Position 6 – Township Hwy 205

Monitor 6 was located in an open grass field near a farm on Township Hwy 205 on the eastern side of the study area.

Figure 2.2.6a *Monitor 6 – Looking SE towards Farm*

Figure 2.2.6b *Monitor 6 – Looking NW toward T. Hwy 205*

Position 7 – Township Hwy 204

Monitor 7 was located an open field between a number of relatively new homes along Township Hwy 204 near its southern termination at Route 161. It should be noted that fairly noisy construction activity (major renovations or the construction of a new outbuilding) was observed at the end of the survey at each of the houses on either side of the field where the monitor was set up.

Figure 2.2.7a *Monitor 7 – Looking SW*

Figure 2.2.7b *Monitor 7 – Looking NE*

Position 8 – Route 161

Monitor 8 was located in an open field approximately 130 ft. south of Route 161 across from a number of houses on the north side of this fairly major State road. The monitor position was 0.85 miles southwest of the Parkview Road intersection with Rt. 161. As can be seen in Figure 2.2.8a, the houses are generally much closer to the road than the monitor.

Figure 2.2.8a *Monitor 8 – Looking N*

Figure 2.2.8b *Monitor 8 – Looking ENE*

Position 9 – State Route 29

Monitor 9 was located in a field adjacent to a farmhouse on the north side of State Route 29 (0.75 miles east of its junction with Hawk Road). Route 29 is the largest and most heavily traveled road in the project area. This monitor was set up to capture environmental sound levels typical of those experienced at the numerous residences along this road. The monitor was set back from the road the same distance as the farmhouse (220 ft.).

Figure 2.2.9a *Monitor 9 – Looking W toward House*

Figure 2.2.9b *Monitor 9 – Looking S toward Rt. 29*

Position 10 – Route 56

Monitor 10 was located in an open area behind a farm on the east side Rt. 56 (0.85 miles south of Rt. 29). This position is completely remote from any roads.

Figure 2.2.10a *Monitor 10 – Looking SW*

Figure 2.2.10b *Monitor 10 – Looking W*

2.3 INSTRUMENTATION AND SURVEY DURATION

Rion Model NL-21, ANSI Type 2, integrating sound level meters were used for the survey. Each instrument was enclosed in a weatherproof case and the microphone was mounted on a temporary post as shown in the photos above. The microphones were protected from self-induced wind noise by oversized, 7 inch diameter weather-treated windscreens (ACO Type WS7-80T). All the microphones were located at a height of approximately 1 m above local ground level and positioned in open areas away from any large reflective surfaces.

All the instruments were field calibrated with a Brüel and Kjær Type 4230 calibrator at the beginning and end of the survey. The observed calibration drift, or change in the instrument's sensitivity over the survey period, was minor and ranged between -0.4 and +0.1 dB at all positions.

Each of these instruments is designed for service as a long-term environmental sound level data logger measuring the A-weighted sound level. The meters were all set to continuously record a number of statistical parameters in 10 minute increments, such as the average (Leq), minimum, maximum, and residual (L90) sound levels. The survey period lasted 18 days beginning at noon on Nov. 3 and ending at noon on November 21, 2011.

As is evident from some of the photographs in Section 2.2, the survey was conducted during fall conditions when most of the trees were in the process of losing their leaves. Although many trees still had at least some leaves, the monitors were deliberately located in open areas away from trees to minimize any effect from leaf rustle (despite the fact that virtually every house has trees immediately adjacent to it). At this time of year contaminating noise from nocturnal insects had ceased and was not a factor in the survey.

2.4 SURVEY WEATHER CONDITIONS

The weather conditions during the survey might be characterized as being generally fair and windy with only one period of significant rain on November 14th. Temperatures were mild and ranged from about 30 to 65 deg. F. The general weather parameters over the survey period, as observed in Bellefontaine, OH a few miles north of the site area, are illustrated below.

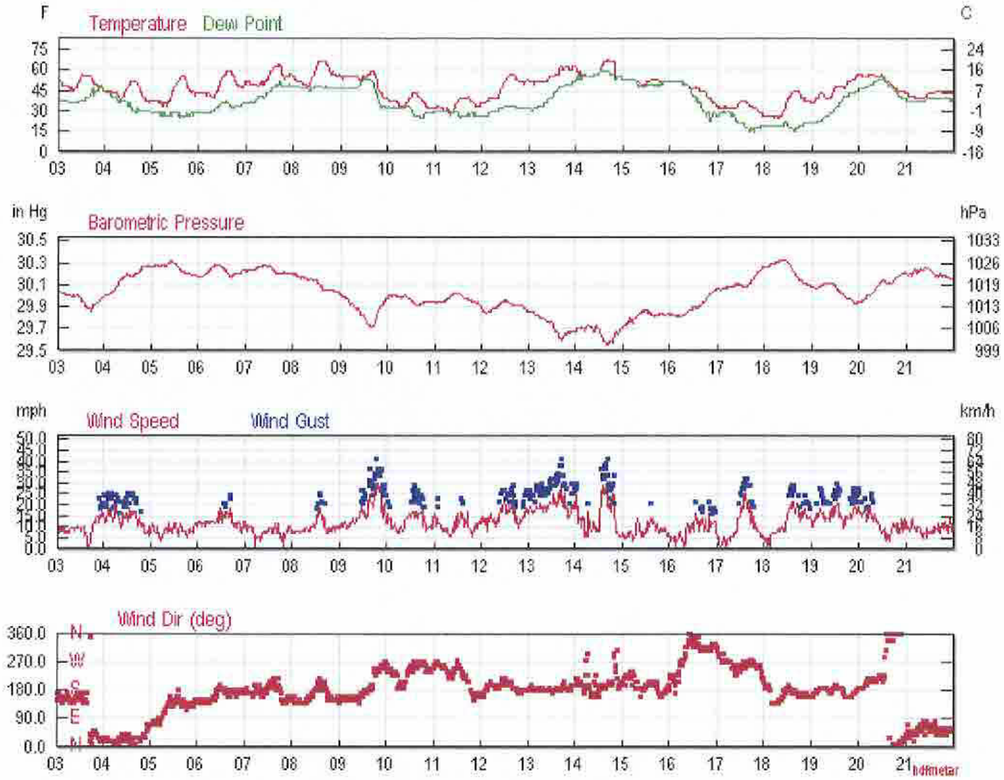

Figure 2.4.1 *General Weather Conditions during the Survey, as Observed in Bellefontaine, OH (from www.weatherunderground.com)*

The wind speed within the study area itself was measured at microphone height (1 m) by a temporary weather station set up at Position 4 near the center of the study area and also at high elevation (58 to 80 m) by 6 on-site met towers. The wind speed at 1 m above ground level and the specific times when it rained at the site are shown in Figure 2.4.2.

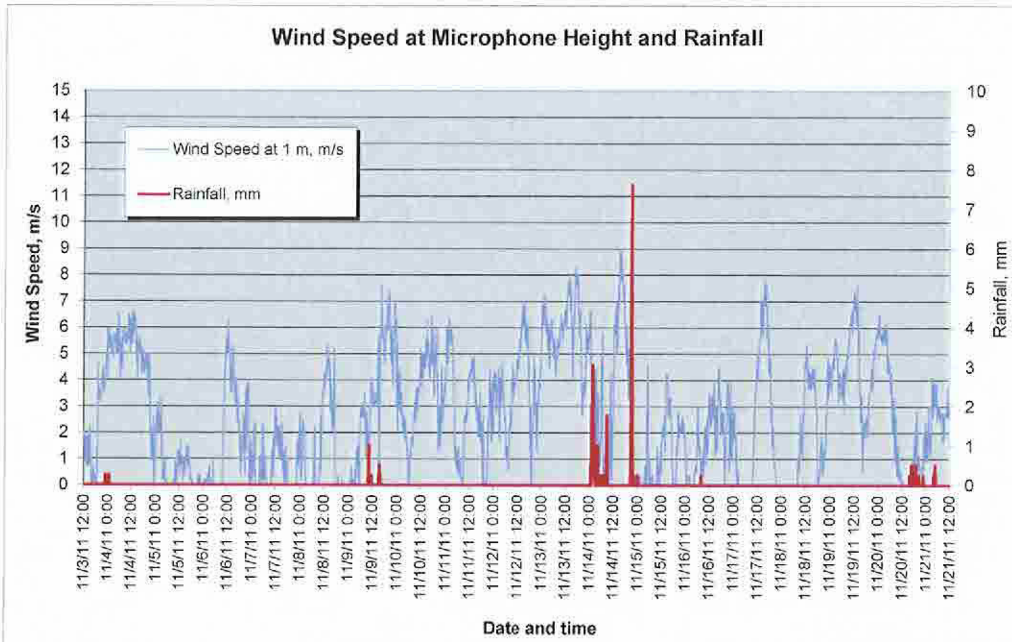

Figure 2.4.2

Because wind turbine sound power levels (measured in accordance with IEC 61400-11[1]) are expressed in terms of the wind speed at a standard elevation of 10 m above ground level, it is necessary to normalize the met tower anemometer data to this height so that all quantities can be compared on an equal footing. The conversion of wind speed at one elevation to the related speed at another elevation is calculated from an empirically derived formula in Reference 1 (Equation (7), Section 8), which describes an exponential profile.

As a general example, the wind profile resulting from Eqn. (7) is shown graphically below in Figure 2.4.3 for a case where the wind is normalized to a speed of 7 m/s at 10 m. This shows that the simultaneous wind speed at an anemometer height of 60 m would be around 9.3 m/s while at 10 m the wind speed is likely to be substantially lower at 7 m/s. The shape of the profile curve varies with wind speed becoming flatter at low speeds and more curved at higher speeds.

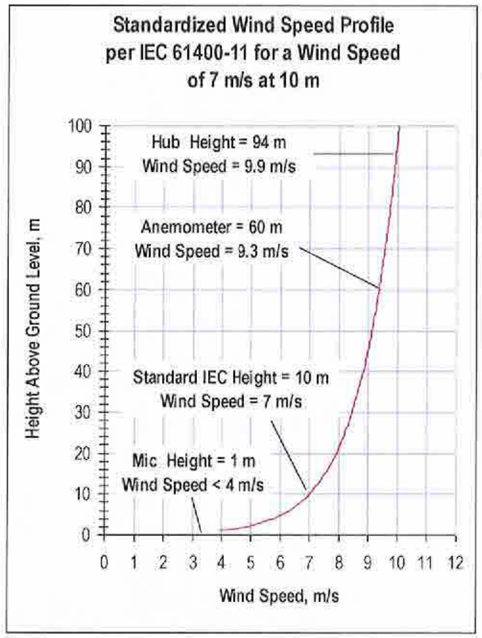

Figure 2.4.3 *Typical Wind Speed Profile above the Surface*

The 6 met towers distributed over the Buckeye II study area range in height from 58 to 80 m (3 at 58 m, 2 at 60 m and 1 at 80 m). The wind speed data measured over the survey period by the mast top anemometers (essentially quantifying the wind speed that would be seen by the turbine rotors) have been normalized to 10 m and plotted in Figure 2.4.4 below.

