Comparison of compliance results obtained from the various wind farm standards used in Australia

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ABSTRACT

There are a number of standards and guidelines which are used in Australia for the assessment of wind farm noise. While there is some variation in the lower noise limit applied, the standards and guidelines typically set noise criteria for wind farms as 40 dB(A) or the background noise level + 5 dB(A), whichever is the greater. Additionally, they provide different methods for measuring compliance once the wind farm is operational. This paper examines the differences that result when assessing compliance against the various measurement and analysis procedures. Compliance measurements from a number of receivers surrounding several wind farm sites are used in the analysis. Differences of between 1.9 and 4.3 dB(A) are observed between the highest and lowest assessment results obtained at individual receivers, although this range is reduced to 1.9 - 2.7 dB(A) when L_{Aeq} results that appeared to be influenced by extraneous noise are discarded. These results complement the findings of our other paper which compares predicted levels against the compliance measurement results, and can be used to compare predictions against wind turbine noise levels measured and analysed using different methodologies.

INTRODUCTION

In recent years there has been significant growth in wind farm electricity generation across Australia. The current national focus on renewable energy and greenhouse gas emissions reduction is likely to maintain or result in increased growth in this sector.

There are a number of standards and guidelines which are used or are intended to be used in Australia for the assessment of wind farm noise. These include, but are not limited to; the South Australian *Wind farms environmental noise guidelines* 2009 (SA EPA, 2009), the South Australian *Wind Farms Environmental Noise Guidelines* 2003 (SA EPA, 2003), Australian Standard 4959:2010 (AS 4959:2010), New Zealand Standard 6808:2010 (NZS 6808:2010), New Zealand Standard 6808:1998 (NZS 6808:1998), and the currently draft *National Wind Farm Development Guidelines* (EPHC, 2010).

A detailed discussion of the slightly different approaches used to set noise criteria for wind farms is beyond the scope of this paper, but the standards and guidelines typically set noise criteria for wind farms to be achieved at sensitive receivers as 40 dB(A) or the background noise level + 5 dB(A), whichever is the greater.

Once noise criteria have been established for a proposed wind farm development it is the acoustic engineer‟s task to provide detailed wind turbine noise level predictions at the noise sensitive receivers around the site. Following the completion of construction, compliance noise measurements are undertaken at the nearest noise sensitive receivers to confirm compliance with the relevant standard or guideline.

It is important that noise levels are accurately predicted at the design stage. Under-prediction of noise levels may result in failure to meet the noise criteria and the expensive shut down of wind turbines, while overly conservative modelling curtails renewable energy generation and reduces the size, and potentially the financial viability, of wind farm developments.

The standards and guidelines used to assess wind farm developments provide different methods for measuring and analysing operational noise levels at the completion of construction. These differences between the measurement methods result in differences in the measured noise level and can therefore potentially affect whether or not compliance with the noise criteria is achieved.

This paper assesses the magnitude of differences that result when assessing compliance measurements using the various measurement procedures. Compliance measurements from a number of residences surrounding four wind farm sites are used in the analysis. When selecting data for analysis, particular focus was placed on using measurement data from locations where wind turbine noise was the dominant noise source, to minimise the influence of background noise on the findings.

This paper complements the finding of our paper titled „Comparison of predicted and measured wind farm noise levels and implications for assessments of new wind farms‟ (Evans and Cooper, 2011), which is also presented at this conference. Together they can be used to compare the accuracy of a number of wind turbine noise prediction methods to compliance monitoring results obtained from a variety of compliance measurement and analysis procedures.

STANDARDS USED IN AUSTRALIA

Several different standards and guidelines are used to assess wind farm noise in Australia. The compliance measurement and analysis requirements of these standards are summarised below.

South Australian Wind farms environmental noise guidelines 2009

The South Australian *Wind farms environmental noise guidelines* 2009 (2009 SA Guidelines) were developed by the South Australian Environment Protection Authority (EPA).

