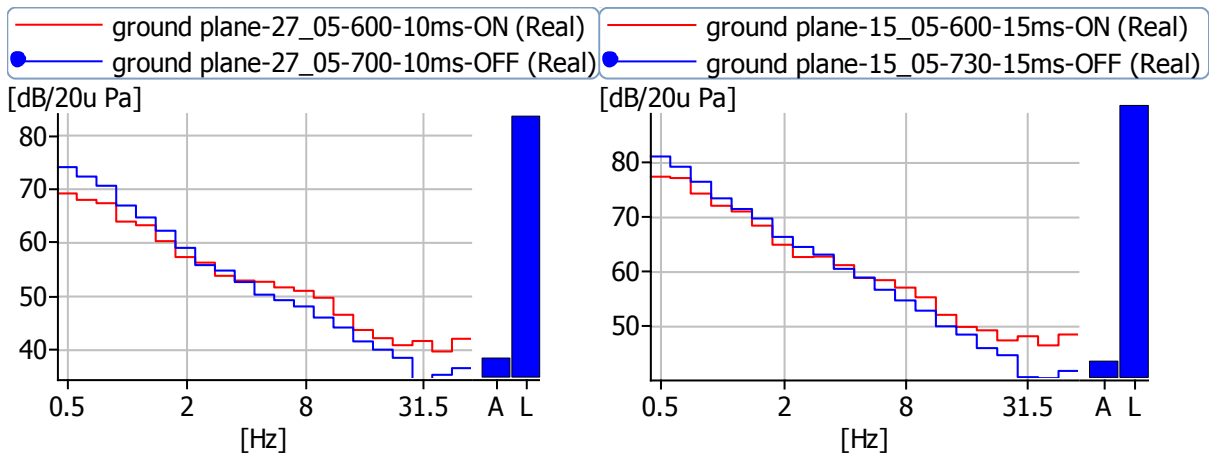


Figure 82: Ground plane house 87 10m/s wind

Figure 83: Ground plane house 87 15m/s wind

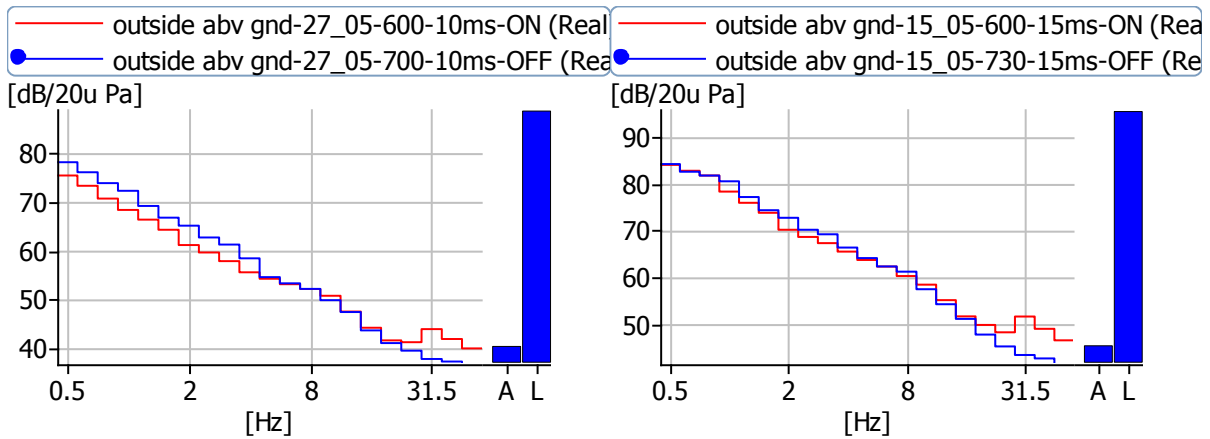


Figure 84: 1.5m above ground house 87
 10m/s wind

Figure 85: 1.5m above ground house 87 15m/s
 wind



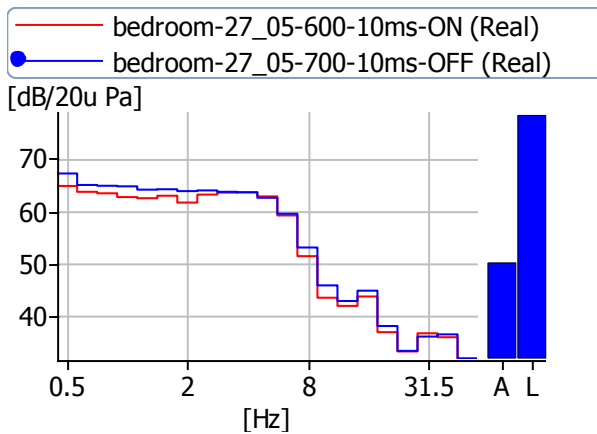


Figure 86: Bedroom house 87 10m/s wind

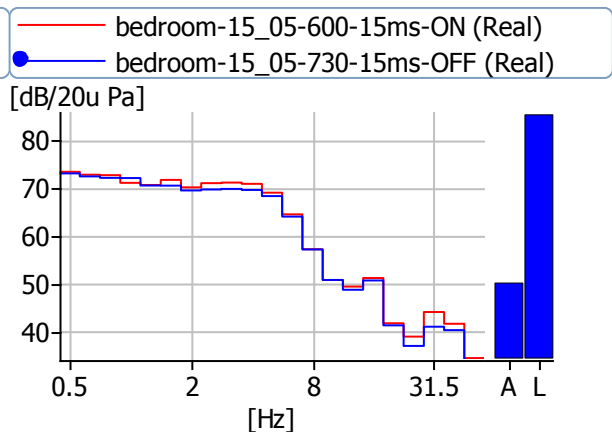


Figure 87: Bedroom house 87 15m/s wind

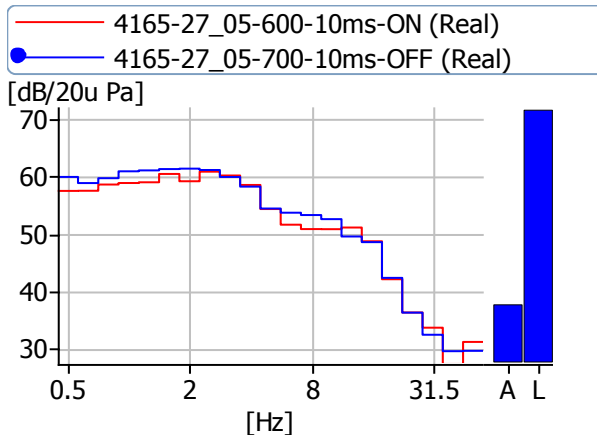


Figure 88: Living room house 87 10m/s wind

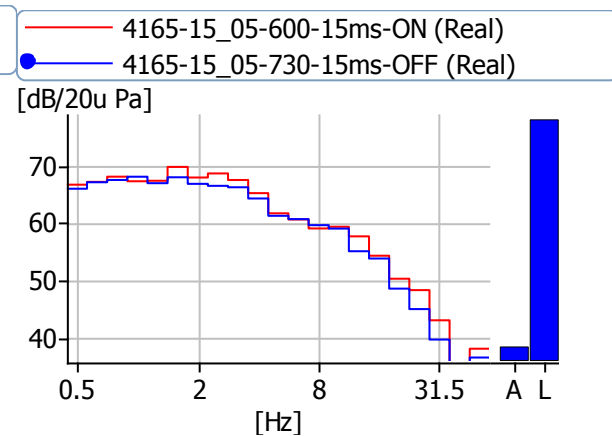


Figure 89: Living room house 87 15m/s wind

Viewing the Leq 10 minute spectrums of the infrasound region for the samples at 6 AM (turbines on) and 7:30 AM (turbines off with a marginally higher wind speed) revealed no significant differences in the 1/3 octave band spectra.

However the FFT spectra for inside the bedroom of house 87 reveal a noticeable difference in the wind turbine signature (BPF and harmonics) and the 31.5Hz modulated component as shown below.



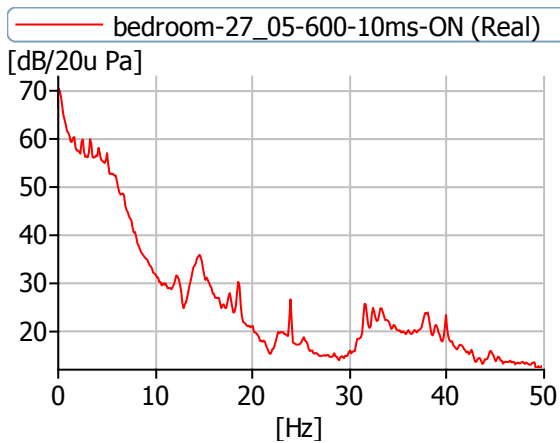


Figure 90: 6am turbines on (0 - 50Hz)

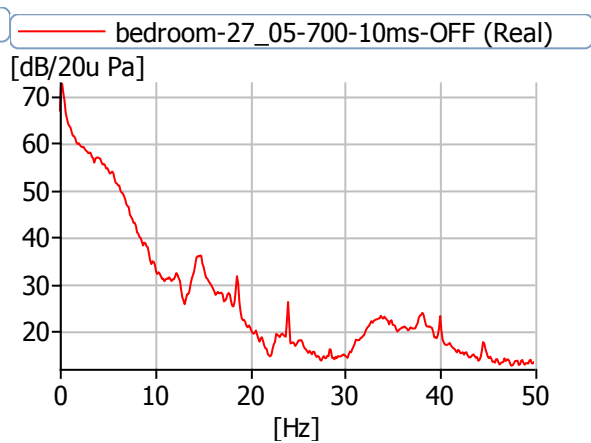


Figure 91: 7am turbines off (0 - 50Hz)

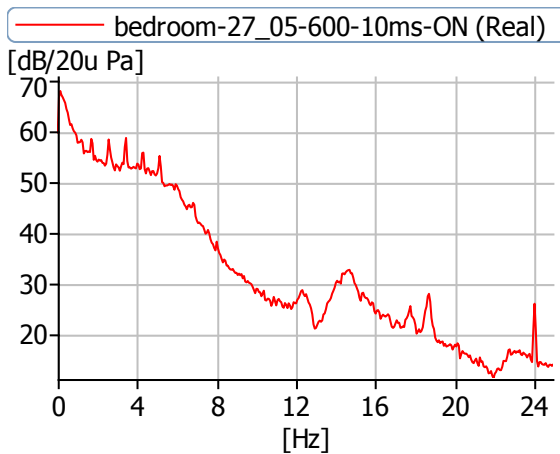


Figure 92: 6am turbines on (0 - 25Hz)

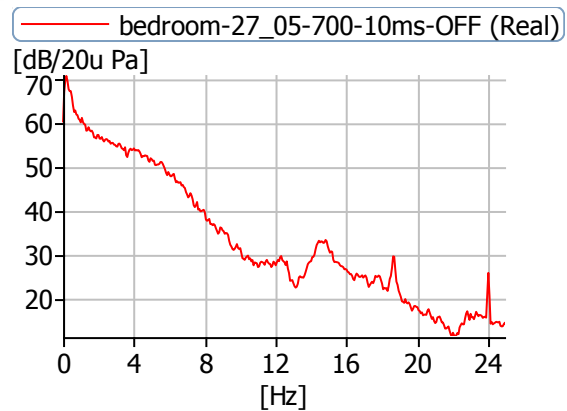


Figure 93: 7am turbines off (0 - 25Hz)

By way of the above narrow band measurements the distinction between “natural” infrasound and wind farm infrasound (that has discrete frequencies and a periodic pattern) for some researchers been the basis of seeking an explanation for the addressing turbine impacts.