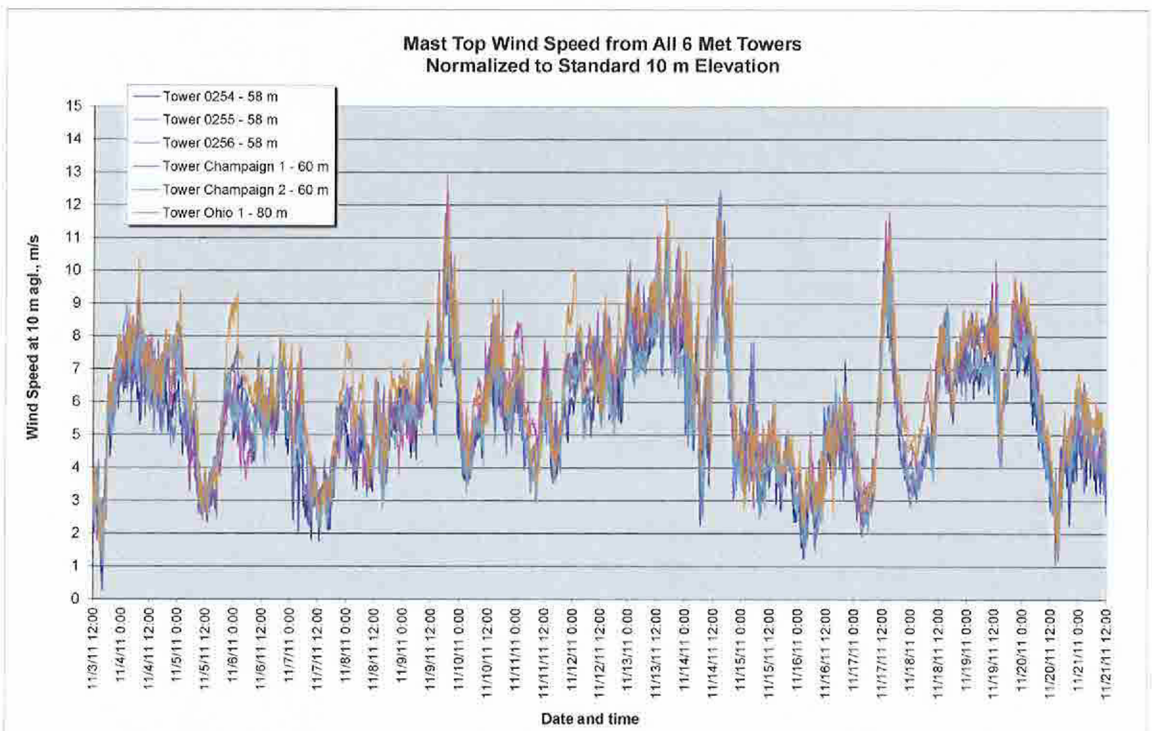

Figure 2.4.4

Because the normalized wind speed is clearly consistent at all locations nearly all of the time, the average of the six towers can be taken for design purposes to represent the approximate 10 m wind speed anywhere in the study area.

2.5 OVERALL SURVEY RESULTS

2.5.1 Average (Leq) Levels

The average, Leq, sound levels measured at all positions over the entire survey period are plotted in Figure 2.5.1.1 relative to the site-wide average wind speed at 10 m.

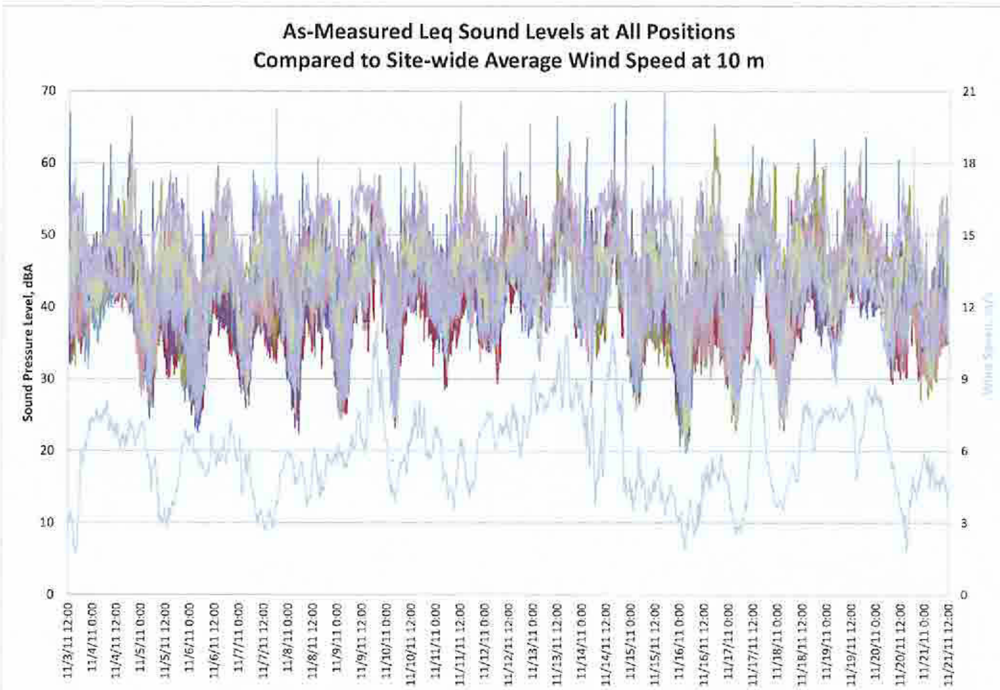

Figure 2.5.1.1

What this chart suggests is that the average sound level generally follows a daily pattern of high levels during the day and relatively low levels at night with a fairly weak dependence on wind speed - mostly limited to high wind periods. The arithmetic average daytime and nighttime Leq level at each position is tabulated below. The nighttime site-wide average is **39 dBA**.

Table 2.5.1.1 *Daytime and Nighttime Leq Sound Levels at All Positions*

Measurement Position	Daytime Average Leq, dBA	Nighttime Average Leq, dBA
1	46	37
2	41	35
3	44	40
4	43	38
5	45	39
6	45	40
7	45	40
8	47	39
9	52	45
10	43	36
Overall Average of All Positions	**45**	**39**

The data can also be looked at as a function of wind speed as illustrated in Figures 2.5.1.2 and 2.5.1.3 where the daytime and nighttime Leq sound levels (averaged over all 10 positions) are plotted against the average site-wide wind speed at the standard elevation of 10 m.

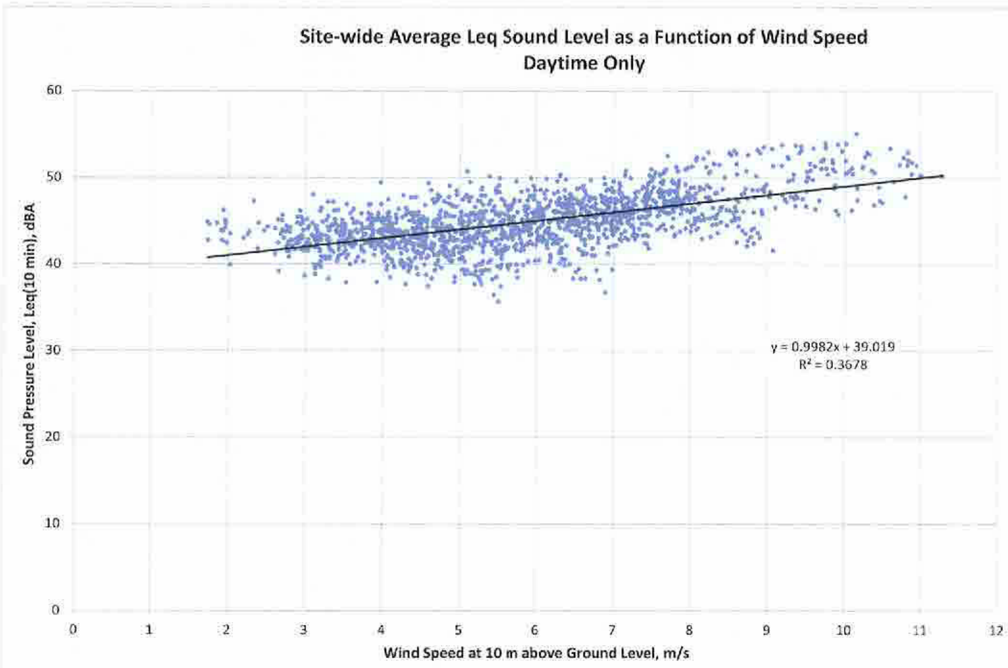

Figure 2.5.1.2

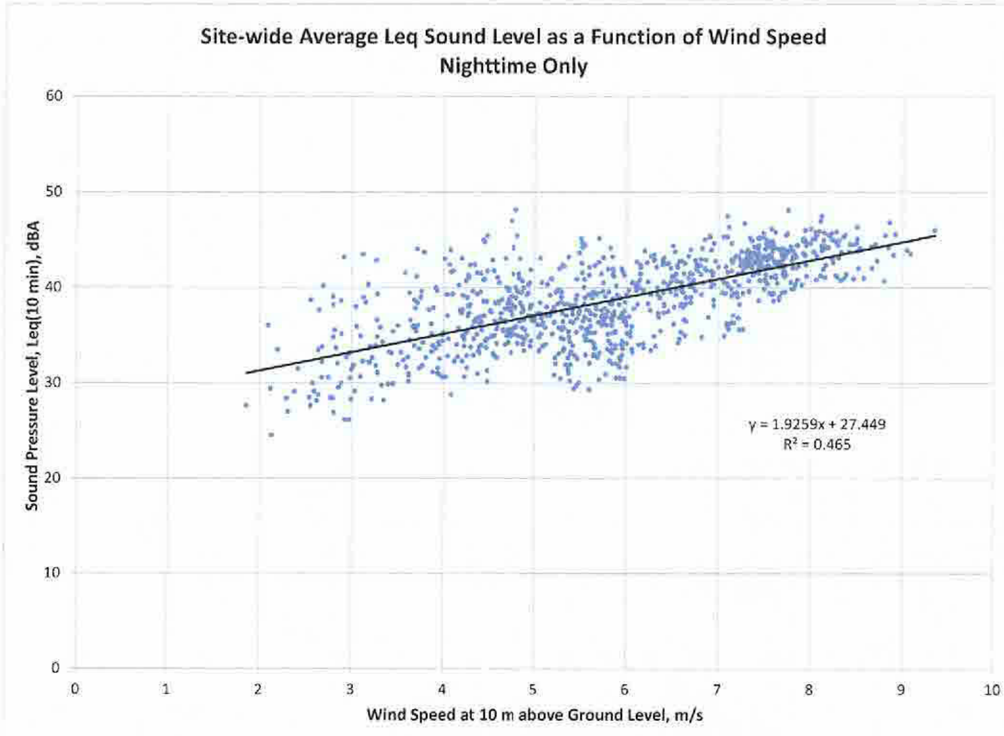

Figure 2.5.1.3

In these figures the dependency of the Leq sound level on wind speed is more evident than in the level vs. time plot (Figure 2.5.1.1) and it can be seen that the sound level increases with increasing wind speed – particularly at night. The mean trend line values at integer wind speeds are summarized below.

Table 2.5.1.2 *Mean Daytime and Nighttime Leq Sound Levels as a Function of Wind Speed*

Wind Speed at 10 m, m/s	3	4	5	6	7	8	9
Mean Daytime Leq, dBA	42	43	44	45	46	47	48
Mean Nighttime Leq, dBA	33	35	37	39	41	43	45

2.5.2 Residual (L90) Levels

As discussed above in Section 2.1, the L90, or residual, sound level is a conservative measure of background sound levels in the sense that it filters out short-duration, sporadic noise events thereby capturing the near-minimum sound level. This level essentially represents the quiet, momentary lulls between such events as cars passing by or tractor activity in a neighboring field.