The 2009 SA Guidelines require that the $L_{A90,10min}$ noise level is measured over the range of wind speeds from cut-in speed to the speed of the rated power of the turbines at a minimum. The data is to cover at least 2000 intervals, with at least 500 intervals corresponding to the worst case wind direction.

The worst case wind direction is defined as wind directions within 45° of downwind of the nearest wind turbine to the measurement site. The compliance assessment is based on only the data measured under the worst case wind direction – all data from other directions is excluded from the compliance assessment. A polynomial regression analysis is undertaken to determine the measured wind turbine noise level, with correction for the previously measured background noise data applied if required.

Where the above method proves unsuitable for compliance checking the 2009 SA Guidelines allow for alternative techniques to be employed, following discussions with the EPA. Suggested alternatives include attended measurements with periodical shutdown of wind turbines if required.

South Australian Wind farms environmental noise guidelines 2003

The South Australian *Wind farms environmental noise guidelines* 2003 (2003 SA Guidelines) were an earlier version of the 2009 SA Guidelines and were also developed by the South Australian EPA. The 2003 SA Guidelines are still used in some States to assess wind farm noise.

Both the 2003 and 2009 SA Guidelines use L_{A90} levels measured under downwind conditions to assess compliance of the wind farm. The compliance result achieved by the two methods should therefore be the same, such that they are not separately assessed in this paper.

New Zealand Standard 6808:2010

New Zealand Standard 6808:2010 *Acoustics – Wind farm noise* (NZS 6808:2010) was recently adopted in Victoria.

NZS 6808:2010 expects that at least 10 days (1440 data points) of compliance measurements are undertaken, with data gathered over the range of wind speeds and directions normally expected at the wind farm. The $L_{A90,10min}$ noise level is measured over this 10 day period.

Unlike the 2009 SA Guidelines, there is no specific requirement to exclude data points outside the downwind direction. However, if the initial background noise measurements indicate a significant difference in the pre-construction noise levels under different wind directions or times of day, noise criteria may be set based on particular wind directions or times of day. There is chance that this difference in pre-construction background noise levels might be noted for a downwind direction, so there is some potential for an unintended downwind compliance measurement to be taken. Additionally, there is a chance that the wind that occurs during the compliance measurements is from predominantly downwind directions. However, for the purposes of our investigation it has been assumed that all directions are assessed together.

NZS 6808:2010 provides the site operator with the option of taking attended „on/off" compliance measurements at receivers if appropriate, but a review of the results from on/off testing is not included in this paper.

New Zealand Standard 6808:1998

New Zealand Standard 6808:1998 *Acoustics – The assessment and measurement of sound from wind turbine generators* (NZS 6808:1998) was used to set noise criteria for new wind farm applications in Victoria until March 2011.

The key difference in the compliance measurement method outlined in NZS 6808:1998 (as compared to NZS 6808:2010) is that $L_{A95,10min}$ levels are used rather than $L_{A90,10min}$ levels. Like the 2010 standard, NZS 6808:1998 potentially requires compliance measurements under different wind directions and times of day.

While not intended by the standard, Planning Permits issued for wind farms in Victoria have typically included the requirement that compliance is assessed separately for the "all-time" (24 hours) and night time (10pm – 7am) period. The requirements for downwind, and 90° sector analysis have also been previously included in Planning Permits although this is not specifically required under NZS 6808:1998 (Delaire and Griffin, 2011).

Australian Standard 4959:2010

Australian Standard 4959:2010 *Acoustics – Measurement prediction and assessment of noise from wind turbine generators* (AS 4959:2010) has been recently introduced.

AS 4959:2010 is the only standard that requires that the L_{Aeq} noise level from the wind farm is assessed against the predetermined noise criteria. It outlines two possible methodologies that might be used for compliance testing, but notes that the method used should be agreed with the Relevant Authority prior to the commencement of testing.

Methodology 1 included in the Standard follows the same approach as the background noise measurements, with approximately 2000 representative measurements to be collected. The standard leaves many assessment decisions, such as the speeds and directions to be assessed, to the Relevant Regulatory Authority, but notes that:

> Generally, data collected when the wind direction is from the wind farm to the receiver would be the data of primary interest to the Relevant Regulatory Authority.

