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Environmental Noise Impact Assessment
Glen Innes Wind Farm
Glen Innes Wind Power

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Contents

1. Introduction

This report relates to the proposed development of a wind farm near Glen Innes in northern NSW. The development will consist of the construction and operation of up to 27 wind turbine generators (WTGs), one electrical substation and associated infrastructure including installation of access tracks and underground cables between turbine sites as shown in Figure 1.

An environmental noise assessment has been carried out to determine any potential noise impacts on noise sensitive properties due to the construction and operation of the turbines and any other associated infrastructure. The assessment addresses the matters stipulated by the Director-General of Planning NSW.

A background noise survey was conducted at four residential properties in the vicinity of the development area. The purpose of conducting the noise survey was to determine the existing background noise environment at representative locations surrounding the wind farm. A regression analysis between wind speed and background noise level was carried out in accordance with the required guideline for each residential location to identify the noise level criteria that the wind farm will need to comply with.

Future noise levels resulting from the operation of the wind farm were predicted at each of the receivers using a virtual environmental noise model of the development using the SoundPLAN noise modeling software. The predicted noise contours took into account the ground contours, air and ground absorption, meteorological conditions as well as position of noise sources relative to the receivers.

The assessment has also addressed the potential noise impact of the operating substation as well the noise impacts during the construction phase of the project.

2. Project Overview

A wind farm is an array of wind turbines that uses wind energy in order to generate electricity. The proposed wind farm will consist of up to 27 wind turbines (each having 2 to 3 MW generation capacity) which are to be located along the top of the Waterloo Range, approximately 10 km west of the Glen Innes township in the New South Wales Northern Tablelands (Figure 1). The substation is proposed to be located at the northern end of the array to the east of Wind Turbine 1 and about 500 metres from the Sinclair Lookout, south of the Gwydir Highway.

2.1 Noise receivers

The surrounding area of the proposed wind farm is zoned Rural 1(a) under the Glen Innes Severn Local Environmental Plan (LEP). There are 28 noise sensitive receivers that are within a 3 km radius from the nearest wind turbines. Wind farmer residences refer to properties on which the wind turbiness are to be located. The 28 noise sensitive receivers are shown in Table 1 and on Figure 1.

Building	**Type of receiver** (see also section 3.4)	**Easting**	**Northing**	**Linear distance to nearest WTG (m)**
Balaclava A	surrounding residence	362484	6706451	2905
Elm Vale	surrounding residence	370996	6705255	2871
Eungai	surrounding residence	368903	6703304	1567
Girrahween	surrounding residence	366978	6710689	2074
Glengarry	surrounding residence	369447	6707518	2065
Glengyle	windfarmer residence	364384	6705252	1094
Highfields	surrounding residence	368204	6703334	957
Hillside	vacant windfarmer residence	367316	6704226	786
Ilparran A	surrounding residence	365191	6702621	1540
Ilparran B	vacant surrounding residence	364665	6703476	1349
Kalanga A	surrounding residence	363584	6704532	2161
Kalanga B	surrounding residence	363211	6704876	2310
Kalanga C	vacant surrounding residence	363435	6704417	2349
Klossie	surrounding residence	368815	6700766	2265
Lombardy	surrounding residence	369589	6704005	1920
Matheson Church	community facility	362050	6709530	2877
Mayvona	vacant surrounding residence	368693	6704706	854
Minamurra A	surrounding residence	363787	6703120	2287
Minamurra B	surrounding residence	363900	6703434	2051
Minamurra C	vacant surrounding residence	363576	6703070	2497
Moonarie	surrounding residence	370958	6704744	2988
Nullagai	surrounding residence	369447	6702207	2096
Oakes	surrounding residence	365090	6700966	2514
Rivoli	surrounding residence	363609	6711568	1849
Rose Hill A	windfarmer residence	367786	6709527	2359
Rose Hill B	windfarmer residence	367642	6709213	2069
Wandsworth	surrounding residence	369683	6702942	2260
Wattle Vale	surrounding residence	366037	6711845	1903

Table 1 Noise Receivers with 3 km of the wind turbines

The locations of the wind turbines and the surrounding residences are shown in Figure 1 below. Sinclair Lookout is also shown in Figure 1 to the north west of Turbine no. 1

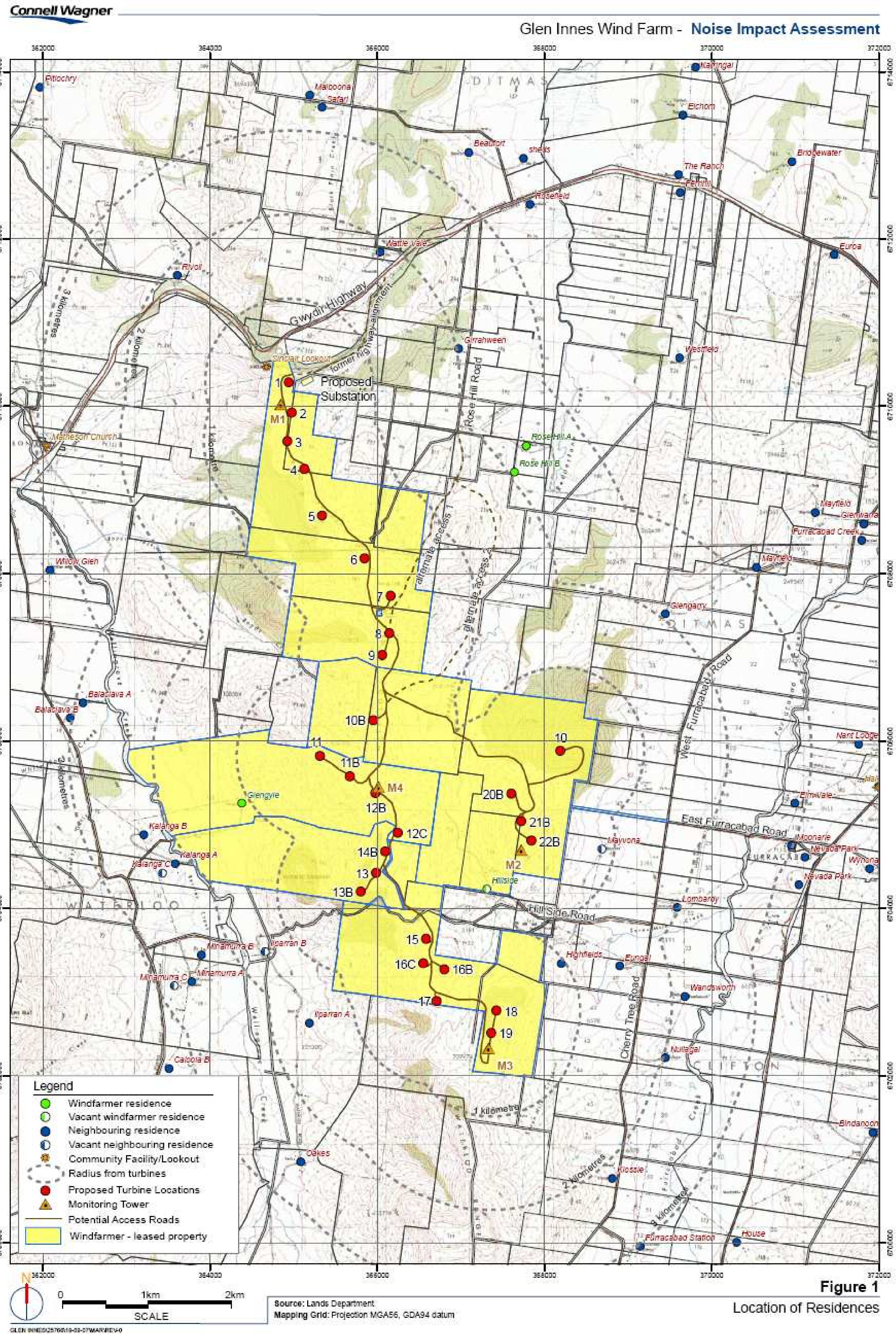


Figure 1 Location of Wind Turbines and Residences

2.2 Wind Turbines

2.2.1 Sources of wind turbine noise

Publications by Lowson [Ref 24] and Grosveld [Ref 25] indicate that there are two main types of sound from a wind turbine, mechanical and aerodynamic. Others such as Hubbard et al [Ref 26] and Wagner et al [Ref 23] provide a review, with Pedersen [Ref 22] and Van den Berg [Ref 21] providing a summary of these issues.

Mechanical noise is mainly generated by the gearbox but also by other parts such as the generator and yaw drives as shown on Figure 2. Since the emitted noise is associated with the rotation of mechanical and electrical components it has tonal and broadband components. Mechanical noise can be efficiently reduced through standard noise control practices such as vibration isolation, damping and noise enclosures.

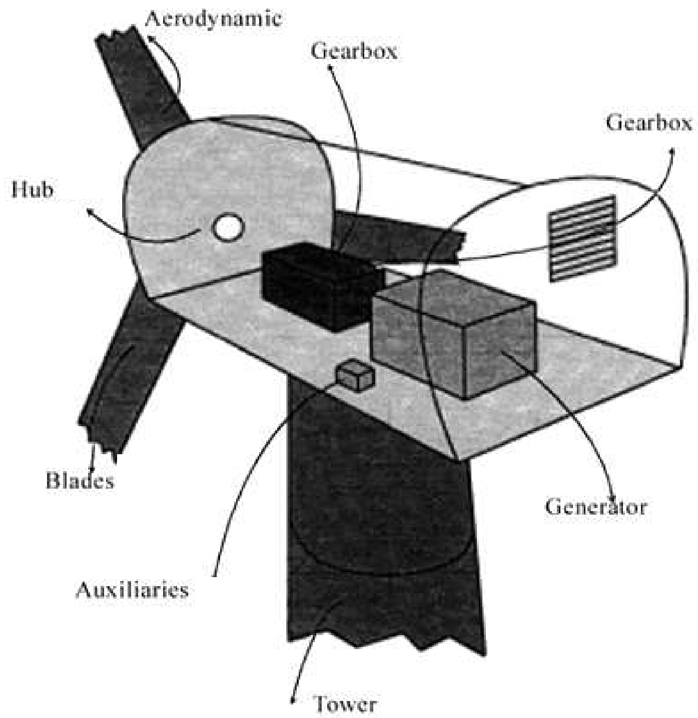


Figure 2 Wind turbine components, Wagner [Ref 23].

Aerodynamic noise originates from the flow of air over the blades and is the dominant component of wind turbine noise. Aerodynamic noise increases with rotor speed and can be considered to consist of the following elements:

- Low Frequency Noise: Generated when the rotating blade encounters localized flow deficiencies due to flow around a tower, change in wind speed or wakes shed from other blades. Tonal, with the frequency related to the blade passing frequency and its harmonics
- Inflow Turbulence Noise: Atmospheric turbulence results in local force or pressure fluctuations around the blade. The maximum level occurs at about 10Hz and decreases at 3-6dB per octave
- Airfoil Self-Noise: Related to the boundary interaction with the blades with tonal noise generated due to vortex shedding (at the training edge or blade irregularities), otherwise broadband due to boundary layer turbulence interaction with the blade trailing edge. Trailing edge noise is the dominant noise from wind turbines

As will be discussed in Section 3.3, Van den Berg [Ref 21] has demonstrated that atmospheric stability has a significant effect on the character of wind turbine noise not only due to the turbulence intensity but also the change in velocity profile. The change in velocity profile causes a change in angle of attack on the turbine blades which increases the thickness of the trailing edge boundary layer and thereby increases noise level, especially when a blade passes the tower. The resulting broadband noise is modulated at the blade passing frequency.

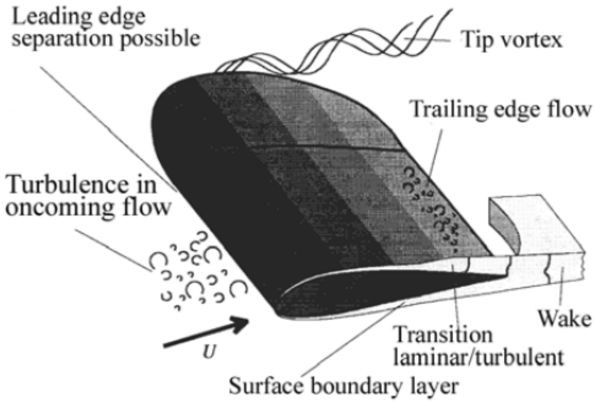


Figure 3 Schematic of flow around a rotor blade, Wagner [Ref 23]

2.2.2 Technical specification

A Vestas V90-3.0 MW turbine has been specified for use in the noise assessment for the wind farm. Its selection is based on it having the highest noise levels of the turbines that are being considered for the wind farm and providing a conservative assessment of impacts relative to the other turbines.

The Danish Vestas V90-3.0 MW wind turbine has high efficiency due to its lightweight construction as well as minimising unwanted power output fluctuations due to variation in the rotor speed using the proprietary OptiSpeed system. The turbine can also be operated in five modes with each mode emitting a different sound power. Key aspects of the manufacturer’s specification for the wind turbine used for this assessment are shown in Table 2a and 2b. The noise curves of the turbine during each operation mode and wind condition along with spectral noise data are shown in Appendix D.

Manufacturer	Vestas
Model	V90 – 3.0 MW
Generator Output	3.0 MW
Number of Blades	3
Diameter	90 m
Hub Height	80 m
Cut-in wind speed	4 m/s
Nominal wind speed	15 m/s
Cut-out wind speed	25 m/s
Nominal revolution speed	16.1 rpm
Operational interval	8.6 – 18.4 rpm

Table 2a Vestas V90 – 3.0 MW wind turbine specification used for this assessment

Wind speed at hub height m/s	Sound Power Levels dB(A) for various operating modes and wind speeds (80m hub height)				
	Mode 0	Mode 1	Mode 2	Mode 3	Mode 4
5.6	97	97	97	97	97
7.0	102	102	102	102	102
8.4	105.8	105.8	105.6	104.4	102.8
9.8	108.2	107.7	106.8	104.4	102.8
11.2	109.3	107.8	106.8	104.4	102.8
12.6	109.4	107.8	106.8	104.4	102.8
14.0	106.7	106.7	106.8	104.4	102.8
15.3	105.9	105.9	105.9	104.9	102.8
16.7	105.7	105.7	105.7	105.7	105
18.1	105.7	105.7	105.7	105.7	105.7
Note: Summarised from Vestas V90-3MW noise data provided in Appendix D					

Table 2b Vestas V90 – 3.0 MW wind turbine summary of sound power levels in various operating modes

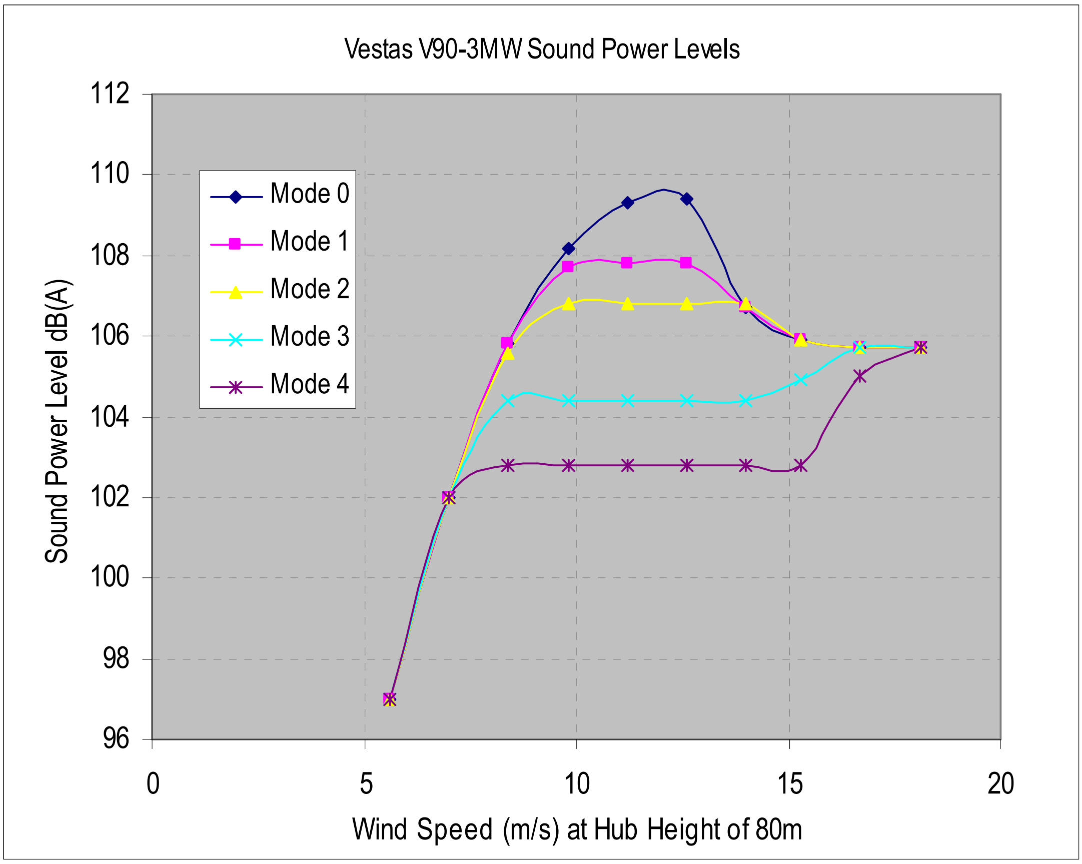


Figure 4 Vestas V90-3MW turbine sound power levels for various operating modes.

