SIMULTANEOUS MEASUREMENTS OF AMBIENT SOUND LEVELS AND WIND SPEEDS

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ABSTRACT

Continuous measurements of ambient sound level and wind speed were made for about 17 months at a wind farm site prior to construction, to obtain baseline sound levels. The site is in the middle of an agricultural field on a meteorological tower. Wind was measured at 3, 10, 30, 40, and 50 m above the ground. As expected the diurnal pattern showed high values of wind shear at night, compared to daytime in summer, but little day/night variation in winter. Relating sound level to wind speed indicated that the Ontario MOE approach of increasing the noise criteria with wind speed is appropriate and that above 5m/sec., ambient sound levels exceeded the MOE wind turbine sound limits due to wind action, in the absence of any wind turbines.

SOMMAIRE

Des mesures continues du niveau de sons ambiants et de la vitesse du vent ont été faites au cours de 17 mois à un site de ferme d'aérogénérateurs avant la construction, afin d'obtenir les niveaux de sons de base. Le site est au milieu d'un champ agricole sur un tour météorologique. Le vent a été mesuré à 3, 10, 30, 40 et 50 mètres au dessus de la terre. Comme prévu, la tendance quotidienne a montré des hautes valeurs de décalage de vent la nuit, par rapport aux journées pendant l'été, mais peu de variation jour/nuit pendant l'hiver. Comparant le niveau de son avec la vitesse du vent indique que la méthode du Ministre de l'Environnement de l'Ontario d'augmenter le principe de bruit avec la vitesse du vent est approprié et qu'après plus de 5 mètres par seconde, les niveaux de sons ambiants ont excédés les limites éolienne du Ministre de l'Environnement à cause du mouvement du vent dans l'absence d'aucune éolienne.

1. INTRODUCTION

Continuous measurements of sound level and wind speeds at different heights have been made between May 2007 and October 2008 to provide baseline reference information on ambient sound levels as a function of wind speed on a major wind power project site (wind farm). The current analysis presents information on measured wind and ambient sound data up until the end of October 2008, after which the operation of the wind turbines began. The measurement program is still on-going.

The measurement results were used to examine the validity of the Ontario Ministry of the Environment (MOE) sound limit criteria for wind turbines. These sound limits are based on ambient sound levels that increase with local wind speed at the sensitive receptor locations. The validity of this approach has been questioned due to the possible diurnal reduction in wind speed close to the ground that would result in reduced ambient sound levels, while wind speeds at wind turbine hub height show lesser or no reduction.

2. THE MEASUREMENTS

Sound level was measured at a height of about 3 metres (m) above ground with an integrating sound level meter sampling continuously and set to provide hourly summaries of Leq and cumulative probability (L_n) values. Wind speed was measured at heights of 3 m, 10 m, 30 m, 40 m and 50 m above ground.

3. THE SITE

The area is quite flat and used primarily for agriculture. There is very little road traffic on the nearby roads. The site is in the middle of an agricultural field. Thus, other than grass/weeds at the base of the measurement mast (a round-pipe) and crops during the growing season, there is very little major foliage in the immediate vicinity. There are hedgerows and trees along the border of fields and property lines and in the vicinity of a farm and other sparsely located houses. Figure 1 shows the sound measurement set up and the anemometers at 3 m.

4. WIND PROFILES

4.1 Wind Speeds

The MOE sound level limits for wind turbines are referenced to the wind speed at 10 m height. The IEC standard for measurement and rating of wind turbine sound emission also requires reporting the data referenced to wind speed at 10 m height. This appears to be an arbitrary height to introduce standardization because the average driving effect is wind speed at wind turbine hub height which varies with turbine type and installation. Figure 2 shows the measured hourly

Figure 1. Measurement Set-up.

wind speeds, at 10 m height, on a monthly basis. Figure 3 shows a histogram of wind speed for the whole time period measured.

Generally, wind speed was higher during the day (roughly 0700 to 1800 hours). However, this effect varied by month/season. The effect was greatest during summer (June to September) and least during winter (December and January) when wind speeds were more constant around the clock. Typically, the wind speeds were higher during winter, especially at night.