In acknowledgment of the difficulty of measuring L_{Aeq} compliance levels directly without contribution from extraneous noise sources, Methodology 1 of the Standard requires the measurement of the L_{A90} noise level, with a numerical addition of a minimum of 1.5 dB added to each measurement to account for the expected difference between the wind farm L_{Aeq} and L_{A90} levels. Methodology 1 considers that all noise measured at the receiver is the result of noise from the wind turbines, with no allowance provided to correct for background noise. The standard notes that this method is likely to be a conservative method.

For the purposes of our assessment we have assumed that the Relevant Regulatory Authority has required compliance measurements are taken under downwind conditions, with a direction tolerance of ±45°.

Methodology 2 provided by the standard requires the use of attended noise measurements at one noise sensitive receiver, to validate prediction model outputs and therefore compliance with criteria at the other receivers. At least ten 10-minute L_{Aeq} measurements are required both above and below the „critical" wind speed, with the attended measurements to extend to speeds at least 3m/s above and below the „critical" wind speed. Attended L_{Aeq} measurements with the wind turbines turned off may be used to correct for the influence of background noise if necessary.

While this paper presents no results from attended measurements we provide some comment on the suitability of Methodology 2 for determining compliance at all receivers around a wind farm.

Draft National Guidelines July 2010

The draft *National Wind Farm Development Guidelines* (Draft National Guidelines) were introduced for a 12 month trial in July 2010. The Draft National Guidelines suggest that initially Methodology 1 of AS 4959:2010 is used for compliance measurements. Where compliance is unclear from those measurements and it is suspected this is as a result of background noise, it is recommended that the same measurement procedure is to be followed, but repeated at a „secondary location". The secondary location is a location selected near the receiver that is the same distance from the same wind turbines, where the geographical setting and predicted noise level is the same as the original location, but is further from extraneous noise sources.

Where it is not possible or practical to confirm compliance through measurements at a secondary location, attended measurements using Methodology 2 of AS 4959:2010 are recommended. However, it is important to note that the Draft National Guidelines use attended measurements at each problematic receiver, rather than trying to use measurements at one receiver to confirm the accuracy of noise predictions and compliance at other receivers like AS 4959:2010.

In extreme cases where none of the above methods are able to demonstrate that compliance is achieved but the Relevant Authority agrees that compliance is likely to be achieved, the Draft National Guidelines suggest „derived point measurements". Derived point measurements use measurement results at a location closer to the wind farm where noise levels are clearly controlled by wind farm noise to calibrate the noise model.

As the Draft National Guidelines initially follow Methodology 1 of AS 4959 they are not separately assessed in this paper. However, comment on the suitability of the secondary methodologies suggested by the Guidelines is provided.

Summary of assessment methods

The key requirements of the various assessment methods considered in our analysis are presented in Table 1

Table 1. Summary of compliance assessment methods

Method	*Descriptor*	*Wind direction*
SA Guidelines	L_{A90}	Downwind
NZS 6808:2010	L_{A90}	All
NZS 6808:1998	L_{A95}	All
AS 4959	L_{Aeq}	Downwind

We note that wind direction used during the AS 4959:2010 compliance assessment methodology is to be determined by the Relevant Regulatory Authority. For the purposes of our assessment it has been assumed that the Authority has requested that a downwind assessment is undertaken to provide more direct comparison to the 2009 SA Guidelines.

SITE DESCRIPTIONS

Four wind farm locations and ten measurement sites have been selected for comparison in this paper as the measurements collected at these wind farms appear to be controlled by noise from the wind turbines across a reasonable wind speed range.