2.2.3 Turbine locations

The 27 wind turbine sites are located along the Waterloo Range. Their position relative to the noise receivers is shown in Figure 1 while Table 3 below outlines the exact coordinates of each wind turbine.

Turbine	Easting (MGA56)	Northing (MGA56)	Base Elevation (m)	80 m Hub Height (m)
1	364943	6710288	1177	1257
M1	364842	6710022	1183	1263
2	364981	6709924	1176	1256
3	364926	6709583	1175	1255
4	365131	6709251	1169	1249
5	365343	6708692	1166	1246
6	365850	6708179	1194	1274
7	366162	6707735	1217	1297
8	366146	6707285	1205	1285
9	366063	6707025	1217	1297
10	368193	6705878	1237	1317
10B	365955	6706247	1165	1245
11	365319	6705820	1166	1246
11B	365675	6705575	1180	1260
12B	365980	6705375	1195	1275
12C	366250	6704900	1194	1274
13	365988	6704420	1207	1287
13B	365804	6704198	1183	1263
14B	366100	6704675	1201	1281
15	366585	6703630	1214	1294
16B	366805	6703267	1251	1331
16C	366555	6703337	1245	1325
17	366712	6702887	1209	1289
18	367429	6702773	1261	1341
19	367367	6702507	1265	1345
M3	367325	670234	1268	1348
20B	367605	6705367	1225	1305
21B	367725	6705037	1234	1314
22B	367845	6704807	1235	1315
M2	367716	6704693	1245	1325
Note: - While all 27 sites have been included in the assessment not all of them may be developed - Coordinates are for Map Grid of Australia (MGA) Zone 56 - M1, M2 and M3 are the proponents met masts				

Table 3 Wind turbine locations

2.2.4 Transformer sound power levels

Australian Standard AS 2374.6 - 1994 relating to transformer sound power levels and includes an appendix providing a guide to sound power levels over the range of transformer power ratings. Reference to Figure AA1 of the Standard indicates that a transformer of 85 MVA could have a sound power level in the range of 92 to 101 dB(A). Advice from a senior transmission engineer indicates that modern transformers are being designed to have lower noise levels than earlier models however the actual transformer noise level specification can vary with the sensitivity of the location.

The noise emitted by transformers increases with the load. The load for the wind farm transformer will relate to the wind farm performance and will be greatest at the times of strong winds when background noise is also high. the location of Sinclair Lookout on the ridgeline is in an exposed position where the background noise is likely to mask the transformer noise from the substation site about 500 metres away.

3. Noise Criteria and Directive

3.1 Environmental assessment directive

The Director-General of the NSW Department of Planning set-out a list of requirements for the Environmental Assessment (1/5/07) including those relating to noise impacts as follows:

"The Environmental Assessment must include a comprehensive assessment of the predicted noise impacts resulting from the construction and operation of the proposal.

The assessment must include consideration of noise impacts of the project, with a particular focus on scenarios under which meteorological conditions characteristic of the locality may exacerbate impacts (such as the van den Berg effect for wind turbines) at sensitive receivers. The probability of such occurrences must be quantified.

If any noise agreements with residents are proposed for areas where noise criteria cannot be met, sufficient information must be provided to enable a clear understanding of what has been agreed and what criteria have been used to frame any such agreements.

The noise assessment must be undertaken in accordance with:

- *Wind Turbines - The South Australian Environment Protection Authority's Wind Farms - Environmental Noise Guidelines, 2003*
- *Remaining Structures - In accordance with the NSW EPA Industrial Noise Policy, January 2000*
- *Construction noise - undertaken in accordance with Chapter 171 of the Environmental Noise Control Manual (EPA, 2004) for noise impacts associated with the proposal, particularly along the main access routes to the site*

The Environmental Assessment must clearly outline:

- *The noise mitigation*
- *Monitoring*
- *Management measures the Proponent intends to apply to the project*

This must include an assessment of the feasibility, effectiveness and reliability of proposed measures and any residual impacts after these measures have been implemented."

3.2 Overview of wind farm noise assessment approaches

The South Australian EPA "Wind Farm Noise Guidelines" (2003) [Ref 5] was based on the New Zealand Standard NZS 6808-1998 "Acoustics-The Assessment and Measurement of Sound from Wind Turbine Generators" [Ref 15] which in turn was based on the report ETSU-97-R "The Assessment and Rating of Noise from Wind Farms" by the United Kingdom's Energy Technology Support Unit.

Both the SA EPA guideline and NZS 6808 have been used in New South Wales and South Australia. Victoria and Tasmania require compliance with the New Zealand Standard. Queensland has used NZS6808 while Western Australia and the Northern Territory have used the SA EPA guideline without formal requirements in place by any authority.

The New Zealand Wind Energy Association (NZWEA) and Energy Efficiency and Conservation Authority (EECA) jointly commissioned an unofficial review of NZS6808 with the following outcomes that differ from the SA EPA guideline:

- In cases where the distance between turbines and receivers are significant and have significant terrain features, the ISO9613 model produces more accurate results (compared to Concawe or simple prediction methods)
- Any revised version of NZS6808 should avoid under-prediction of WTG sound levels by utilising wind speed data collected at the expected hub height of the proposed WTG or correctly adjusted with site specific wind shear to reflect hub height wind speed
- Assessment criteria are based on the predicted L_{A90} noise level being no more than 40 dBA, which is equivalent to an L_{Aeq} of 42.5 dBA and an L_{A10} of 45 dBA. At night-time, with an allowance of 10 dBA for transmission loss through a partially open window, these levels are equivalent to L_{A90}, L_{Aeq}, and L_{A10} respectively of 30 dBA, 32.5 dBA and 35 dBA for an indoor environment

An Australian Standard DR 07153 CP “Acoustics-Measurement, prediction and assessment of noise from wind turbine generators” [Ref 17], based on NZS6808 has been in preparation over the past few years. The following important requirements of this draft standard that differ from the SA EPA guideline are:

- All sound power level and background noise data shall be referenced to the hub height wind speed of the proposed WTG
- At each nominal wind speed, the noise limit should be the higher of:
  - Minimum noise level limit
  - Background noise levels plus the specified amount
- Should special audible characteristics not usual to a correctly functioning wind turbine such as tonality be present it is recommended that the predicted noise levels from the WTG or wind farm be adjusted by adding a penalty to the predicted level to take into account the adverse subjective response likely to be generated by the characteristic
- Tonality can be objectively determined by the methodology contained in IEC 61400-11 or other methods such as ISO 1996-2

3.3 Van den Berg Effect

While assessing complaints of noise from wind turbines, Van den Berg [Ref 7] originally demonstrated the well known fact in meteorology (and in particular atmospheric boundary layer physics that effects many disciplines) that wind profiles change significantly with atmospheric stability. This is shown below in Figure 5, with the exponent of a logarithmic or power law expression for the velocity modified under differing stability conditions (see for example Irwin [Ref 29]). Prior to this work the wind profile had been assumed to be constant for varying meteorological conditions when considered in environmental noise assessments. It is apparent from Figure 5 that low ground level wind speeds and therefore low background noise levels can correlate with high upper level wind speeds under stable conditions, and therefore potential exceedance of noise criteria derived from background noise levels correlated to ground level wind speeds.

In Australia and New Zealand there remains misunderstanding as to how van den Berg’s effect can be incorporated into noise assessments with commentary and draft standards suggesting assessments of noise levels relative to hub height wind speeds will resolve the issue. It is demonstrated in this report (section 4.3) that a proper account also requires definition of hub height wind speeds relative to stability.

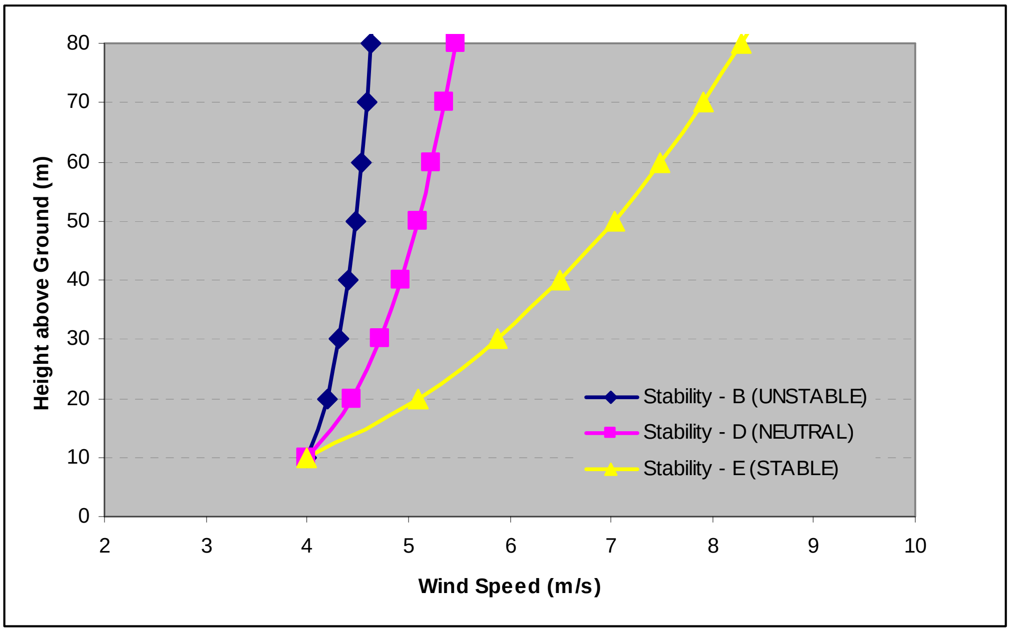


Figure 5 Wind speed profile variation with stability

3.4 South Australian EPA Wind Farm Noise Guidelines

The noise guidelines followed in this study are the ones developed by the South Australian Environmental Protection Authority: "Wind Farms - Environmental Noise Guidelines". This document details the procedure for measuring background noise and wind speeds, predicting noise levels, analysing results and checking compliance.

The noise criteria set out for new wind farm development is as follows:

The ambient noise level ($L_{Aeq,10}$) measured in accordance with the SA EPA Guideline and determined by the associated regression analysis procedure adjusted for tonality in accordance with the Guidelines, should not exceed:

- *35 dB(A), or*
- *The pre-existing background noise level ($LA_{90,10}$) by more than 5 dB(A)*

whichever is greater, at all relevant receivers for each integer wind speed from cut-in to rated power of the wind turbine generator

The above-mentioned criteria have been developed to minimise impact on 'relevant' premises that **do not** have an agreement with the wind farm developer as indicated below.

Relevance of SA EPA Guideline for setting criterion	Terminology	Relationship of land on which the residence is located to the wind farm project
relevant	non wind farmer	The landowner is unconnected with the wind farm project
non-relevant	wind farmer	Landowner has entered into lease with the wind farm proponent for the wind farm operation and is a beneficiary of the project

Table 4 SA EPA Guideline terminology

This clause however does not absolve the developer from their obligation to minimise *"adverse effect on an amenity value of an area"* due to entering into an agreement with a land owner.

The background noise should be as determined by the collection and regression analysis procedure outlined in the SA EPA Wind Farm Guidelines. The collection of noise data should be carried out within 20 meters of noise sensitive dwellings, with data being collected at 10 minute intervals so that it can be correlated with wind speed at 10 meters above ground level at the wind farm site. A minimum of 2000 valid points of wind and noise data have to be correlated to create the regression curve. Data points which are below the cut-in wind speed of the WTG, rain effected noise measurements and noise measurements where it is obvious that an abnormal high noise activity has taken place, eg human intervention of noise logger are excluded from the analysis.

The following important issues are to be noted:

- The guideline gives no consideration to the effect of atmospheric stability which has been accounted for in this study (to some degree as will be shown later) by referencing background noise and emitted sound power levels to WTG hub height
- The guideline requires all wind speeds to be expressed at 10m above ground level

3.5 NSW EPA Industrial Noise Policy

NSW Industrial Noise Policy [Ref 3] deals with noise emitted from industrial sites however it does not apply to wind turbines. It has been used to assess noise emitted from all other infrastructure associated with the wind farm. The only other noise source associated with the operating wind farm that warrants assessment is the transformer located at the substation. Intrusiveness and amenity criteria are determined based on type of receiver and existing ambient and background noise environment. The **intrusiveness criterion** is based on the existing background noise and is summarised by the following equation:

$$L_{Aeq,\ 15\ minute} \leq \textit{rating background level} + 5\ dB$$

Note: Rating Background Level (RBL) being defined as the median value of the Assessment Background Level (ABL) for that time period. ABL is a single figure for each time period, it is the tenth percentile of the measured $L_{A90,\ 15\ minute}$ for the assessment period.

The **amenity criterion** is based on the ambient noise level of the receiver. Recommended noise levels from industrial noise sources for the type of receivers encounter during this assessment are shown in Table 5 below.

Type of Receiver	Indicative Noise Amenity Area	Time of Day	Recommended L_{Aeq} Noise Level (dBA)	
			Acceptable	Recommended Maximum
Residence	Rural	Day	50	55
		Evening	45	50
		Night	40	45
Place of worship – internal	All	When in use	40	45
Area specifically reserved for passive recreation	All	When in use	50	55

Table 5 Recommended Noise Levels from Industrial Sources

The Acceptable Noise Level (ANL) from Table 5 is compared to the ambient noise level from which amenity criterion is determined by set of conditions outlined in the Industrial Noise Policy.

The design criterion is taken to be the lower of the intrusive criterion and amenity criterion

Times of day are defined as: Day – 7:00 to 18:00; Evening – 18:00 to 22:00; Night – 22:00 to 7:00.

3.6 WHO Guidelines for community noise

The above described guidelines correspond to the residential properties that are not classified as wind farm residences. In the case of wind farm residences where noise criteria may be exceeded, the proponent is able to enter into an agreement with the landowner to provide for 'reasonable' exceedance of noise criteria. In reaching the agreement, the proponent must clearly outline to the landowner the expected impact of the noise from the wind farm and its effect upon the landowner's amenity.

In determining 'reasonable' noise impact for wind farm residences, the World Health Organisation (WHO) [Ref 8] noise amenity guidelines are deemed applicable. The related criteria are shown in Table 6.

Specific Environment		Critical health effect(s)	$L_{Aeq,}$ (dBA)	Time base (hours)	$L_{Amax,f}$ (dB)
Outdoor living area		Serious annoyance, daytime and evening	55	16	-
		Moderate annoyance, daytime and evening	50	16	-
Dwelling	Indoors	Speech intelligibility and moderate annoyance, daytime and evening	35	16	-
	Inside bedrooms	Sleep disturbance, night-time	30	8	45
Outside bedrooms (with window open)		Sleep disturbance, night-time	45	8	60

Table 6 WHO Guidelines for community noise in specific environments

3.7 Construction noise

Construction noise is excluded from the NSW DECC's Industrial Noise Policy. The criteria are outlined in the DECC's "Environmental Noise Control Manual" [Ref 4]. Variation to the criteria outlined in this manual can be made to take into account long term construction projects (>26 weeks) along with local conditions. Basic level restrictions are outlined as follows:

- Construction period of 4 weeks or under
  $L_{10,\ 15\ minutes}$ *(when the construction site operational)* < $L_{90,\ 15\ minutes}$ *+20 dBA*
- Construction period of longer than 4 weeks and not exceeding 26 weeks
  $L_{10,\ 15\ minutes}$ *(when the construction site operational)* < $L_{90,\ 15\ minutes}$ *+10 dBA*
- Construction period of exceeding 26 weeks
  $L_{10,\ 15\ minutes}$ *(when the construction site operational)* < $L_{90,\ 15\ minutes}$ *+5 dBA*

It is noted that the application of these time frames can be logically applied to a specific site where the impacted community stays the same during the period of construction. In the case of the wind farm, the construction works will progress across a site spanning some 8.5 km of the Waterloo Range and noise impacts at any specific location are likely to occur over a period much shorter than the full construction period for the wind farm.

