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Assessing Sound Emissions from Proposed Wind Farms & Measuring the Performance of Completed Projects

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BEST PRACTICES GUIDELINES FOR

ASSESSING SOUND EMISSIONS
FROM PROPOSED WIND FARMS
and
MEASURING THE PERFORMANCE OF COMPLETED PROJECTS

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Prepared for:

The Minnesota Public Utilities Commission

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1.0 Introduction

The noise produced by wind turbines differs fundamentally from the noise emitted by other power generation facilities in terms of how it is created, how it propagates, how it is perceived by neighbors and how it needs to be measured. Essentially everything about it is unique and specialized techniques need to be employed in order to rationally assess potential impacts from proposed projects and to accurately measure the sound emissions from newly operational projects.

Existing ISO[1,2], and ANSI[3,4] standards that are perfectly appropriate for evaluating and measuring noise from conventional power generation and industrial facilities were not written with wind turbines in mind and contain certain provisions that make them unsuitable for application to wind turbines. For example, most test standards, quite sensibly, allow valid measurements only under low wind or calm conditions in order to preclude, or at least minimize, wind-induced directional effects, among other things. At a conventional power plant, which may operate around the clock, this requirement simply implies a wait for appropriate weather conditions. At a wind turbine project, however, there is nothing to measure during calm wind conditions, since the project is normally idle. Significant noise generation largely occurs during wind conditions that are generally above the permissible limit. At the present time, a lone standard, IEC 61400-11[5] exists for evaluating wind turbine sound levels, but only for the specific purpose of measuring the sound power level of a single unit. Sound power level is an arcane, intangible, derived quantity that is used as an input to analytical noise models and has little relevance to the sound level a wind farm is producing at someone's home. Consequently, this highly specialized test cannot be used or even adapted to serve as a way of determining whether a new multi-unit project is in compliance with a noise ordinance, for instance.

What all this suggests is that the standards and methodologies that exist for assessing and measuring noise from conventional industrial noise sources cannot be applied wholesale to wind turbine noise and completely different assessment and field measurement methodologies are required that are tailored to, and take into account, the unique circumstances and technical challenges surrounding their noise emissions. These guidelines seek to address this situation by describing suggested assessment and measurement techniques that have been developed over the past decade through field experience on roughly 70 wind projects, primarily in the Midwest and Eastern United States, nearly all of which were located in rural, yet moderately populated areas. Without question many mistakes were made in the early going into this uncharted field of study and many naïve assumptions about wind turbine noise were found to be incorrect. It is hoped that what was learned from this experience and what is summarized in these guidelines can help others circumvent this learning curve.

After a brief discussion on the nature of wind turbine noise, the following principal topics are discussed:

- Suggested design goals for new projects
- Evaluating potential noise impacts from proposed projects through noise modeling and field surveys of existing conditions
- Measuring the noise emissions from operational projects to determine compliance with design goals or regulatory limits

1.1 Executive Summary

Wind turbine noise differs fundamentally from the noise produced by other power generation and industrial sources in how it is produced, how it propagates and how it is perceived by neighbors. Because existing sound measurement standards were never written with wind turbines in mind they are largely unsuitable for use in wind turbine analyses, if only because measurements both prior to and after construction essentially must be performed in the windy conditions necessary for the project to operate – conditions that are prohibited by virtually all current test standards. Consequently, new and unique evaluation and measurement techniques must be used that are adapted to the special circumstances germane to wind turbines. These guidelines are intended to help remedy this situation by suggesting design goals for proposed project, outlining a methodology for evaluating potential impacts from new projects and describing how to accurately measure the noise emissions from operating projects.

Studies and field surveys of the reaction to operating wind projects both in Europe and the United States generally suggest that the threshold between what it is normally regarded as acceptable noise from a project and what is unacceptable to some is a project sound level that falls in a gray area ranging from about 35 to 45 dBA. Below that range the project is so quiet in absolute terms that almost no adverse reaction is usually observed and when the mean project sound level exceeds 45 dBA a certain number of complaints are almost inevitable. In view of this, it would be easy to avoid any negative impact by simply limiting the sound level from a proposed wind project to 35 dBA at all residences, but the reality is that such a stringent noise limit cannot normally be met even in sparsely populated areas and it would have the effect of preventing noise impacts by making it virtually impossible to permit and build most projects. In fairness then, any noise limit on a new project must try to strike a balance that reasonably protects the public from exposure to a legitimate noise nuisance while not completely standing in the way of economic development and project viability. It is important to realize that regulatory limits for other power generation and industrial facilities never seek or demand inaudibility but rather they endeavor to limit noise from the source to a reasonably acceptable level in terms of either an absolute limit or an allowable increase relative to the background level.

Based on the observed reaction to typical projects in United States, it would be advisable for any new project to attempt to maintain a mean sound level of 40 dBA or less outside all residences as an ideal design goal. Where this is not possible, and even that level is frequently difficult to achieve even in sparsely populated areas, a mean sound level of up to 45 dBA might be considered acceptable as long as the number of homes within the 40 to 45 dBA range is relatively small. Under no circumstances, however, should turbines be located in places where mean levels higher than 45 dBA are predicted by pre-construction modeling at residences. It is important to note that a project sound level of 40 dBA does not mean that the project would be inaudible or completely insignificant, only that its noise would generally be low enough that it would probably not be considered objectionable by the vast majority of neighbors.

Noise impact assessments for proposed projects can be absolute or relative in nature. In an absolute analysis the sound level contours from the project are plotted over a map of the turbine layout and the surrounding potentially sensitive receptors, normally permanent residences, and the sound levels are evaluated relative to the 40 and 45 dBA criteria discussed above. A relative assessment involves, as a first step, a field survey of the existing soundscape at the site followed by a noise modeling analysis. The potential impact of the project is evaluated in terms of the differential between the existing background sound level and the calculated project-only sound level, importantly, under identical wind conditions. As a general rule of thumb, an increase of up to 5 dBA above the pre-existing L_{A90} sound level is usually found to be acceptable whereas greater increases should be avoided. This design approach only holds for background levels of about 35 dBA or above. When lower background sound levels are found a design goal of 40 dBA or less at all residences should be sought.

Commercially available software packages based on ISO 9613-2 are suggested for noise modeling analyses. Recommended modeling procedures would consist of the following steps.

- Begin with a base map showing the turbine locations and all potentially sensitive receptors in and around the project area (residences, schools, churches, etc.)
- Build up the topography of the site in the noise model if the terrain features consist of hills and valleys with a total elevation difference of more than about 100 ft. – otherwise flat terrain can be assumed
- Locate point sources at the hub height of each turbine (typically 80 m)
- Use the maximum octave band sound power level spectrum, measured per IEC 61400-11, for the planned turbine model or the loudest model of those being considered
- Assume a ground absorption coefficient (A_g from ISO 9613-2) appropriate to the site area (a moderate value of 0.5 generally works well as an annual average for rural farmland)
- Assume ISO "standard day" temperature and relative humidity values of 10 deg. C/70% RH unless the prevailing conditions at the site are substantially and consistently different than that
- Plot the sound contours from the project assuming an omni-directional wind out to a level of 35 dBA
- Evaluate the potential impact of the project at residences relative to the suggested 40 and 45 dBA thresholds

A relative impact analysis is recommended whenever unusually high or low background levels are suspected at a site, the project is large or controversial, or when there is simply a desire to carry out a thorough analysis. The baseline field survey of existing environmental sound levels should:

- Use 6 to 14 measurement positions depending on the complexity of the site
- Select positions at residences (to the extent possible) that are representative of all the distinct settings that may be present within the site area, such as sheltered valleys, exposed hilltops, wooded areas, near major roadways, remote and secluded, etc.
- Monitor in continuous 10 minute intervals for a period of at least 14 days to capture a wide variety of wind and weather conditions
- Record a number of statistical parameters, giving precedence to the relatively conservative L_{A90} measure
- Use Type 1 or 2 integrating sound level meters fitted with oversize (7” diameter, or greater) windscreens
- Mount the microphones approximately 1 m above ground level, where feasible, to minimize self-induced wind noise
- Use one or more temporary weather stations at the most open and exposed measurement positions to record wind speed at microphone height and other parameters, such as rainfall.
- Apply a correction, if necessary, to the A-weighted sound levels for wind-induced, self-noise based on the microphone height anemometer readings
- Evaluate the L_{A90} results for consistency over the various measurement positions, segregating the results for different settings if there are clear and consistent differences
- Normalize the wind speed measured by the highest anemometers on all on-site met towers to a standard height of 10 m per Eqn. (7) of IEC 61400-11
- Correlate the design site-wide or individual setting background levels to the normalized wind speed to determine the mean value as a function of wind velocity
- Use the 6 m/s result as the critical design wind speed or determine the site-specific critical wind speed from a comparison between the turbine sound power and background levels
- Use the mean L_{A90} background level at the critical wind speed as a baseline for evaluating the modeled sound emissions of the project under those same conditions

The accurate measurement of noise from an operational project requires a determination of the concurrent background sound level present at the time each sample of operational noise is measured so that the wind and atmospheric conditions are consistent. Background levels measured at a different time and under inevitably different conditions are not suitable for use in correcting operational sound measurements.

The objective of an operational survey is to quantify the project-only sound level exclusive of background noise, which can easily be comparable to the project level at typical set back distances. Ignoring this background component will normally result in an overestimate of the project’s actual sound levels.

A methodology is outlined in these guidelines for estimating the simultaneous background sound level by monitoring at a number of positions outside of the site area in locations and settings that are similar in nature to the on-site positions but remote from all turbine noise. In general, an operational survey to determine the sound emissions exclusively due to the project should:

- Use 6 to 10 on-site measurement positions depending on the complexity of the site and focused on the residences with maximum exposure to turbine noise (irrespective of their participation in the project)
- Set up 3 to 4 off-site background measurement positions at positions at least 1.5 miles from the project perimeter in diametrically opposed directions. These positions should be similar in setting and character to the on-site positions but removed from any exposure to project noise
- Monitor in continuous 10 minute intervals for a period of at least 14 days to capture a wide variety of wind and weather conditions
- Record a number of statistical parameters, giving precedence to the L_{A90} measure
- Use Type 1 or 2 integrating sound level meters fitted with oversize (7” diameter, or greater) windscreens
- Mount the microphones approximately 1 m above ground level, where feasible, to minimize self-induced wind noise
- Use one or more temporary weather stations at the most open and exposed measurement positions to record wind speed at microphone height and other parameters, such as rainfall.
- Apply a correction, if necessary, to the A-weighted sound levels for wind-induced, self-noise based on the microphone height anemometer readings
- Evaluate the off-site L_{A90} results for consistency over the various measurement positions, segregating the results for different settings if there are clear and consistent differences. Develop one or more design background levels to be used to correct the on-site levels.
- Subtract the appropriate design background level from the total measured level at each on-site receptor to derive the project-only sound level at each receptor position
- Normalize the wind speed measured by the highest anemometers on all on-site met towers to a standard height of 10 m per Eqn. (7) of IEC 61400-11
- Plot the derived project-only sound levels as a function of time or wind speed.
- Exclude all data points measured during calm conditions when the project was not operating
- Exclude all data points that appear to be associated with local contaminating noises; i.e. noise spikes, usually occurring at only one position, that are not accompanied by a simultaneous spike in wind speed
- Evaluate the final results with respect to the applicable design goal or ordinance limit. If the measured levels are lower than the design target at least 95% of the time the project can be considered in compliance.

2.0 Characteristics of Wind Turbine Noise

The magnitude and nature of wind turbine noise is entirely dependent on time-varying wind and atmospheric conditions, whereas a conventional fossil-fueled power station operates, often continuously and steadily, in a manner that is completely independent of the local environment. Consequently, a combustion turbine plant, for example, is most apt to be perceptible and a potential noise problem during calm and still weather conditions while a wind turbine project would, under most normal circumstances, not make any noise at all under those same conditions. During moderately windy conditions increased background noise would tend to diminish the perceptibility of the fossil fueled plant while the wind project would generally be at its loudest relative to the background level. At very high wind speeds background noise often becomes dominant to the extent it can obscure both sources.

In addition to simply being dependent on prevailing wind and atmospheric conditions, wind turbine noise usually has a distinctive, identifiable character to it that makes it more readily perceptible than other industrial sources of comparable magnitude[6,7,8]. The fundamental noise generation mechanism, the turbulent interaction of airflow over the moving blades, is dependent on the characteristics of the air mass flowing into the rotor plane. For example, when the airflow is fairly constant and steady in velocity over the swept area noise is generally at a minimum. While such ideal, laminar flow conditions may exist much of the time, particularly during the day, they do not occur all of the time, and the reality is that the wind often blows in the form of intermittent gusts separated by short periods of relative calm rather than as a smooth continuous stream of constant velocity. In addition, the flow may contain turbulent eddies, may be unstable in direction and the mean velocity may vary considerably over the vertical diameter of the rotor, which is typically in the 77 to 112 m (250 to 370 ft.) range on the utility scale turbines now in common use. These uneven and unstable airflow conditions generally cause more noise to be generated - and it is generated sporadically as each gust sweeps past and as the wind varies amorphously in speed or direction over the rotor plane. Such unstable conditions can lead to sound levels that change very noticeably in the short-term not only in general volume but also in character.

Qualitatively, under average circumstances rotor noise, as perceived at a common set back distance of around 400 m (1200 ft.), might be described as a churning, mildly periodic sound due to blade swish, particularly when there are several units at comparable distances from the point of observation. The normally non-synchronized and incoherent sounds from multiple units tend to blur the sound and minimize the perception of swish, although it is most commonly weak during “normal” circumstances even if only one unit is present. Another common description is that the noise is reminiscent of a plane flying over at fairly high altitude. This apt comparison is probably partly due to the basic similarity in frequency content of the two sounds but also to the phenomenon where the sound can fade in and out randomly. In the case of an actual plane it is the intervening non-homogeneous atmosphere that alternately enhances or hinders sound propagation from the distant source producing this effect while, in the case of the wind turbine, it is more likely to be short-term variations in noise generation at the source itself, or a combination of both source and path effects.

A pure path effect that occasionally occurs is the enhanced propagation of turbine noise due to thermal layering, known as a stable atmosphere, where the air is warmer above the surface than at the surface causing sound rays to diffract downward and making a distant sound louder than it would otherwise be. At night, this phenomenon, most likely in combination with the wind speed gradient, is most likely to lead to an increase in periodic noise (generally referred to as amplitude modulation, or AM)[9,10]. The exact mechanism behind this noise, particularly when it becomes unusually pronounced, is not entirely understood, but, in simple terms, it is thought to be caused when the wind speed at the top of the rotor is significantly higher than the wind speed at the bottom; i.e. when the vertical wind speed gradient is more slanted and less vertical, as is usually the case at night. Having said that, however, this phenomenon is not always present or particularly pronounced at all sites, but *when of sufficient magnitude*, the fairly pronounced swishing or thumping sound that can result on certain evenings can and does give rise to quite legitimate complaints. In fact, this is probably the primary cause of serious complaints about wind project noise. In general, the occurrence of this phenomenon in its pronounced or enhanced form is rather rare making detailed measurements difficult[11] but a major effort(ibid) is currently underway in the United Kingdom seeking to quantify and further understand this noise.

2.1 Low Frequency Noise and C-weighted Sound Levels

When the swishing, thumping or beating noise alluded to above does occurs it is usually at a rate of about once per second, or 1 Hz, which is the blade passing frequency of a typical three-bladed rotor turning at 20 rpm. Although the "frequency" of its occurrence at 1 Hz obviously falls at the very low end of the frequency spectrum, this noise is not "low frequency" or infrasonic noise, per se. It is simply a periodic noise where the actual frequency spectrum may contain some slightly elevated levels in the lower frequencies but where the most prominent noise is roughly centered around 500 Hz near the middle of the audible frequency spectrum. In general, the widespread belief that wind turbines produce elevated or even harmful levels of low frequency and infrasonic sound is utterly untrue as proven repeatedly and independently by numerous investigators[12,13,14,15,16] and probably arose from a confusion between this periodic amplitude modulation noise and actual low frequency noise. Problematic levels of low frequency noise (i.e. those resulting in perceptible vibrations and complaints) are most commonly associated with simple cycle gas turbines, which produce tremendous energy in the 20 to 50 Hz region of the spectrum – vastly more than could ever be produced by a wind turbine.

The mistaken belief that wind turbines produce high levels of low frequency noise can also be attributed, perhaps even more definitively, to wind-induced microphone error where wind blowing through virtually any windscreen will cause the low end, and only the low end, of the frequency spectrum to substantially increase due to self-generated distortion. The magnitude and frequency response of this error has been theoretically/mathematically quantified by van den Berg[10] and empirically by Hessler[17] by subjecting a variety of commonly used windscreens to known air speeds in a massively silenced wind tunnel – thereby directly measuring the frequency response to air flow alone (the specific results of this study and its applications are discussed further in Section 5.1). The results of this wind tunnel experiment were used to evaluate measurements of actual wind turbine noise at a site in Southern Minnesota by Hessler in 2008[18]. Figure 2.1.1 below shows, as an example, the frequency spectra measured under fairly windy conditions in a rural soybean field 1000 ft. from an isolated unit and, at the same time, in an identical soybean field 3 miles away from any turbines.

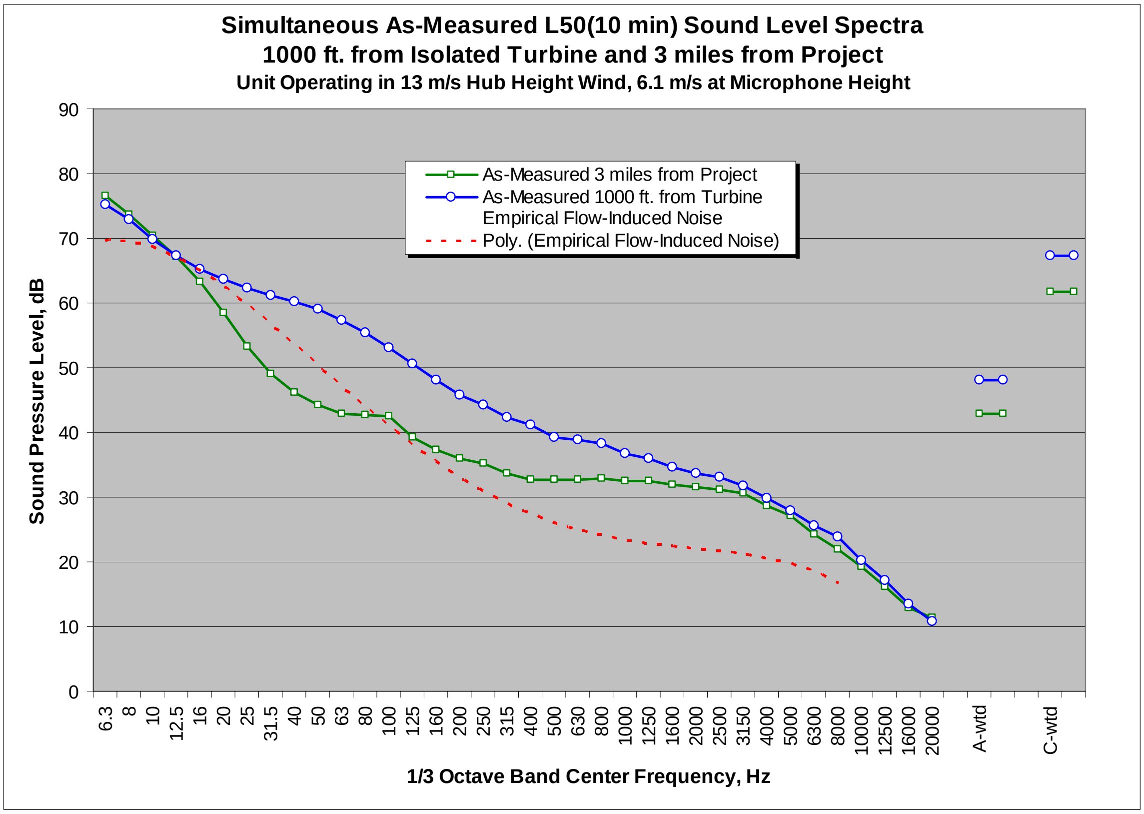

Figure 2.1.1

The two measurements show the same values in the lowest frequency bands. Since there is clearly no source of low frequency noise present in the background measurement, the low frequency levels - in both measurements – simply represent self-generated distortion and are not the actual sound emissions of anything. This can be confirmed from the wind tunnel study where the measured frequency spectrum for this particular windscreen (7" diameter) subjected to a 6.1 m/s wind is also plotted in Figure 2.1.1[a].

What all this shows is that virtually any measurement taken under moderately windy conditions will be severely affected by false-signal noise in the lower frequencies, even

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[a] It should be noted that the wind tunnel results quantify the minimum amount of false-signal noise measured under more or less laminar flow conditions in the absence of possible further distortion from turbulence and atmospheric conditions.

when a large windscreen is used as in the example above. The measurement will appear to show high levels of low frequency noise - whether a wind turbine is present or not.

Figure 2.1.1 also illustrates another important point concerning C-weighted sound levels; namely, that the C-weighted levels at 1000 ft. and 3 miles are somewhat similar at 67 and 62 dBC, respectively. The significance of this is that C-weighted sound levels, as opposed to the much more common A-weighted metric, are normally used for the specific purpose of quantifying, investigating or placing a limit on noise sources that are rich in low frequency noise. The reason for this is that C-weighting does not mathematically suppress the low frequencies the way A-weighting does making it highly sensitive to and usually dominated by the low frequency content of a sound. Figure 2.1.2 shows this graphically for the example measurement at 1000 ft. from a wind turbine.

