Soundscape of a wind farm – The Cape Bridgewater experience

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The general concept for describing the noise environment in proximity to a wind farm is expressed in terms of the A-weighted level that will vary dependent upon the wind strength. The compliance methodology in general use for wind farms relies upon a measurement that includes wind and an average line of fit through such data. Measurements at residential receivers when conducted using full spectrum recording/analysis revealed unique characteristics extending into the infrasound region that are normally inaudible that would appear to be present when disturbance is noted. There are no traditional dose-response investigations for the full spectrum of wind farm noise on which to describe the soundscape. A different approach to assessing wind farm noise emissions was used for the Cape Bridgewater wind farm study identifying different concepts for describing the soundscape of the wind farm.
1.0 INTRODUCTION

In a course “Soundscape Studies” available at the RMIT University in Australia the course study for participants is “to investigate the nexus of listener experience, aural cultural and acoustic environments”.

The course describes a soundscape:

“an environment of sound (or sonic environment) with emphasis on the way it is perceived and understood by an individual, or by a society. It thus depends on the relationship between the individual and any such environments” [1].

Generally, the concept of soundscape has been used in relation to traffic environments associated with urban centres where one deals with audible noise in the context of people’s attitude to soundscapes as a whole and whether the entire environment can be changed to be more pleasing to the ear.

2.0 METHODS OF ASSESSMENT

2.1 Different environments but same Leq

In an environmental assessment the basis of evaluation is made on a numerical measurement of the subject noise without considering the relationship of the remaining environment without the subject (usually traffic) noise source.

If one considers traffic noise at night the Regulatory Authorities in Australia specify noise limits in terms of an $L_{Aeq, 9hr}$ for main roads and $L_{Aeq, 1hr}$ for local roads [2].

One can for two different scenarios have the same $L_{Aeq, 9hr}$ level for residential receivers in proximity to a road. One scenario arises from a constant flow of traffic throughout the night. Another scenario arises from say 40 heavy vehicle truck movements throughout the night with negligible traffic at other times.

Whilst the two traffic scenarios have the same $L_{Aeq, 9hr}$ level the soundscape is different, particularly if the second scenario occurs in a quiet semi-rural area.

Figure 1 identifies truck movements 62 metres from the measurement location for a highway with a sign posted speed of 100km/hr.

Figure 1 represents scenario 1 that if continued throughout the night would give a façade reflected $L_{Aeq, 9hr}$ level of 55 dB(A).
Extracting the Sound Exposure Level for a truck movement for scenario 2 and applying 35 of those movements at night also gives a façade reflected $L_{Aeq, 9\, hr}$ level of 55 dB(A).

In describing the two traffic scenarios that have the same $L_{eq, 9\, hr}$ the perception of the scenarios would on a “statistical” basis have the same annoyance level but could have a different perception when placed in terms of sleep disturbance.

The second scenario (for the same $L_{eq}$) will have a truck noise event that will have a maximum level significantly above the ambient background and therefore the emergence of the truck event is significant. The residents in the rural environment for the second scenario have at present a significant lower ambient noise level at night and therefore the introduction of the second scenario by way of a new development can have a significant impact.

General environmental noise assessments in Australia utilise the A-weighted parameter as a descriptor of the acoustic environment with reference to the results of multiple socio-acoustics studies to determine a dose-response to the individual noise source (e.g. aircraft noise, road traffic noise and rail traffic noise). The basis of such measurements/investigations involve computer predictions utilising standard formulae that can generate noise contours taking into account topography and the built environment to provide contours from the traffic source. These acoustic predictions may be considered on their own (referenced to Environmental Authority guidelines), or in some cases compared with the natural acoustic environment, may include any adjustments for weather conditions that affect the propagation of noise and variations in the noise source (number of movements, time and spectral variations).

\[ \text{Figure 1 – traffic movements at 62 m from highway} \]
2.2 Technical issues of using dB(A) for describing wind farm soundscapes

Acoustic assessments in relation to a proposed wind farm use computer programs to determine the likely noise contribution noting the variation in the noise emitted from turbines is a function of the wind speed. As the level of noise emitted from a wind farm is dependent upon the wind speed there is an acknowledgement that in terms of the criteria that may be applied to such developments there will be a sliding scale of permitted noise emission levels that is also related to the wind speed. The concept for determining the permitted limits is to utilise ambient measurements at residential receivers versus the wind speed recorded at the hub height of the turbines or 10 m above ground level at the wind farm site.

