WIND FARM NOISE ASSESSMENT IN AUSTRALIA AND MODEL COMPARISON

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ABSTRACT

Wind farm development in Australia has grown significantly since 1999. From 2003 to 2005, there were several proposals submitted for approval with numbers of turbines ranging from 30 to over 100. Noise impacts from wind farms remains a contentious issue for the community and statutory authorities, but there is no nationally agreed approach to assessment. Prediction methods can include computer modelling, but there are no preferred models and it is up to the developer to justify the model. Very little, if any, data has been published comparing the accuracy of models. Compliance assessment is only required at the nearest residential or noise sensitive locations. Operators seem loathe to provide actual data to allow such comparisons to be made and provide some confidence in the predictions. This paper describes the noise assessment process for wind farms in Australia and compares the predictions of a number of models, including two commonly used industrial noise packages and one model specially developed for wind turbines.

RÉSUMÉ

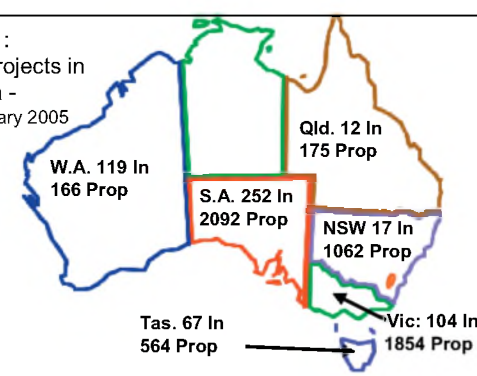
Le développement des parcs d'éoliennes en Australie a connu une croissance élevée depuis 1999. Entre 2003 et 2005, plusieurs propositions avec un nombre de turbines variant de 30 à plus de 100 ont été soumises pour approbation. L'impact au niveau du bruit des parcs d'éoliennes demeure un problème contentieux pour les autorités municipales et légales, mais il n'y a pas d'approche d'évaluation du bruit acceptée dans l'ensemble du pays. Les méthodes de prédiction peuvent inclure la modélisation par ordinateur mais il n'y a pas de modèle privilégié et la justification d'un modèle incombe au développeur. Très peu de données ont été publiées comparant la précision des modèles. La conformité est seulement requise à la plus proche résidence ou endroit sensible au bruit. Les opérateurs semblent réticents à fournir des données mesurées qui permettraient d'effectuer des comparaisons et donner une certaine confiance dans les prédictions. Cet article décrit la procédure d'évaluation du bruit des parcs d'éoliennes en Australie et compare les prédictions d'un certain nombre de modèles, incluant deux suites de modèles de bruit industriel utilisées couramment ainsi qu'un modèle spécialement développé pour les éoliennes.

1. INTRODUCTION

The first modern wind turbine generator installed in Australia was a 60kW unit in 1987 (1). Early developments were generally single units, although there were some 6 and 9 turbine developments. Most were in remote or rural coastal areas. From about the year 2000, larger wind farms with larger units began to be installed, with numbers of generators being from 12 to 46 in the one installation, with power ranges from 600 kW to 1.75 MW. In 2005, two wind farms of over 50 turbines of 1.65 MW were installed. The currently installed generating capacity from wind farms in Australia is 572 MW, with a further 5,914 MW proposed – see Figure 1 (1). There are likely to be many more in planning. The rate of development depends to some extent on Government policy, with the Commonwealth and State governments requiring fixed percentages of power generation to be from renewable resources. Technology development has also assisted, with the newer wind farms proposed having 2 to 3 MW generators in projects of over 100 turbines in the one area.

In Australia, as in most countries, proposals for industrial developments require statutory approval from local and State authorities. These require the preparation of an environmental impact assessment to support the development and assist authorities and the public determine the suitability of the project. For wind farms, the assessment of impacts range from archaeological to visual, radio-transmission, bird-strikes

Figure 1:
Wind Energy Projects in Australia -
AUSWEA February 2005



and noise. In most cases, noise assessment requires the use of computer software prediction modelling. Noise models have been used for prediction of industrial projects since the mid 1980's. In Australia, one model was developed with national government funding to provide a common approach to prediction and assessment across the country. This model, ENM, was released in 1987 and has been successfully used in Australia and other countries since that time, with many projects providing verification of its accuracy for Australian conditions. However, when it came to prediction of wind turbine noise, results were much higher than expected. Alternative models were used and some acousticians modified ENM. However there was no consistent approach. Some States require the use of a geometric spreading algorithm without consideration of ground topography or ground absorption, while others allowed any model to be used – justification was up to the developer.

