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Assessing wind turbines against relative noise standards

Kevin M. Hathaway^a & Kenneth Kaliski^b

Resource Systems Group, Inc.
55 Railroad Row
White River Junction, VT 05001
USA

ABSTRACT

Some community noise standards are “relative”, meaning that they limit noise from a source to a certain decibel level above the ambient level. While this may be predicted with some certainty for fixed industrial sources in urban areas, wind turbines present a unique challenge. First, wind turbine noise emissions vary by wind speed, and second, background ambient noise levels also vary – both due to anthropogenic factors, and in more rural areas, due to wind speed. Thus the standard by which the wind turbine is assessed against is constantly changing. This paper presents a method to determine the probability of exceedences of a relative noise standard given the ambient and wind turbine noise levels as functions of wind speed. It applies this method to a proposed wind turbine project in the United States. The findings show that it is difficult, if not impossible, to forecast with 100% certainty that exceedences of the noise standard will not take place. This calls into question the appropriateness of relative noise standards for variable noise sources operating in rural areas, such as wind turbines.

1 INTRODUCTION

Despite significant improvements in reducing mechanical noise from wind turbines over the last decade [1], the development of wind energy continues to create highly contested community discussions about their noise impacts. Technical experts are commonly needed to quantify these impacts, requiring background sound level monitoring, propagation modeling, technical reports and public testimony. This task for acoustics professionals can be made particularly difficult if the applicable noise standards are poorly written or complicated to assess. Some noise guidelines quantify violations in relation to the pre-development ambient sound levels. As an example, one U.S state’s noise policy determines a source of noise to be in noncompliance with their regulation if that source:

- 1) Increases the broadband sound level by more than 10 dB(A) above ambient (L_{90}), or
- 2) Produces a “pure tone” condition – when any octave band center frequency sound pressure level exceeds the two adjacent center frequency sound pressure levels by 3 decibels or more.

Analysis for a wind energy project relating to Part 1 above presents particular challenges, since as the ambient level rises and falls with both anthropogenic (e.g. traffic) and biogenic factors (e.g. wind speed, wind direction, and stability), the standard level also changes. At the same time, the noise generated from the wind turbines is affected by many of the same biogenic factors.

^a Email address: khathaway@rsginc.com

^b Email address: kkaliski@rsginc.com

Effectively, at each given wind speed, wind direction, and stability, the likelihood that turbine noise will be in noncompliance at a particular property would need to be evaluated individually. Natural variations in ambient sound levels make any prediction efforts less certain.

This paper presents the use of common statistical tools in combination with sound level monitoring and sound propagation modeling as a method for such an evaluation.

2 BACKGROUND SOUND LEVEL MONITORING

Background sound level monitoring was conducted at three residential locations near a proposed wind energy project. Figure 1 depicts the study area with the proposed turbine locations and the three residential background monitoring stations. ANSI Type I and Type II sound level meters were used for the background monitoring. All meters were enclosed in an environmental kit and attached to an external microphone via a 2 meter cable. Each microphone was fitted with a 2 inch weather-proof wind screen. The microphone height was approximately 1.2 meters at each location. The monitors were set to record 10-second L_{Aeq} , L_{AS10} , L_{AS50} , L_{AS90} , L_{ASmin} , and L_{ASmax} . All of the sound level monitors were calibrated before and after the measurement period and were found to have negligible drift.