The as-measured L90 sound levels recorded at all 10 positions are plotted below.

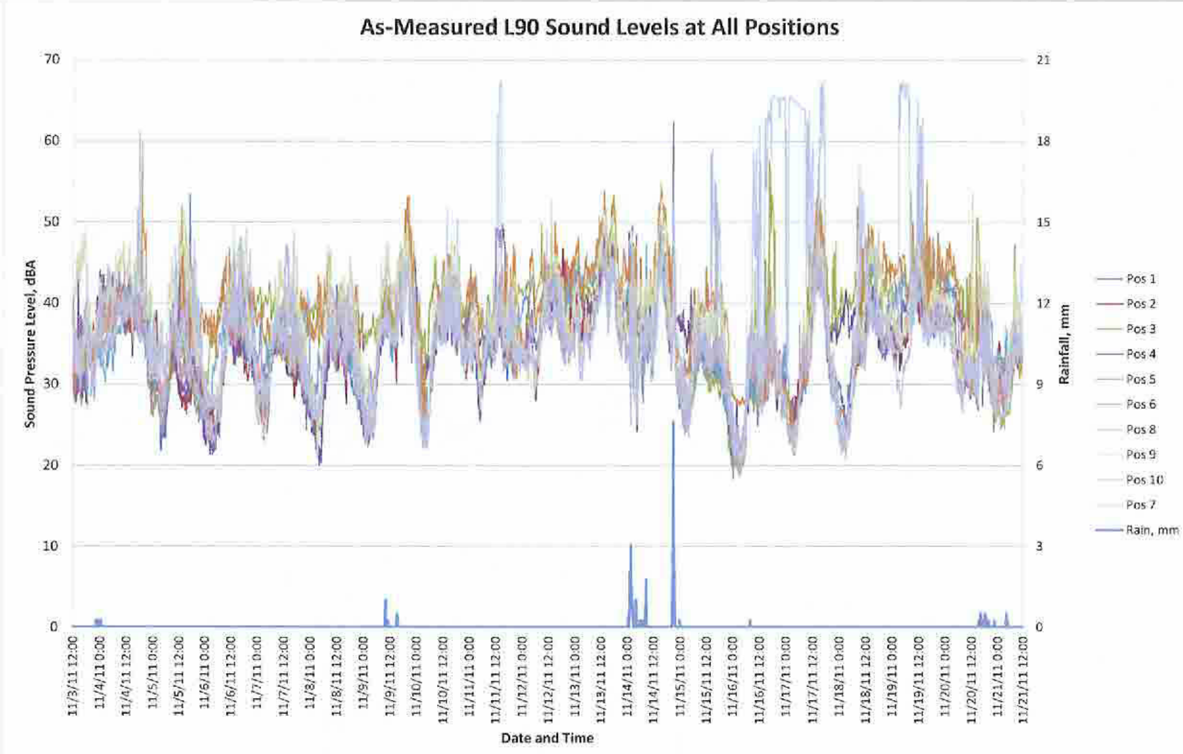

Figure 2.5.2.1

This plot shows that there was general consistency among the various positions except for several periods of unusually high levels at Position 7; particularly on November 17. Although some construction activity was observed near this position at the end of the survey, the precise cause of these noise excursions is not known with any certainty. Consequently, the data from this position will be set aside. Figure 2.5.2.2 shows the sound levels at the 9 remaining positions.

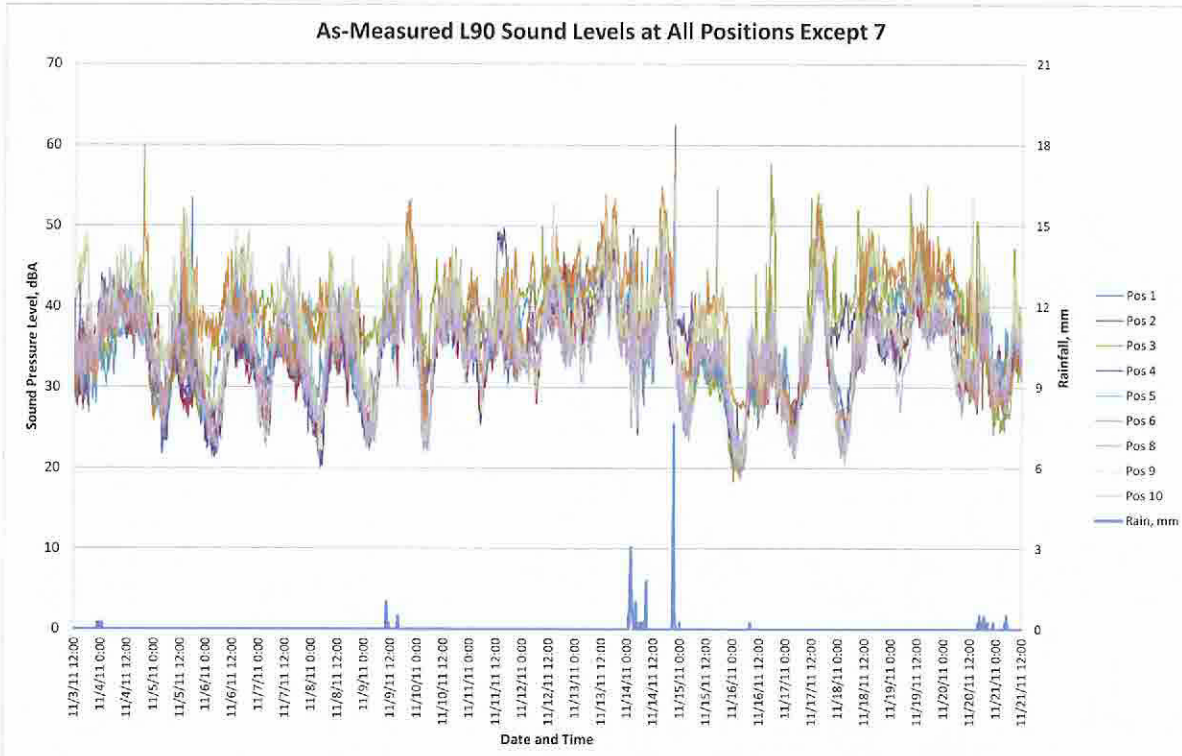

Figure 2.5.2.2

Once spurious local noise events and all measurements taken during periods of significant rain, such as on Nov. 14, are removed the site-wide consistency in the data is more evident, as shown in Figure 2.5.2.3.

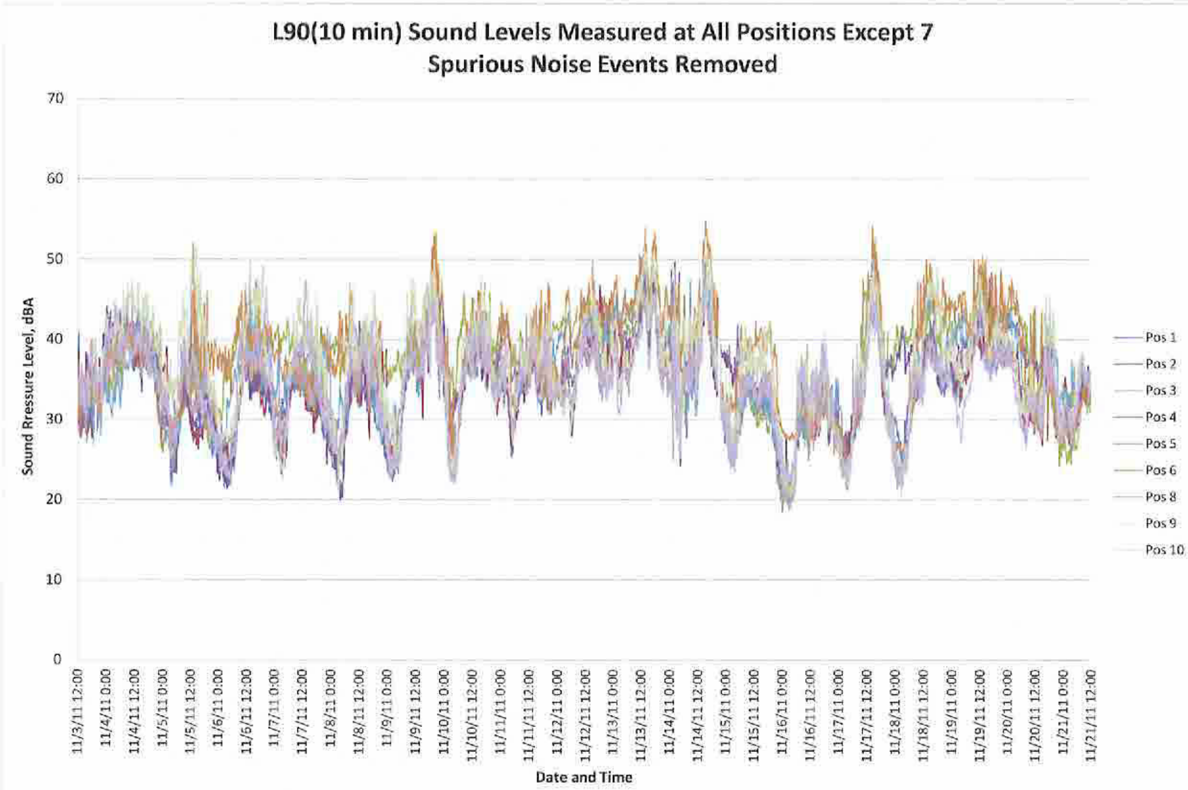

Figure 2.5.2.3

Because these levels generally intertwine and follow the same temporal trends, the average of all 9 positions can be considered, for design purposes, to be a reasonable estimate of the L90 sound level anywhere within the project area. This average design level is compared to the concurrent wind speed in Figure 2.5.2.4.