In Europe, concern had also been raised about predicting noise from wind farms in the 1990's, and the EU Commission funded a research project into noise from wind turbines – measurement, propagation, immission and tonality (2). One of the outcomes of the EU Project was a software prediction model for wind turbines, known as WiTuProp. As a part of the Project, there were validation studies published for European conditions.

An earlier paper in 2004 (3) described the approach to noise assessment of wind farms in Australia. This will be described in this paper. The 2004 paper also described predicted sound levels using ENM and some other models, including WiTuProp. The difference in predictions between models was significant, with up to 24 dB difference in sound level at 1000 metres for a single turbine being reported. In late 2004, the developer of ENM issued a technical note that was intended to provide improved accuracy for ENM with elevated noise sources, such as wind turbines (4). A subsequent paper in 2005 (5) compared the results of the modified ENM predictions with predictions from other software. The difference still remained significant. Other authors have also published comparisons of predictions from other software models or algorithms. Further analysis with WiTuProp has identified an error in the results presented in the 2004 and 2005 papers, and this paper will present corrected values for comparison.

Despite the work on model development and comparison pf predictions between them, little work has been done on verification of model predictions for accuracy. Individual model developers may have tested the accuracy of their models with one or two wind turbines, but there has been no detailed publication of model validation – that is comparing predicted sound levels with measured sound levels for the same meteorological conditions. This is considered to be a consequence of compliance assessment of wind farm developments only being required at the residential receivers. If the software predictions in the environmental noise assessments are anywhere near accurate, the sound levels at the residential receivers should be less than or within the ambient sound levels and very difficult to measure. Measurements at closer distances may be required to verify the predictions, but they cost money because of the additional work required. So verification of predictions is not done and model accuracy remains unknown.

This fact was discussed at the October 2005 Wind Turbine Noise Conference in Berlin (6). One suggestion has been made that a round robin type of approach be taken to model verification. Real wind farm operating data at distances where the wind turbine sound levels can be accurately measured, should be provided for calculation using the models that people have. Accuracy of predictions can then be published.

Validation and accuracy of predictions is an important issue for the further development of the wind generation industry. Until the community, both professional and the general public, have confidence in the predictions made, there will be opposition to wind farm developments. Once accuracy is known, noise as an issue can be easily addressed.

This paper describes the two approaches to noise assessment of wind farm projects taken in Australia. It also presents comparisons of some prediction software models for the same conditions and corrects previously presented material. A combination of setting acceptable objective sound levels based on the measurements of existing background, along with the predictions made from widely used or verified models, can help in ensuring environmental noise from wind farms is not an issue for future developments.

2. ASSESSMENT OF WIND FARM NOISE IN AUSTRALIA

Within Australia's six states and two territories, there are two main methods of noise assessment of wind farms. States and territories have jurisdiction over environmental approvals of industrial developments. There are some common quality objectives in other areas of environmental assessment, such as air and water quality. But each assesses noise and set quality objectives in different ways.

Most wind farms are located in rural or coastal locations because of resource location and minimal environmental impact. This can at times cause objections from those who see rural living as an alternative lifestyle to their former, noisier urban environments. Earlier wind farms may have been located much closer to houses and had much smaller (power and height) turbines than the latest generation of turbines, and there is always anecdotal evidence of how noisy they are. The general approach to wind farm noise impact assessment is the same as for any industrial development. Noise objectives for the proposed project are developed from measurements of existing background sound levels – that is sound levels without the contribution of wind farms. Rural environments can have very low sound levels, but these occur when there is no wind. At these times, wind farms do not operate. So the assessment needs to cover the range of wind conditions that occur when a wind turbine will operate.

Objectives are set differently in different States. In Victoria (7) and Tasmania (8), assessment and objectives are based on the approach given in the New Zealand Standard NZS 6808-1998 (9). The background noise is measured at the noise sensitive location over a period long enough to provide a range of wind conditions during which a wind farm would operate. Ten-minute measurement intervals are used to match meteorological data, to obtain a statistical analysis of sound levels over a period typically of at least two weeks. The objective is based on a regression analysis of the LA95.10-min sound level at the residential receiver location, with the wind speed at 10 metres in the location of the wind farm. The objective for the contribution sound level from the wind farm is set at an LAEQ.10-min of 40 dB(A) or LA95.10-min +5 dB(A), which ever is greater, over the range of operating wind speeds. Figure 2 shows this analysis for one site. Tasmania requires predictions of sound level to be made down to the 35 dB(A) noise contour. The intent of this approach is to achieve an internal sound level of less than 30 to 35 dB(A).