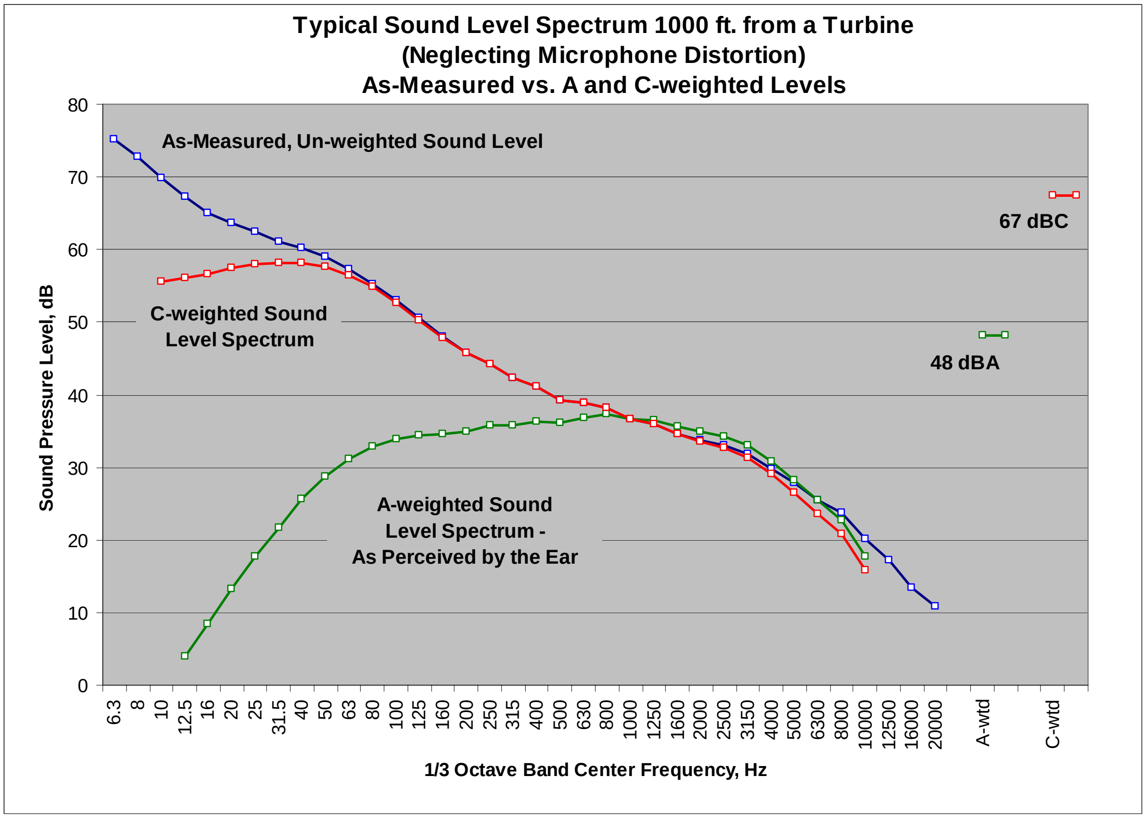

Figure 2.1.2

The as-measured sound level, warts and all, without any weighting applied is the blue trace. C-weighting reduces the low end of the frequency spectrum by a moderate amount whereas A-weighting reduces it substantially. There is no tangible or physiological rationale behind C-weighting but A-weighting serves the very useful purpose of adjusting the frequency spectrum of the sound so that it matches the way it is subjectively perceived by the human ear, which is relatively insensitive to low frequency sounds. Figure 2.1.2 shows that what is actually heard at 1000 ft. from this turbine is mid-frequency sound from roughly 100 to 2500 Hz – and even if the artificially elevated low frequency levels were actually attributable to the turbine nothing would still be audible in the low frequencies (recall that this measurement is unadjusted for low frequency false-signal noise).

The ultimate point of this discussion is that C-weighted sound levels cannot be measured in any kind of meaningful way in the windy conditions associated with turbine operation, since they essentially quantify the level of low frequency microphone distortion rather than any actual noise.

As another example, the plot below shows the C-weighted sound levels measured over a two week period at a residence surrounded by several wind turbines and simultaneously by a monitor located miles away from the project area in a similar setting (rural Midwestern farm country).

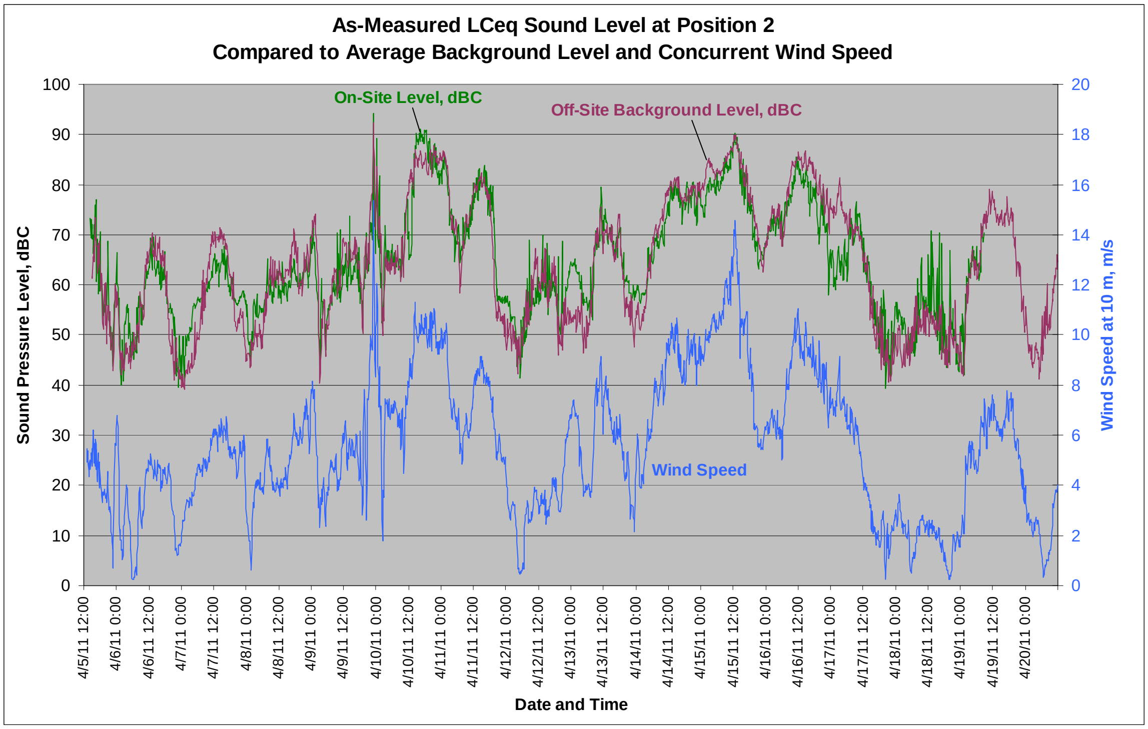

Figure 2.1.3

In essence, the levels are largely the same at both places and are more a measurement of the prevailing wind speed and its effect on the microphone rather than any real source of low frequency noise.

Consequently, despite their occasional appearance in local ordinances as an intended way of limiting the low frequency noise emissions from wind projects, by either an absolute limit or a dBA-dBC differential, C-weighted sound levels have no practical place in the measurement of wind turbine sound.

3.0 Recommended Design Goals

It would be a trivial solution to set an extremely low sound level of, say, 30 dBA as a permissible sound level for a new wind project at potentially sensitive receptors or to impose massive set back distances to any residences. While such restrictions would probably ensure that there was no adverse impact whatsoever from the project, the effective inaudibility of project noise would be due more to the fact it was never built than to its low sound emissions. Realizing virtual inaudibility or maintaining set backs of several thousand feet from all residences is generally an impracticality at all but the most remote sites. In fairness then, any noise limit on a new project must try to strike a balance that reasonably protects the public from exposure to a legitimate noise nuisance while not completely standing in the way of economic development and project viability. It is important to realize that regulatory limits for other power generation and industrial facilities never seek or demand inaudibility but rather they endeavor to limit noise from the source to a reasonably acceptable level either in terms of an absolute limit (commonly 45 dBA at night) or a relative increase over the pre-existing environmental sound level (typically 5 dBA[19]).

Research, principally by Pedersen[20,21] and Persson-Waye[22], on what the reaction is to wind turbine sound levels and what levels might be considered acceptable has been on-going for some time now in Europe. These studies analyze the responses to blind questionnaires distributed to residents living near wind farms in Sweden and The Netherlands in an effort to correlate the level of annoyance with noise and other factors with the calculated project sound level at each residence. In general, the results suggest among many other important findings that a project sound level in the 40 to 45 dBA range can lead to relatively high annoyance rates of around 20 to 25%(ibid); however, it important to understand that these numbers refer to the percentage of those with exposure to such sound levels and not the entire population in the vicinity of the projects. Viewed within the context of the total survey population the rate of adverse reaction comes down to a handful of individuals or very roughly about 4 to 6% when residences are exposed to project sound levels in the 40 to 45 dBA range.

A somewhat similar rate of complaints/annoyance expressed as a percentage of the total population living within 2000 ft. of a turbine was found by Hessler[23] during compliance sound testing at a number of typical, newly operational wind projects in the United States. In each survey the total number of residents where complaints or even mild concerns about noise had been called in was obtained from project operations and the actual sound levels at all of these locations were measured over 2 to 3 week periods. The fundamental results are summarized in the following table.

Table 3.0.1 *Number of Observed Complaints Relative to the Total Number of Households in Close Proximity to Turbines [Hessler, 23]*

Project	Total Households in the Site Area (Approx.)	Number of Complaints as a Function of Project Sound Level (dBA) (a)			Total Number of Complaints	Percentage Relative to Total Households
		< 40	40 - 44	45 or Higher		
Site A	107	0	2	1	3	3%
Site B	147	0	3	3	6	4%
Site C	151	0	3	0	3	2%
Site D	268	0	2	4	6	2%
Site E	91	1	1	4	6	7%
					Overall Average:	4%

(a) Sound levels expressed as long-term, mean values

Although the purpose of these surveys was to confirm compliance with regulatory noise and not specifically to evaluate community reaction, the findings, taken together with the European research mentioned above, suggest that the vast majority of residents living within or close to a wind farm have no substantial objections to project noise, particularly if the mean sound level is below 40 dBA. It is important to add that all of the sites investigated in these studies were just as prone as any other site to all the adverse character issues mentioned above, such as amplitude modulation, stable atmospheric conditions, highly variable sound levels and higher nighttime noise levels. While the possibility of annoyance, if not serious disturbance, can almost never be completely ruled out, it appears that the total number of complaints would be fairly small as long as the mean project level does not exceed 40 dBA. Above that point, specifically in the 40 to 45 dBA range, complaints can be expected with some certainty but, as indicated in Table 3.0.1, still at a fairly low rate of about 2% relative to the total population in close proximity to the project.

Consequently, it would be advisable for any new project to attempt to maintain a mean sound level of 40 dBA or less outside all residences as an ideal design goal. Where this is not possible, and it frequently is difficult to achieve even in sparsely populated areas, sound levels of up to 45 dBA might be considered acceptable as long as the number of homes within the 40 to 45 dBA range is relatively small. Under no circumstances, however, should turbines be located in places where mean levels higher than 45 dBA are predicted by pre-construction modeling at residences. A project sound level of 40 dBA does not mean that the project would be inaudible or completely insignificant, only that its noise would generally be low enough that it would probably not be considered objectionable by the vast majority of neighbors based on the actual reaction to other projects.

It is important to note that the sound levels in Table 3.0.1 and the suggested sound level targets discussed above are mean, long-term values and not instantaneous maxima. Wind turbine sound levels naturally vary above and below their mean or average value due to wind and atmospheric conditions and can significantly exceed the mean value at times. Extensive field experience measuring operational projects indicates that sound levels commonly fluctuate by roughly +/- 5 dBA about the mean trend line and that short-lived (10 to 20 minute) spikes on the order of 15 to 20 dBA above the mean are occasionally observed when atmospheric conditions strongly favor the generation and propagation of noise. Because no project can be designed so that all such spikes would remain below the 40 or 45 dBA targets at all times, these values are expressed as long-term mean levels, or the central trend through data collected over a period of several weeks.

4.0 Noise Impact Assessments

4.1 Noise Modeling

The principal mechanism for evaluating the potential impact of a proposed wind project is to analytically model its noise emissions. A sound level contour map showing the expected sound emissions from the project relative to all the residences in the area is essentially a graphic illustration of the potential impact. It follows from the preceding discussion of ideal design goals that predicted levels below 40 dBA at residences can be associated with a relatively low adverse impact, while higher levels, particularly those higher then 45 dBA, suggest a relatively high probability of serious complaints.

Because there are few options to reduce noise from a project once it becomes operational, any necessary noise abatement must essentially be designed into the project while it is still in the planning stage. Computer modeling allows the potential noise impact to be visualized but, importantly, also allows mitigation options to be explored, since the effects of relocating or removing individual turbines or using alternate turbine models can be easily evaluated. Such optimization studies are best performed early in the development process while there is still some flexibility to move things around. This process can be repeated iteratively as the design develops and lease and easement agreements evolve to help keep community noise levels as low as possible within the context, of course, of many other constraints.

4.1.1 *Acceptable Sound Propagation Standards*

Wind turbine noise is actually rather simple to model because the project consists of more or less ideal point sources located high in the air. Consequently, the dominant sound propagation factor is simply spherical wave spreading with distance, which is an axiomatic law of physics that is built into every modeling software package. All other effects, such as ground or air absorption, are minor subtleties by comparison so great sophistication in modeling software is not required. In fact, all that is really necessary is to calculate sound propagation from the project using ISO 9613-2 *Acoustics – Attenuation of sound during propagation outdoors. Part 2: General method of calculation* (1996)[24], which is, by far, the prevailing and most widely accepted worldwide standard for such calculations and the basis for essentially every commercial noise modeling program.

Like the other test standards alluded to in the introduction, ISO 9613-2 was not written with wind turbines in mind and its applicability to elevated sources (usually 80 m) and long propagation distances is occasionally questioned. Table 5 in the standard gives the estimated accuracy of the method for noise sources up to 30 m high and for propagation distances up to 1000 m. This 30 m height figure is sometimes interpreted to mean that the standard cannot be used for 80 m high sources, but it is just that no specific accuracy estimate is given for such cases, not that the standard is inappropriate. As mentioned earlier, the principal sound propagation loss in wind turbine modeling is simple geometric spreading of the sound wave, which is a phenomenon that has no dependence on the specific point of origin or its height above ground level.

Source height is a factor, however, in the relatively minor ground absorption loss (i.e. the tendency of the ground surface to variously absorb or reflect sound waves) but measurements of actual wind turbine sound levels vs. predictions show reasonably good agreement indicating that the calculation of the ground absorption loss and, indeed, the entire methodology, is perfectly valid for wind turbines.

Having said that, it should be noted that ISO 9613-2 does not consider atmospheric conditions, such as the wind and temperature gradients, stability, turbulence, etc., and was always intended to portray very long-term or average propagation conditions under slightly conservative downwind conditions. Consequently, the model results using this standard need to be interpreted as the expected sound level under "average" conditions, meaning that the actual sound level will be close to the prediction much of the time but higher *and* lower levels will occur with about equal regularity due to fluctuating atmospheric conditions, which affect both the generation and propagation of wind turbine noise. The plot below shows a typical comparison between the measured project-only sound levels over a two week period compared to predictions at various wind speeds. The model predictions tend to agree with the central trend line. The scatter evident in this chart is normal and inevitable and reflects the natural variability of wind turbine sound levels as observed at a distant point.

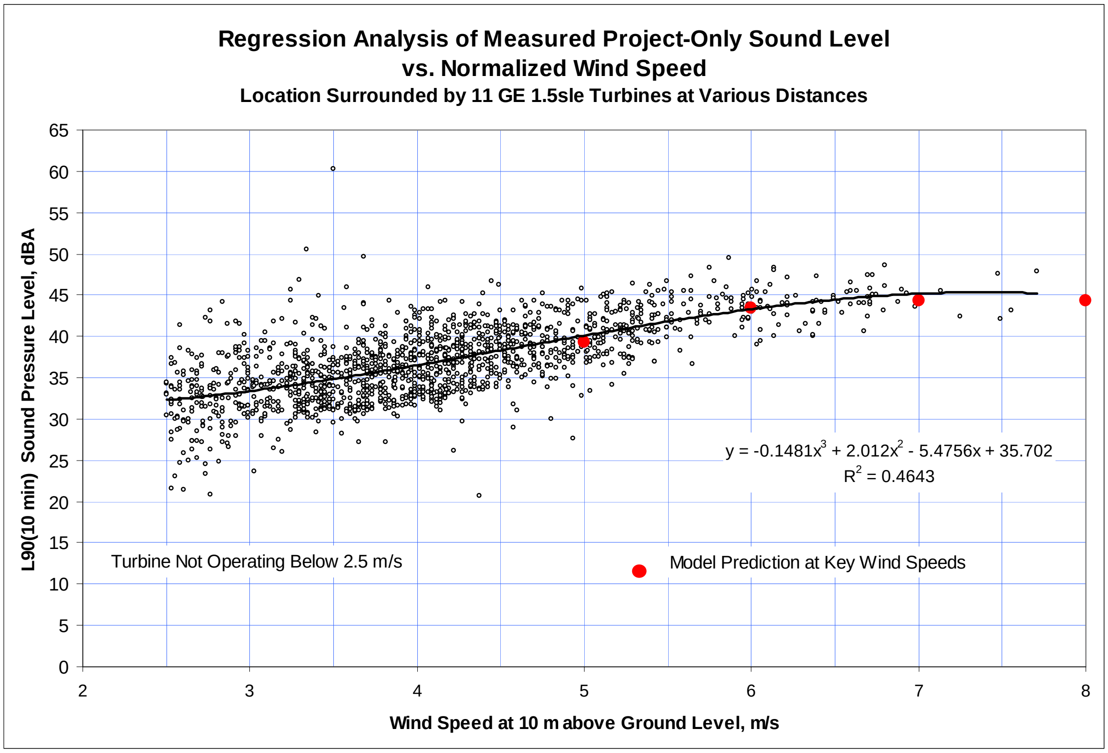

Figure 4.0.1

It should be pointed out that there is an alternative prediction methodology to ISO 9613-2 that takes atmospheric conditions into account: NORD2000[25], which is a proprietary software package that has been in development in Denmark for quite some time. However, it is rather complicated and is not in wide use partially because it has not been integrated or fully integrated into the most commonly used modeling programs. This sound emissions model is based on the fundamental mathematics of wave propagation rather than the empirical studies that form the basis for most of the propagation losses in ISO 9613-2, but despite its sophistication it does not seem to yield substantially better results than ISO 9613-2[26]. As exemplified by Figure 4.0.1, there is no reason why the more common and simpler ISO 9613-2 methodology should not be used.

4.1.2 *Modeling Software*

In theory, then, any program based on ISO 9613-2 can ostensibly be used to model wind turbines but there is more to it than the calculation of sound propagation losses. What emerges as the key differentiation between programs is basically how well and easily the site plan can be imported into the program and the quality and nature of the program's output.

Typical wind projects consist of dozens of units either spread out over many square miles in flat or rolling country or strung out along ridgelines. At the first type of site the turbines are frequently mixed in with potentially sensitive receptors (typically permanent residences) that can easily number into the hundreds. With ridgeline projects the nearest receptors are usually all around the base of the mountain or promontory on which the turbines are proposed and the effective project area (i.e. the region where residences exist within possible earshot of the project) can be vast. Consequently, it is best, if not essential, to use a modeling program that allows for the reasonably easy importation and scaling of a site map that shows not only the turbine locations but also all of the surrounding potentially sensitive receptors. Such a map is normally in shapefile (.shp) format with a layer for the turbines, a layer for structures (unfortunately not often differentiated into houses, barns, garages, commercial buildings, etc.) and layers for other features such as roads or topography. While nominally possible, it is not normally desirable to use only numerical tables of turbine coordinates to create the model for the principal reasons that a separate base map needs to be found and imported and different coordinate systems can become confused. In addition, publically available maps (used as a base map for the model) almost never show, or at least accurately show, all the residences in the vicinity of the project.

In addition to the turbines and houses the topography of the site often needs to be considered in the model – not only because of the line sight between the turbines and houses may be partially blocked or obstructed, but more generally because the source-receptor distance at sites with fairly dramatic terrain is affected and usually lengthened when modeled in three-dimensions. Consequently, a program that has the ability to import terrain contours and then mathematically consider their effect on sound propagation is essential for any project in a hilly or mountainous setting. This factor can only be safely ignored for sites with fairly flat or gently rolling topography.

In terms of output the most important element is the ability of the program to map sound contours in high resolution over the input base map. The potential impact from any wind project is normally graphically evaluated from contour plots. It is the number of houses within a certain threshold or sound level that usually determines whether the project is likely to result in complaints or not or whether it will comply with regulatory noise limits.

In terms of specific programs, Cadna/A® developed by Datakustik GmbH (Munich, Germany), appears to be used most often by engineers and consultants and is fully capable of importing shapefiles, modeling complex terrain and producing detailed contour maps.

The second most common noise prediction program is the sound emissions component of the WindPRO® software package (EMD International A/S, Denmark), which is a generalized siting tool for wind farms. The noise prediction module is only one aspect of the much larger program.

SoundPLAN® (Braustein & Berndt GmbH, Backnang, Germany), is evidently similar in capability to Cadna/A® but, for reasons that are unclear, is not often used for wind turbine analyses despite its apparent capability to integrate the NORD2000 algorithm as an optional calculation methodology.

One other program, WindFarm® (ReSoft Ltd, U.K.), is another general project design package of which the noise component is only a small part.

Any one of these programs would be generally acceptable for modeling the noise from a new project.

4.1.3 *Model Inputs*

In contrast to models of acoustically complex fossil fueled power plants that consist of dozens of major sources, the sound levels of which often need to be estimated, the input to a wind turbine project model is a single sound power level spectrum that is known with considerable accuracy. Turbine sound power levels are tested in accordance with IEC 61400-11[5], in which highly specialized and meticulous techniques are used to derive the sound power level of a wind turbine over a range of wind speeds from 6 to 10 m/s (as measured at 10 m above ground)[b]. The best input to use for any model is the maximum octave band sound power level frequency spectrum taken directly from a field test report.

Although such reports are sometimes made available by manufacturers, it is more common for the acoustical performance to be reported second-hand (based on either an IEC 61400-11 test or analytical calculations) in a technical specification document published by the manufacturer. The reported sound levels may or may not contain an explicit design margin and/or may be stated as warranted sound levels. While input sound levels that have been artificially inflated would tend to needlessly overstate the potential impact of a project, there often isn't any alternative to using whatever performance the manufacturer decides to publish. Whatever the source of the data is, it should be clearly stated in the impact assessment report.

4.1.4 *Modeling Methodology*

Recommended procedures for modeling wind turbine project noise are as follows:

- Begin with a base map showing the turbine locations and all potentially sensitive receptors in and around the project area (residences, schools, churches, etc.)
- Build up the topography of the site in the noise model if the terrain features consist of hills and valleys with a total elevation difference of more than about 100 ft. – otherwise flat terrain can be assumed
- Locate point sources at the hub height of each turbine (typically 80 m)
- Use the maximum octave band sound power level spectrum for the planned turbine model or the loudest model of those being considered
- Assume a ground absorption coefficient (A_g from ISO 9613-2) appropriate to the site area (a moderate value of 0.5 generally works well as an annual average for rural farmland, although higher values specifically for farm fields during summer conditions may be appropriate. A value of 0 (100% reflective ground) is likely to produce highly conservative results)

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[b] In its current edition (2.1). A revision to this standard has been in development for some time that would expand this wind speed range and add a number of other refinements (and complexities) to the test procedure. It is unclear whether this new edition will ever actually be adopted.