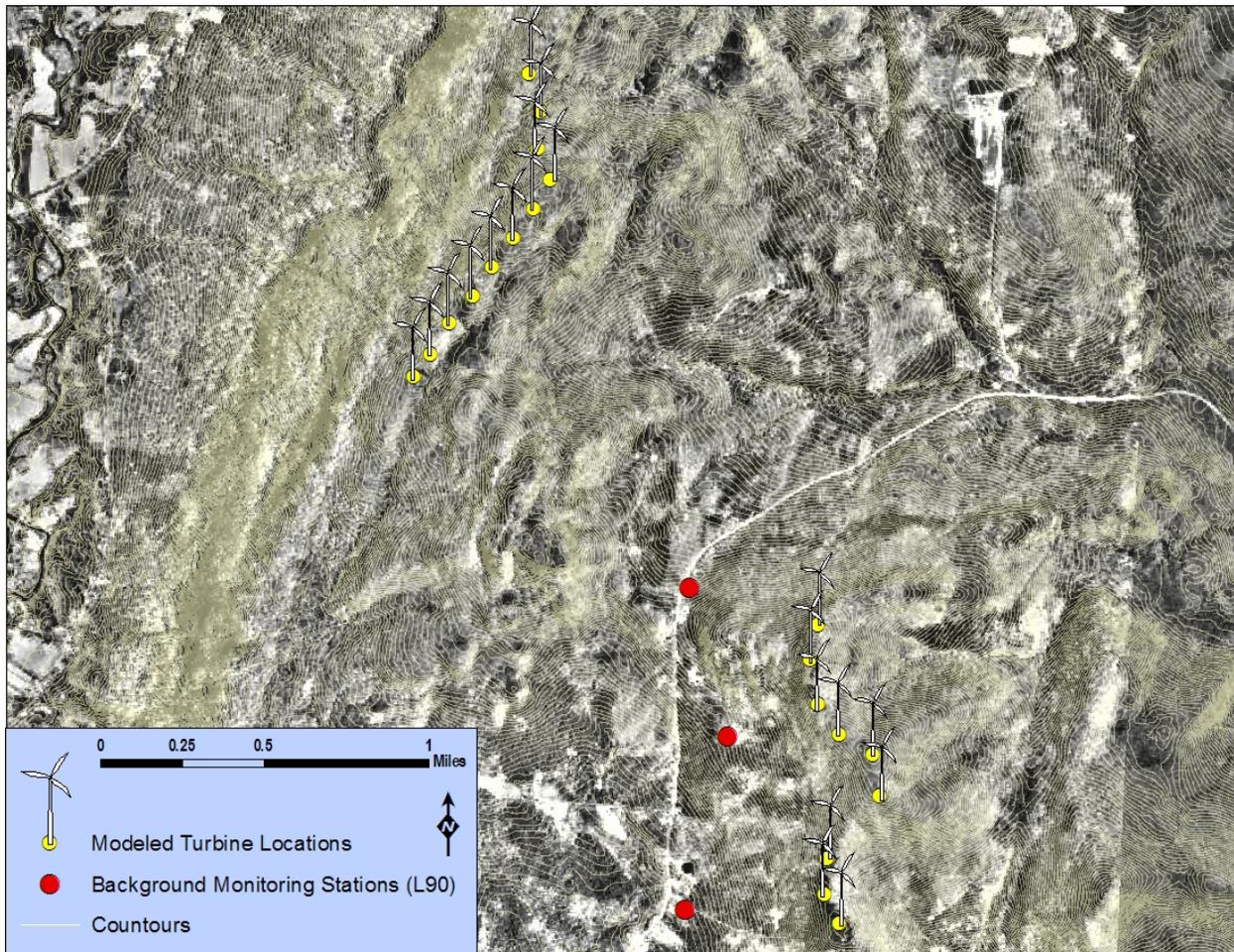


Figure 1: Map of Study Area

At the same time, meteorological data from 30 meter and 40 meter towers at the site of the proposed turbines along a ridgeline were summarized and time-matched to the sound level data. These data included the average temperature, and average, minimum, maximum, and standard deviation of the wind speed, and wind direction for each 10-minute period during the monitoring.

We also collected precipitation data from a nearby weather station. This was needed to separate the L_{90} s for periods without rain, as the rain can increase background levels significantly.

3 TURBINE NOISE PROPAGATION MODELING

Noise propagation modeling was conducted using the CADNA/A acoustical model, and included appropriate terrain and site detail for the area. In this case, we specified 96 modeling scenarios to cover six wind speeds, eight wind directions, and two atmospheric stability classes. In all, one can consider:

- *wind speeds* – 5, 6, 7, 8, 9, and 10 m/s, at hub-height, as appropriate for the chosen stability class
- *wind directions* – N, NE, E, SE, S, SW, W, and NW
- *stability classes* – B through E (*Based on a turbine cut-in speed of 3 m/s measured at a 10 meter height*)

Source sound power data from the turbine manufacturer were entered for each wind speed modeled. Table 1 summarizes the sounds powers assumed.