The regression analysis method in some situations use an aggregate of the total amount of measured data upon which the average line of fit is determined for a series of noise measurements that could be as little as two weeks of data.

Compliance testing utilises a similar concept to determine the resultant line of fit for operational wind farm (that may in some cases be restricted to only downwind operations with respect to the receiver locations) but relies upon a regression line analysis carried out prior to the operation the wind farm. Problems that may arise with the methodology can be changes in the base data for the different seasons and/or wind direction that leads to different regression line curves. Expanding the time period for data collection to more than just 14 days has obvious benefits (Figure 2).

Figure 2 relates to 3 months of data associated with a wind farm in a rural environment. The receptor point is 1800 metres from the nearest turbine resulting in all of the occupants being affected to the point the house has been abandoned.

Problems that arise from considering the soundscape of a wind farm affected environment is the use of a measured level that includes wind noise and ambient noise in the environment, the concept of a regression curve based upon the hub height wind speed and ignoring the ambient background level.

The projection of wind farm noise using computer models to determine a contribution has difficulty in a validation exercise for operating wind farm because at residential receivers one normally cannot extract the A-weighted contribution of the wind farm by way of frequency analysis or similar from the measured level of wind + wind farm noise.

In terms of socio-acoustic studies to determine the A-weighted level that is acceptable for communities reference is normally made to three studies (two in Sweden and one in the Netherlands) conducted many years ago [3] [4]. Those studies used wind turbines that are significantly smaller both in terms of size and capacity to that that is now experienced. The studies would appear to rely upon a predicted level from the turbines for the residential receivers without identification of the actual noise contribution that was received.
Reference [3] indicates on dose-response basis the results of the three wind farm communities have a lower threshold of annoyance when compared to road, rail and aircraft noise exposure.

Examination of the data for the three quoted studies reveals a different response for communities in rural areas versus urban areas.

In evaluating the soundscape of wind farms it would therefore be necessary to identify the difference between urban environments and rural environments.

If one is utilising the soundscape concept for an assessment of a wind farm it would appear that in the absence of socio-acoustic studies related directly to wind farms then on a holistic basis there is some difficulty in utilising the findings of traffic studies in urban areas, that have determined an acceptable level for sleep disturbance, to wind farms.
Acoustic assessments in Australia are not required to identify or explain the acoustic impact, or health impact (or any impact) that may arise from a proposed wind farm, but simply rely upon determining a predicted A-weighted noise level of the proposed wind farm for comparison with nominated criteria obtained by the regression analysis method.

One therefore finds in rural communities that for “complying” wind farms that there is still disturbance generated in the community by the operation of the wind farm that is not apparent when the wind farm is off-line for extended periods of time or the residents move away from the wind farm.

In considering the soundscape for environments influenced by wind farms one has many different/possible scenarios that can be averaged out in the $L_{Aeq}$ process. One has permutations of wind speed and wind directions that will result in large variations in the $L_{Aeq}$ level that becomes evident in the regression line approach typically adopted for wind farm compliance testing. One also has the audible characteristics of the wind farm, the variation in amplitude modulation of the audible noise and then the potential impacts from non-audible noise (both in the normal range of hearing and in the infrasound region) that do not get picked up in the A-weighted $L_{eq}$ levels.

Various investigations into complaints from residents have identified that there are other components other than just the A-weighted noise level that form the soundscape, the acoustic environment around a wind farm is simply not addressed by the overall A-weighted value. Additional concepts that are identified as altering the subjective impact of wind farm noise had been described as special audible characteristics involving amplitude modulation, low frequency noise and individual tones. However other researchers have identified that there are noise signatures in proximity to wind farms that result in discrete peaks that occur in the infrasound region that are based upon the blade pass frequency (number of revolutions per minute for the turbine shaft times the number of blades and divided by 60) and multiples of the blade pass frequency are clearly evident. This periodic pattern follows the laws of physics in relation to a mechanical fan and readily appears in acoustic analyses for narrowband analysis where the concept is to determine the periodic patterns by the Fast Fourier Transform.

The discrete patterns in the infrasound region can be more evident for measurements inside a dwelling where the higher frequencies (occurring in the external environment) are filtered by the building structure. The infrasound signatures when assessed as an $L_{eq}$ result in levels below the nominal threshold of hearing for the infrasound region and whilst being present are inaudible.