The measurement sites are typically representative of the closest receivers to wind farms in South Australia, although we note that several of the measurement sites were not actually in the vicinity of a noise sensitive receiver. Turbine noise levels at the measurement sites are generally higher than noise levels at typical receivers adjacent to wind farms. While this restricts the range of distances at which measured and predicted noise levels are compared in this paper, the sites are representative of the distances at which actual noise levels from turbines are between approximately 35 and 40 dB(A), where noise from a wind farm represents a design constraint.

For commercial reasons, the names and locations of the wind farms have not been disclosed and the wind farms will be designated as Wind Farm A through to D. Based on compliance monitoring conducted at each site, all of these wind farms are in compliance with the environmental noise criteria. A description of each wind farm is presented in the following sections.

Wind Farm A

Wind Farm A involves a line of turbines (approximately 2 MW) stretching for about 10 kilometres along the top of a range of hills. The turbines are spaced approximately 400 metres apart from each other. Three noise measurement sites have been considered as part of this comparison and have been designated A1, A2 and A3. Each of the measurement sites are located between 800 and 1000 metres from the nearest turbine, and are situated 50 to 70 metres lower than the base height of that turbine.

Wind Farm B

Wind Farm B also involves a line of turbines (approximately 2 MW) stretching for about 10 kilometres along the top of a range of hills. The turbines are spaced approximately 300 metres apart from each other. Three noise measurement sites have been considered as part of this comparison and have been designated B1, B2 and B3. The measurement sites are located between 900 and 1,700 metres from the nearest turbine, and are situated 130 to 200 metres lower than the base height of that turbine.

Wind Farm C

Wind Farm C involves a group of turbines (approximately 1.5 MW) distributed over an area of about 20 square kilometres. The turbines are spaced approximately 350 metres apart from each other. Four noise measurement sites have been considered as part of this comparison and have been designated C1, C2 and C3. The measurement sites are located between 300 and 900 metres from the nearest turbine.

Wind Farm D

Wind Farm D involves a line of turbines (approximately 1.5 MW) stretching over about seven kilometres. The turbines are spaced approximately 250 to 400 metres apart from each other. One noise measurement site has been selected for this comparison and has been designated D1. The measurement site is located approximately 350 metres from the nearest turbine but is also located approximately 800 metres from another four turbines from another direction.

NOISE MEASUREMENT PROCEDURE

A-weighted $L_{eq,10min}$, $L_{90,10min}$ and $L_{95,10min}$ noise levels from the operational wind farms were logged at each of the measurement sites over a period of three to four weeks. Class 2 noise monitoring equipment was used at each of the sites and the calibration checked both before and after the measurement period to check that no significant drift had occurred. The microphone was located at 1.2 to 1.5 metres above ground and fitted with a 90 mm thick windshield, which was adequate to reduce the influence of wind-induced noise on the measurement (Cooper, Leclercq and Stead, 2010).

Measurements that were obviously affected by extraneous noise sources or that did not coincide with wind speeds between the cut-in and cut-out of the turbines were excluded from the analysis. For certain situations, the measurements were filtered based on wind direction when results for specific wind directions were required, e.g. for the 2009 SA Guidelines. Following the removal of data points, between 2000 and 4000 data points remained at the various measurement sites for the situations where all wind directions were being considered. For those situations where only a single wind direction ±45º was considered, between 200 and 1000 data points remained at the various measurement sites. Where less than 500 data points remained at a particular wind speed, these were confined mainly to the small range of wind speeds where site measured sound power data was available.

The measured noise levels were correlated with wind speeds for the period, measured at the most representative hub height meteorological mast. A single "measured" noise level value for each integer wind speed was then determined by fitting a polynomial regression line to the data.

A significant issue that can affect measurement results from operational wind farms is the contribution of the background noise environment to the overall measured level. While this can be somewhat overcome by subtracting the measured pre-construction noise levels from the measurements, this method is susceptible to error as background noise levels have been shown to change across seasons and years (Delaire and Walsh, 2009), and because of differences between pre- and post-construction measurement locations.