Table 1: Turbine Sound Power Levels (in dBA) for Modeling

Wind Speed	1/1 Octave Band Center Frequency (Hz)										
	31.5	63	125	250	500	1000	2000	4000	8000	L_{W-A}	L_{W-Z}
5 m/s	62.9	72.7	85.4	85.9	86.1	82.1	82.4	80.4	68.7	92.1	106.3
6 m/s	68.2	78.3	88.9	91.4	92.1	88.1	88.1	86.4	76.6	97.5	111.2
7 m/s	73.3	84.0	89.6	94.1	95.9	92.9	91.9	90.2	80.4	100.9	115.6
8 m/s	74.3	84.4	90.7	95.2	96.6	93.9	93.6	92.9	83.2	102.1	116.4
9 m/s	73.4	83.7	91.1	96.4	96.2	93.6	93.9	93.7	84.3	102.4	115.9
10 m/s	72.2	82.5	91.0	96.7	96.0	93.9	94.6	94.6	84.9	102.7	115.0

4 STATISTICAL MODELING

Log-transformed linear regression using least-squares (SPSS®, V 12.0.1) was performed to estimate the effect of wind speed on background L_{90} sound levels at the residential monitoring stations. The resulting model helped predict future mean sound levels for the six wind speeds considered. In reality, we know that ambient sound levels are most accurately specified with multivariate models, since other sources of sound besides wind contribute to the L_{90} . However, bivariate specification is adequate in this context, since our goal is to estimate only two simple parameters:

- 1) The mean L_{90} at each wind speed
- 2) The variation in the L_{90} at each wind speed

To estimate the distribution of future individual sound levels at these wind speeds, 95% prediction intervals were calculated using Equation 1 [2],

Equation 1: 95% Prediction Interval for an Individual Y Observation Given X

$$Y_0 = \hat{\mu}_0 \pm t_{0.025} s \sqrt{1 + \frac{(x_0 - \bar{x})^2}{\sum_i (x_i - \bar{x})^2} + \frac{1}{n}} \quad (1)$$

Where:

$\hat{\mu}$ = predicted mean L_{90} given some wind speed

$t_{0.025}$ = critical two tailed t-statistic at 95%

s = estimated standard deviation of the L_{90} s

x_0 = the wind speed for which Y_0 is being predicted

\bar{x} = mean wind speed

x_i = the i^{th} wind speed (this denominator term is the sum of squares for all wind speeds).

n = sample size

With these intervals assigned, we infer that 95% of future L_{90} levels measured during comparable periods will be contained within these boundaries.

The second component in our statistical model involves estimating the probability that noise from turbines be in violation over the future L_{90} s. Interpreting the noise standard in Section 1, turbine noise would need to be 10 dBA above some future L_{90} to be a problem. To calculate this probability, we referred the sample of ambient sound levels to the standard normal distribution. Equation 2 represents the number of standard deviations each threshold is away from the predicted mean L_{90} at each wind speed,

Equation 2: Formula for Determining the Z-statistic

$$Z = \frac{(X_{mi} - 10) - \bar{X}_i}{SD_i} \quad (2)$$

Where:

X_{mi} = the modeled turbine noise at a residential receiver for the i^{th} wind speed

\bar{x}_i = the mean L_{90} at i ,

SD_i = the standard deviation of the L_{90} for i .

Subtracting 10 dB(A) from X_{mi} provides the threshold. Referring the Z-statistic to a 1-tailed standard normal distribution, we then know the probability that the L_{90} will be at or below the threshold. This probability (P_t) in combination with the probability of such a meteorological scenario occurring (P_m) results in the joint probability of exceedence. This is summed across all modeled scenarios, as defined in equation 3.

