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WIND FARMS TECHNICAL PAPER

Environmental Noise

Prepared for

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INTRODUCTION

Australian wind farms currently provide 1841MW of power or enough energy to power 772,286 homes (Clean Energy Council Renewable Energy Database, April 2010). With this level of generation comes a need to ensure their advantages are balanced against the amenity of the communities that live in their vicinity.

This Technical Paper has been prepared to provide the latest information to communities, developers, planning and enforcement authorities and other stakeholders on environmental noise from wind farms and includes:

- An explanation of the sources of noise from a wind farm and its characteristics;
- A summary of the various Australian wind farm noise standards and guidelines and a comparison of the local and International approaches;
- A description of the methodology associated with a detailed environmental noise assessment prepared for a wind farm in accordance with the relevant standards and guidelines;
- A description of the various terms used in those assessments including the ambient noise environment, background noise levels and characteristics such as modulation, tonality, infrasound and low frequency;
- A summary of the research conducted into a range of issues including:
    - Health impacts and annoyance;
    - Infrasound and low frequency;
    - Amplitude modulation; and
    - Sleep disturbance

EXECUTIVE SUMMARY

Virtually all processes generate noise, including wind farms. The response to noise by individuals can be wide and varied. Noise is often the most important factor in determining the separation distance between wind turbines and sensitive receivers. The assessment of noise therefore plays a significant role in determining the viability of and the size of wind farms.

Australian jurisdictions presently assess the noise from wind farms under a range of Standards and Guidelines applicable to each individual State or Territory.

The Standards and Guidelines used in Australia and New Zealand are stringent in comparison to other International approaches. They are also the most contemporary in the World, with recent updates and releases of the main assessment approaches occurring in both late 2009 and early 2010.

Notwithstanding the above, there are community concerns relating to both annoyance and health impacts associated with environmental noise from both planned and operating wind farms. As such, the Clean Energy Council has engaged Sonus to make an independent review of the available information relating to noise from wind farms.

The information in this Technical Paper results in the following key conclusions:

- The standards and guidelines used for the assessment of environmental noise from wind farms in Australia and New Zealand are amongst the most stringent and contemporary in the World;

- There are inherent discrepancies associated with a number of different approaches from jurisdiction to jurisdiction;

- The rate of complaints relating to environmental noise emissions from residents living in the vicinity of operating wind farms is very low;

- There are complaints relating to environmental noise emissions from residents living in the vicinity of operating wind farms. These complaints generally relate to concerns regarding low frequency noise and health related impacts; and

- There is detailed and extensive research and evidence that indicates that the noise from wind farms developed and operated in accordance with the current Standards and Guidelines will not have any direct adverse health effects.

THE NOISE FROM A WIND FARM

The acoustic energy generated by a wind turbine is of a similar order to that produced by a truck engine, a tractor, a large forklift or a range of typical earthmoving equipment. However, a wind turbine is a stationary source that operates in conjunction with other turbines in a generally windy environment, is located high above the ground and has different noise characteristics compared to these other noise sources.

This section provides information relating to the level and characteristics of noise from a wind farm.

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

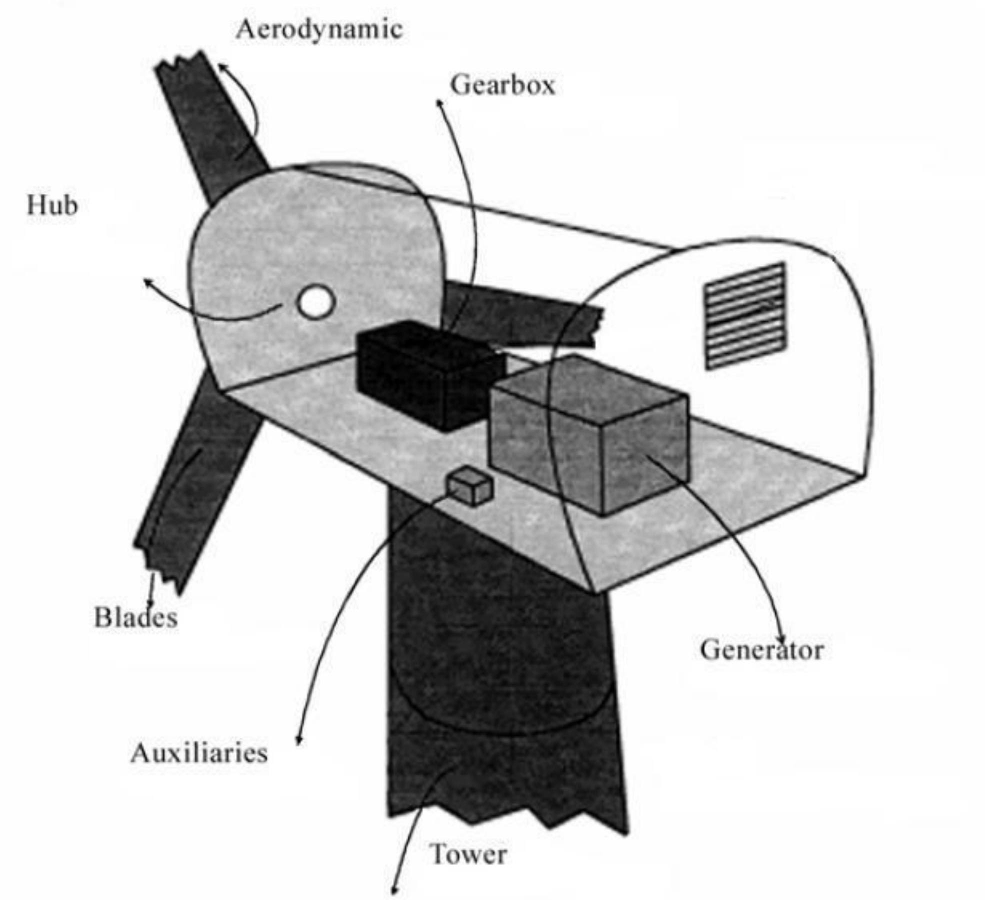

Figure 1 - (Modified from Wagner 1996)

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

Mechanical Noise

Mechanical noise sources are primarily associated with the electrical generation components of the turbine, typically emanating from the gear box and the generator. Mechanical noise was audible from early turbine designs. On modern designs, mechanical noise has been significantly reduced (Moorhouse et al., 2007), such that aerodynamic noise from the blades is generally the dominant noise emission from a wind turbine.

Aerodynamic Noise

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

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

In general terms, the noise we hear in any environment is a combination of energy at different frequencies. There are noise sources that have their dominant content of energy present in the higher frequencies, such as a whistle, and noise sources that have their dominant content in the low frequencies, such as a diesel locomotive engine. Most noise sources are “broadband” in nature; that is they possess energy in all frequencies. A typical broadband noise is music, where the bass content is in the low frequency region, and the voices and general melody are in the middle and higher frequencies.

Aerodynamic noise is broadband in nature and present at all frequencies. Weighting networks are applied to measured sound pressure levels to adjust for certain characteristics. The A-weighting network (dB(A)) is the most common, and it is applied to simulate the human response for sound in the most common frequency range. Therefore, the A-weighted network (dB(A)) is the network used in wind farm standards and guidelines.

Aerodynamic noise can be further separated into the following categories, generally termed “characteristics”:

Amplitude Modulation

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

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

Other explanations for the rise in noise level that occurs on the downward stroke relate to the slight tilt of the rotor-plane on most modern wind turbines to ensure that the blades do not hit the tower. An effect of the tilt is that when the blades are moving downwards they are moving against the wind. Conversely, when moving upwards they are moving in the same direction as the wind. Therefore, with the effective wind speed being higher on the downward stroke, it is suggested that a higher noise level is produced (Sloth, 2010).