- Assume ISO “standard day” temperature and relative humidity values of 10 deg. C/70% RH unless the prevailing conditions at the site are substantially and consistently different than that
- Plot the sound contours from the project assuming an omni-directional wind out to a level of 35 dBA (shading the area between each 5 dBA gradation with a different color often greatly improves legibility)

The assumption of an omni-directional wind means that the sound power level of the turbine, which is measured in the IEC 61400-11 procedure downwind of the unit, is modeled as radiating with equal strength in all directions; i.e. the sound level in every direction is the downwind sound level. Although this may seem be depict an unrealistic situation and over-predict upwind sound levels, the fact of the matter is that this approach generally results in predictions that are consistent with measurements irrespective of the where the receptor point is located. Although somewhat counterintuitive, the reason for this is that wind turbine noise under most normal circumstances is not particularly directional and generally radiates uniformly in all directions. As an example, the plot below shows the sound levels measured in three directions 1000 ft. from a typical unit in a rural project in Southern Minnesota. Although there are periods when the levels differ, implying some directionality, the majority of the time all three sound levels are generally about same irrespective of the wind direction. Moreover, the sound level at the downwind position is almost never elevated relative to other directions as one might expect.

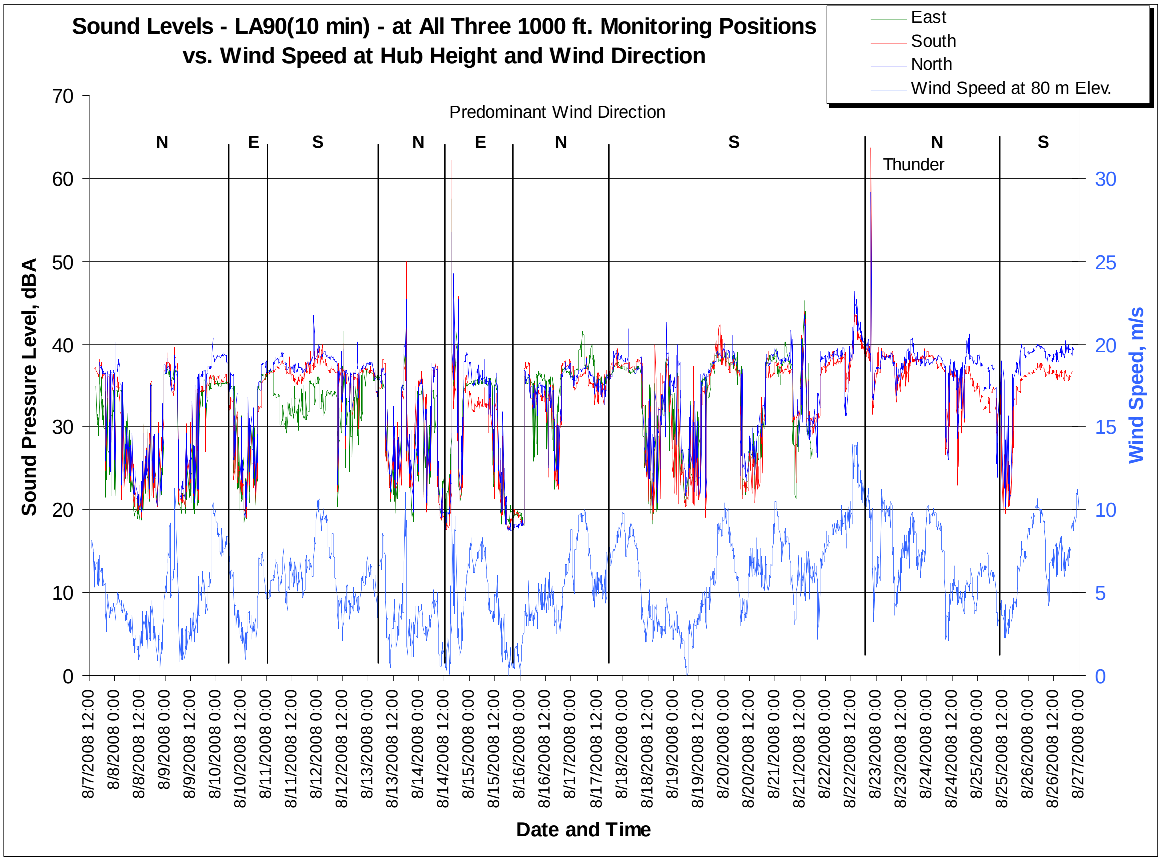


Figure 4.1.4.1 *Sound levels at 1000 ft. from a Typical Unit in Three Directions*

4.1.5 *Interpretation of Model Results*

An example plot for a hypothetical project, prepared using Cadna/A® and the procedures outlined in Section 4.1.4, is shown in Figure 4.1.5.1. In this instance, the units are located on a fairly prominent ridgeline and the topography has been recreated in the model.

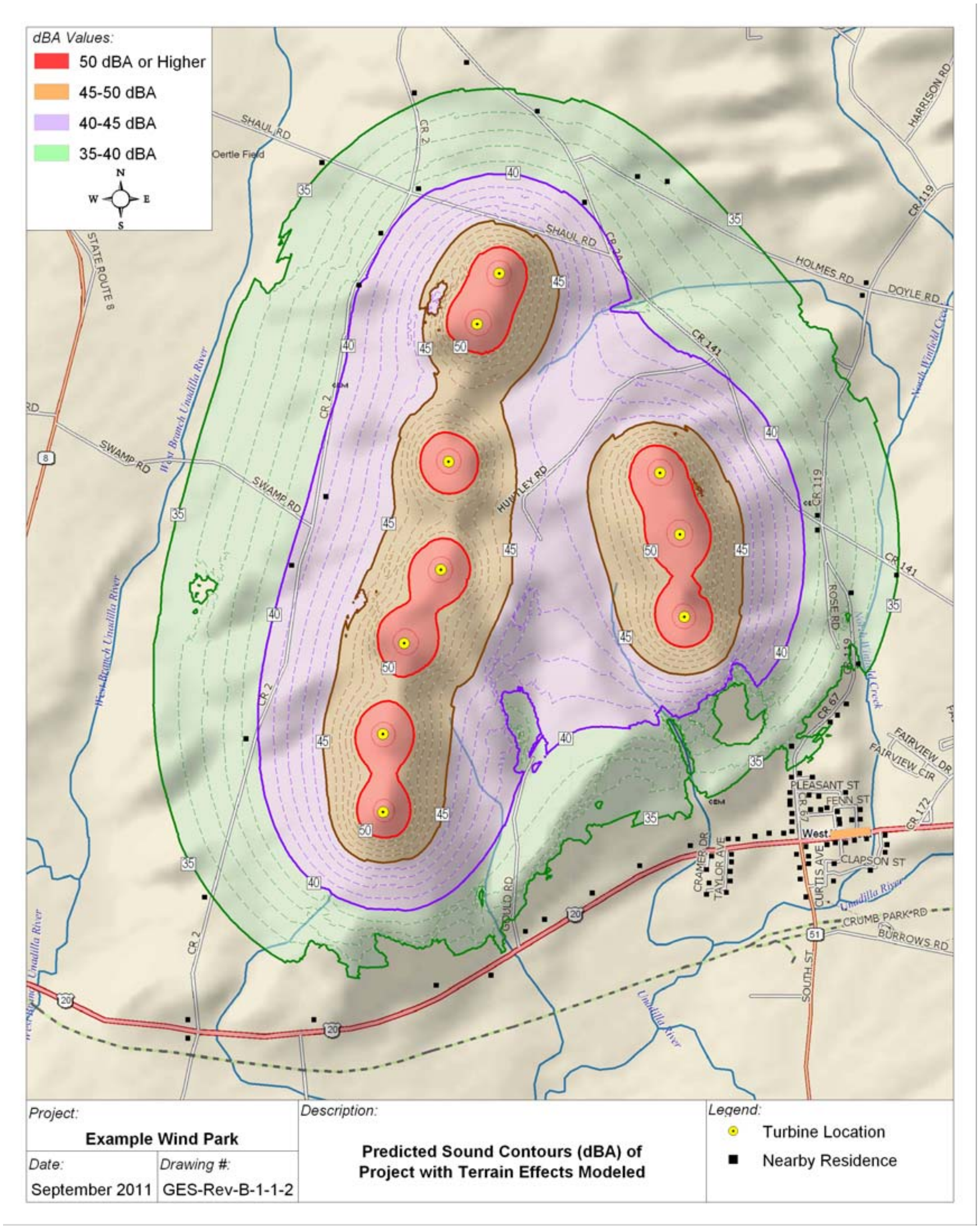
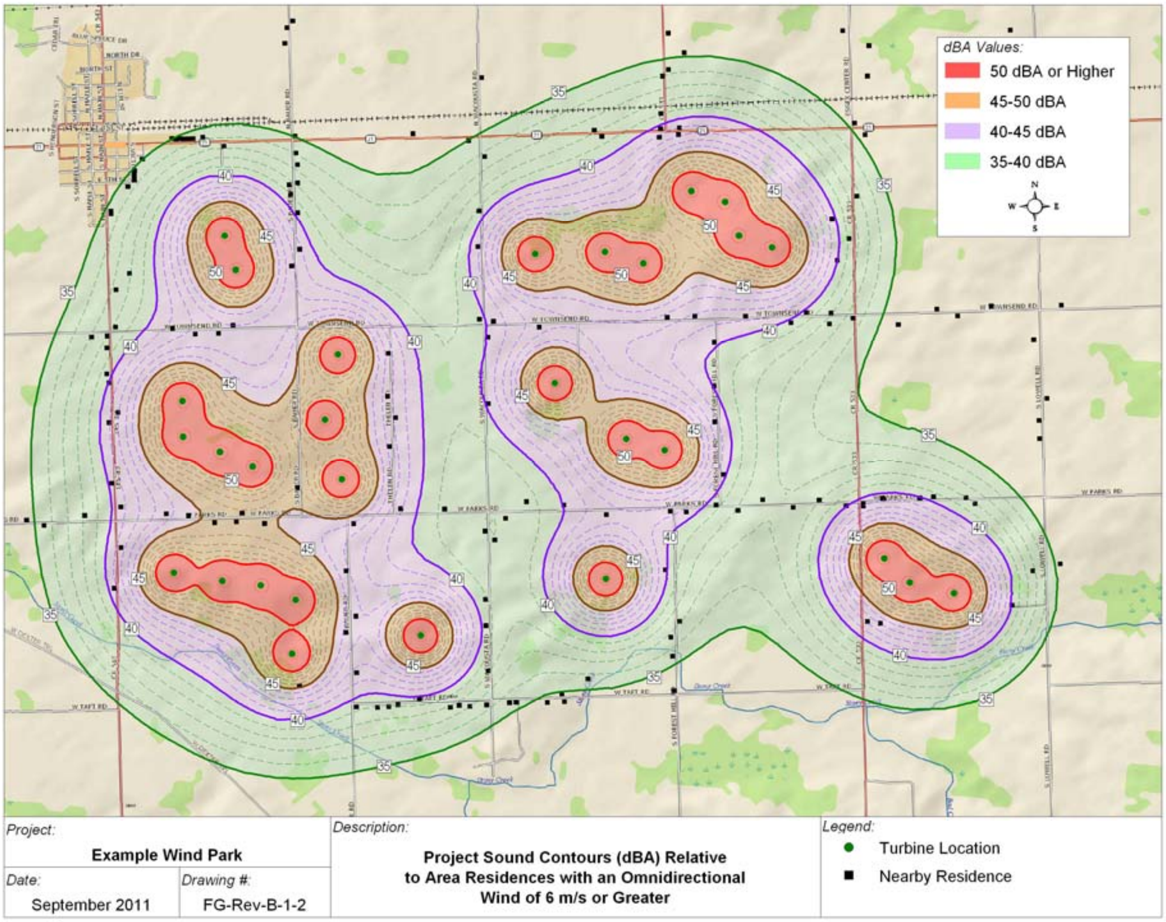


Figure 4.1.5.1 *Noise Model Plot – Example A*

Based on the plot, the potential noise impact from this project can be characterized as being fairly mild in the sense that nearly all of the residences in the vicinity of the project are expected to see a mean sound level of 40 dBA or, in most cases, less. The few houses that are nominally above 40 dBA are only marginally above that threshold and none are close to the 45 dBA absolute upper limit. The green region between 40 and 35 dBA generally represents the area where in all likelihood project noise would still be readily audible some of the time, if not much of the time, but at a fairly low magnitude. The audibility of and reaction to sound levels in this range would be somewhat dependent on the level of natural background sound in the area, since environmental sound levels in rural areas are commonly in the mid to high 30's dBA during the moderate wind conditions necessary for the project to operate – or, in other words, the background sound level could be roughly equivalent to the project sound level limiting its perceptibility. Below 35 dBA project noise generally becomes so low that it is only rarely considered objectionable even in extremely low noise environments. Complete inaudibility does not occur for quite some distance from most projects in quiet areas because of the distinctive, periodic nature of wind turbine noise. The actual distance to the point of inaudibility varies amorphously with atmospheric conditions and is generally much further at night than during the day. Consequently, the exact reaction to any project can never be predicted with certainty because project noise is often audible to some extent, at least intermittently, far from the project. However, the studies of response to wind turbine noise discussed in Section 3.0 suggest that the threshold between a mild or acceptable impact and a fairly significant adverse reaction is a gray area centered at 40 dBA.

An additional sound contour plot is shown in Figure 4.1.5.2 representing another hypothetical but typical project, this time in essentially flat Midwestern farm country.



Project:	Example Wind Park
Date:	September 2011
Drawing #:	FG-Rev-B-1-2
Description:	Project Sound Contours (dBA) Relative to Area Residences with an Omnidirectional Wind of 6 m/s or Greater

Figure 4.1.5.2 *Noise Model Plot – Example B*

In contrast to Example A, there are many homes inside of the 40 dBA sound contour in this scenario and even a few above 45 dBA, which is a common occurrence. One would have to conclude that at least a few complaints about noise would arise from this project if it were to proceed to completion in this configuration. The population density is such at this site that an optimization study should be undertaken to evaluate the feasibility of removing and relocating turbines outside of the present site area so that sound levels are substantially reduced at the homes with predicted levels of above 45 dBA and so that the number of residences above 40 dBA is dramatically diminished.

4.2 Pre-Construction Background Sound Surveys

Noise impacts can be evaluated in both absolute and relative terms. In the discussion immediately above the reaction to the example projects was estimated directly from the predicted project sound levels, neglecting background noise or essentially assuming a rural setting with generally quiet background sound levels. However, not all sites are the same and it is often prudent to perform a survey of existing conditions to establish just what the baseline sound levels are at residences in the proposed project area. In general, the audibility of, and potential impact from, any project is a function of how much, if at all, its noise exceeds the prevailing background level. A comparison between the predicted/modeled sound level from a proposed project and the actual background sound level measured in the project area under comparable wind and weather conditions gives a site-specific indication of the potential relative impact from the project.

Such a survey is not essential in all cases but is recommended when:

- Unusually high background levels are suspected (e.g. due to the proximity of a major highway, urban areas or existing industrial facilities)
- Unusually low background levels are suspected
- The project is unusually large or controversial
- There is simply a desire to carry out a complete and thorough assessment

4.3 Recommended Field Survey Methodology

The objective of a pre-construction survey is to establish what levels of environmental sound are currently being experienced at typical residences within the general project area in order to form a baseline against which the predicted sound emissions from the project can be compared. There is no need, nor would it be practical, to measure at every house. The idea is to get a set of samples that can be considered representative of the overall site area. In rural areas away from significant sources of man-made noise, it is common to find that the sound levels at all positions are generally similar indicating that background sound levels are for all intents and purposes uniform throughout the site area.

Contrary to popular belief, such a survey is *not* useful for the purpose of establishing the pre-existing environmental sound level as a baseline against which to compare the measured sound emissions from the completed project. The background sound level varies dramatically with time, typically over a dynamic range of 30 dBA or more, depending not only on the wind speed but many other factors, such as the prevailing atmospheric conditions, the time of day, season of the year, etc., so the level measured one or two years earlier cannot be taken to accurately represent the background level present during an operational compliance test. In fact, the only valid background level is the background level occurring, literally, at the same time that the operational sound level is measured. A methodology for overcoming this seeming impossibility is discussed later in Section 5.1.

4.3.1 *Measurement Positions*

Specific monitoring positions should ideally be located at or near typical residences in the site area. It is the sound level where people actually are most of the time and especially at night that is of primary importance (rather than at property lines, for instance). Permission to set up equipment on private property is usually freely granted upon request.

If a site is largely flat and homogenous in nature (e.g. rural farmland away from any major highways, urban areas or industry) monitor positions should be selected at points that are more or less evenly distributed over the project area. In such simple cases, 6 to 8 monitoring positions are usually more than sufficient even if the project area is fairly large.

For more complex sites, where the topography is significant or where man-made noise sources already exist, more monitoring positions will generally be required with the objective of capturing sound levels at residences in each kind of setting. A "setting" is defined as an area where the prevailing environmental sound level is suspected of differing significantly from other parts of the project area. For example, houses in the bottom of ravines or valleys may experience different ambient sound levels than nearby houses on exposed hilltops. Monitors should be located at positions representative of both of these settings. Another type of unique setting might be at homes that are located directly on a major road or highway or in an urban area versus others in the project area that are in remote areas. In some cases, a wind farm already exists adjacent to the area where a new project is proposed. Measurements should be made at homes that have maximum exposure to the sound emissions from the operating turbines for comparison to measurements at residences that are remote from the existing project. The total number of monitoring positions is generally limited by equipment availability and logistical concerns but no more than about 12 to 14 positions are normally required, even for the most complex sites.

4.3.2 *Survey Duration and Scheduling*

Short duration spot samples are insufficient to capture environmental sound levels over the variety of wind and atmospheric conditions that are relevant to project operation. For example, a brief sample on a calm, quiet night is meaningless in the sense that it does not represent the background sound level that will exist on a continuous basis or during the moderately windy conditions necessary for the project to generate noise. In fact, background sound levels in the rural areas where wind projects are most commonly sited are remarkable for their variability and substantial dependency on wind speed. It is the background sound level that occurs when it is moderately windy that is actually of interest for comparison to project sound emissions. In the very typical example below, the background sound level measured at four positions widely distributed over a proposed wind project site in the Midwest can be seen to parallel the concurrent wind speed and, moreover, to vary dramatically from 17 dBA during calm conditions to 54 dBA during windy conditions.

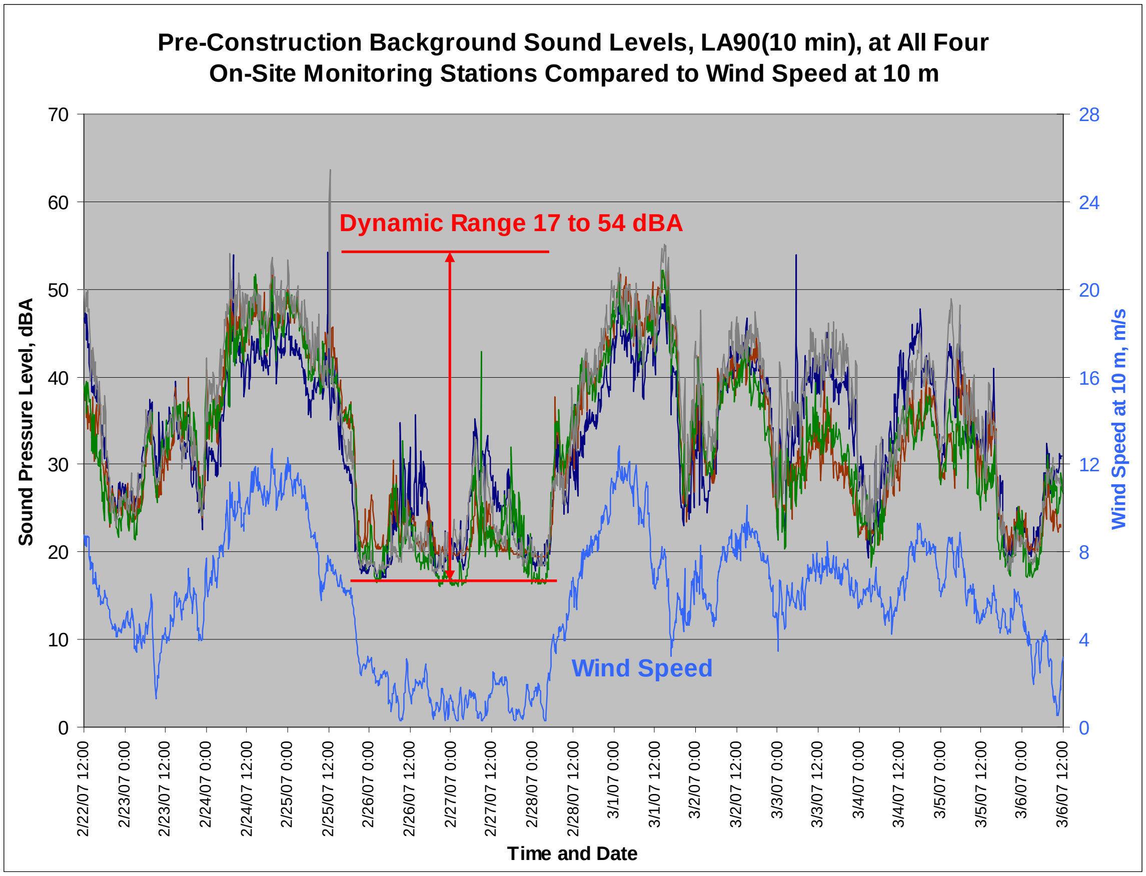


Figure 4.3.2.1

Consequently, a long-term, continuous monitoring approach is needed in which multiple instruments are set up at key locations and programmed to run day and night for a period of about two weeks or more. In essence, it is necessary to cast a wide net in order to capture sound levels during a variety of wind and atmospheric conditions and provide sufficient data so that the relationship between background noise and wind speed can be quantitatively evaluated.

Field experience suggests that an adequate range of wind speeds, from 0 to 10 m/s at 10 m above ground level, will usually be observed over any given 14 day period at most wind energy project sites, except perhaps during the low wind season at sites that might have very pronounced seasonal wind characteristics. Probably the principal reason for this observation is that this length of time is large relative to the time normally taken for weather patterns, wind directions and general atmospheric conditions to change, which essentially ensures that the data are statistically independent, as discussed in great detail in ANSI S12.9-1992/Part 2[27]. Data independence implies that the test results can be taken to represent the longer-term acoustic situation for that area, at least for the general time of year of the test. However, if a review of the weather conditions that occurred during the survey period shows that the winds were unusually calm or if an insufficient number of data points were collected at the higher wind speeds, the survey may need to be extended for another two weeks. Low wind conditions are most commonly captured and the vast majority of the measurements will be for conditions below or just above the cut-in wind speed. High winds normally occur intermittently over a few hours or a few days separated by sometimes lengthy periods of relatively calm conditions. It may sound counterintuitive, but it is not critical to capture extremely high wind conditions, say higher than about 12 m/s at 10 m, since most complaints and issues with wind turbine noise occur during moderate or even light wind conditions, while background noise tends to predominate under very windy conditions.