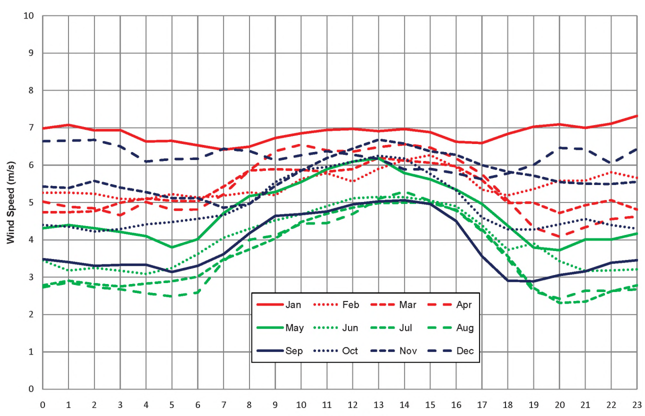

Figure 2. Wind Spped at 10 m Height.

4.2 Wind Shear

Normally, the wind speed increases with height. The equation that is commonly used to relate wind speeds at different heights is:

$$\frac{V_u}{V_l} = \left(\frac{H_u}{H_l}\right)^{\alpha} \qquad 1$$

where V_u is the wind speed at the upper height H_u. V_l is the wind speed at lower height H_l and α is the wind shear exponent (sometimes referred to simply as the wind shear).

This results in a logarithmic wind profile of speed vs.

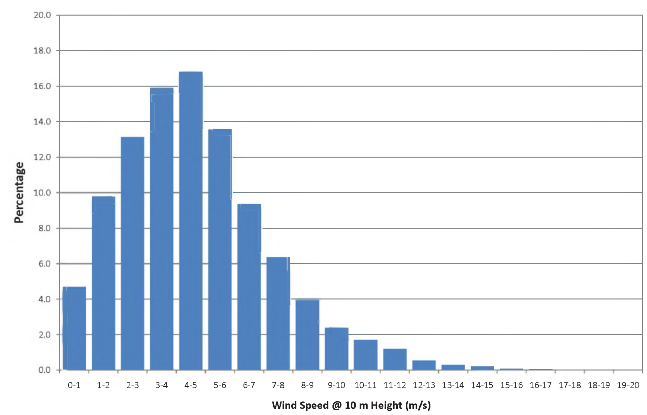

Figure 3. Wind Speed Profile.

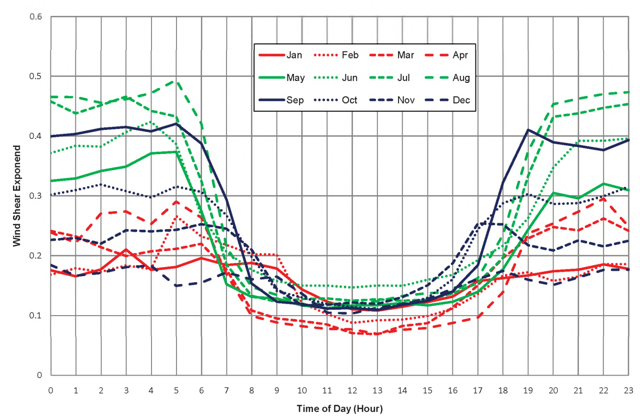

Figure 4. Wind Shear.

height. The values of α were calculated using the wind speed at all heights by an exponential curve fit, for each hour, on a monthly basis. Figure 4 shows the results. The pattern is believed to be typical of an open flat area in Ontario, although the specific absolute values of α will be site dependent. As might be inferred from Figure 4, the day values of α were low (0.1 ±) all year round. For winter, α remained low around the clock. During summer (June to September), the nighttime values rose to 0.4 to 0.5.

5. WIND SPEED AND SOUND LEVEL

5.1 Time History

The relationship between ambient sound level and wind speed can be examined for wind at any height. The patterns remain the same. The wind speed values are a function of height. For direct comparison to the MOE guidelines, the wind speed at 10 m height was used. Figure 5 shows a sample segment of time history, over two weeks, of hourly sound levels in terms of L_{eq} and L_{90} and hourly wind speed averages at 10 m and 3 m heights. The wind speeds at 3 m, which are more representative of what people and objects at ground level would experience, tracks that at 10 m but at lower levels.