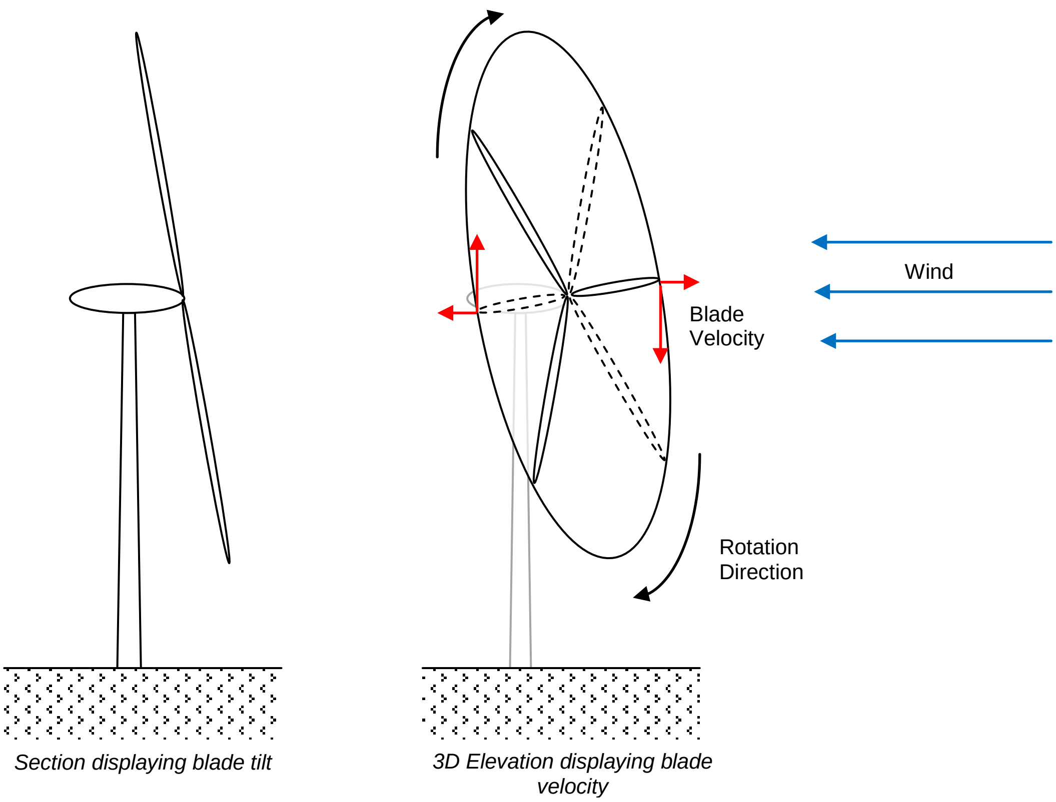

Figure 2 - Blade Velocity due to Tilt

Low Frequency Noise

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

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

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

This effect is exacerbated in an environment that includes masking noise in the mid and high frequencies, such as that produced by wind in nearby trees.

A typical separation distance between wind farms and dwellings is of the order of 1000m. At similar distances, in an ambient environment where wind in the trees is present, it is possible that only low frequencies remain audible and detectable from a noise source that produces content across the full frequency range. This effect will be more prevalent for larger wind farms because the separation distances need to be greater in order to achieve the relevant noise standards. A greater separation distance changes the dominant frequency range from the mid frequencies at locations close to the wind farm to the low frequencies further away, due to the effects described above.

The low frequency content of noise from a wind farm is easily measured and can also be heard and compared against other noise sources in the environment. Low frequency sound produced by wind farms is not unique in overall level or content and it can be easily measured and heard at a range of locations well in excess of that in the vicinity of a wind farm. The C-weighting network (dB(C)) has been developed to determine the human perception and annoyance due to noise that lies within the low frequency range.

Infrasound

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

Audible levels of infrasound have been measured from downwind blade wind turbines (Jakobsen, J., 2005). Modern turbines locate the blades upwind of the tower and it is found that turbines of contemporary design produce much lower levels of infrasound (Jakobsen, J., 2005), (Hubbard and Shepherd 2009).

Infrasound is often described as inaudible, however, sound below 20 Hz remains audible provided that the sound level is sufficiently high (O'Neal et al, 2009). The thresholds of hearing for infrasound have been determined in a range of studies (Levanthall, 2003).

Non-audible perception of infrasound through felt vibrations in various parts of the body is not possible for levels of infrasound that are below the established threshold of hearing and only occurs at levels well above the threshold (Moeller and Pedersen, 2004).

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

A common audibility threshold from the range of studies is an infrasound noise level of 85 dB(G) or greater. This is used by the Queensland Department of Environment and Resource Management's (DERM's) draft Guideline for the assessment of low frequency noise as the acceptable level of infrasound in the environment from a noise source to protect against the potential onset of annoyance and is consistent with other approaches, including the UK Department for Environment, Food and Rural Affairs (DEFRA., Leventhall, 2003).

Whilst the aerodynamic noise from a rotating turbine blade produces energy in the infrasound range, measurements of infrasound noise emissions from modern upwind turbines indicates that at distances of 200 metres, infrasound is in the order of 25 dB below the recognised perception threshold of 85 dB(G) and other similar recognised perception thresholds (Hayes Mckenzie Partnership Ltd, 2006). A 25 dB difference is significant and represents at least a 100 fold difference in energy content. Infrasound also reduces in level when moving away from the source, and separation distances between wind farms and dwellings are generally well in excess of 200m.

Notwithstanding the above, there are natural sources of infrasound including wind and breaking waves, and a wide range of man-made sources such as industrial processes, vehicles and air conditioning and ventilation systems that make infrasound prevalent in the natural and urban environment (Howe, 2006).

Future Designs

A wind turbine converts wind energy into rotational energy (which in turn becomes electricity) and acoustic energy. An efficient wind turbine converts more of the wind energy into rotational energy with all other factors, such as blade angles, being equal. Therefore, it is in the best interests of wind turbine manufacturers to research and make available quieter turbines, as this indicates an increase in the available electricity generating capacity as well as the benefits of lower noise levels:

> *The sound produced by wind turbines has diminished as the technology has improved. As blade airfoils have become more efficient, more of the wind energy is converted into rotational energy, and less into acoustic energy. Vibration damping and improved mechanical design have also significantly reduced noise from mechanical sources.*
> *(Rogers et al, 2006)*

STANDARDS AND GUIDELINES

Australia presently assesses the noise from wind farms under a range of Standards and Guidelines applicable to each individual State or Territory, shown below in Table 1

Table 1 – Summary of Australian State Standards and Guidelines for Wind Farms

State or Territory	Assessment Procedure	Comments
South Australia	SA EPA Wind Farms Environmental Noise Guidelines July 2009	The 2009 Guidelines is an updated version of the original 2003 Guidelines. The release follows a review process initiated in 2006
New South Wales	SA EPA Wind Farms Environmental Noise Guidelines February 2003	New South Wales has not automatically endorsed the 2009 version of the Guidelines, and at this stage retains the 2003 version as the primary assessment procedure.
Western Australia	SA EPA Wind Farms Environmental Noise Guidelines February 2003	The document EPA Guidance for the Assessment of Environmental Factors No. 8 – Environmental Noise Draft May 2007 refers to the 2003 version as the primary assessment procedure. The WA Government has not endorsed the 2009 version of the Guidelines at this stage.
Queensland	No formal assessment procedure	The New Zealand Standard and the South Australian 2003 Guidelines have been referenced by the Queensland Government in the past.
Victoria	New Zealand Standard NZS 6808:1998 *Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators*	The document Policy and Planning Guidelines for Development of Wind Energy Facilities in Victoria refers to the 1998 version of the New Zealand Standard as the primary assessment procedure. The 2010 version of the Standard has not been endorsed in the Guidelines at this stage.
Tasmania	Department of Primary Industries, Water and Environment (Tasmania) *Noise Measurement Procedures Manual 2004*	The document does not provide objective criteria and therefore the use of one of the assessment procedures noted for the States above will be required in conjunction with the 2004 Manual.
ACT and Northern Territory	No formal assessment procedure	To be assessed on a case by case basis.