3.8 Blasting Noise and Vibration Criteria

Blasting activities could potentially be used during the construction process should follow the ANZECC guidelines [Ref 6] as recommended by the NSW EPA. These have been developed to prevent damage from ground vibration along with minimising annoyance and discomfort of the local residents. The criteria are summarised below:

Blasting Noise Criteria

- Airblast overpressure must not be more than 115 dB (linear) peak for 95% of total blasts initiated in a 12 month period (regardless of the interval between blasts)
- Airblast overpressure must not exceed 120 dB (linear) peak at any time

Blasting Vibration Criteria

- Ground-borne vibration must not exceed peak particle velocity (PPV) of 5 mm/s for 95% of total blasts initiated in a 12 month period (regardless of the interval between blasts)
- Ground-borne vibration must not exceed PPV of 10 mm/s for any blast

4. Assessment Methodology

4.1 Overview of assessment methodology

In simple terms, the assessment aims to fulfil the following objectives:

Objective 1 – Define the ambient noise environment and noise control criteria through:

- Monitoring of the ambient noise environment at representative sensitive receiver locations surrounding the wind farm and its relation to wind speed measured at turbine sites (Section 5)
- Development of acceptable noise level thresholds for the various impacts at sensitive receiver locations. This broadly relates the thresholds to the measured ambient levels. (Section 7)

These aspects are described in Sections 5 and 7

Objective 2 – Identify the characteristics of likely noise sources through:

- Identification of the characteristics of the noise sources for the project components under various circumstances where the sources include:
  - The wind turbines under various operating conditions including a range of wind speeds (see Appendix E and Section 2.2.2)
  - The key substation items being the main transformer(s) (Section 9.2)
  - Construction plant and activities (Section 9.3)

Objective 3 – Provide reliable predicted noise levels for sensitive receivers through:

- Use of modelling that is able to realistically extrapolate the noise source impacts to the various sensitive receivers. The modelling process needs to take into account a range of factors affecting noise propagation such that predictions are realistic under a range of atmospheric conditions and due to the complexity of contributory factors to ideally incorporate a degree of conservatism. Factors affecting noise propagation are further discussed in Sections 6 and 8 and noise modelling and the results are discussed in Section 9

Objective 4 – Identify potential mitigation, monitoring and management options for potential impacts.

4.2 Elements of the assessment

The following elements were undertaken as part of this noise assessment:

- Ambient noise monitoring was undertaken at four representative noise receivers. This required establishing noise loggers to monitor noise levels every 10 minutes synchronised to wind speed measurements at hub height. Weather data (rainfall, temperature, local wind speed) was also measured and used to correct the noise data in accordance with the SA EPA guideline.
- Acquire wind speed, direction and standard deviation of wind direction from the hub height mast and use this to determine atmospheric stability in accordance with the US EPA's methods
- Regression analyses were undertaken to determine the noise criterion curves at representative receiver locations referenced to hub height wind speed rather than 10 metre height.
- TAPM was used to estimate meteorological data throughout the entire year using synoptic data. It has been shown through verification studies that this method provides accurate predictions of weather parameters.
- Sound power data in third-octave bands was obtained for a wind turbine that could potentially be used at the site and which had the highest noise level of the turbines under consideration
- Modelling was undertaken using SoundPLAN noise model software and prediction methods therein, together with analysed meteorological data, terrain data and turbine sound power levels to predict noise levels at all receivers

- Predicted noise levels at integer speeds were reviewed against criterion curves as required by the SA EPA Guideline and in addition for specific stability classes
- Where potential exceedances were indicated, options for achieving compliance, if required, by varying the turbine operating mode were identified

4.3 Matters affecting assessment of wind turbines

For the assessment of the impacts from the operating wind turbines, the EA Directive requires the use of the SA EPA guidelines. The EA directive also requires consideration of meteorological conditions characteristic of the locality, such as the Van den Berg effect [Ref 7], that may at times exacerbate wind turbine impacts at sensitive receiver sites. Van den Berg noted the importance of atmospheric stability on wind noise given changes in the vertical profiles of wind speed and turbulence intensity.

The Van den Berg effect has been recognised recently by the Environment Courts in New South Wales, Victoria, and New Zealand. A review [Ref 16] of NZS 6808 [Ref 15] (used in Victoria), and the SA EPA Guidelines [Ref 5] (used recently in South Australia and New South Wales) has been used in the preparation of draft Australian Standard DR 07153 CP [Ref 17] which acknowledges the work of Van den Berg with regards to the effects of stability but assumes that an assessment relative to the wind turbine's hub height will resolve this issue (as also noted by van den Berg [Ref 21]). On the contrary, and as evidenced in this report, reference to hub height alone, without accounting for stability, does not provide a reliable prediction of noise impacts in all circumstances. The need to consider both aspects is explained further with reference to typical example below.

It is most common to determine the assessment criterion based on the 10 m AGL (above ground level) wind speed. The standard criterion curve of background noise relative to 10 m AGL integer wind speeds is shown on Figure 6. Background noise levels, when referenced to ground level wind speeds, will always have the same mean curve, but the variation about the mean will depend on stability. This is because the level of turbulence (or turbulence intensity) increases with growing unstable conditions.

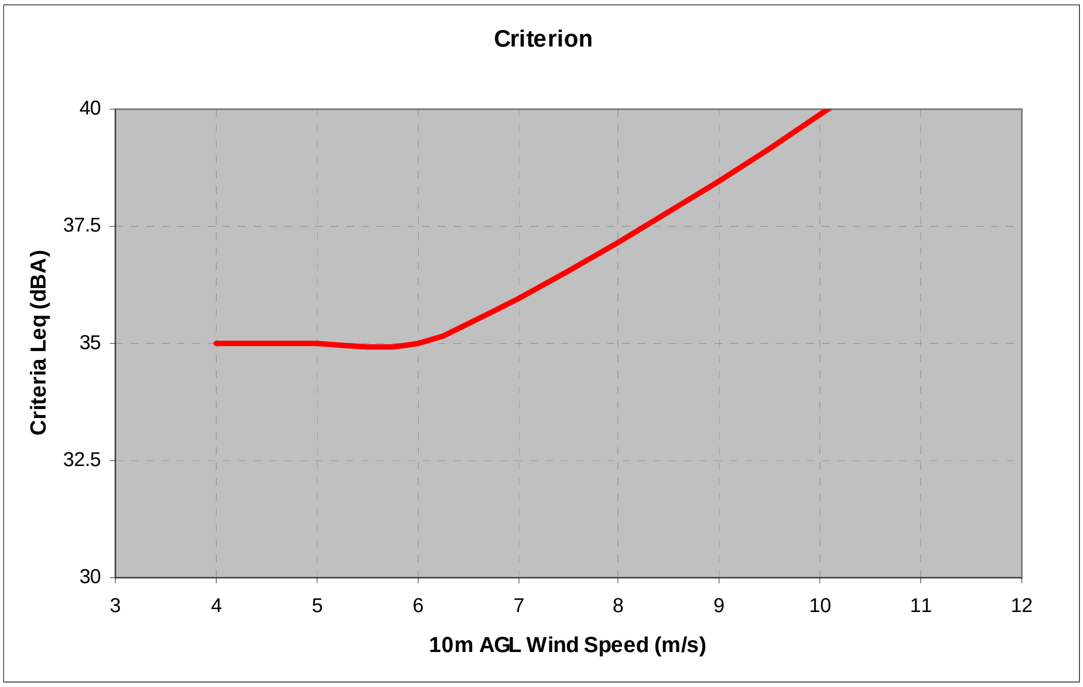


Figure 6 Noise criterion curve versus 10 m level wind speed based on background noise measurements

The Van den Berg effect (as discussed in Section 3.3), describes the change in velocity profile with stability class, as shown in Figure 7**Error! Reference source not found.**. This example shows that for a 12 m/s hub height wind speed and the applicable wind speed profile depending on the atmospheric stability condition at the time, then the 10 m AGL wind speeds vary as follows:

- Stability B (unstable) - 10 m/s
- Stability D (neutral) - 9 m/s
- Stability E (stable) - 6 m/s

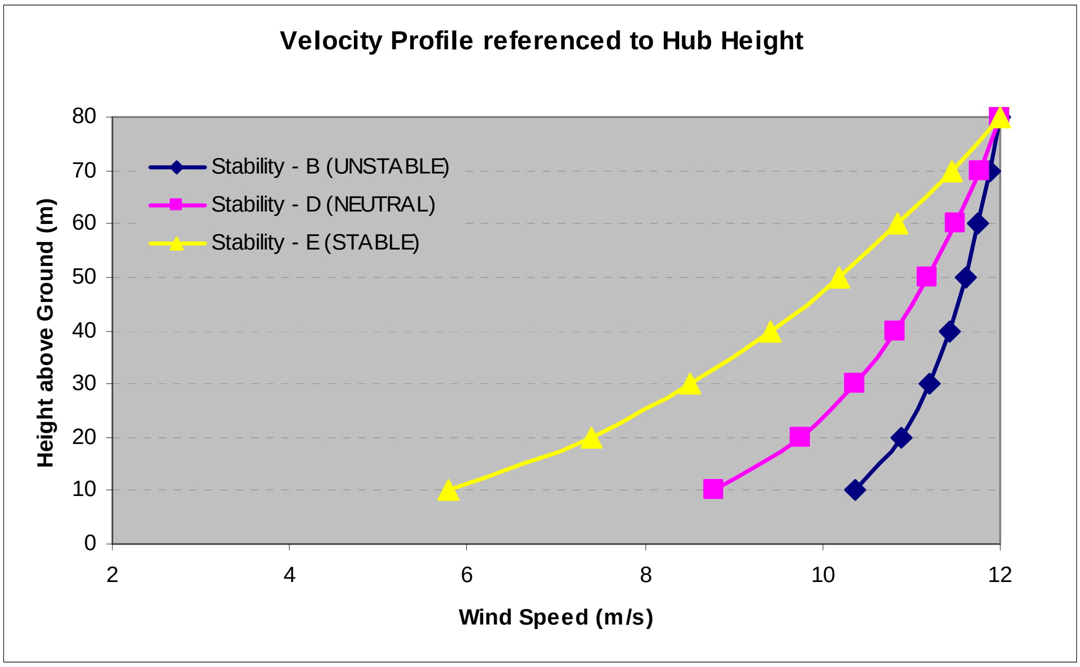


Figure 7 Velocity profile referenced to hub height

Criterion curves when referenced to hub height wind speeds can be derived from the above two data sets. That is, continuing the example, 10 m level wind speeds of about 10 m/s (unstable), 9 m/s (neutral) and 6 m/s (stable) will correspond to criteria of about 40 dBA, 38 dBA and 35 dBA respectively. The criterion curves can then be developed for each integer hub height wind speed using this approach, and these are shown in Figure 8.

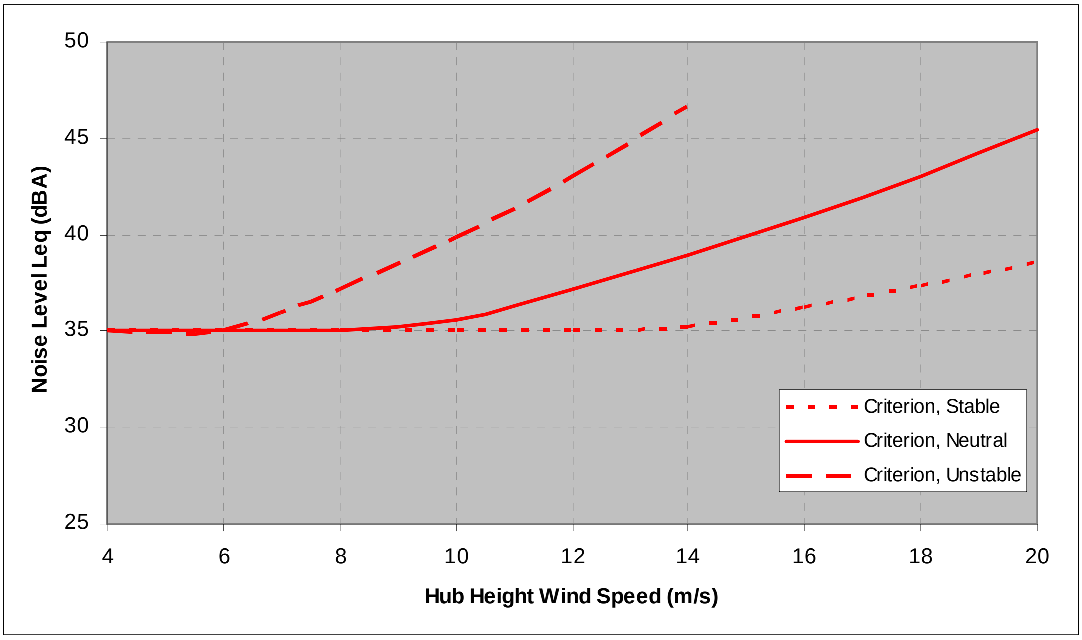
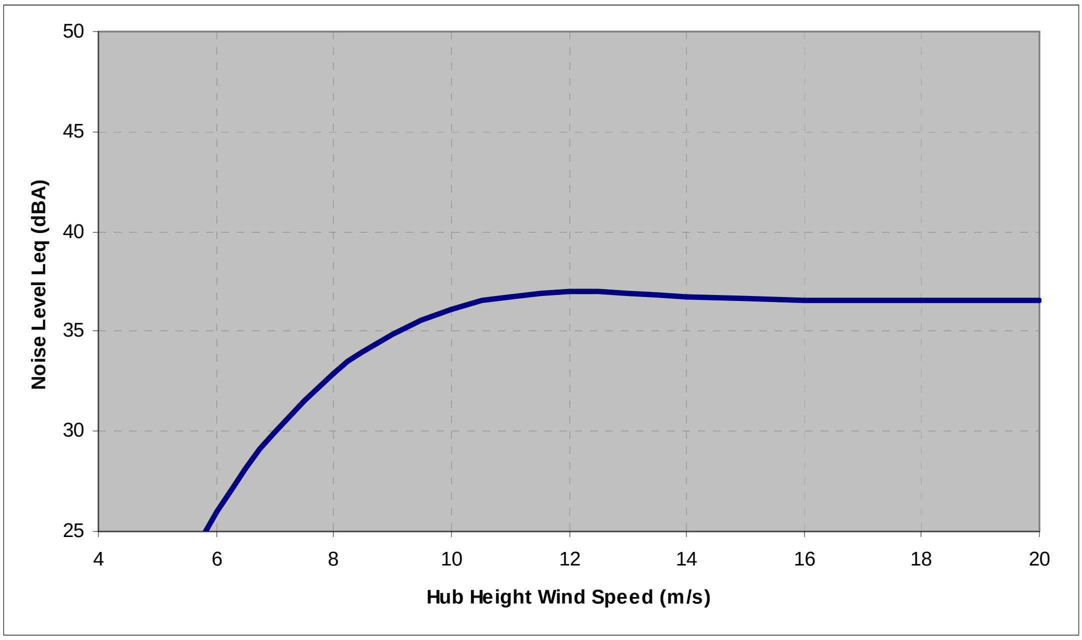


Figure 8 Criterion curves for different atmospheric stabilities relative to hub height wind speeds

Figure 9 shows an example of a predicted turbine noise level at an arbitrary receiver relative to hub height wind speed. It should be noted that this is a simplified case, considering only dispersion with distance (ie. it ignores meteorological, shielding and ground absorption effects associated with noise propagation which are considered in the manner as discussed in Section 8).



Note: Predicted noise levels ignore meteorological, shielding and ground absorption effects associated with noise propagation which are considered in the manner as discussed in Section 8)

Figure 9 Wind turbine noise levels at an arbitrary receiver relative to hub height wind speeds

In summary, the criterion curves change with stability class, while the turbine noise level profile is unchanged with stability class. The combined curves are shown in Figure 10 and demonstrate that without considering stability (usually neutral conditions prevail), wind turbine noise levels comply with the criterion curve. In contrast, under stable conditions the criterion curve is exceeded by about 3 dBA in the example shown in Figure 10. Under unstable conditions noise from wind turbines will not exceed the criterion curve.