The L_{90} values track the L_{eq} values very well. This leads to the conclusion that it is the wind that is the prime determinant of the measured sound levels, in this quiet, rural

Figure 5. Time History of Sound Levels.

environment. In a typical urban environment, with various activities, including traffic on other than expressways, it is common to have elevated values of L_{eq} (peaks) with more steady values of L_{90}. This is because many high sound level (noisy) events (e.g., vehicle pass-bys) that elevate L_{eq} do not last long enough (i.e., at least 90% of the time) to affect L_{90}. Subjectively, as illustrated in Figure 5, the sound level values and wind speeds also tracked very well. The area is very quiet, with minimum sound levels as low as 20 dBA, when wind speeds were negligible.

5.2 Ambient or Artefact

One of the concerns with sound measurements of this type is to be sure that the observed sound levels are, in fact, true ambient and not artefacts resulting from air flow over the microphone windscreen or the microphone itself. The sound level meter manufacturers do not provide data about the minimum sound levels that can be measured with their windscreens in the presence of air movement. It is known that the bigger the windscreen, the lower the potential for spurious readings. Hessler (2008) studied the sound levels generated by different air speeds flowing over a variety of windscreens in a specially built "quiet" wind tunnel [1]. Figure 6 shows the data and curve fit from the Hessler study for a windscreen similar to that was used in the current study. The comparison of the current sound level data to this curve showed that the measured sound levels are ambient and not artefacts.

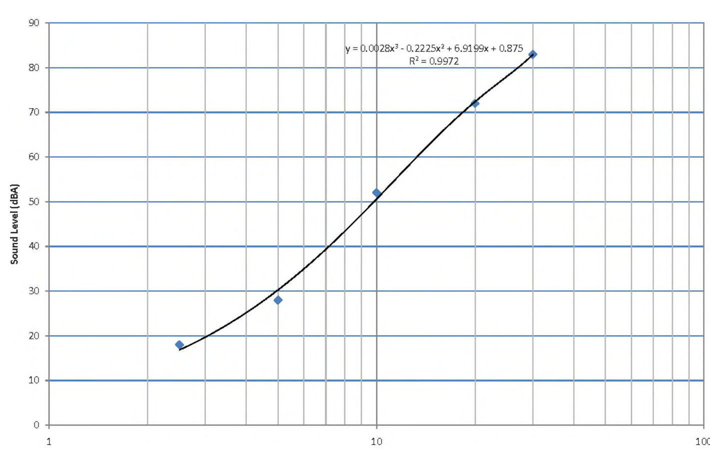

Figure 6. Wind Screen Noise Levels.

5.3 Results

Figure 7 shows a plot of all hourly sound data points (some 13,000 plus data points) as a function of the corresponding wind speed, at 3 m, the same height as the microphone. Particularly above 5 m/sec there is a definite trend pattern of increasing sound level with wind speed. At lower wind speeds there is more scatter and variation because wind generated sound levels are lower and other sources would be expected to be more dominant. Also shown on Figure 7 is the curve of the Hessler, laboratory-determined sound levels attributable to the air flow over the windscreen. In general, the measured data is well above this curve. Some measured sound levels were less than 10 dBA above the "windscreen line". Thus, to be rigorous, all data points were corrected for the sound