In addition to the above, Australian Standard AS4959 – 2010 *Acoustics – Measurement, prediction and assessment of noise from wind turbine generators* has been released recently. The Standard does not provide any objective criteria, but rather it aims to provide a suitable framework to develop a method for the measurement, prediction and assessment of noise from wind farms.

Based on the above, a wind farm proposal could be subject to a range of assessment procedures depending on the jurisdiction. Whilst there are consistent elements in the different procedures, there are inherent and important discrepancies.

Objective Standards

In general terms, the noise from a wind farm increases with wind speed up until the rated power (electrical output capacity) of the particular turbine, when the noise then remains constant or even reduces at higher wind speeds. The increase in wind turbine noise as the wind speed increases normally plateaus, or even potentially diminishes, occurs in an environment where the background noise level continues to increase, the effect of which is to assist in masking the wind farm noise.

Therefore, wind farm standards and guidelines in Australia and New Zealand set a base noise limit that generally applies at lower wind speeds when the background noise is relatively low, and a background noise related limit that allows the wind farm to generate higher noise levels as the wind speed increases.

In circumstances where the background noise levels are sufficiently low, the base noise limit applies. This generally occurs at lower wind speeds and/or at dwellings that are not subject to a sufficiently high background noise environment, such as might occur at a dwelling deep in a valley with little to no surrounding vegetation.

In circumstances where the background noise levels increase sufficiently, the background noise related limit applies. This generally occurs at higher wind speeds and/or at dwellings that are subject to a high background noise environment, such as might occur at a dwelling on a ridge top surrounded by trees.

Where the wind farm is able to achieve the base line noise limit at higher wind speeds, the masking effect of the background noise environment does not need to be taken into account. This is because the base line noise limit is generally established to ensure there are no adverse noise impacts, even in a low background noise environment when the masking effects are limited.

The objective standards provided by the various assessment procedures is summarised in the table below:

Table 2 - Objective Standards

Assessment Procedure	Objective Standard	Comments
Government of South Australia Wind Farms Environmental Noise Guidelines February 2003	Base noise limit: 35 dB(A) Background noise limit margin: 5 dB(A). The greater of the above limits applies.	The limits are an equivalent (or effectively an average) noise level.
Government of South Australia Wind Farms Environmental Noise Guidelines July 2009	Base noise limit: 35 dB(A) (Rural living locality) Base noise limit: 40 dB(A) (in other localities including general farming and rural areas) Background noise limit margin: 5 dB(A). The greater of the above limits applies.	The base noise level limit has been increased to 40 dB(A) to ensure consistency with the assessment limits applied by the *South Australian Environment Protection (Noise) Policy 2007* to other noise sources in a general farming or rural locality.
New Zealand Standard NZS 6808:1998 *Acoustics – The Assessment and Measurement of Sound from Wind Turbine Generators*	Base noise limit: 40 dB(A) Background noise limit margin: 5 dB(A). The greater of the above limits applies.	Whilst there is conflicting information in the Standard, the limits are taken to be an equivalent noise level.

Assessment Procedure	Objective Standard	Comments
New Zealand Standard NZS 6808:2010 *Acoustics – Wind Farm Noise*	Base noise limit: 35 dB(A) (High amenity area) Base noise limit: 40 dB(A) (Other areas) Background noise limit margin: 5 dB(A). The greater of the above limits applies.	The limits are expressed explicitly in the Standard to be a 90th percentile level (L_{A90}). The L_{A90} is inherently less than the equivalent noise level and therefore the limits are higher (less stringent) than those in the South Australian Guidelines. A high amenity area is related to a review of the planning system and the specific requirement in the relevant plan to maintain a high degree of protection to the "sound environment". If the area is deemed to be of high amenity, then the L_{A90} 35 dB(A) base noise level limit applies only during the night period, and for wind speeds less than 6 m/s or other defined threshold for that specific proposal.
Australian Standard AS4959 – 2010 *Acoustics – Measurement, prediction and assessment of noise from wind turbine generators*	Deferred to the relevant jurisdiction.	Notes that the jurisdiction should have a base noise level limit and a background noise level limit.
Environment Protection Heritage Council (EPHC) prepared Draft National Guidelines October 2009 and July 2010	Deferred to the relevant jurisdiction.	Notes that the jurisdiction should have a base noise level limit and a background noise level limit.

Comparison of the objective standards with International approaches

The objective standards provided by a range of International assessment procedures is summarised in the table below (Reference 1 unless noted otherwise):

Table 3 – Summary of International Standards

Assessment Procedure Country of Origin	**Objective Standard**	**Comments**
Sweden	Base noise limit: 40 dB(A) Low background areas: 35 dB(A)	The approach does not provide a definition for a low background area.
Denmark	Noise limit: 44 dB(A) @ 8m/s 42 dB(A) @ 6m/s For sensitive areas such as institutions, allotment gardens and recreation: Noise limit: 39 dB(A) @ 8m/s 37 dB(A) @ 6m/s	No background noise limit is applied. The noise limits are determined for wind speeds taken at 10m above the ground.
France	Background noise limit margin: 5 dB(A) – day time Background noise limit margin: 3 dB(A) – night time	Based on a background noise measurement made at a wind speed of 8m/s
The Netherlands	Noise limit: 40 dB(A) at night increasing incrementally up to 50 dB(A) at 12m/s	

Assessment Procedure Country of Origin	Objective Standard	Comments
United Kingdom	Base noise limit: 40 dB(A) (day time) Base noise limit: 43 dB(A) (night time) Background noise limit margin: 5 dB(A). The greater of the above limits applies.	The limits are a 90th percentile level (L_{A90}). The L_{A90} is inherently less than the equivalent noise level. The UK assessment procedure indicates the L_{Aeq} from a wind farm is typically of the order of 2 dB(A) greater than the L_{A90} The procedure notes that the recommended noise levels take into account “swish”.
USA (Illinois) (Reference TD178-01F06)	Base noise limit: 55 dB(A) (day time) Base noise limit: 51 dB(A) (night time)	The noise limits are determined for an 8 m/s wind speed taken at 10m above the ground. There are no uniform noise standards in the USA, with local counties establishing their own approaches which vary considerably.

In broad terms, the Standards and Guidelines used in Australian jurisdictions include the following common elements:

- Objective standards that provide a base noise limit and a background noise related limit, with the exception of the EPHC draft Guidelines and the Australian Standard;
- A background noise and wind speed measurement procedure to determine the applicable background noise related limits at each dwelling;
- A noise level prediction methodology to enable a comparison of the predicted noise level from the wind farm against the noise limits at each dwelling;
- The required adjustments to the predicted noise levels to account for any special audible characteristics of the wind farm noise;
- A compliance checking procedure to confirm the operational wind farm achieves the predicted noise levels at each dwelling.

In addition, Australian jurisdictions are amongst the most stringent and the most contemporary in the World.

Noise Levels

A common issue for people considering the environmental noise from wind farms is the ability to place the wind farm's noise levels and characteristics in context compared to the ambient environment.

A site visit to an operating wind farm at different times and at typical separation distances between a wind farm and a dwelling, starting from the order of 700m from the nearest turbine, greatly assists in providing this context.

To assist in providing context for typical noise levels from a wind farm, Chart 1 (below) provides the order of noise level in the vicinity of a modern wind turbine. It should be noted that the noise levels presented in the chart will vary according to a range of variables discussed in further detail in the noise propagation section of this Paper.

The base noise level requirement of 35 or 40 dB(A) provided in the main assessment tool in Australia, the South Australian EPA Wind Farm Guidelines, represents a low (stringent) noise level in an environmental noise context. It is significantly more stringent than the World Health Organisation's recommended guideline value of 45 dB(A) for sleep disturbance effects and than the recommended noise levels for road or rail infrastructure development that might occur in a rural environment, where levels of the order of 55 and 60 dB(A) respectively are typically recommended.

The base noise level requirements also need to be considered in the context of the ambient environment. Wind farms are generally located in a rural environment, where the associated planning system often envisages and promotes activity associated with primary industry.