**2.3 Non dB(A) components for describing Wind Farm Soundscapes**


The Cape Bridgewater wind farm is “claimed” by the operator to be compliant with the permit conditions which are expressed in A-weighted values using the standard regression analysis method.
Residents in proximity to the Cape Bridgewater wind farm have reported disturbances since the commencement of the operation of the wind farm with some people abandoning their homes on medical advice as a result of the deterioration of their health.

Following adverse publicity concerning ongoing disturbance from a screeching noise generated by the turbines, ultimately identified as a brake issue on the yaw mechanism, the wind farm operator agreed to undertake a noise study to investigate the resident’s complaints.

After consultation with the residents as to the issues of disturbance the wind farm operator provided a specific brief for the investigation:

*noise and vibration measurements shall be undertaken to determine certain wind speeds and certain sound levels that relate to the disturbance reported by specific local residents.*

The study brief was NOT to:

- conduct a normal A-weighted acoustic compliance method,
- undertake a socio acoustic study, or
- undertake a health investigation.

The specific brief for the investigation required a different approach that necessitated extensive discussions with residents to identify the disturbance that they were experiencing. In discussing the disturbances that the residents received (six residents in the study) it became apparent that typical acoustic descriptors for noise do not cover the disturbance that was experienced leading to the use of two other descriptors to be added to the social survey, one being vibration and the one being sensation.

The discussions with residents prior to the main study, following a trial run of a previous wind farm community survey method [5], found that sensation is an appropriate description descriptor of the disturbance and that in the past many disturbances that have been reported as noise disturbances were not actually disturbance as a result of noise. The residents were requested to use a diary reporting system where the ranking of severity from 1 to 5 was applied to noise, separately to the concept of reporting vibration, that was separate to the concept of reporting sensation.

The results of the Cape Bridgewater investigation [6] reveals that there were certain wind speeds related to the operation of the wind farm that did give rise to the disturbance upon individuals that created adverse impacts such as sleep disturbance, pressure in the head, pulsations, or nausea. These adverse impacts fell under the description of “sensation”.
Testing undertaken in the Cape Bridgewater study confirmed the presence of an infrasound signature (previously described by the author as the “wind turbine signature” that follows the slope shown in Figure 3) when the turbines are operating that was not there when the turbines are off. The observations of disturbance indicated four scenarios for the operation of the wind farm to give rise to the disturbance that suggested a possibility of inefficient alignment of the blades to the wind that would occur during start-up, change in the output power of the wind farm by some 20% and apparent when the wind increased and the blades were de-powered.

Investigation of various acoustic parameters with respect to those disturbance patterns did not find any correlation or trend with respect to general acoustic indices but ultimately found there was a trend or pattern with respect to the infrasound signature.

The study considered the concept of a worst-case scenario being sensation 5 was either harmful to the health of the residents or had reached a level where the residents wish to leave (or actually left) their premises to escape the impacts and upon looking at that restricted data one could see an increase in the levels in the infrasound region.
The report identifies that on looking at the infrasound region the levels increase with the level of sensation whilst maintaining the same slope of the curve (Figure 3).

The assessment methodology for the Cape Bridgewater study started from complaints, and then worked backwards to find the acoustic signature/changing operation of the wind farm revealed the A-weighted level concept has no direct relationship with the disturbance.

It is noted that the residents involved in the study are sensitised to the wind turbine noise, having been exposed on virtually a continuous basis to the emissions of the wind farm for six years and therefore appear to have a heightened sensitivity than other residents (in relation to other wind farms) that have lower exposure periods [6].

However, the results of the study indicated a possible descriptor (Wind Turbine Signature “WTS”) could be introduced for the assessment of a wind farm noise. The WTS provides a measurable difference when the turbines are operating (versus the natural environment) and gives a tool for use in medical investigations into wind farm noise.

3.0 CONCLUSIONS

In considering the development of soundscape for wind farms the use of the A-weighted level has limited value.

For development of the soundscape for a wind farm much more work needs to be undertaken to establish the actual impacts that are related to the relatively low A-weighted noise levels emitted by turbines (when compared to road traffic noise). The presence of inaudible infrasound signatures, modulation and tonal characteristics that do not get considered or picked up in general environmental acoustics needs to be measured, and studied in greater detail.