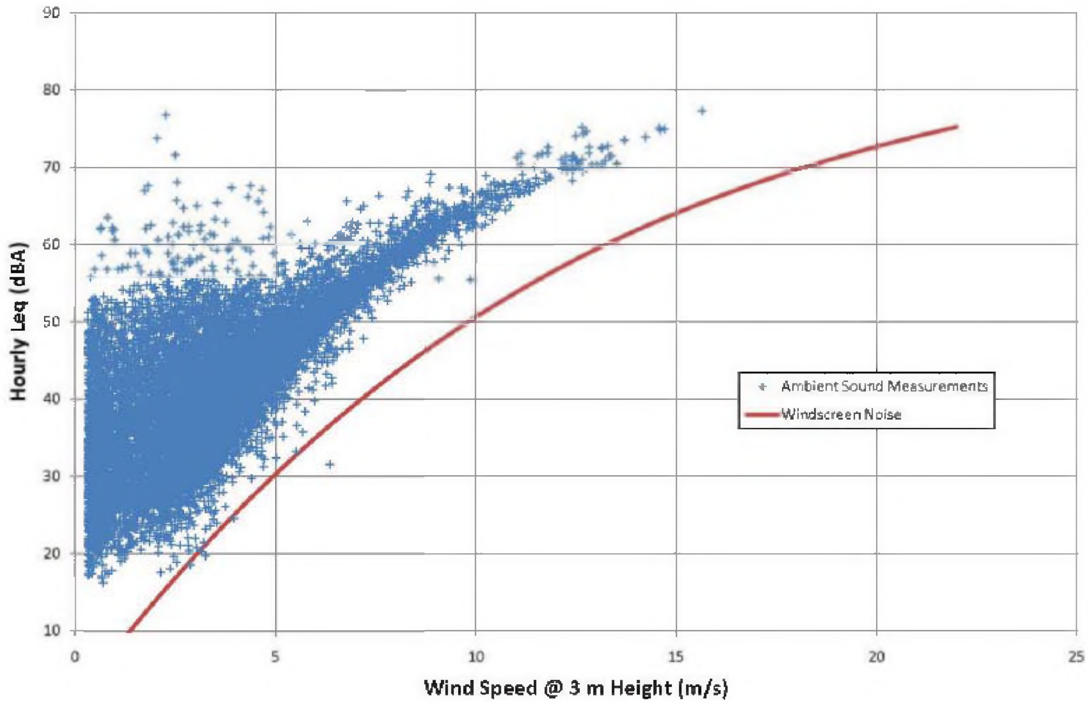

Figure 7. Hourly Noise Levels at 3 m.

level attributable to the windscreen.

Figure 8 shows all of the hourly sound level data points plotted against the wind speed at 10 m height, with a polynomial curve fit to the data. Figure 9 shows this data curve as well as the Ontario MOE wind turbine sound limit curve. (Recall the MOE criteria are referenced to wind speed at 10 m height.) Above 5 m/sec wind speed the ambient sound levels exceed the MOE criteria. Below 5 m/sec, the ambient sound levels were lower than the MOE criterion, which remains constant at 40 dBA at and below 6 m/sec wind speed. This approach is consistent with the MOE stationary source exclusion sound limit of 40 dBA in quiet rural areas, where a source is not required to attenuate below 40 dBA, regardless of the ambient sound level.

5.4 Analysis Intervals

Because the MOE noise guidelines are based on hourly time periods, the ambient sound levels were measured as one hour L_{eq} and related to hourly averages of wind speed. In addition