To address this, each measurement site was selected such that it was as far away as possible from potential sources of background noise (e.g. trees, occupied dwellings) and such that the noise environment at the site was typically controlled by wind turbine noise. In addition, only wind speeds where the noise level appears to be controlled by wind turbine noise have been considered. These wind speeds have been selected based on analysis of the measurement data and observations carried out on site during the measurements.

As an example, Figure 1 presents measurement results for Site B3, indicating a range of wind speeds where the measured noise level is controlled by turbine noise. This is evident due to the small spread of the measurement data when compared to wind speeds where the background noise level causes significant variation between measured levels at the same speed. At lower wind speeds, there are a number of measurements where the turbine clearly cut-out due to low wind speed during the measurement period. These have been excluded from further analysis.

The change in measured noise levels with wind speed correlated almost precisely with the change in sound power levels for the turbines, an indication that the noise levels were controlled by noise from the turbines. This is discussed in more detail in our other paper (Evans and Cooper, 2011).

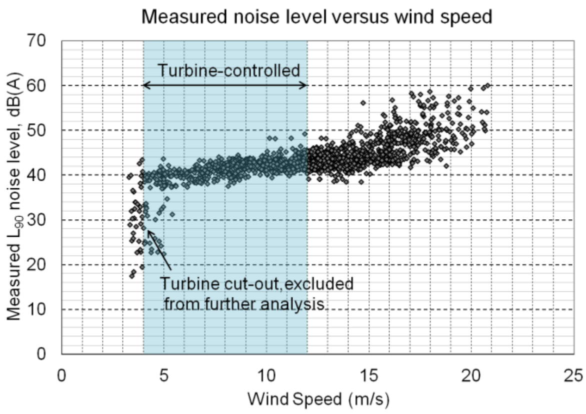

Figure 1. Example of measured noise levels versus wind speed with turbine-controlled wind speed range

RESULTS

The compliance noise level measured using the 2009 SA Guidelines was selected as a reference level, against which the results from all other compliance measurement methods were compared. The 2009 SA Guidelines use the worst case wind direction and the L_{A90} noise level, which is expected to make them less susceptible to variation than some other methods. The use of the downwind directions should, in practice, provide a more repeatable compliance measurement as the result will not be influenced by variations in the distribution of wind directions that occur during the compliance measurement period. Additionally, L_{A90} levels should be less susceptible than L_{Aeq} levels to the influence of short term extraneous noise.

In support of this supposition, compliance measurements were recently repeated at one of the sites in this study, almost two years after they were first assessed using the 2009 SA Guidelines. The variation in the measured compliance level was less than 1 dB(A) over the entire range of wind speeds where the noise level appeared to be turbine-controlled. This demonstrates the repeatability of the 2009 SA Guidelines compliance measurement method when used at locations not influenced by extraneous noise.

Table 2 summarises the average difference in compliance measurement results achieved between the tested methods at each site. The single value has been obtained by averaging the single „measured" noise level at each integer wind speed over the range of wind speeds that appeared to be turbine noise controlled.

We note that Method 1 of the AS 4959:2010 for compliance assessment requires the measurement of L_{A90} levels, with a numerical adjustment applied to account for the likely difference between the L_{A90} and L_{Aeq} level. Our assessment is based on measured L_{Aeq} levels instead. As both the 2009 SA Guidelines and AS 4959:2010 have been applied assuming a downwind direction, comparison between the AS 4959:2010 and 2009 SA Guidelines results provides the difference between the measured L_{Aeq} and L_{A90} level.

No difference is provided between the 2009 SA Guidelines and NZS 6808:1998 for site D1 as L_{A95} levels were not measured at that site.

Table 2. Compliance level measured using the different compliance methods, relative to the 2009 SA Guidelines (dB(A)).

