5th International Conference
on
Wind Turbine Noise
Denver 28 – 30 August 2013

Wind farm noise commissioning methods: A review of methods based on measuring at receiver locations

Christophe Delaire, Justin Adcock, Daniel Griffin, Sean McArdle
Marshall Day Acoustics 6 Gipps Street, Collingwood VIC 3066 Australia
E-mail: Melbourne@marshallday.com

Summary

Noise commissioning studies are a common regulatory requirement for new wind farm developments in Australia and New Zealand. These studies usually involve unattended A-weighted noise measurements, and in some cases assessment of noise characteristics such as tonality, at surrounding receiver locations to enable comparisons with background noise levels and noise limits established prior to construction of wind farms. This paper presents several examples of commissioning studies that have been completed at Australasian wind farms to explore the benefits and challenges associated with commissioning work based on measurements at receiver locations. Consideration is given to supplementary and alternative commissioning methods such as noise prediction model verification, use of intermediate measurement locations and attended monitoring. Additionally, the commissioning data provides an opportunity for a retrospective review of the suitability of design and planning processes used to develop new wind farm projects.

1. Introduction

Environmental noise is an important consideration in the development of new infrastructure projects in Australia and New Zealand (Australasia). Consistent with this, and in recognition of the sensitivities surrounding wind farm development, regulatory authorities in Australasia have established stringent noise policies for the development and operation of wind farms, comprising:

- Low allowable noise levels relative to wind farm policies in other countries
- Requirements for consented projects to submit detailed design verification data before construction
- Mandatory commissioning measurements at receptor locations once the wind farm is operational.

A key aim of commissioning monitoring is to provide confidence to regulators and local communities that new development adheres to noise limits. The requirement for commissioning measurements at receptor locations is not uncommon for major infrastructure projects in Australasia and abroad. Australia and New Zealand are, however, among the few countries to apply this requirement to wind farms. One of the main challenges to commissioning noise monitoring for any type of development is separating the source and ambient noise influences. This is particularly problematic for wind farms owing to the complexity of noise measurements in windy conditions and the requirement to adhere to limits which are comparable to the background noise. As a result, many other countries address compliance requirements via sound power testing and predictions, or restricting monitoring to instances of complaints.

The requirement for wind farm noise commissioning measurements has been in place in Australasia for at least 10 years, and has been applied to a number of operating schemes. The results of measurements carried out to date provide the opportunity for a retrospective view of the commissioning results. This paper presents an overview of compliance measurements carried out by Marshall Day Acoustics at fifty-eight (58) residential receiver locations in the vicinity of ten (10) operational wind farms with power generating capacity ranging from several megawatts to several hundred megawatts. To provide some context to this number of monitoring locations, of the ten (10) wind farms sites included in this study, a total of sixty-nine (69) receptor locations were predicted to have noise levels higher than the base limit.

The results presented in this paper are based solely on the results of measurements made in accordance with the relevant requirements, and are primarily concerned with A-weighted wind farm noise levels. A discussion is provided about the benefits and limitations of mandatory receptor noise monitoring, and the types of alternative or additional measurement data which can be used in aid of compliance assessments.

2. Australasian wind farms

2.1 Overview

In the *2012 Annual Report* of the World Wind Energy Association [1] a combined wind farm capacity of 3.21GW was reported for Australasia by the end of 2012 (358MW growth in 2012). This places Australasia in thirteenth place worldwide with China and the United States of America leading with 75.3 and 59.9GW respectively (13GW growth each in 2012). Installed wind energy capacity for the top twenty countries is presented in Figure 1.