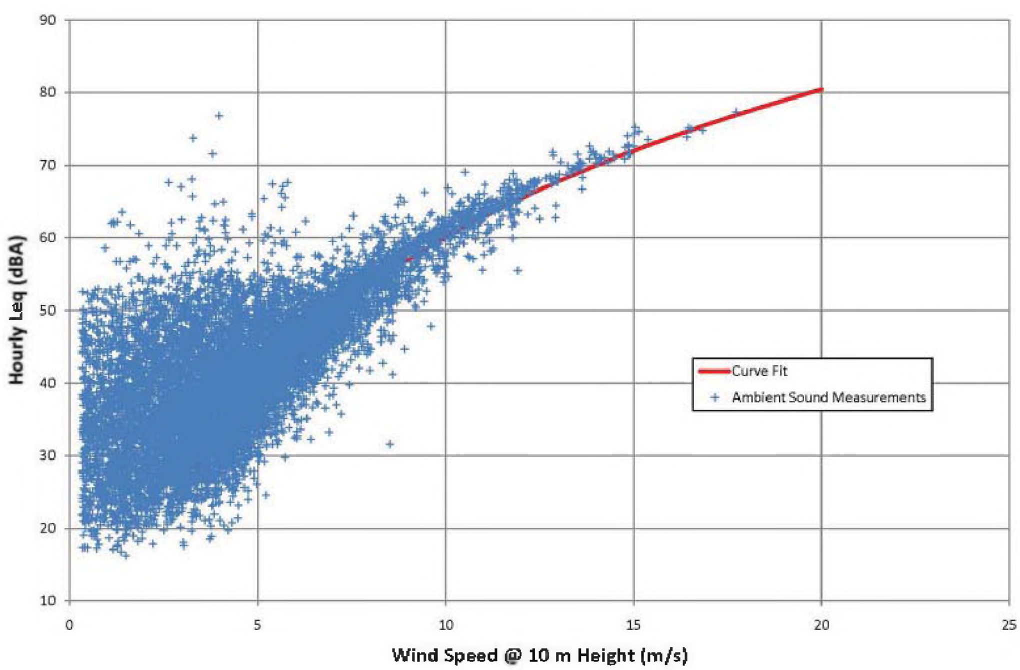

Figure 8. Hourly Noise Levels and Wund Speed at 10 m.

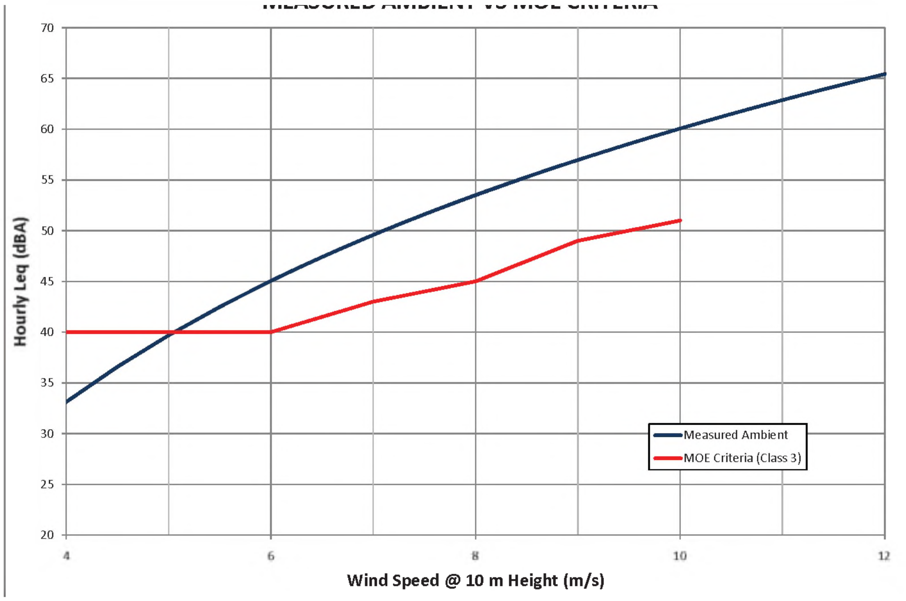

Figure 9. Hourly Noise Levels and MOE Noise Criteria.

to hourly L_{eq}, various hourly L_n sound level parameters were also recorded. The wind speed data was actually obtained as 10 minute averages; that is, as six samples per hour that were averaged together. The variability of the data within the hourly periods was examined. It may be surmised that during gusty conditions, the wind speed may vary significantly over short periods (within the hour). Correspondingly, the ambient sound levels may fluctuate significantly over the same time.

Figure 10 shows a plot of L_5 vs L_{eq}. A linear relationship fits well; basically L_5 is L_{eq} + 3.8 dBA, with very little scatter. For any hour, the difference between L_5 and L_{99} is the range of sound levels that existed for most (94%) of the time. Figure 11 plots the range of sound level vs. hourly L_{eq}. For any given hour there was a wide range of instantaneous sound levels contributing to the hourly Leq value.

Figure 12 plots the Standard Error (SE) and the Standard Deviation (SD) of the 10 minute wind speed values, binned to integer values for each hour. The SE is close to zero and the SD is small. That is, the variation in wind speed in any hour was small. However, the corresponding range of sound levels is relatively large (about 15 dBA). This apparent discrepancy may be due to significant wind speed variations that are averaged out using the 10 minute averaging periods.