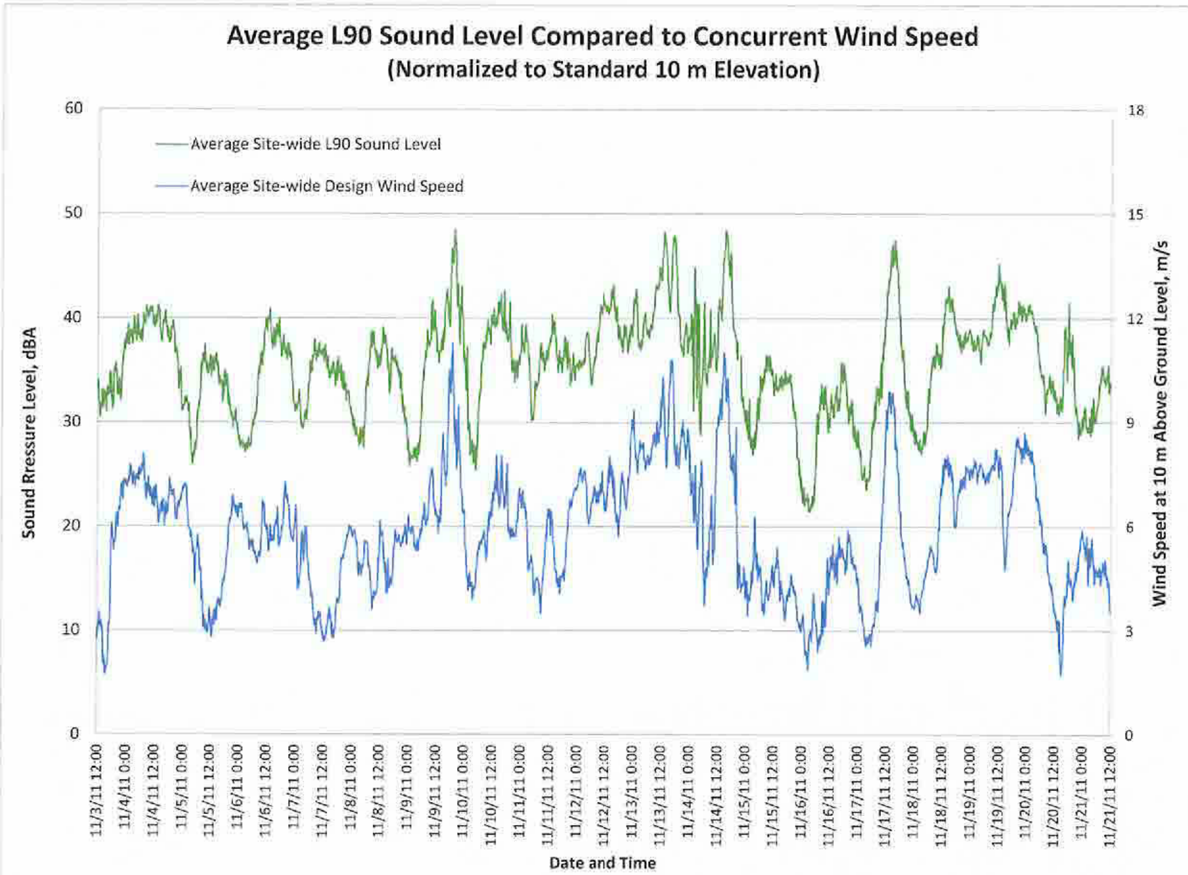

Figure 2.5.2.4

In this plot the correlation between the near-minimum, L90 background level and wind speed is much more evident than it was with the Leq data shown in Figure 2.5.1.1. If the L90 sound levels are plotted as a function of wind speed (Figure 2.5.2.5) it can be seen that low levels are generally only observed during calm or low wind conditions, while significantly higher sound levels are experienced during windy periods.

yes, yet low L90s (under 30) also seem to occur quite often in conjunction with wind speeds that are moderate (5-6m/s), not always very low (circa 3-4m/s). What's cut-in? (of course this is 10m, turbine cut-in is based on hub height; so, what's typical 10m wind speed at which hub height hits cut-in?

See below; cut in is 2.5 or 3 m/s, (sound power level ratings start at 3m/s; AND are referenced to that speed at 10m)

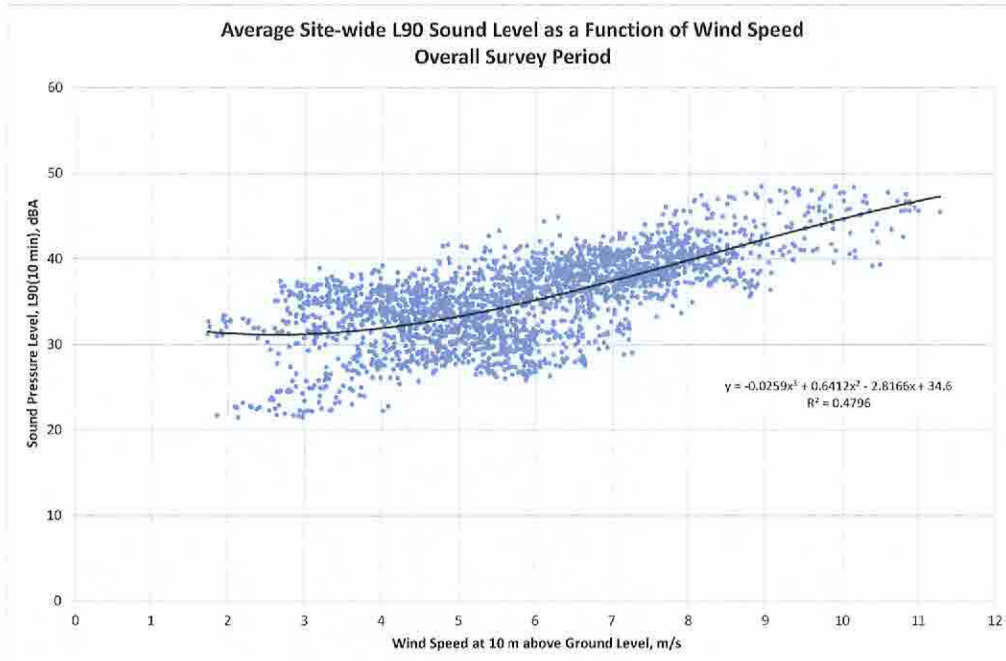

Figure 2.5.2.5

Figures 2.5.2.6 and 2.5.2.7 show the daytime and nighttime L90 levels versus wind speed. The mean daytime and nighttime L90 levels are summarized in Table 2.5.2.1.

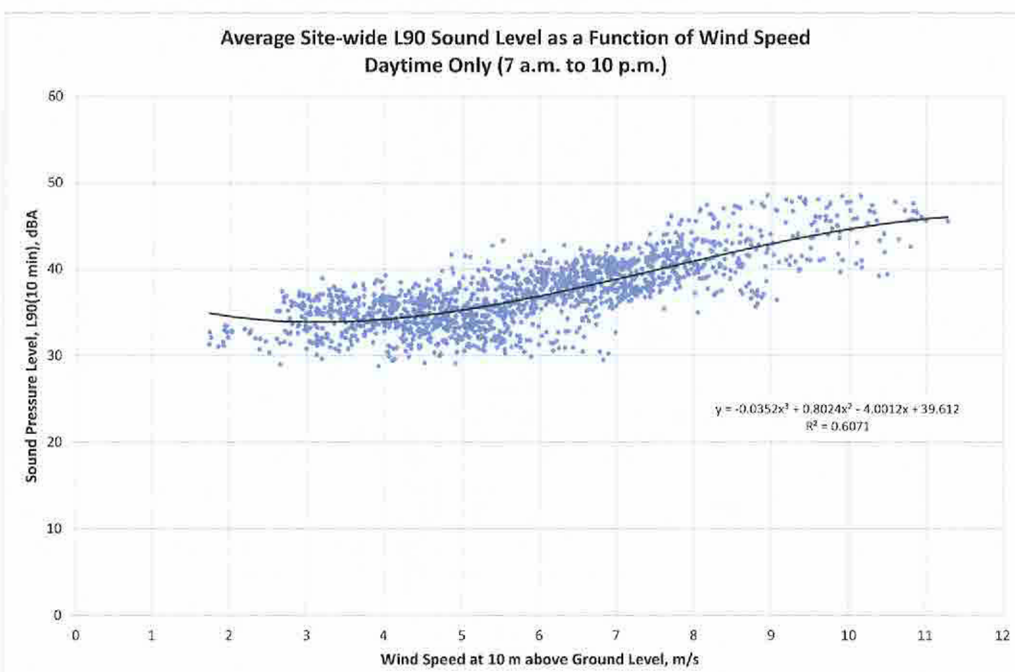

Figure 2.5.2.6

fascinating variation, especially at middle wind speeds (eg, 5-6m/s… 25-42dB) Why, I wonder? Time of night? are they using insect technique?

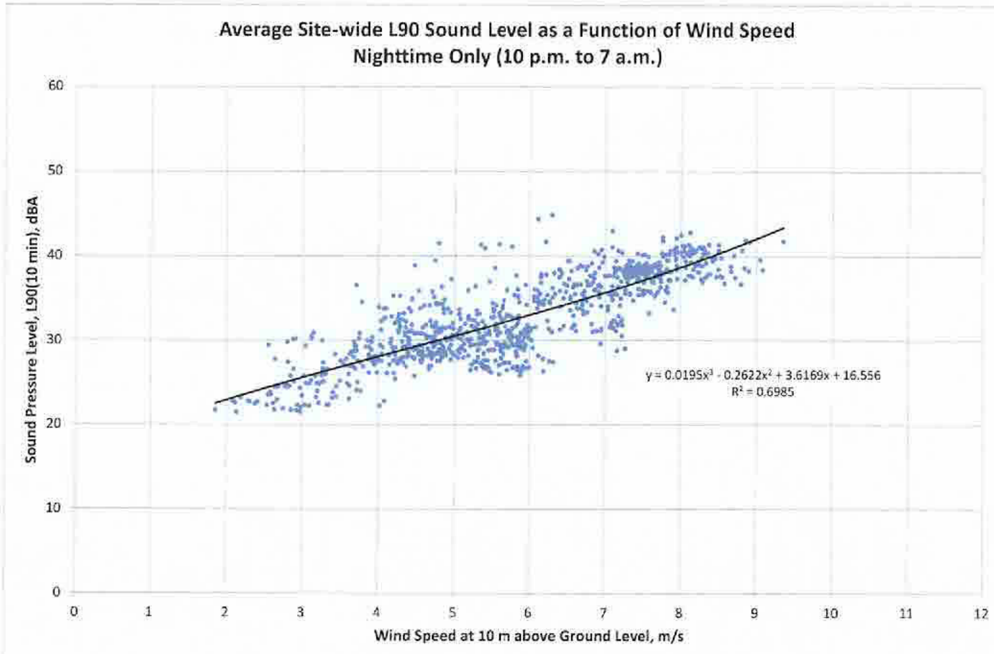

Figure 2.5.2.7

it would be interesting to see proportion of night time that wind is at each speed.

Overall mean gets at that, though.

Table 2.5.2.1 *Mean Daytime and Nighttime L90 Sound Levels as a Function of Wind Speed*

Wind Speed at 10 m, m/s	3	4	5	6	7	8	9
Mean Daytime L90, dBA	34	34	35	37	39	41	43
Mean Nighttime L90, dBA	26	28	31	33	36	39	42

3.0 PROJECT NOISE MODELING AND IMPACT ASSESSMENT

3.1 ASSESSMENT CRITERIA

In the absence of any specific local, State or federal noise regulations, the project's potential noise impact will be evaluated in accordance with (1) Ohio Power Siting Board (OPSB) precedent on other approved wind projects in the State that imposes a noise condition limiting the project sound level to no more than 5 dBA above the average nighttime Leq background level at non-participating residences and (2) the actual observed reaction to other comparable wind projects.

OPSB Precedent

As will be more fully discussed in Section 3.3, the average nighttime Leq background level can be interpreted as either a simple average or, since background levels are normally dependent on wind speed, as the average nighttime Leq sound level that occurs under "critical" wind conditions when project noise would theoretically be most prominent and audible relative to the background level.

In this instance, both approaches coincidentally lead to the same value of 39 dBA, so the effective OPSB noise limit would be a project sound level of 44 dBA at non-participating residences.