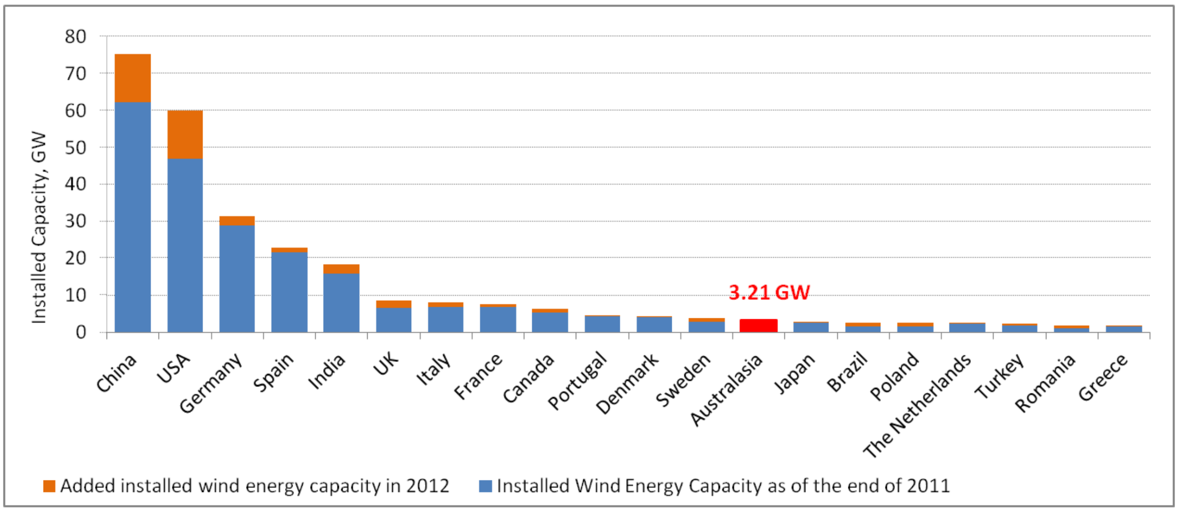


Figure 1: Installed wind energy capacity – top 20 countries

Although generating capacity in Australasia is much lower than leading countries, the post-construction commissioning work required for wind farm sites has been extensive, spanning years in some cases, in order to satisfy planning permit conditions and/or demonstrate compliance.

2.2 Australasian noise commissioning requirements

Wind farm noise assessment in Australasia is guided by a number of different documents which are applicable in different regions. These documents include:

- Australian Standard AS 4959-2010 *Acoustics – Measurement, prediction and assessment of noise from wind turbine generators* [2]
- New South Wales Department of Planning and Infrastructure consultation document *The Draft NSW Planning Guidelines: Wind Farms* dated 2011 [3]
- New Zealand Standard NZS 6808:1998 *Acoustics – The assessment and measurement of sound from wind turbine generators* [4]
- New Zealand Standard NZS 6808:2010 *Acoustics – Wind farm noise* [5]
- South Australian Environment Protection Agency document *Environmental Noise Guidelines: Wind Farms* dated 2003 [6]
- South Australian Environment Protection Agency document *Wind farms environmental noise guidelines* dated 2009 [7]

Some regions of Australasia such as Queensland, Tasmania, Victoria and Western Australia do not have their own detailed assessment methodologies, and instead prescribe the use of either the South Australian guidelines or New Zealand standards.

An overview of the various requirements and methodologies detailed in the relevant assessment documents is provided in Table 1.

Table 1: Summary of wind farm noise assessment methodologies in Australasia

Item	Description
Criteria	The noise contribution of the wind farm at receptor locations is not to exceed the base noise limit or the background level plus 5dB, whichever is higher.
Base limit	A fixed value limit irrespective of wind speed. The value of this limit is 35dB or 40dB depending on the applicable assessment document. The value may be increased to 45dB for receiver locations with an agreement in place with the proponent (stakeholder).
Background level	Measured using the $L_{A90,10min}$ or $L_{A95,10min}$ noise descriptor. Determined from unattended measurements typically spanning 2-6 weeks at multiple receptor locations. Data measured prior to construction is correlated with wind speed at the wind farm site. A regression curve is used to describe the variation in noise level with wind speed, and subsequently forms the basis of background dependent limits. (The transition between the background dependent limit

	and the base limit is referred to as the 'knee' throughout this paper.)
Compliance measurements	Compliance measurements are carried out at noise sensitive locations normally at the same position as background measurements. The same method used for background measurement is used to measure total noise levels (combined background and wind farm noise). The same statistical measurement parameters are primarily used, however some assessment documents refer to the use of equivalent noise levels.
Background level adjustment	If total noise levels are higher than the criteria, an estimate of the wind farm noise contribution is determined by logarithmic subtraction from the total noise of the background noise at integer wind speeds based on the regression curves.
Compliance periods	Criteria and total noise levels may be determined for all hours of a measurement survey. Alternatively some regions or planning permits require separate analysis of data recorded for day and night periods.
Wind speed	Determined at 10m above ground level for older sites. All current assessment documents refer to wind speeds at hub-height.
Wind direction	Criteria and total levels may be determined from measurements made in all wind directions. Some regions or planning permits specify compliance assessments to be restricted to downwind conditions.
Audible characteristics	Audible characteristics which are distinct from the regular and occasional noise associated with a wind farm can attract penalties to the measured noise levels. The relevant characteristics considered vary by region and may include tonality, excessive amplitude modulation, and impulsiveness. Reference is made to objective assessment methods which should be used in the event that audible characteristics are observed. (Audible characteristics are referred to as 'special audible characteristics' in some regions.)

3. Commissioning studies

3.1 Wind farm sites

The characteristics of ten (10) wind farm projects in Australasia in which Marshall Day Acoustics has undertaken noise commissioning are summarised in Table 2.

Table 2: Summary of wind farm sites

Item	Description
Number of turbines	2 to 128
Turbine type	3-blade rotors upwind of the tower
Turbine rated power	1.5MW to 3MW

Item	Description
Hub-height	68m to 80m
Rotor diameter	64m to 90m
Speed regulation	Mostly pitch-controlled variable speed turbines. Some stall regulated turbines.
Environment	Rural areas generally distant from dense populations and high volume traffic corridors
Geography	Mix of flat & undulating terrain with some tall ridges. Mostly inland with some coastal sites

3.2 Commissioning assessment considerations

This review of commissioning studies includes fifty-eight (58) locations across ten (10) wind farm sites. Assessment details vary from site to site. Key differences are outlined in Table 3.