As a practical matter, the instruments for such a survey are set up, started and left to run unattended for the nominal two-week test period following which they can be retrieved and downloaded. Of course, one could stay on site through the test making additional intermittent manned measurements and observations but the very high cost of such an effort would be difficult to justify, particularly since it would not necessarily guarantee a better or more definitive result than could be derived from the monitor data alone.

In terms of scheduling, it is highly preferable to conduct this type of survey during cool season, or wintertime, conditions to eliminate or at least minimize possible contaminating noise from summertime insects, frogs and birds. In addition, it is best for deciduous trees to be leafless at sites where they are present in quantity to avoid elevated sound levels that might not be representative of the minimum annual level. Human activity, such as from farm machinery or lawn care, is also normally lower during the winter. While summertime surveys can be successful they should, as a general rule, be avoided wherever possible because nocturnal insect noise, for instance, can easily contaminate the data and make it impossible to quantify the relationship between sound levels and wind speed.

In addition to seasonal concerns, it is desirable, when practical, to attempt to schedule the survey set up to just precede a predicted period of moderate or high winds. This not only ensures that the survey period will capture these winds but also creates an opportunity for manned observations and measurements to be made for a day or two to augment to the longer term monitoring survey.

4.3.3 *Instrumentation and Test Set-up*

As with any field sound survey, what equipment is used and how it is deployed must adhere to certain minimum technical standards. These requirements are generally described in numerous standards, such as ANSI S12.9-1992/Part 2[27]; however, the focus of this section is not to repeat and belabor those details but rather to point up what adaptations need to be made for the specific application of performing general site-wide surveys for wind turbine projects. As mentioned earlier, no standard exists that can be directly used for this purpose, if only because they limit data collection to low wind conditions.

In terms of instrumentation, most environmental sound measurement standards recommend the use of Type 1 precision equipment per IEC 61672-1[28] or ANSI S1.43-1997[29] while also allowing for the use of Type 2 equipment. There is certainly no reason on technical grounds to oppose this recommendation but, from a practical perspective, it is often necessary to use Type 2 equipment for surveys of this type because of the large number of instruments needed. The normally negligible difference in technical performance between these two instrument classes is totally inconsequential within the inherently and unavoidably imprecise nature of this type of survey. It is much more important that the equipment is durable, reliable and specifically designed for extended use in the outdoors. Delicate and expensive Type 1 precision grade equipment can be unreliable in such applications or even unable to be programmed as a data logger.

Although high cost and extreme precision are not essential, the functional capabilities to statistically integrate sound levels over a user defined time period and automatically store the results are necessary. Because the on-site wind and weather monitoring towers, or met towers, normally integrate and store measurements in 10 minute increments it is convenient, if not necessary, to measure and store sound data in synchronization with the wind data collected by these towers for later correlation. It is evidently universal practice for met towers to store data 6 times an hour in 10 minute intervals that begin at the top of the hour; as in 9:00, 9:10, 9:20, etc. Consequently, sound data logging should be started using a trigger function to begin at the top of an hour and not randomly by the manual push of the start button. The timers on all instruments should be exactly synchronized to local time. Of course, all of the instruments must be field calibrated at the beginning of the survey and checked again for drift at the end of the survey.

Because this long-term survey approach involves unattended monitoring, the instrument and the microphone must be capable of withstanding damage, interference or outright destruction from rain and snow, which, among other things, means that the ground plate technique specified in IEC 61400-11 – where the microphone is laid flat in the center of a board on the ground and covered with one or more hemispherical windscreens – is not a viable option, despite its otherwise highly desirable advantage of minimizing wind-induced pseudo noise. Consequently, the microphone must be mounted above ground level and protected from wind-induced distortion by a spherical weather-treated windscreen, which normally entails a higher density foam that is hydrophobically treated to shed water (windscreens and wind-induced noise are discussed in detail later). As a general rule, a slightly lower than normal microphone height of about 1 m above ground level is preferred for this application on the premise that wind speed diminishes exponentially with decreasing elevation theoretically going to zero at the surface, or boundary layer. To illustrate this, the nominal wind speed profile, or shear gradient, per Eqn. (7) in IEC 61400-11 is illustrated below in Figure 4.3.3.1 for a common turbine operating condition where the wind speed is 6 m/s at the standard elevation of 10 m above ground level.

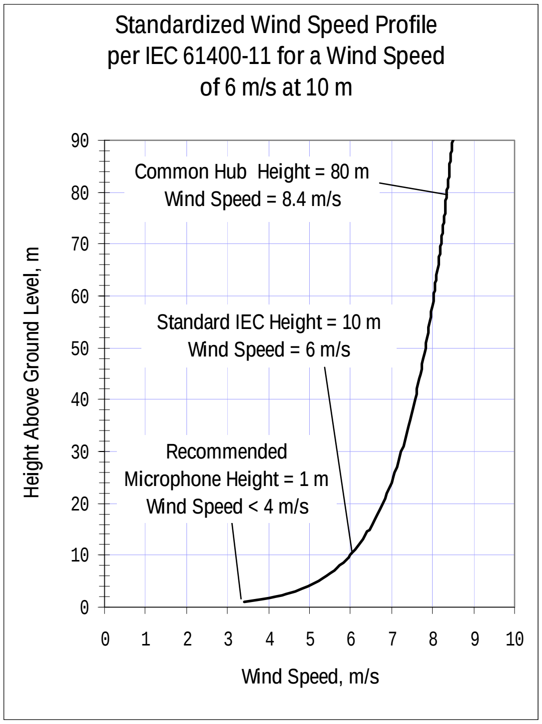


Figure 4.3.3.1

For these moderate wind conditions, the wind speed at a 1 m microphone height would be less than about 3 or 4 m/s, which as shall be seen later, means that distortion from wind blowing through the windscreen is of little or no consequence with respect to the A-weighted sound level so long as an extra large windscreen is used (typically 7” in diameter, as a minimum).

In addition to arranging for the microphone to be about 1 m off the ground so that it is not adversely affected by precipitation, it is also necessary to keep the instrument itself dry and secure in a waterproof case, which is best mounted above the ground on a fencepost, utility pole or other support.

While the microphone can be remotely connected to the instrument with a cable and independently supported, another option is to use a self-contained system where the microphone is attached to the instrument case with a rigid boom to hold the microphone away from the box and the entire assembly is mounted 1 m above ground level with a strap as shown, for example, in Figure 4.3.3.2. While there is nothing wrong with supporting the microphone separately on a tripod there is a tendency, unique to wind turbine survey work, for tripods to blow over, even after being weighted down and/or firmly staked to the ground. The use of temporary metal fence posts to support either the microphone alone or the entire system is a more reliable option and is sometimes the only option in places where there are no existing supports, such as in open fields.

Figure 4.3.3.2 *Typical Integrating Sound Monitor with 7" Weather-treated Windscreen*

In addition to sound level meters it is also advisable to set up at least one temporary weather station at the most exposed measurement position in order to measure the wind speed at microphone height and other parameters such wind direction and rainfall. All weather data should also be logged in 10 minute increments for later correlation to the sound data.

4.3.4 *Measurement Quantities*

For a background survey of this type the principal quantity of interest is the L_{A90} statistical measure, which is the A-weighted sound level exceeded 90% of the measurement interval (10 minutes in this case). What this means is that the sound level is higher than the L_{A90} value most of the time and, conversely, that the L_{A90} level represents the near-minimum sound level for each interval. It essentially captures the momentary, quiet lulls between sporadic noise events, like cars passing by, and, as such, is a conservative measure of the environmental sound level.

The average A-weighted sound level, or L_{Aeq}, which is the fundamental metric for highway noise surveys and the calculation of the Day-Night Average Level, L_{dn}, is unsuitable for wind turbine background surveys in rural areas because this level is extremely sensitive to contaminating noise events, such as from occasional traffic, planes flying over or dogs barking – things that cannot be relied on to be consistently present and available to potentially mask project noise on a permanent basis. The L_{A90} measure, on the other hand, automatically excludes these events for the most part and essentially defines the true "background" noise floor.

4.4 Analysis and Interpretation of Results

4.4.1 *Data Analysis and Wind Speed Correlation*

At the completion of the survey the L_{A90} sound levels measured at all positions should be plotted together to evaluate their consistency and to determine if the levels in different settings should be segregated. For example, if the sound levels at sheltered valley locations are consistently lower than measurements on higher ground then the data should be analyzed separately to develop typical background levels for each setting. Somewhat surprisingly, the need for this kind of separate treatment is rare and the much more common result is for the sound levels at all of the positions to be generally similar in magnitude at any given time with each generally following the same temporal trends and intertwining with each other. As a typical example, the as-measured L_{A90} levels at 7 positions spread over a fairly large site in Southern Minnesota are shown below.

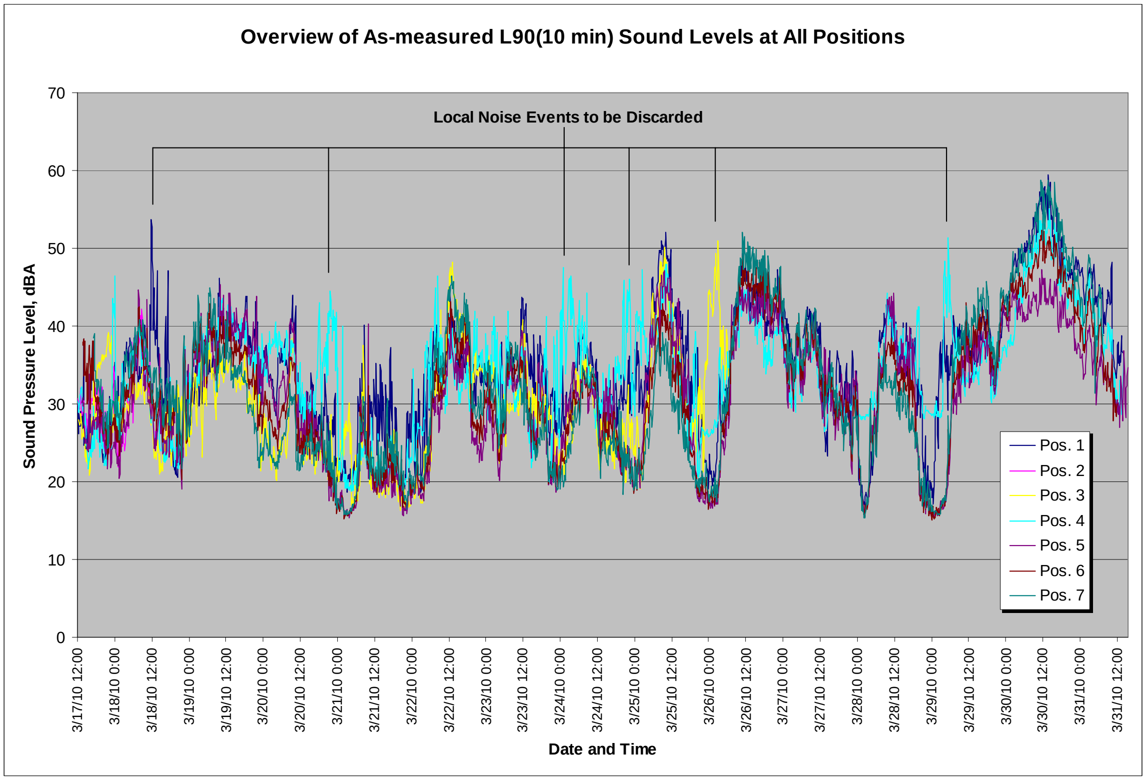


Figure 4.4.1.1

All positions follow each other and there is no one position that is consistently higher or lower than the others. Since these positions are miles apart from each other one would not expect exact agreement yet the levels are remarkably similar indicating that the environmental sound level over the entire site are is more or less uniform (sometimes termed a “macro-ambient”). If obvious contaminating events - those occurring at only one position - are discarded (as noted in the figure) the arithmetic average of the remaining data points can reasonably be considered the typical sound level over the site area. However, the question becomes: what is the sound level? The level varies substantially with time from almost complete silence (17 dBA) to nearly 60 dBA. The background level is obviously not a single number. The reason for this variation becomes clear if the average site-wide sound level is compared to the concurrent wind speed (Figure 4.4.1.2).

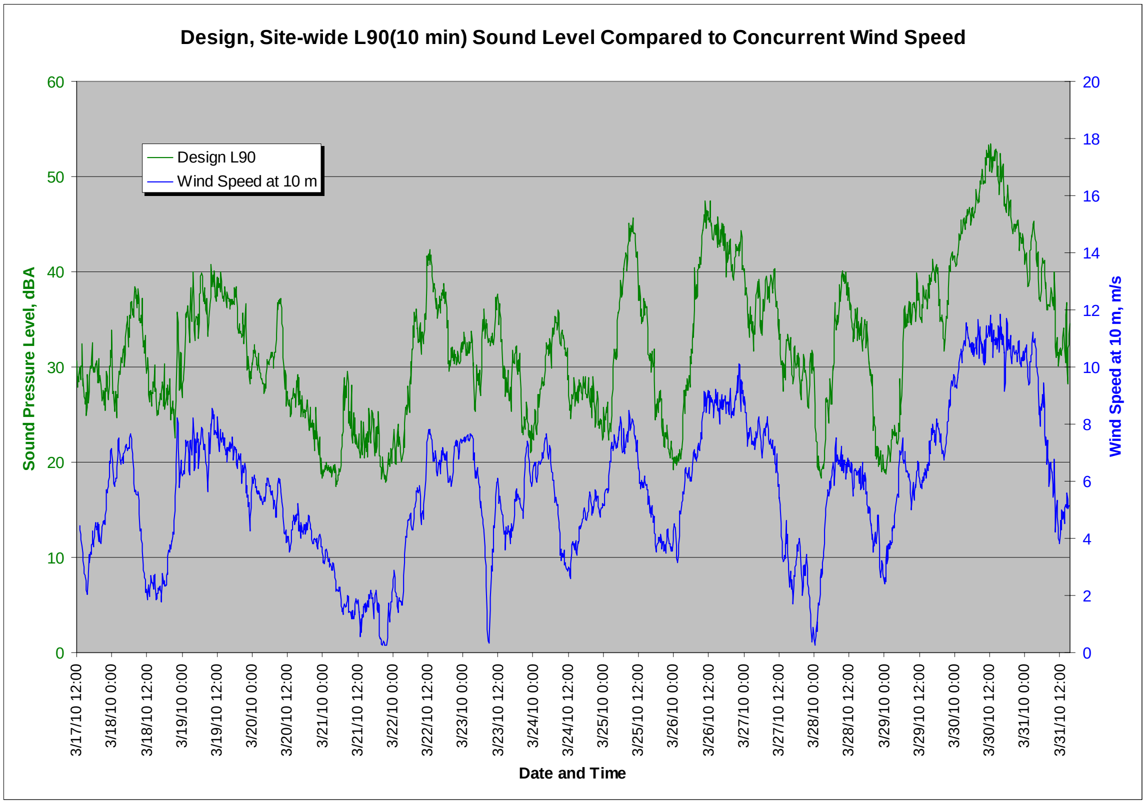


Figure 4.4.1.2

Clearly, the sound level in this area is driven by wind-induced sounds; in this case, mostly grass or crops rustling. Consequently, the sound level is almost entirely a function of the wind speed occurring at any given moment. This relationship can be quantified by re-plotting the sound levels in Figure 4.4.1.2 as a function of wind speed (normalized to a standard height of 10 m per Eqn (7) in IEC 61400-11).

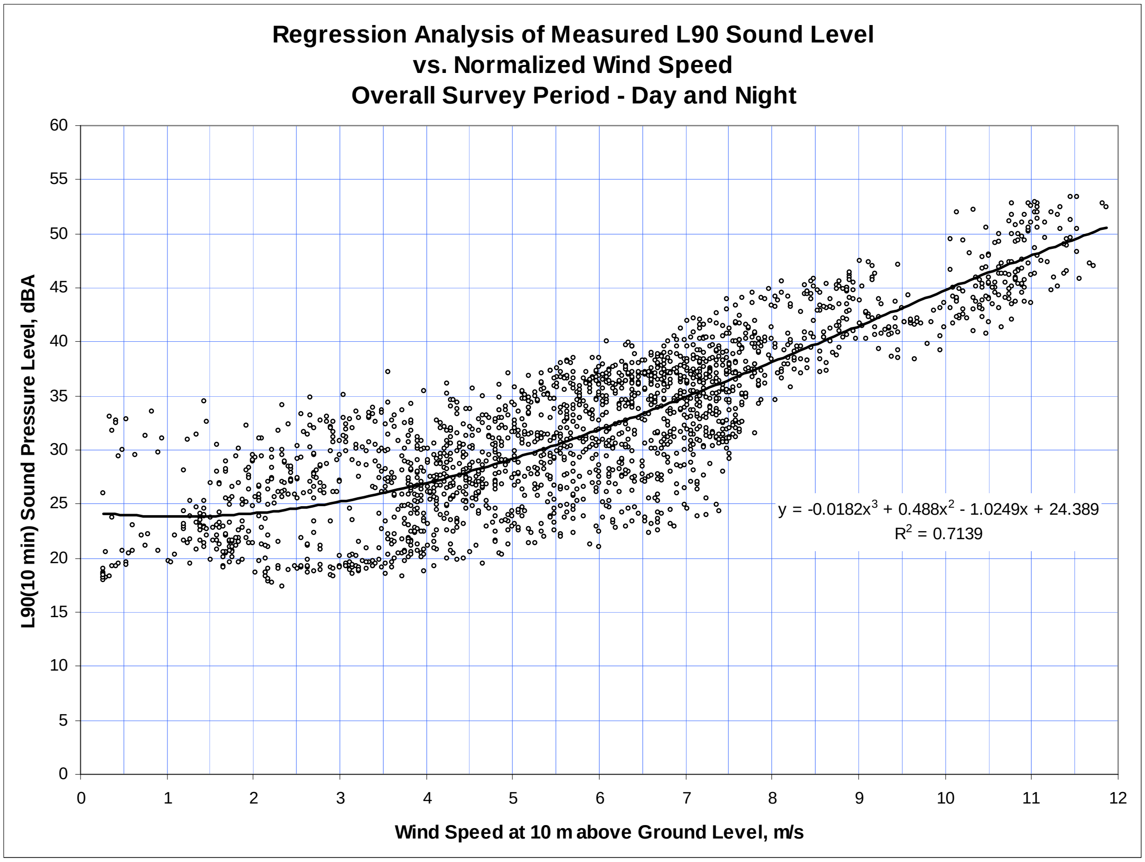


Figure 4.4.1.3

The central trendline through the data gives the mean L_{A90} sound level for any particular wind speed – at least in terms of the overall survey period.

It is important to point out in this context that, although the wind speed correlated to the sound data is the normalized value at the IEC standard elevation of 10 m, the measurement is actually taken at the top of the met tower, usually 60 m (197 ft) above ground level. Thus, the wind speed associated with turbine operation (not far below hub height) is directly correlated to the sound level measured near ground level; where the wind speed may well have been negligible. In other words, Figure 4.4.1.3 is *not* showing the relationship between the sound level and wind speed at the measurement position, as is quite often supposed.

4.4.2 *Daytime vs. Nighttime Levels*

Since nighttime conditions are of the most relevance with respect to potential disturbance from project noise, the data should be broken down into daytime (7 a.m. to 10 p.m.) and nighttime (10 p.m. to 7 a.m.) levels to see if it is significantly quieter at night - something that is not always particularly apparent in the level vs. time data (Figure 4.4.1.1). In this instance, the nighttime levels (Figure 4.4.1.4) are substantially quieter than during the day (Figure 4.4.1.5), particularly, in the vicinity of 6 m/s, which is usually the point where wind turbines first start to generate significant noise but the background level is typically still rather low thereby maximizing the potential audibility of project noise. In these examples, the mean background level for 6 m/s wind conditions during the day is 34 dBA while the nighttime level is about 28 dBA. Both of these levels are extremely quiet, but 28 dBA is so low that any potential masking from background noise can essentially be neglected as insignificant.