For road traffic, rail traffic or aircraft noise assessments, generally the noise events being considered generate audible noise well above the background level and are easily measured.

In considering the impacts of wind turbines one has a noise contribution similar to or below the ambient background level. As such there needs to be an acknowledgement that the limited dose response data is very much out of date and if restricted to predicted A-weighted levels, not the actual sound level contribution, is therefore not appropriate for assessing the impact. The presence of special frequency characteristics (including infrasound and low frequency) are not the normal everyday concept in environmental acoustics, but are issues that require a different approach and a more detailed investigation into determining the soundscape of a wind farm.

Acousticians working in noise control for industry are well aware a small number of complainers who persistently complain require a different approach to that from the general acoustical planning concepts for industry because there is a need to investigate the noise signature that relates to the disturbance. Unique situations/operation of compressors, exhaust ducts, stacks etc., that generate an intermittent noise that may have special frequency characteristics (including low
frequency and infrasound) are not the normal everyday concept in environmental acoustics, but are issues that have required a different approach in resolving the complaints.

If one considers the impact of wind farms on an acoustic environment from the perspective of complaints, rather than from computer-generated predicted levels, undertaking acoustic assessments from that perspective will provide a more meaningful appraisal of the soundscape for such areas.

For the benefit of soundscape researchers, the methodology employed in Cape Bridgewater study to work from the complainant end of an acoustic investigation should be considered as an appropriate method for investigating complaints where there is a heightened level of disturbance.

For determination of a wind farm soundscape the social survey method used in the Cape Bridgewater study (that added the concept of vibration and sensation) should be considered as sensation was the major disturbance reported by the residents, rather than noise or vibration.

### 4.0 APPENDIX A: Severity Ranking for CBW Study

With the acknowledgement of the AECOM Wind Farm Noise Complaint Methodology (in NANR 277 DEFRA April 2011) the following severity rankings with respect to noise are set out below:

1. **No impact (No noise)**  
   Noise can be heard, but does not cause any change in behaviour or attitude, e.g. turning up volume of television; speaking more loudly; closing windows. Can slightly effect character of the area but not such that there is a perceived change in the quality of life.

2. **Slight impact (Non-intrusive)**  
   Noise can be heard, but does not cause any change in behaviour or attitude, e.g. turning up volume of television; speaking more loudly; closing windows. Can slightly effect character of the area but not such that there is a perceived change in the quality of life.

3. **Moderate Impact (Intrusive)**  
   Noise can be heard and causes small changes in behaviour and/or attitude, e.g. turning up volume of television: speaking more loudly; closing windows. Potential for non-awakening sleep disturbance. Affects the character of the area such as there is a perceived change in the quality of life.

4. **Substantial Impact (Disruptive)**  
   Causes a material change in behaviour and/or attitude, e.g. avoiding certain activities during periods of intrusion. Potential for sleep disturbance resulting in difficulty in getting to sleep, premature awakening and difficulty getting back to sleep. Quality of life diminished due to change in character of the area.

5. **Severe Impact (Physically Harmful)**  
   Significant changes in behaviour and/or inability to mitigate effect of noise leading to psychological stress or physiological effects, e.g. regular sleep deprivation/awakening: loss of appetite, significant, medically definable harm, e.g. noise induced hearing loss.

   **NB** In some case residents relate severity 5 to be equivalent to having to leave their premises and go somewhere else because of the noise.

In utilising the same ranking methodology for vibration one would substitute the word “noise” with “vibration”, e.g. for slight impact “the vibration can be felt, but does not cause any change in behavioural attitude…”
Similarly, in relation to sensation in the ranking table “noise” is substituted with sensation, e.g. for 1 slight impact (Non-intrusive) “Sensation can be felt, but does not cause any change in behavioural attitude….

In dealing with sensation (as reported by residents) there is a wider range of effects than that associated with the general concept of noise.

Residents subject to operational wind farms have identified a range of sensations that can vary from individuals to individuals. Residents have in some cases attributed “sensation” to “noise” complaints where the sensations as felt by residents can include such things as:

- Headache
- Pulsating pressure in the head
- Pressure in the ears
- Ringing in the ears
- Drowsiness (or heaviness)
- Pressure in the chest
- Effect like heart racing

5.0 REFERENCES