A wind farm is also inherently located in areas where wind is present and therefore background noise levels from wind in the trees and around structures such as houses and sheds can be elevated. The effect of elevated background noise levels is to provide masking of other noise sources in the environment.

Regardless of the stringency of the base noise level or the available masking effect of the ambient environment, wind farm standards and guidelines are not established to ensure inaudibility. The ability to hear a wind farm designed and operated in accordance with the standards and guidelines in Australia will vary according to a range of variables such as the influence of the ambient environment, the local topography, the distances involved and the weather conditions at the time.

All noise, from any noise source including wind farms, which is audible, will result in complaints from some people. In addition, recent research indicates the potential for complaints, annoyance and its associated stress and health impacts may be exacerbated by rhetoric, fears and negative publicity (Colby et al, 2009). There is a significant amount of mis-information and negative publicity about the impacts of wind farms available in the broader community.

Only a few field studies on noise annoyance among people living close to wind turbines have been conducted and further investigations have been recommended by these studies. The European studies (Pedersen, 2005) indicate correlation between the noise level and annoyance, but stronger correlation with factors such as overall sensitivity to noise, attitude towards the noise source, attitude towards the area as a pristine place or a place for economic development, influence over the proposal, daily hassles, visual intrusion and the age of the turbine site.

Tickle (2006) compared the incidence of complaints in Australia and New Zealand, about noise from wind farms and complaints about noise in general and found that once wind farms are built the rates of complaints are very low in Australia and New Zealand.

Notwithstanding the above reasons or information, if a noise source can be heard, then annoyance can result for some people, regardless of the noise level or the standard or guideline that applies.

Figure 3 below provides some relative noise level information and compares wind turbines against common community noise levels:

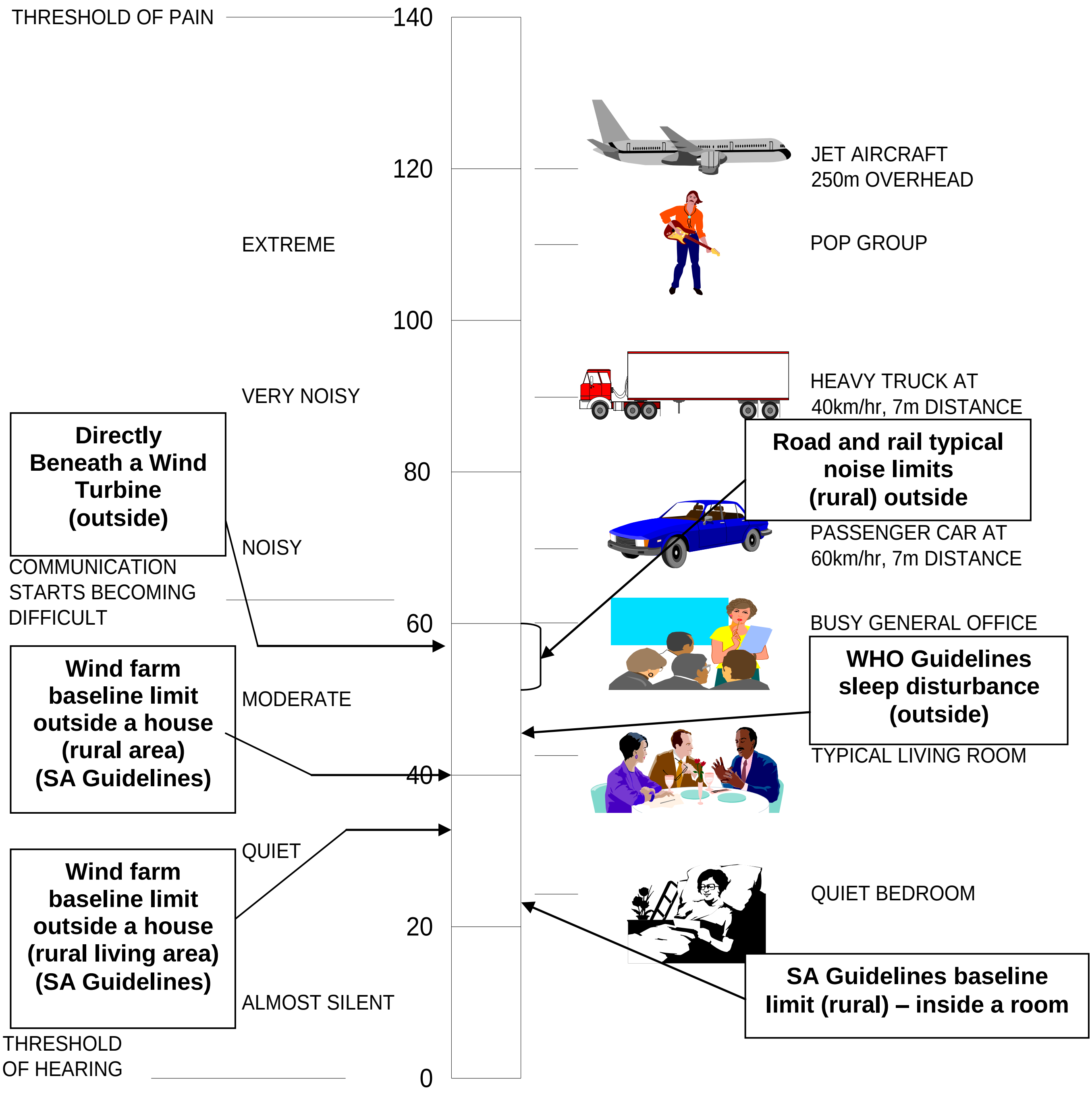

Figure 3 – Subjective Comparison of Noise Levels

ASSESSMENT METHODOLOGY

Whilst each Australian jurisdiction is subject to its own Standards and Guidelines and associated detailed requirements, the broad methodology for an environmental noise assessment of a wind farm proposal is similar amongst jurisdictions.

This section of the Technical Paper provides the background to the assessment process to assist in interpretation and understanding of the technical information that will generally be provided as part of a wind farm proposal and assessment.

Environmental Noise Assessment

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

The developer of a wind farm makes an assessment of the environmental noise from the proposed layout and to determine any necessary modifications to ensure compliance with the relevant Standard and Guidelines. The modifications during the planning and design phase of the project might comprise the removal or relocation of some turbines or the operation of certain turbines at reduced speeds or “modes” that correspond to lower noise levels. The assessment is generally made by an independent acoustic engineer specialising in the prediction and assessment of noise and vibration impacts across a broad range of sectors, including wind farms.

Methodology

The broad methodology associated with an environmental noise assessment of a wind farm proposal is as follows:

1. <u>Review the proposed layout to identify dwellings where the relevant criteria might be exceeded;</u>

   The purpose of the identification is to determine the locations at which background noise monitoring will be conducted.

   The background noise monitoring is a measurement method used to establish the existing ambient noise environment at a dwelling. The technical definition of the background noise is the noise level that is exceeded for 90% or 95% of the measurement period. In subjective terms, it represents the "lulls" that occur in the environment, in between intermittent events such as the overhead passage of an aircraft, a dog barking, wind gusts in trees, or the occasional passing of a vehicle on a nearby road. This is because the background noise excludes all noise level data that is not present for at least 90% (or 95% depending on the Standard or Guideline used) of the time. A common term used in the assessment is the "ambient" noise. The ambient noise is generally taken to include all the intermittent events, whilst the background noise effectively removes these events and represents the noise environment in their absence.

   The background noise at a dwelling is important because it can mask the noise of a wind farm, and the level of that masking can be an important factor in the assessment. The most general source of background noise level masking, particularly at higher wind speeds, is wind in nearby trees.

   The land owners who have a turbine on their land are also identified during this process, as the assessment criteria applied to them are relaxed by most Standards and Guidelines in comparison to dwellings without an association with the proposed wind farm.

Land holdings where a development approval exists to construct a dwelling are also generally identified as most Standards and Guidelines define these as locations where the relevant criteria need to be met.