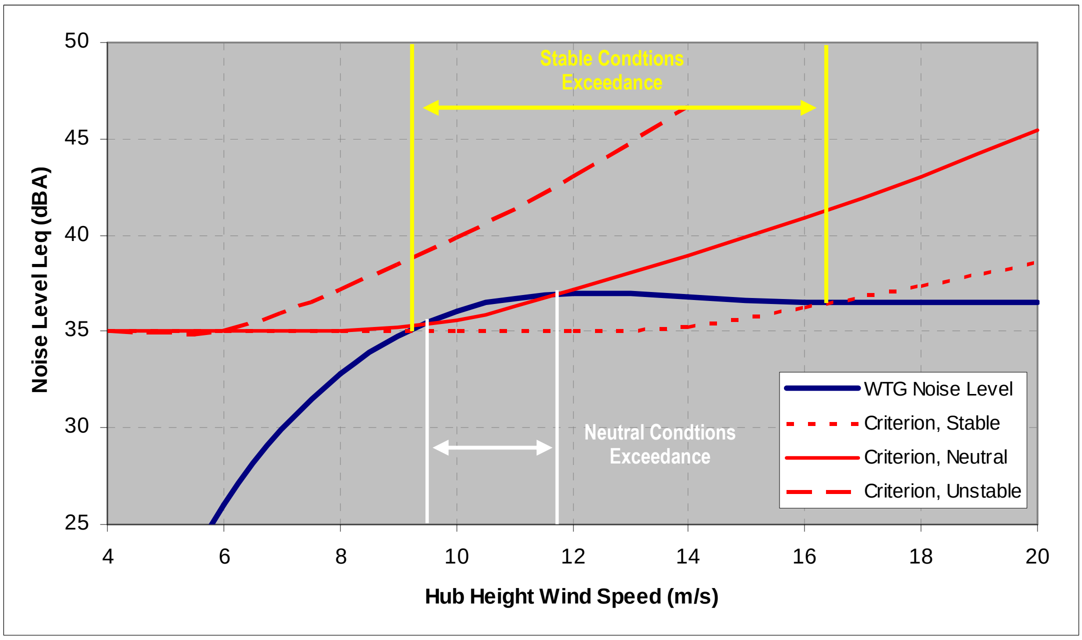


Figure 10 WTG noise assessment during various stabilities

As a result of this understanding, the approach used in this assessment references noise levels to wind speeds measured at hub height and also takes into account atmospheric stability when considering criterion curves. Atmospheric stability was included in the assessment as follows:

- Short Term : For the regression analysis of background noise levels referenced to hub height wind speeds have been classified by determining stability class from the standard deviation of the change in wind direction as measured at 80 m for the proponent's reference mast location. It is noted that limited background noise level data is available at the higher wind speeds for the more stable conditions due to these conditions being less frequent (Refer to Section 6.4).

- Long Term : The effect of atmospheric stability on velocity profile has been well known in the field of air quality dispersion modelling with Australian models such as AusPlume and TAPM having been developed by the Victorian EPA and the CSIRO respectively. These models use meteorological data either from the Bureau of Meteorology's weather stations or predicted from synoptic weather data. Predicted stability categories were used from these models in preference to analysis of weather station data from the BOM as it is often very difficult to obtain reliable data from the BOM, given stability is usually determined from cloud cover and ceiling height therefore requiring observations and most standard weather stations are unattended (other methods to determine stability require measurements of temperature and insolation which are also not usually included in standard weather stations). The approach used herein was to predict weather for an entire year (in this case 2001 was considered to be a representative year) and from this determine stability class throughout the year. The variation of hub height wind speeds with stability could then be determined. Refer to Section 6 for results of this analysis.

5. Background Noise and Meteorological Survey

5.1 Noise and weather monitoring locations

Continuous monitoring of existing background noise was conducted from the 24 May 2007 to 19 June 2007 at four residential locations. The chosen residence locations and number of usable data points collected were:

- Rose Hill B - 3,012 noise measurements
- Glengyle - 3,135 noise measurements
- Highfields - 3,005 noise measurements
- Eungai - 3,128 noise measurements

The monitoring sites were selected as the closest occupied residences to the turbine sites and are considered as representative of the range of receiver locations surrounding the wind farm. They are also potentially the worst case existing sensitive noise receivers at various positions relative to the array of the WTG. The positions of the residences are highlighted in Figure 11 below. All the noise monitoring residential properties are within about 2 km radius from the nearest proposed turbine site.

ARL EL-316 Type 1 Noise Loggers were used to collect the noise data with noise levels recorded in 10 minute intervals using an "A" frequency weighting and a "Fast" response time. The noise floor of each of the instruments was limited to 25 – 27 dBA. Whilst instruments with a lower noise floor would have been desirable, the SA EPA Guidelines only specify that noise monitoring equipment be of at least Type 2 certification. Also, given the criterion is limited to no less than 35 dBA and that the instrument noise floor was 10 dBA less than this, the noise floor is not considered to have significantly affected the analysis used to determine acceptable criteria for receiver locations.

Three weather station units were installed at three residential locations adjacent the noise logging equipment, Rose Hill, Glengyle and Eungai, in order to acquire weather data such as wind speed, wind direction, rainfall, relative humidity, solar radiation. As Eungai and Highfields are very close it was not necessary to install a second weather station at Highfields. Out of the aforementioned acquired data, wind speed and rainfall are of high importance. As per the SA EPA Guidelines rain periods can adversely affect the collected data; therefore data which corresponds to rainfall periods should not be used for the analysis.

An Environdata Mark4 weather station was installed at Rose Hill residential property. It was mounted on a 10 m high mast which enabled collecting the wind speed and wind direction data at the height of 10 m above ground level. The two other weather stations were Environdata WeatherMaster 2000 models which collected wind speed and wind direction data at 1.5 m above ground level. Like the noise data recording interval all the weather data was also recorded at 10 minute intervals in order to correlate weather data with the background noise level data and the 80 m met mast data.

During some periods of the survey, a malfunction of the weather stations occurred, creating a gap in the collected weather data. The missing information is supplemented by BOM data collected at Glen Innes [Ref 12] during this period. If significant rainfall occurred on a certain date that whole days worth of noise measurements was excluded due to the unknown times of the rainfall occurring at each site. Despite the deletion of unsuitable data, over 3,000 usable measurements of background noise levels were obtained at each monitoring location which significantly exceeds the 2,000 data points required by the SA EPA Guidelines.

Wind speed data at the wind turbine site locations were obtained from the proponent's wind monitoring masts located along the Waterloo Range. Data was collected at 10 minute intervals at the hub height (80 m) of the WTG.
The pictures showing the noise and weather monitoring units at each residential location are included in Appendix B. Figure 11 shows the location of noise logging position as well as the wind monitoring masts.

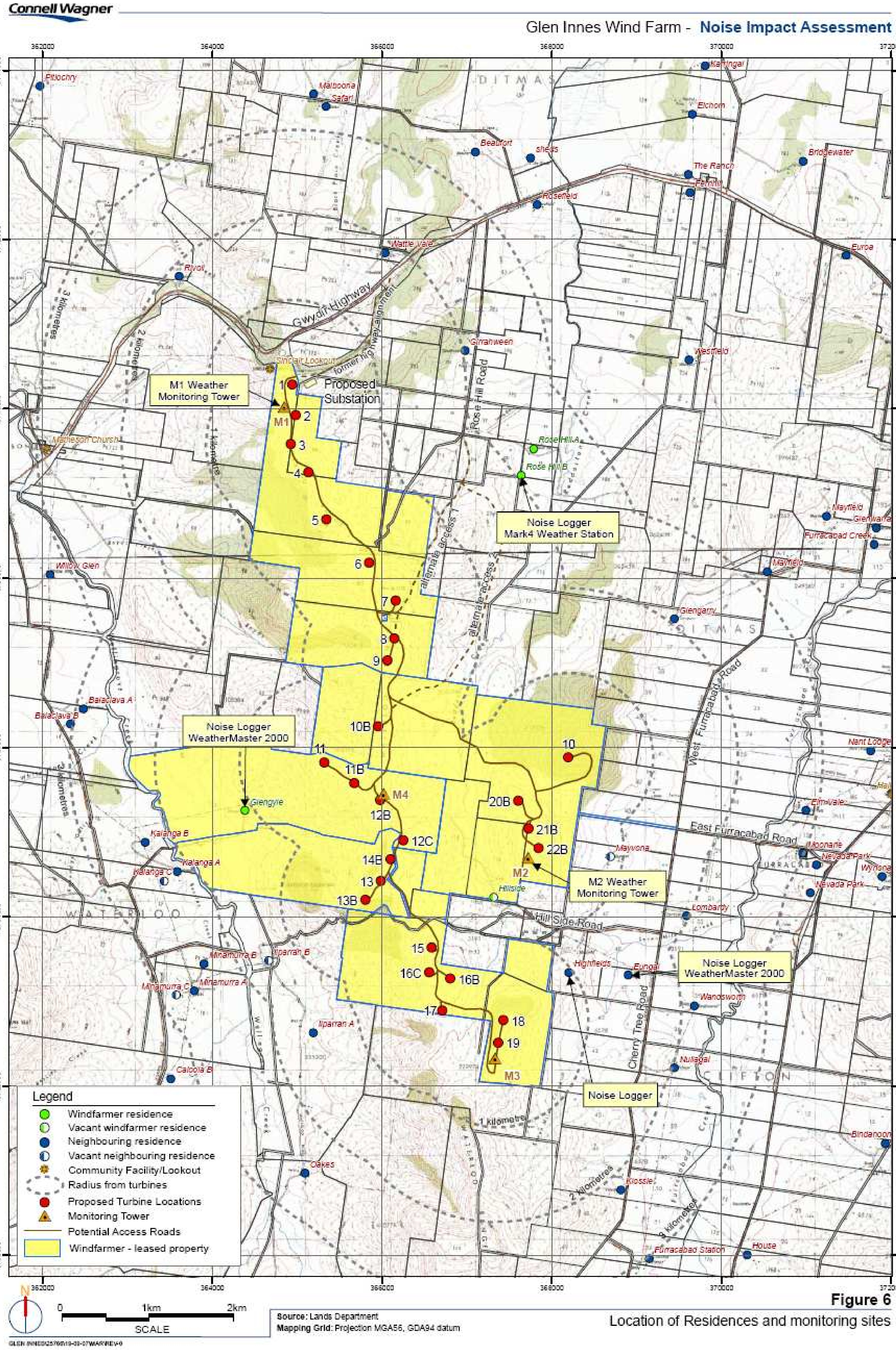


Figure 11 Location of Noise loggers, weather stations and wind monitoring towers

5.2 Noise survey results

The graphs containing the collected data noise levels L_{Aeq}, L_{A10} and L_{A90} over the full monitoring period for each noise logging location are shown in Appendix C. The average daytime and night noise levels (rain affected data) for the entire monitoring period are tabulated in Table 7 and Table 8 respectively.

Residential properties	Average daytime noise levels, dBA, 7:00 am-10:00 pm		
	L_{Aeq}	L_{A10}	L_{A90}
Rose Hill B	48	47	32
Glengyle	42	43	34
Highfields	51	49	33
Eungai	44	46	35

Table 7 Measured averaged daytime noise levels for the residential properties

Residential properties	Average night noise levels, dBA, 10:00 pm-7:00 am		
	L_{Aeq}	L_{A10}	L_{A90}
Rose Hill B	42	44	29
Glengyle	37	39	33
Highfields	42	41	31
Eungai	36	37	30

Table 8 Measured averaged night noise levels for the residential properties

Graphs showing the plot of wind speed versus background noise level for each residential property are shown in Appendix D. As per the SA EPA *Wind Farms- Environmental Noise Guidelines*, best fit regression analysis between the wind speed and background noise level was carried out and the curve of best-fit is shown in each plot. Also, the equation of the best-fit line along with the correlation co-efficient is included in each plot. For the purpose of comparing the future noise levels at different wind speeds, a criteria curve (35 dBA or background noise level plus 5 dB as applicable) is also shown on each plot.

Because rain periods during the monitoring may also adversely affect the recorded data the noise level data, during which rain was detected by the corresponding weather stations, was discarded as evident from the plots. As mentioned above the number of data points collected exceeded the SA EPA Guidelines and provides a robust basis for analysis of variation in background noise levels compared to wind speeds measured at the reference masts M1 and M2. M1 is at the north of the wind farm site and has only been used as a reference for the Rosehill background monitoring site. M2 is 6.05 km south of M1 and M3 is a further 2.38 km south of M2 and is at the southern end of the wind farm. Masts M2 and M3 are approximately equal distance away from both the Highfields and Eungai background noise measuring locations, however M2 is approximately in the middle of the turbines that are closest to the Eungai and Highfields residences.

Table 9 shows a comparison of the data collected at the proponent's three noise monitoring masts. Data from M4 was not used due to the proponent not having direct access to the data and it being for a different measurement height. It can be observed that the wind statistics are very similar at all three masts with the difference between M2 and M3 being quite negligible.

CSIRO Mast	M1	M2	M3
Mean (μ)	6.54	5.90	6.13
Variance (σ^2)	6.80	5.32	5.95
Standard Deviation (σ)	2.61	2.31	2.44

Table 9 Statistical comparison of wind speeds at 80 m from 25/5/07 to 19/6/07

6. Meteorology Assessment

The propagation of sound in the atmosphere depends strongly on the state of the atmosphere. Factors affecting the propagation of noise include atmospheric absorption, refraction and scattering of sound energy. The key factors are described below:

- **Temperature and Humidity** affect the amount of atmospheric absorption of sound
- **Wind** speed, profile and turbulence intensity (which are affected by terrain) affect refraction of sound
- **Atmospheric Stability** varies in relation to the temperature gradient and wind speed profile, and therefore has a significant effect on the refraction of sound
- **Mixing Height** affects the height at which temperature inversions are maintained, when conditions are conducive to inversions occurring

Noise prediction methods are largely based on empirical methods to account for meteorological effects, and are thus considered to be well behind air quality dispersion algorithms which incorporate detailed analytical methods to include meteorological effects. Recently the European research and development project, HARMONOISE, aims to improve prediction techniques through development of appropriate analytical methods. Noise prediction models will be considered later in Section 9, with this section providing a review of relevant meteorological parameters that effect noise propagation.

6.1 Analysis method

6.1.1 Site data

Automated Weather Stations were used at three of the four monitoring sites to measure temperature, humidity, wind speed/direction, rainfall and sigma-theta (variation of wind direction). Data from the proponent's wind masts were also used to estimate atmospheric stability in accordance with the US EPA's method [Ref 13] and as referenced in the NSW Industrial Noise Policy [Ref 3].

6.1.2 Bureau of Meteorology data

A year of meteorological data (for 2001) was obtained for the Bureau of Meteorology's weather station at Glen Innes Post Office. Satellite synoptic meteorology datasets (LAPS/GASP) were also obtained for use in meso-scale modelling to predict weather conditions over an entire year. A comparison of 2001 monthly climate statistics with averages over at least the last 50 years indicate (refer to Appendix G):

- Mean monthly maximum temperatures for 2001 are very similar to the long term average. Mean monthly minimum temperatures for 2001 are slightly higher than the long term average primarily in the winter and summer months.
- Mean monthly rainfall for 2001 was similar to the long term average for months other than March and November which recorded significantly higher rainfall. This is reflected in a significant increase in the number of cloudy days in November compared with the long term average, with only a slight decrease in the number of clear days in November. While for March the number of clear and cloudy days differed little from the long term trend.
- Mean monthly 9 am wind speeds were relatively similar to the long term trend, while mean monthly 3 pm wind speeds were less than the long term trend. This might suggest that wind speeds will be less than usual if 2001 is used as a reference year, however the peak in the wind turbine sound power profile occurs at wind speeds that are within this range.

Overall, it has been concluded that 2001 is a representative year in terms of climate averages, and will overall result in a conservative assessment.