A clearer interpretation of the differences in infrasound of the natural environment versus the wind farm affected environment can be seen by superimposing the narrowband FFT results onto the 1/3 octave band results as shown below.



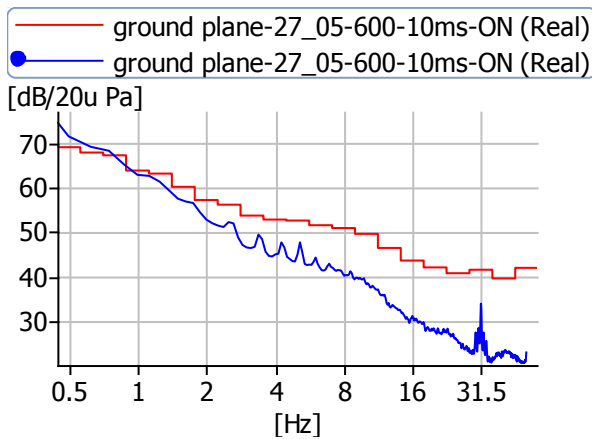


Figure 94: Ground plane house 87, turbines ON - 10m/s wind

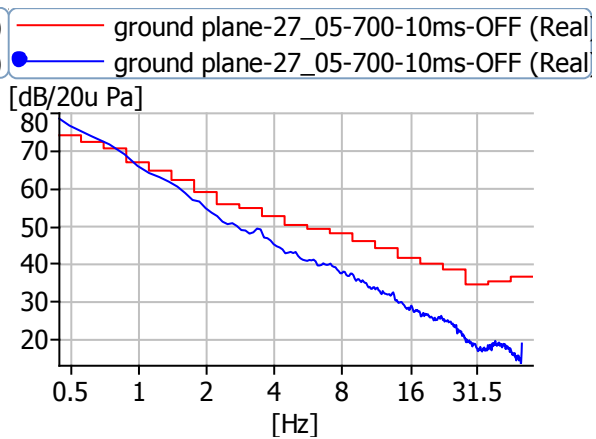


Figure 95: Ground plane house 87, turbines OFF - 10m/s wind

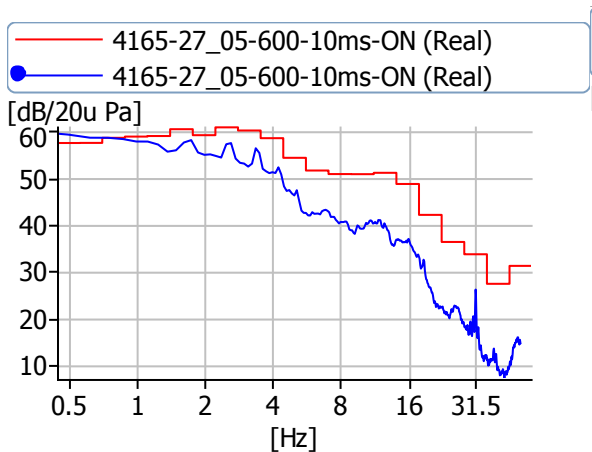


Figure 96: Living room house 87, turbines ON - 10m/s wind

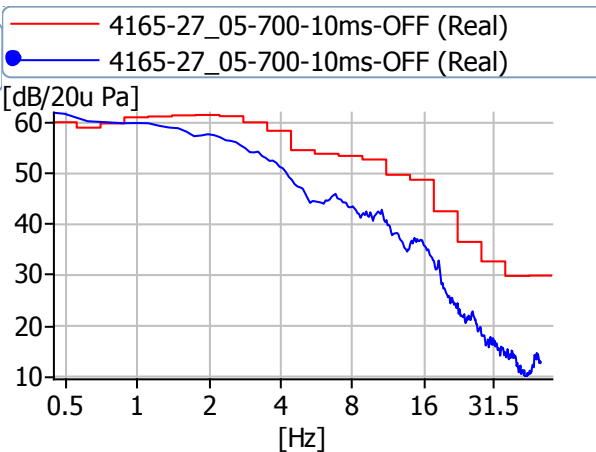


Figure 97: Living room house 87, turbines OFF - 10m/s wind

The above graphs clearly identify that on utilising a finer frequency resolution in the infrasound range that it is impossible to claim the infrasound of the environment at house 87 with the wind farm not operating is the same as when operating. The presence of distinct signatures when the turbines are operating versus not operating is clearly obvious.

In all of the above graphs the results are Leq (energy average) levels that are subject to variation in amplitude and frequencies by reason of the different operating speeds of the turbines. By use of a time analysis the changes in the spectra can be viewed in any sample of concern.



Examination of time records show the presence of individual narrow band components that become merged (or even disappear) in the averaged results. The time records in the presence of wind also reveal lower background levels across the spectra than indicated in the averaged result.

The sonograms show the influence of the wind on the overall levels with pulses generated across the entire infrasound frequency range and portions of the low frequency range. Testing of the individual turbines revealed noise levels near the turbines (and vibration on the towers) to reveal an extension in the frequency range of the pulses to be up to 1000Hz.

Huson [26] has identified by the use of micro-barometer measurements the presence of individual narrowband peaks in the infrasound region with the turbines stationary, with a suggestion such peaks are related to natural frequencies of the towers and the turbine blades responding to wind gusts. The presence of intermittent pulsations was identified in the hotspot testing and the individual turbine testing.

Examination of the narrow band spectra by stepping through the time signal reveals discrete frequencies that appear in the spectra following wind pulses that indicate even with the wind farm fully shutdown the acoustic environment at the residential properties does not return to the “natural” environment. This concept is based on the potential for the generation of resonances in the tower and blades, i.e. having a wind farm shutdown does not necessarily lead to the provision of a “natural” ambient as the presence of the turbines themselves (whilst being stationary) has the potential to generate intermittent infrasound pulsations that are dependent upon the fluctuations in the wind.

The presence of discrete infrasound frequencies for stationary turbines provides an explanation for some residents noting sensations and vibration even with wind farm shut down.

TAG has previously established periodic patterns in the infrasound acoustic signature (both external to and inside dwellings) in proximity to wind farms. The signature of the blade pass frequency and the first 6 harmonics has been labelled by TAG as the “Wind Turbine Signature” (“WTS”) as to date only that specific signature has been found by TAG near wind farms.



The results of testing by TAG at the Waterloo, Capital, Waubra and Hallett Wind Farms has presented the WTS over a number of years with the view that in the presence of infrasound levels (having both a periodic nature and narrow band components as determined using FFT analysis) when internal levels in dwellings were above a threshold of around 50 dB at 4 Hz the occupants detect the effect of the wind farm. The observations by the residents was not of an audible noise but was something that they could detect or sense.

Kelley in the 1980s [21] [28] considered a noise/vibration/sensation curve (LSL curve) which is not too dissimilar to the G-weighted value if one shifts the whole curve up in frequency. The LSL would appear to be based upon work undertaken by Japanese investigators [38] and then reviewed by Kelley [21]. However the laboratory studies were limited in the lower frequency limit that could not reproduce the signature attributed to wind farms. Kelley [21] provides a LSL curve and a LSL (impulsive) curve with identification that the curve relates to low frequency annoyance.

As discussed in section 3 the matter of what the residents perceive in different parts of their body varies from individual to individual. In some cases there is difficulty for the residents to describe what is affecting them. However the introduction of “sensation” to the survey has assisted the residents in describing this impact.

If one takes the possibility that there is some form of energy or signal present in the acoustic spectrum of the environment then the matter of investigating the sensation, identified as the major factor for the residents impacted in this study, can be of assistance to other researchers.

9.2 Ambient Testing at Cape Bridgewater

Whilst the ON-OFF testing shows a distinct difference in the wind farm generated infrasound versus the same locations with the wind farm off, for the purpose of addressing the matter of infrasound in different acoustic environments one can undertake measurements in different environments utilising the standard 10 minute samples as required by the NZ Standard or the SA EPA Guideline. Considering the results both in terms of 1/3 octaves and narrowband analysis covering different frequency ranges (that may be supplemented by time varying signals both in terms of the linear domain and the A-weighted domain, or using any other weightings that may be considered as appropriate) assists in obtaining a finer resolution than just 1/3 octave bands.



With respect to the issue of the “natural” environment versus wind farm affected environments and whether there is a difference in terms of the infrasound components for those different environments, in addition to measurements conducted at the residential locations and on the wind farm, measurements were conducted external to the Cape Bridgewater Wind Farm to identify the existing acoustic environment and permit examination of the concept that adding narrowband measurements to the analysis (so as to create a subset) applies to locations removed from the wind farm.

Measurements conducted in the vicinity of a few turbines on the subject wind farm are discussed in Section 7 and gives an insight into different spectral and time characteristics of the turbines at Cape Bridgewater Wind Farm. As set out in Appendix N measurements in proximity to the Cape Bridgewater Wind Farm has found a distinct peak at 31.5Hz with sidebands at multiples of the blade pass frequency. Also shown in Appendix N and noted above the narrow band spectra identify the presence of the wind turbine signature (blade pass frequency and multiple harmonics) when the Cape Bridgewater turbines are operating.

Measurements conducted on and near the Cape Bridgewater Wind Farm set out in the Sonus report [33] were restricted to 1/3 octave bands with identification of G weighted levels. However the time period of the measurements, weather conditions and operating conditions of the turbine etc., are not identified by Sonus and as such introduces a restriction on the use of that data.

To identify the benefit of an additional subset of data (narrowband FFT results) superimposed onto the 1/3 octave spectra, Appendix T also being linear average of the same 10 minute sample can identify the presence of any narrowband components.

This is a similar format to that set out in Appendix P detailing the on-site measurements that show results in proximity to other turbines at different distances.

Measurements conducted at a number of locations along Blowholes Road revealed the presence of discrete low-frequency and infrasound components associated with the turbines identified from the testing at the residential locations.

Measurements were conducted in the turning circle at the western end of Blowholes Road (at a similar location identified in the Sonus report) was subject to relatively strong winds at the time. However, even in such wind the discrete spectral components that have been identified at residential dwellings were apparent.



At the time, the orientation of the wind would place the measurement location approximately 220 metres upwind of the nearest turbine (CBW 25). On a 1/3 octave band basis there were no distinct characteristics of the signature. However, with the inclusion of the narrowband components in the 1/3 octave band graphs reveals the infrasound and low frequency generator characteristics.

Measurements conducted on Blowholes Road opposite the access road to the substation, being south-west of turbine CBW 15 and the north east of turbine CBW 27, being a location readily accessible by the public or other researchers, found the narrowband spectral components that was expected at that location as well as the typical “whoosh” noise associated with turbines.

At the time of the measurements at this location turbine CBW 15 would be downwind of the location (thereby meaning the monitoring was occurring on the upwind side) and downwind of CBW 27. The acoustic signature shown in the frequency analysis for this location is consistent with that obtained at other locations in proximity to the wind farm but obviously being closer to the noise source has high noise levels at which can only be attributed to the turbines, not any other natural source.

A third location on Blowholes Road is at the eastern end of the study area where the road is elevated above the ground level of house 88 and slightly elevated above the ground level of house 87. The location was at the most elevated position along Blowholes Road (that happens to coincide where one can get our reliable mobile telephone reception) and was use that was considered to be in line with turbine CBW 14. At the time of the measurements the location would be downwind of turbines CBW 27, 28 & 29.