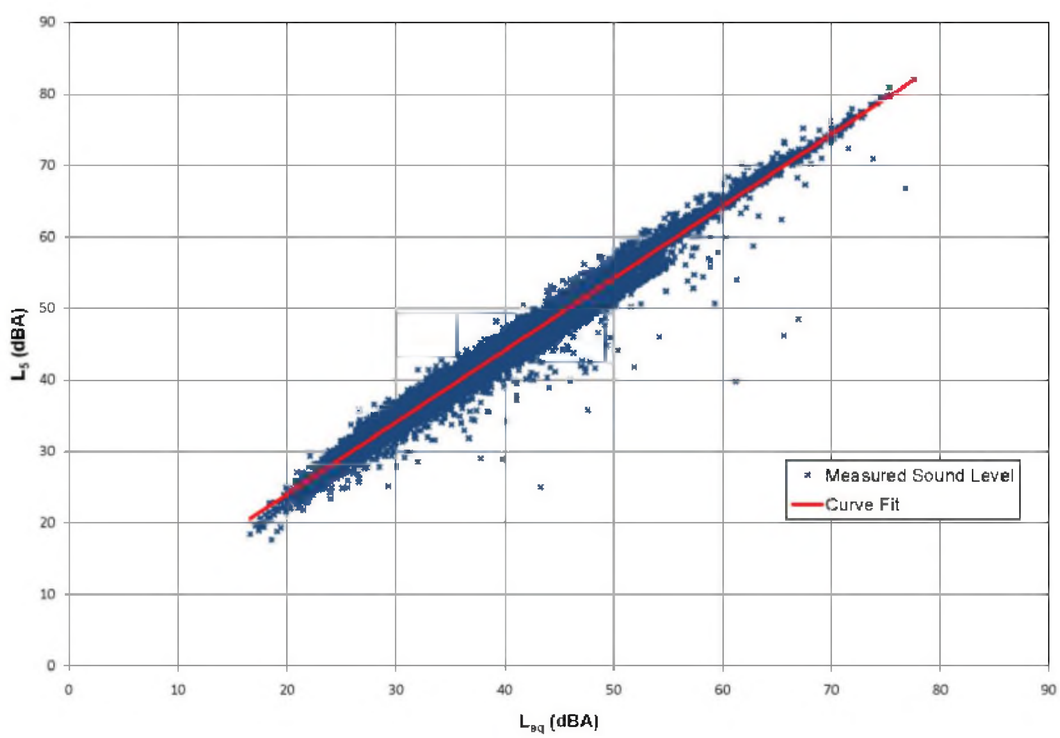

Figure 10. Hourly Noise Levels L_5 and L_{Eq}.