6.1.3 Meso-scale modelling to derive wind speed and stability data

The Air Pollution Model (TAPM) uses an independent prognostic equation in order to generate hourly gridded wind field data which is derived from detailed Australian synoptic data. This software uses the Navier-Stokes equations to develop the three dimensional wind field data and uses the synoptic data from sites around the grid point as boundary conditions for these calculations. It is an attractive tool as it generates accurate wind field data across large study areas and at 25 levels above ground. In addition to the three dimensional wind field data it is also possible for the user to output the stability classes and mixing height which are required to determine the impact of meteorological effects on noise propagation.

However, an issue with the use of TAPM, that is currently being researched by the developer (CSIRO), is the under prediction of the frequency of low nocturnal wind speeds at a height above ground level of 10 m. Although this program has an assimilation tool which can be used to push the wind field data towards observed Bureau of Meteorology (BOM) or measured figures, due to there being no guarantees in the quality of the BOM wind data, the use of the assimilation process should be considered with caution..

The accuracy of TAPM is demonstrated in Figure 12 and Figure 13 for times throughout 2001 during a given stability class and season for predicted wind direction and speed respectively, as compared with data from the Bureau of Meteorology. The accuracy at predicting atmospheric conditions at higher elevations such as 80 m hub height is better than at 10 m height. This approach has been verified for numerous air dispersion models across Australia and internationally.

TAPM also enables profiles of wind speed, temperature and turbulent kinetic energy to be obtained for any given point at any given hour simulated. Predicted profiles of wind speed, temperature and turbulence intensity are shown in Figure 14 for times with differing stability during a given 24 hour period at the location of the wind turbines. Temperature inversions are clearly apparent under stable night time conditions as is the large variation in wind speed profile with stability, and turbulence intensity is observed to be high during unstable conditions and reducing to low during stable conditions, as expected.

Statistic Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean maximum temperature (Degrees C)	26.5	25.6	23.9	20.7	16.7	13.4	12.7	14.2	17.7	20.9	23.7	25.8	**20.2**
Mean minimum temperature (Degrees C)	13.3	13.2	11.5	7.8	4.5	1.9	0.6	1.3	3.9	7.1	9.7	12.1	**7.2**
Mean 9am temperature (Degrees C)	18.6	17.8	16.8	14.4	10.4	7	5.9	7.6	11.3	14.7	16.1	18.1	**13.2**
Mean 9am relative humidity (%)	74	79	77	74	80	82	80	75	68	65	68	70	**74**
Mean 9am cloud cover (okas)	3.8	3.9	3.7	3.2	3.3	3.4	3.1	2.8	2.7	3.2	3.4	3.5	**3.3**
Mean 9am wind speed (km/h)	9.1	9.9	9.8	8.2	8.5	8.8	8.5	9.5	10.4	10.6	9.9	9.1	**9.4**
Mean 3pm temperature (Degrees C)	24.7	24.1	22.4	19.5	15.4	12.4	11.8	13.3	16.4	19.2	21.7	23.8	**18.7**
Mean 3pm relative humidity (%)	51	53	52	51	57	58	54	50	45	47	48	48	**51**
Mean 3pm cloud cover (oktas)	5.1	5.4	4.9	4.4	4.6	4.3	3.8	3.8	3.9	4.6	5	5	**4.6**
Mean 3pm wind speed (km/h)	10.9	10.7	10.7	9.7	10.9	12.4	12.9	13.7	13.9	12.5	12.6	11.5	**11.9**

Table 10 Long term (since records commenced) climate Statistics for Glen Innes Airport (BOM ID: 05613) (9 am and 3 pm)

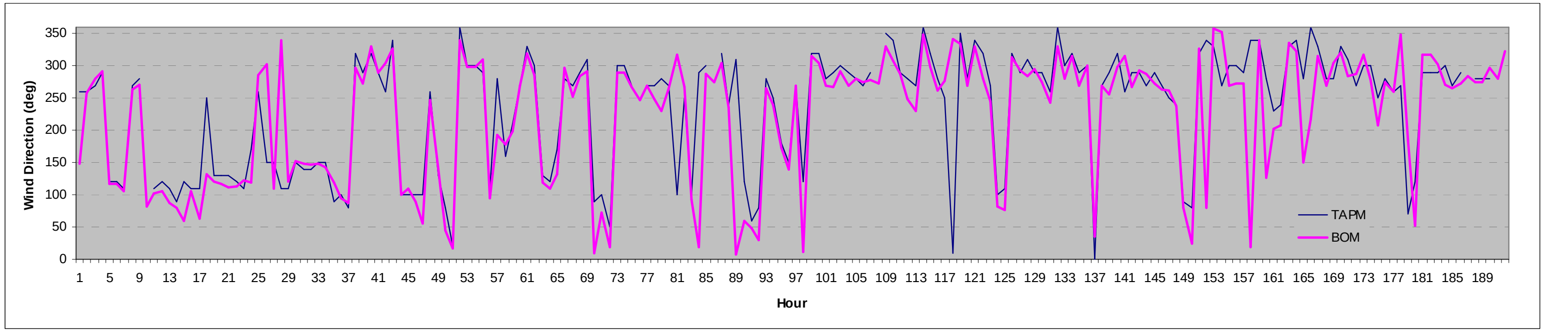


Figure 12 Wind direction at 10 m AGL (for Glen Innes) as predicted by TAPM compared with BOM measured data

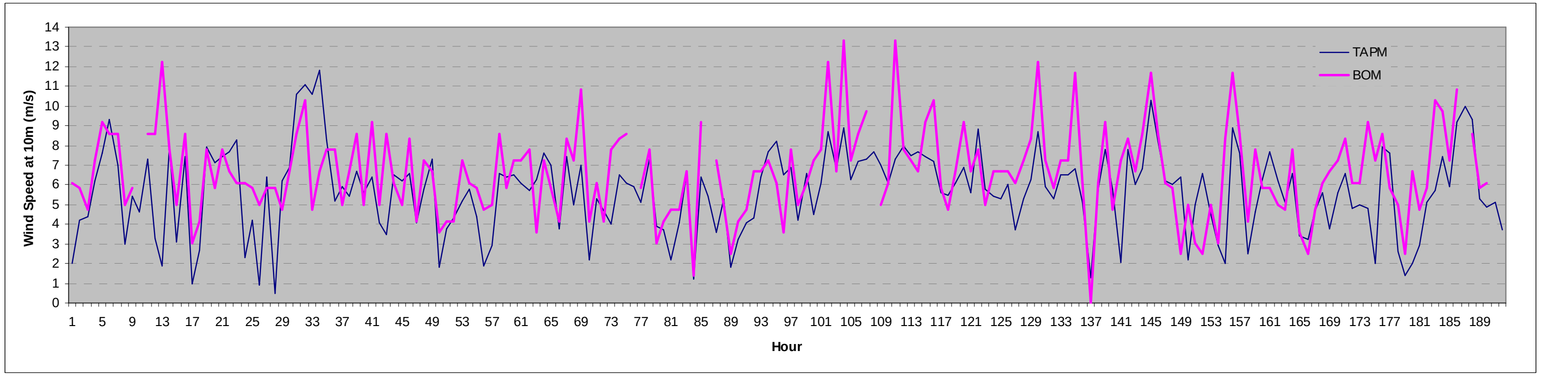


Figure 13 Wind speed at 10 m AGL (for Glen Innes) as predicted by TAPM compared with BOM measured data

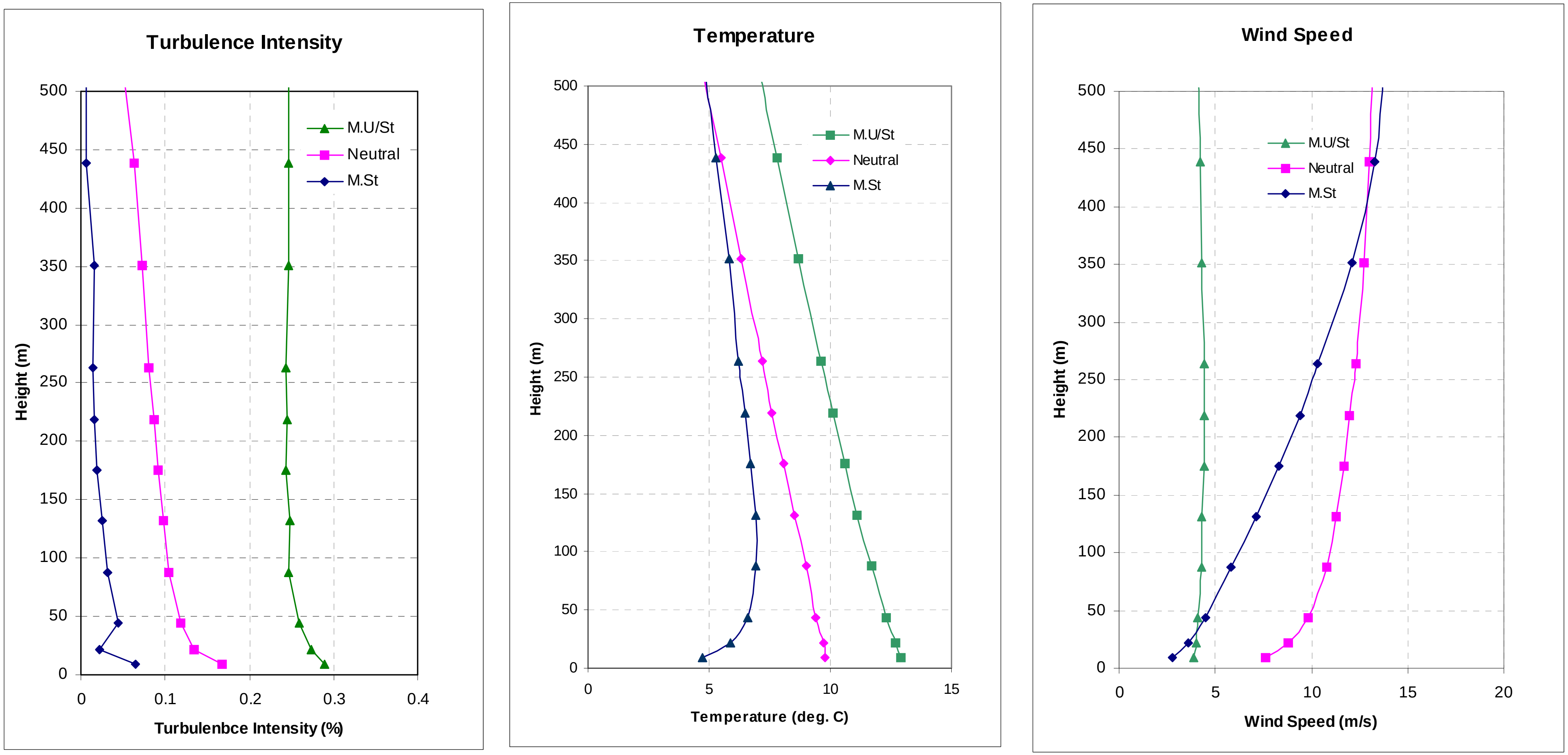


Figure 14 Predicted (using TAPM) profiles of wind speed, turbulence intensity and temperature for varying stability classes through one day at the wind farm site

6.2 Wind

Wind speed data is used in this assessment for several purposes. It is used to relate background noise levels at receiver locations to the range of wind speed conditions at the turbine sites. In general, the background noise level increases with wind speed. At the same time, the increasing wind speeds will generally result in increased turbine noise levels. Wind data can also be used to assess atmospheric stability and noise propagation that will affect the noise levels experienced at receiver locations.

Traditionally, the wind industry has measured wind speed at a height of 10 m and referenced turbine performance and turbine noise levels to the wind speeds at 10 m height. As turbine heights have increased, more emphasis has been placed on hub height wind speeds and associated performance and noise levels are also referenced to these levels. Where only 10 m data is available then it is necessary to adjust the wind speed with height based on the terrain category according to formula used to model the atmospheric boundary layer. As will be discussed later, noise propagation algorithms still use 10 m height wind data and provide empirical corrections for meteorological effects.

For this assessment, hourly records of mean wind speed and direction at 10 m height above ground were provided by the Bureau of Meteorology for their Automatic Weather Station at Glen Innes Airport (ID: 05613, Lat: -29.68, Lon: 151.69, Height: 1044.3 m). As each stability class was modeled independently, the probability of wind from any given direction was determined (see Figure 15) from data obtained from the Bureau of Meteorology and from stability class as determined from TAPM.

Mean wind speeds from any given direction were also determined (refer to Figure 16). It is noted that wind speed and direction as measured at 10 m above ground varies depending on topography. Therefore the data at the airport was used as it is relatively flat terrain and therefore not unduly effected (note that sound propagation algorithms are not yet as sophisticated as air dispersion algorithms and do not allow variation of wind speed/direction with variations in terrain). This data was used in the noise model in accordance with ISO 9613-2.

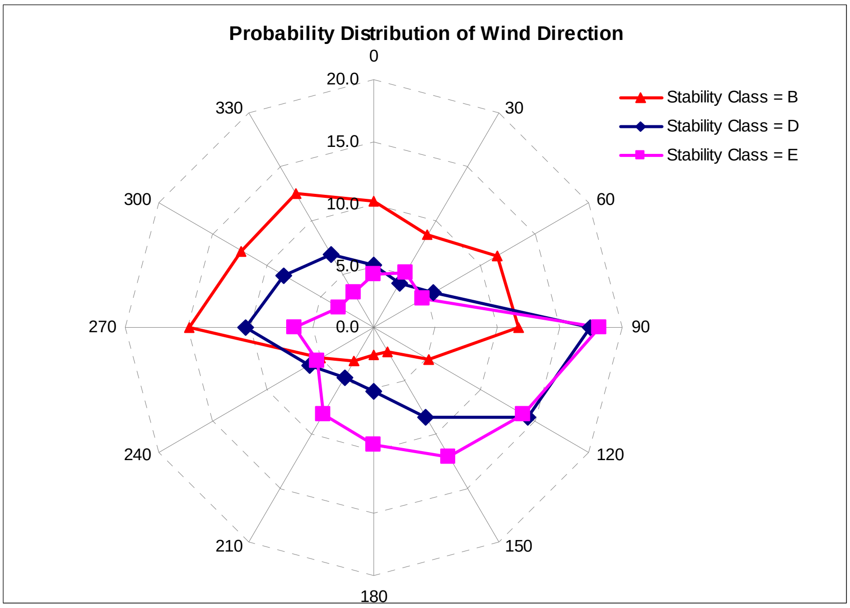


Figure 15 Glen Innes Airport - Probability distribution of wind direction

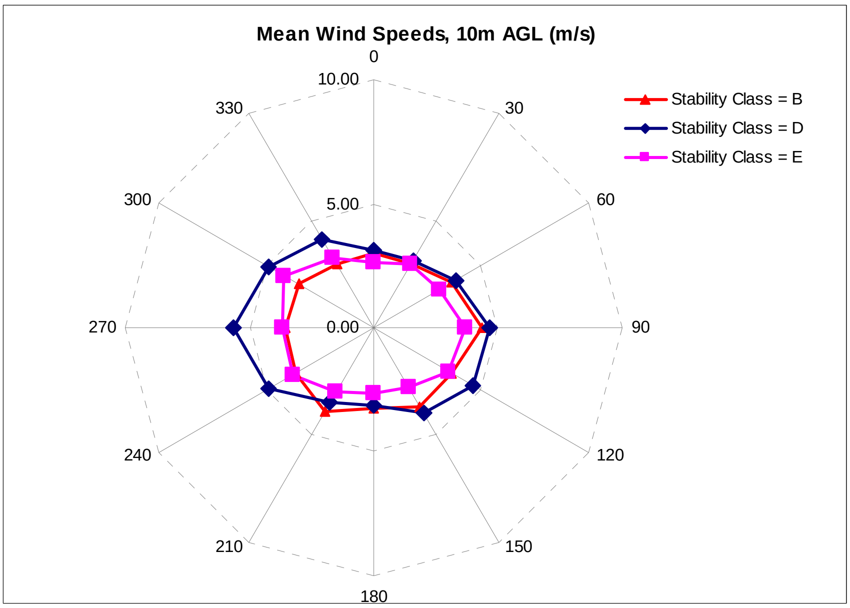


Figure 16 Glen Innes Airport - Mean wind speed at 10 m AGL.

6.3 Temperature and humidity

The long term average meteorological data for Glen Innes is presented in Table 10 and discussed in the paragraphs to follow. Data were provided by the Bureau of Meteorology for their Automatic Weather Station at Glen Innes Airport (ID: 05613, Lat: -29.68, Lon: 151.69, Height: 1044.3 m).