Site	*Compliance measurement method*		
	NZS 6808:1998	*NZS 6808:2010*	*AS 4959:2010*
A			
A1	-1.5	-1.1	+2.8
A2	-1.5	-1.0	+2.5
A3	-2.0	-1.5	+1.9
B			
B1	-1.0	-0.7	+1.7
B2	-0.7	-0.4	+1.2
B3	-1.1	-0.7	+1.5
C			
C1	-0.5	-0.2	+1.6
C2	-0.7	-0.4	+1.4
C3	-0.7	-0.4	+1.3
D			
D1	-	-0.3	+1.1
Mean Difference	**-1.1**	**-0.7**	**+1.7**
Standard Deviation	**0.6**	**0.4**	**0.5**

Table 2 indicates that the application of other wind farm standards used in Australia results in levels up to 2.0 dB(A) lower, and 2.8 dB(A) higher than respective results obtained through application of the 2009 SA Guidelines. However, as later discussed, the 2.8 dB(A) difference between the 2009 SA Guidelines and AS 4959:2010 results at site A1 is believed to be affected by extraneous noise.

Discussion of L_{A90} and L_{A95} results

It is observed that measurements undertaken using NZS 6808:1998 provide the lowest compliance levels, with a mean level 1.1 dB lower than the 2009 SA Guidelines and a range of results between 0.5 and 2.0 dB lower than the 2009 SA Guidelines. However, we note that this does not necessarily translate to a 0.5 to 2.0 dB less stringent end result at the residences. Existing background noise levels used to determine noise criteria would also be measured using the L_{A95} assuming that the NZS 6808:1998 method had been applied throughout the planning phase as well as during the compliance monitoring phase. Noise criteria determined based on the background L_{A95} + 5 dB approach would be more stringent than those determined using an L_{A90} level.

The variation in differences between noise levels measured under the 2009 SA Guidelines approach and NZS 6808:1998 approach was 1.5 dB (differences of between -2.0 and -0.5 dB). This result appears to be attributable to the combination of the difference in wind directions used for the assessments, turbine layout, and difference between the L_{A95} and L_{A90} levels. The difference in L_{A95} and L_{A90} is 0.3 to 0.5 dB, as provided by comparison of the NZS 6808:1998 and NZS 6808:2010 results in Table 2 (the only difference between these being the NZS 6808:2010 use of the L_{A90} rather than L_{A95}). The remaining variation in levels is attributable to different proportions of downwind measurements in the total measurement period, and layout of turbines on site.

Discussion of L_{Aeq} results

The AS 4959:2010 results provide the highest measured levels across all measurement sites. The comparison of the AS 4959:2010 and SA Guidelines methods provides the average difference between L_{A90} and L_{Aeq} levels across the measurement sites.

From site observations at the base of a turbine it might have been expected that locations close to turbines would experience greater differences between L_{A90} and L_{Aeq} levels, due to the blade passing of a single close turbine being more noticeable than the blade noise on a group of distant turbines. Figure 2 presents the difference between the measured L_{A90} and L_{Aeq} levels with distance.

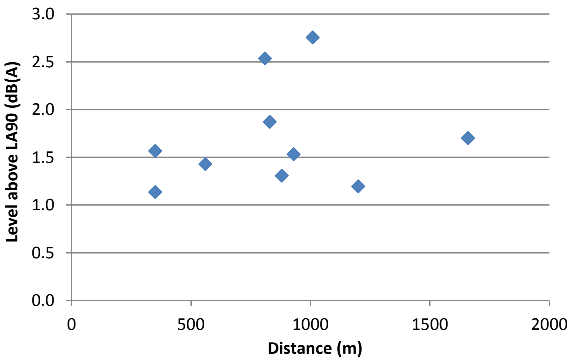

Figure 2. Level of L_{Aeq} above the L_{A90} with distance.

There is no observable trend in difference between the L_{A90} and L_{Aeq} results with distance over the measurement range of 350 to 1700m. Rather, the sites where both site observations and plots of noise level v‟s wind speed suggested greatest influence of ambient noise correspond to the sites with highest difference between the L_{A90} and L_{Aeq} levels.