Recommended Design Goals Based on the Actual Reaction to Comparable Projects

First-hand experience measuring the sound emissions of newly completed wind projects very similar to this one indicates that the number of complaints or concerns about noise remains quite low at all project sound levels below 45 dBA and such a level is recommended as a design goal/regulatory limit for this or any wind project because it appears to balance the interests of all parties by generally protecting the public from unreasonable annoyance while not standing completely in the way of economic development. The rationale behind this conclusion, including a review of existing noise regulations pertaining to wind turbines, is detailed in a peer-reviewed article[2] written by the author and published in the *Noise Control Engineering Journal*. In brief, the article summarizes the observed reaction to the sound emissions from five wind turbine projects in rural farm communities (all very comparable to the Buckeye site) where extensive measurements were taken at all residences, whether participating or not, where complaints or even mild concerns about project noise had been reported to the project operator. Thus the total number of complaints was determined along with the actual project sound level at each location. Even though all of the projects involved in the study were subject to a 50 dBA noise limit and were found to produce sound levels above 45 dBA at a substantial number of residences, the total number of complaints was remarkably small compared to the total number of residences in the immediate project area (defined, in this case, as within 2000 ft. of a turbine). More specifically, the average number of complaints at all sound levels was 4% relative to the total population and, perhaps more importantly, only 2% for all residences exposed to mean sound levels below 45 dBA; hence the recommendation of 45 dBA as a design level that is associated with an ostensible acceptance rate of 98%. Since level essentially coincides with the OPSB noise standard of 44 dBA, 44 dBA will be considered the nominal impact threshold at non-participating residences for this project.

Another significant finding from the field survey of newly operational wind projects discussed above was that there were virtually no complaints (only 1 person at one of the five sites) below a project sound level of 40 dBA. Consequently, 40 dBA may be considered the approximate threshold for *any* substantial adverse noise impact and is suggested as an *ideal* design goal for new projects. Although desirable, such a level is not usually achievable at most wind projects in the Midwest or Eastern United States because project locations that are otherwise suitable in terms of transmission lines and wind resource are rarely unpopulated. Levels less than 40 dBA at the nearest residences are normally only seen at very remote sites. Nevertheless, contour maps will be developed to evaluate the potential exposure to sound levels of 40 dBA or more at this site.

Sound Impacts at Project Boundaries

The design criteria described above are considered appropriate for existing permanent residences where people actually are most of the time. At the boundaries of the project, or, more specifically, at the property lines of adjoining non-participating land parcels, a relatively low project sound level is generally unnecessary because no one is usually permanently present at the fringe of a land parcel, particularly at night, to be potentially affected by noise. Nevertheless, Rule 4906-17-08 *Social and Ecological Data*, Section (A)(2) "Noise", Part (b) of the Ohio Administrative Code (OAC) requires an evaluation of the operational sound levels expected at the nearest property boundaries to each turbine due to that turbine and to the cumulative effect of all other turbines in the project.

In order to carry out this evaluation a criterion of 50 dBA will be used as a nominal impact threshold at property lines. In the rare instances where property line noise limits have been imposed on wind turbine developments (based on our experience with dozens of other wind projects), an absolute noise limit of 50 dBA is typically used.

In summary, then, the thresholds for evaluating potential noise impacts from this project would consist of:

- 44 dBA - A relative increase of 5 dBA above the pre-existing average nighttime Leq background level at non-participating residences.
- 40 dBA - An absolute, *ideal* design goal largely defining the point at which complaints are possible but still extremely rare and unlikely irrespective of the background level. Applicable at residences.
- 50 dBA – At the boundaries of non-participating land parcels.

3.2 TURBINE SOUND LEVEL

The starting point for any wind turbine noise modeling study is the sound level, or more specifically, the sound power level of the turbine model that will be used in the project. Although several turbine models are being considered for the project, the Nordex N100 has been assumed for this analysis because it has the highest sound power level.

Overall Sound Power Level as a Function of Wind Speed

In this instance, input data for the Nordex N100/2500 turbine has been obtained from Nordex in the form of a set of five technical reports[3] giving the octave band sound power levels as a function of wind speed for normal operation (Mode 0) and for four low noise modes of operations (Mode 1 through 4) all determined from field measurements per IEC 61400-11 at the Bargeshagen site in Germany. The overall A-weighted sound power levels for Mode 0 as a function of wind speed are tabulated below.

Table 3.2.1 *Nordex N100/2500 Sound Power Level Data, Mode 0, 100 m Hub Height [Ref. 3]*

Wind Speed at 10 m, m/s	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Sound Power Level, Mode 0, dBA re 1 pW	97.0	99.0	101.5	105.0	106.0	106.0	106.0	106.0

The lower noise operating modes, Modes 1 through 4, progressively reduce these sound levels in roughly 1 dBA increments, such that in Mode 4 the maximum sound level is 102 dBA re 1 pW during high wind conditions. Operation in these modes reduces the electrical power output of the unit from a normal maximum of 2500 kW to 1750 kW in Mode 4.

Frequency Content and Tones

The detailed frequency spectrum in 1/3 octave bands associated with the maximum sound power level (first reached under 7 m/s wind conditions) is plotted in Figure 3.2.1. This data derives from a sound power level field test[4] per IEC 61400-11 at another site in Germany (Ravensburg) and shows that the frequency spectrum is smooth and does not have any tonal content.

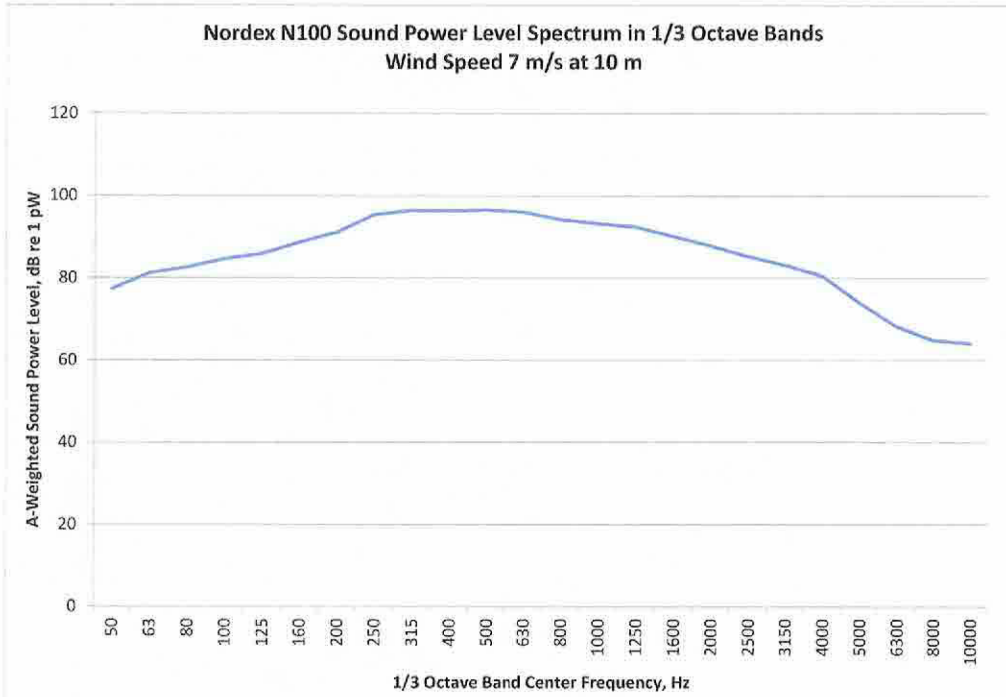

Figure 3.2.1 [From Ref. 4]

3.3 CRITICAL DESIGN LEVELS

From the field survey it was determined that the background sound level varies with wind speed; essentially increasing indefinitely. From Table 3.2.1 above it can be seen that the turbine sound level also varies with wind speed rising just after cut-in and then flattening off fairly quickly at a fixed maximum value irrespective of wind speed. The two quantities must be compared under the same wind conditions to be meaningful. For example, it would be incorrect to compare the maximum turbine sound level, which first occurs at a wind speed of 7 m/s (at 10 m), to a very low background sound level that might only exist on a calm night when the project would not be operating.

In terms of potential noise impacts the worst-case combination of background and turbine sound levels would occur at the wind speed where the background level is lowest relative to the turbine sound level – or, in other words, where the differential between the background level and turbine sound power level is greatest.

The following chart shows that this worst-case situation with respect to the nighttime Leq background level occurs at a wind speed of 6 m/s. During this particular wind condition project noise would theoretically be most prominent and audible relative to background masking noise. At higher wind speeds the background level continues to rise rapidly while the turbine sound level stays the same making the project progressively less audible under high wind conditions.

Table 3.3.1 *Critical Design Wind Speed*
Nordex N100 Sound Power Levels, Mode 0, and Nighttime Leq Background Levels vs. Wind Speed

Wind Speed at 10 m, m/s	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Max. Design Turbine Sound Power Level, dB re 1 pW	97.0	99.0	101.5	**105.0**	106.0	106.0	106.0	106.0
Mean Nighttime Leq Background Sound Level, dBA	33.2	35.2	37.1	**39.0**	40.9	42.9	44.8	46.7
Differential, dB	63.8	63.8	64.4	**66.0**	65.1	63.1	61.2	59.3

Based on the maximum differential of 66 dB, the critical design conditions for this project would therefore be a turbine sound power level of 105 dBA re 1 pW and a background sound level of 39 dBA. Coincidentally, the average nighttime Leq value, irrespective of wind speed, is also 39 dBA (see Table 2.5.1.1 above). Based on this sound level the nominal OPSB threshold for significant noise impacts (nighttime Leq + 5 dBA) would be a project sound level of **44 dBA**.

The frequency content of the turbine sound power level at 6 m/s is given below in Table 3.3.2 per Nordex.

Table 3.3.2 *Nordex N100 Mode 0Design Sound Power Level Spectrum for Modeling, 100 m Hub Height*

Octave Band Center Frequency, Hz	**31.5**	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**	**dBA**
A-wtd Sound Power Level, dBA re 1 pW	*78**	84.8	91.0	98.3	100.4	99.2	94.3	90.2	91.4	**105**

** Not reported by Nordex - estimated value.*

Note that the low end of the frequency spectrum is accounted for using an estimated value in the 31.5 Hz octave band, since no value is given by Nordex. This estimate is based on the essentially universal trend of a rapidly falling A-weighted spectrum in the lower frequency bands, as illustrated in Figure 3.3.1, which is a compilation by Petersen[6] of the measured sound power level spectra of 78 wind turbines ranging in output from 75 kW to 3.6 MW.

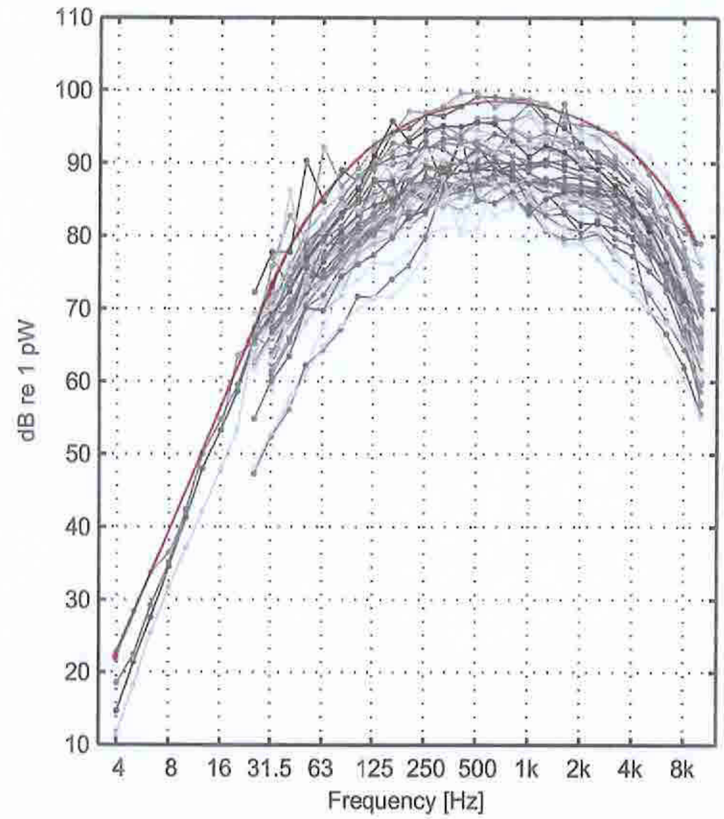

Figure 3.3.1 *Wind Turbine Sound Power Level Spectra, 78 Turbines Ranging in Output from 75 kW to 3.6 MW [Ref. 6]*

The model input sound power level is actually the octave band frequency spectrum given in Table 3.3.2 rather than the overall A-weighted sound level. Consequently, the model considers the low frequency emissions from the turbines and uses this frequency spectrum to calculate frequency dependent propagation losses, such ground and air absorption.