Equation 3: Formula for Total Joint Probabilities

$$P_J = \sum_1^k P_t P_m \quad (3)$$

Where:

- P_J = the joint probability of an exceedence (10 dB above the L90)
- P_t = the probability of observing an L_{90} at or below the violation threshold
- P_m = the probability of a given meteorological scenario (k)
- k = the number of meteorological scenarios

To demonstrate this graphically, consider a distribution of L_{90} s at a residential receiver for nearby^c wind speeds of 5 m/s (Figure 2). In this example, the modeling scenario for turbine noise assumes D atmospheric stability with winds from the west. The predicted turbine noise level at the residential home is 29 dBA, thus an L_{90} of 19 dBA or less would be required to have a violation. This probability, P_t , is then multiplied by the corresponding event probability for the meteorological scenarios (P_m), yielding the joint probability. Again, this is done for *each* of the 96 modeled scenarios. The summed probability of all 96 scenarios estimates the percentage of time that turbine noise will violate the noise regulation. Figure 3 provides an example L_{90} regression with modeled turbine noise.

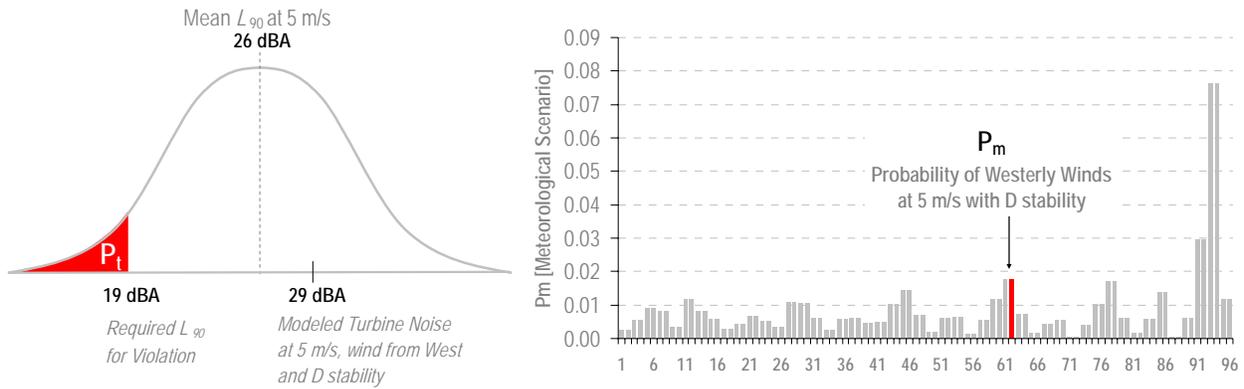


Figure 2: Graphical Representation of Probabilities

^c The actual wind speeds at the residential home are not known – they refer to wind speeds at the turbine.