Measurements at this location on the ground (not on a ground plane reflection board but simply a microphone placed on the ground) and an elevated location revealed the classic signature has been attributed to the operation wind farm that as such could not be described as what occurs in the natural environment.

Measurements conducted at night at beach edge of the parking area outside the Cape Bridgewater Surf Club experienced an acoustic environment that was dominated by surf noise having waves crashing at approximately 100 metres from the microphone. It is estimated that the wave height of the time was 1 – 1.5 metres. There was no prevailing wind at the time of the measurements at the surf club.



Even though this location is 2.1 kms from the nearest turbine (CBW 12) and approximately 1.5 m above the sea level, and shielded from the turbines by the topography, at the time of the measurements the spectra indicate some slight narrow band components in the infrasound region that have been identified as originating from the wind farm.

Measurements at Discovery Bay, being west of the northern section of the wind farm, under a relatively strong onshore wind recorded high infrasound levels (due to the wind) but no discrete frequency components in the narrowband spectra.

It is noted on an A-weighted basis the measurements at Cape Discovery car park are lower than the surf club which is reflected in the difference in the low-frequency and broadband noise between the surf club location and the Cape Discovery car park location which is attributed to the waves rather than the wind.

The difference in the audible characteristic of wind versus the surf also appears in the Bridgewater Lakes car park location where there were no narrowband components in the spectra. The natural environment as an audible noise was the roar of the surf to the south of the measurement position.

At the car park for Shelly Beach, being approximately 5 km from the nearest turbine, the ambient noise level was primarily a result of the wind and to a lesser extent some surf noise. The measurement results whilst showing high level of infrasound (as a result of the wind) do not show any discrete infrasound components.

The Shelly Beach car park would be deemed to be a natural environment.

9.3 Ambient Measurements at Other Wind Farm Sites

TAG have similar full spectrum 10 minute measurements of the natural environment at dwellings in proximity to proposed wind farms and measurements in relation to existing wind farms upon which a similar exercise can be undertaken.



Measurements at residential locations with respect to the proposed Collector Wind Farm, the proposed Bocco Road Wind Farm and the proposed Gullen Wind Farm all relate to the “natural” environment, as the wind farms are not in existence for the first two locations, but was in existence for the third wind farm but not operational at the time of the measurements. NB Permission has been obtained from the individuals who authorised measurements at the above sites for inclusion in this report.

Appendix T provides the results of ambient measurements at properties that will potentially be impacted by the above three wind farms. The measurements in relation to the first two wind farms are prior to any construction of the turbines. The Gullen measurements occurred during erection of the turbines that were not operational at the time of the measurements. Therefore the monitoring results with respect to the three proposed wind farms would be “natural” environment measurements and will become relevant for any subsequent investigations following commencement of operations of those wind farms.

The 10 minute ambient measurements have been assessed using the same methodology as the measurements external to the Cape Bridgewater Wind Farm site.

Examination of the material reveals that none of those locations exhibit discrete narrowband components in the infrasound region.

Utilising measurements from properties in proximity to the Waterloo Wind Farm in South Australia, the Hallett Wind Farm in South Australia, the Waubra Wind Farm in Victoria, and the Capital Wind Farm in New South Wales all exhibit narrow band components in their infrasound spectra

It is noted that the other wind farm sites utilise different turbine models to that for the Cape Bridgewater Wind Farm and exhibit the similar pattern of multiples of the blade pass frequency in the infrasound region. They also exhibit a modulated peak between 25 and 35 Hz.

The distinct modulated frequency at other turbines could not be related to any operating speed of the turbines themselves but can be taken as a speed slightly above the maximum rotor speed multiplied by the gearbox ratio that would appear to be a frequency associated with the operation of the generator in each turbine.



The nature of the distance from the nearest turbine to the residential receivers for each of the measured results at different wind farms would suggest that there is a significant source of noise emission attributed to that frequency that may be originating from the gearbox and radiated from the nacelle of the turbine.

None of the testing for the above wind farms had the benefit of a full wind farm shutdown.

In addition to the other wind farm site, Appendix T also includes measurements of night time noise in the Hunter Valley in NSW related to emission from a coal mine. The ambient background levels are well below 30 dB(A) and audible noise could be detected from the operation of the mine. Infrasound and audible tones are evident in the spectra, but the periodic pattern found for wind turbines is not.

The above material identifies that undertaking comparison measurements of the infrasound levels in the natural environment versus that of the wind farm will find similar results and therefore if restricted to only 1/3 octave band results one will agree with the conclusions proffered by the SA EPA in their infrasound report issued in January 2013.

The natural environment that involves waves on the beach, wind in the trees or wind in an open area does not on the basis of these measurements exhibit a periodic pattern to that obtained in wind farm affected environments that can be directly related to the nominal blade pass frequency of the turbine and its first 5-10 harmonics which has a direct mathematical relationship (to the blade pass frequency) so as exhibit a periodic pattern.

Providing a comparison of natural environment versus wind farm environments and restricting the measurement results to only dB(A) or 1/3 octave bands will not identify any significant difference between the two environments, whereas the inclusion of narrowband components identifies the differences between those environments.

Utilising the Cape Bridgewater narrow band results superimposed onto the 1/3 octave band results shows there is a difference between the natural environment and a wind farm affected environment in the infrasound region. Therefore one cannot claim that infrasound levels in the natural environment are similar to that of wind farm affected environments.



10. MEASUREMENT UNCERTAINTY

Appendix E lists the instrumentation used in the study that ranged from standard sound level meters used for general environmental acoustics to specialised data analysis of full spectrum noise and vibration.

During the course of the analysis and post-processing of the data a number of issues emerged that questioned the validity of the results, due to differences in the performance of instrumentation.

Issues concerning the low frequency performance of meters in providing results for the infrasound region have been previously raised by TAG. As a result of identifying conflicting data for different instruments used in the study the project was placed on hold for three weeks whilst further investigations were undertaken to resolve a number of instrumentation issues.

The results of this work are provided to identify the potential for measurement uncertainty and limitation of the results, and to assist others in future work. Some of these issues have been previously raised by TAG with researchers at Adelaide University to assist in their investigations.

The general measurement of audible noise is adequately addressed by standard instrumentation that have the capability of recording data above 20 Hz. Questions have been raised as to the accuracy of wind farm measurements in the infrasound region and the instrumentation used – based on recording the signal using a microphone.

There are issues of obtaining accurate data and comparable data from microphones by the use of large windscreens, double windscreens, ground plane microphones and microphones below ground.

Investigating infrasound (below 20 Hz) presents difficulties for instrumentation that is not designed to measure down to frequencies in the order of 1 Hz.

Conducting noise level measurements inside dwellings, where the background level is often below 20 dB(A) presents an issue with respect to the electrical noise floor of the instrumentation.

In addition to the instrumentation failures encountered during the course of the investigation, that may be attributed to electromagnetic radiation or static electricity effects, a number of challenges have been presented in the investigation as to the accuracy of the data and/or the requirement for qualification of what has actually been measured.



Similar issues as to the accuracy of the measurements by the EPA have been raised by the community and researchers at Adelaide University with respect to measurements in the vicinity of the Waterloo Wind Farm.

As the acoustic test program would be subject of further reviews and could be used as a basis for further testing (by others), matters pertaining to instrumentation issues that have been highlighted during the study are presented for the benefit of further research work and identification of instrumentation issues that must be addressed.

10.1 Differences in Instrumentation

Not all instruments are capable of providing full spectrum analysis with many sound level meters having a lower limiting frequency in the order of 5 Hz, 6.3 Hz or 10 Hz (related to the lower 1/3 octave band that can be recorded).

Typically precision sound level meters will have a specified noise floor in the order of 20 - 25 dB(A) although they may be able to record slightly lower noise levels.

To provide accurate low-frequency and low-level measurement results generally requires specialised instrumentation different to that encountered for normal precision sound level meters.

In many cases, apart from specification for electrical characteristics of sound level meters, there may be limitations on the frequency response of microphones that are used to record low-level and/or low-frequency response. Seeking to obtain low-level and low-frequency results presents challenges with respect to the instrumentation selected.

One of the issues that is commonly encountered which such measurements is whether the measurement results provided by sound level meters are accurate and represent what is being recorded. For example, it may be stated that a sound level meter has been calibrated to the relevant standards and then utilised a superior microphone that has a specification to extend the low-frequency performance, where it is implied that the complete measurement system obtains accurate results across the entire frequency range.

It is not uncommon in wind farm measurements to utilise a meter from one manufacturer with a microphone from another manufacturer rather than the original microphone supplied with the meter.



However examination of manufacturer's information indicates that in many cases the capacitance of a microphone when coupled to a microphone preamplifier can affect the noise floor leading to a different filter response that can affect the low-frequency performance of the system [39].

For example in the SA EPA's Infrasound Report [34] there is identification of the use of a Sinus Soundbook having "negligible deviation of the instrument frequency response to frequencies as low as 0.1Hz", a B & K microphone Type 4193 with UC-211 low frequency adapter and a GRAS 26AK preamplifier (claiming a uniform frequency response for 0.2Hz – 20kHz) [40]. There is an implied assumption of an accurate result over the frequency range of 0.2Hz – 20kHz "based on the minimum frequency response of the analyser or microphone".

However the GRAS 26AK specification nominates ± 0.2 dB with a 18pF microphone dummy for 2.5Hz to 200 kHz. The B & K 4193 microphone has an 18pF capacitance, but the B & K UC-211 specification states a 100pF capacitance [39]. A combination of the above instrumentation components does not necessarily mean a flat response across the frequency range of concern.

The correct mechanism for assessing the capabilities of the instrumentation used for testing is to calibrate the entire signal chain from microphone to the display, by use of a dedicated calibrator that is capable of generating at the microphone an accurate pressure and frequency signal down to the frequencies of concern.

10.2 Low Frequency Performance

For the purpose of this study, calibration of the various system chains was carried out using a GRAS 42AE low-frequency calibrator to generate sound pressure levels between 0.1 Hz and 100 Hz that was used to supplement a Bruel & Kjaer Multifunction Calibrator Type 4226 (that covers the octave bands of 31.5Hz – 8 kHz).

The GRAS calibrator was purchased for the purpose of the investigation and holds current manufacturer's calibration, whilst the multifunction calibrator holds current NATA certification from the National Measurement Institute.

The use of both calibrators permitted calibration of the frequency response of not just the microphones used for the measurements but the entire systems.



Extensive testing by the use of the two calibrators found that whilst the sound level meter/microphone combinations were accurate for the audible range, for the infrasound region there were issues in terms of deviation from the manufacturer's documentation for some meters. In addition the frequency response of microphone/meter combinations were subject to variation especially when the frequencies of concern were below the specified tolerance limits for the subject microphones or meters.

It was necessary to establish that the individual noise loggers by way of statistical measurement results, spectrum results, and where available wave files, agreed with the multichannel recording system (that is specified as having a flat frequency response and noise floors significantly below the standard sound level meter).