Table 3: Commissioning assessment details (refer to Table 2 for item definitions)

Item	Approach for review of compliance outcomes
Base limit	Review of compliance outcomes applies the relevant base limit for each project.
Noise descriptor	No adjustment is made to measured levels. The practical differences between $L_{A95,10min}$ and $L_{A90,10min}$ levels are not expected to be significant.
Time of day	Review of compliance outcomes is based on 24 hour data sets only.
Wind speed reference height	Sites referenced to turbine hub height have been re-referenced to 10m AGL using the power law and site specific average wind shear values. All wind data presented in this paper is referenced to 10m AGL.
Wind direction	Review of compliance outcomes applies the wind direction based assessment requirements specific for each wind farm. In some cases, compliance assessment includes filtering for wind direction while in others all wind directions are included in the assessment.

3.3 Measurement results overview

To highlight the difficulties in measuring wind farm noise in environments where the background levels are comparable, Figure 2 presents total, background and predicted levels as a function of the separating distance between each monitored receptor and the nearest turbine.

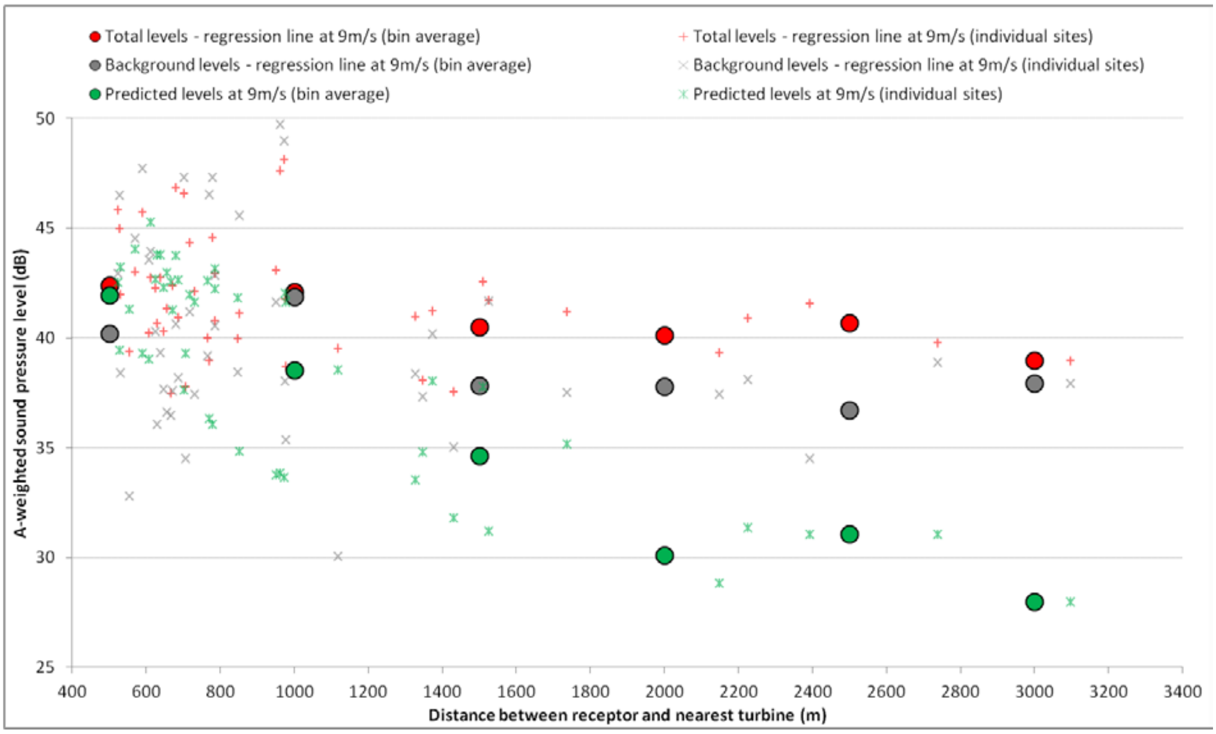


Figure 2: Total, background and predicted levels vs. separation distance

Figure 2 demonstrates that predicted levels decrease with distance between receptors and wind turbines. As a result, it becomes difficult to practically measure wind farm noise as distance increases due to increasing influence from background noise.

To provide an indication of the average range of levels encountered during the studies, Figure 3 and Figure 4 present average total level trends with wind speed for wind farm stakeholders and non-stakeholders, respectively. In each case, the trends are presented with an associated variation indicated by one standard deviation either side of the average. Additionally, each figure presents an average background level and the associated standard deviation.