South Australia developed a guideline in 2003 and this is also used in New South Wales (10). A similar period of background noise measurement is done, with at least 2000 data points required. The objective sound level is based on the regression analysis of LA90.10-min at the noise sensitive location, with the wind speed at the wind farm location. The objective for the contribution sound level from the wind farm is set at an LAEQ.10-min of 35 dB(A) or LA90.10-min +5 dB(A), which ever is greater. Figure 3 shows this analysis for the same site data as used in Figure 2. This LA90 based objective is considered to be tighter or lower than that in Figure 2. Figure 4 compares the two objectives with the LAEQ data for the same site. If the Victorian approach is used, there will be times when the objective sound level will be 10 dB(A) or more above the background LAEQ.

Figure 2: Development of Objectives for Victoria and Tasmania based on NZ Standard (LA95 + 5) for one site

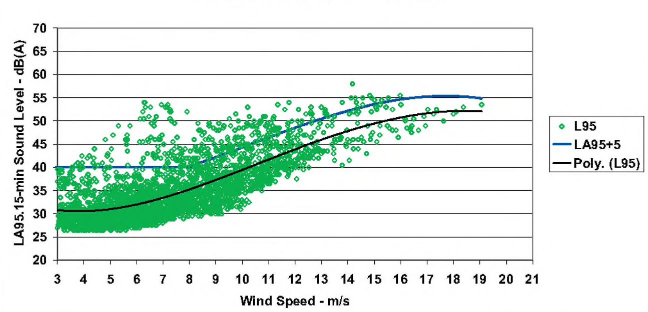


Figure 3: Development of Objectives based on SA approach (LA90+5 for the same site as Figure 2

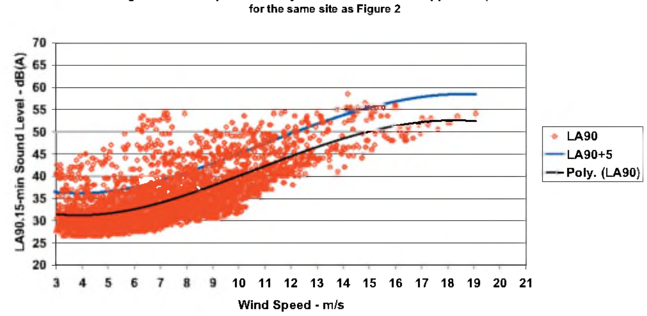
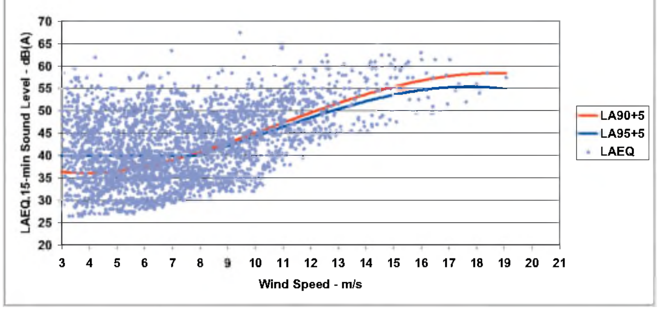


Figure 4: Comparison of Measured LAEQ with Objectives based on SA approach (LA90+5) and NZ Standard approach (LA95 + 5) for one site



3. PREDICTION MODELS

This sections describes models used in the comparison in Section 4. In Victoria and Tasmania, the approach to assessment requires that predictions of sound levels from wind farms be made according to the New Zealand Standard. This uses the simple algorithm

$$L_R = L_w - 10Log(2\pi R^2) - \Delta L_a \quad (1)$$

where:

- L_R is the sound pressure level at a distance R
- L_w is the sound power level (PWL) in dB(A)
- ΔL_a is the attenuation caused by atmospheric absorption over distance R

This is considered by some to be a conservative model because it does not consider topographical effects or ground surface absorption between the source and receiver. However, with higher-powered wind turbines with increased low-frequency energy, it may not provide adequate accuracy. Tasmania required in 2004 that compliance assessment include measurements to validate the prediction model used (8). An interactive version of this algorithm is provided on the National Physical Laboratory (NPL) web-page **Wind turbine Noise Model**. This allows the user to have either spherical or hemi-spherical spreading and include or ignore an atmospheric attenuation rate of 5 dB/km (11).

Use of a required model or algorithm is not unusual, allowing for all projects to be assessed on the same basis. Set algorithms are known to be required in the Netherlands, Germany, Sweden, Norway and Denmark (12).