Once those dwellings and land holdings are identified, the locations that best represent the range of dwellings in the locality are selected. These are generally defined as dwellings that are closest to the wind farm. The Standards and Guidelines generally allow a single dwelling to represent a range of dwellings that are either in the near vicinity or expected to be subject to a similar background noise environment.

A term that is commonly used in the Standards and Guidelines is “relevant receiver location”. These locations are generally:

- Where someone resides or has development approval to build a dwelling; and
- Where the predicted noise level exceeds the base noise level for wind speeds up to the rated power of the wind turbine; and
- Representative of the worst case location when considering the range of dwellings, such as a dwelling that is located amongst a similar group in the near vicinity and is the closest to the wind farm.

2. <u>Conduct a background noise monitoring regime at the relevant receiver locations;</u>

The measurement of background noise levels is a critical aspect of the environmental noise assessment as it is the method by which criteria are determined.

The exception to the need to conduct a background noise monitoring regime is in circumstances where the wind farm is able to achieve the base noise level limit (or a prescribed noise level that is less than the base noise level) at wind speeds where the noise output of the particular turbine is at its maximum. This is because the base noise level limit is generally established to ensure there are no adverse impacts even in a low background noise environment where the masking effect is limited or negligible.

Notwithstanding compliance with the base noise level limit, a background noise monitoring regime may still be conducted as it the means by which compliance checking procedures are generally based upon. The compliance checking procedure is discussed in further detail in a dedicated section below.

Where conducted, the background noise monitoring can be over a range of the order of 10 days to 4 weeks, depending on the particular requirements of the relevant Standard or Guideline. The period of monitoring can also be extended where excessive wind or rain adversely affect the data. The apparatus used to continually measure and record the background noise levels over this period is known as a “logger”.

The location of the logger is typically at least 5m from the building facade to remove the effects of large reflecting surfaces. The location is also required to be representative of background noise levels and this is generally achieved by placing the logger at an equivalent distance to tall trees as the facade of the house. The logger is also generally placed on the windfarm side of the dwelling to enable any future compliance checking measurements at dwellings to be taken at the same point.

Photographs and a GPS grid reference are typically used to identify each noise logging location. A typical installation is shown in Figure 4 below. The noise logger, comprising a sound level meter and batteries within a weatherproof container connected to a pole mounted microphone, is located in the centre of the photograph.

Figure 4 – Typical Noise Monitoring Installation

Some Standards and Guidelines explicitly require the removal of adverse data and data outside of the wind speed operating range of the turbines and it is considered good practice to do so. The 2003 and 2009 SA Guidelines require data points where rain has occurred and when wind on the microphone has had an impact on the measured noise levels to be removed. A way of measuring the occurrence of these factors is to place a weather logger adjacent to one of the background noise loggers to record rainfall, wind speed and wind direction. If in close proximity, a local Bureau of Meteorology weather station can also be used to identify adverse weather periods.

An acoustic engineer would take of the order of one hour to set up the noise logging equipment at each location. Access is normally organised directly with the land holder or dwelling occupier in accordance with established project protocols. Clearly, a land holder or occupier does not need to grant access to their property, however, an advantage of doing so is the ability to confirm compliance, or otherwise, of the operational wind farm against the relevant Standards or Guidelines at a point in the future.

3. Analyse the background noise monitoring data to determine the noise level criteria;

Following the removal of data adversely affected by local weather conditions, the remaining data points are correlated against the wind speed collected at the same time and for the same period as the background noise levels. The background noise level is determined for every ten minute period throughout the 2 to 4 week monitoring regime.

The wind speed is measured by the developer or another independent expert at a representative location within the wind farm by erecting a wind mast with anemometers, sometimes at a number of different heights. There may be more than one wind mast depending on the size of a wind farm.

Earlier Standards and Guidelines required the wind speed to be measured at 10m above the ground, however, recent requirements relate to measurements at or near the proposed hub height of the wind turbine, which may be of the order of 80m above the ground. The reason for the 10m measurement height was to provide correlation with the way the sound power level of a wind turbine is measured in accordance with IEC 61400 – 11 (IEC, 2002)[1], whereas the increase to at or near hub height has been introduced to better represent actual operating scenarios.

The purpose of the correlation of the two sets of data, being the wind speed measured at the wind farm site (data set one) and the background noise levels measured at a relevant receiver (data set two), is to establish the relationship between the operating wind farm and the average background noise level at dwellings in the vicinity, and in turn, to determine the applicable criteria at those dwellings. That is, the correlated data will determine whether the wind farm will be operational during periods when the background noise levels are on average low, providing limited masking, or when the background noise levels are on average high, providing a greater level of masking.

A best fit regression analysis is conducted on the two sets of data. An example plot produced from background noise measurements is given in Figure 5 below.

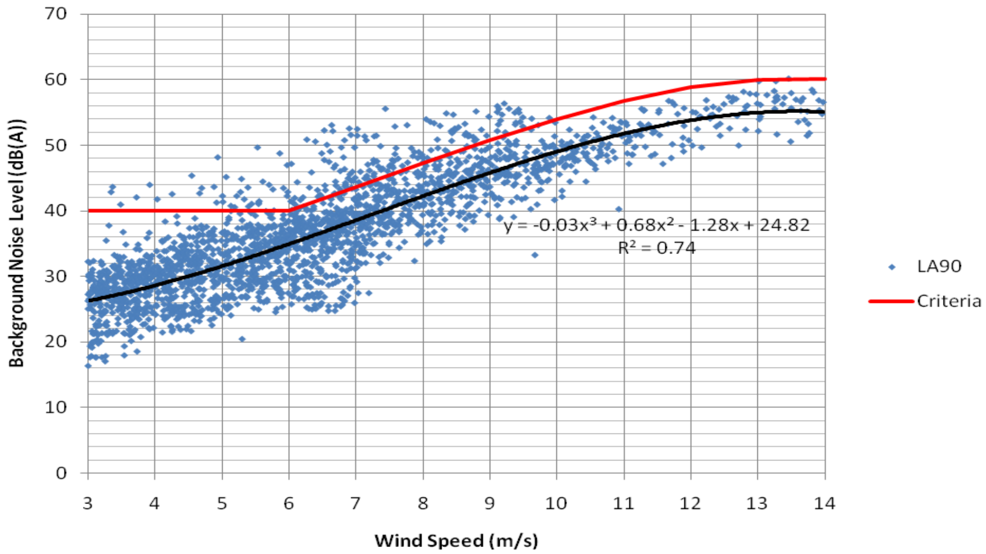

Figure 5 – Example Regression Analysis Plot

[1] An expected revision of the IEC standard will include reference to a hub height measurement position

Whilst most regression analyses will show the trend of the background noise level increasing with an increasing wind speed at the wind farm, the analyses will vary for each individual dwelling. Figure 5 shows a strong relationship between the background noise level and the wind speed at the wind farm, but this will not be the case in all circumstances. Some dwellings may be located such that they are shielded from the effects of the wind at the wind farm site.

The red line in the figure shows how the correlated data is used to determine the applicable noise level criteria at a dwelling. In this example, the base noise level limit is 40 dB(A), and this is not increased until the average background noise level increases sufficiently to provide a suitable level of masking. In this example, the background noise level becomes suitably high at wind speeds at the wind farm site that are at and above 6 m/s.

An important feature of the regression analysis is that it represents a line of best fit or effectively an "averaging" of the data. Therefore, there will be times when the environment provides more masking than indicated by the line of best fit, and other times when the environment provides less masking.

4. Predict the noise level from the proposed wind farm;

The prediction of noise from a wind farm can be made at any location from a range of available models, and the various Standards and Guidelines provide flexibility with respect to the selection of that model and the assumptions that are made.

In broad terms, the most basic noise models determine the noise level at a location based on the acoustic energy of the noise source, in this case the wind turbine, and the attenuation of noise over distance. These types of noise models do not account for other attenuation factors such as ground absorption, meteorological effects and screening due to ground contours and as such are considered to be inherently conservative (predicting higher noise levels than expected in situ). Basic models are often used by developers to establish a preliminary layout of a wind farm. The more complex and refined models include attenuation due to the factors noted above.