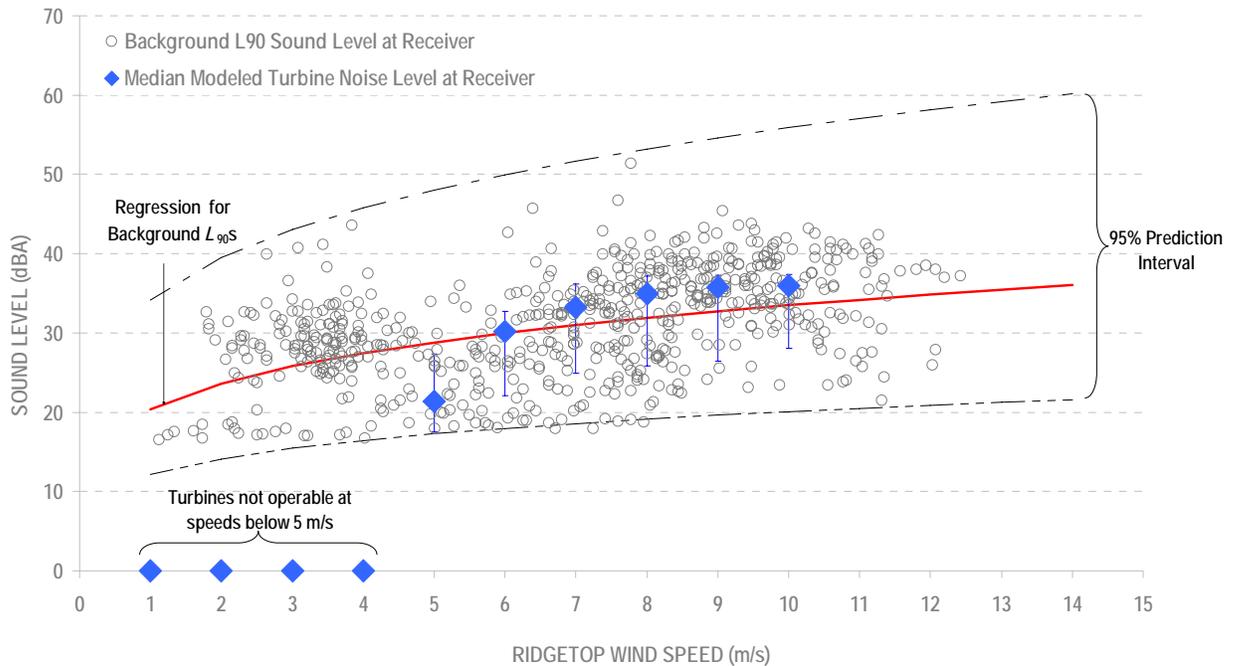


Figure 3: L_{90} Regression with Modeled Turbine Noise at One Residential Receiver

5 IMPLEMENTATION

Some improvements to this approach are important to note. Primarily, by extending the baseline monitoring period, we get a greater confidence in the outcome. By conducting monitoring over several seasons or under various meteorological conditions, the estimates for the corresponding predicted means, standard error, and predicted future L_{90} s would improve. Further, the distribution assumptions for least-squares regression are sensitive to outliers, and while our data did not present problems, this should always be evaluated in any future sample.

If enough data are available, more modeling scenarios can be considered. Specific variations that may also be relevant are temperature and forest cover. However, increasing propagation model scenarios requires the calculation of the corresponding probabilities of that meteorological scenario. Similarly, with enough background sound level data, this too can be further partitioned and regressed in greater detail.

In the end, however, we are left with a statistical probability that a standard will be exceeded. As in any probability, there is a certain degree of uncertainty, however small. In noise propagation modeling, the uncertainty is magnified by interactions among geometric spreading, diffraction, refraction, ground effects, and the complexities of three-dimensional meteorology, not to mention variability in source emission levels [3].

Standards however, are written for absolutes. They generally say that noise from a source cannot exceed a certain level. Therefore, any noise study that evaluates the *probability* of exceedence must also educate its readers regarding statistical distributions and their applicability to fixed (or variable) standards. Preferably, poorly written standards will come to be modified with probability in mind.

6 CONCLUSIONS

The purpose of our method has been to place both the ambient monitoring and propagation modeling results into real-world context. Often times, modeling results are interpreted so one can state that a noise standard will (or will not) be violated under ‘worst-case conditions’, however, this language alone can be inadequate given the complexities surrounding noise modeling – interactions of atmospheric conditions, varying ground factor, changing anthropogenic conditions, varying source levels etc. [3].

There is a finite likelihood that an event can happen, even if it is extremely small. With any probability distribution, there is no “zero probability.” Further, there may be several different conditions that produce violations, but they might not occur with comparable prevalence. Noise standards that are referenced to a background sound level may result in particularly ambiguous conclusions, since they add even further variation that must be accounted for in determining the probability of exceedence.

Ultimately, a thorough and proper assessment can reveal important information pertinent to planners. In our case study, we found that the probability that turbine noise could exceed 10 dB above the L_{90} was 2% to 8% for different residences. It was possible to offer specific information on wind speeds, directions, and times of year in which this was most likely to occur at each home. This added detail placed the turbine noise into perspective, and thus enhanced the discussion and decision-making regarding its impacts.

Though we believe methods employing statistical models are useful in noise assessment, their use is often confusing to regulators. While it is important to effectively communicate how probability works, it is equally important to modify state and community noise standards to account for statistical uncertainty.