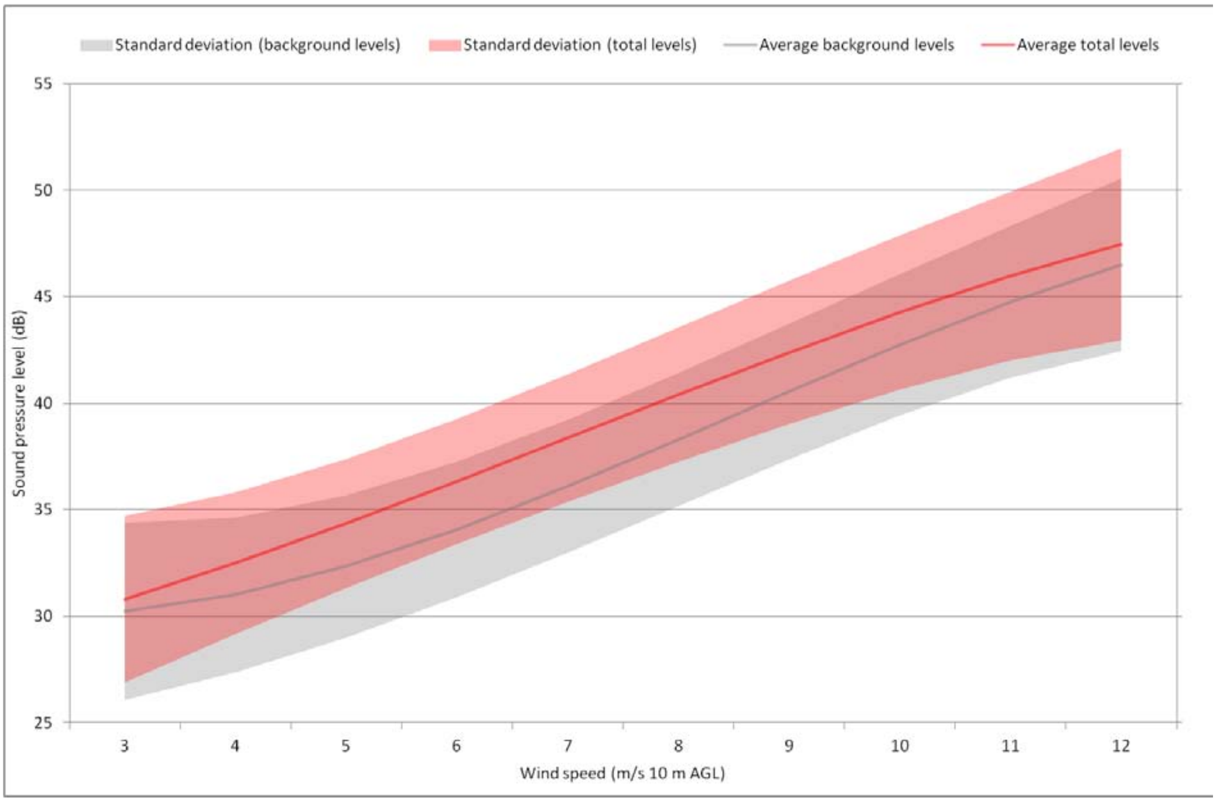


Figure 3: Average measured noise levels vs. wind speed (non-stakeholders)