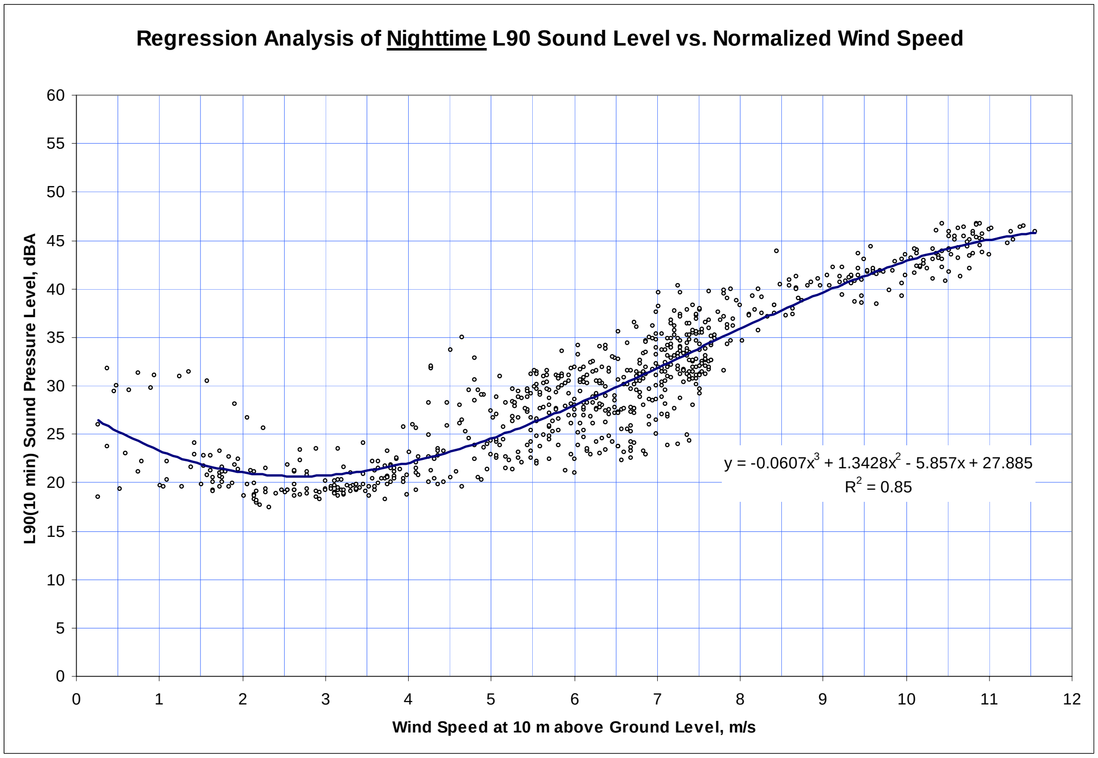


Figure 4.4.1.4

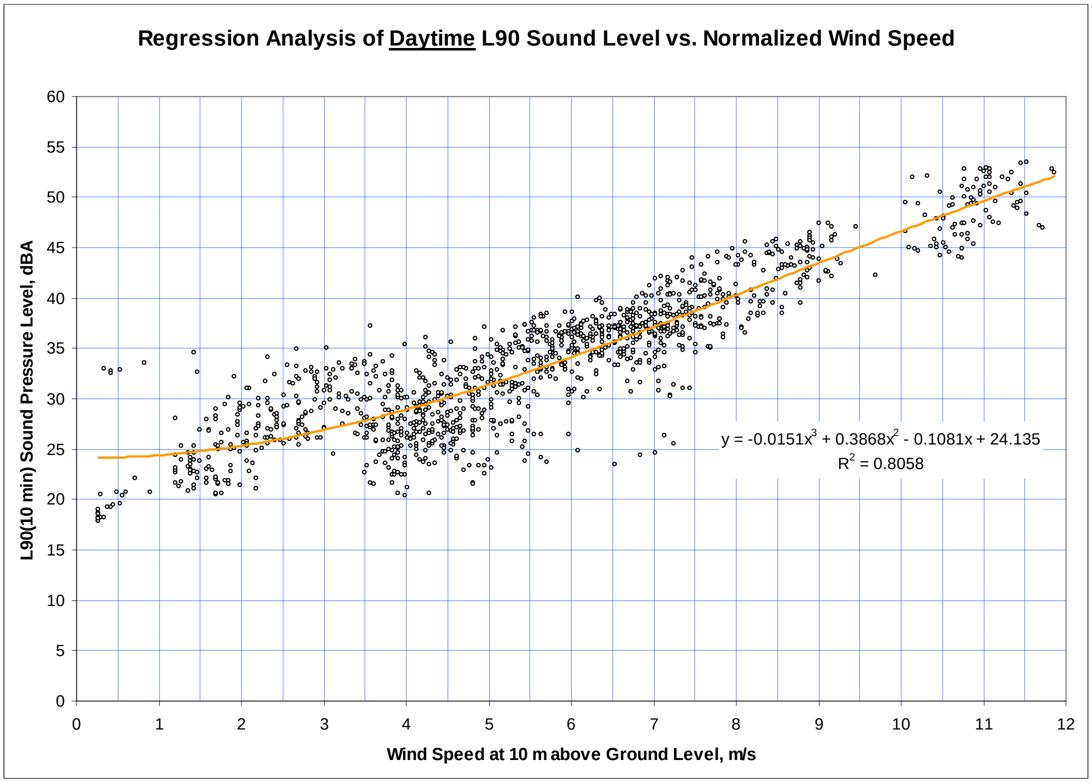


Figure 4.4.1.5

4.4.3 *Assessing the Potential Impact*

The sound levels measured in this survey, especially at night, indicate this site is an extremely quiet rural environment where any masking from wind-induced background noise can effectively be disregarded during moderate wind conditions (4 to 7 m/s). Under high wind conditions, say around 10 m/s, background noise is in the mid-40's dBA irrespective of time of day and therefore will act to partially obscure project noise, but during low wind conditions when the project is operating at low load an adverse impact can be expected unless the mean project sound level is kept to a relatively low level at residences. In this instance, it would be advisable to strictly design the project so that all residences are predicted to have average sound levels no higher than 40 dBA.

In general, background survey results may be used to establish a very rough impact threshold of 5 dBA over the ambient when the nighttime L_{A90} is about 35 dBA or more under what is usually the critical wind speed of 6 m/s. For example, if the measured level is 40 dBA then little adverse reaction might be expected from project levels up to 45 dBA (predicted with the project operating during comparable 6 m/s wind conditions). This 5 dBA increase metric does not hold for very low background levels (<35 dBA) because the background sound level and the project level both become so low as to be insignificant in absolute terms. If the background were 10 dBA, for instance, there would be no need to design a project to not exceed 15 dBA – both levels represent almost complete silence and are inconsequential. For low background situations like the example discussed above the outcome of the survey would be to set a firm upper limit of 40 dBA at residences. In terms of a potential noise impact, a low background level combined with predicted project levels of more than 40 dBA at numerous residences would be an undesirable situation likely to lead to complaints.

Although 6 m/s may be assumed in most cases to be the critical wind speed - i.e. the point where turbine noise is likely to be loudest relative to the amount of background noise available to potentially obscure it – the site-specific critical wind speed may also be calculated by comparing the sound power levels of the particular turbine model planned for the project with the L_{A90} background levels actually measured at the site. The critical condition corresponds to the point where the simple differential between these two values is maximum, as illustrated in the following example.

Table 4.4.3.1 *Comparison of Turbine Sound Power Levels to Measured Background Levels to Determine Critical Wind Speed*

Wind Speed at 10 m, m/s	Measured Overall L_{90}, dBA	Turbine Sound Power Level, dBA re 1 pW[c]	Differential
4	27	95	68
5	29	99	69
6	**32**	**102**	**70**
7	35	104	69
8	38	104	66
9	41	104	63
10	45	104	59
11	48	104	56

In this case (based arbitrarily on the data in Figure 4.4.1.3) the maximum differential of 70 occurs at 6 m/s – meaning that the sound emissions from the turbine are the highest at this particular point relative to the background level indicating that project noise would theoretically be most audible under these conditions. Ironically, the maximum audibility point does not usually correspond to the wind speed when the turbine first reaches its maximum noise emission point (in this example 7 m/s and a sound power level of 104 dBA re 1 pW).

As a side note, this analysis illustrates one of the reasons why it is beneficial to normalize the met tower wind speed data to 10 m; namely, because wind turbine sound power levels are expressed as a function of wind speed at 10 m above grade (and not at hub height). Consequently, the background sound levels and the turbine sound levels are all compared on an equal footing.

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[c] The fundamental unit of sound power is Watts and sound power levels are expressed with reference to 1 picoWatt, or 10^{-12} W. By convention this reference is explicitly stated to help distinguish power levels from pressure levels, which are measured in terms of Pascals.

5.0 Measuring Wind Turbine Sound Emissions

5.1 Project-wide Compliance Testing

5.1.1 *Historical Approaches*

In general, it has been difficult, historically, to devise or settle on a completely satisfactory methodology for testing newly completed wind projects for the purpose of determining whether or not they are in compliance with permit or regulatory conditions. One of the principal stumbling blocks has generally been accounting in some meaningful way for background noise, since the total measured sound level at the typically substantial distances to residences and, therefore, the point of measurement, commonly contains a very prominent background component that cannot be disregarded without causing the result to be erroneously high. It is, of course, the project-only sound level and not the total sound level that is limited by regulations. Consequently, it is the project-only sound level that is sought in such surveys.

Existing guidelines and standards that mention the topic of compliance testing at all do not lay out or detail test procedures that are entirely satisfactory in this and other respects. For example, the often beleaguered[30] ETSU-R-97 report *The Assessment and Rating of Noise from Wind Farms*[31] published by the Department of Trade and Industry in the U.K. addresses the issue of background noise in one sentence, quoted below, by suggesting simply that one might want to measure operational turbine noise at night.

> To minimize the effects of extraneous noise sources it may be necessary to perform these measurements during night-time periods when other human and animal activity noise sources are likely to be at a minimum.

This approach, which involves measuring only for a relatively short period of time (20 to 30 $L_{A90,\ 10\ min}$ samples), is connected with the idea of taking measurements only at, or close to, a specific critical wind speed identified from "monitoring", carried out in an unspecified manner, and correlated to logged observations by complainants as to when the "noise is most intrusive" (ibid). In short, the idea is for the test engineer to be physically at the location and ready to take measurements when the wind conditions that result in maximum noise are occurring - so long as those conditions are happening at night on a night when the background sound level is negligible (i.e. roughly 10 dBA or more lower in magnitude than the turbine sound level). As might be imagined, the unfortunate reality is that the probability of all these things coming together at the same time is miniscule. In particular, it is typically difficult, for a number of reasons, for a test engineer to schedule a site visit to coincide with a particular wind speed or direction.

In general, the notion of being on hand to observe and measure wind turbine noise when it is at its loudest may sound reasonable on paper but it is seldom practical to actually do it.

Another approach to the issue of background noise that has been used, for example in the New Zealand Standard NZS 6808:1998 *Acoustics – The assessment and measurement of* *sound from wind turbine generators*[32], is to measure the background level at one time, say, prior to construction or start-up, and the operational noise from the project at another time - and then subtract the two to derive the project-only sound level. While this is often thought of or suggested as a reasonable approach, the problem is that both the background and wind turbine sound levels are extremely dependent on circumstances that vary significantly with time in both the short and long-term. The two sounds are highly specific not only to the prevailing wind speed at a particular time but also to factors such as the stability of the wind (whether it's gusty or constant in nature, for instance), wind direction, shear gradient, thermal gradient, time of day and time of year. Moreover, the background level is also exclusively influenced by foliage (bare trees vs. leafed out trees, for example), insects, frogs, distant or nearby traffic, farm equipment and a myriad of other human activities that occur sporadically and unpredictably. Consequently, a background sound level measured days, months or years before can't be used with a tremendous amount of confidence to correct a later measurement of operational noise, even if both have been normalized to similar wind speed conditions, because so many other unquantifiable factors may have had a hand in shaping the final results. What is needed, of course, is the background sound level that would have existed at that particular time and at that place if the project had not been operating.

This latter objective can sometimes be essentially realized by using the technique of temporarily shutting down, or parking, the nearest turbines to a measurement position, if not the entire project. While this technique has its applications, which will be discussed later, it is not usually a practical method that can be used for a general site-wide compliance test. Widespread or complete shutdowns would be required repeatedly over a variety of wind speed conditions and times of day to get even a minimally complete set of usable background levels.

Thus, there are certain impracticalities associated with the few existing guidelines, standards or common practices that deal with the testing of operational noise from wind turbine projects.

5.1.2 *Test Methodology*

The suggested methodology outlined below, which has been developed over time through field experience on a variety of wind projects, does not purport to completely solve the problems of background noise and capturing the periods of maximum noise, among other things, but it has been found to work very well in numerous field applications.

5.1.3 *Survey Duration and Scheduling*

In order to overcome the problem of being on hand to take short-duration measurements when conditions might favor noise generation at the source and/or sound propagation from the turbines to typical receptor points, a long-term, continuous monitoring approach is needed in which multiple instruments are set up at key locations and programmed to run day and night for a period of about two weeks or more. In essence, it is necessary to capture sound levels during a variety of wind and atmospheric conditions; something that is extremely difficult to achieve by taking intermittent manned samples, which amount to static snapshots of a dynamic situation.

Field experience suggests that an adequate range of wind speeds, from 0 to 10 m/s at 10 m above ground level, will usually be observed over any given 14 day period at most wind energy project sites, except perhaps during the low wind season at sites that might have very pronounced seasonal wind characteristics.

As a practical matter, the instruments for such a survey are set up, started and left to run unattended for the nominal two-week test period following which they can be retrieved and downloaded.

In terms of scheduling, it is highly preferable to conduct this type of survey during cool season, or wintertime, conditions to eliminate or at least minimize possible contaminating noise from summertime insects, frogs and birds. In addition, it is best for deciduous trees to be leafless at sites where they are present in quantity to decrease this source of wind-driven background noise and maximize the signal to noise ratio. Human activity, such as from farm machinery or lawn care, is also normally lower during the winter. While summertime surveys have been successful they should, as a general rule, be avoided wherever possible because nocturnal insect noise, for instance, can easily render the project sound level indeterminate at some or all of the measurement positions. If measurements are required during the summer, and they often are for reasons of project scheduling, high frequency contamination can be analytically factored out by taking the measurements in octave or 1/3 octave bands and correcting the spectra, as will be discussed later in greater detail.

In addition to seasonal concerns, it is desirable; when practical, to attempt to schedule the survey set up to just precede a predicted period of moderate or high winds. This not only ensures that the survey period will capture these winds but also creates an opportunity for manned observations and measurements to be made for a day or two to augment to the longer term monitoring survey. There is generally nothing to observe or measure at a wind turbine site when the winds are calm, so if one can be on site with the proper equipment just before a windy period useful short-term measurements can probably be made that can later be viewed within the context of the long-term monitor results for that time period.

As an alternative or supplemental approach, another opportunity for these supplemental manned observations can sometimes be arranged by coordinating the instrument retrieval visit with a predicted windy period. The specific end date for the survey is usually flexible, although instrument battery life is normally the limiting factor. The principal danger in carrying out manned measurements just before the end of a survey, however, is that all of the long-term monitors may not still be recording due to power supply issues or any number of other lamentable and sometimes comical things, such as tampering, weather damage or the removal of the windscreen by livestock.

5.1.4 *Test Positions*

The test positions should be selected to capture data at a number of potentially sensitive receptors (usually non-participating and participating residences within or near the site area) or other relevant points of interest, where maximum project sound levels might be expected either from modeling or a simple inspection of the site plan. In just about every case, it is not practical or even possible to establish a monitoring station at every house in the vicinity of a project so it is necessary to carefully select a limited but adequate number of sites that are representative of the worst-case exposures at potentially sensitive receptors in all relevant settings. Examples of specific settings would be: homes in sheltered valleys below ridge top turbines; homes on high, open ground with exposure to the wind and nearby project turbines; homes in generally flat open country with turbines in multiple directions; homes in wooded area; homes on the outer edge of a project area, etc. Because every site is unique the number of monitoring stations required to adequately evaluate project noise will vary but the general concepts are to reasonably account for different settings, to cover a number of points were maximum project sound levels are likely to occur at residences and to cover the entire project area with a generally even but somewhat random distribution. Adding one or two deliberately random positions can help increase the statistical independence of the data and avoid inadvertent bias. For sparsely populated sites in open and uniform farm country only about 4 or 5 on-site monitors might be needed while at more densely populated sites with more complex topography the number of monitoring stations would only be limited by the quantity of equipment reasonably available to the test engineer either from in-house stock or outside rental. Realistically, it is seldom possible to gather enough equipment for more than about 10 to 14 on-site monitoring points, but that is normally enough. A typical survey at a fairly large project site with numerous residences intermixed with the turbines might call for about 10 positions at receptors within the project area.

As mentioned above, the general objective is to capture sound levels throughout the site area at key receptors in all distinct settings within the project area. In addition, it is commonly necessary and desirable to establish a measurement position at all homes where complaints or concerns about noise have been expressed to the operations staff. In these instances, it is sometimes possible to enlist the help of residents by having them try to keep a date and time log of when the noise becomes particularly noticeable or unusually loud or when other non-project sounds are present; for example, from lawn moving, farm activity, etc. When this is actually done the comments can provide some valuable insights that help explain and identify peaks in the recorded sound levels.

It is often assumed that project noise is of no concern to project participants who were, and presumably still are, favorably disposed to the project and are receiving lease royalties for units on their land; however, experience at a number of sites suggests that this is not always the case largely due to the confluence of two factors: (1) these residences are typically the closest ones to turbines (sometimes only a few hundred feet away) and (2) the actual sound levels from these nearby units can turn out to be substantially louder than they expected them to be or they were led to believe. Consequently, monitoring at the homes of project participants in response to complaints is fairly common – even though participants are often, but not always, technically exempt from ordinance or permit noise limits.

It is usually best to start the site selection process a week or two in advance of the actual survey by circling proposed measurement areas on a site map or sound contour plot and submitting this to operations personnel at the site for their input on who, within or near each designated area, might be willing to host a sound monitor at their house and where else, outside of these proposed areas, it might be also be desirable to measure (at complaint locations, for instance). The objective of this preparatory review is to obtain approval and permission from homeowners to set up equipment on their property prior to arrival. Although it is desirable to inspect the proposed locations and make a judgment as to their suitability in person, attempts to arrange for permission on the day of the survey are often unsuccessful due to the simple fact that people are not at home and cannot be reached. Calling ahead usually settles the issue before the equipment is shipped to the site. Setting up the equipment in the rear yard of a house where permission has been obtained generally ensures that the equipment will still be there upon returning at the end of the survey, that the equipment won't be interfered with and that it can be minimally attended to, if necessary (replacing the windscreen after the family dog has run off with it, for example). Positions that are not at anyone's house, such as on utility poles along the public right-of-way, are sometimes necessary to collect data at strategic locations without a suitable host, but they do not have any of these advantages and, in fact, the risk of theft or tampering is uncomfortably high.

In terms of the specific placement of the monitor at each position, it should be located in an area representative of but away from the house, or any other building with large reflective surfaces, and that is not prone to frequent activity or contaminating local noises, such as from air conditioning units, milking machines at dairy farms or flowing streams or rivers.

As a final note on placement, it is best to avoid using fences or posts to mount the monitor or microphone in areas where livestock or other domestic animals may be able to get at the equipment during the survey. Microphone windscreens are evidently of keen interest to cows, horses and dogs, among others.

5.1.5 *Background Noise*

On the important issue of background noise, an approach that has worked well in a number of field applications is to set up a number of monitoring stations outside of the project area in settings similar to those at the on-site monitor positions. Of course, considerable judgment is involved in selecting these positions but in an ideal situation of, say, an isolated project in open farm country that is largely uniform in character both within and beyond the project area one would want monitors at least 1.5 to 2 miles from the perimeter of the project (nearest turbines) in the four cardinal directions. The locations should be far enough away that project noise is negligible and yet close enough that they are reasonably representative of the site area. At the end of the survey the off-site positions can then be evaluated for consistency. If the levels are generally similar, and, somewhat surprisingly, this is usually the result, the average can be taken as a time history record of the background sound level that probably would have existed within the site area and then used to correct the on-site measurements taken, importantly, at the same time under identical environmental conditions.

Figure 5.1.5.1 below is an example from a site in the Eastern United States where the landscape is rural and generally homogenous in nature within the project area and for some distance beyond it in terms of topography (rolling hills), vegetation (a mix of farm fields and wooded areas) and population density (farms and residences scattered more or less uniformly over the site area). The 80 or so 1.5 MW turbines are spread throughout a roughly 20 sq. mi. project area on numerous parcels of private land and thoroughly intermixed with the residences in the area. Proxy background measurement positions were set up about 1.5 miles beyond the perimeter of the turbine array to the northwest, east and south of the project (a neighboring wind project to the west prevented measurements in that direction) at locations that were similar in character to the various settings near on-site residences: one was on an open and exposed hilltop, another was at the edge of a field with nearby trees and a third was essentially in a forested area. The expectation was that there might be a consistent difference between these different positions – with the sheltered forest location being quieter than the windy hilltop, for instance – in which case background corrections for a particular setting would be applied to on-site measurements at positions with comparable settings. However, as can be seen from the figure, the levels at all three locations, each many miles from the others, were largely the same at any given time and, perhaps more significantly, no one position is consistently higher or lower than the others. Consequently, the arithmetic average of all three, with the site area physically lying between them, can be taken as a reasonably reliable estimate of the on-site background level at any particular time that accounts for the specific wind speed, direction, time of day and atmospheric conditions prevailing during that 10 minute period.

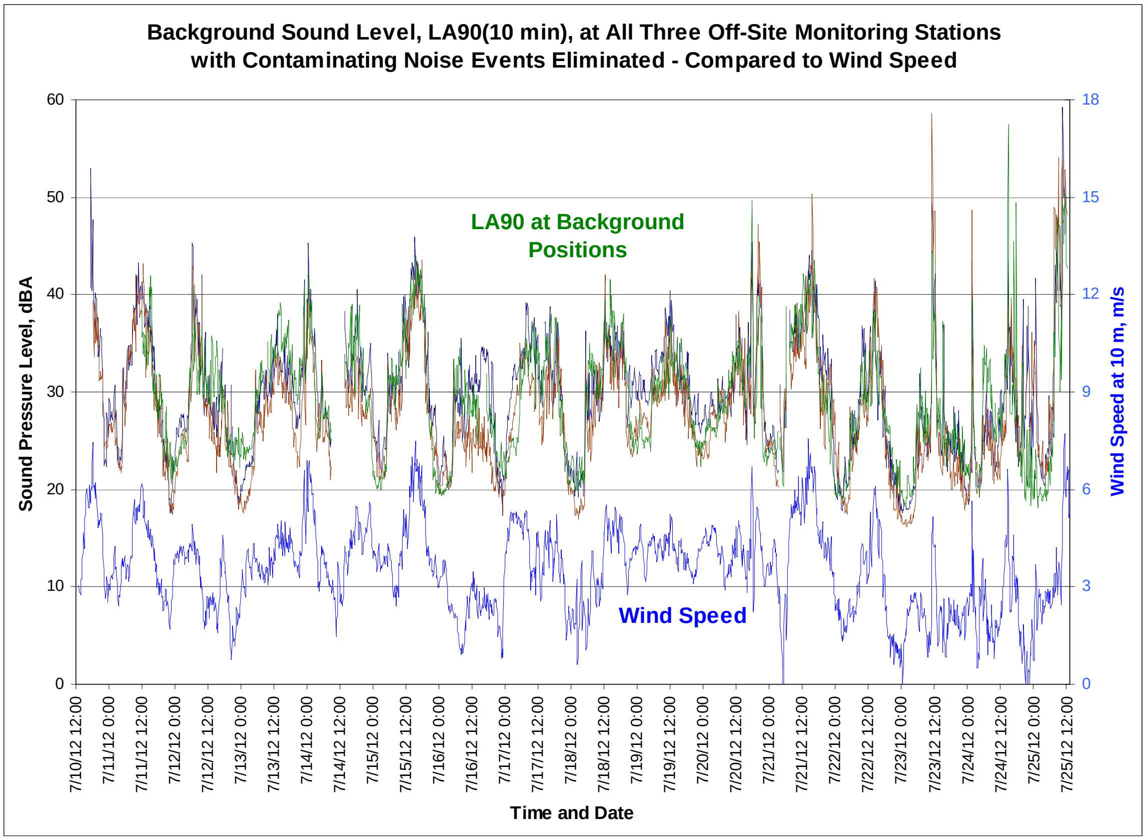

Figure 5.1.5.1 *Measured Background Sound Levels at Three Off-Site Proxy Positions*

The data in Figure 5.1.5.1 have been edited to remove noise spikes that were observed only at one position and not at any others, indicating a contaminating local noise event that is not representative of the area as a whole. Spikes were also deleted (from both the on-site and background data) if there were no concurrent spike in wind speed, even if they may have occurred at multiple locations, on the premise that the noise was not associated with the turbines and may have been due to thunder, rain, a helicopter flyover or some other area-wide noise event.