Some other software models use a similar approach to the above algorithm, with the ΔL_a term set at a typical 2 dB/km attenuation rate. However this does not take account of the frequency content of the source sound spectrum. **WindFarmer** is one such model (13). **CadnaA** is a noise prediction model developed for industrial noise sources, and has different algorithms for different types of sources, such as road, rail, and aircraft (14). It is used more in Europe and North America than in Australia. ENM is an Australian developed program that has been used and verified widely in Australia.

ENM and CadnaA were originally used for low level sources such as industrial sources, but both have had algorithms or modifications made for other sources, such as road and rail traffic, and elevated sources such as wind turbines. Other models that include wind turbine noise propagation include WindPRO and Nord2000.

The two main models used in this comparison are ENM and WiTuProp. ENM in its original form predicts unusually high noise levels for wind turbine types of noise sources (3). Because of this difference, the developer issued a technical note to recommend a correction to the wind speed used in the model (4). The note explains that the ENM wind effect algorithm is based on measurements reported by Parkin and Scholes in 1964 and 1965, for a source height of 1.8m above grass and wind speed measured at the standard meteorological height of 10m. As wind effects are related to wind gradient, and wind gradients are significantly lower at the 60 to 120m elevation of wind turbine noise sources than they are at ground level, it was not surprising that the ENM algorithms did not appropriately address the sound propagation of wind turbines. For source heights of greater than 10m, a correction needed to be applied to the wind speed used in the ENM model. For example, for a source height of 100m, a 10m-wind speed of 8m/s and an open exposed terrain category, the wind speed correction factor is 0.129, giving a modelling wind speed of 1.032m/s. The technical note explains how the correction factor is derived.

WiTuProp is a heuristic model, based on classical geometrical ray theory for a non-refractive atmosphere, modified for a refractive atmosphere (2, 15, 16). It was developed from a European Commission funded joint project, to investigate wind turbine noise measurement methods, the knowledge of noise propagation under different meteorological conditions, measurement of immission at dwellings and the assessment of possible tonal noise from machinery components. The study was a collaboration between nine European partners in six countries, which commenced in January 1997. The noise propagation model aspects of the study were undertaken by Delta Acoustics & Vibration, of Denmark. One of the outcomes of this project was the development and validation of a noise propagation model for wind turbines, known as WiTuProp. This algorithm was used by the author in a recent EIS. The need to understand the difference between its predictions and those of other methods is one of the reasons for the work reported in this paper. Those involved with environmental regulation in Australia have requested validation studies be presented for WiTuProp and other models using Australian conditions. Data to enable this to be done has yet to be obtained.

4. MODEL INPUTS AND SCENARIOS

Model input parameters are similar on basic components and as they become more complex, and hopefully more accurate, the number of parameters increases. Basic inputs include distance, source height, source sound power level, and wind speed and direction. More detailed inputs include source spectrum, topography, ground absorption, air temperature and humidity, lapse rate and wind speed profile.

Some parameters have more influence than others once the basic distance, and source sound power level are set. The main determining parameter is the wind speed, which affects both turbine sound power level and sound propagation rates. Wind direction and lapse rate are probably the next ranked parameters for influence on the final sound level, followed by ground absorption, temperature and humidity. These details will be illustrated in the graphs and tables for WiTuProp and ENM.

The basic scenario used for comparison of several models was a single 2MW wind turbine of 105 dB(A) PWL, set at 70m hub-height above a flat rural landform with a surface absorption of 200 CGS Rayls. Figure 5 shows the sound power level increase with increasing wind speed for this type of turbine, and Figure 6 shows the spectra for four wind speeds, including the spectrum used for 8m/s wind. Meteorological conditions were 5oC and 95% rh, to represent a cold winter's morning in Australia and other temperate countries, with a low atmospheric attenuation for sound propagation. Lapse rate used, where it was a variable in the equation, was –0.66oC/100m. Use of positive (inversion) lapse rates was not made for the general comparison on the basis that with at least 4m/s of wind speed – the starting speed of many turbines, an inversion would not be present. (However, lapse rate sensitivity has been checked for WiTuProp and ENM.)

The basic comparison has been made at a wind speed of 8m/s at 10m elevation, and downwind. This is the standard wind condition for reporting of sound power level in IEC-614100-11 (17), although amendments to the Standard will also require reference to the wind speed at hub-height.