While it is difficult to quantify the influence of ambient noise on the measurement sets it is believed that the L_{Aeq} results at sites A1, A2 A3 and probably B1 have been significantly altered by ambient noise. If the significant outliers A1, A2 and A3 are excluded from the data set the mean difference between L_{A90} and L_{Aeq} across the seven remaining sites is only 1.4 dB(A). This is less than the previously suggested correction of 1.5 to 2.5 dB(A) (ETSU, 1996). Our result suggests that L_{A90} levels should be increased by no more than the minimum required by AS 4959:2010, which is 1.5 dB(A).

It is possible that the difference between our findings and those reported in ETSU is the result of extraneous noise during the ETSU assessment, or measurements undertaken at very close distances to a single turbine where amplitude modulation may have been greater.

Finally, we note that the AS 4959:2010 Methodology 1 does not allow for the correction of L_{A90} compliance measurements for background noise, which the standard notes is a conservative approach. The lack of the ability to correct for the contribution of background noise when using this method will further increase the difference between the SA Guidelines and AS 4959:2010 results. There is potential for the inability to correct for background noise to be sufficient to incorrectly indicate non-compliance with criteria.

Comment on alternative measurement techniques

There are a number of alternative compliance measurement techniques proposed by the various standards including; attended on/off measurements, long term measurements at „secondary locations‟ adjacent to residences, long term measurements at „derived locations‟ between the turbine and residence with a correction applied for the predicted difference in noise level between the derived location and residence, and attended measurements at one residence to calibrate a noise model for the site.

Of all the alternative compliance measurement techniques proposed by the standards, the authors most prefer the use of measurements at a „secondary location‟ which is a location selected where turbine noise levels are expected to be the same as at the residence but background noise levels are expected to be much lower.

In practice it is not always practical to place a noise logger in a „secondary location‟ where the terrain and distance to all turbines match those at the receiver. Where it would be necessary to place a logger slightly closer or further from the turbines we suggest it is preferable to measure in that location and correct for the slight difference in noise level, rather than use attended measurements gathered over a limited range of conditions.

Our other paper (Evans and Cooper, 2011) demonstrates there is a consistent difference between the measured and ISO 9613-2 (G=0) modelled results at receivers scattered across different wind farm sites provided that the terrain between the turbines and receivers is consistent. We therefore also support the use of logging at a location slightly removed from a receiver i.e. in a „derived location‟. The correction applied for the difference in location should be determined using the ISO 9613-2 (G=0) prediction method, and the distance between the measurement location and residence should be always be minimised as far as is practical. If this method is used it is critical that significant differences in terrain between the derived measurement location and residence are avoided, based on our findings regarding influence of terrain on modelling results.

We believe that at sites where there is significant background noise the above two approaches are likely to provide a better indication of turbine noise than the primary compliance measurement methods currently used by the various Standards and Guidelines. The primary measurement methods involve taking measurements strongly influenced by background at receivers and then correcting them through subtraction of historical L_{A90} levels or alternatively measuring at the receiver and ignoring the presence of the significant extraneous noise.

The suitability of attended measurements for determining wind farm noise levels at an individual location has not been examined in this paper but we anticipate they would provide acceptable results provided that the sample size is sufficiently large. It may be simpler and less labour-intensive to take long term measurements at a secondary or derived location than it is to take a large number of attended measurements at a location influenced by background noise.

The alternative compliance technique provided by Methodology 2 of AS 4959:2010 uses attended noise measurements at one noise sensitive receiver to validate prediction model outputs and therefore compliance with criteria at the other receivers.

We have significant concerns regarding the suitability of Methodology 2 for checking compliance across a wind farm site. Using the receivers at Wind farm A as an example; sites A2 and A3 are at a very similar distance but on opposite sides of a small group of turbines. Predicted noise levels at the two sites were almost identical, but the terrain between the turbines and measurement sites varied greatly. The difference in terrain resulted in the difference in noise level measured between the two sites being 5.9 dB(A). If Methodology 2 had been applied using attended measurements at Site A2 the compliance level determined for Site A3 would have been almost 6 dB(A) too low. We therefore strongly suggest that the use of Methodology 2 should be avoided and this method in the Standard revised as soon as practical.