The hottest month of the year is January, with a mean daily maximum temperature of 26.5°C, while the coldest month of the year occurs in July with a mean daily maximum temperature of 12.7°C. The mean daily minimum temperature follows the same trend. The annual average mean daily temperature used in the noise model is 20°C (relatively conservative).

Humidity is recorded at 9 am and 3 pm. The mean relative humidity ranged from a maximum of 82% at 9 am and 58% at 3 pm in June. While the 9 am minimum of 65% occurred in October whereas the 3 pm minimum of 45% occurred in September. The annual average mean daily humidity used in the noise model is 50% (conservative).

6.4 Atmospheric stability

The degree of stability in the atmosphere is determined by the temperature difference between an "air parcel" and the air surrounding it. This difference can cause the "air parcel" to move vertically and this movement is characterised by four basic conditions that describe the general stability of the atmosphere as follows:

- **Stable** conditions occur when vertical movement is discouraged
- For **unstable** conditions the "air parcel" tends to move upward or downward and to continue that movement
- **Neutral** conditions neither encourage nor discourage that movement beyond the rate of adiabatic heating or cooling
- An **inversion** occurs when conditions are extremely stable, cooler air near the surface is trapped by a layer of warmer air above it and there is virtually no vertical air motion

Three basic schemes may be used to determine the occurrence of different stability classes at a particular site based on the following combinations of meteorological parameters:

- Direct measurements of temperature lapse rates and wind speed at 10 m height
- Cloud cover, wind speed and solar elevation (Pasquill-Gifford and Turner scheme)

- Measurements of sigma-theta (the standard deviation of wind direction), wind speed and time of day

The Pasquill-Gifford (P-G) stability category scheme assigns a designated letter from A-F (and sometime G) to stability classes, ranging from highly unstable (A) to extremely stable (G). Turner's method is an extension to the Pasquill-Gifford method, and it estimates the effects of net radiation on stability from solar altitude, total cloud cover and ceiling height. The stability class is estimated as a function of wind speed and net radiation.

Wind Speed at 10m[a] (m/s)	Day-time incoming Solar radiation (mW/cm^2)				1 hour before sunset or after sunrise	Night-time Cloud cover (octas)		
	>60	30-60	<30	Overcast		0-3	4-7	8
< 1.5	A	A-B	B	C	D	F or G[b]	F	D
2.0 – 2.5	A-B	B	C	C	D	F	E	D
3.0 – 4.5	B	B-C	C	C	D	E	D	D
5.0 – 6.0	C	C-D	D	D	D	D	D	D
> 6.0	D	D	D	D	D	D	D	D

[a] Wind speed is measured to the nearest 0.5m/s.
[b] Category G is restricted to night-time with less than 1 octa of cloud and a wind speed less than 0.5m/s.

Table 11 Stability categories derived using Pasquill-Gifford's method

As can be seen from Table 11, the stability class does not vary significantly with location and is largely dependent on time of day as can be seen later in Table 12..Stability is normally neutral-stable during night-time and neutral-unstable during day-time, where Class D represents neutral stability.

Stability class was estimated during noise measurements by considering sigma-theta (standard deviation of wind direction over the averaging period) at given monitoring heights. Stability class for a typical year (2001) was estimated using TAPM which considers the variation of temperature with height to determine stability class. Estimates of stability for the site were centered on the proposed turbine locations, specifically between turbines 9 and 10B. Conditions may become more stable at night-time when temperature inversions prevail with light winds and cold drainage flow (cool slope winds).

The frequency distribution of stability class for the site is shown in Figure 17. It is important to note that neutral stability dominates conditions (about 50%, primarily during the day-time) with stable and very stable conditions also strong contributors (about 30%, primarily during the night-time). There is little seasonal variation.

	Time of Day																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	13	71	114	108	87	54	13	2	1	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	78	194	206	163	160	153	157	160	81	9	2	0	0	0	0	0	0
D	151	156	150	148	140	248	346	287	158	88	87	96	125	154	192	282	355	319	209	104	130	139	147	148
E	136	136	140	140	149	76	12	0	0	0	0	0	0	0	0	0	0	18	102	172	154	153	145	142
F	78	73	75	77	76	41	7	0	0	0	0	0	0	0	0	0	0	26	54	89	81	73	73	75
Total	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**	**365**

Table 12 Diurnal variation of Stability Class (wind farm site)

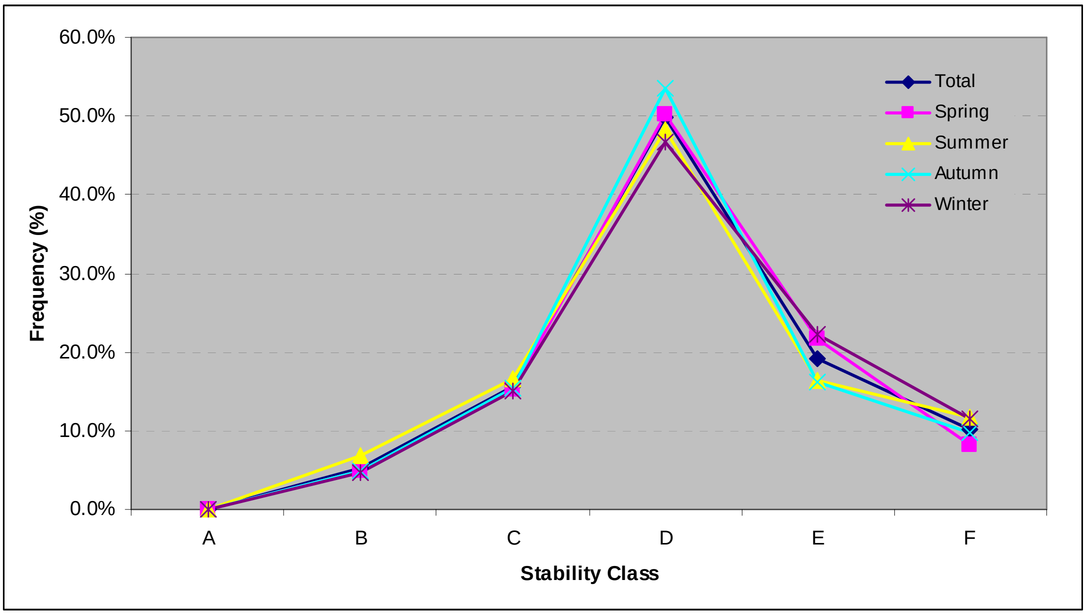


Figure 17 Frequency Distribution of Stability Classes A to F (for the wind farm site)

The frequency distribution of wind speed versus stability class is a key parameter in this assessment as it determines the likely wind speeds at which the turbines can operate critically during the night time period. Figure 18 shows this distribution and it is apparent that neutral conditions (stability class D) occur over the range of hub height wind speeds up to 20 m/s, whereas stability class E conditions occur over a lesser range of hub height wind speeds up to 13 m/s, which is above the wind speed at which maximum sound power is generated from the turbine. This will be discussed later.

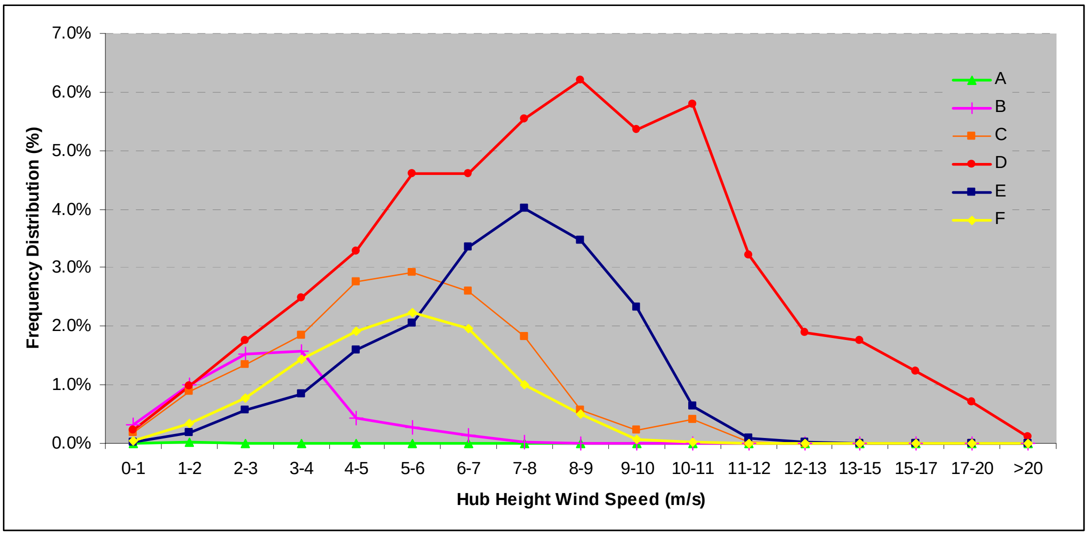


Figure 18 Frequency Distribution of Hub Height Wind Speed for Stability Class (wind farm site)

Figure 17 and Figure 18 provide a guide to the proportion of time that particular wind speed and stability class conditions will occur for a particular location. It is noted that the turbine noise specification in Appendix D (summarized in Section 3.2.2) shows that the highest turbine noise levels greater than 105 dBA occur only above about 8 m/s wind speeds and that stability classes E and F only represent about 7% of the time for wind speeds > 8 m/s.

6.5 Temperature inversions and mixing height

The NSW INP [Ref 3] requires considerations of whether temperature inversion effects occur frequently enough to warrant inclusion in the prediction of noise impacts. It states that it is considered unreasonable to expect a development to comply with noise limits under inversion conditions if inversions occur infrequently. The INP (Table E2) indicates that if F or G stability categories occur for a period of 30% of the night time or more, either separately or in combination, then temperature inversions are considered to be a significant feature of the area and need to be assessed. While this threshold may apply to noise sources that operate independent of wind speed, the period of occurrence for the F and G stability in respect of a wind farm assessment could exclude the periods where wind speeds are less than 4 m/s (the start up wind speed for the turbines). Given the infrequency of stability class F and G, the effects of temperature inversions and associated mixing heights relative to turbine heights have not been considered in this assessment.

7. Design Criteria

7.1 Non wind farmer residences

The developed noise criteria from the regression analysis of the collected noise data compared to the hub height wind speed at the WTG locations are shown in Table 13. The criteria have been calculated from cut-in wind speed for the WTG to a maximum wind speed (15 m/s) (above the turbine rated output level) without regard to stability and with respect to stability classification.

Shaded areas of Table 13 indicate criterion estimates for the integer wind speed where no background noise data was recorded for that stability class during the measurement period. No criterion values have been derived for Stability Class B for wind speeds greater than 6 m/s and for Stability Class E above wind speeds of 9 m/s as hub height wind speeds do not exceed the respective levels for these stabilities. These estimates are for wind speeds at the upper end of the range where the stability class may be applied. The lack of measured background noise data for these stability classes and wind speeds appears to indicate that the stability class occurs infrequently at these wind speeds. In such cases the criterion derived using the SA EPA guideline method independent of stability class appears more relevant for the bulk of the time. As expected there is reasonable correspondence between the criterion derived for Stability Class D and the criterion derived independent of stability class.

		Criterion $L_{Aeq,10}$ (dBA) for each Hub Height Wind Speed (m/s)											
	Stability Criterion	4	5	6	7	8	9	10	11	12	13	14	15
Eungai	None	35	35	35	35	35	35	37	38	40	43	45	48
	B	35	36	38	41	-	-	-	-	-	-	-	-
	D	35	35	35	35	35	35	37	38	40	43	45	48
	E	35	35	35	35	35	35	35	35	35	-	-	-
Highfields	None	35	35	35	35	35	37	38	40	42	44	47	49
	B	35	36	38	39	-	-	-	-	-	-	-	-
	D	35	35	35	35	35	37	38	40	42	44	46	47
	E	35	35	35	35	35	35	35	35	35	-	-	-
Glengyle	None	35	35	35	35	36	37	38	39	41	42	44	46
	B	35	35	35	35	-	-	-	-	-	-	-	-
	D	35	35	35	35	36	37	38	39	40	42	44	45
	E	35	35	35	35	35	35	35	35	35	-	-	-
Rose Hill B	None	35	35	35	35	35	35	35	36	37	37	39	40
	B	35	35	37	42	-	-	-	-	-	-	-	-
	D	35	35	35	35	35	35	35	36	37	38	39	41
	E	35	35	35	35	35	35	35	35	35	-	-	-

Table 13 Noise Criteria for Non Wind Farmer residences

The criteria from the four background noise monitoring sites can be applied for the assessment of neighbouring properties which are expected to contain similar background noise; these are outlined in Table 14.

Background Monitoring Site	Sites considered to have similar background noise environment
Eungai	Elm Vale, Klossie, Lombardy, Mayvona, Moonarie, Nullagai, Wandsworth
Glengyle	Balaclava A, Ilparran A, Ilparran B, Kalanga A, Kalanga B, Kalanga C, Minamurra A, Minamurra B, Minamurra C, Oakes, Rivoli (on western side of Range and similar to GlenGyle location)
Rose Hill B	Girrahween, Glengarry, Matheson Church,
Highfields	Wattlevale (also close to Gwydir Highway (about 100m) so may have a higher background noise environment). Highfields is surrounded by large trees and appears to have high background levels

Table 14 Representative background noise sites with similar design noise criteria

7.2 NSW EPA Industrial Noise Policy

The one or two transformers located at the proposed substation will be the only significant noise source to fall under the criteria outlined by the NSW EPA Industrial Noise Policy. The criteria will be driven by the intrusiveness criteria by the night-time rating background noise level at the Rose Hill B measurement location. Properties considered to have similar background noise environments as the other monitoring sites are not going to be affected by the transformer noise due to the large distance between source and receiver. The criterion is as follows:

- **$L_{Aeq,15}$ (transformer) ≤ 34 dBA** at noise sensitive receiver

The nearest residences to the substation site are Rivoli, Wattle Vale and Girrahween all of which are located at about 2 km from the substation site and where the impact of the transformer(s) is predicted to be acceptable.

Sinclair Lookout is located close to the northern end of the wind farm and about 500 metres from the proposed substation site. The lookout is at the top of the unsealed Sinclair Lookout Road and comprises a turning circle within a small clearing on the partly cleared ridge. The view from the lookout is to the west over Wellingrove Valley. The DECC has suggested that the impact at the lookout should be assessed against passive recreation amenity criteria where an L_{Aeq} level of 50 is the recommended acceptable level and an L_{Aeq} level of 55 is the recommended maximum level when the area is being used.

The lookout does not appear to have frequent visitation and has no facilities that would encourage other than short term visits. It is also a fairly exposed site and at times of strong winds would be likely to discourage lengthy stays. As such any noise impact for visitors to the lookout would be likely to be of a short term nature and once the wind farm is operating any audible noise from the wind turbine at the lookout could potentially form part of the experience of viewing the wind farm at a relatively close distance.

7.3 Wind farmer residences

The criteria shown in Table 15, relates to the Wind Farmer residences (Glengyle, Hillside, Rosehill A & B), and are based on the WHO Community Noise Guidelines. Meeting these guidelines will ensure that the amenity value of the area is not unreasonably interfered with. It is noted that these are above those shown in Table 11 for neighbouring residences (relevant receivers).

Specific Environment	Critical health effect(s)	$L_{Aeq,}$ (dBA)	Time base (hours)	$L_{Amax,f}$ (dB)
Outdoor living area	Serious annoyance, daytime and evening	55	16	-
Dwelling Inside bedrooms	Sleep disturbance, night-time	30	8	45
Outside bedrooms (with window open)	Sleep disturbance, night-time	45	8	60

Table 15 Noise criteria for wind farmer residences

Agreements will be established with the relevant wind farmers in respect of Glengyle and Hillside. Rose Hill A and B are about 2 km from the nearest turbine and are well beyond the distance where criteria developed in accordance with the SA EPA guideline would be exceeded and an agreement in relation to noise impact is not necessary.

8. Noise Models

8.1 Noise prediction

The prediction of noise in the environment requires the definition of the sound power level and frequency spectrum of the noise source as well as directivity for each source and the estimation of noise propagation for each source based on:

- Geometric spreading
- Enclosures
- Barriers
- Air absorption
- Wind effects
- Temperature gradient effects
- Ground effects

Various prediction methods have been developed over the past 30 years and continue to be developed to more accurately account for environmental effects which are strongly dependent on meteorological conditions. In 2003, the European Directive on the Assessment and Management of Environmental Noise (2002/49/EC) was accepted acknowledging lack of harmonised methods of sufficient accuracy for the prediction and assessment of noise from roads, railways and industrial sites. It was considered a main priority in the Harmonoise project to improve the description of weather conditions and their influence on sound propagation, because the state-of-the-art methods for noise prediction do not fully account for these effects. For this reason, TAPM was used to properly account for meteorological effects in this assessment.