Figure 5: 2MW 105 dB(A) Wind Turbine - PWL vs Wind Speed

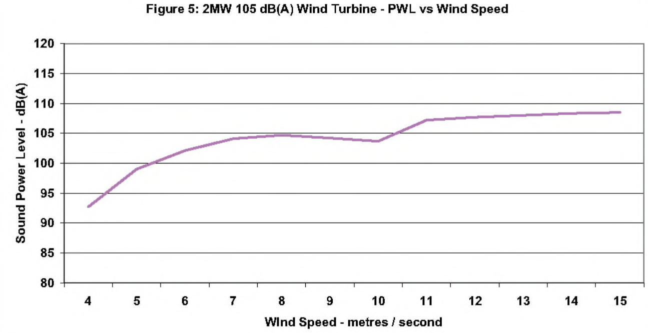


Figure 6: 2MW Wind Turbine PWL Spectra at increasing wind speed

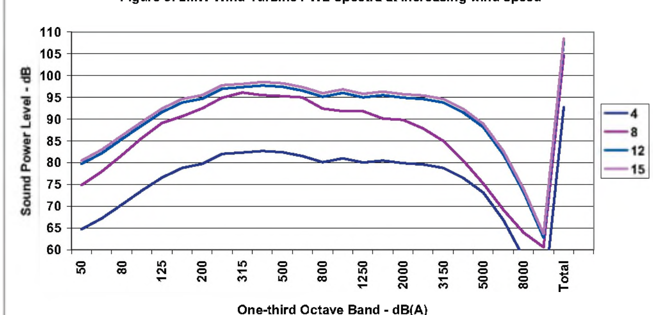


Table 1 and Figure 7 show the comparison of results from four models or algorithms, with different settings. Figure 8 reduces the number of results to those of four models. The results for the original ENM calculations are not included in the statistical review at the bottom of Table 1, as they have been shown to not be relevant.

Model or Algorithm	Sound Level dB(A) at Distance metres			
	500	**1000**	**1500**	**2000**
ENM	*52*	*46*	*42*	*39*
ENMRev	41	34	24	16
WiTuProp	39	32	28	24
CadnaA 0	42	35	31	27
CadnaA 0.5	38	31	27	23
CadnaA 1.0	35	28	23	20
NPL Sph$_{no\ air}$	40	34	31	28
NPL Sph $_{air}$	38	29	23	18
NPL Hem$_{no\ air}$	43	37	34	31
NPL Hem$_{air}$	41	32	26	21
NZ Std	42	35	30	27
Max*	***43***	***37***	***34***	***31***
Min*	***35***	***28***	***23***	***16***
Difference	***8***	***9***	***11***	***15***
Average*	***40***	***33***	***28***	***24***

Note: * Calculations of Maximum, Minimum and Average in Table 1 do not include the ENM original results.

Table 1: Comparison of Predictions for 8 m/s

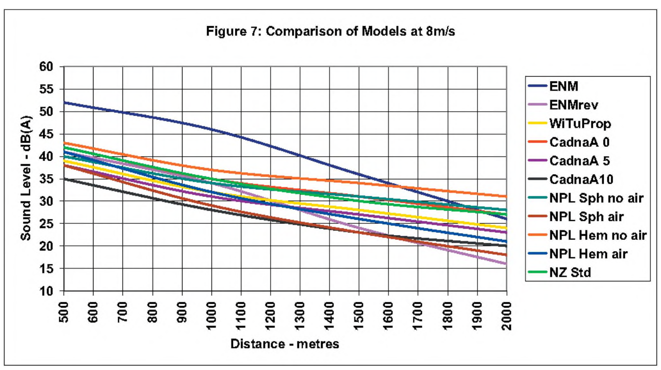


Figure 7: Comparison of Models at 8m/s

At 1000m, the range between highest and lowest result is 9 dB, and this increases as wind speed increases. This difference is considered to be significant in terms of the expected accuracy of the commercial models. It also has a significant potential effect on the predicted acceptability of a wind farm project. CadnaA with a surface absorption of 1.0 (fully absorptive) gives the lowest result out to 1500m, when the revised ENM becomes the lowest. One of the main comparisons that can be noted between ENM and the other methods is that the ENM calculated results continue to reduce with increasing distance at a greater rate – most of the other models approach a logarithmic curve.

Effects of wind direction have been calculated at the same 8m/s wind speed and 1000m distance for WiTuProp and ENMrev, and are shown in Figure 9. WiTuProp is the same as ENM for cross-wind but lower in upwind or downwind. Figure 10 shows the effect of increasing distance and wind direction for WiTuProp - after a distance of 1500m, the difference between upwind and other directions remains relatively constant at 10 to 13 dB.