CONCLUSION

A comparison of the compliance results obtained from the various wind farm standards used in Australia has been undertaken. Noise measurements collected from 10 measurement sites around four different wind farms have been used during our assessment. Each measurement site selected for this analysis exhibited wind speeds where noise measurements were clearly controlled by wind turbine noise, with only data from those speeds assessed.

The compliance noise level measured using the 2009 SA Guidelines was selected as a reference level, against which the results from all other compliance measurement methods were compared. The measurement results obtained using the other wind farm standards are at levels up to 2.0 dB(A) lower, and 1.7 dB(A) higher than respective SA Guideline results at some measurement locations.

Application of NZS 6808:1998 results in the lowest measured compliance levels, with mean level 1.1 dB lower than the SA Guideline. This result is attributable to both the use of an L_{A95} descriptor rather than L_{A90}, and assessment over all wind directions rather than just downwind conditions. When compared to the NZS 6808:1998 standard, the new NZS 6808:2010 standard provides compliance results approximately 0.4 dB(A) higher.

AS 4959 provides the highest measured compliance results, with mean difference between the L_{A90} and L_{Aeq} found to be 1.4 dB when several outlier sites which were believed to have been influenced by extraneous noise are excluded.

This paper complements the findings of our paper titled „Comparison of predicted and measured wind farm noise levels and implications for assessments of new wind farms‟ (Evans and Cooper, 2011), which is also presented at this conference. Together they can be used to compare the accuracy of a number of noise prediction methods to compliance results obtained from a variety of compliance measurement approaches.

Based on the findings of both papers some commentary is provided on the range of alternative compliance measurement methods used in Australia. The authors strongly suggest that Methodology 2 of AS 4959:2010 is revised as soon as is practical.

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REFERENCES

Cooper, J, Leclercq, D & Stead, M 2010, *Wind induced aerodynamic noise on microphones from atmospheric measurements*, Proceedings of 20th International Congress on Acoustics, Sydney, Australia.

Delaire, C & Walsh, D 2009, *A Comparison of Background Noise Levels Collected at the Portland Wind Energy Project in Victoria, Australia*, Third International Meeting on Wind Turbine Noise, Aalborg, Denmark.

Delaire, C & Griffin, D 2011, *Review of noise conditions from planning permits recently approved in Victoria Australia*, Fourth International Meeting on Wind Turbine Noise, Rome, Italy.

DELTA 2002, *Nordic Environmental Noise Prediction Methods, Nord2000 – Summary Report*, Danish Electronics, Light & Acoustics, Lyngby, Denmark.

DELTA 2009, *Noise and energy optimization of wind farms – Validation of the Nord2000 propagation model for use on wind turbine noise*, Report PSO-07 F&U project no 7389, Hørsholm, Denmark.

ETSU-R-97 1996, *The Assessment and Rating of Noise from Wind Farms*, Final Report by the Working Group on Noise from Wind Turbines, United Kingdom.

Evans, T and Cooper, J 2011, *Comparison of predicted and measured wind farm noise levels and implications for assessments of new wind farms*, 2011 Conference of the Australian Acoustical Society, Gold Coast, Australia.

International Organization for Standardization 1996, *Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation*, ISO 9613-2:1996, International Organization for Standardization, Geneva, Switzerland.

SA EPA 2003, *Wind Farms Environmental Noise Guidelines*, South Australian Environment Protection Authority, Adelaide, Australia.

SA EPA 2009, *Wind farms environmental noise guidelines*, South Australian Environment Protection Authority, Adelaide, Australia.

Standards Australia 2010, *Acoustics – Measurement, prediction and assessment of noise from wind turbine generators*, AS 4959:2010, Standards Australia, Sydney, Australia.

Standards New Zealand 1998, *Acoustics – The assessment and measurement of sound from wind turbine generators*, NZS 6808:1998, Standards New Zealand, Wellington, New Zealand.

Standards New Zealand 2010, *Acoustics – Wind farm noise*, NZS 6808:2010, Standards New Zealand, Wellington, New Zealand.