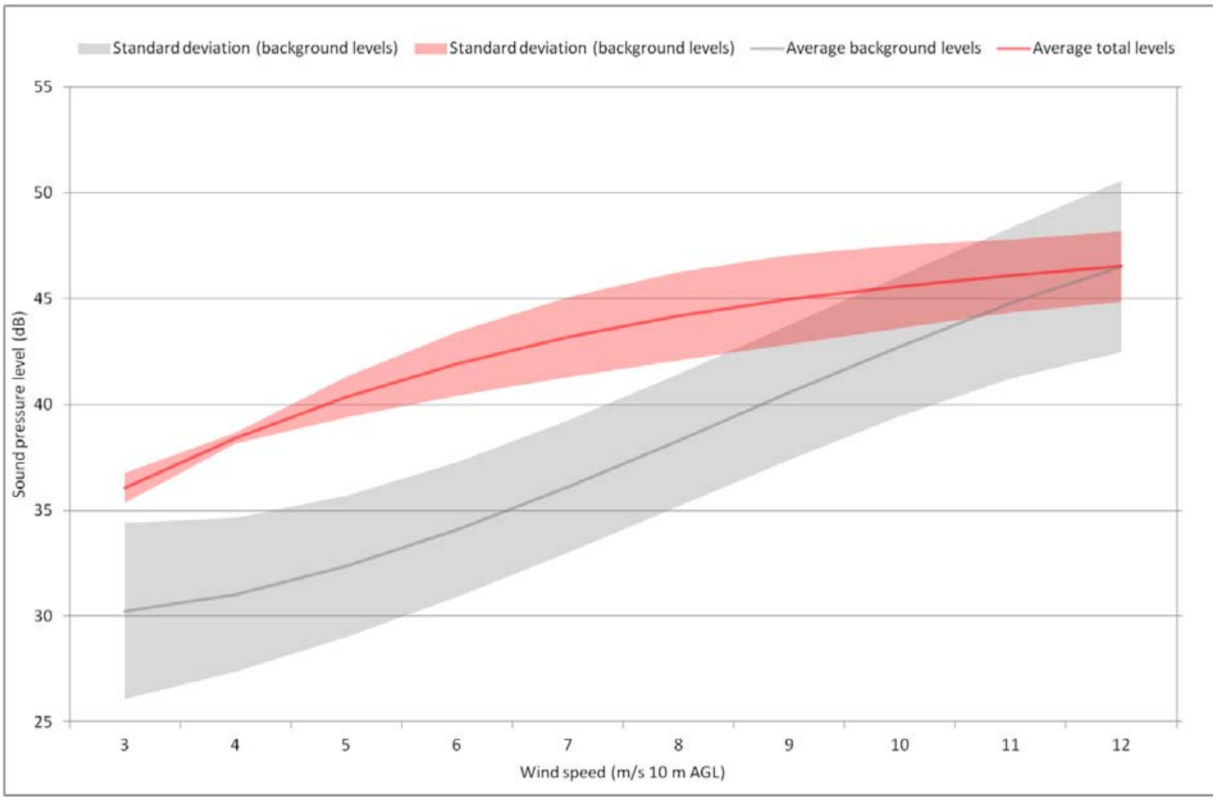


Figure 4: Average measured noise levels vs. wind speed (stakeholders)

It can be seen that the measured background and total levels range from approximately 30dB to 45dB and greater. Figure 3 illustrates that the average difference between background and total levels at non-stakeholder properties is generally not greater than 3dB. The difference at stakeholder properties, shown in Figure 4, is more pronounced at up to approximately 7dB at 5m/s.

These results, particularly those in Figure 3, demonstrate the comparatively small difference that can occur between background and total levels, highlighting the difficulties associated with undertaking commissioning measurements at receiver locations.

3.4 Compliance outcomes

The results presented in this study demonstrated compliance at all of the fifty-eight (58) locations where compliance surveys were carried out. The compliance results are categorised as follows:

- At thirty-nine (39) of the fifty-eight (58) locations, compliance with the criteria was demonstrated at all wind speeds by direct comparison of the total levels with the criteria.
- At twelve (12) of the fifty-eight (58) locations, compliance with the criteria was demonstrated at all wind speeds by adjusting the measured total levels for the influence of background noise according to the relevant assessment documents. The adjustments were based on estimates of the background influence by logarithmic subtraction of the background levels. Given the inherent variability of background levels, this type of procedure can only be regarded as an estimate. However, in recognition of this, the background adjustment is limited to a maximum value of 1.3dB (in accordance with IEC 61400-11:2006 [8], Section 8.2). Adopting this limitation, the method is considered to provide a reasonable and conservative estimate of the true background noise influence.
- At seven (7) of the fifty-eight (58) locations, compliance was ultimately demonstrated at all wind speeds, but significant variations in background noise were a complicating factor. Specifically, it was not possible to demonstrate compliance solely on the basis of background adjusted measurements. In each case, a number of site-specific factors indicated background noise was the major contributor to measured levels. These factors included the measurement of lower levels at locations near to the wind farm where background levels were lower. Other factors included the relationship between noise levels and wind speeds, and how this differed from the relationship observed at positions where wind farm noise was able to be directly measured (and differed from the relationship evident in the sound power test data). Relying on a combination of extended measurement durations (sometimes in excess of several months), audio records, frequency data, and trends in noise levels such as those exhibited in different wind directions, compliance with the criteria was able to be determined from the total collection of data sources. Whilst these situations were confined to a minority of the fifty-eight (58) locations surveyed, the level of monitoring and analysis work required to ultimately prove the measurements were dominated by background influences represented a significant portion of the total survey effort.

As detailed above, at nineteen (19) locations comparison of measured total noise levels and noise limits was not sufficient to demonstrate compliance. In fourteen (14) of these nineteen (19) cases, the wind speed range where the measured total level exceeds the noise limit spanned the knee of the noise limit. At these locations it is effectively the knee which becomes the critical assessment point.

At the five (5) locations where the knee was not the critical point, the measured total noise level exceeded the limit at wind speeds above the knee. For two (2) of these locations stall regulated turbines were installed.

4. Case studies

4.1 Location A: Complex compliance

Figure 5 shows an extract of monitoring results at a typical receiver location. It can be seen that the measured total levels are greater than the criteria between 7.5 and 9.5m/s.