As a result of the calibration testing a number of issues were identified that may be relevant to other researchers:

1. Undertaking a frequency calibration check by use of a signal generator attached to the microphone by an isolating capacitor revealed a linear response across the frequency range.
2. Conducting the same exercise but using the low-frequency acoustic calibrator and having a microphone in place (instead of a voltage from a signal generator) revealed for some microphones a noticeable low-frequency roll off.
3. The SVAN manuals indicate the meter is suitable for acoustic pressure above 10Hz.
4. The SVAN 957 and SVAN 979 sound level meters identify that the spectrum settings can utilise different filter responses.
5. The SVAN 957 can select filtering in terms of the A, C and Z filter curves. The Z filter curve set out in the manual indicates a noticeable roll off for frequencies below 10 Hz with the indication that the attenuation at 1 Hz is in the order of 30 dB (see graph below from the SVAN 979 manual). There is no linear frequency response on the SVAN meter.



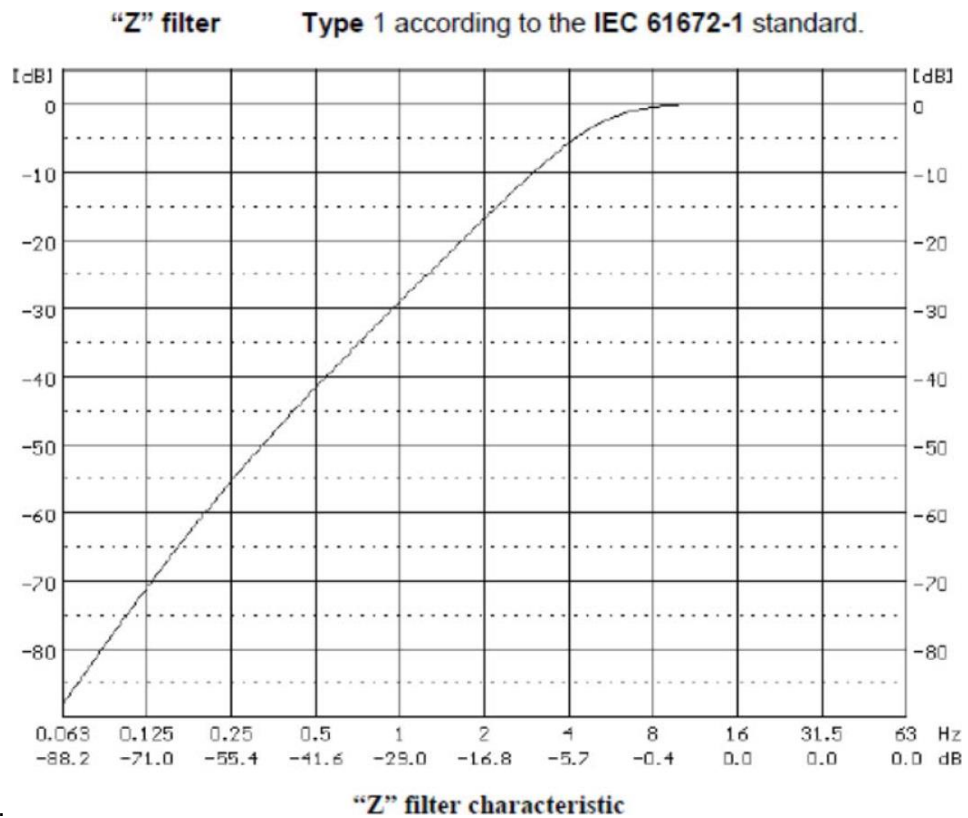


Figure 98: Z filter extracted from the SVAN 979 manual

6. The SVAN 979 sound level meter manual indicates there are filter responses for the spectrum of A, B, C, Z and HP. For consistency between the SVAN meters the meters were set to have Z spectrum as the weighing response (with the exception of the hired 979 logger in house 87 that had been set for HP filter).
7. Examination of calibration results for the two different SVAN models (entire microphone and meter) set on Z filter revealed different curves.
8. Utilisation of the low-frequency calibrator identified that the Z related spectrum for the SVAN 957 meter was flat whilst the Z weighted spectrum on the SVAN 979 meter followed the nominated Z weighting filter.
9. In all cases the SVAN 979 meters had a GRAS 40AZ microphone which is specified as having a flat response ± 1 dB down to 1 Hz.



10. The SVAN 957 meters showed a relatively flat response until below the specified tolerance by the manufacturer of 2 Hz where there was a deviation in terms of the response that is attributed to the microphone supplied with the meter. In the following graph loggers 3 & 4 are SVAN 957s whilst loggers 5, 6 & 7 are SVAN 979s.

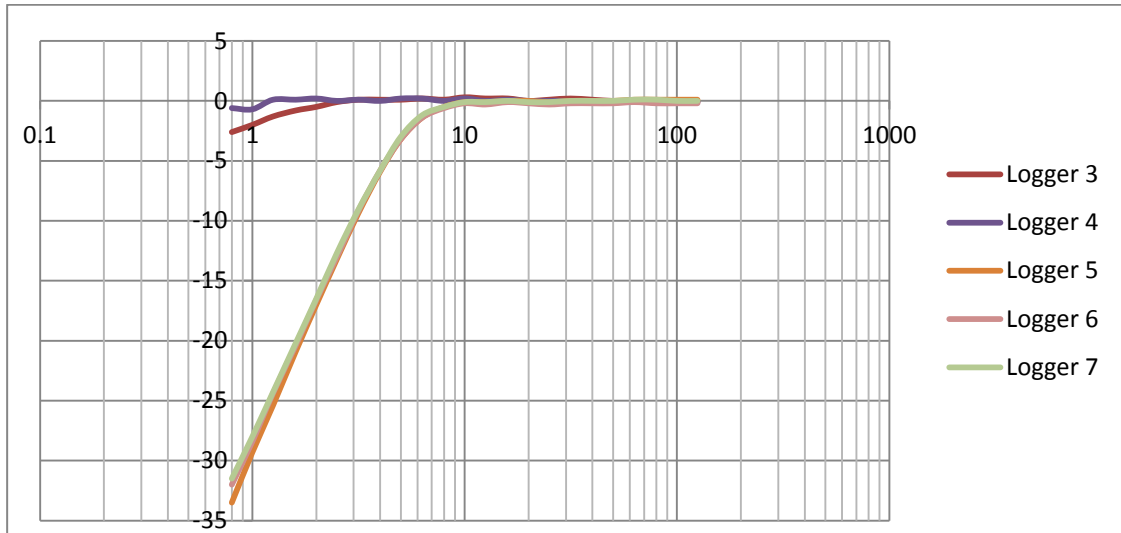


Figure 99: Frequency response of SVAN meters

11. Similarly with respect to the various 200v polarity microphones (used inside the dwellings) there are different frequency responses below the manufacturer's specified lower frequency limit.

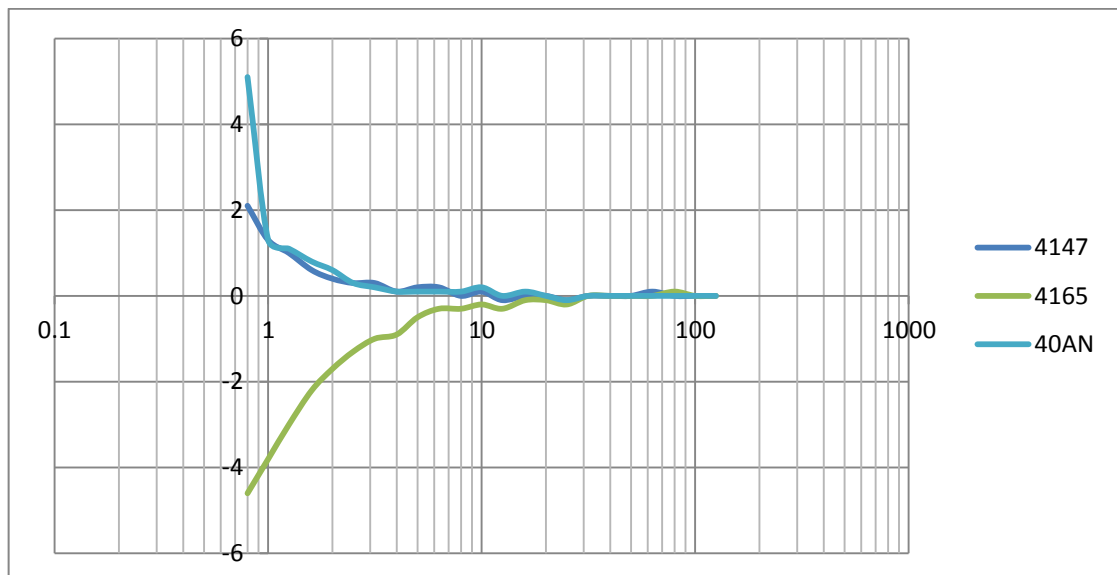


Figure 100: Frequency response of microphones



12. The consequence of the above tests indicates that corrections are required for the different instrumentation combinations to achieve a normalised flat response.

In some wind farm assessments there is reliance upon WAVE files.

However if the system of obtaining the WAVE files cannot be checked across the entire frequency spectrum of concern, one is uncertain of the results. Use of high performance A-D convertors (such as the B & K Pulse system or the dedicated instruments developed by Bruce Walker in the Shirley Wind farm testing [25]) is required. Use of computer based sound cards and general A-D converters have limitations in providing accurate results in the infrasound region.

Questions have been raised as to listening to wave files for the determination of special audible characteristics. Using a computer sound card and speakers can give different results from computer to computer, and room to room, dependent upon the ambient background level in the rooms, the quality of the playback system, and the level at which the signal is played back. Similar questions can be raised in relation to the use of headphones.

The SVAN 979 Meters have the capability of providing WAVE files but the recorded signal is from the profile channel that does not have an HP or Flat setting. The WAVE file output can be A, C or Z weighting.

Using the B & K Reflex program that takes results from the B & K Pulse and B & K Data Recorder (with embedded calibration data) the field results and post processed results from the available WAVE files can be compared.

By examining two SVAN WAVE files (with and without Z filtering) the Reflex analysis agreed with the logger files in the critical low frequency/infrasound region.

In dealing with 1/3 octave band calculations for the different frequency response (by use of an excel program) the corrections to un-weight the SVAN Z filter and the individual microphones is relatively straightforward.

However un-weighting the SVAN Z filter or the microphone response for narrow band analysis is more difficult. What was required was the development of an inverse filter to the relevant response curves (based upon a Finite Impulse Response filter) to occur at the beginning of the analysis chain in Reflex.



The FIR filter was then checked with the relevant WAVE files for the same room and same time period to validate the results.

The above discussion highlights the relevance of knowing the full frequency response of the measurement system from microphone through to the numerical outputs.

As observed during the study one can, from similar (and the same) instruments, obtain conflicting data in the infrasound region that has been suggested as being critical in assessing wind farm “noise” impacts.

10.3 Z-Weighting

Typically manufacturer’s specification for sound level meters refer to International Standard *IEC 61672 – 1: Acoustics – sound level meters – part 1: Specifications* [41].

In general the concept is to consider reference to the Z weighting filter as replacing the original Linear (un-weighted) filter that was used on sound level meters, but did not necessarily extend or define the full frequency performance of such meters.

Section 5.1.1 of the Standard indicates that Z weighting relates to 0 frequency weighting that is reflected in Table 2 of the Standard that provides frequency weightings and tolerance limits for different classifications of meters.

Table 2 in the Standard indicates for the frequency range of 10 Hz to 20,000 Hz the Z-weighting frequency correction is 0 dB. There is no identification in the frequency weighting table of any allocation for frequencies below 10 Hz.

An extract of Table 2 from IEC 6172-1:2002 for frequencies below 25Hz is shown below.