SoundPLAN noise modeling software was used for this analysis. It incorporates various analysis methods including

- German - VDI 2714/2720
- United Kingdom - CONCAWE
- Norwegian – NORD2000
- International - ISO 9613

NORD2000 is rarely used in Australia, hence only CONCAWE and ISO 9613-2 (which is based on the German standard) are summarised below, with reasoning given as to the preferred method used for this assessment.

For all noise propagation models, it should be noted that effects of wind are considered relative to measurements carried out at a height of 10 m AGL. Typically the wind speed at this height varies to about 6 m/s, with a mean of about 4 m/s, and a Weibull type distribution. As presented herein, wind speeds at hub height vary substantially from this subject to the degree of atmospheric stability.

8.2 Propagation algorithms

In assessing the two most frequently used models to account for meteorology (ISO 9613-2 and CONCAWE), the following international references have been used:

- Bass, J.H., Bullmore, A.J. and Sloth, E. (1996), "Development of a wind farm noise propagation prediction model", Contract JOR3-CT95-0051. This is a European funded commission into noise from wind farms, which provides recommended modifications of ISO 9613-2 to improve its accuracy at predicting noise from wind farms
- "Stakeholder Review and Technical Comments", Malcolm Hunt & Assoc, Marshall Day Acoustics, May 2007. This is a study of noise from wind farms from an Australian and New Zealand context

- Brittain, F. (2004), "Noise Modeling using ISO 9613-2 for designing facilities to meet a not-to-exceed community noise limit", Noise-Con 2004, pp 861-873. This is an study considering the USA context of noise models, not specifically for wind farms

8.2.1 CONCAWE

The CONCAWE method for calculating noise attenuation due to meteorological effect includes empirical corrections for wind and temperature inversions. The temperature gradient is expressed in terms of the Pasquill-Gifford Stability category which is then combined with the wind speed and direction to determine one of six meteorological categories (CAT). The attenuation in each octave band for each category are then provided and range from +10 dB being unstable and a strong wind blowing away from the receiver to -5 dB being very stable (temperature inversion) with wind blowing towards the receiver. That is a difference of 15 dB reducing to 0 dB as the distance between source and receiver reduces from 1000 m. It includes corrections for ground absorption and barrier attenuation but without accounting for meteorological effects which are important for large distances between sources such as is the situation for wind farms.

Both papers acknowledge the overly conservative estimates obtained using CONCAWE to adjust for meteorological effects. From the European review *"… the CONCAWE procedure was found to over-predict noise levels within a few hundred meters of the noise source …* ", which was consistent with the New Zealand/Australian study.

8.2.2 ISO 9613-2

This standard predicts noise levels under meteorological conditions favourable to propagation. Conditions favourable to propagation are defined as "downwind propagation" (wind speed between approximately 1 m/s and 5 m/s) or "propagation under a well-developed moderate ground based temperature inversion, such as commonly occurs at night". However it should be noted that the wind speed range refers to wind at 10 m AGL, which can vary quite significantly when compared to hub height level especially during stable conditions due to the Van den Berg effect. Corrections were implemented in the model to take into account noise propagation under higher wind speeds as is discussed in Section 8.3 below using the C_0 factor which is part of the meteorological correction formula applied in the ISO 9613-2 model:

$$C_{met} = C_0[1-10(h_s+h_r)/d_p]$$

Where:

- C_{met}= Noise attenuation correction applied to the overall A-weighted level
- C_0 = a factor in dB which depends on local weather statistics, range 0 to +10 dB
- h_s = source height (m)
- h_r = receiver height (m)
- d_p = horizontal distance between source and receiver (m)

The major disadvantages of this method are that it:

- Does not provide attenuation under unfavourable wind conditions (ie upwind noise propagation)
- Does not provide spectral corrections rather an overall noise level adjustment.
- It only gives guidance for C_0 and states that it "may be estimated from an elementary analysis of the local meteorological statistics" or it "may be established by the local authorities", with experience indicating that in practice is limited to "the range from 0 to approximately +5 dB, and values in excess of 2 dB are exceptional". This is considerably different to CONCAWE which indicates a difference of up to 15 dB between inversions with receivers downwind and lapses with receivers upwind. SoundPLAN includes a difference of +10 dB for this situation in ISO 9613-2.

The major advantage of this method is that it includes a coarse allowance for meteorological effects in barrier and ground attenuation calculations. It also allows for reflections from obstacles (eg hillsides) which CONCAWE does not.

Both papers note the improved accuracy of the ISO 9613-2 method, with in particular Bass et al (1996) noting *"…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 1.5 dBA on flat, rolling and complex terrain sites. The only observed exceptions to the excellent accuracy achieved by the model occur in the presence of marginal or partial acoustic screening, and also where the ground falls away significantly between the source and receiver. However, these two situations are easily accounted for by means of simple correction factors."* The correction factors suggested are:

- The excess attenuation attributable to the barrier effect should be limited to no more than 3 dBA, given that a positive component of wind from the source to the receiver can significantly reduce the effective barrier performance
- Where the ground falls away significantly between the source and receiver, such that the mean propagation height is at least 1.5x that over flat ground and particularly where the ground falls away steeply from the receiver, it is recommended that 3 dBA be added to the calculated sound pressure level. This accounts for the reduction in excess ground attenuation due to the increased height of propagation

Provided the suggested correction factors are applied to the output of the ISO model, the calculated sound pressure levels have been validated to agree to within 2 dBA of noise levels measured under practical "worst case" conditions at distances of up to 1000 m from a noise source. These corrections have been included in the model and have accounted for less than a 0.5 dBA increase in the noise level at receivers.

8.3 Preferred Method

As reported by the European Directive, there are deficiencies in both analysis methods. Notwithstanding this, the analysis method used herein was ISO 9613-2 as it includes meteorological effects when considering barrier (eg terrain) attenuation and ground absorption, as opposed to CONCAWE.

This is substantiated by recent research in New Zealand/Australia, as it has also been shown recently [Ref 16] to provide more accurate estimates of emissions from turbines, though it was based on worst case downwind noise propagation with a "well developed moderate ground based temperature inversion" as used by ISO 9613-2 (reference clause 5). This report [Ref 15] also states:

- "The goal of any noise prediction method should be to assist wind farm developers to design a wind farm which complies with noise limits, without requiring an excessively onerous safety margin due to prediction uncertainty"
- "In cases where the distances between turbines and receivers are significant and have significant, correctly understood terrain features, the ISO 9613 model produces more accurate results. As typical setbacks to NZ wind farms are 800 m or more, ISO9613 would appear to most accurately predict measured sound levels. To achieve this the model needs to be well informed with respect to terrain information (necessitating the use of digital terrain models in most hilly situations"
- "The inclusion of the directional wind factor in either the ISO 9613 or the Concawe model made negligible difference to the noise levels predicted"

Inputs into the SoundPLAN model have been entered as follows:

- Positions of sources, receivers and ground contours input from electronic data created for this project with features specified in the MGA coordinate system
- Meteorological inputs used by ISO 9613-2;

- Relative humidity
- Ambient temperature
- Atmospheric pressure
- Wind rose data as per estimates for each stability class (Figure 16)
- Meteorological correction factor (C_0) has been modified as clearly there is no “moderate ground based” temperature inversion for unstable or neutral stability classes

9. Predicted Noise Levels at Receiver Locations

9.1 Operation

Noise levels due to the operation of wind turbines are shown in the tables below for each wind speed (at hub height) without taking into account atmospheric stability as well as in the applicable atmospheric stability criteria. Worse case sound powers emitted by the WTG (in Mode 0) have been used in the calculation with an adjustment being made depending on the wind speed. Calculations were only made up to the maximum wind speed experienced at each stability criteria based on meteorological survey wind data and TAPM predicted wind data. At wind speeds over 12 m/s the sound power of the wind turbines decreases (as shown on Figure 4) while the criterion increases, hence where compliance occurs at 12 m/s there is no need to present levels above that wind speed.

Receiver	Predicted $L_{Aeq,10}$ (dBA) at various Wind Speeds (m/s)								
	4	5	6	7	8	9	10	11	12
Balaclava A	9	15	20	24	27	29	30	31	31
Elm Vale	7	13	18	22	25	27	28	29	29
Eungai	13	20	25	29	31	33	35	36	36
Girrahween	10	16	21	25	27	30	31	32	32
Glengarry	7	14	19	22	25	27	29	29	30
Glengyle	15	21	26	30	33	35	36	37	37
Highfields	17	23	29	32	35	37	39	39	40
Hillside	20	26	31	35	38	40	41	42	42
Ilparran B	14	20	26	29	32	34	36	36	37
Ilparran A	14	20	25	29	32	34	35	36	36
Kalanga A	12	18	23	27	29	31	33	34	34
Kalanga B	11	17	22	26	29	31	32	33	33
Kalanga C	11	17	22	26	29	31	32	33	33
Klossie	7	13	19	22	25	27	29	29	30
Lombardy	11	18	23	27	29	31	33	34	34
Matheson Church	7	14	19	22	25	27	29	30	30
Mayvona	17	23	28	32	35	37	38	39	39
Minamurra A	11	17	22	26	28	31	32	33	33
Minamurra B	11	18	23	26	29	31	33	34	34
Minamurra C	10	17	22	25	28	30	32	33	33
Moonarie	7	14	19	22	25	27	29	30	30
Nullagai	7	14	19	23	25	27	29	30	30
Oakes	9	16	21	24	27	29	31	31	32
Rivoli	8	14	19	23	26	28	29	30	30
Rose Hill A	10	16	21	25	28	30	31	32	32
Rose Hill B	8	15	20	23	26	28	30	30	31
Wandsworth	11	17	22	26	28	30	32	33	33
Wattle Vale	9	15	20	24	27	29	30	31	31

Note: Highlighted noise levels exceed the design criteria (See Table 24)

Table 16 Predicted Noise Levels at each receiver not taking into account atmospheric stability

Receiver	Stability B Predicted $L_{Aeq,10}$ (dBA) at various Wind Speeds (m/s)			
	4	5	6	7
Balaclava A	9	15	20	24
Elm Vale	8	14	19	23
Eungai	15	21	27	30
Girrahween	11	17	22	26
Glengarry	9	15	20	24
Glengyle	17	23	28	32
Highfields	19	25	31	34
Hillside	22	28	34	37
Ilparran B	15	22	27	30
Ilparran A	16	22	27	31
Kalanga A	13	19	24	28
Kalanga B	12	18	23	27
Kalanga C	12	18	23	27
Klossie	9	15	20	24
Lombardy	13	19	25	28
Matheson Church	8	14	20	23
Mayvona	19	25	31	34
Minamurra A	12	18	23	27
Minamurra B	12	19	24	28
Minamurra C	11	17	23	26
Moonarie	8	14	20	23
Nullagai	10	16	21	25
Oakes	10	17	22	25
Rivoli	9	15	20	24
Rose Hill A	11	17	22	26
Rose Hill B	10	16	22	25
Wandsworth	12	18	23	27
Wattle Vale	9	16	21	25

Table 17 Predicted Noise Levels at each receiver for Stability Class B

Receiver	Stability D Predicted $L_{Aeq,10}$ (dBA) at various Wind Speeds (m/s)								
	4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Balaclava A	8	14	19	23	25	27	29	30	30
Elm Vale	5	11	17	20	23	25	27	27	28
Eungai	12	18	24	27	30	32	34	34	35
Girrahween	8	15	20	23	26	28	30	31	31
Glengarry	6	12	18	21	24	26	28	28	29
Glengyle	14	20	26	29	32	34	36	36	37
Highfields	16	22	28	31	34	36	38	38	39
Hillside	19	26	31	34	37	39	41	42	42
Ilparran B	13	19	24	28	30	33	34	35	35
Ilparran A	13	19	25	28	31	33	35	35	36
Kalanga A	10	17	22	25	28	30	32	32	33
Kalanga B	10	16	21	25	27	29	31	32	32
Kalanga C	10	16	21	25	27	30	31	32	32
Klossie	6	12	17	21	24	26	27	28	28
Lombardy	10	16	21	25	28	30	31	32	32
Matheson Church	6	12	18	21	24	26	28	28	29
Mayvona	16	23	28	31	34	36	38	38	39
Minamurra A	9	16	21	24	27	29	31	32	32
Minamurra B	10	16	22	25	28	30	32	32	33
Minamurra C	9	15	21	24	27	29	31	31	32
Moonarie	6	12	17	21	23	25	27	28	28
Nullagai	6	12	17	21	24	26	27	28	28
Oakes	8	14	19	23	26	28	29	30	30
Rivoli	7	13	18	22	25	27	28	29	29
Rose Hill A	8	15	20	24	26	28	30	31	31
Rose Hill B	7	13	18	22	25	27	28	29	29
Wandsworth	9	15	20	24	27	29	30	31	31
Wattle Vale	8	14	19	23	26	28	29	30	30

Table 18 Predicted Noise Levels at each receiver for Stability Class D

Stability Class D is the most frequent atmospheric condition representing a frequency of about 50%. It occurs predominantly during the day-time.

Receiver	Stability E Predicted $L_{Aeq,10}$ (dBA) at various Wind Speeds (m/s)								
	4	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Balaclava A	9	16	21	24	27	29	31	31	32
Elm Vale	6	13	18	21	24	26	28	28	29
Eungai	13	19	24	28	31	33	34	35	35
Girrahween	10	16	21	25	27	29	31	32	32
Glengarry	7	13	19	22	25	27	29	29	30
Glengyle	15	22	27	30	33	35	37	37	38
Highfields	17	23	28	32	34	37	38	39	39
Hillside	20	26	31	35	37	40	41	42	42
Ilparran B	14	20	25	29	32	34	35	36	36
Ilparran A	14	20	26	29	32	34	36	36	37
Kalanga A	12	18	23	27	30	32	33	34	34
Kalanga B	11	18	23	26	29	31	33	33	34
Kalanga C	11	18	23	26	29	31	33	34	34
Klossie	6	13	18	21	24	26	28	28	29
Lombardy	11	17	22	26	29	31	32	33	33
Matheson Church	8	14	19	23	26	28	29	30	30
Mayvona	17	23	28	32	34	36	38	39	39
Minamurra A	11	17	22	26	29	31	32	33	33
Minamurra B	11	18	23	27	29	31	33	34	34
Minamurra C	10	17	22	26	28	30	32	33	33
Moonarie	7	13	18	22	24	27	28	29	29
Nullagai	7	13	18	22	24	27	28	29	29
Oakes	9	15	20	24	27	29	30	31	31
Rivoli	8	15	20	23	26	28	30	31	31
Rose Hill A	10	16	21	25	27	30	31	32	32
Rose Hill B	8	14	20	23	26	28	30	30	31
Wandsworth	10	16	21	25	27	30	31	32	32
Wattle Vale	9	15	20	24	27	29	30	31	31

Note: Blue highlighted noise levels exceed the design criteria (See Table 25). No noise data was obtained for this stability class at wind speeds > 8m/s during the monitoring period and its occurrence may be infrequent for wind speeds 9m/s to 12 m/s.

Table 19 Predicted Noise Levels at each receiver for Stability Class E

Stability Class E represents moderately stable atmospheric conditions occurring predominantly during night-time. Minor exceedances of criterion have been predicted when the turbine is operating in Mode 0, which represents the highest noise level mode. While potential exceedances are identified, these may not result in annoyance at receiver locations. Should the exceedance cause concern at a receiver location it is possible to operate the turbine in a quieter mode as indicated in Section 11.

9.2 Substation noise impacts at residences and Sinclair Lookout

Due to the distances involved (about 2 km) and a degree of topographic shielding, it is predicted that noise levels arising from the substation transformer(s) will be below the criterion of 34 dBA at the three closest receiver locations (Rivoli, Wattle Vale and Girrahween). It is noted that two of the three receiver locations (Rivoli and Wattle Vale) are within 200 to 300 m of the Gwydir Highway and they will also be impacted by traffic noise such that background noise levels and associated criteria are higher than for the reference receiver locations where monitoring was undertaken.