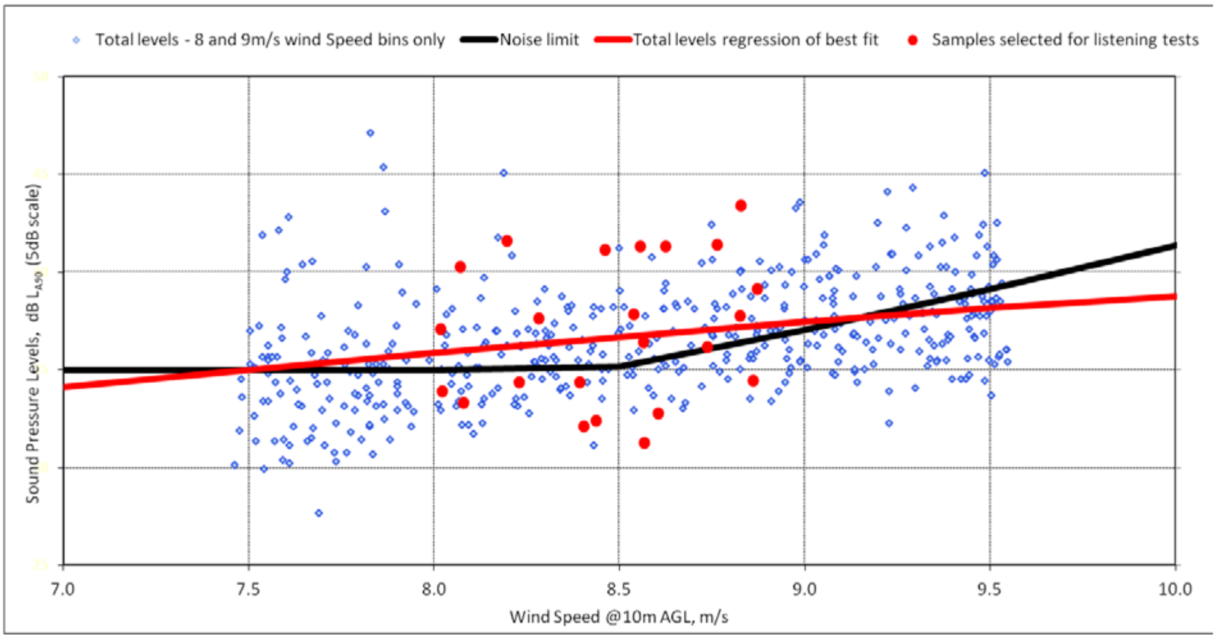


Figure 5: Example extract of a typical receiver location monitoring analysis

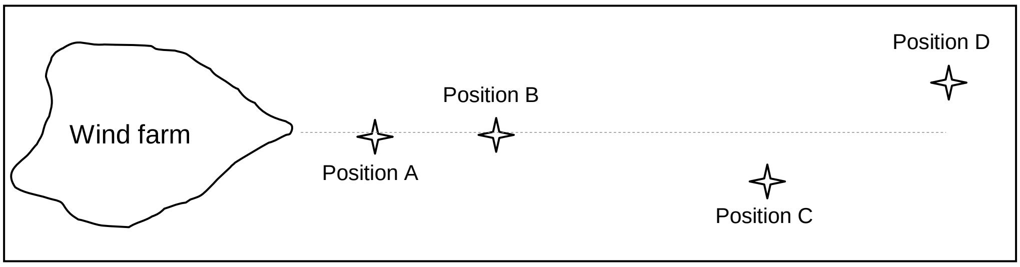
In this instance, audio recordings were available to enable listening tests. A selection of the audio samples within the critical wind speed range (shown as red dots in Figure 5) were used as a complementary means of gauging the extent to which the operation of the wind farm contributes to the total level. It was found that periods with noise levels above the limit typically included extraneous noise sources such as bird noise and cattle noise.

This information was used in conjunction with other trend data to demonstrate the wind farm contribution was below the applicable noise limit.

4.2 Location B: Intermediate measurement points

Measurement locations at intermediate points between the wind farm and receptor locations offer an advantage in measuring wind farm noise distinct from background. This method enables the relationship between turbine emissions and wind speed to be established, particularly above rated power. Additionally, multiple intermediate measurement locations can be used to better understand trends of decreasing wind farm levels with increasing distance.

Figure 6 presents predicted and measured levels at increasing distances from a wind farm. The position of the wind farm relative to the measurement locations is shown schematically below.



Comparison of the data at 250m and 500m from the wind farm indicates a consistent relationship between measured and predicted noise levels. Comparison of the 1400m and 2400m locations demonstrates little to no drop in measured noise level. In contrast, the change in predicted levels between these two locations provided support for the measured levels at 2400m being dominated by background noise levels.