Nominal Frequency a) Hz	Frequency weightings b) dB			Tolerance limits (dB)	
	A	C	Z	1	2
10	-70.4	-14.3	0.0	+3.5; -∞	+5.5; -∞
12.5	-63.4	-11.2	0.0	+3.0; -∞	+5.5; -∞
16	-56.7	-8.5	0.0	+2.5; - 4.5	+5.5; -∞
20	-50.5	-6.2	0.0	±2.5	±3.5
25	-44.7	-4.4	0.0	±2.0	±3.5

- a) Nominal frequencies are from the R10 series given in table 1 of ISO 266:1997 [5].
- b) C and A frequency weightings were calculated by use of equations (6) and (7) with frequency computed from $f = (f_r)[10^{0.1(n-30)}]$ with $f_r = 1$ kHz and n and integer between 10 and 43. The results were rounded to a tenth of a decibel.

The mathematical expression for the frequency adjustment identified in equation 8 in clause 5.4.8 is Z (f) = 0.

It would therefore appear that for frequencies below 10 Hz there is an implied frequency adjustment of 0 dB (to accord with the concept of Linear). However it can also be argued that the Standard does not provide any specific frequency correction below 10 Hz.

Of concern as to the relevance of the Z weighting used on different sound level meters is that the tolerance limits set out in IEC 6162 – 1:2002 at 10 Hz is +3.5 dB and - ∞ dB.

If one extends the 10 Hz tolerance limit down to 0.8 Hz (being the lower frequency limit of the SVAN meters in 1/3 octave bands) it can be seen that the +3.5 dB and - ∞ dB tolerance permits a significant variation (for the Z-weighted value) that would not provide consistency with measurements from other instrumentation, such as the Pulse system where the frequency limit of the analyser extends down to DC subject to the various high pass filters that may be selected.



10.4 G-Weighting

The G-weighting value provides a frequency weighting characteristic for the determination of weighted sound pressure levels of sound or noise whose spectrum lies partly or wholly within the frequency band from 1 to 20 Hz.

G-weighted values have being nominated in some cases to identify infrasound from wind turbines and refers to International Standard ISO 7196:1995 (E) [42].

Section 4 of the Standard identifies:

The G-weighting curve is so defined that has a gain of 0 dB at 10 Hz, that is, the G-weighted sound pressure level of a pure tone and 10 Hz is equal to the unweighted sound pressure level. Between 1 Hz and 20 Hz the curve approximates a straight line with a slope of 12 DB per octave. In this way, each frequency weighted in accordance with its relative contribution to the perception.

Below 1 Hz and above 20 Hz, the curve has cut-offs with rates of 20 dB per octave.

In a graphical representation the G-weighting the curve on a logarithmic frequency scale is shown below.

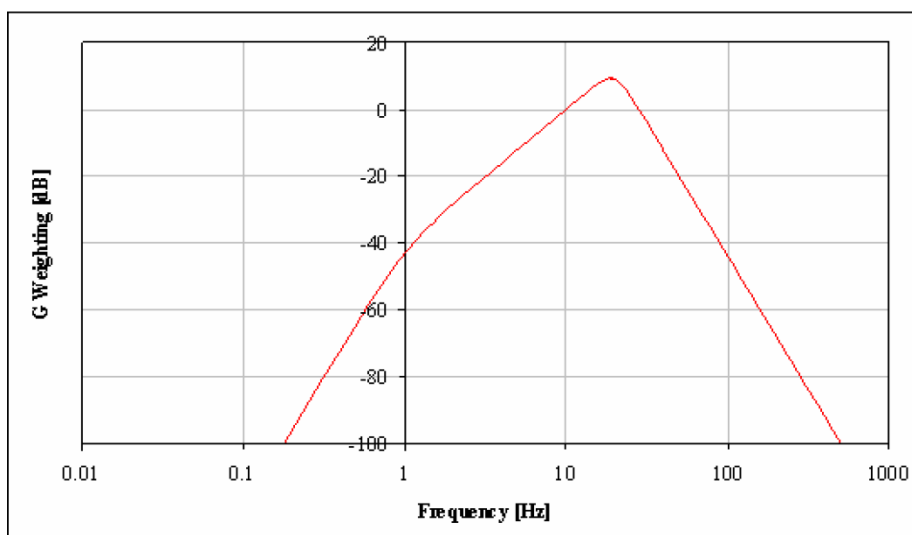


Figure 101: G-weighting curve



The perception in relation to infrasound by reference to the bibliography in the Standard refers to the audible perception of infrasound. By definition, in terms of audibility one is unable to determine the audible perception for a sound that is inaudible. If the audible perception is determined for an average person then it is possible for sensitive people to have a threshold of audibility lower than the nominal audible perception curve.

The application or use of a G-weighting value for inaudible infrasound, that is the situation at each of the houses investigated, therefore has little value.

Because of the frequencies of concern in seeking to determine or measure a G-weighted value there is a requirement for a long integrating time constant so that the observed value is to be representative of the infrasound being measured. This is relevant when utilising a sound level meter with an output of the G-weighting value simply because if one utilised FAST response to observe the noise from a wind farm the level will vary up and down and not give rise to a constant value.

By way of explanation if one looks at a 1 Hz sine wave and inputs that signal into a sound level meter using FAST response the value displayed for that signal will vary up and down, as the FAST response uses a time constant of $1/8^{\text{th}}$ of a second and therefore will automatically show the variations in the sine wave.

If one applies the same signal to a meter that gives a G-weighting readout there will be a constant level that is determined by way of the time constant (of the display) used for G-weighting.

If one has frequencies restricted to the upper portion of the infrasound region then a lower time constant may be used and still give the same value as that of a longer time constant simply because of the higher frequency.

The discussion as to the integrator – indicator for a sound level meter appears in Section A.5 of the ISO Standard.

If however one seeks to derive a G-weighted sound pressure level by the use of 1/3 octave real-time analysis then the use of a real-time analyser provides strict limitations in terms of the analysis, where the minimum time for analysis is governed by the bandwidth of concern such that the product of the bandwidth x the sample time equals 1.0 (i.e. $BT = 1.0$).



If one deals with an Leq level over 10 minutes in 1/3 octave bands then the averaging time for the determination of the Leq is sufficiently long enough to provide a G-weighted value under that scenario and as such would achieve the intent of the Standard. The difference in the actual G-weighted value versus a 1/3 octave analysis is noted because in various documents concerning the measurement of wind farms there would appear to be some confusion in relation to the Infrasound Standard or inadequate information to identify the method and analysis procedure used in terms of obtaining the dB(G) Leq value.

For example determining a G-weighted value from a 10 second analysis of a signal would appear to be inappropriate and should not be confused or implied to be equivalent to a meter directly reading a G-weighted value, or the G-weighted Leq using the “standardised” 10 minute assessment period.

In this study for the purpose of considering the G-weighted value (or any other descriptor based on 1/3 octave bands) the Leq 1/3 octave spectrum (when expressed in a linear format) utilised the entire 10 minute sampling. However, due to the levels measured in the residential dwellings not giving rise to audible infrasound the relevance of G-weighting in terms of considering infrasound impacts (i.e. audible impacts) would appear to be irrelevant in the assessment of wind farm noise at Cape Bridgewater.

10.5 Noise Floors

When dealing with external noise measurements most instrumentation for general community noise is capable of measuring the range of noise levels that may occur.

Due to the various weighting curves that may apply to assessment procedures there is a technical advantage in conducting measurements in a linear format and then determination of the resultant values by way of corrections/adjustments to those measured levels.

The majority of microphones available for acoustic measurements and instrumentation that is used for general measurement procedures tend to have a specified noise floor in the order of 20 to 25 dB(A).

In conducting measurements inside dwellings there is an issue as to whether the results obtained are valid or simply measuring the noise floor of the instrumentation.



In measuring low levels the normal approach is to utilise a microphone with a higher sensitivity that in turn can produce a higher voltage output for the same sound pressure level (when compared to standard microphones) and therefore obtain a lower noise floor. Such microphones become significantly more expensive when one seeks to obtain very low noise levels.

Another issue in relation to noise floor of microphones becomes the issue of nonlinearity across the frequency spectrum. Documentation with respect to Bruel & Kjaer microphones [39] indicates that for the low levels and frequencies of concern (inside dwellings) there are noise floor limitations associated with the microphones separately to that of the preamplifiers that are used.

In a general sense the microphone generates a noise floor which is related to the higher frequencies, whereas the noise floor in the lower frequencies is determined by the preamplifier.

An issue identified previously in the SA EPA Waterloo study is related to the use of a low-frequency microphone designated B & K Type 4193. The microphone has a frequency response specified as 0.07 Hz to 20 kHz and an inherent noise floor of 19 dB(A).

If the same microphone is fitted with an adapter UC-0211 to restrict the low-frequency response to be from 0.13 Hz to 20 kHz the inherent noise floor of the microphone increases to 29 dB(A) and the sensitivity of the microphone decreases from 12.5 mV/Pa to 2 mV/Pa.

If one uses a low noise microphone that is normally required for qualification of anechoic chambers such as a Bruel & Kjaer Type 4179 microphone, whilst the output voltage of the microphone is noticeably higher (100 mV/Pa) than standard microphones, the specified frequency response is identified as 10 Hz to 10,000 Hz. This microphone when used with a special dedicated preamplifier (B & K Type 2660 or 2660- W – 001) has a specified dynamic range of -2.5 dB(A) to 102 dB(A).

Similarly when dealing with the SVAN meters that were used for logging purposes the meter has a specified noise floor of around 24 dB(A), although the results of the measurements indicate levels down to around 15 dB(A).

Utilising the direct output of the noise loggers indicates in many of the graphs for the houses a noise floor (which is the electrical noise for the meter) is not representing the actual noise level in the bedrooms of the houses of concern.



Where ambient background levels are less than 15 dB(A) in such houses then the concept of 30 dB(A) as a basis for sleep disturbance represents a significant impact for those households.

The challenge in seeking to obtain valid measurements with respect to this study is determining the noise floor of the instrumentation and the need for an acknowledgement that the actual noise levels in the receiver locations can be lower than that indicated in the measurement results.

For example, the SA EPA Waterloo study [3] indicates for internal locations (and even external locations) the ambient background level at night is below 20 dB(A) for a significant proportion of the time. There is no identification of the noise floor limitations of the meters used in the study.

If however one examines the instrumentation that was used by the SA EPA against the manufacturer's specifications then it would appear there are significant limitations in that study, if there is an intent in determining the actual background levels that exist in the residential premises both with and without the turbines operating.

In the early stages of the Cape Bridgewater study it was identified that there was no correlation with the A-weighted value observed inside the rooms versus the operation of the wind farm, although there are severe limitations in that concept by reason of the noise floor of the instrumentation systems as identified above.

With respect to the subject study there was an emphasis on the infrasound components with the primary reason for the data recording systems to obtain measurement data for different operating situations of the wind farm.

As the measurements of the data recorder are measured on a linear (un-weighted) basis there were concerns as to the dynamic capabilities of the system and the levels being recorded.

Initial testing indicated that with respect to noise levels recorded inside the dwellings there could be a very significant dynamic range in the infrasound range. The input settings for the internal channels (set so as to not create an overload) resulted in some of the data disappearing into the noise floor of the instrumentation chain (determined by the input settings) similar to that that occurs with the noise loggers.



To provide an evaluation of the usable data from the system, measurements for all the systems used in the study were conducted in a small hemi-anechoic room where at night the ambient background levels were below 5 dB(A).