It is important to note in this context that a sound *power* level is not the same thing as a sound *pressure* level, which is the familiar quantity measured by instruments and perceived by the ear. A power level is a largely intangible, calculated measure, expressed in terms of Watts, that is primarily used for acoustical modeling and design analyses. It is a function of both the sound pressure level produced by a source at a particular distance and the effective radiating area or physical size of the source. The basic mathematical relationship between power and pressure is as follows:

$$Lw = Lp + 10 \log (S), \text{ dB re 1 pW}$$

Where,

Lw = Sound Power Level, dB re 1 pW
Lp = Sound Pressure Level, dB re 10 μPa
S = The effective radiating surface area at the point of the pressure level measurement, m^2

In general, the ostensible magnitude of a sound power level is always considerably higher than the sound pressure level near a source because of the area term. For example, the sound *pressure* level at 100 m from a wind turbine might be about 53 dBA and the area term at this distance (10 log $(4\pi 100^2)$) would be 51 dBA with a resulting total *power* level of 104 dBA re 1 pW (the units of power levels are always denoted as decibels with reference to 1 picoWatt, or 10^{-12} W).

The fundamental purpose of a power level is to provide a means of calculating the sound pressure level of a source at any distance; hence its importance to noise modeling. It is *not* the sound pressure level at the hub or near the unit, as is sometimes believed.

3.4 NOISE MODELING METHODOLOGY

Using the Mode 0 sound power level spectrum in Table 3.3.2 above for most units and lower low noise mode spectra for 16 specific turbines, project sound levels were calculated for 6 m/s critical wind conditions using the Cadna/A®, ver. 4.2 noise modeling program developed by DataKustik, GmbH (Munich). This software enables the project and its surroundings, including terrain features, to be realistically modeled in three-dimensions.

3.4.1 *Modeling Standards and Uncertainty*

Cadna/A® modeling software is essentially an automated version of ISO 9613-2 *Acoustics – Attenuation of sound during propagation outdoors*[5], which is the primary worldwide standard for sound predictions and modeling. It should be noted that ISO 9613-2 was not written with wind turbines in mind and its applicability to elevated sources (in this case 100 m) and long propagation distances is occasionally questioned. Table 5 in the standard gives an estimated uncertainty of +/- 3 dBA 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 or 100 m high sources; however, what this actually means is that there is simply no specific uncertainty range given for such heights, not that the standard is inappropriate. Nor is there another standard that is more suitable to this situation. The principal sound propagation loss in wind turbine modeling is simple spherical spreading of the sound wave, which is an axiomatic law of physics that has no dependence on the specific point of origin or its height above ground level. In fact, as will be shown below, comparisons between predictions and measurements of wind turbine noise at many positions at many sites indicate that ISO 9613-2 is a perfectly valid methodology for the prediction of wind turbine sound levels; i.e. the model predictions agree quite well with the mean measured sound level.

This is true despite the fact ISO 9613-2 was never designed to consider the short-term atmospheric conditions to which wind turbines are subject - such as 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 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 as a function of wind speed over a two week period compared to ISO 9613-2 predictions at various integer wind speeds. The model predictions tend to agree with the central trend line or mean measured sound level. 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.

Most actual measurements are within 5dB; at lower wind speeds (below5m/s) more scatter above that, some to 10dB; few to 15.

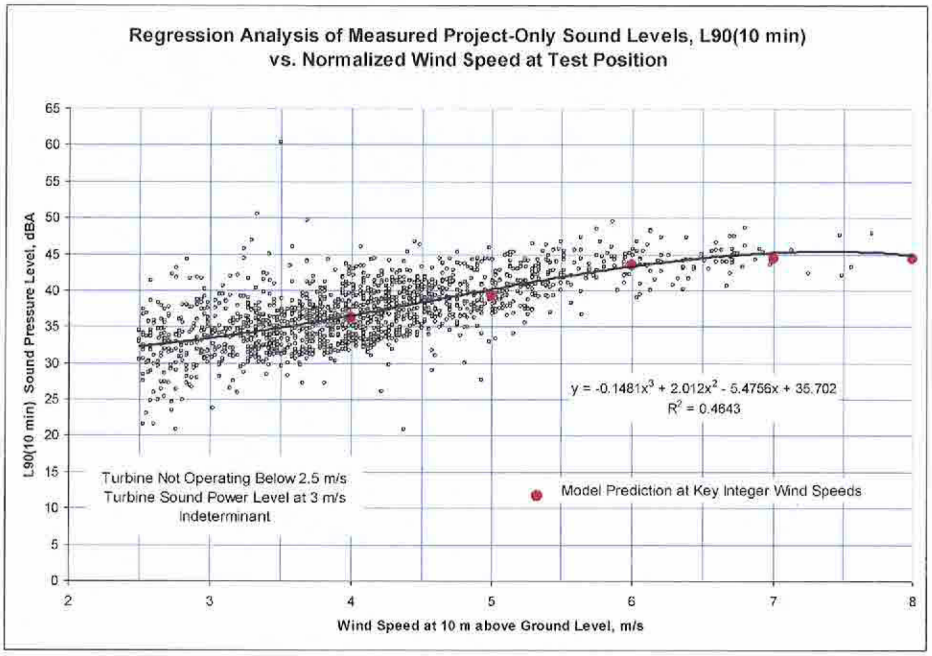

Figure 3.4.1.1 *Comparison Between Measured and Predicted Sound Levels at a Typical Wind Farm* – ***As a Function of Wind Speed***

Figure 3.4.1.2 below also illustrates the typical correlation between measured and modeled levels - this time as a function of time.

almost always within 1-3dB; rare peaks to 5dB.

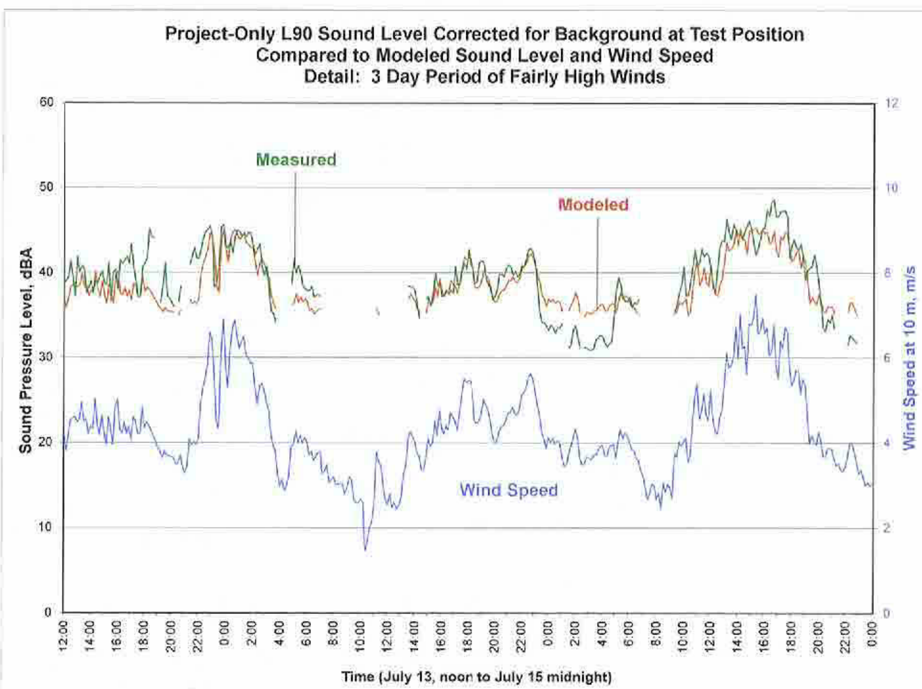

Figure 3.4.1.2 *Comparison Between Measured and Predicted Sound Levels at a Typical Wind Farm* – ***As a Function of Time***

or, it would more closely reflect measured worst-case situations, rather than the mean

Differences occur because the modeled performance (orange trace) is dependent purely on wind speed while the actual sound level (green trace) varies due to both wind speed and all other atmospheric phenomena, such as wind and thermal gradients, cloud cover, stability, etc. – effects that don't lend themselves in any kind of practical way to precise calculation. Nevertheless, the graphic shows that the direct application of ISO 9613-2 yields a very reasonable result corresponding to the mean sound level of the project over time. If a positive uncertainty factor of, say, 3 or 4 dBA were added to the prediction to cover possible error in the turbine source level or modeling methodology the model results would consistently overestimate the sound emissions from the project and suggest a substantially higher noise impact than is, in fact, the case.

3.4.2 *Modeling Assumptions*

Each turbine is represented as a point noise source at a height of 100 m above the local ground surface.

Although there are a few low hills in the study area, they are not substantial enough to affect the sound propagation from turbines to far off points; consequently, flat terrain has been assumed in the model. Experience modeling many types of wind projects indicates that only fairly dramatic, mountainous terrain has a meaningful impact on sound propagation.

A somewhat conservative ground absorption coefficient of 0.5 has been assumed in the model since all of the intervening ground between the turbines and potentially sensitive receptors is either open fields or woods, both of which are acoustically "soft". The ground absorption coefficient (from ISO 9613-2) ranges from 0 for water or hard concrete surfaces to 1 for absorptive surfaces such as farm fields, woods or sand. Consequently, a ground absorption coefficient on the order of 0.8 or 0.9 could be justified here; however, a value of 0.5 has been used largely because such a value leads to agreement between predicted and measured level in rural farm country similar to the Buckeye site (as in the figures in Section 3.4.1 above, for instance).

The downwind sound level – the value measured in the IEC sound power level test - is assumed to exist in all directions simultaneously. This approach essentially represents a hypothetical situation where the wind is blowing from all directions at the same time making the predictions valid for any given wind direction.

In general, then, the model represents the following conditions at any given receptor point:

- **Observer Outside** – the plotted sound levels occur outside; sound levels inside of any dwelling will be at least 15 dBA lower and probably much more (a noise reduction of 30 dBA or more is not uncommon).
- **Low Ground Porosity** – Open fields would normally be considered somewhat more acoustically absorptive than assumed in the model.
- **Downwind Sound Level** – the downwind sound level measured per IEC 61400-11 is assumed to exist in all directions from every unit.

3.5 Model Results

3.5.1 *Buckeye II Project*

44 dBA Threshold

The overall results from the model are shown in **Plot 1**, which illustrates the mean sound levels attributable solely to the Buckeye II Project that are expected to occur under the conditions described above in Section 3.4. For clarity with respect to OPSB noise limit, the figure shows only those residences and structures on non-participating land parcels.

Sound levels have been mapped out to the nominal OPSB design goal of 44 dBA, which, as discussed in Sections 3.1 and 3.3, represents the point at which the project's sound emissions would be 5 dBA higher than the average nighttime Leq sound level. The figure shows that all non-participating homes are located outside of this threshold and would experience lower sound levels.