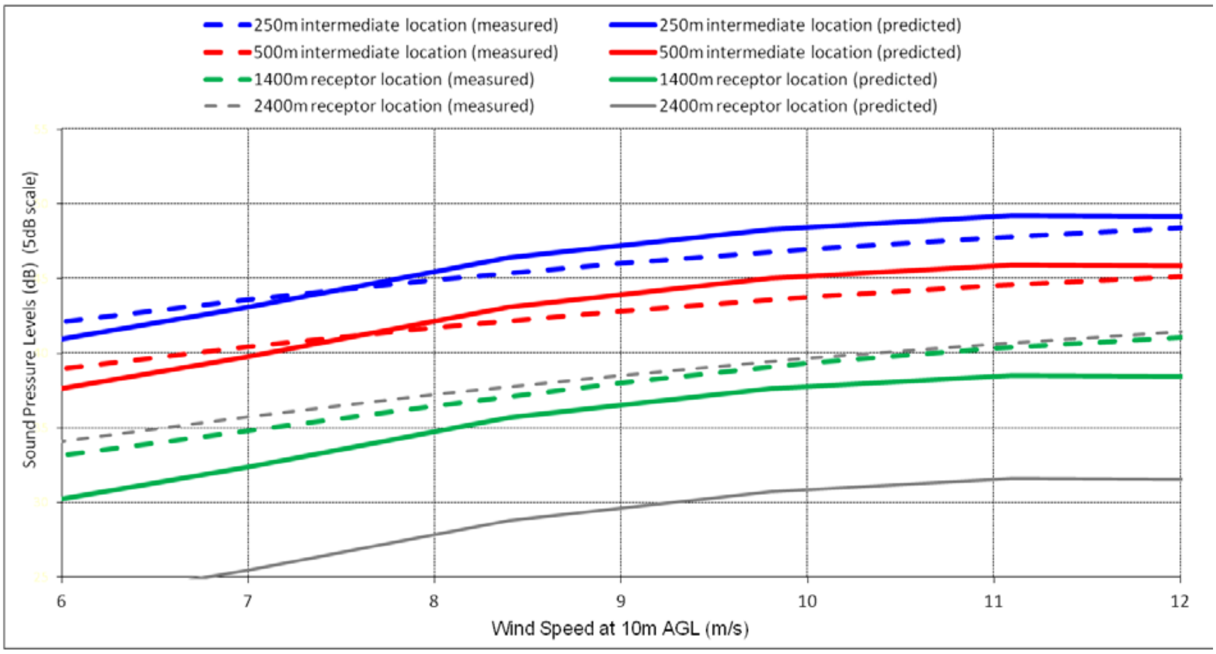


Figure 6: Comparison of measured and predicted noise levels with distance

5. Discussion

5.1 Benefits and limitations of existing compliance monitoring methods

Based on the results of this study, the following advantages and disadvantages of commissioning measurements at receptor locations were identified.

Pros	Cons
Direct account of the actual noise levels at the receptor locations, rather than relying on predictions.	Evidence supports that predictions offer a reliable means of determining wind farm noise levels at receptor locations.
Demonstrates that noise levels at receptor	Measurements at some receptor locations

locations comply with the requirements.	are significantly complicated by background noise variations. Complex results can create uncertainty about compliance outcomes.
Supports the methods used to design wind farms, in turn offering credibility for the use of those methods for future projects.	Continued emphasis on the need for measurements at receptor locations may inadvertently undermine the perceived reliability of predictions.
Extended unattended survey durations enable a range of conditions to be assessed.	Repeated wide scale surveys at receptor locations are impractical to demonstrate ongoing compliance. The bias toward prolonged unattended surveys limits the amount of compliance information available for audible characteristics.
The results offer a valuable reference for objective noise policy reviews.	The results are not retained in centralised public records, and the results are not correlated with community satisfaction/dissatisfaction with noise.
Allows for a practical method of adjusting for background influence which is sufficient for demonstrating compliance at the majority of receptor locations.	Background noise levels are inherently variable, and in instances where background noise levels are higher, the assessment is dependent on alternative data sources not detailed in the guidance documentation.

5.2 Community expectations

The observation that compliance has been demonstrated at all fifty-eight (58) receptor locations demonstrates that commissioning results are broadly consistent with planning assessments.

It could be expected that this consistency of outcome would provide confidence to the community including wind farm regulators. However, the Renewable Energy (Electricity) Amendment (Excessive Noise from Wind Farms) Bill 2012 (Cth) read in the federal parliament of Australia on 29 June 2012 and seeking to impose accrediting sanctions for wind farms generating ‘excessive noise’, suggests that confidence in the current compliance methodologies is lacking for some members of the community.

There may be many complex factors influencing an individual’s or community’s confidence in the planning and development process for wind farms and to consider noise commissioning without a broader context over-simplifies the situation. Nonetheless, it is noted that changes to how commissioning results are reported may be helpful. For example, as noted above, in nineteen (19) of the fifty-eight (58) sites considered, demonstrating compliance required more than a simple comparison of total measured noise levels with noise limits. The additional analysis required for compliance can result in lengthy and detailed descriptions of the assessment methodology which are more difficult for the community to understand.

Improving the reporting of outcomes could be addressed in part during commissioning studies. There may also be some advantage in having reporting requirements clarified in regulatory assessment documents. For example, commissioning measurements at locations beyond the base noise limit contour of the wind farm are likely to be heavily influenced by background noise and require complex methodologies to assess compliance. Acknowledgement of this kind of issue in regulatory assessment documents could simplify reporting of commissioning outcomes and may also provide assurance to wind farm neighbours that assessment techniques used during commissioning are valid.

5.3 Balance of methodologies used during commissioning

The regulatory system in Australasia prioritises commissioning measurements at receptor locations. There may, however, be merit in reviewing the balance of measurement techniques used during a commissioning study in order to:

- Increase the certainty of commissioning outcomes
- Improve the efficiency of commissioning methods

A range of alternative commissioning methods are discussed in Table 4 below.