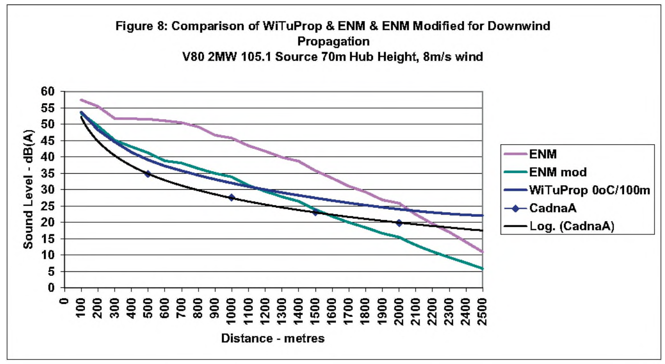


Figure 8: Comparison of WiTuProp & ENM & ENM Modified for Downwind Propagation
V80 2MW 105.1 Source 70m Hub Height, 8m/s wind

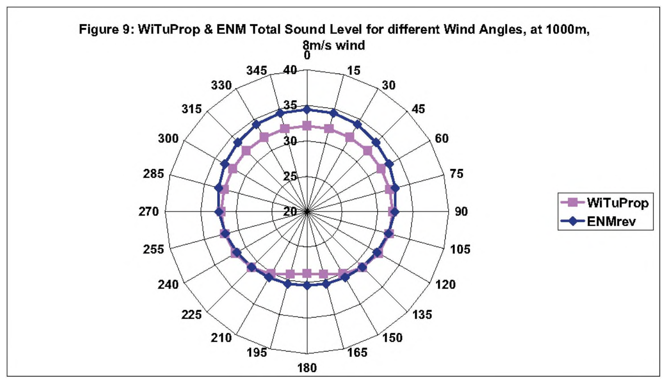


Figure 9: WiTuProp & ENM Total Sound Level for different Wind Angles, at 1000m, 8m/s wind

Lapse rate can have a significant effect on received sound levels at distances of more than about 500m. As noted earlier, the calculations have been done assuming a normal lapse rate of –0.66oC/100m. Some situations can arise where inversions do occur and wind speed is sufficient to power wind turbines, so an understanding of the effect of lapse rate is also important. Figure 11 compares the results for the same conditions modelled in Table 1 with WiTuProp, using four different values of lapse rate. Even with a relatively strong inversion of 7 oC/100m, the difference at 2000m is only 2dB.
Figure 12 compares results for ENMrev and WiTuProp models with lapse rate variation. It should be noted by ENM and WiTuProp users that ENM uses a lapse rate input value of oC/100m, while WiTuProp uses oC/m. For the unsuspecting,

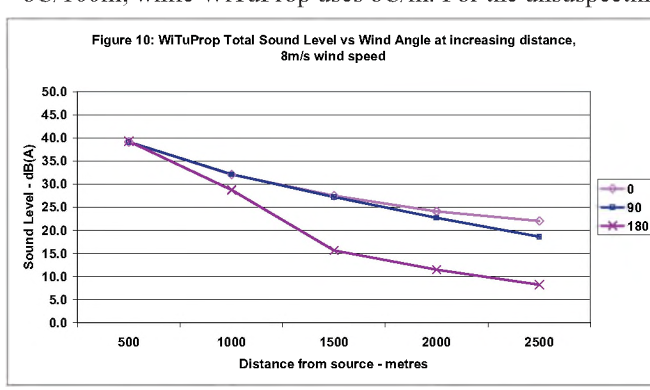


Figure 10: WiTuProp Total Sound Level vs Wind Angle at increasing distance, 8m/s wind speed

including the author, this difference can cause a significant effect on calculated results, if –0.66 oC/m is used in WiTuProp rather than the correct –0.007 oC/m. The difference in calculated sound level at 1000m is 10 dB. Unfortunately, this error was made in previous papers (3, 5).

Figure 11: Comparison of WiTuProp results for different lapse rates for Downwind Propagation
V80 2MW 105.1 Source 70m Hub Height, 8m/s wind speed

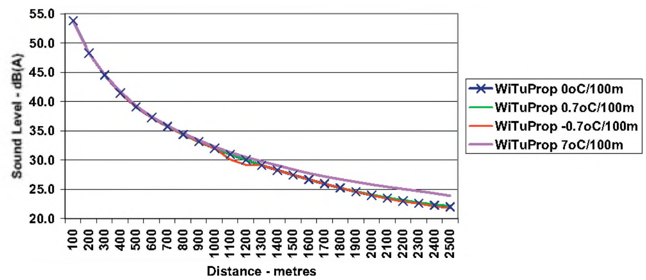
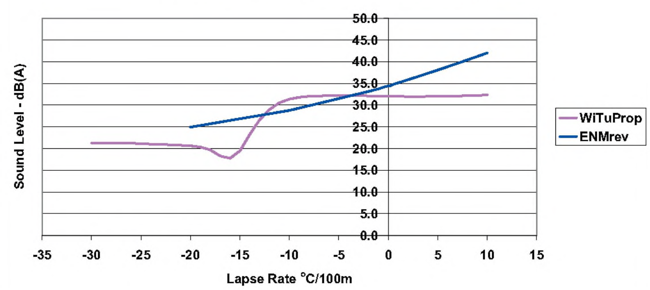