Testing was undertaken to establish the noise floors for the system set up at Cape Bridgewater which, as identified above with respect to the requirement to ensure there was no dynamic overloading of the infrasound, is not the noise floor that is experienced for the instrumentation under normal circumstances.

The result of the testing indicated that for the recorded data there are limitations in terms of the noise floor for frequencies above 500 Hz on a number of the channels and therefore the data recording information, which was primarily looking for low-frequency and infrasound, only considers frequencies below 200 Hz.

For future studies the dynamic range could be increased by using B & K LANXI units (160dB range) instead of the B & K IDE Pulse units (80 dB range) that has a significant cost implication.

The results of the investigation and extensive analysis in terms of the frequency response and the noise floor of the instrumentation chain indicates that if further wind farm studies are to be undertaken for determining noise levels inside dwellings then there is a need to define the limitations of the instrumentation used in terms of the noise floor and dynamic level across the entire frequency spectrum. Similar questions should be raised as to the validity of previous test results.

Based on this study there are limitations in determining the background levels by way of standard noise loggers that as such may require (for other studies) more sensitive microphone/preamps to provide a valid signal for the purpose of the assessment.



10.6 Danish dBA LF

A method proposed by the Danish EPA for determination of sleep disturbance (not from wind turbines has been to consider a low frequency threshold level of 20 dB(A) when the A-weighted level is restricted to below 160 Hz. The Danish EPA [6] identify that the concept is in relation to low frequency noise not specifically infrasound. An extension into the infrasound region was provided to cover the concept that a noise source at 16 Hz could influence the 20 Hz result.

As sound level meters do not have the capability in their A-weighted measurement to accommodate the dB(A) LF concept it is necessary to calculate the dB(A) LF value from the 1/3 octave band measurement results.

In seeking to undertake that exercise requires the instruments to be set for a Linear (in some cases Z weighted if equivalent) result and then utilise the 1/3 octave band information to derive the dB(A) LF value.

In the subject study the linear octave band levels (requiring an un-Z weighting adjustment for the majority of the SVAN 979 meters) was used to derive a dB(A) LF value.

Extending the range to cover 0.8Hz – 160Hz did not reveal any appreciable difference to the results from the specified dB(A) LF.

Utilising the noise floors for the instrumentation as discussed in the preceding sections by the linear 1/3 octave band methodology a valid dB(A) LF down to 5dB(A) LF could be obtained.

Questions that must apply to obtaining a dB(A) LF value is can the meter obtain valid results (level and frequency) for the infrasound region, do the 1/3 octave bands represent a Linear or A-weighted result or are they subject to a non-uniform Z-weighting applied by the manufacturer for the instrumentation used?



10.7 Presentation of Measurement Data

From the above and having identified that the data obtained is valid both in terms of dynamic range, frequency response and above the noise floors, then there is a requirement to qualify the measurement data that has been provided.

In dealing with the Leq values for wind farms the derivation of such results relates to the NZ Standard and the general concept of measurements over 10 minutes

In dealing with the background noise level the permit conditions for the subject wind farm utilise the 1998 version of the New Zealand Standard [2] where the background is specified as an L95.

The wind farm Standard does not provide a definition of the background level in terms of its measurements but refers to New Zealand Standard 6801 [43]. That Standard indicates that for the purpose of statistical measurements they are obtained using a FAST response which therefore indicates an exponential averaging of the results that are sampled at whatever rate is being used by the instrument, upon which the statistical values are determined.

Determining the wind farm in terms of a background level (whether an L95 or an L90 as used in other states) if following the relevant Standards then theoretically one must utilise a different averaging concept to that used for an Leq.

The noise emitted from the wind farm is subject to variations in level. When such variations occur, by definition the Leq level will be above the background by a different margin to that that occurs when the wind farm is operating without any such fluctuations.

In expressing noise levels in Australia the concept is to utilise the dB level that is referenced to 2×10^{-5} Pascals.

The A-weighted value uses a defined curve, just as there is a curve for a C-weighting and a G-weighting curve where the G-weighting is subject to limitations as discussed in Section 10.4.

In dealing with 1/3 octaves the analysis mechanism has constraints in terms of the timing with respect to the frequencies being investigated. To provide a statistically valid result, the lower the frequency the longer the sampling period.



In real-time analysers one can select exponential averaging, linear averaging over a certain time period, and linear averaging over the entire sample period. The use of the different averaging methods can give rise to different results. To provide valid statistical levels of the turbine noise would require exponential averaging of the signal and statistical analysis of the sampled result.

When using narrowband analysis the normal procedure is to apply a Fast Fourier Transform (FFT) to the time signal so as to determine the periodic patterns that occurs in the time signal. These periodic patterns are then derived as specific frequencies.

Normally a narrowband analysis is described as an FFT and provides the results of the analysis in a linear frequency commencing at 0 Hz and continuing to the upper limit of the selected analysis.

As general concept analysers utilises 400 lines over the bandwidth of concern, although to obtain finer resolution one can increase the number of lines in the same bandwidth if the computational power in the instrumentation is available.

10.7.1 Resolution of narrowband frequency analysis

In dealing with 1/3 octave bands there is a defined bandwidth and shape of the 1/3 octave with the results normally expressed as rms (root mean square) in dB units.

One can utilise other units of measurement with earlier work on wind farm noise (e.g. NASA studies in the 1970s and 1980s) expressed in terms of the peak level rather than the rms level.

In dealing with the narrowband analysis the correct method for the provision of results is to express the levels as a Power Spectral Density which moves away from rms dBs by reason of expressing the amplitude in terms of Pascals squared normalised to a 1 Hz bandwidth.

If one uses PSD as the vertical axis for assessment purposes then there is a common basis in the results and one can compare the results without having to be aware of the bandwidth and the number of lines being used for analysis purposes.

The spectral information contained in the appendices in this report are presented primarily in terms of rms levels, both in 1/3 octave bands and the narrowband results where the narrowband analysis has generally been expressed in the default concept of 400 lines over the nominated bandwidth.



By reason of the concept of the standard formula $BT = 1$ it follows that if the bandwidth of any analysis is reduced then the time required for a statistically valid result must be increased on the basis that the time is the inverse of the bandwidth.

As a consequence of providing a finer resolution the averaging time increases and in terms of a 10 minute sample there can be limitations on the output that is determined by that procedure that gives rise to different values for different bandwidths.

If one seeks as in the case of the Shirley Wind Farm study [25] to present the narrowband analysis over a wide frequency range it follows that at the high frequencies of the spectrum the results are valid by reason of the large number of lines that are available in the analysis. For the lower region of the analysis the individual lines do not have the same degree of frequency resolution as for the high frequencies, therefore leading to a less defined narrowband frequency on the left-hand side of the graph.

If the data samples are assessed over different frequency bandwidths that have the same resolution, a finer resolution of the discrete frequency components can be obtained for the lower frequencies of concern.

In expressing the narrowband results either in terms of a standard RMS value or the more accurate PSD value the number of lines that are used in the analysis (or the alternative terminology of the sample rate) should be identified so as to have consistent results.

The 1/3 octave band information when being directly compared with the narrowband results should also be in a Power Spectral Density format.

However, in general acoustics the use of power spectral density is an uncommon situation and whilst PSD may be accepted for narrowband analysis it is generally not the case with respect to 1/3 octave band analysis with that spectra typically presented as an rms value.

For example utilising the outside locations at house 87 in the 10 m/s wind speed that have been provided for the ON-OFF situation for 27 May 2014 that clearly show the presence of the multiples of the blade pass frequency the following examples are presented to highlight the nature of definitions required for the analysis.



Figure 102 presents the RMS levels in terms of 1/3 octave and narrowband analysis for the 0 – 10 Hz bandwidth on the basis of 400 lines. The results show the periodic pattern attributed to the turbines and described in this report as the Wind Turbine Signature. On an RMS basis there is a distinct difference in amplitude between the two signals, noting that the presentation of the data expresses the frequency axis in terms of constant percentage bandwidth locations (a logarithmic frequency scale) whilst in Figure 103 the same material is presented using a linear axis for the frequency domain.

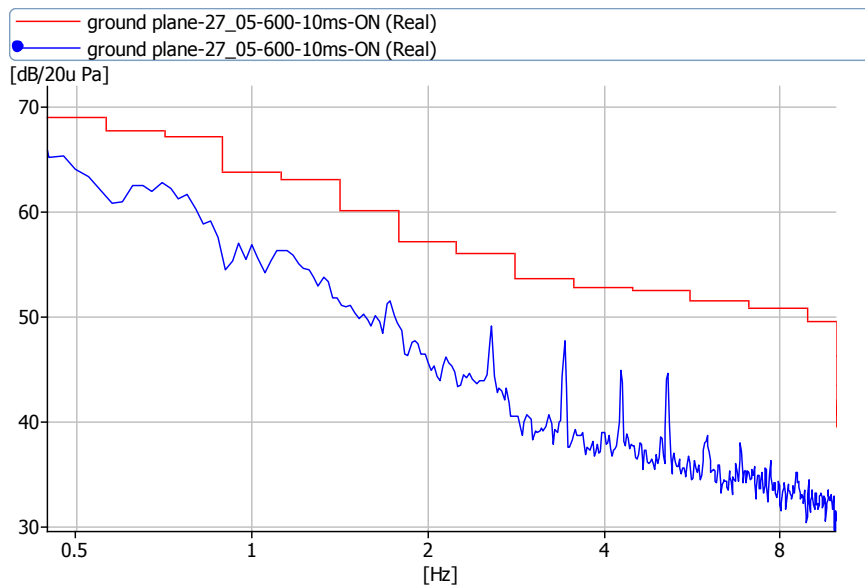


FIGURE 102: 1/3 octave and narrowband RMS levels in constant percentage bandwidths

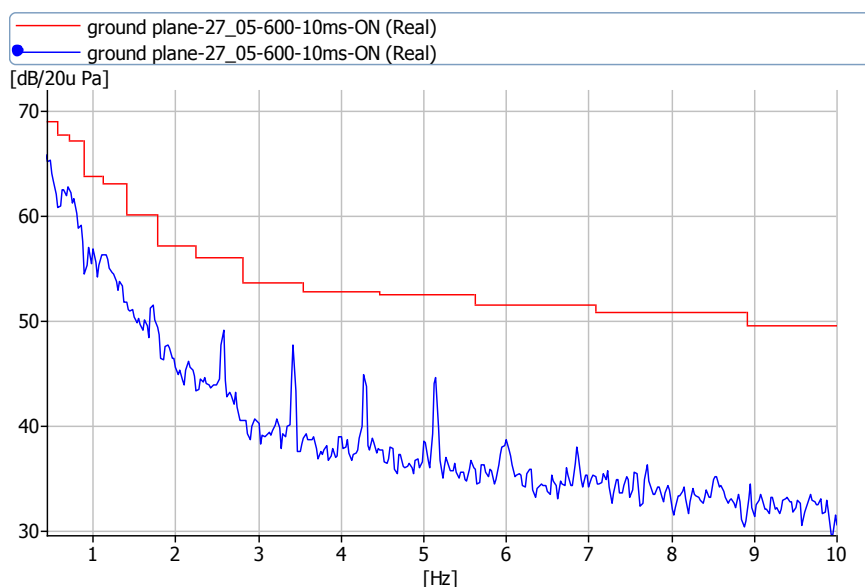


Figure 103: 1/3 octave and narrowband RMS levels in linear frequency domain



Figure 104 presents the 1/3 octave bands in the typical RMS value and presents the narrowband analysis for 400 lines as PSD values.