Wind Turbine Sound Power Levels for input to the noise model

The acoustic energy of the noise source is commonly termed the "sound power level", and for wind turbines it is determined in accordance with the International Standard IEC 61400-11 "Wind turbine generator systems – Part 11: Acoustic noise measurement techniques". The sound power level is generally provided for each integer wind speed ranging from the speed that the turbine "cuts in" for operation through to the speed at which it approaches its rated power. The sound power level increases with wind speed and then remains constant or even reduces in higher wind speeds. The sound power level is a constant that does not alter with location for a given wind speed.

The final selection of the wind turbine to be used at a site is typically subject to a competitive tendering process. The tendering process generally occurs in the design and development phase of the project after project approval is granted. This is consistent with a range of other industries and sectors, where plant and equipment contracts are not finalised until after project approval is granted, when all conditions of that approval are known and commitments to outlay significant capital cost can be made.

In addition, lead times between the project approval and procurement stage of a major project can be over a period of years, in which time there may be changes in the turbine models, their available technology and their noise levels. Therefore, it is common practice that noise assessments conducted for the purposes of project approval are made based on representative turbines, rather than a final selection.

The selection of the representative turbines is often made by the proponent or by the proponent in conjunction with an acoustic engineer, to ensure the turbines used are representative of the final turbine selection.

It is in the best interest of a proponent in any major wind farm project to select representative turbines for noise assessment purposes during the project approval stage, as any approval granted is likely to result in conditions and site constraints based on that selection and subsequent assessment. These constraints need to provide sufficient flexibility to invite a range of suppliers to tender for the project as part of a competitive process during the design development and documentation stage of a project.

It is a common arrangement for the wind turbine manufacturer to guarantee a sound power level of a particular make and model of a turbine to a wind farm developer. This guarantee is then confirmed in situ repeating the methodology provided by the International Standard (IEC, 2002).

Attenuation factors for input to the noise model

The attenuation factors are generally chosen to represent the “worst case” situation, such as assuming that the wind is blowing from the turbine to the dwellings or “downwind”, however, there is flexibility in the Standards and Guidelines with respect to the factors used for inputs to the models, provided the rationale for these inputs is included in the assessment. Ultimately, the selection of the model and its input factors must be conservative enough to ensure compliance of the operational wind farm. A requirement to conduct a “compliance checking” procedure is included in the Standards and Guidelines used in Australia.

A typical approach to the modeling process is to conduct initial predictions with a simple model that provides a preliminary estimate of the noise. This assists in confirming the proposed background noise logger locations and the preliminary wind farm layouts. These initial predictions are then refined after the background noise monitoring has been completed with a more complex model. In Australia, this is typically either the CONCAWE or ISO-9613 noise propagation model using conservative assumptions.

Joule (*Reference*) has conducted a study of the accuracy of the ISO-9613 model as it relates to wind farms and found that:

> *The accuracy of output from the ISO model is impressive. Agreement with sound pressure levels measured under conditions of an 8 m/s positive vector wind speed has been measured to within 1.5dB(A) on flat, rolling and complex terrain sites.*

As with any model, the accuracy is subject to its inputs which are summarised in the Joule Paper (Bass et al, 1998*)* and in other summary works (Bowdler et al, 2009). These include the temperature and humidity to be used, how hard or soft the ground should be taken to be, the relative height of the receiver and the amount of "barrier" attenuation that should be applied to the ground contours.

Provided these inputs are applied to the ISO 9613 model, the Joule study found that the calculated sound pressure levels are validated to agree to within 2dB(A) of noise levels measured under practical 'worst case' conditions at distances of up to 1000m from a noise source, and that due to the

> *observed scatter of measured sound pressure levels under these same conditions*, ….. *an 85% level of confidence can be placed on the noise levels measured in practice not exceeding the calculated level by more than 1dB(A).*

A 1 dB(A) difference is negligible in terms of perception.

The ISO 9613 model assumes that a receiver is downwind from all wind turbines. In some circumstances such as where the turbines are on opposite sides of a dwelling but at similar distances this will provide a conservative outcome (a predicted noise level higher than that expected in situ). The Standards and Guidelines used in Australia therefore provide the flexibility to use other models that account for an upwind scenario.

5. Compare the predicted noise levels with the criteria;

A comparison is made between the predicted noise levels and the noise level criteria established by the background noise monitoring regime. This comparison is made for each integer wind speed, generally within the operating range of the wind turbine.

Where the predicted noise levels achieve the criteria, then the process and results are summarised in a report suitable for submission to the relevant authority. The extent of information provided in the reports is summarised in Step 6 below.

Where the predicted noise levels do not achieve the criteria, then mitigation options are considered. The options considered will depend on the number of locations the criteria are exceeded at, the difference between the predicted noise level and the criteria, and the number of integer wind speeds at which the predicted noise level exceeds the criteria. The mitigation options include:

- The operation of wind turbines under reduced noise level modes for particular conditions;
- The consideration of alternative turbines with lower sound power levels;
- The adjustment of the wind turbine layout;
- The consideration of removing turbines from the layout.

An example is provided for a dwelling in a low background noise environment:

- *Due to the background noise levels being low on average at the closest dwelling to the proposed wind farm over the required monitoring period, the baseline noise limit applies at all operating wind speeds. In this example, the dwelling is located in a general farming area and the baseline limit is 40 dB(A);*
- *The highest sound power level from the representative turbine selection occurs at a hub height wind speed of 10m/s;*
- *The predicted noise level at wind speeds of 10m/s or greater is 43 dB(A) at the closest dwelling and therefore exceeds the noise level criterion of 40 dB(A);*
- *The options available to reduce the predicted noise level by 3 dB(A) include:*
    1. *Adjusting the layout of the closest turbines to the dwelling;*
    2. *Operating the closest 4 turbines to the dwelling in a low noise mode at wind speeds of 10m/s or greater. This is only required to occur under downwind conditions (wind from the turbines to the dwelling), as the model shows that under upwind conditions (wind from the dwelling to the turbines) the wind farm complies with the baseline limit, even at full mode operation;*
    3. *Selecting an alternative wind turbine with a lower sound power level.*
    4. *Removing the closest turbine to the dwelling.*
- *Of the above, Option 2 is selected, due to the flexibility it provides in the future competitive tendering process for the final wind turbine selection, and the ability of contemporary turbine control systems to implement an operating strategy where certain turbines can be operated in certain "modes" under specific operating conditions like wind speed and/or wind direction.*

Once the predicted noise levels achieve the environmental noise criteria at each relevant receiver and for each operational wind speed, a summary report is prepared that is suitable for submission to the relevant regulatory authority.

6. Prepare a report suitable for submission to the relevant regulatory authority;

A report is prepared by the developer that summarises the above five steps. In general terms, the report would typically provide the following information, subject to the particular requirements of the regulatory authority assessing the development proposal:

- Background noise measurement locations;
- Time and duration of the background noise monitoring regime;
- Wind speed monitoring locations and heights above ground;
- Graphical correlation plot of the wind speed versus background noise level data;
- A summary of the environmental noise criteria for the project at each integer wind speed based on the correlation;
- The make and model of the representative wind turbine/s;
- The positions of the wind turbines;
- The model used to predict the wind farm noise levels;
- The input assumptions and factors used in the model;
- The predicted noise levels at the closest dwellings to the wind farm at each integer wind speed;
- A comparison of the predicted noise levels against the criterion at each integer wind speed for the closest dwellings to the wind farm;
- The modifications or operating strategy required to ensure compliance with all noise criteria for all wind speeds and at all locations;
- A comparison of the predicted noise levels against the criteria at each integer wind speed for the closest dwellings to the wind farm, showing compliance with the proposed modification or operating strategy in place.

The above six steps provide an overview of the typical assessment methodology. The following information provides frequently asked questions during the preparation and finalisation of such an assessment.