Figure 12: Comparison of WiTuProp and ENMrev with Varying Lapse Rate at 1000m for
V80 2MW 105.1 Source 70m Hub Height, 8m/s wind speed



The effect of wind speed on calculated result is the major determinant in most calculations. It affects the sound power level of the noise source, and the propagation rate. Figures 13 and 14 compare the downwind sound levels for increasing distances using ENM and WiTuProp for four different wind speeds, while Figures 15 and 16 show the sound levels for increasing wind speeds at six different wind speeds.

It is interesting to compare the increase in PWL in Figure 5 with the increase in sound level in Figures 15 and 16. These are shown in Figures 17 and 18 for a distance of 1000m. The increase in calculated sound level and sound power level is greatest in the speed range 4 to 7 m/s. The increase in the WiTuProp result is higher for that range than for ENM or PWL, but all are relatively similar on other ranges shown.

Figure 13: WiTuProp Variation in Received Sound Level with Distance for Different Wind Speeds

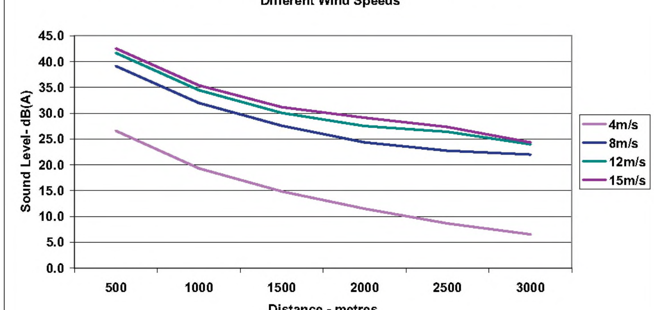


Figure 14: ENMrev Sound Levels Downwind with Increasing distance for various wind speeds

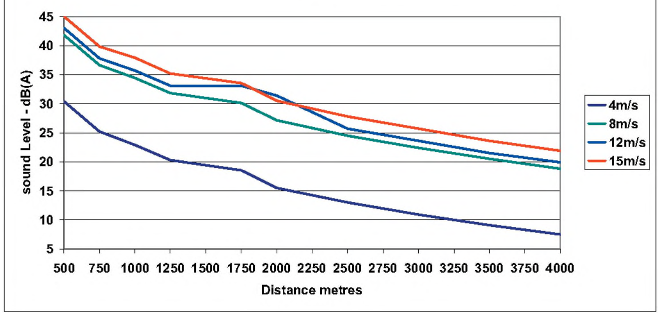


Figure 15: WiTuProp Downwind Sound Level vs Wind Speed for Distance Variation

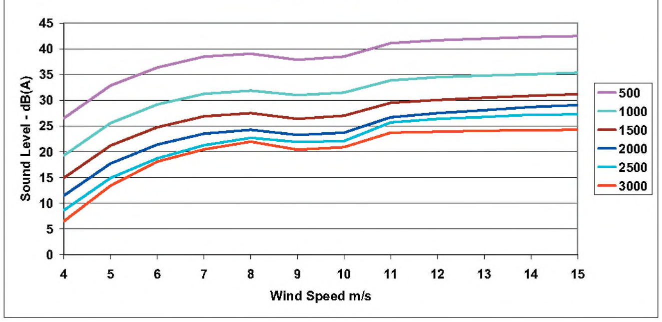


Figure 16: ENMrev Sound Levels Downwind with Increasing Speed for various distance

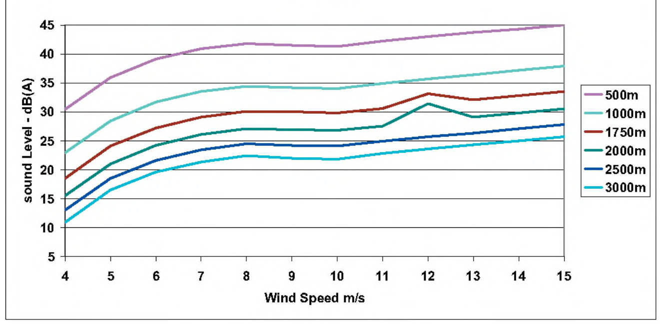
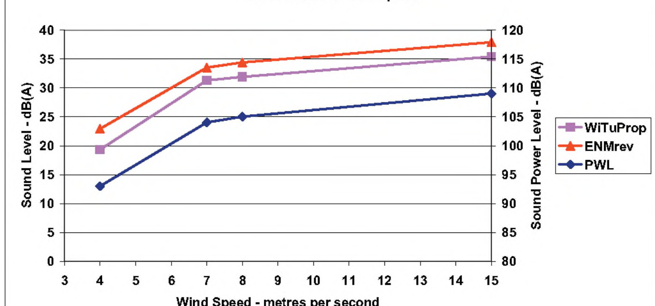