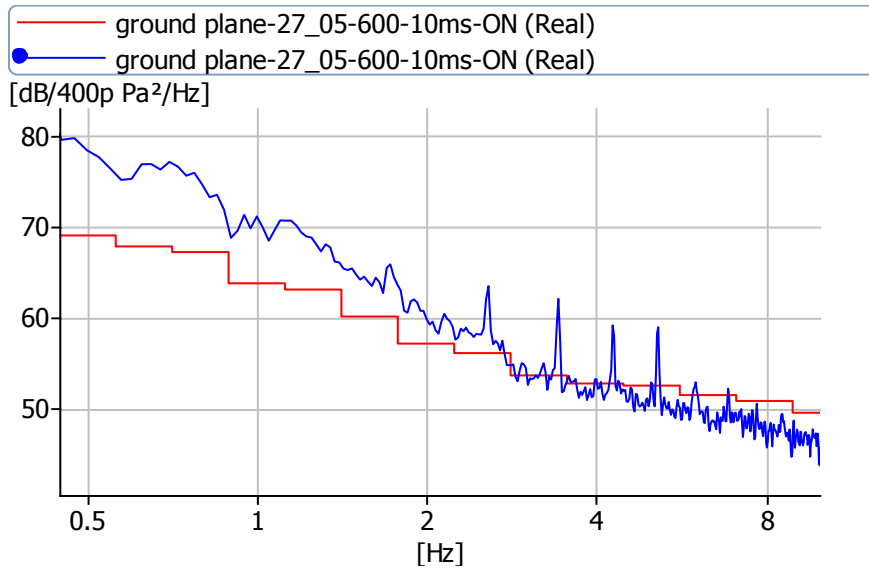


Figure 104: 1/3 octaves in RMS levels and narrowband in PSD levels

Figure 105 presents the 1/3 octave band information and the narrow band 400 line spectrum as power spectral density. One can see that on the PSD basis for both spectra they line up as there is an equal averaging basis of the bandwidths of concern.

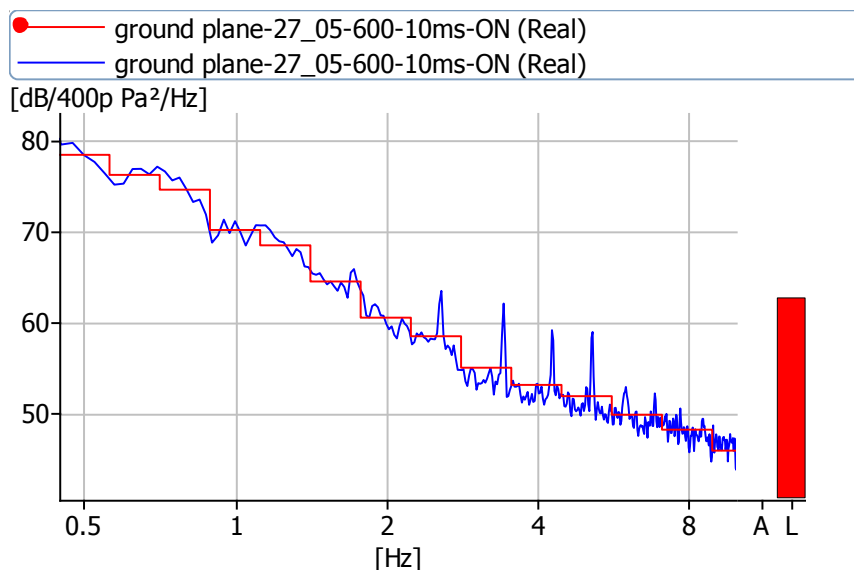


Figure 105: 1/3 octaves and narrowband in PSD levels



However, most acousticians do not measure 1/3 octave bands in power spectral density (nor are narrowband typically presented as power spectral density). For the purpose of comparing the different analysis techniques this report has adopted the “typical” RMS 1/3 octave band approach and at the same time presented the RMS narrowband approach based upon 400 lines.

If one is seeking to provide criteria in terms of the narrowband analysis then the correct terminology is to express Power Spectral Density, with a definition of the number of lines of resolution for the bandwidth of concern.

Utilising the same sample period and the same timescales different numbers of lines will produce different RMS levels, and different PSD levels by reason of the different averaging time constants as discussed above.

Obtaining a high-resolution in limited bandwidths presents technical difficulties in some analysers by way of the complexity in the mathematics and computing power that is required when one is utilising an Leq averaging basis.

10.7.2 Instrumentation Considerations

As a result of instrumentation difficulties and multiple reanalysis of the data a number of conclusions with respect to the presentation of acoustic material are provided for the benefit of researchers into wind farm noise.

Not all instruments are the same and even from the same manufacturer can give rise to different measurement results for the same signal being recorded

In order to provide accurate sound level measurement results in the infrasound region of concern it is necessary to establish the frequency response of the entire instrumentation chain from the lowest frequency of concern up into the audible spectrum.

Calibration facilities in Australia for the purpose of general sound level measurements utilise an acoustic coupler where the assessment is undertaken in octave bands with the lowest frequency of concern being 31.5 Hz.



The establishment of a frequency response by way of a signal generator applied to the microphone input is not the same as the provision of an acoustic signal applied to the microphone/ instrumentation of concern. This applies particularly in the case of manufacturer's specifications for various preamplifiers and microphones that do not extend down to the frequencies of concern. An assumption of linearity does not necessarily apply.

Without a complete calibration from the microphone input to the analyser output it is impossible to be assured that the results that have been obtained are accurate.

Similarly for the use of micro-barometers (pressure sensors) there is a need for verification of the output of those units.

The calibration mechanism needs to check the frequency response of various meters and weighting curves that may be applied on various meters, including the Z-weighting, which by way of the IEC Standard has an extremely wide tolerance at 10 Hz and whilst having a nominal zero weighting at that frequency (and below) has no specified tolerance below 10 Hz. Therefore a Z-weighting that is generally assumed to be a flat response is not necessarily a flat response.

In the use of data processing where modems may be involved some manufacturer's specification places limits on the low frequencies for such data transfer and therefore it is not necessarily the case that the full spectrum in a linear fashion is obtained.

In dealing with different instrumentation and the dynamic range of the levels that may be recorded there are competing interests in terms of the capability of instrumentation to obtain valid results. Many of the sound level meters do not have the capability to measure over the full range of concern (both in terms of dynamic range and the frequency response) with respect to wind turbines.

For monitoring inside residential dwellings in rural environments is not uncommon to record ambient noise levels below 15 dB(A) that as such presents difficulties when the manufacturer of any instrument specifies a noise limiting floor of 22 dB(A).

Similarly different microphones (and adapters) and preamplifiers may have frequency limitations themselves (and also noise floor limitations) that make the measurement of low-level low-frequency noise difficult unless one uses specialised instrumentation for that purpose.



When recording on a linear scale for the wide range of frequencies of concern there is also a wide dynamic range that occurs, that in some cases is limited by the dynamic range and frequency response of the instrumentation used.

In the subject study the unattended noise monitoring multichannel recorder was set to prevent overloading of the signal resulting in high-frequency levels being buried in the noise floor thereby leading to that multichannel system primarily for the purpose of investigating low-frequency and infrasound.

Various combinations of microphones and preamps when tested using a dedicated low-frequency calibrator were found to be within the manufacturer's specifications but for regions outside the specified lower frequency limit did not necessarily exhibit a flat response and required corrections to the data so as to obtain a normalised response.

If the exercise was to be repeated at the subject wind farm or another wind farm there would be different instrumentation used for that exercise to overcome a number of the issues identified above.

For the recording of wave files by use of a SVAN sound level meter the wave file is taken from the first profile. On using SVAN's version of a Z filter (957 being a different Z filter to that of a 979) the output is not necessarily a linear flat response. An approach has been made to the manufacturer for the possibility of the firmware upgrade to address that issue and as such would be of assistance for future measurements turbines using that instrumentation.

This study considers the Danish dB(A) LF not relevant to wind turbine assessments. As such the limitations of instrumentation to obtain a dB(A) LF result are academic interest – unless there is a specification of that descriptor.

The use of narrowband analysis is of significant benefit in the investigation of wind turbine noise and in a strict technical sense should be expressed in terms of the Power Spectral Density. In this report it is suggested to use in limited bandwidths rather than an expanded bandwidth, but in any event the number of lines should be specified so as to provide uniformity.

There is a trade-off in standard analyses by increasing the number of lines in a bandwidth that automatically changes the averaging technique and as such loses detail in the time signature of intermittent events.



Whilst the noise emission from turbines are expressed in an Leq level the nature of multiple turbines on a wind farm give rise to variations in amplitude and individual frequencies over a 10 minute sample period which is not always evident in the Leq results.

The use of three-dimensional concepts such as sonograms enable the variations in levels to be observed, which is a benefit to researchers are in this area of acoustics.

In summary there is a need for a greater degree of instrumentation details and analysis settings used to obtain a measurement results with respect to wind turbines that are not currently required under existing guidelines or standards and as such needs to be amended.



11.0 CONCLUSION

In late 2013 Pacific Hydro approached The Acoustic Group to enquire as to the possibility of undertaking an acoustic investigation along the lines of full spectrum measurements inside and outside dwellings (not just restricted to dB(A) measurements external to residential properties). The enquiry was presented as a genuine desire by Pacific Hydro to take a fresh approach to noise from the Cape Bridgewater Wind Farm.

The brief from Pacific Hydro was to undertake noise and vibration measurements (full spectrum) to determine whether certain wind conditions or certain sound levels give rise to disturbance experienced by specific local residents at Cape Bridgewater.

The study was limited to six residents (3 houses) who all identify that they are impacted by the wind farm. Whilst the sample size is small and does not include all people up to 1600 metres from the turbines who may not be as impacted by the turbines, the task was to use the six residents as the basis of the task to assess if there were any relationships of the wind farm “noise” to disturbance i.e. the sample size was from the outset considered to be sensitive to the wind farm operation.

Noise monitoring was nominated for a 6 week period and then expanded to 8 weeks to take advantage of a 2 week shut down of the wind farm that was to occur as a result of high voltage cabling work.

The original concept was to start with the diary observation format used by the South Australian EPA for the Waterloo Wind Farm study in 2013 [3]. The residents indicated that disturbance was not just related to noise. This led to the SA EPA diary format being modified to be a more workable document for the residents by separating the observations into noise, vibration and sensation using a 1 to 5 severity scale. “Sensation” includes headache, pressure in the head, ears or chest, ringing in the ears, heart racing, or a sensation of heaviness.

A graphical method of displaying the A-weighted noise level results with respect to the resident’s observations was developed using a display of the different parameters in terms of coloured arrows with the sensation value inserted in the arrow.

When plotting the power output of the wind farm the initial assessment could not correlate the measurement results with the observations, except for showing changes in the power output of the wind farm were associated with higher sensation values.



Subsequent discussions with the residents found that they were reporting changes that they had noticed with respect to perceived impacts and not undertaking observations on a regular basis. This was considered to be a major finding with respect to reporting, where it was expected the results to be made on a regular basis.

The diary procedure was then changed to (where possible) provide regular observations (every 1 to 2 hours), not just the perceived changes. The high ranking of sensation in the first analysis was not found to relate to any specific noise level but related to changes in the wind farm power output and wind conditions.

The amended diary observation method used by the six residents highlighted the higher sensation values associated with specific power output conditions of turbines starting, changing power situations, and when the wind exceeds lowest wind speed for the maximum power output of the turbines, i.e. observations not necessarily associated with noise level parameters.