Separation Distances

A common request from the surrounding community is to provide a set separation distance between the wind farm and the nearest dwelling.

Where an objective assessment method is used as outlined above, there is no set distance that could be applied with equity to every wind farm. This is because of the range of factors that affect the predicted and the resultant operational wind farm noise level. These factors include the number of turbines, their locations relative to the dwelling, the sound power level of the turbine, the topography between the turbines and the dwelling, the existing background noise environment at the dwelling and the resultant criteria applied by the relevant Standards and Guidelines.

Separation distances between wind farms and dwellings can be of the order of 800 to 1200m. These separation distances will change according the above factors. The separation distances are related to the stringency of the assessment criteria within the relevant Standards and Guidelines.

Assessment Process

An environmental noise assessment for a wind farm needs to contain significant detail to show compliance with Australian jurisdiction's Standards and Guidelines.

As with all assessments, there might be areas that are contended to be at variance with the requirements of those Standards and Guidelines.

Each State Jurisdiction will have its own specific rules with respect to the ability to appeal in situations where the parties do not agree that the assessment provides the necessary information or where a decision of the relevant regulatory authority is in dispute.

A number of wind farms have been considered in the environmental courts in their relevant jurisdictions, including:

- Taralga Landscape Guardians Inc vs Minister for Planning and RES Southern Cross Pty Ltd, NSW Land and Environment Court Proceedings No. 10196 of 2006;
- RES Southern Cross Pty Ltd v Minister for Planning (DOP) and Taralga Landscape Guardians Incorporated (TLG) NSW Land and Environment Court Proceedings No. 11216 of 2007;
- Epuron Pty Ltd & Gullen Range Wind Farm Pty Ltd & Ors vs Parkesbourne / Mummel Landscape Guardians Incorporated (PMLG), NSW Land & Environment Court Proceedings No. 41288 of 2008.

Judgments made in matters such as these provide important clarification in interpretation of the Standards and Guidelines or their general application and scope. Relevant outcomes from the above judgments include:

- An additional 5 dB(A) penalty for excessive amplitude modulation is not necessary when using the SA 2003 Guidelines. However, the application of acoustic treatment to the facades of dwellings in the vicinity might be a precautionary approach for the established presence of such excessive modulation;

- The heightened sensitivity of an individual to noise should not be taken into account in the assessment of a wind farm, but rather the objective and empirical methods of the relevant Standards and Guidelines adopted by consent authorities and regulators should be relied upon.

The judgment relating to the heightened sensitivity of an individual is important and can be found at Paragraph 154 of the Gullen Range judgment as follows:

> *Inserting subjectivity consent requirements based on an individual's or a group of individuals' reaction to the noise from the wind farm, based on their opposition to the development, is entirely alien to the planning system. Whilst, in some areas such as streetscape impact, individual aesthetic considerations may arise and judgments made upon them, we are unaware of any authority to support the proposition that, where there is a rationally scientifically measurable empirical standard against which any impact can be measured and determined to be acceptable at a particular empirically determined level, that there should be some allowance made for a subjective response to the particular impact.*

Compliance Checking

The assessment process occurs well before a wind farm is operational. Therefore, to confirm compliance with the assessment criteria, a measurement procedure is conducted once the wind farm is operational.

The Standards and Guidelines in Australian jurisdictions all provide a methodology for noise level measurements of an operational wind farm.

The term commonly applied to these measurements is “compliance checking”.

It is common for a planning or relevant regulatory authority to impose a condition of approval for a wind farm development that requires “compliance checking” and reporting thereon within a certain timeframe of commissioning the wind farm.

In general terms, compliance checking can effectively be a repeat of the background noise monitoring regime. The variations that are applied to the compliance checking procedure might include collecting a minimum number of noise level data points under downwind conditions. A comparison is then made of the noise environment before the wind farm and after the establishment and operation of the wind farm.

As wind farm assessments account for the masking effect of the ambient environment, there will be inherent difficulties in identifying the wind farm noise amongst other noise, in particular and most commonly, the background noise generated by wind in the trees. Therefore, compliance checking procedures generally provide a level of flexibility in the methodology, which might include turning the turbines on and off to determine their influence amongst other noise in the environment, or measuring at a location much closer to the wind farm, where the noise from the wind farm is more dominant in comparison to other noise in the environment.

TOPICS OF INTEREST

A range of topics of interest exist for wind farms that are raised by the community, by acoustic engineers, by health professionals, by the industry and by regulatory authorities.

The key topics to be addressed are those that relate to the health of the surrounding community.

There has been extensive research conducted into the relationship between noise levels and characteristics of wind farms and the potential for adverse health impacts, and the research overwhelmingly concludes that wind farm noise does not adversely impact on a person's health.

Health Effects

In 2009 the American and Canadian Wind Energy Associations established a scientific advisory panel comprising medical doctors, audiologists and acoustic professionals from the United States, Canada, Denmark and the United Kingdom to produce "an authoritative reference document for legislators, regulators, and anyone who wants to make sense of the conflicting information about wind turbine sound". (Colby et al, 2009)

The Panel concluded:

> *there is no reason to believe, based on the levels and frequencies of the sounds and the panel's experiences with sound exposures in occupational settings, that the sound from wind turbines could plausibly have direct adverse health consequences.*

The Victorian Department of Health (DH) (WorkSafe, 2010) has examined both the peer-reviewed and validated scientific research and concluded that

> *the weight of evidence indicated that there are no direct health effects from noise (audible and inaudible) at the levels generated by modern wind turbines.*

The Australian Government's National Health and Medical Research Council (NHMRC, 2010) has examined the "evidence from current literature on the issue of wind turbines and potential impacts on human health" and concludes:

> *There are no direct pathological effects from wind farms and that any potential impact on humans can be minimised by following existing planning guidelines (NHMRC, 2010).*

Notwithstanding the above, Dr Nina Pierpont (Pierpont, 2009) contends that adverse health outcomes are caused by wind farm noise and in particular, its low frequency content. Pierpont uses the term "wind farm syndrome" to describe the effects, which include headaches, sleeplessness and anxiety. The Pierpont report is not peer reviewed and the hypothesis is based on the assumption that infrasound levels near wind farms are higher than infrasound levels in the general environment.

The American and Canadian Wind Energy Association's panel reviewed the Pierpont report and the "wind farm syndrome" and concluded:

> *"Wind turbine syndrome," not a recognised medical diagnosis, is essentially reflective of symptoms associated with noise annoyance and is an unnecessary and confusing addition to the vocabulary on noise. This syndrome is not a recognised diagnosis in the medical community. There are no unique symptoms or combinations of symptoms that would lead to a specific pattern of this hypothesized disorder. The collective symptoms in some people are more likely associated with annoyance to low sound levels (Colby et al, 2009).*

To this end, the panel's report provides information on "the complex factors culminating in annoyance", which includes the nocebo effect (Spiegel, 1997).

The nocebo effect is "an adverse outcome, a worsening of mental or physical health, based on fear or belief in adverse effects. This is the opposite of the well known placebo effect, where belief in positive effects on an intervention may produce positive results" (Colby et al, 2009).

With respect to the nocebo effect, the panel concludes:

> *..the large volume of media coverage devoted to alleged adverse health effects of wind turbines understandably creates an anticipatory fear in some that they will experience adverse effects from wind turbines. ….The resulting stress, fear, and hyper vigilance may exacerbate or even create problems which would not otherwise exist. In this way, anti-wind farm activists may be creating with their publicity some of the problems they describe (Colby et al, 2009).*

There is a large amount of publicly available material that deals with alleged adverse health effects of wind turbines regardless of the overwhelming research to the contrary. A recent and relevant example includes an article as part of a series in the Sydney Morning Herald (SMH, 2010) on wind farms which included a quote that linked Hitler's torture methods to noise from a wind farm without any further information regarding the conclusions of recent health related research in the article.