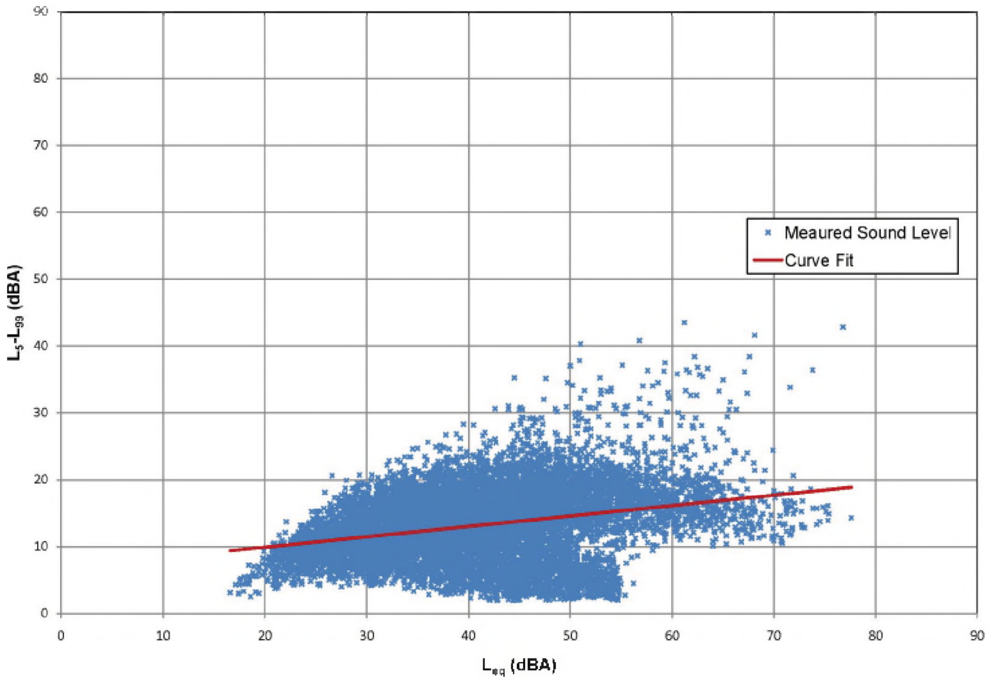

Figure 11. Hourly Noise Levels Range and L_{EQ}

6. CONCLUSIONS

1. Care must be taken in the selection of microphone windscreens, to measure low ambient sound levels in the presence of, or due to wind. There is the potential for air flow over the microphone/ windscreen assembly (or in fact over or past other objects close to the microphone) to produce spurious sound level readings. Of course, the resulting sound levels due to turbulent flow over objects such as residential buildings or trees, etc., that are part of a receptor's environment are legitimately part of the ambient environment.
2. As expected, wind speeds were generally higher in winter than in summer, with spring and fall being intermediate.
3. The expected diurnal variation in wind shear exponent was observed. This effect was strongest in summer, with wind shear exponent variation of 0.4 or 0.5 to 0.1, between night and day, and negligible in winter, with very little diurnal variation. The other seasons exhibited intermediate effects.
4. Above 5 m/sec wind speed, the ambient sound levels attributable to wind at a flat, open, agricultural site, were above the Ontario MOE sound limits for wind turbines. At and above 6 m/sec, the increment was at least 5 dBA, increasing with wind speed.
5. At and below 5 m/sec wind speed, the ambient sound levels were below 40 dBA, the applicable MOE criterion limit. The 40 dBA criterion is consistent with the "exclusion limit" used by the MOE noise guidelines for other types of stationary sources in quiet areas where the

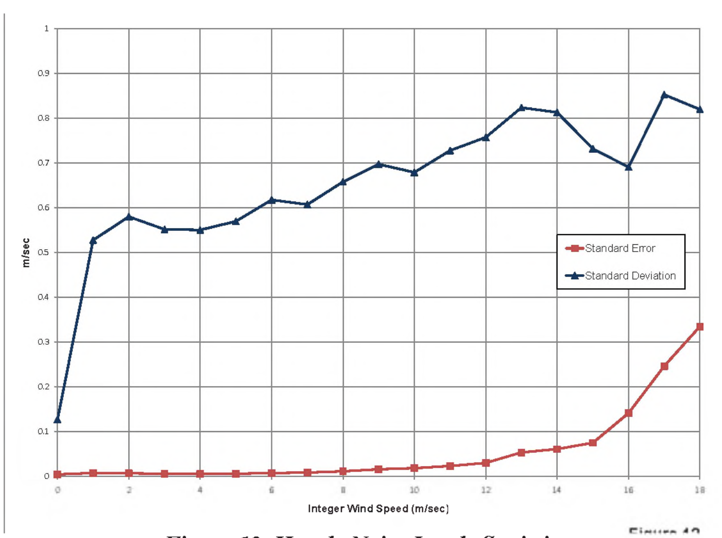

Figure 12. Hourly Noise Levels Statistic.

ambient can be expected to be lower.

6. It is concluded that, at least for a flat, quiet, rural, agricultural environment in Ontario, the MOE sound level limits for wind turbines are appropriate and are consistent with the notion that the sound limits should increase with wind speed above 6 m/sec, due to increasing ambient sound.
7. For measuring ambient sound in a quiet area, hourly averages of wind and sound (energy) data are acceptable. During gusty wind conditions it would be expected that ambient sound levels would follow in step with changes in wind speed and be appropriately reflected in the averages. However, large commercial wind turbines would not be expected to respond to rapid wind speed changes; in effect, averaging them out. Thus, significant fluctuations in sound level may be observed due to the ambient. To do a valid sound audit of a wind farm, and properly account for ambient sound levels, it appears that relatively short sampling periods for both sound level and wind speed are needed; possibly one minute or less, so that measured sound levels and wind speeds can be correlated. Further research is required to determine an appropriate data sampling rate.