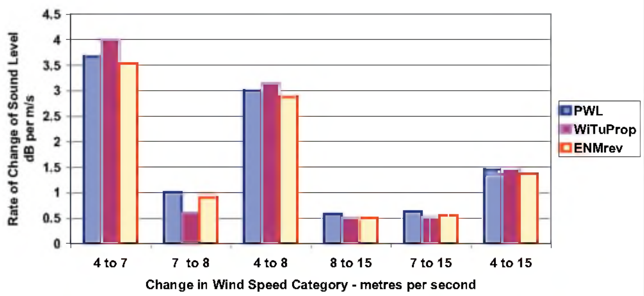
Figure 17: Comparison of increase in PWL and SPL at 1000m with increase in wind speed



5. COMPLIANCE ASSESSMENT

The current approach to compliance assessment once the wind farm is operating, is to measure the sound levels at the nearest residences or noise sensitive areas over the range of operation of the wind turbine. This approach generally repeats the

Figure 18: Comparison of rate of increase in PWL and SPL at 1000m with wind speed



measurements at the locations where the background sound levels were measured and compares the measured sound levels with objectives – increases in sound level and tonality are to be identified, along with turbine operational conditions.

The difficulty with this approach is that the accuracy of predictions of the model used is rarely obtained. For example, if an objective is set at 40 dB(A) for a 6m/s wind speed, as in the data of Figure 3, the existing background LAEQ sound level will be well above the objective most of the time. The assessment needs to include measurement of sound levels at distances close enough to the turbines to provide an accurate measurement of the immission sound level from the turbine. This means it has to be at least 6 dB and preferably more than 10 dB above the background sound levels measured for the area. Tasmania is the only State in Australia at present to require by regulation, a validation of the model predictions made in the EIS.

For the examples and calculations presented in this paper, this means measurements for validation of predictions need to be taken in the range of 200m to 500m from the turbine. And such measurement locations would also preferably need to be measured as part of the background noise studies, because location will affect the range of background sound levels – distance to trees and vegetation cover, local topography and associated vegetation cover will all have a significant effect.

Planning for compliance assessment will also require involvement of construction scheduling. If the wind-farm site is on a hill or ridge or bluff, then suitable measurements at some locations will not be possible because of the landform. Other suitable locations at the range of distances required could very likely also be the site of other turbines. This means that the timing of measurements would need to be done before noise from the operation of other turbines influences the sound levels being measured. The alternative would be to shut-down operating turbines to allow the measurements to be done, and this is likely to be unattractive to the wind farm operator.

Most models have yet to be validated against the measured results of several wind farms, either in Australia or elsewhere. As time proceeds, this will be done, but at present this provides a difficulty for developers and the involved acoustical profession. This gap in credibility could be overcome with specific measurement projects, to allow measured data be made available to prediction modellers to provide comparative predictions. Only when this comparison is widely available will credibility over noise be answered.

6. CONCLUSIONS

Noise immission from wind turbines remains an emotive issue affecting proposed and existing wind farms in Australia and other countries. The setting of objectives is considered reasonable and defensible in terms of community health and amenity goals.

Noise emission from wind farms and their wind turbine noise sources has been described by agreed international standards. (14). These are continuing to develop and will improve with subsequent revisions and amendments.

Prediction models have been used to assess the impacts of proposed wind farms for the range of conditions expected. The models generally indicate that a distance of about 1.2 to 1.5km is required from a multi-turbine wind farm to achieve a sound level of less than the ambient sound level under most conditions.

The missing part in the analysis, and that which provides a credibility gap for developers and regulators, is validation of the models. Until this occurs, the public and affected communities will continue to claim that wind farms are noisy. International round-robin model validation could be done through the provision of measurement data on a website, with predictions for the measurement conditions passed on to a body such as the technical committee responsible for IEC 614100 – 11.

By way of example, an Australian ABC TV news article of an approved wind farm in a rural village area of southern NSW on 24 February 2006, residents claimed it would be too noisy (18). This type of argument can be reduced to a much lower significance, through improved and known accuracy in prediction modelling, that shows wind farms can achieve acceptable objective sound levels.

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