The NHMRC review provides consistent conclusions to the panel with respect to health:

> *It has been suggested that if people are worried about their health they may become anxious, causing stress related illnesses. These are genuine health effects arising from their worry, which arises from the wind turbine, even though the turbine may not objectively be a risk to health (Chapman, 2009)*

Based on the above, it is essential that all stakeholders have access to a source of consolidated information that summarises the topics of interest that are commonly raised and the research that is available on these topics. A broad summary of health effects has been provided above, and the specific topics of interest commonly linked to adverse health effects are addressed in detail below, which include infrasound and low frequency content of a wind farm, amplitude modulation and sleep disturbance effects.

Infrasound and low frequency noise

The hypotheses regarding a link between infrasound from wind farms and the presence of adverse health effects including dizziness, headaches and nausea made by Pierpont (Pierpont, 2009) are not based on measured levels of infrasound from operational wind farms.

Specific International studies that have measured the levels of infrasound in the vicinity of operational wind farms indicate the following:

- The levels of infrasound are significantly below recognised perception thresholds and are therefore not detectable to humans (Hayes McKenzie Partnership Ltd, 2006); and
- The levels of infrasound are of the same order as those measured in residential areas due to general urban activity (Howe, 2006).

Similar studies are currently being conducted in Australia in order to provide an objective assessment and confirmation of the European research.

Notwithstanding the results of the objective assessments, Colby et al, 2009, have critiqued the Pierpont hypotheses and conclude:

> *No foundation has been demonstrated for the new hypothesis that exposure to sub-threshold, low levels of infrasound will lead to vibroacoustic disease. Indeed, human evolution has occurred in the presence of natural infrasound.*

Infrasound is a specific component of low frequency noise that requires a specific measurement methodology to identify it as it is readily affected by wind on the microphone. Wind is a source of natural infrasound.

Whilst the hypotheses regarding adverse health effects often refer to "low frequency noise", this is often a generic description which is taken to include infrasound.

The low frequency content of noise from a wind farm is easily measured and can also be heard and compared against other noise sources in the environment. Low frequency sound produced by wind farms is not unique in overall level or content and it can be easily measured and heard at a range of locations well in excess of that in the vicinity of a wind farm.

Colby et al (2009) notes with respect to low frequency noise:

> *The low frequency sound emitted by spinning wind turbines could possibly be annoying to some when winds are unusually turbulent, but there is no evidence that this level of sound could be harmful to health. If so, city dwelling would be impossible due to the similar levels of ambient sound levels normally present in urban environments.*

Amplitude Modulation

Amplitude modulation is an inherent noise character associated with wind farms. It should be noted that the ambient environment modulates in noise level by a significantly greater margin and over a significantly greater time period than that which would be audible from a wind farm at a typical separation distance. Notwithstanding, the South Australian Guidelines (2003 & 2009) note that the objective standards include a 5 dB(A) penalty for this fundamental and inherent character of amplitude modulation.

A 5 dB(A) penalty is a significant acoustic impost. To reduce a noise source by 5 dB(A) requires either the distance between the source and the receiver to be approximately doubled, or the noise source to reduce its output by two thirds. In wind farm terms, this means the distance between the farm and the nearest dwellings might need to be doubled, or up to two thirds of the total turbine numbers would need to be removed, compared to a wind farm not subject to such a penalty.

The ability to hear the “swish” (amplitude modulation) depends on a range of factors. It will be most prevalent when there is a stable environment (temperature inversion) at the wind farm and the background noise level at the listening location is low. In addition, amplitude modulation is greater when located cross wind from a wind turbine (Olermans and Schepers, 2009). It is noted that whilst the amplitude modulation is greater at a cross wind location, the actual noise level from the wind farm will be lower than at a corresponding downwind location. These conditions are most likely to occur when wind speeds at the wind farm are low under a clear night sky.

The swish is at its greatest under the above conditions as the change in wind speed at increased heights above the ground is also at its greatest, and this results in an increased difference in wind speed as the blades move through the top of their arc and down past the tower. In addition, if there are several turbines subject to similar conditions, then it is possible this can have an amplifying effect on the modulation. The increase in swish under these specific conditions is termed the Van Den Berg Effect, and it is suggested higher levels of swish might result in higher levels of annoyance and potentially sleep disturbance.

The Van Den Berg effect was observed on a flat site in Europe under specific conditions and in the two matters before the NSW Land and Environment Court (Gullen Range wind farm NSW LEC 41288 of 2008 and Taralga wind farm NSW LEC 11216 of 2007), it has been determined by the relevant experts that the required meteorological conditions to trigger the effect were not a feature of the environment. In Gullen Range (NSW LEC 41288 of 2008), the meteorological analysis prepared by Dr Chris Purton concluded that suitable conditions for this effect are not a feature of the area because of the elevated ridgeline location of the wind farm (Purton, evidence NSW LEC 41288 of 2008).

If suitable conditions did exist to regularly generate high levels of swish, then there is no scientific research to indicate that the existing Standards and Guidelines do not adequately account for it. Indeed, given the conditions are more likely to occur at night, then sleep disturbance would be the main issue to address, and the noise standards applied to wind farms are significantly more stringent than limits established for the potential onset of sleep disturbance. This is discussed in further detail in the following section.

In the first draft of the National Wind Farm Development Guidelines (EPHC, 2009), excessive swish is referred to as one of the potential Special Audible Characteristics (or SACs) along with low frequency, infrasound and tonality. It recommends that:

> *With the exception of tonality, the assessment of SACs will not be carried out during the noise impact assessment phase, that is, pre-construction. This arrangement reflects two key issues:*
>
> *i. There are, at present, very few published and scientifically-validated cases of any SACs of wind farm noise emission being problematic at receivers. The extent of reliable published material does not, at this stage, warrant inclusion of SACs other than tonality into the noise impact assessment planning stage.*
>
> *ii. In the case that reliable evidence did demonstrate merit in assessing such factors during the pre-construction phase, there is a gap in currently available techniques for assessing SACs as part of the noise impact assessment. In part this is due to the causes of most SACs in wind turbine noise emission not yet being clearly understood.*

In summary:

- Swish is an inherent noise characteristic of a wind farm;
- Modulation in noise level is a feature of the ambient noise environment surrounding a wind farm;
- The level and depth of swish can vary with meteorological conditions, and under certain conditions, will be more prevalent;
- The conditions to consistently generate high levels of audible swish have not been established to be a typical feature of Australian wind farms;
- The level, depth, time and testing regime for excessive swish that would justify introducing a more stringent standard have not been established;
- Sleep disturbance is the key issue associated with excessive swish, if it is to occur.

Sleep Disturbance

The World Health Organisation (WHO) establish a recommendation of 30 dB(A) inside a bedroom to prevent the potential onset of sleep disturbance effects (WHO, 1995).

The WHO guidelines indicate a noise level of 30 dB(A) inside a typical bedroom correlates to an external noise level with the windows open of the order of 45 dB(A). The typical baseline limit criterion of 35 dB(A) to 40 dB(A) found in Australian wind farm Standards and Guidelines is therefore significantly more stringent than the WHO guidelines recommendation of 45 dB(A), by a margin of at least 5 dB(A) and up to 10 dB(A).

For comparison purposes, a wind farm that complies with a 40 dB(A) baseline limit could introduce twice as many turbines again onto the site, or move of the order of half as close to the nearest dwelling, and still achieve the WHO recommendations to prevent the potential onset of sleep disturbance.

It should also be noted that the WHO recommendations are considered conservative in that they consider all available research and then use the most stringent approach to indicate the “potential onset” of sleep disturbance effects, which is not defined as full awakening, but rather as a change in the stage of sleep.

The UK Department of Trade and Industry (ETSU, 1997) recognise the above effect and recommend increasing the allowable noise level for wind farms during the night period, based on sleep disturbance effects. The baseline limit for wind farms during the night time in the UK is therefore 45 dB(A).

Based on the above, the baseline limits of Standards and Guidelines in Australia are sufficiently stringent to ensure the potential onset of sleep disturbance effects from the operation of a compliant wind farm does not occur.

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