ACKNOWLEDGEMENTS

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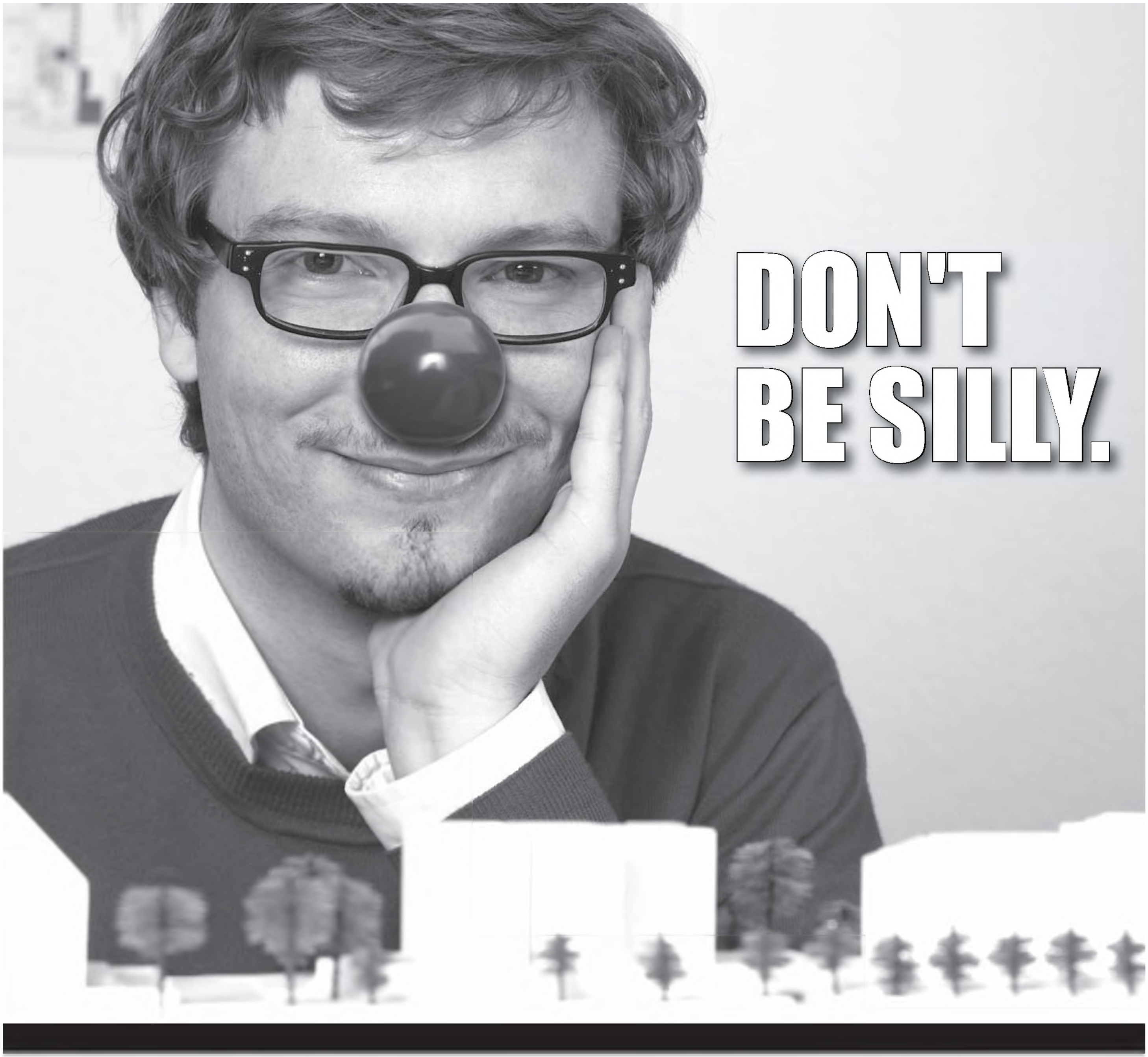
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