The results shown in the example above are not unique to that site and a similar consistency between the off-site proxy location sound levels has been observed at a number of other projects in rural areas even though the background monitors are deliberately set up in diverse settings. Fortunately, for the purpose of estimating simultaneous background sound levels, most wind projects are located in rural areas but, of course, not all of them are and other situations exist. In urban settings or near major highways the background sound is no less important, in fact more so, but its dependence on wind and atmospheric conditions is greatly diminished, if not relegated into complete insignificance. In such cases, the proxy background technique is still theoretically viable although the selection of background positions that are representative of receptors potentially affected by project noise becomes highly specific to the circumstances at each receptor. In the case of a highway, for instance, one might try to find a background position that is the same distance from the roadway as the actual point of interest and similar in all other ways but far enough from any turbines that they are undetectable. In this kind of a complicated situation where the background level is more dependent on man made noise than natural, wind-induced sounds it may be necessary to perform a pre-construction survey at the key receptors near turbines and at a number of candidate background positions to evaluate the validity of the proxy locations before the project turbines become operational.

5.1.6 *Sound Test Equipment and Set up*

As with any field sound survey, what equipment is used and how it is deployed must adhere to certain minimum technical standards. Most environmental sound measurement standards recommend the use of Type 1 precision equipment per IEC 61672-1[28] or ANSI S1.43-1997[29] while also allowing for the use of Type 2 equipment. There is certainly no reason on technical grounds to oppose this recommendation but, from a practical perspective, it is often necessary to use Type 2 equipment for surveys of this type because of the large number of instruments needed. The utterly intangible difference in technical performance between these two instrument classes is totally inconsequential within the inherently and unavoidably imprecise nature of this type of survey. It is much more important that the equipment is durable, reliable and specifically designed for extended use in the outdoors.

Although high cost and extreme precision are not essential, the functional capabilities to statistically integrate sound levels over a user defined time period and automatically store the results are necessary. Because the on-site wind and weather monitoring towers, or met towers, normally integrate and store measurements in 10 minute increments it is convenient, if not necessary, to measure and store sound data in synchronization with the wind data collected by these towers for later correlation. It is evidently universal practice for met towers to store data 6 times an hour in 10 minute intervals that begin at the top of the hour; as in 9:00, 9:10, 9:20, etc. Consequently, sound data logging should be started using a trigger function to begin at the top of an hour and not randomly by the manual push of the start button. The timers on all instruments should be exactly synchronized to local time or to the project's SCADA control system clock, if it is different from the actual time, which it often is.

Of course, all of the instruments must be field calibrated at the beginning of the survey and checked again for drift at the end of the survey.

Because this long-term survey approach involves unattended monitoring, the instrument and the microphone must be capable of withstanding damage, interference or outright destruction from rain and snow, which, among other things, means that the ground plate technique specified in IEC 61400-11 – where the microphone is laid flat in the center of a board on the ground and covered with one or more hemispherical windscreens – is not a viable option despite its otherwise highly desirable advantage of minimizing wind-induced pseudo noise. Consequently, the microphone must be mounted above ground level and protected from wind-induced distortion by a spherical weather-treated windscreen, which normally entails a higher density foam that is hydrophobically treated to shed water (windscreens and wind-induced noise are discussed in detail later). As a general rule, a slightly lower than normal microphone height of about 1 m above ground level is preferred for this application on the premise that wind speed diminishes exponentially with decreasing elevation theoretically going to zero at the surface, or boundary layer.

For these moderate wind conditions, which are often when turbine noise tends to be most prominent relative to the background level, the wind speed at a 1 m microphone height would be less than about 3 or 4 m/s, which as shall be seen later, means that distortion from wind blowing through the windscreen is of little or no consequence with respect to the A-weighted sound level.

In addition to arranging for the microphone to be about 1 m off the ground so that it is not adversely affected by precipitation, it is also necessary to keep the instrument itself dry and secure in a waterproof case, which is best mounted above the ground on a fencepost, utility pole or other support.

While the microphone can be remotely connected to the instrument with a cable and independently supported, another practical option is to use a self-contained system where the microphone is attached to the instrument case with a rigid boom to hold the microphone away from the box and the entire assembly is mounted 1 m above ground level with a strap. While there is nothing wrong with supporting the microphone separately on a tripod there is a tendency, unique to wind turbine survey work, for tripods to blow over, even after being weighted down and/or firmly staked to the ground. The use of temporary metal fence posts to support either the microphone alone or the entire system is a more reliable option and is sometimes the only option in places where there are no existing supports, such as in open fields.

5.1.7 *Weather Stations and Wind Speed Monitoring*

In addition to the sound monitors it is also advisable to establish at least one temporary weather station at the sound monitoring position with the most exposure to wind. The primary reason for this station is to measure the maximum wind speed at microphone height (about 1 m) for use in correcting the measured sound data for wind-induced distortion as described in a later section. Wind speed at 1 m, direction and rainfall are the primary parameters to be recorded by this station, or others set up in other settings as appropriate, such as at a sound monitoring position sheltered from the wind by the local terrain (to demonstrate, for instance, that wind-induced distortion is negligible at such locations). This data should be integrated and stored in 10 minute blocks in synchronization with the sound monitors.

This temporary anemometer at 1 m above ground is solely there to evaluate microphone wind exposure and it is the on-site met tower anemometers, usually at 50 to 80 m above ground level, that should be used to correlate the measured sound levels at ground level to the wind speed essentially experienced by the turbine rotors. Turbine nacelle anemometers scattered throughout the site may also be used to determine wind speed, but this is somewhat less desirable because a free field correction usually needs to be applied to this data to account for the energy extracted from the wind by the rotor just upstream of the wind speed sensor.

It is customary to normalize mast top or nacelle wind speeds to a standard elevation of 10 m above grade per IEC 61400-11. It is this result that is compared to the measured sound levels.

5.1.8 *Measurement Quantities and Parameters*

The objective of a compliance survey is to extract the project-only sound level from the total soundscape and compare that result to the permissible limit. As such, the principal challenge is identifying and eliminating contaminating noises that are unrelated to the project over many days and thousands of measurements. If it were practical to take a manned sample for 20 minutes, removing spurious noises by pausing the instrument or discarding contaminated subsamples, and declare the result as the performance of the project it would be a trivial matter; however, over a relatively long time period of unattended monitoring it is necessary to use the L_{A90} statistical measure to generally perform this function in an automated manner, since it captures the consistently present sound level during relatively quiet periods between common interfering and identifiable noise events like cars passing by or planes flying over. A 10 minute sampling duration has been found to work very well since it allows direct correlation with met mast wind speed data and is generally short enough that fairly rapid changes in project noise are captured.

The use of the average, or $L_{Aeq,\ 10\ min}$, sound level or a finer time resolution of, say, 1 minute come to mind as alternatives to the L_{A90}, but these approaches have their own serious drawbacks. If the L_{Aeq} is used to measure at on-site positions with the idea of better quantifying turbine sound levels, then the L_{Aeq} measured at the proxy background positions must also be used as an apples-to-apples correction factor. But the L_{Aeq} is often completely unusable for this application. As an example, multiple statistical measures were recorded at the off-site background measurement positions previously mentioned in connection with Figure 5.1.5.1, including the L_{Aeq}. Figure 5.1.8.1 below shows the average L_{A90} and L_{Aeq} levels measured at all three locations compared to wind speed.

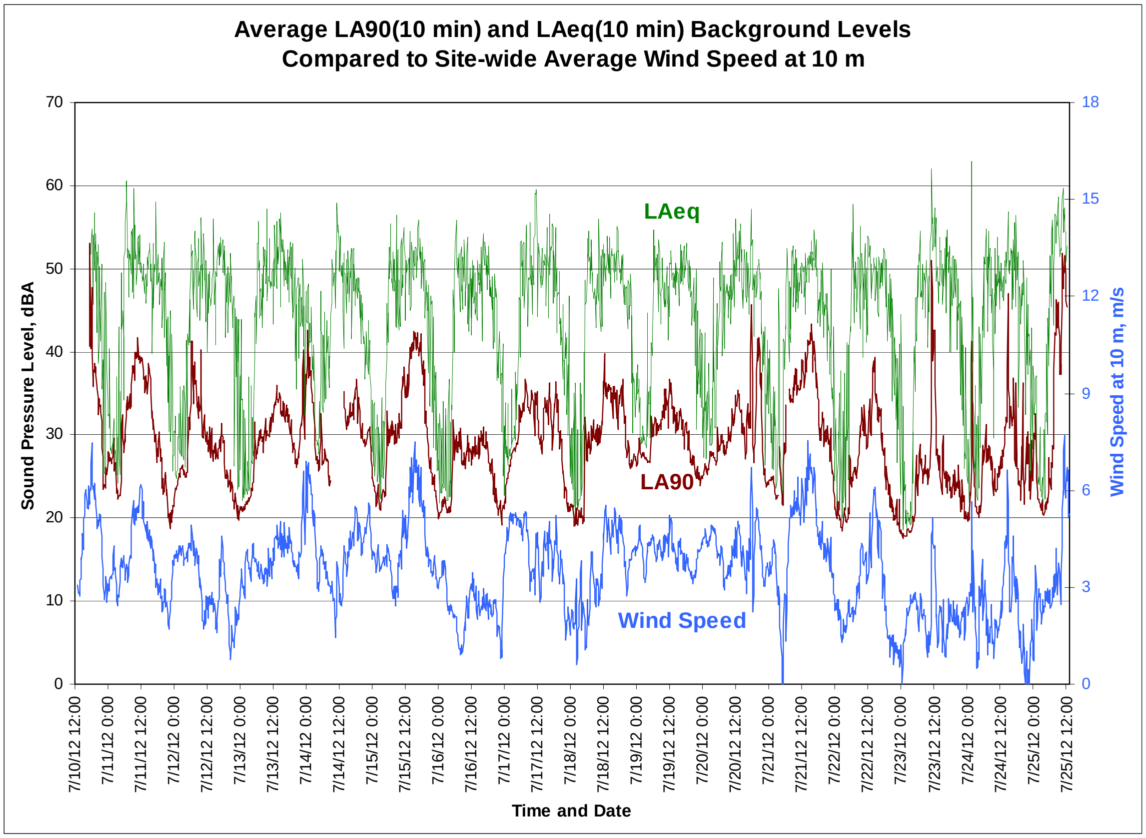

Figure 5.1.8.1

What is immediately obvious from this plot is that the $L_{Aeq,\ 10\ min}$ level is clearly driven by daily human activity; primarily intermittent vehicular noise on nearby sparsely traveled roads (noise that is filtered out by the L_{A90}). The L_{Aeq} levels rise to about 53 dBA every morning, stay there all day irrespective of the wind conditions and then gradually fall off in the evening hours bottoming out briefly somewhere around 23 dBA every night. The L_{A90} level, on the other hand, is clearly more attuned to the natural environmental sound level, which in rural areas like this one is normally a function of wind speed. The unsuitability of the $L_{Aeq,\ 10\ min}$ as a measure that might quantify project noise can be seen in Figure 5.1.8.2 where the average background L_{Aeq} level from Figure 5.1.8.1 is compared to the L_{Aeq} level measured at a typical, randomly selected on-site receptor.

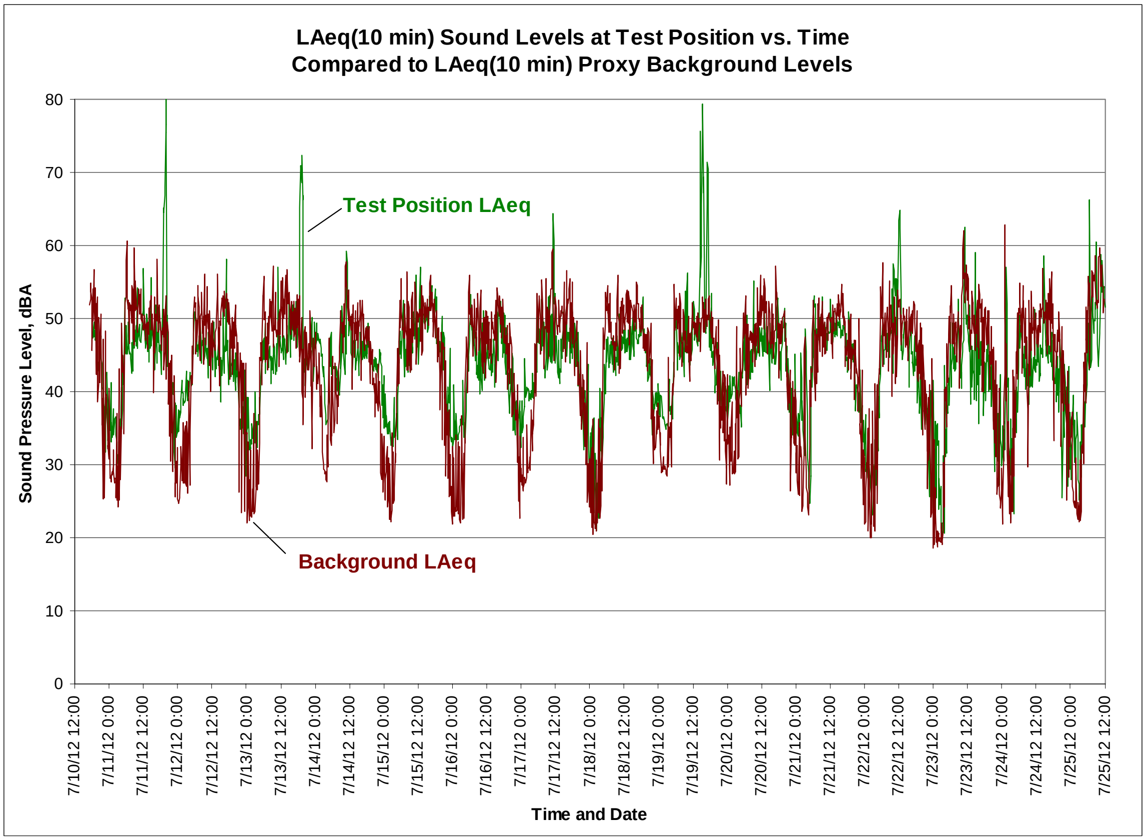

Figure 5.1.8.2

The $L_{Aeq,\ 10\ min}$ sound levels at both positions are virtually indistinguishable meaning that the project-only sound level simply cannot be deduced. Furthermore, it could even be reasoned that project noise is utterly inconsequential at this location because the on-site level is about the same or even lower than the off-site level, which is entirely free of any turbine noise, but, as we shall see later, that is not at all the case at this particular test position.

Finally, it is desirable to use instruments capable of measuring the frequency spectrum in 1/3 octave bands at one or two key locations with, usually Type 2, monitors measuring overall A-weighted levels at the majority of positions. The use of one or more frequency analyzers at key positions allows for some frequency analysis, although great caution must be exercised with the lower frequency bands, as discussed later, since wind-induced false signal noise is largely inevitable and the low frequency results cannot be taken at face value. Fortunately, this phenomenon does not significantly affect the measurement of A-weighted sound levels, however.

The use of 1/3 octave band analyzers is largely essential for surveys that, for one reason or another, must be conducted during summertime conditions when insect, frog or cicada noise is present. Measurements taken under these unfavorable conditions can be "corrected" to a certain extent by smoothing the high end of the frequency spectrum, where this kind of noise is usually obvious, and then recalculating the overall A-weighted sound level as shown in the (generic) example below.

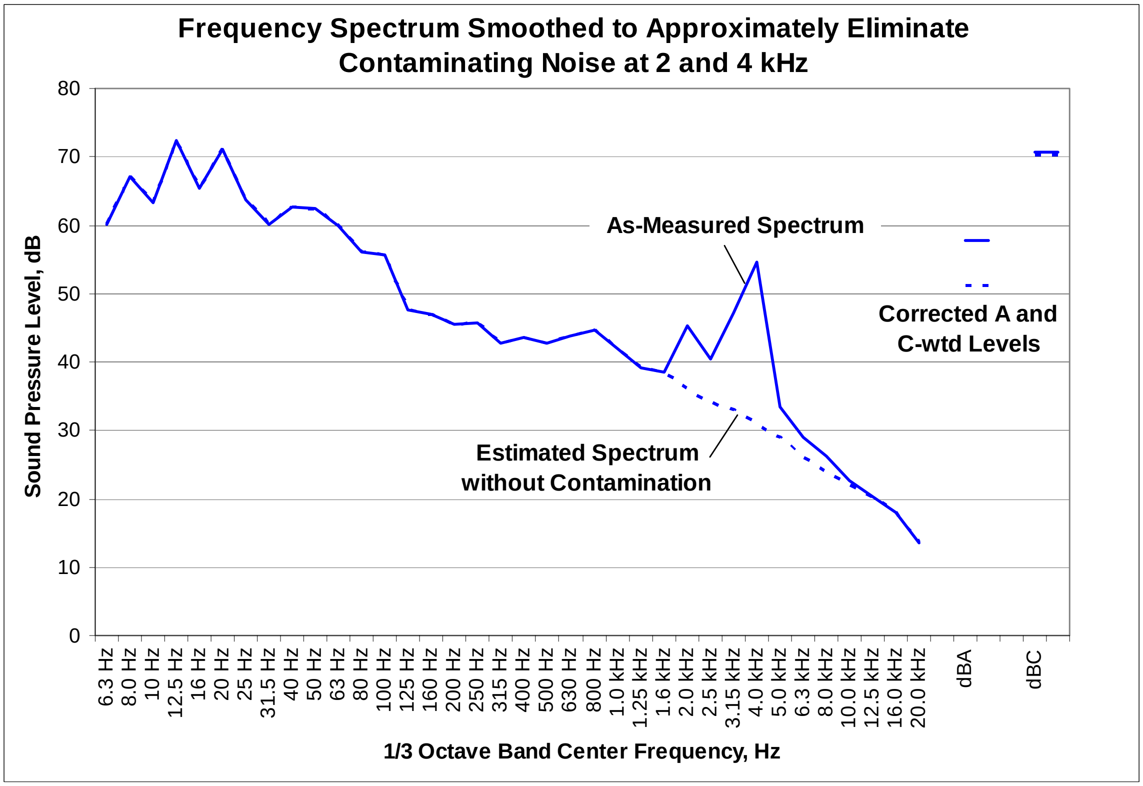

Figure 5.1.8.2

Of course, this correction would be laborious to perform for thousands or even just dozens of measurements so it is usually necessary to determine a typical correction, such as the -7 dBA adjustment that resulted in the example above, and apply that to all periods when this noise was apparently present. This is, of course, an imperfect remedy and the best policy is to avoid, if possible, measuring under these circumstances in the first place.

A solution to this common problem is currently being proposed by Hessler[33] and Schomer[34] in the form of a modified A-weighted network, termed “Ai-weighting”, where all of the measured sound above 1000 Hz, or the 1250 Hz 1/3 octave band, is disregarded in situations where insect noise is present and an adjusted A-weighted sound level is calculated from the truncated spectrum.

5.1.9 *Wind-induced Microphone Distortion*

One of the principal errors in measuring wind turbine noise is false signal noise from wind blowing through the windscreen and over the microphone tip, which is manifested in the form of artificially elevated sound levels in the lower frequency bands. Taken at face value any measurement made in moderately windy conditions will ostensibly indicate relatively high levels of low frequency noise, irrespective of whether a wind turbine is present or not. This measurement error is probably one of the principal reasons wind turbines are mistakenly believed to produce high, if not harmful, levels of low frequency and infrasonic noise.

Some degree of distortion is essentially inevitable in any measurement taken above ground level when the wind is blowing, even when using an extra-large windscreen. It is in an effort to minimize this error that the IEC 61400-11 test procedure prescribes measuring on a reflective plate at ground level, where the wind speed is theoretically, although often not actually, zero. As previously mentioned, this ground plate technique is fine for short-term, attended measurements but is impractical for long-term surveys due to the potential for rain or melted snow to damage the microphone. Consequently, for lengthy compliance and evaluation surveys it is necessary to measure above ground level using a large, weather-treated windscreen - perhaps augmented with a very large secondary windscreen, although the practicality of such devices is questionable in harsh winter conditions.

Because environmental sound measurements of most other sources apart from wind turbines are not generally conducted in windy conditions as mandated by applicable standards, the significance and even existence of this measurement error has long gone unnoticed. Although this phenomenon and its physical basis were theorized decades ago by Strasberg[35,36] it is only fairly recently that its relevance to wind turbine sound measurements has been examined in detail and quantified. In particular, the subject of wind generated self-noise was thoroughly reviewed in 2006 by van den Berg[37] where he showed that the magnitude of the distortion depends not only on the mean incident wind speed but also on the amount of atmospheric turbulence present at the microphone position (largely a function of the local surface roughness) and on atmospheric stability. Measurements taken at 1 or 2 m above a smooth surface during stable, nighttime atmospheric conditions, when the surface winds are usually light, generally contain the least amount of self-generated noise ultimately replicating the case where the principal noise generation mechanism is wake turbulence trailing off the windscreen. In other less ideal circumstances self-noise levels can be developed by estimating the local surface roughness and atmospheric turbulence factor, Ψ, from wind speed measurements at two heights and/or from observations of cloud cover, time of day, general wind conditions, or meteorological data, if available.

The minimum level of false-signal noise due to wind, excluding the effect of atmospheric turbulence, can be estimated based on an empirical wind tunnel study carried out by Hessler and Brandstätt in 2008[38] in which conventional ½" microphones fitted with an array of common windscreens and were subjected to known wind velocities in a massively silenced wind tunnel. The measured sound levels during each test were essentially a direct measure of the false-signal noise – although for more or less laminar flow conditions corresponding to an outdoor setting with a very low surface roughness in neutral atmospheric conditions. Nevertheless, for the specific windscreens examined it is possible to generally estimate both the overall A-weighted or un-weighted (dBZ) sound level of the distortion from the microphone height wind speed and then subtract it from the total measured level to *largely* reverse the error.

An example is shown in Figure 5.1.9.1 where the overall A-weighted level of self-noise is calculated as a function of wind speed and subtracted from the as-measured sound level. The plot is a three day detail of a wind turbine survey where oversized 175 mm (7”) diameter treated windscreens (ACO Model WS7-80T) were used. This particular windscreen was found to be the best performer, in terms of minimizing wind-induced self-noise, in the wind tunnel study.