Plotting the diary observations versus the power output of the wind farm versus various acoustic parameters was then assessed for measurement results inside and outside the dwellings. The response to sensation gave higher severity rankings than for noise or vibration.

The resident's observations (for the limited data set) found four specific power output conditions where there was an increase in the resident's perception of sensation that was related to narrow band infrasound levels.

Preliminary measurements suggest the resident's perception of intermittent vibration to be associated with pulses in the ground borne vibration that was detected on and in the vicinity of the turbines and requires further investigation

To address the results of the investigation this report sets out the methodology of the investigation that covered various acoustic indices that have been applied to wind farm investigations and other indices previously untried.

The requirement to address the project brief involved a significant expansion of the work originally envisaged and well past the time and financial budgets that were allocated for the study.



A number of findings arise from the study and have been grouped as follows:

11.1 Non-acoustic findings

The following **non-acoustic findings** of the study are considered to be significant:

- The resident's observations and identification of sensation (separately to vibration and noise) indicates that the major source of complaint from the operation of the turbines would appear to be related to sensation rather than noise or vibration.
- A significant sensation disturbance was found to be occurring when the turbines were seeking to start up, when there was apparent change in the power output of the wind farm in the order of 20% (being either an increase in power or a decrease in power), and the situation when the turbine has reached maximum power (normally wind above 15 m/s) and the wind was increasing in strength thereby requiring the pitch angle to be changed so as to de-power the turbines. The latter situation with excessive winds can occur for extensive periods at Cape Bridgewater with residents reporting that at times they have to leave the area to seek relief.
- For some residents experiencing adverse sensation effects the impact can be exacerbated by bending over, rather than standing, with the effect in some cases being reported as extremely severe and lasting for a few hours.
- With the wind farm not in operation the residents indicated noise, vibration and sensation are low in severity ratings.
- There are 2 residents that clearly have a greater sensitivity than the other residents. One resident, being hearing impaired, is able to identify noise that are below the standard hearing threshold levels and reported higher than normal severity with the wind farm shut down.

11.2 Acoustic findings

There are a significant number of acoustic based findings obtained from the study. Due to the complex interaction of various components of the study the findings have been grouped as follows.

dB(A)

- The use of dB(A) noise levels external to a dwelling did not correlate with internal noise levels or impacts that residents identified as coming from the wind farm.



- There is no correlation between the power output level of the wind farm versus the Danish dB(A) LF level (0.8 Hz to 160 Hz) determined inside residential dwellings. On an A-weighted basis the dB(A) LF level (extended down to 0.8Hz) has its major contribution from frequencies above 100 Hz.
- Ambient noise from waves from the ocean and wind direction was found to be relevant in terms of contributing to the overall A-weighted level for this wind farm and can affect any regression analysis method.

Other Acoustic Parameters, including infrasound

- **Comparison of the dB(A) LF, dB(C) dB(Z) found the wind influenced the measured levels such that by the use of 1/3 octave measurements there is no mechanism to separate the wind farm component from the overall noise levels that include the wind.**
- At none of the houses was an internal level above 85 dB(G) detected.
- **If 85 dB(G) is taken as the hearing threshold of infrasound then the study has found no audible infrasound in any of the houses.**
- The use of only 1/3 octave band information to compare infrasound generated by turbines and infrasound in the natural environment (when assessed either externally or internally) does not contain the required information to identify any difference. However when supplemented by narrow band analysis in the infrasound region the measurement results clearly shows a periodic pattern in the infrasound (the wind turbine signature) whilst the natural environment for infrasound has no such periodic patterns.
- When dealing with narrow band investigation of infrasound the presence of the wind turbine signature (blade pass frequency and multiple harmonics of that frequency) and a frequency of 31.5 Hz was regularly identified inside the dwellings and outside dwellings. The wind turbine signature does not exist when the turbines are not operating.
- It may be more appropriate to identify that at times the acoustic signature from a wind turbine exhibits “pressure pulses” as opposed to explicit tones in the infrasonic region.
- Monitoring on the wind farms itself revealed that in proximity to the turbines there was no significant infrasound when viewed in terms of narrow band periodic functions suggesting directivity of the source of the infrasound



Modulation

- The A-weighted level is found to vary (modulated/modulate) at the rate of the blade pass frequency.
- When dealing with a dB(A) level that modulates it should be expressed as either “modulation” or “modulation of the amplitude”.
- Amplitude modulation of 31.5 Hz at the blade pass frequency was detected near the turbines and at residential locations

Attenuation

- On a dB(A) basis the attenuation rate of 6 dB per doubling of distance appears to be valid for the A-weighted level of the turbines.
- For the infrasound region the attenuation rate is lower than the nominal 6 dB/doubling of distance assigned for audible noise.
- It is suggested that further investigation of attenuation in the infrasound region is best based upon a single turbine rather than a wind farm due to the influence of multiple turbines.

Vibration

- Vibration in the ground recorded at residential properties reveals random surges in vibration when viewed in the time domain.
- Monitoring of vibration near the turbine towers indicates surges associated with wind gusts where a significant increase above the ambient vibration in the ground was recorded
- The same pattern of vibration surges was recorded at location moving out from the turbines and is similar to that recorded outside and inside house 88.
- The vibration surges described by some residents as disturbance during the shutdown could be attributed to wind gusts exciting resonances of the blades/towers and requires further investigation.

Instrumentation

- There are limitations of the use of normal noise loggers to provide accurate results of dB(A) Leq and dB(A) L95, due to the noise floor of instrumentation and the relatively low noise levels inside such dwellings.



- Electrical interference/surges in mains, and very strong winds created some problems with data collection.
- The frequency response of the complete signal path should be verified to ensure the manufacture specifications are not comprised by the interaction components contained in the measurement system.

Turbine Operation

- On low and medium power settings the speed of the turbine rotors varies at a different rate to the wind whilst maintaining a relatively constant electrical power output.
- The operation of ventilation equipment in the turbine structures induces vibration into the tower (but at relatively low levels). Such equipment whilst having nominal operating speeds incorporates variable speed drives and gives rise to a range in vibration levels. Typical vibration frequencies recorded on towers as a result of the ventilation fan varies between 23 and 30 Hz.
- Monitoring in proximity to the towers over a number of hours found a significant variation in noise levels from the tower structure including the typical “aircraft that never lands” signal often quoted by residents. The noise appeared to change with loading on the turbine.
- The downward sweep of the turbine has a slightly higher level of mid band noise than the upward sweep of the turbine.
- When located on the upwind side of a turbine a maximum sound level occurs at about 2 o’clock.
- The Wind Turbine Signature that has been found at other wind farms is also evident at Cape Bridgewater.
- Measurements of infrasound levels before and after a series of full shutdowns identified the Wind Turbine Signature concept can be applied to the subject turbines at Cape Bridgewater.
- The disturbance experienced by specific local residents (for the resident’s sensation 5 observations) shows a trend line that was used to develop the dB(WTS).



11.3 Subjects of further investigation

As the basis of the study was to start from the complaints end of the equation, rather from a noise end, material/advice and comments are provided to assist others in further studies or an extension to this study in relation to wind farm operations.

- It is suggested that in expressing disturbance from this wind farm, rather than claiming disturbance is from noise or infrasound from wind farms, the primary issue of disturbance for the subject wind farm is related to sensation.
- One outcome of the study is the need for the determination of a sensation response curve that has to be related to the acoustic/vibration signature generated as a result of the operation of a wind farm. It is considered that a laboratory study is unlikely to reproduce the physical impact that occurs at or in dwellings in proximity to a wind farm.
- The presence of the discrete frequencies (by way of FFT analysis) of the blade pass frequencies (with multiple harmonics) and the 31.5 Hz tone identifies the operation of turbines in an acoustic environment (including wind) and overcomes some of the issues associated with general acoustic parameters.
- Whether the infrasound components (derived by the FFT analysis) trigger conscious or unconscious responses in individuals by of the individual frequencies, the pattern of the frequencies or modulation of those frequencies, is outside the limits of the team's expertise but are factors that should be considered in any future medical studies.
- The survey methodology used for the Cape Bridgewater study can form the basis of surveys for the next step in investigating "wind farm noise" that would incorporate acoustic measurements with the medical studies.
- This study did not include any testing in relation to sleep disturbance or health effects. An exercise relating to balance was suggested as a result of observations. The outcome of that exercise is best addressed by persons qualified for such an assessment in that it is a relatively simple exercise to undertake – however the effect that occurred for some residents would not have them repeat the exercise.



11.4 Suggestions

During the course of the study there were significant issues in terms of instrumentation that requires for other researchers in this area identification of problems and the **essential** need for persons involved in the measurements of noise, and particular infrasound, in proximity to wind farm affected environments to utilise calibrated instrumentation covering the entire signal chain from the microphone (or pressure sensor) through to the read out. Reliance upon manufacturer's data does not always cover the entire spectrum of concern, with an entire section of this study report addressing instrumentation issues that have been established during this study.

From the resident's subjective observations a wind turbine signature has been derived that indicates the averaged unacceptable presence of sensation inside a dwelling (for those 6 residents) occurs at an level of 51 dB(WTS) – when assessed as rms values 400 lines for analysis range of 25 Hz. Utilising PSD values (400 line 25 Hz range) the unacceptable level for the 6 residents occurs at 61 dB(WTS).

Being the first study to document or to identify “sensation” associated with the wind farm and the wind turbine signature, it is noted that the sample data is small and has persons already affected by the “noise”. The findings must be considered as **preliminary** and warrants further detailed studies of the scientific rigour necessary for the purpose of confirming/verifying the suggestions for the use of the nominated dB(WTS) thresholds.

On the basis of a limited number of affected residents for the study, it is suggested that:

- **for these residents the presence of “sensation” is the major impact;**
- **surveys of residents near other wind farms should utilise the Cape Bridgewater Wind Farm survey method so as to include “sensation” in any investigations;**
- **the use of dB(A) or dB(C) for internal measurements of the wind farm does not separate the results from that generated by the wind – for residences that are directly exposed to the wind.**

There is not enough data from this study to justify any change in regulation. However, the following matters are suggested for further investigation:



- the validity of the dB(WTS) and the appropriate threshold levels be the subject of further studies to provide the necessary scientific rigour for a threshold to protect against adverse impacts;
- examination of the use of the dB(WTS) index (both external and internal) to supplement the external dB(A) index currently used for wind farms;
- the use of the internal dB(WTS) method can assist in medical studies in that the internal dB(WTS) identifies the presence of energy from the operation of a wind farm. The dB(A) level measured inside dwellings is of no assistance in such studies;
- the use of an external dB(WTS) can overcome the limitations of the dB(A) method that can be influenced by extraneous sources (i.e. wind); and
- the issues of directivity and identification of the noise emission sources of a turbine relative to sound power testing at ground level be examined, particularly for the generation of infrasound. Whilst there are significant costs involved, further investigations are required (by the use of a crane or similar) to measure noise levels at the hub height and the top and bottom of the swept path for say 150 metres from the tower, including directivity testing at those heights around the turbine.

On the basis of a limited number of affected residents for the study, it is suggested that:

- for these residents the presence of “sensation” is the major impact;
- surveys of residents near other wind farms should utilise the Cape Bridgewater Wind Farm survey method so as to include “sensation” in any investigations;
- the use of dB(A) or dB(C) for internal measurements of the wind farm does not separate the results from that generated by the wind – for residences that are directly exposed to the wind.



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