This outcome would not be the case if all the units were operating normally in what is referred to as Mode 0, but rather requires mitigation on 16 units, shown in yellow in the figure, in the form of lower noise operating modes – at least during the night when the 44 dBA criterion is relevant. This mitigation measure is assumed for all subsequent plots and analyses.

As developed in Table 3.3.1 the plot represents the mean sound emissions from the project during critical 6 m/s wind conditions when the turbines are most apt to be audible above the natural background level. Sound emissions from the project will be substantially lower and less audible at lower wind speeds, since the turbine sound power level drops rapidly below 6 m/s (see Table 3.2.1). At higher wind speeds natural background noise will progressively mask operational noise as it continues to increase indefinitely while the turbine sound level only increases by a largely inconsequential 1 dBA and then remains constant.

The choice of 6m/s is logical; yet I also wonder about that higher scatter of >5dB over mean at lower wind speeds (observed on a different project; see Fig 2.5.2.7, p28 above)

This plot represents nighttime conditions in the sense that the threshold for potential impacts is based on the nighttime background level of 39 dBA. During daytime conditions the Leq background sound level during 6 m/s wind conditions is substantially higher at 45 dBA (see Table 2.5.1.2), which would move the impact threshold to 50 dBA. Since the turbine sound level is not dependent on time of day the nighttime conditions in Plot 1 represent a worst-case analysis.

40 dBA Threshold

In **Plot 2** the sound emissions from the Buckeye II project, assuming noise mitigation is in effect on 16 of the units, have been mapped out to 40 dBA, which may be regarded as the threshold below which complaints are extremely rare irrespective of the background sound level. Where sound levels above 40 dBA exist at non-participating residences the possibility of complaints cannot be ruled out and, based on the study alluded to in Section 3.1, a 2% rate of complaint might expected in the region between 40 and 44 dBA.

It is important to note in this context that 40 dBA is not necessarily the threshold of audibility. Because the near-minimum, L90 background levels were found to be fairly low during low to moderate wind conditions, the turbines will probably be audible from time to time, depending on wind and weather conditions, for quite some distance - perhaps on the order of one mile or more at times. Wind turbine sound emissions are highly variable with time and will fluctuate above and below the mean predicted levels shown in the graphics due to natural irregularities in wind flow and other factors. Wind turbines can also produce a periodic swishing sound, known as amplitude modulation, that can become pronounced during periods of high wind shear (high winds aloft and lower winds near the surface) and/or during stable atmospheric conditions (higher temperatures aloft and cooler temperatures near the surface). This distinctive sound, when it occurs – and it does not always occur – makes turbine noise much more noticeable than if it were steady in character. Mechanical noise from cooling fans in the nacelle can also be noticeable at short distances from some turbine models.

Consequently, the potential for annoyance from wind turbine noise goes beyond the A-weighted sound level to a certain extent but it is important to realize that the 40 dBA sound level suggested as a threshold for significant impacts and as an approximate cut off point for complaints is based on the mean measured sound levels at a number of wind projects, which were all just as prone to amplitude modulation, nighttime effects and nacelle noise as any other site.

50 dBA Threshold at Property Lines

Rule 4906-17-08 *Social and Ecological Data*, Section (A)(2) "Noise", Part (b) of the Ohio Administrative Code (OAC) requires an evaluation of the operational sound levels expected at the nearest property boundaries to each turbine due to that turbine and to the cumulative effect of all other turbines in the project. The maximum cumulative sound level at non-participating land parcels is mapped out to the property line design goal of 50 dBA in **Plot 3**. This figure illustrates that the 50 dBA sound contour occurs within the participating land parcels in all but four instances where units 71, 88, 127 and 133 are sited fairly close to the edges of their respective parcels. In these cases, sound levels slightly in excess of 50 dBA are expected in the corners of certain non-participating parcels. However, no substantive adverse impact is anticipated from this.

3.5.2 *Cumulative Sound Emissions from Both the Buckeye I and II Projects Operating Together*

44 dBA Threshold

Plot 4 shows the cumulative sound levels that would be possible if both the Buckeye I and II projects were built. The sound levels from each project and their cumulative total are all plotted out to the OPSB design goal of 44 dBA. The light green areas represent the Buckeye II turbines, the blue areas represent the Buckeye I units and the reddish area represents the region where the cumulative sound levels would be above 44 dBA with both projects operating together.

In general, the combined sound emissions from both projects would have an ostensible effect on the community that is similar that of Buckeye II operating by itself in the sense that all of the non-participating homes remain outside the 44 dBA outer contour. This outcome is based on operating 16 of the 56 units in low noise operating modes.

40 dBA Threshold

Plot 5 shows the cumulative sound levels from each project and their combined total plotted out to 40 dBA. In this example, the pink area represents the region where mean sound levels above 40 dBA can be expected with both projects operating. Based on Reference 4, a 2% rate of complaint (statistically speaking) can be anticipated relative to the total number of homes within the 40 dBA contour.

50 dBA Threshold

The maximum cumulative sound level is mapped out to the property line design goal of 50 dBA in **Plot 6**. This figure illustrates that the 50 dBA sound contour occurs within the participating land parcels in all but a few instances where units are sited fairly close to the edges of their respective parcels. In these cases, sound levels slightly in excess of 50 dBA are expected near the edges of certain non-participating parcels. However, no substantive adverse impact is anticipated from this.

3.6 LOW FREQUENCY NOISE

Modern wind turbines of the type proposed for this project do not generate low frequency or infrasonic noise to any significant extent and no impact of any kind, whether related to annoyance or health, is expected from this. Early wind turbines with the blades downwind of the support tower were prone to producing a periodic thumping noise each time a blade passed the tower wake - but this particular effect no longer exists with the upwind blade arrangement used today.

Concerns about excessive low frequency noise from proposed wind farms are commonly voiced but they have apparently grown out of misinformation or anecdote without any basis in fact. 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[6,7,8,9,10] and probably arose from a confusion between periodic amplitude modulation noise (swishing) 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.

When amplitude modulation 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 sound 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.

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 almost 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[11] 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 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[12]. Figure 3.6.1 below shows, as an example, the frequency spectra all the way down to 0.4 Hz (in the extreme infrasound region of the spectrum) measured at a location surrounded by 12 Vestas V90 turbines with the project operating and then a few minutes later with the turbines shut down. The wind speed at the microphone was approximately 5 to 6 m/s during both measurements.

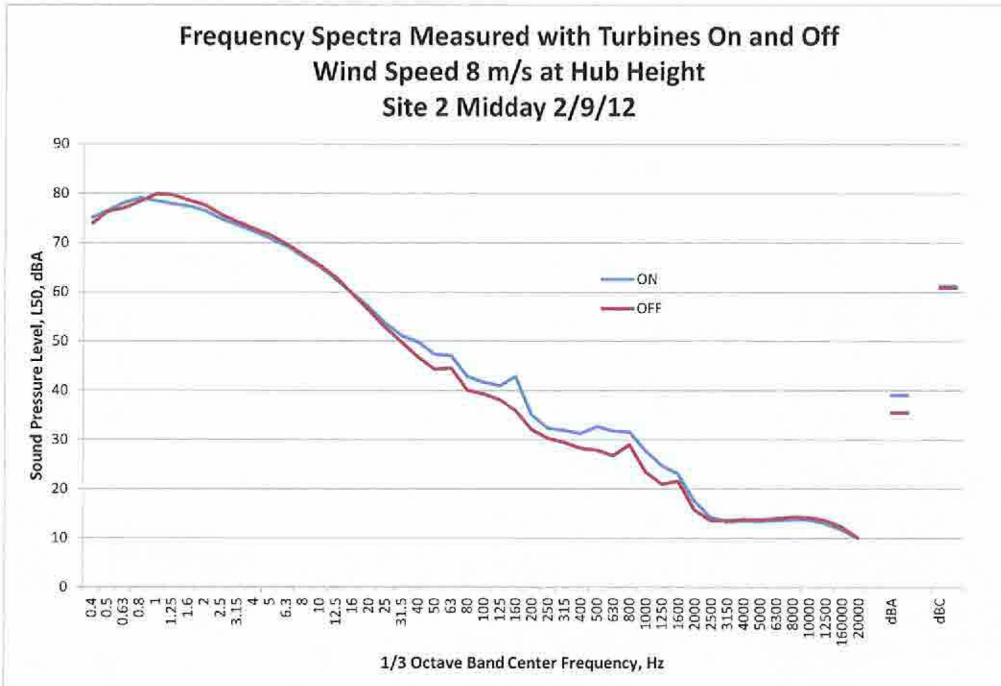

Figure 3.6.1

The salient point is that the two measurements show essentially the same values in the low frequencies (below about 20 Hz). Since there was clearly no source of low frequency noise present in the background measurement (taken in a remote farm field with all the surrounding turbines deliberately idled), the low frequency levels - in both measurements – simply represent self-generated distortion and are not the actual sound emissions of anything.

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

Figure 3.6.1 also illustrates another important point concerning C-weighted sound levels; namely, that the C-weighted levels in both measurements are nearly identical at 61 dBC each. 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 3.6.2 shows this graphically for an example measurement at 1000 ft. from a wind turbine.

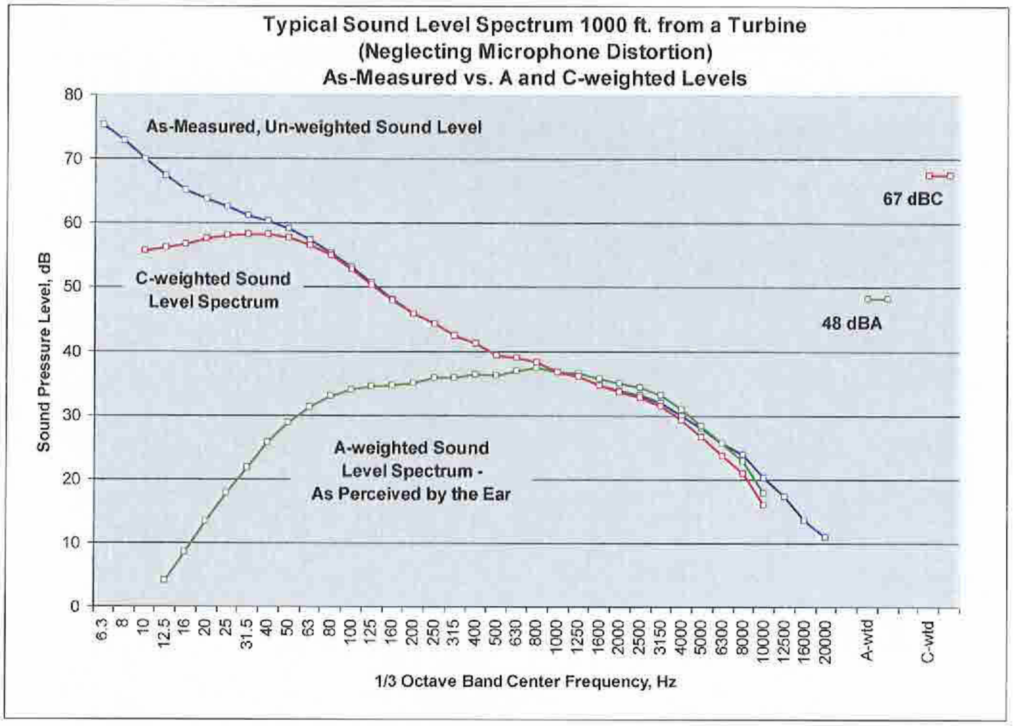

Figure 3.6.2

The as-measured sound level, including wind-induced distortion, 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 generally matches the way it is subjectively perceived by the human ear, which is relatively insensitive to low frequency sounds. The A-weighted spectrum in Figure 3.6.2 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).