Table 4: Alternative commissioning methods

Item	Comment
Intermediate survey points	As outlined in Case study A, intermediate points can offer a better signal to noise ratio for wind farm measurements.
Derived survey points	Derived survey points away from receptor locations at positions with lower background levels, but at a similar distance from a wind farm, and therefore with similar noise exposure, can provide helpful complimentary analysis of wind farm levels and, in particular, the possible influence of ambient noise at the receiver location. This is particularly relevant for exposed windy locations where wind farms are usually sited, as residential locations will frequently feature increased levels of vegetation for the purpose of wind breaks.
Shut downs	Shut down testing can assist in confirming the contribution of ambient to total levels. However, there can be difficulties in coordinating site wide shut down and start up of turbines. Additionally, a significant amount of shut down testing may be necessary to capture a sufficient amount of data over a suitable range of wind conditions.
Frequency data, audio records	One-third octave band filtering of measured levels, coupled with listening studies of collected audio samples, can identify periods significantly influenced by extraneous noise.[9]

6. Conclusions

Significant variation of background noise, inherent in windy environments, represents the greatest technical challenge to commissioning measurements at receptor locations. Despite this, and contrary to expectations, compliance with the relevant criteria was able to be demonstrated in more than 85% of cases by direct measurement of total levels with limited adjustments for background influences when necessary.

Significant measurement complications from background noise influence were evident at less than 15% of sites. These locations, however, required disproportionate and protracted efforts to achieve an acceptable level of confidence in the compliance status of the wind farm. In particular, some locations required measurements spanning several months or more in different seasons to capture suitable wind directions. Extensive analysis was also required to ultimately prove that background influences were responsible for measured levels above the criteria. Whilst these situations occurred at a minority of measurement locations, the complexity of these situations contributed to regulator and community concerns about the compliance status of the wind farms. The complexity of the assessment, and the lack of directly measured levels below the criteria, frequently proved difficult for regulators and the community to interpret, somewhat undermining the level of confidence sought from commissioning measurements.

Given that compliance was ultimately demonstrated at all of the fifty-eight (58) receptor locations, it could be expected that confidence in the regulatory system and processes should be supported by commissioning work. There is, however, no objective data to demonstrate that the extensive commissioning obligations placed on Australasian wind farms has significantly enhanced regulator or community confidence in the management of wind farm developments. A centralised regulator record of compliance outcomes may assist, and may also provide a more objective reference for periodic policy reviews.

The demonstration of compliance at all locations does however suggest that commissioning measurements at receptor locations is not necessarily justified on technical grounds. Specifically, these findings, in conjunction with research into wind farm noise predictions [10] [11] [12] support that wind farm levels can be reliably calculated on the basis of sound emission data determined from international standard test methods. Regulatory systems in Australasia do however prioritise commissioning measurements at receptor locations, particularly given the absence of endorsed or standardised prediction methodologies. Accordingly, despite the technical data suggesting commissioning monitoring may not be required, surveys at receptor locations are likely to be an ongoing requirement for new wind farm projects. These findings do however provide justification for considering:

- Reduced emphasis on measurements at receptor positions, particularly those locations where predicted wind farm levels are less than the base limit
- Increased emphasis on the utility and acceptability of alternative commissioning data, such as measurements at intermediate and derived points combined with prediction based data.

References

[1] World Wind Energy Association, World Wind Energy Report 2012 (May 2013).

[2] Standards Australia, Acoustics – Measurement, prediction and assessment of noise from wind turbine generators, AS4959:2010, Standards Australia, Sydney, (2010).

[3] New South Wales Department of Planning and Infrastructure, NSW Planning Guidelines: Wind Farms Draft for consultation, State of New South Wales through the Department of Planning & Infrastructure, Sydney, (2011).

[4] Standards New Zealand, Acoustics – The assessment and measurement of sound from wind turbine generators, NZS6808:1998, Standards New Zealand, Wellington, New Zealand, (1998).

[5] Standards New Zealand, Acoustics – Wind farm noise, NZS6808:2010, Standards New Zealand, Wellington, New Zealand, (2010).

[6] South Australia Environment Protection Authority, Environmental noise guidelines: Wind farms, South Australia Environment Protection Authority, Adelaide, (2003).

[7] South Australia Environment Protection Authority, Wind farms Environmental noise guidelines, South Australia Environment Protection Authority, Adelaide, (2009).

[8] International Electrotechnical Commission, Wind turbine generator systems – Part 11: Acoustic noise measurement techniques, IEC 61400-11.

[9] Griffin, D, Delaire, C and Pischedda, P, Methods of identifying extraneous noise during unattended measurements, 20th international congress on sound and vibration, Bangkok, Thailand, 7-11 July 2013.

[10] Bass, J.H., Bullmore, A.J. & Sloth, E, 1998 Development of a Wind Farm Noise Propagation Prediction Model, Non-Nuclear Energy Programme Joule III, Contract JOR3-CT95-0051.

[11] Adcock, J.G., Bullmore, A.J., Cand, M, Jiggins, M, Wind Farm Noise Predictions and Comparisons with Measurements, Third International Meeting on Wind Turbine Noise, Aalborg, Denmark, 2009.

[12] Delaire, C, Griffin, D & Walsh, D 2011, Comparison of predicted wind farm noise emission and measured post-construction noise levels at the Portland Wind Energy Project in Victoria, Australia, Fourth International Meeting on Wind Turbine Noise, Rome, Italy.