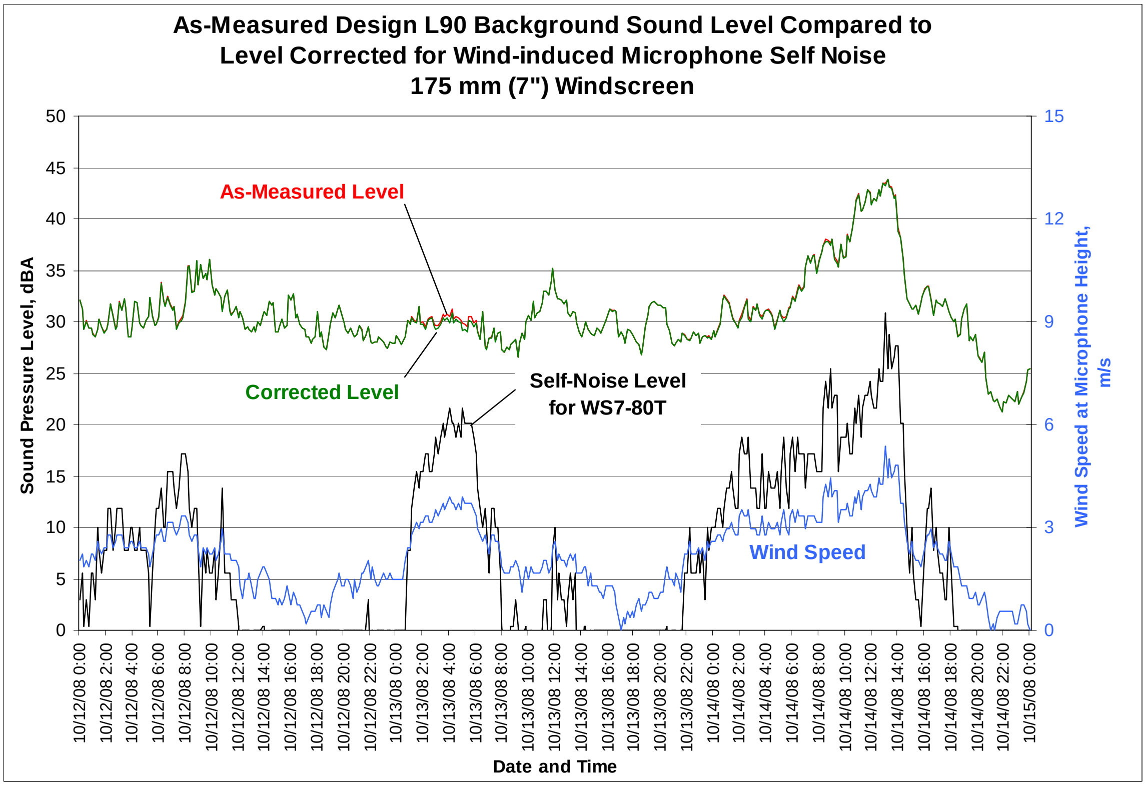

Figure 5.1.9.1

This figure shows the very typical result, at least where extra-large windscreens are used, that the correction is insignificant and can be essentially neglected when it comes to A-weighted sound levels. This is because with a large windscreen the distortion is confined to the very lowest frequencies where it has almost no impact on the A-weighted sound level. With a conventional 75 mm (3”) windscreen, on the other hand, wind-induced noise begins to become significant in the mid-frequency region, between about 63 and 400 Hz, where it has much more influence on the A-weighted sound level. Consequently, standard windscreens are not recommended for this type of survey and windscreens with a minimum diameter of 7” are recommended for wind turbine field work.

The empirical wind tunnel study results for 175 and 75 mm treated windscreens are shown below.

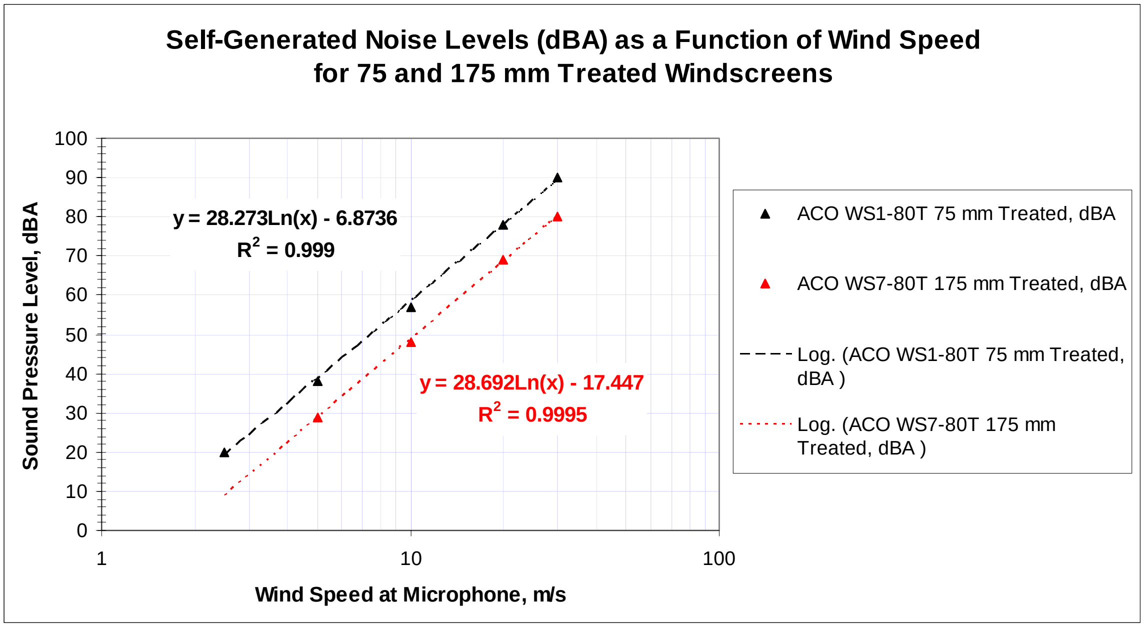

Figure 5.1.9.2

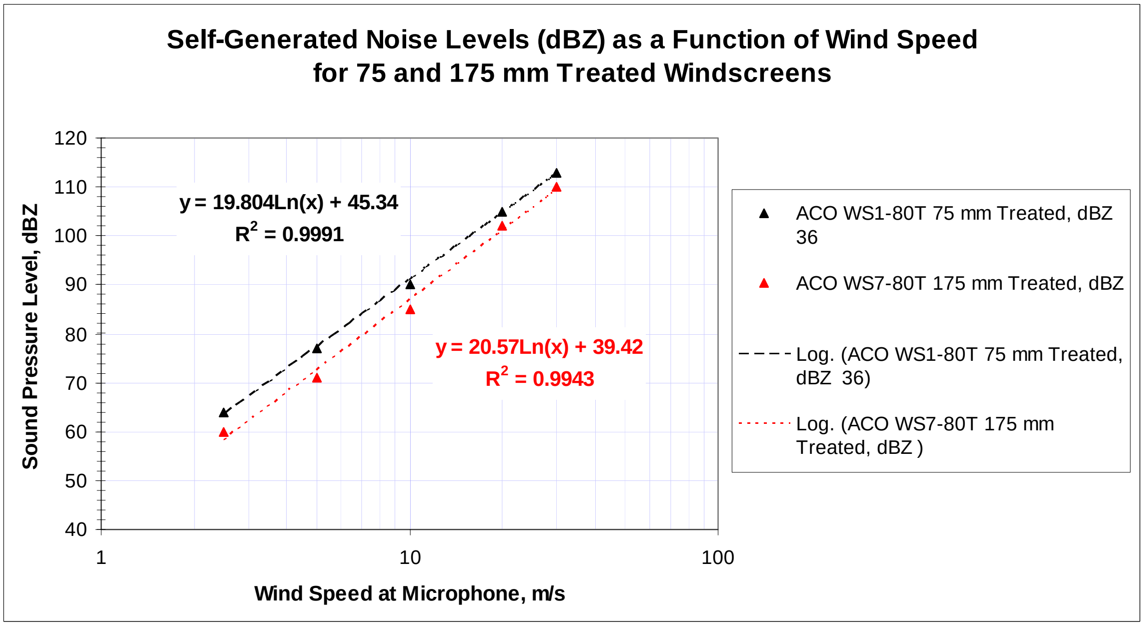

Figure 5.1.9.3

The overall level of self-generated noise for these windscreens may be estimated from the general expression below with the understanding that local atmospheric turbulence is not accounted for and a neutral atmosphere is assumed.

$$L_{p,self} = A \ln(v) + C, \text{ dB} \quad \text{for } v>1.5 \text{ m/s} \quad (1)$$

Where A and C are constants given in the table below and v is the normally incident wind speed at the microphone in m/s.

Table 1 *Constants for A and Z-wtd Self-Noise Calculation Algorithm (Neglecting Atmospheric Turbulence)*

Windscreen Type	A-weighted Sound Level, dBA		Un-weighted Sound Level, dBZ	
	A	C	A	C
75 mm (3") Treated	28.273	-6.8736	19.804	45.34
175 mm (7") Treated	28.692	-17.447	20.57	39.42

In a real atmosphere the sound level may be higher or lower than given in Table 1, depending on the turbulent energy present, which again depends on the stability of the atmosphere. In a neutral atmosphere, which occurs at higher wind speeds (> 6 m/s at 10 m height) or in very clouded conditions, the wind-induced level might be anywhere from 5 to 9 dB higher than the levels shown above. After sunset, when the atmosphere is more prone to be stable, the wind-induced noise levels will be more similar to the values given above.

5.1.10 *Correction for Background Noise*

Once a design L_{A90} background sound level has been developed from averaging the data collected at the off-site proxy positions it can then be subtracted in the usual logarithmic manner[d] from the levels measured at each of the on-site positions to deduce the project-only sound level. However, this correction process is only relevant to samples recorded while the turbines were actually in operation and not necessarily to all samples; consequently, the data must be sifted to ignore all periods of calm winds. This can be accomplished by dealing only with data sets collected above the effective cut-in wind speed for the turbine model in question (bearing in mind whether that wind speed is measured at 10 m or hub height) or, more preferably, by comparing the measured data to a time history of project electrical output obtained from the SCADA, or project control system. For this latter option it is best to compare the operational output of the 2 or 3 units closest to each on-site measurement position rather than the total project output because this not only accurately defines the on and off times at each monitoring station but also may reveal, the fairly common occurrence, that certain units were temporarily down for maintenance or due to some unexpected malfunction. The relevance of this, of course, is that the measurements of project noise during this period would not have captured the maximum possible sound level.

Because the proxy background level is, for practical reasons, an inexact estimation of the site-wide background level, there will usually be instances when the background level exceeds the total measured level at certain on-site positions. Under this circumstance, and when the background level is below but within 3 dB of the total level, the project-only sound level would normally be considered indeterminate. While the calculation of

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[d] $Lp_{Project} = 10 \log [10\text{^}(Lp_{Total}/10) - 10\text{^}(Lp_{Background}/10)]$, dBA

the project-only sound level is mathematically possible when the background level is below but within 3 dB of the total level, doing so tends to create spurious mathematical artifacts where the project level can be estimated at unrealistically low and obviously incorrect sound levels. Since most standards, such as ISO 3746[39], essentially disallow this calculation it is best to follow that policy here as well.

5.1.11 *Typical Test Results and Comparison to Model Predictions*

Representative examples from typical test positions within two different wind projects using two different turbine models and located in two different states are discussed below as a way of illustrating the outcome of the test methodology outlined above.

Example 1

The first example is from a test position at a residence within a project in a rural area in the Eastern United States where the turbines and homes are thoroughly mixed together – a common situation in this region and the Midwest. This location is surrounded in nearly all directions by a number of turbines at various distances, the closest being about 490 m (1600 ft.) away from the home with another 10 lying within a 1500 m (4900 ft.) radius. The terrain is gently rolling hills with a mixture of open fields and wooded areas. Mild complaints about noise had been received by the project from the residents of this home, which is the primary reason it was selected as a monitoring position.

The overall test results from a two week measurement survey in terms of the total measured level at the test point, the design background level derived from proxy positions and the normalized 10 m wind speed, are shown in Figure 5.1.11.1. This is same test position that was previously discussed in conjunction with Figure 5.1.8.2 and L_{Aeq} sound levels.

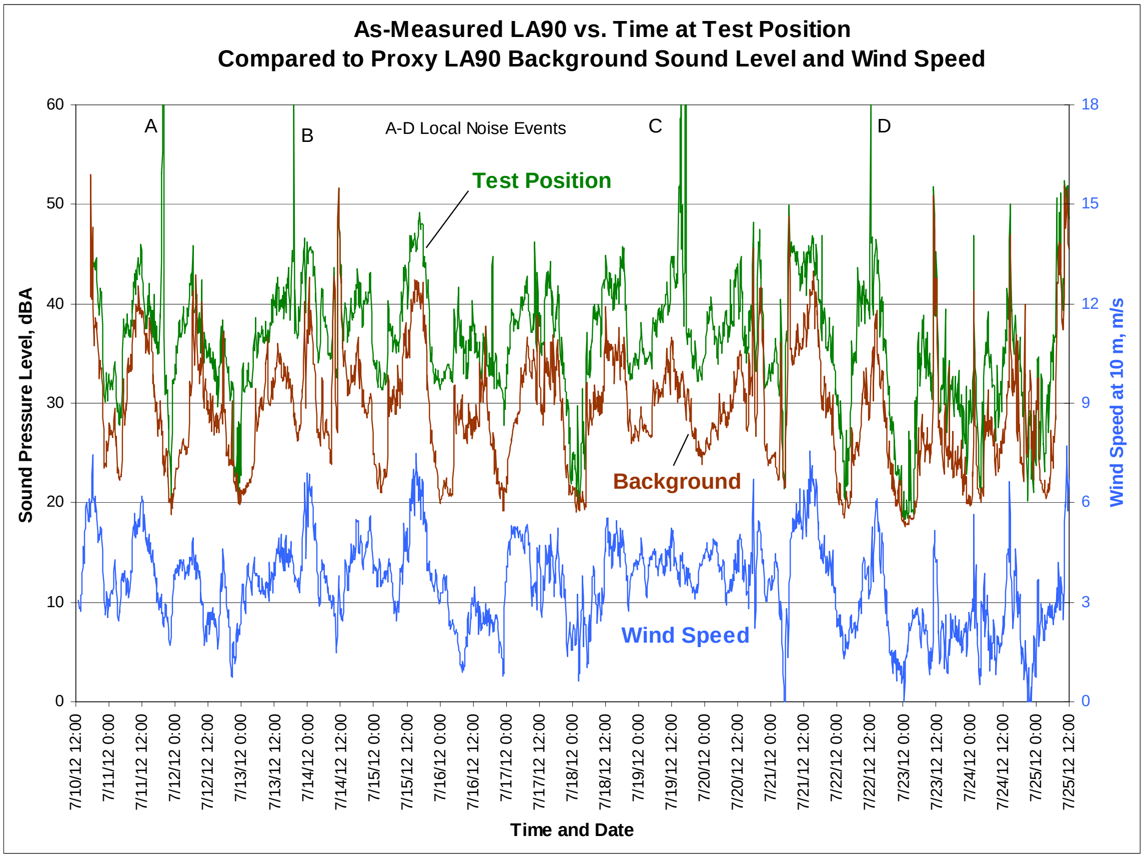

Figure 5.1.11.1

Although the raw results may appear unintelligible at first glance, a closer look reveals that the design background level (developed from an average of three off-site measurement positions) and the sound level at the test position both generally parallel the wind speed indicating that the measured levels are due to wind-induced sounds associated with the natural environment in the first case and to both natural and wind turbine sound in the second. As expected, the on-site level at the position surrounded by almost a dozen turbines is usually substantially higher than the background whenever a moderate wind is blowing and, also as expected, the on-site level is similar to the background during calm conditions when the project is not operating. It is the difference between these two levels during windy conditions that essentially constitutes and quantifies the noise impact of the project. As is evident from the plot, it is an ever-changing dynamic situation where the project sound level variously exceeds the background by anywhere from 0 to 10 dBA. This figure graphically points up the inadequacy of attempting to determine the project's noise emissions from a few short-term manned samples. The greatest differentials between the on- and off-site level tend to occur at night but it is important to note that while the project level may be quite a bit higher than the background, the sound level at the receptor point often remains very low in absolute terms with unadjusted raw levels commonly in low to mid 30's dBA.

Taking these test results through the next steps of correcting the on-site level for background noise and parsing out the low wind periods when the project was idle produces the following plot where the nominal project-only sound level is shown as a function of time over the survey period.

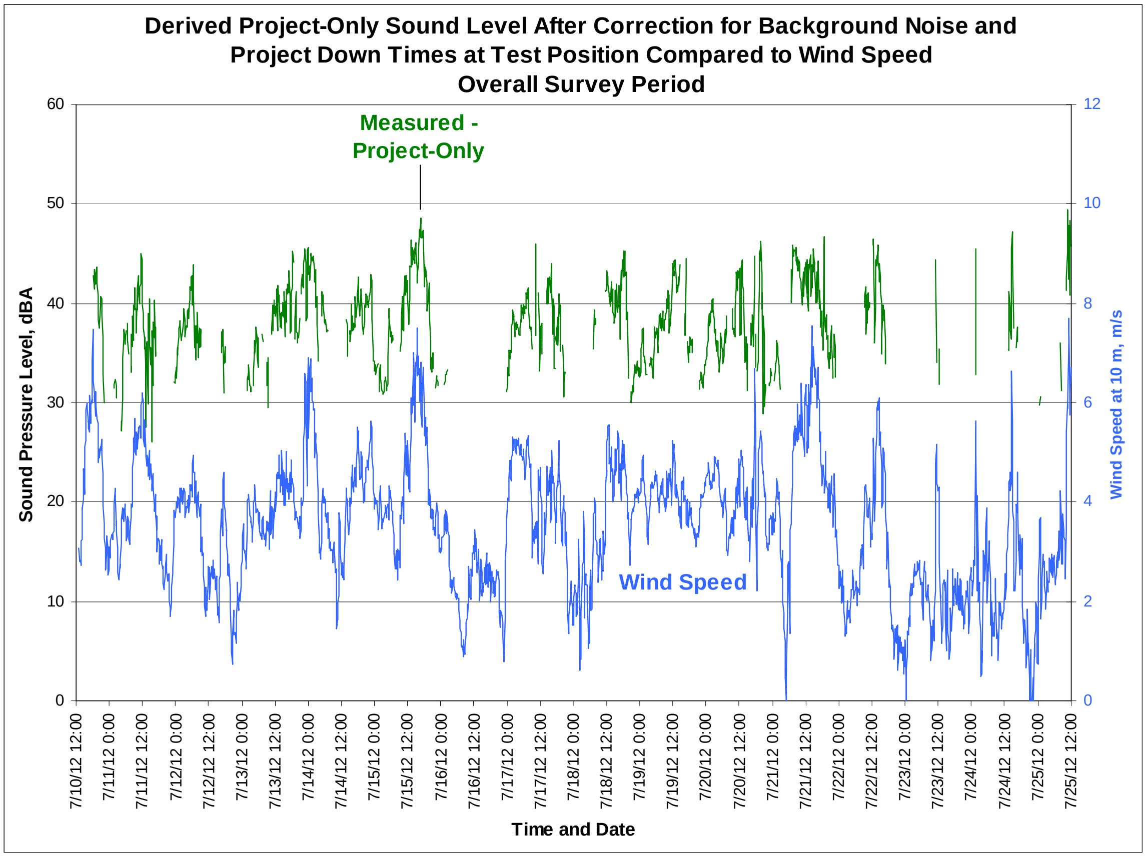

Figure 5.1.11.2

In terms of magnitude the project apparently generates sound levels ranging from 30 to 49 dBA at this location, depending largely but not only on wind speed. The fact that the project sound level does not exactly parallel the wind speed (which was derived from high elevation, rotor height anemometers) indicates that other atmospheric factors play a significant role in determining exactly how loud the project is at this location at any given moment.

What Figure 5.1.11.2 is technically showing is the baseline - L_{A90} - project sound level that is consistently present during each 10 minute measurement period. This means that somewhat higher sound level excursions lasting a few seconds to a few minutes are possible, if not probable, but it is not practical to capture the moment to moment variation over the lengthy survey period needed to adequate evaluate long-term project sound levels. However, comparing these results to model predictions based on the turbine sound power level indicates that the L_{A90} approach does not inadvertently underestimate project levels, as might be suspected. Figure 5.1.11.3 plots the modeled project sound level at this test position (using the procedures outlined in Section 4.1) against the measured project-only sound level. For clarity a detail of a representative three day period from the third to the sixth day of the survey is shown.

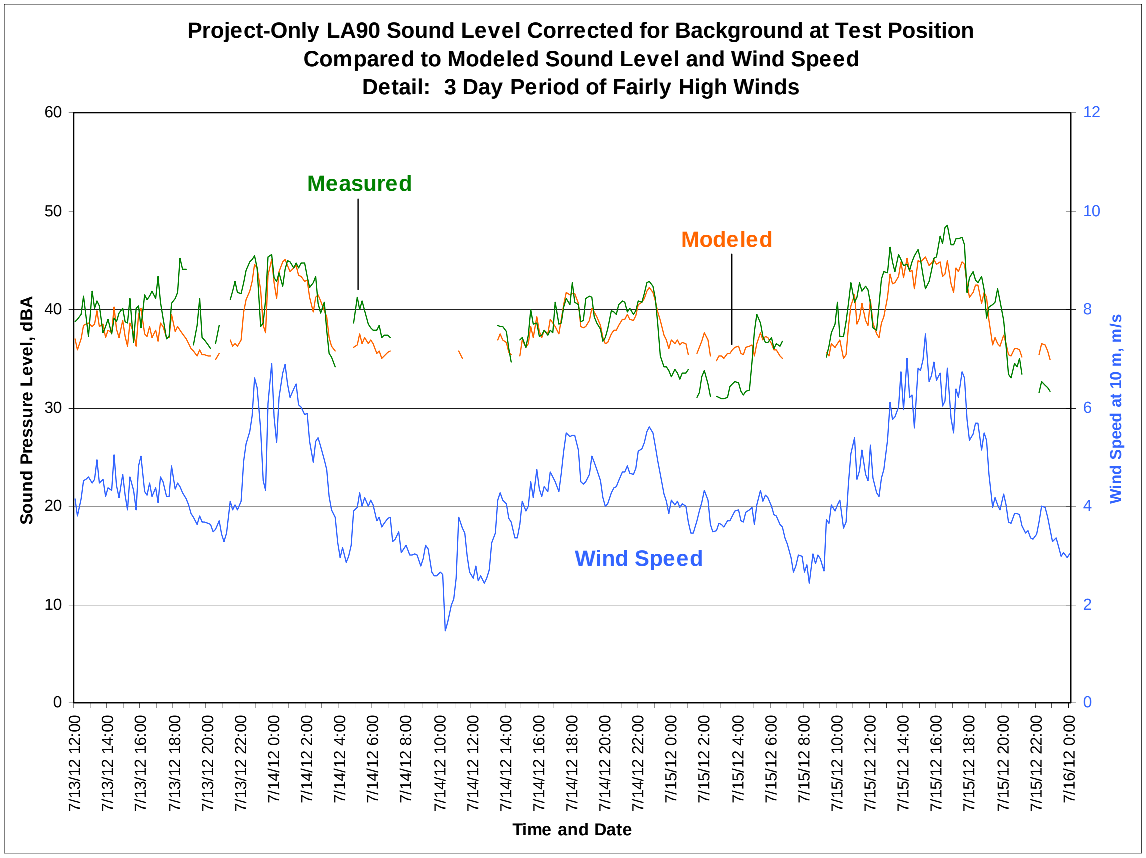

Figure 5.1.11.3

The modeled level is derived using a curve-fit polynomial function based on the predicted project sound level at integer wind speeds, which in turn is based on the turbine sound power level at those wind speeds taken directly from an IEC 61400-11 field test report. In general, the plot shows that the model prediction, based solely on the turbine's sound power level at specific wind speeds, provides a reasonably good approximation of the actual observed sound level.