Sinclair Lookout is only about 500 metres from the proposed substation site which may have one or two transformers with a combined power rating of up to 85 MVA. As indicated in Section 2.2.4 the substation transformer(s) may have sound power levels of 92 to 101 dB(A) and this would reduce to less than 35 dB(A) at a distance of 500 metres. The sound power levels produced by the transformers will increase with the load and will be greatest at the maximum wind farm output which will correspond to times having high wind speeds, maximum turbine output and the highest sound power levels.

The noise from the substation and the northernmost turbines may be additive at the Lookout but due to the turbines having higher sound power levels than the transformer and in the case of Turbine 1 it being closer to the Lookout, the noise impact at the Lookout is likely to be dominated by Turbine 1 and of the order of 50 dB(A). While this is at the level of the acceptable amenity criterion, due to the short time spent at the Lookout during visits and the nature of the noise associated with the turbines this is not expected to be annoying. There are many instances where people have commented on being below wind turbines and being able to hold a conversation despite the turbine operating above. Once the wind farm has been installed the turbine noise when they are operating and audible at the lookout would form part of the viewing experience.

9.3 Construction noise impacts

Construction noise is dependant on the specific equipment used and the proximity of that equipment to noise sensitive areas. The assessment of potential noise impacts arising from construction of the Wind Farm includes the installation of the wind turbines, substation, underground cables and access tracks.

9.3.1 Criteria relevant to construction noise

The assessment of potential noise impacts arising from construction of the Glen Innes Wind Farm including the wind turbines, substation underground cables and access tracks is not governed by the Environmental Noise Guidelines : Wind Farms; rather, the guidelines laid out in the NSW Department of Environment and Climate Change's (DECC) Environmental Noise Control Manual (ENCM) are applicable to construction noise. The ENCM noise criteria for construction works are as follows:

- *Construction period of 4 weeks or under*
  $L_{10,\ 15\ minutes}$ *(when the construction site operational)* < $L_{90,\ 15\ minutes}$ *+20 dBA*

- *Construction period of longer than 4 weeks and not exceeding 26 weeks*
  $L_{10,\ 15\ minutes}$ *(when the construction site operational)* < $L_{90,\ 15\ minutes}$ *+10 dBA*

- *Construction period of exceeding 26 weeks*
  $L_{10,\ 15\ minutes}$ *(when the construction site operational)* < $L_{90,\ 15\ minutes}$ *+5 dBA*

It is noted that while the construction works for the wind farm will continue over a period of at least 6 months that the works are spread over a large area involving about 8.5 kilometres of the Waterloo Range. In addition, the nature of works at any particular location will vary in time, with the noisier activities, namely excavation in basalt for; the turbine footing (several days), pouring of the concrete footing (one day) and erection of the supporting tower and turbine (several days), being a small proportion of the overall construction period.

The consequence of the wide geographic distribution of the construction works and short term activities for turbine installation is that for a particular receiver location surrounding the wind farm, any noise impacts arising from the construction of the wind farm will be for a much shorter duration than 6 months and will not be continuous but an irregular series of different activities with varying noise characteristics.

9.3.2 Construction work hours

The construction activities will also generally be limited to the working hours shown in Table 20:

<table>
<tr><th>Days on which construction occurs</th><th>Acceptable construction times</th><th>Excursions beyond acceptable construction times</th></tr>
<tr><td>Monday to Friday</td><td>7:00 am to 6:00 pm</td><td rowspan="4">Certain work outside acceptable hours as indicated below.</td></tr>
<tr><td rowspan="2">Saturday</td><td>7:00 am to 1:00 pm if inaudible</td></tr>
<tr><td>8:00 am to 1:00 pm if audible</td></tr>
<tr><td>Sunday</td><td>Nil</td></tr>
</table>

Table 20 Construction time restrictions

For wind farm projects, some excursions from the normal working hours may be necessary to address issues of safety and practicality of construction. These aspects are indicated in Table 21.

Item	Reason for excursion
Erection of the turbine structures (Mostly in daylight hours for up to 27 turbines and involving about two days per site)	To take advantage of low wind conditions that ensure the safety of the turbine erection operation. Due to the high wind energy at a wind farm site and the substantial cost and demands on the equipment used for the turbine construction it is necessary to utilise times of suitable wind speeds as they arise.
Pouring concrete footings (up to 27 days and mostly within standard hours)	The pouring of a concrete footing for a turbine site can take up to 10 hours and needs to be completed within a single operation. The ability to do this is impacted by the number agitator trucks available, return travel times from the batch plant to turbine site and any incidences occurring during the pour that may delay the completion of the pour in the optimal time.

Table 21 Excursions to acceptable working hours

It is understood that the proponent may seek approval for limited excursions to the normal operating hours to allow for the operations indicated in Table 16. Due to the small proportion of the total construction period allocated to the erection of the turbines and the likelihood that much of it can be undertaken within standard hours the number of excursions related to turbine erection is expected to be limited. In the case of the pouring of turbine footings these will occur on up to 27 days and be undertaken in the day time, commencing as early as practicable, within the acceptable hours.

Extension of the pour, beyond the latest acceptable time may be needed to complete a pour if unforeseen difficulties occur during the day. It is expected that the sites with least travel time are least likely to have any significant exceedance of the acceptable times while the more distant sites with greater travel time would be more prone to excursions.

Both of the abovementioned reasons for excursions from acceptable operating hours are expected to be uncommon and represent a minor component of the construction works. Nevertheless, provision is sought for such departures of the normal construction operations. Also due to the distributed nature of the development as mentioned above, construction noise impacts associated with any excursions from standard hours would be expected to represent a short duration at any particular receiver location.

With construction activities occurring predominantly during acceptable working hours with rare excursions for specific tasks, the potential for sleep disturbance to occur is low, and the risk of evening and night time amenity of residents in the vicinity of the construction activities being affected by the construction activities is low.

As far as possible, existing roads and tracks will be utilised, minimising the time and cost of constructing additional infrastructure and reducing the impact of temporary road construction on residential locations. The short-term increase in heavy vehicle movement may be noticeable to residences along the existing roads utilised during construction (predominantly the Gwydir Highway as local roads are not planned to be used by the large construction vehicles). The number of concrete agitator truck movements on local roads would be lower if an on-site Batching Plant were used however as such movements would be on the Gwydir Highway rather than local roads the potential for noise disturbance will be minor.

9.3.3 Nature of construction activities and equipment used

The noisiest activities are likely to be the excavation in basalt for turbine footings and trenches for underground cables, the use of bulldozers for earthworks and the use of a large crane for turbine erection. The actual noise levels and and their duration for the earthworks will be proportional to the strength of the rock involved. Preliminary indications are that significant jointing is evident in the basalt as well weaker clay layers and that the rocks will be able to be excavated with a hydraulic excavator. If harder rock is encountered limited blasting may be required. The plant in Table 22 is predicted to operate on site during construction. The associated noise levels for each item of plant are also shown together with the indicative noise levels at various distances from various items of plant.

It is unlikely that all of the equipment below will be operating simultaneously for extended periods of times and as mentioned earlier, the nature of activities will vary at each site during the course of the construction.

Equipment to be used	L_w (dBA) [Ref 19]	Noise Level (dBA) at indicated distance			
		800 m	1000 m	1200 m	1600 m
Batch Plant (if used)	120	54	52	50	48
Bulldozer	119	53	51	49	47
Compressor	95	29	27	25	23
Concrete agitator truck	116	50	48	46	44
Large Crane	118	52	50	48	46
Excavator	110	44	42	40	38
Grader	118	52	50	48	46
Heavy Truck	108	42	40	38	36
Hydraulic rock breaker	119	53	51	49	47
Vibratory Roller/ Concrete Vibrator	104	38	36	34	32
Water truck	105	39	37	35	33
Wheeled Loader	116	50	48	46	44
Total Noise Level		**61**	**59**	**57**	**55**

Table 22 Worse case predicted noise level at nearest existing receiver

The closest occupied residence "*Highfields*" to a turbine site (Turbine 18) is at about 1,000 metres and near the south eastern part of the wind farm. The predicted noise levels at Highfields from the higher noise level plant such as a bulldozer, hydraulic excavator or large crane will be up to 51 dBA. Each of these plants will only operate for up to several days at Turbine Site 18 and predominantly during day time hours. The impact will be of a short term nature and would be no greater than various farm machinery or trucks operating at times close to the residence or on Hillside Road.

9.3.4 Blasting impacts

Impacts associated with potential blasting activities have been predicted according to Section J7.2 and J7.3 for airblast overpressure and ground vibration respectively from AS 2187.2-2006 [Ref 20]. It should be noted that the prediction methods outlined in the Australian Standard do not take into account topographical shielding or meteorological effects for airblast overpressure and variations in ground conditions for ground vibration which could significantly alter the predicted levels. Prior to any blasting occurring further investigation should be carried out to take into account blasting design, location and ground conditions to ensure the ANZECC criteria are satisfied.

Table 23 shows the minimum recommended distance between the blasting site and nearest sensitive receiver to comply with the criteria outlined in Section 3.8 should be taken as conservative guide.

Effective Charge Mass per delay (kg)	Distance (m) to achieve:	
	Airblast overpressure < 115 dB (lin)	PPV < 5 mm/s
5	185	67
25	316	149
50	398	210
100	502	298
200	632	421
500	858	666

Table 23 Minimum recommended distances between blasting and sensitive receivers

10. Assessment and Recommendations

10.1 Operation noise

Table 24 and Table 25 demonstrates the amount by which the criteria are exceeded for any given hub height wind speed. When atmospheric stability is not taken into account (Table 21) the exceedences are generally very small (1-2 dB) which is not perceptible to the human ear.

The exceedances shown in Table 25 are without mitigation and reach a maximum of 4 dBA in several instances. It is noted that such exceedances only occur infrequently when the Stability Class E conditions prevail and at the wind speeds indicated in Table 25 which represent only a small part of the overall time (about 6% or about 525 hours per year). Also, these predicted exceedances are relative to criterion for Stability Class E at the higher wind speeds (9 to 12) where background noise data was not available and levels were extrapolated. Accordingly, post commissioning monitoring at the potentially affected residences is recommended to verify the actual noise impact.

Receivers	$L_{Aeq,10}$ (dBA) at various Wind Speeds (m/s)								
	4	5	6	7	8	9	10	11	12
Highfields									
Predicted noise level	17	23	29	32	35	37	39	39	40
Criterion (Highfields)	35	35	35	35	35	37	38	40	42
Exceedance	-18	-12	-6	-3	0	0	1	-1	-2
Mayvona									
Mayvona	17	23	28	32	35	37	38	39	39
Criterion (Eungai)	35	35	35	35	35	35	37	38	40
Exceedance	-18	-12	-7	-3	0	2	1	1	-1

Table 24 Predicted exceedances of the criterion at each receiver without consideration of stability

Receivers	Stability E $L_{Aeq,10}$ (dBA) at various Wind Speeds (m/s)								
	4	5	6	7	8	9	10	11	12
Highfields									
Predicted noise level	17	23	28	32	34	37	38	39	39
Criterion (Highfields)	35	35	35	35	35	35	35	35	35
Exceedance	-18	-12	-7	-3	-1	2	3	4	4
Ilparran B									
Ilparran B	14	20	25	29	32	34	35	36	36
Criterion (Glengyle)	35	35	35	35	35	35	35	35	35
Exceedance	-21	-15	-10	-6	-3	-1	0	1	1
Ilparran A									
Ilparran A	14	20	26	29	32	34	36	36	37
Criterion (Glengyle)	35	35	35	35	35	35	35	35	35
Exceedance	-21	-15	-10	-6	-3	-1	1	1	2
Mayvona									
Mayvona	17	23	28	32	34	36	38	39	39
Criterion (Eungai)	35	35	35	35	35	35	35	35	35
Exceedance	-18	-12	-7	-3	-1	1	3	4	4

Table 25 Predicted exceedances of the criterion at each receiver for Stability Class E

Exceedance of the noise criteria has only been predicted to occur in stable atmospheric conditions (Stability E or F) at four properties: Mayvona, Highfields, Ilparran A & B. The dominating wind turbines at those locations are shown in Table 26 below.

Highfields		Ilparran A		Ilparran B		Mayvona	
WTG	**Noise Level (dBA)**	**WTG**	**Noise Level (dBA)**	**WTG**	**Noise Level (dBA)**	**WTG**	**Noise Level (dBA)**
18	33.3	17	28.3	13B	29.6	22B	34.4
19	31	16C	28.2	13	28.3	21B	32.3
16B	28.8	15	27	14	27	10	29.8
17	27.9	16B	26.9	16C	26.2	20B	29.8
22B	27.9	13B	26.8	15	26.1	18	23.8
15	27	13	25.7	17	25.2	15	23.2
16C	27	19	24.7	16B	24.9	16B	23.2
Total	**39**	**Total**	**37**	**Total**	**36**	**Total**	**39**

Table 26 Contributing WTG at the exceedance locations (noise based on Stability E and 12 m/s wind)

If mitigation were shown to be required at relevant receivers, the offending wind turbine(s) will have to be attenuated so that the overall noise level complies with the criteria at each receiver. To attenuate noise being emitted from the wind turbine(s), their operating mode can be changed. This in turn lowers the emitted noise, however it also reduces the power generated by that turbine.

Selection of turbine noise mode can be implemented by using the turbine SCADA control system based on real-time measurements of wind speed and calculated stability class based on wind direction measurements at hub height for the nearest monitoring mast. These data inputs to the SCADA will determine modes of operation for the critical turbines based on pre-determined control logic that is designed to ensure compliance at relevant receiver locations.

Table 27 outlines the required wind turbine operating modes to satisfy criteria individually at each receiver as well as simultaneously at all receivers. These attenuation measures only need to be implemented when Stability E and wind speeds are greater or equal to 9 m/s.

Receiver	**Required operating WTG Mode when Stability E occurs at wind >= 9 m/s**											
	10	**13**	**13B**	**15**	**16B**	**16C**	**17**	**18**	**19**	**20B**	**21B**	**22B**
Highfields	-	-	-	4	4	4	4	4	4	-	-	4
Ilparran A	-	-	-	-	-	4	4	-	-	-	-	-
Ilparran B	-	3	3	-	-	-	-	-	-	-	-	-
Mayvona	3	-	-	-	-	-	-	-	-	4	4	4
Satisfy All	**-**	**-**	**3**	**-**	**4**	**-**	**3**	**4**	**4**	**3**	**4**	**4**

Notes: 3 - Operating Mode 3, 4 - Operating Mode 4, - Standard Operating Mode 0

Table 27 Required operating modes of WTG to satisfy noise criteria

In accordance with technical guideline [Ref 28] a tonal analysis was carried out. The results of the tonal analysis (for the Vestas V90-3 MW turbine operating at Mode 0 as assessed at 500 m) confirmed a reduction in the tonal audibility of tones at around 900 Hz of more than 10 dB. Therefore, a tonal penalty is not considered appropriate.

Post commissioning monitoring of noise impacts and consultation with neighbours will be undertaken to assess the extent of any impacts and the need for mitigation. Noise monitoring at critical relevant receiver locations will monitor compliance and be used to calibrate noise mode selection in the SCADA control logic. This aspect should be addressed by the Project Operations Noise Management Sub-Plan as part of the Operations Environmental Management Plan.

10.2 Construction Noise

Noise emissions are best controlled by implementing a noise management plan which is to utilise best practice methods to minimise noise impacts on sensitive receivers. The following recommendations should be included in the noise management plan:

- Construction activities to be generally limited to the following times, apart from approved excursions for lifting of turbine equipment during periods of low winds and completion of concrete pours if necessary:
  - Monday to Friday – 7 am to 6 pm
  - Saturday – 7 am to 1pm if inaudible on residential premises otherwise 8 am to 1 pm
  - No work on Sundays or Public Holidays
- Use low noise machinery wherever possible
- Place stationary equipment such as air compressors and generators as far as possible from the noise sensitive areas and if necessary, behind barriers
- Provide advance notification to the community of any expected noise disruptions that can occur
- Use temporary structures or screens to limit noise exposure where possible
- Create a log and assessment of complaints, as well as routine monitoring of noise levels during construction and where practicable, modify practices as necessary to reduce the impact

11. References

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Appendix A

Noise Receiver Location within 3km of Wind Farm

Appendix B

Site Photographs

Appendix C

Noise Survey Results

Appendix D

Regression Analysis

Appendix E

Wind Turbine Noise Data

Appendix F

Predicted Noise Contours

Appendix G

Climate Statistics for Glen Innes