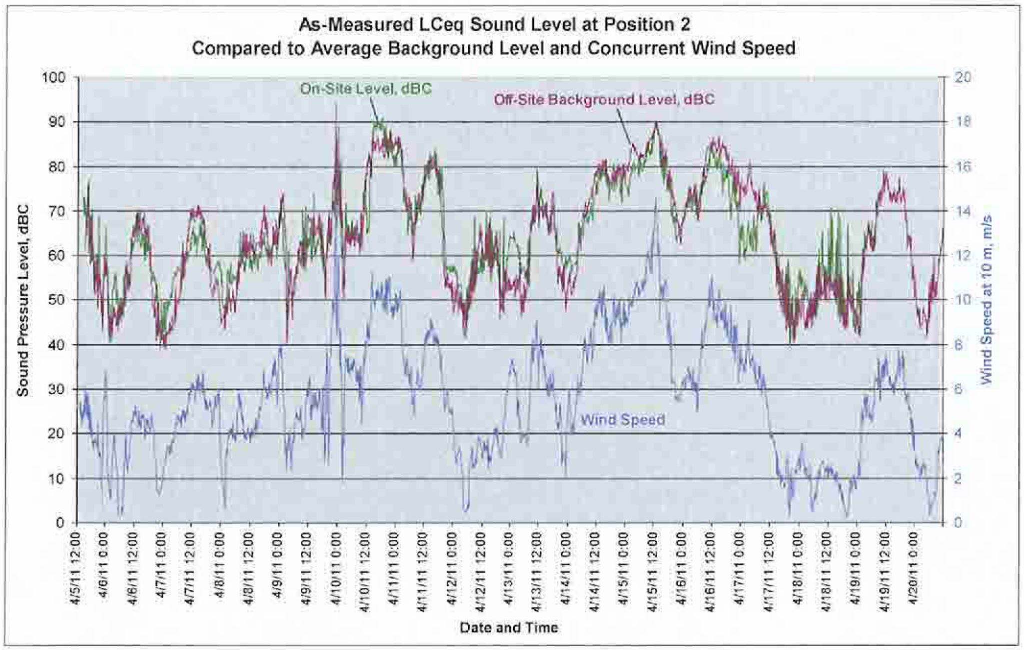

Figure 3.6.3

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.

3.7 CONSTRUCTION NOISE

Noise from construction activities associated with the project may temporarily constitute a moderate, unavoidable impact at some homes in the study area fairly close to turbine sites or adjacent to trenching or road building operations. Assessing and quantifying these impacts is somewhat difficult because construction activities will constantly be moving from place to place around the site leading to highly variable impacts with time at any given point.

In general, the maximum potential noise impact at any single residence or property line might be analogous to a few days to a few weeks of repair or repaving work occurring on a nearby road or to the sound of machinery operating on a nearby farm. More commonly (at houses that are some distance away), the sounds from project construction are likely to be faintly perceived as the far off noise of diesel-powered earthmoving equipment characterized by such things as irregular engine revs, back up alarms, gravel dumping and the clanking of metal tracks.

Construction of the project is anticipated to consist of several principal activities:

- Access road construction and electrical tie-in line trenching
- Site preparation and foundation installation at each turbine site
- Material and subassembly delivery
- Erection

State regulations - OAC 4906-17-08 (2)(a) - require a description of construction noise generated by dynamiting activities and pile driving; however, the use of explosives and the need to drive piles is not anticipated for this project. However, in the unlikely event that a need did arise during construction, such activities would occur intermittently and only for limited periods of time. The location of these activities, if they were needed, would most likely be confined to certain areas of the site and would not be widespread in their application.

The individual pieces of equipment likely to be used for each of these phases and their typical sound levels as reported in the *Power Plant Construction Noise Guide* (Empire State Electric Energy Research Corp.[13]) are shown below in Table 3.7.1. It should be noted that the reference used for equipment sound levels is quite old, dating back to 1977, and that the levels in it are roughly 5 dBA higher than the values that can be found in more recent references, such as from the FHWA[14] for modern construction equipment. These older, higher values have been deliberately used purely to be conservative. Also shown are the maximum total sound levels that might temporarily occur at a distance of 1000 ft. and the distance at which construction sound levels are likely to become inconsequential (at a level of about 35 dBA).

Table 3.7.1 *Construction Equipment Sound Levels by Phase*

Equipment Description	Typ. Sound Level at 50 ft., dBA [Ref. 13]	Est. Maximum Total Level at 50 ft. per Phase, dBA*	Max. Sound Level at 1000 ft., dBA	Distance at which Construction Noise is likely to fall to 35 dBA, ft.
Earth Moving, Road Construction and Electrical Line Trenching				
Dozer, 250-700 hp	88	92	63	7600
Front End Loader, 300-750 hp	88			
Grader, 13-16 ft. blade	85			
Excavator	86			
Foundation Work, Concrete Pouring				
Piling Auger	88	88	59	5900
Concrete Pump, 150 cu yd/hr	84			
Material and Subassembly Delivery				
Off Hwy Hauler, 115 ton	90	90	61	6700
Flatbed Truck	87			
Erection				
Mobile Crane, 75 ton	85	85	56	4800

* Not all vehicles are likely to be in simultaneous operation. Maximum level represents the highest level realistically likely at any given time.

What the values in this table generally indicate is that, depending on the particular activity, sounds from construction equipment are likely to be at least intermittently audible at distances of up to about 1.5 miles. At the very worst, however, sound levels ranging from 56 to 63 dBA might temporarily occur over several weeks at the nearest homes to turbine construction sites, very roughly 1000 ft. away. Such levels would not generally be considered acceptable on a permanent basis or outside of normal daytime working hours (when all project construction is planned), but as a temporary, daytime occurrence construction noise of this magnitude may go unnoticed by many in the area. For others, project construction noise may be an unavoidable but temporary disturbance.

Temporary daytime sound levels on the order of 80 dBA are possible at non-participating property lines where trenching or road work occurs very close to parcel boundaries. Sound levels in vicinity of 70 dBA are possible at property lines within several hundred feet of turbine sites.

Noise from the very small amount of daily truck traffic to and from the current site(s) of construction should be negligible in magnitude relative to normal traffic levels and temporary in duration at any given location.

4.0 CONCLUSIONS

A field survey of existing sound levels throughout the proposed Buckeye II Project site area was carried out to determine how much natural masking sound there might be at residences in the vicinity of the project and how it might affect the perceptibility of sound emissions from the project.

In general, over an 18 day survey period, the equivalent energy average (Leq) and residual (L90) sound levels were measured continuously day and night at 10 locations distributed over the study area near residences with the maximum potential exposure to the proposed turbines. Over 2500 10-minute samples were collected at each location.

Since the background sound level at night is of the most relevance to potential disturbance from wind turbine noise, the data analysis focused primarily on the nighttime (10 p.m. to 7 a.m.) sound levels. Moreover, the Ohio Power Siting Board (OPSB) has previously approved a noise standard for other wind projects in the state, which limits the sound emissions due to wind projects to no more than 5 dBA above the average nighttime Leq sound level.

In this instance, the average daytime and nighttime Leq sound levels measured at all positions irrespective of wind speed were found to be 45 and 39 dBA, respectively. A critical wind speed analysis was also performed on the nighttime Leq data correlating it to wind speed and determining the circumstances under which project noise would be most audible. This analysis indicated that the critical design conditions would occur during 6 m/s wind conditions when the mean nighttime Leq also happened to be 39 dBA. Therefore 39 dBA has been taken as the baseline nighttime background sound level upon which to calculate the 5 dBA increase permitted by the OPSB. The daytime and nighttime Leq sound levels (measured at 3 ft. above ground level) are tabulated below as a function of wind speed for reference.

Table 4.0.1 *Mean Daytime and Nighttime Leq Sound Levels as a Function of Wind Speed*

Wind Speed at 10 m, m/s	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Mean Daytime Leq, dBA	42	43	44	45	46	47	48
Mean Nighttime Leq, dBA	33	35	37	39	41	43	45

Based on these results, first-hand experience observing the actual reaction to newly operational wind projects that are very comparable to this one and OAC Rule 4906-17-08, the following evaluation thresholds were developed:

- A relative design goal of **44 dBA** at non-participating residences per OPSB precedent; i.e. an allowable increase of 5 dBA over the average nighttime Leq sound level (39 dBA).

- A recommended regulatory limit of 45 dBA at non-participating residences based on the very limited adverse response to wind projects that has been observed wherever the mean project sound level is less than 45 dBA at residences. Note that the 44 dBA criterion above takes precedence over this suggested limit.

- An *ideal* design goal of **40 dBA** is also considered in the modeling study as the point where little or no adverse reaction can largely be expected irrespective of the background sound level. This threshold level derives from the same study alluded to immediately above with reference to the recommended regulatory limit of 45 dBA.

- A design goal of **50 dBA**, applicable at the boundaries of non-participating land parcels, has been adopted in order to carry out a quantitative assessment of the operational noise provisions in OAC Rule 4906-17-08.

The sound emissions from the project, using the turbine sound power level associated with critical design conditions (6 m/s winds), were modeled and mapped over the site area in accordance with appropriate standards representing typical or normal atmospheric conditions – with the understanding that project sound levels will vary above and below the mean predicted level with changing atmospheric conditions. Comparisons between modeled sound levels and the levels actually measured at operating wind projects, as shown in several examples, indicate that ISO 9613-2 is perfectly adequate for predicting the mean project sound level.

The modeling analysis of the Buckeye II project operating alone indicates that the project will meet the primary design goal, the OSPB (nighttime Leq + 5 dBA) noise limit of 44 dBA, at all non-participating residences. This performance requires noise mitigation on 16 of the 56 units, which will need to be operated in one of several low noise modes at least during the nighttime hours. This mitigation measure is assumed for all further analyses.

The secondary, ideal design goal of 40 dBA will be satisfied at the vast majority of non-participating residences in the study area but not at all. A substantial number of non-participating homes are predicted to see mean project sound levels in the 40 to 43 dBA range. For projects such as this in similar settings, it is not the least bit unusual for this ideal design goal to be exceeded, but, based on the observed reaction at comparable projects, the possibility of complaints is likely from a small fraction (approximately 2%) of those residents where mean sound levels between 40 and 45 dBA are expected to occur.

An evaluation of property line sound levels indicates that the assumed design goal of 50 dBA, based on the regulatory limit that is typically adopted in the rare instances when such a restriction is imposed on wind projects, will be met in all but a handful of instances where mean project sound levels in the 50 to 52 dBA range might be expected near the edges of adjoining parcels.

Cumulative noise impacts were also evaluated to model the sound levels that would be possible if both the Buckeye I and II projects were built. In general, the combined sound emissions from both projects would have an ostensible effect on the community that is similar to that of Buckeye II operating by itself, in the sense that all non-participating residences remain outside of the 44 dBA sound contour (the nominal OPSB design limit). As with the initial case mentioned above, 16 of the Buckeye II turbines would need to be operated in low noise mode to achieve this result. Low noise operation is not required from any of the Buckeye I turbines to meet the OPSB noise standard.