Example 2

The second example is from a site in the Midwestern United States where the turbines are again intermixed with scattered homes and farms in a rural setting. This particular test location was adopted in response to, what turned out to be understandable, complaints about noise from a participant's "own" turbine that had been sited at the unfortunate distance of only 180 m (600 ft.) from the house. The raw test results are summarized in Figure 5.1.11.4.

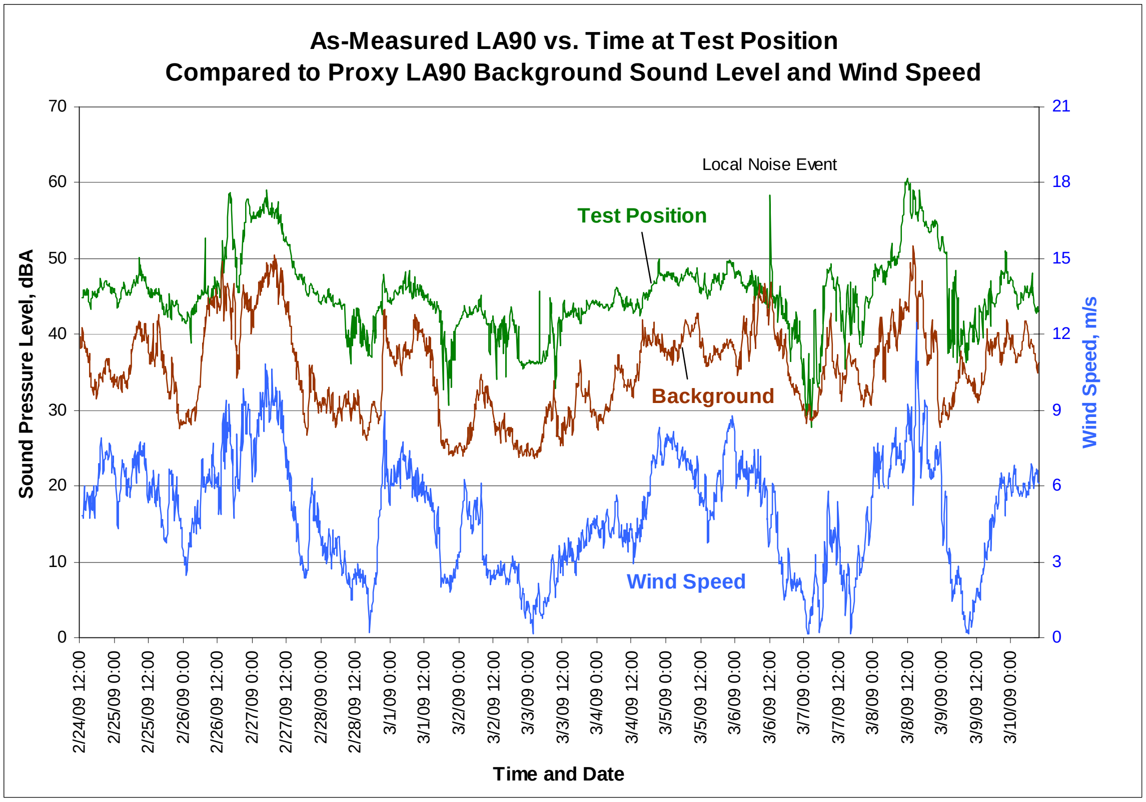

Figure 5.1.11.4

In this instance, the total sound level at the house is consistently and not surprisingly well above the background level developed from four off-site monitoring stations, meaning that much of the time background noise was largely insignificant, if not inaudible. The corrected project-only sound level for a three day windy period near the beginning of the survey is shown below compared to model predictions.

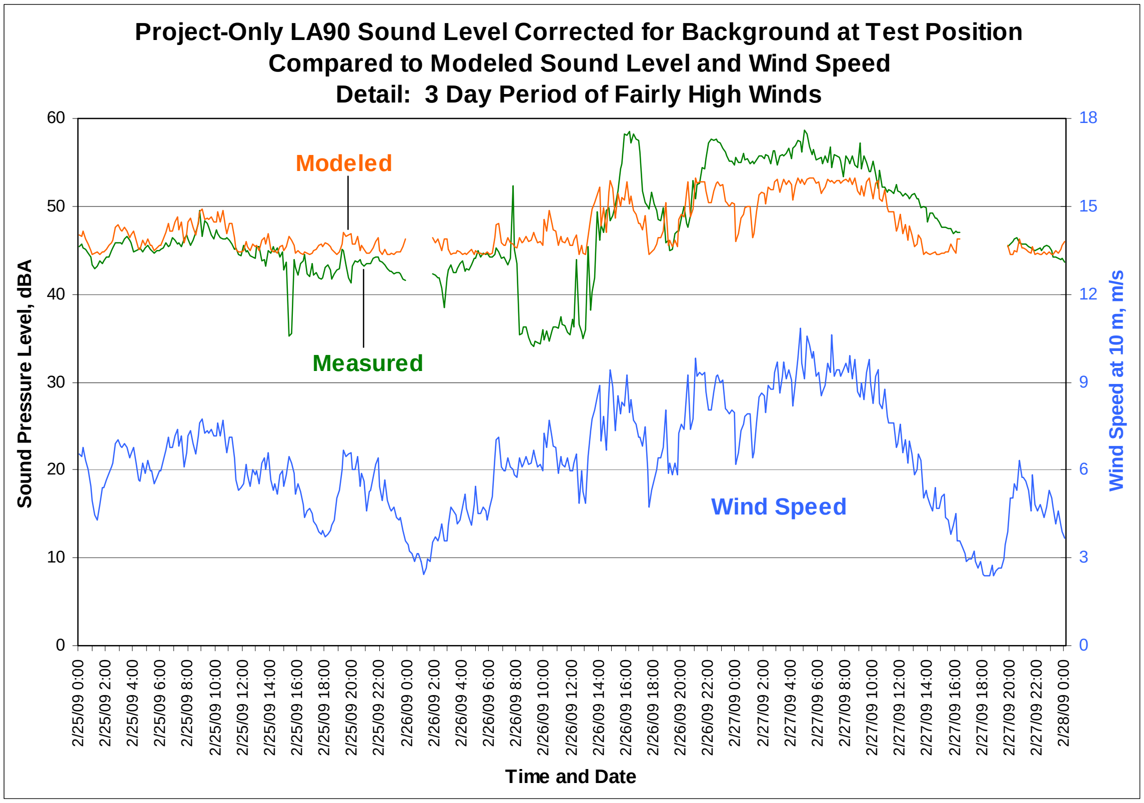

Figure 5.1.11.5

In this instance, as with Example 1, the predicted level intertwines with the measured level, sometimes over-estimating, sometimes underestimating but generally capturing the mean project sound level. The variation above and below the predicted level is largely a measurement of how all other factors beyond the simple wind speed are affecting the total sound level perceived at this location. One of these factors may be unique to the turbine model used at this site, which, based on other surveys and observations, appears to have a tendency to produce sound levels in excess of the manufacturer's stated performance in high wind conditions, which may be part of the reason the actual level significantly exceeds the expected levels in the second half of this sample period. This same departure between the predicted and measured levels also appears in the regression analysis below for the entire survey period where the project-only sound levels are plotted as a function of wind speed.

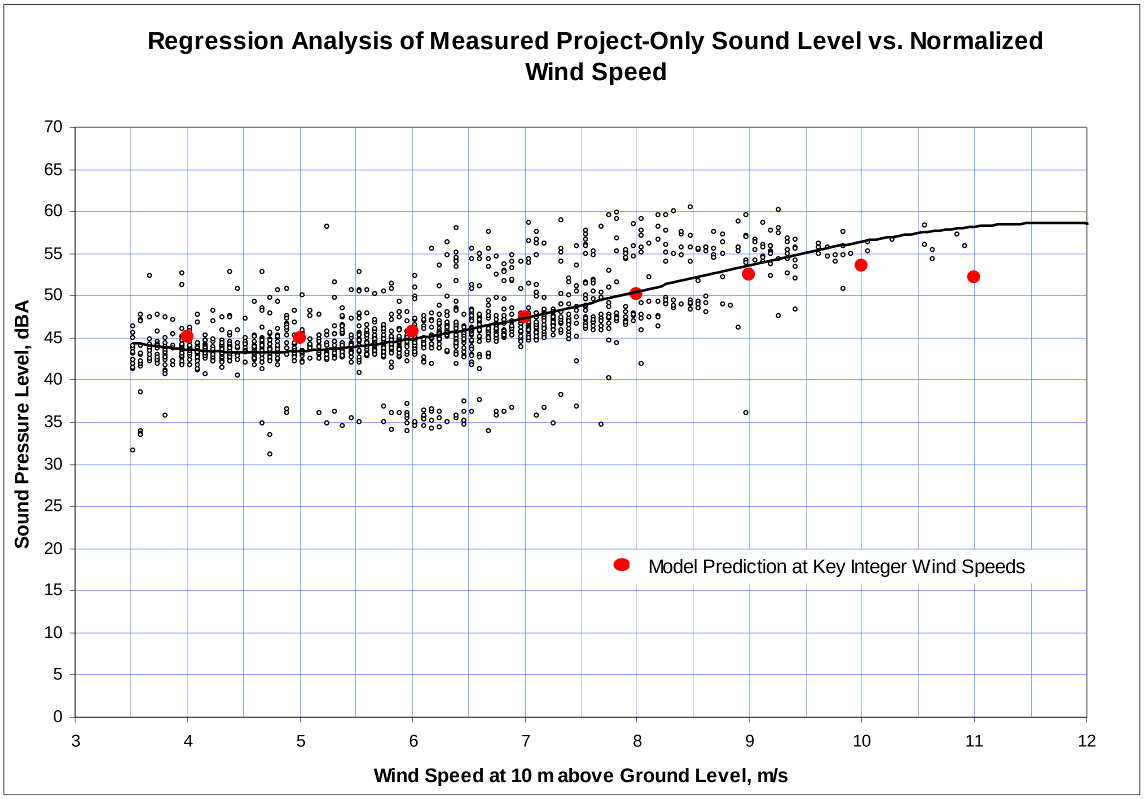

Figure 5.1.11.6

Good agreement with the mean trend is evident up to about 9 m/s but not beyond it.

These two examples are presented to illustrate the outcome of the test methodology and are generally representative of the typical results obtained at a number of test positions over a number of such surveys. That is not to say, however, that the method is infallible and that mismatches between measured and predicted levels will never be found. Testing wind turbine noise is challenging and inherently imprecise because the sound sources themselves and the propagation of sound from them to a given point of interest is dependent on the environment in general and amorphous wind and atmospheric conditions in particular.

5.1.12 *Interpretation of Test Results Relative to Permit Limits*

The regression plot above (Figure 5.1.11.6) exhibits the typical behavior where there is a scatter to the test results and the project sound level is not a perfectly fixed quantity at a given wind speed. This is an unavoidable consequence of the nebulous atmospheric conditions mentioned above. The question that this raises, however, is how to interpret the results of the survey relative to the absolute, or in some cases relative, noise limits contained in planning consent or permit conditions. Excursions, sometimes very substantial excursions, above the mean project sound level are inevitable and under all normal circumstances it would be a complete impossibility to design and lay out a project so that the sound level never exceeded a specific value at a particular point or, more realistically, at a large number of residences within the vicinity of the project. Only projects in obviously remote locations could ever be comfortably designed to such a limit. Consequently, the possibility, even likelihood, that project noise will occasionally spike for short periods should be factored in to regulatory limits. That this issue is not addressed in current laws or limits pertaining to wind turbines is simply a result of the understandable fact that few are aware that it is even an issue.

As a suggestion, it seems reasonable to conclude that a project is in compliance with an absolute regulatory limit if the measurements indicate that the project-only sound level is lower than the stated limit at least 95% of the time, taking that number from the commonly used statistical confidence interval.

5.2 Single Site Investigations

In addition to evaluating operational sound levels on a project-wide basis with regard to regulatory compliance, it is sometimes necessary to carry out dedicated field surveys, usually in response to complaints, that are focused only on a specific point. Although each of these situations is certainly unique, the general test approach outlined above can generally be applied with the exception that more resources can be brought to bear on understanding the project sound level at that particular location.

5.2.1 *General Test Design*

The general test set up for a diagnostic or investigative sound survey at a single point would follow the procedures described for a site-wide test in terms of survey length, equipment and measurement technique with the following enhancements.

The primary measurement position will be outside the residence or point of interest where it is usually prudent to use multiple instruments for redundancy and/or increased functional capability. For example, it is highly desirable to measure the overall A-weighted sound level, the frequency content in 1/3 octave bands and to store audio recordings whenever an appropriate trigger level is reached. While all three of these things can be achieved by some instruments, it would be safer to use the 1/3 octave band analyzer to store numerical data and use a second instrument to store both back-up A-weighted data and the audio files. In any case, having multiple instruments can also allow for additional time resolutions (beside the standard 10 minute periods) to be recorded at the same time; 1 minute or 1 hour data, for instance. In addition to the sound recording equipment a weather station recording wind speed at microphone height, wind direction and rainfall, among other common parameters, should be set up nearby.

The specific measurement position should be at a location with exposure to all of the nearest turbines or at a place that replicates the exposure of the residence to the project but is removed from any sources of local contaminating noise (HVAC equipment, farm machinery, human activities, etc.).

As with a more general survey, the background level is still of just as much concern so 2 to 3 proxy background measurement positions should be found in opposite directions that are remote from any turbines and, in this particular case, replicate as closely as possible the setting of the principal test location in terms of terrain, exposure to wind and exposure to other noise, such as from a road.

The principal and proxy background positions above will theoretically determine what the project sound level is at the residence but may not indicate why it is. To this end several additional monitoring stations close to the 3 or 4 nearest turbines are recommended that are ideally located in line with the principal position at the standard IEC 61400-11 test distance of the hub height plus half the rotor diameter (typically around 125 m, or 400 ft.). A hypothetical test set up involving four nearby turbines is shown in Figure 5.2.1.1.

Figure 5.2.1.1

Note that several of the intermediate positions are slightly off the direct sight line to keep them in open and reasonably accessible areas. Although this hypothetical example was conveniently conducive to this test set up, additional complications are likely to arise; in particular access to private property, which may call for some creativity in designing the test layout. Nevertheless, the idea is to gauge the individual contribution from all of the nearest units over a variety of wind directions and weather conditions to determine if the problematic noise levels are principally associated with perhaps one unit or a particular set of wind conditions. Moreover, the principal purpose for measuring the noise emissions of all the nearest units is to be able to estimate the actual sound power level of each unit and analytically calculate, by means of a simple spreadsheet model, or modeling software, the total sound level at the house for comparison to the measured level there. This approach allows the individual contribution from each unit to be quantified for different conditions and also helps confirm, in a manner independent from the proxy monitoring approach, how much of the received signal at the principal measurement location is due to the project and how much is background noise. In addition, the sound power level of each unit can be informally checked against the manufacturer’s warranty value.

While the ground board technique specified in IEC 61400-11 is not practical for long-term, unattended measurements - mainly because of concern about rain - a comparable, if somewhat less rigorous, result can be obtained from measuring at 1 m above grade by placing the microphone or monitor on a tripod or temporary post at the appropriate distance. In Figure 5.2.1.2, for example, measurements were made simultaneously at 1 second resolution with a microphone on a ground plate and with two additional microphones at 1 and 2 m above it. The average and consistent differential between both above ground positions and the microphone on the reflective plate was 2.7 dB, which is close to the ideal 3 dB differential that one would expect.

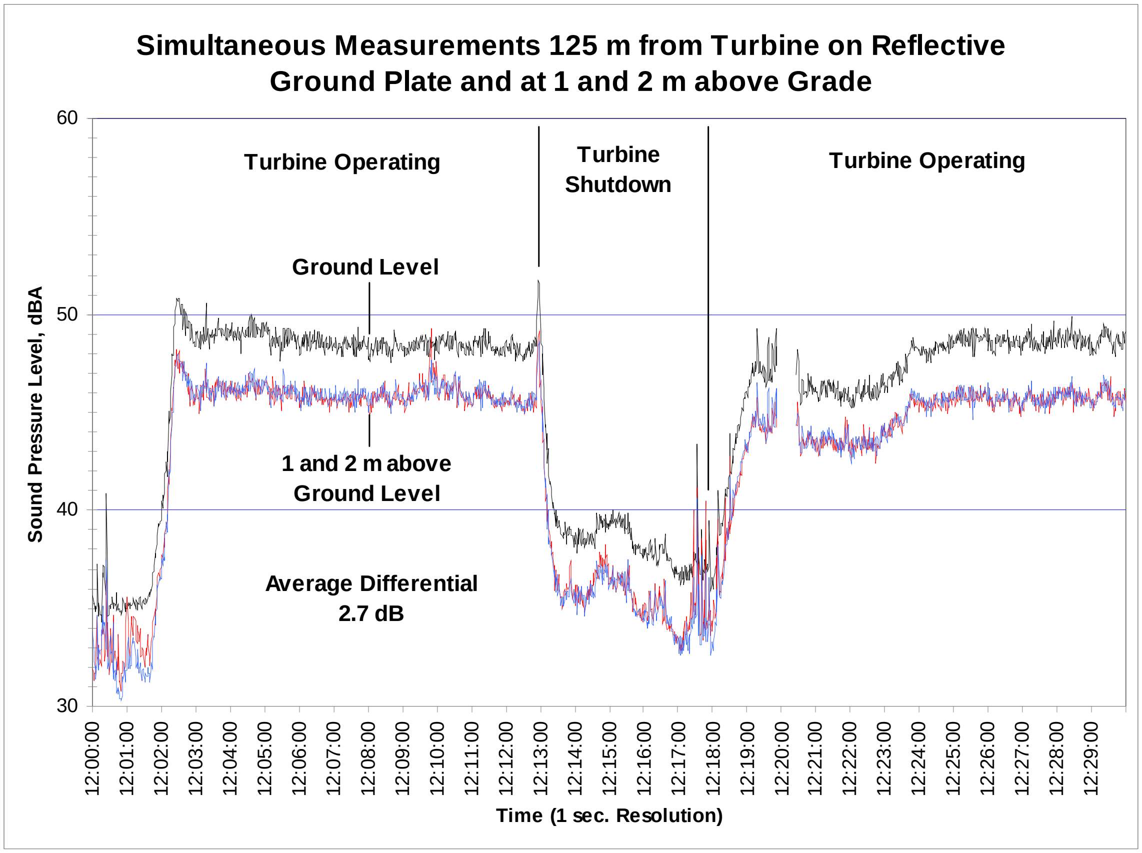

Figure 5.2.1.2

This example illustrates that it is possible under certain circumstances to reasonably measure the apparent A-weighted turbine sound power level above ground level without serious degradation due to wind distortion. Of course, this may not be true when it is particularly windy at 1 m above ground level. Another potential complication arises when multiple turbines are in unusually close proximity to each other, as they are in Figure 5.2.1.1, and background noise or cross-contamination from one unit to another must be taken into account in such cases. In general, however, the only substantive modification to the IEC 61400-11 process for calculating sound power level would be to change the constant “6” to “3” in Eqn. (9) of the standard since above ground measurements are being used.

As suggested by Figure 5.2.1.2, an additional tool that is normally useful and practical for single site investigations is to temporarily shutdown, for 10 to 20 minutes, the nearest turbines to the point of interest, if not all those that could conceivably be affecting the sound level there, in order to obtain direct measurements of the background level so the project-only level can be derived with some confidence from the operational sound levels occurring just before or after the shutdown. A short-duration shutdown helps ensure that the wind and weather conditions are essentially identical for both the on and off measurements. This technique also offers a way of verifying the validity of the levels measured at the off-site background positions. It is usually during the times of peak noise that it is most desirable to have an exact measurement of project’s sound level, since these are the noise levels that most likely engendered the complaint in the first place. Consequently, it becomes a matter of either being there when these conditions occur, which is frequently at night, to organize the shutdown - or putting control over the shutdown in the hands of the resident who can call in by pre-arrangement to the control room if and when the noise becomes objectionable in terms of its overall magnitude and/or begins to exhibit some adverse character, such as from amplitude modulation. Although this latter approach of allowing the resident identify the time of maximum noise has been used successfully to quantify the overall magnitude of project noise and its frequency content in 1/3 octave bands, one must really be on hand to manually measure amplitude modulation, since it calls for the use of an extremely fine time resolution, on the order of milliseconds, to capture the sound oscillations that normally have a period of roughly 1 second. Such manual measurements can be taken indoors, where this kind of noise is most often observed to be objectionable, as well as outdoors.

Only with attended measurements it is possible, and then only occasionally, to measure indoor sound levels in any kind of meaningful way because contaminating noises can be observed and, hopefully, factored out. Long-term monitoring is effectively limited to the outdoors for the fundamental reason that there is no way to ascertain the background sound level inside of a dwelling at a particular time with the project operating. This is because the background sound level indoors is driven by a unique set of seemingly minor but significant sound sources that cannot be replicated by a proxy measurement position. Indoor background sound levels are partially a function of the outdoor conditions, particularly when it is windy or raining, but are also driven by such things as air flow from the heating and air conditioning system, appliances, computers and, of course, human activity even when it is in a distant part of the house. These usually very minor sounds are significant because the intruding noise level from the project is often very low or extremely low in terms of the A-weighted sound level. For example, it would not be unusual for a project sound level to be in the vicinity of 30 dBA inside of the house (perhaps being in the 40 to 45 dBA range outdoors). The successful measurement of the project-only sound level would then require the indoor background level to be 20 dBA or less, which is usually not the case. Sound levels in a bedroom at night are commonly at least 30 dBA even when no wind project is present.

In any event, it is sound level outside of dwellings that is normally (but not always) restricted by regulations or permit conditions and this level can typically be measured with the long-term monitoring methodology described above.

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