7 REFERENCES

- [1] U.S. Department of the Interior, Bureau of Land Management, “*Final Programmatic Environmental Impact Statement on Wind Energy Development on BLM-Administered Lands in the Western United States*” Chap. 5.5, June 2005.
- [2] William Mendenhall and Terry Sincich, “*Using the Model for Estimation and Prediction*” Chap. 10.9 in *Statistics for the Engineering and Computer Sciences*, (Dellen Publishing, Santa Clara, CA, 1984).
- [3] D. Keith Wilson, “Uncertainty in Outdoor Noise Measurements and Predictions,” *Proceedings of the Institute of Noise Control Engineers NOISE-CON 2005 (October, 2005)*

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1pNSd1. Calculating annualized sound levels for a wind farm

Kenneth Kaliski* and Eddie Duncan

***Corresponding author's address: Resource Systems Group, Inc., 55 Railroad Row, White River Junction, VT 05001, kkaliski@rsginc.com**

Modeling done for wind farms usually focuses on calculating a worst-case short term average sound level. However, the impact to homes is not simply defined by a single meteorological condition. Rather, a more complete picture of the impacts is given by calculating sound levels under various meteorological conditions that occur during the year. The actual sound level at a receiver will depend on variations in atmospheric stability, wind speed, wind direction, and other parameters that change hourly. This paper will describe a method to calculate hourly sound pressure levels for individual receivers over the course of an 8760 h year and give examples of different wind farm configurations and how they affect annualized sound levels.

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Problem statement

- **Modeling done for wind farms focuses on a worst-case short term average sound level (Lmax)**
- **“Impacts” are not defined by a single meteorological condition or single hour**
 - **WHO 8 hr and annual guidelines**
 - **EPA annual Ldn guideline**
- **How do we characterize impacts of a source with sound emissions and propagation highly dependent on meteorology, over the course of an 8,760 hour year?**



2

Sound propagation modeling for wind farms is usually done assuming a single meteorological condition – a moderate nighttime inversion, or equivalently, winds blowing from the source to the receiver. For wind farms, this is usually sufficient to estimate a typical one-hour maximum sound level. However, the actual impact to a resident is not fully described by a single condition. This is recognized by several guidelines and standards that look to multi-hour levels, like the WHO 8-hour nighttime guideline of 45 dBA (WHO 1999), the WHO Europe outdoor annual average nighttime guideline of 40 dBA (WHO Europe 2009), and U.S. EPA’s annual average Ldn guideline of 55 dBA (EPA 1974). The problem is then to try to characterize impacts from a wind farm over the course of a year. This is difficult, in that the sound emissions from a wind farm are constantly changing due to changes in wind speed and direction, and the propagation characteristics are also constantly changing.

Outline

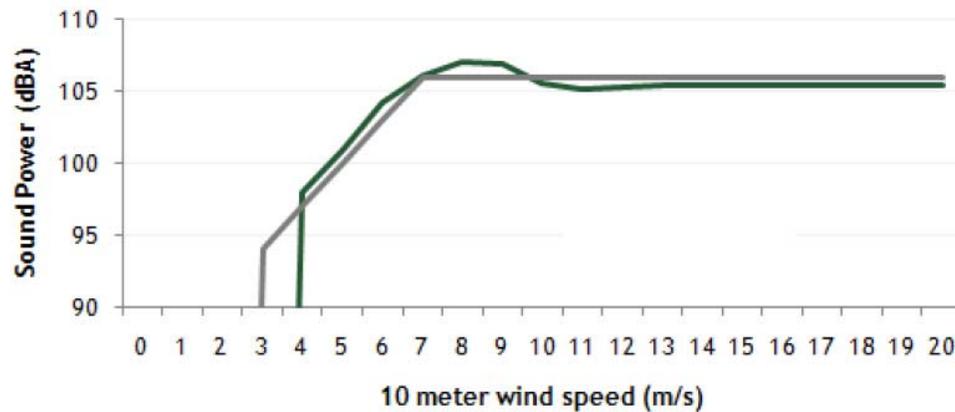
- Sound emissions from turbines
- Refresher on factors affecting downwind propagation
- Method to calculate annualized impacts
- Results from case studies

This paper looks at the changes in sound emissions of wind turbines as a function of wind speed. It then discusses meteorology and downwind propagation. Finally, we show a method to calculate hourly sound levels and annualized impacts, with examples.

Wind Turbine Source Sound Levels

- Sound power is primarily dependent on wind speed

Sound power by wind speed for two variable speed turbines



Sound power from a wind turbine is a function of wind speed. Shown above are graphs of sound power for two different turbines. There is no significant sound below the cut-in wind speed of 3 to 4 m/s. Sound levels gradually rise after cut-in to a maximum level and approximately stay at the maximum sound emission until the cut-out wind speed of 20 to 25 m/s.

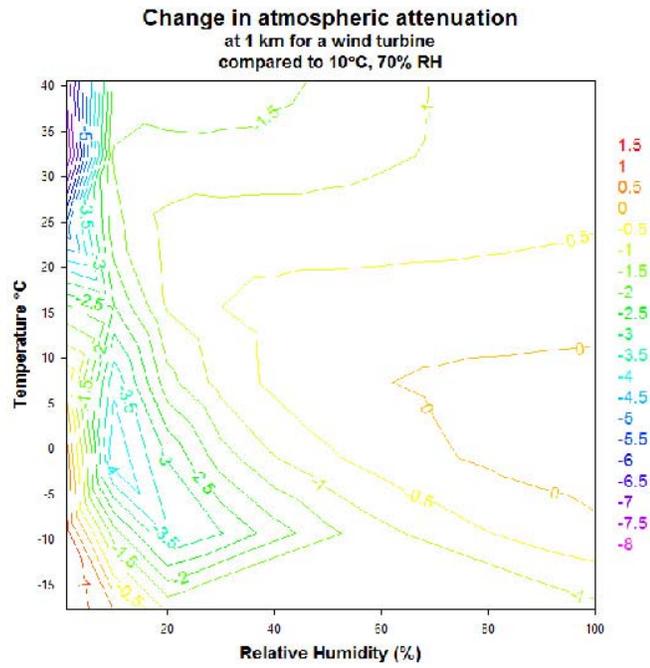
Meteorological factors affecting propagation

- Temperature, pressure, and humidity - Sound absorption
 - Wind direction
 - Vertical wind speed gradient
 - Vertical temperature profile
 - Atmospheric turbulence
- 
- Atmospheric Stability

Sound propagation is affected by meteorology. Temperature, pressure, and humidity affect the level of sound absorbed by the atmosphere. Wind direction combined with the vertical wind speed gradient affects the refraction of sound (and to some extent, the directionality of the sound.) Temperature and turbulence also affect refraction and scattering. These latter three variables can be simplified into a term “atmospheric stability” which we will use here to simplify meteorological parameters affecting propagation.

Atmospheric Attenuation

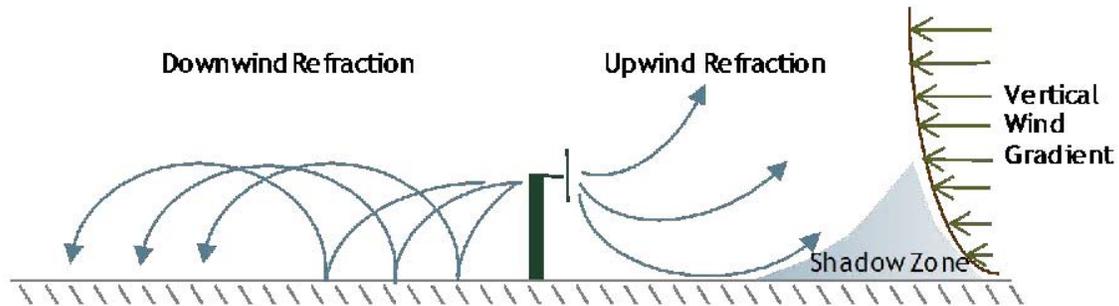
- Function of temperature humidity and pressure
- Default is to use 10°C and 70% relative humidity when modeling Lmax



6

Atmospheric absorption is a function of temperature, humidity, and pressure. For wind farm modeling, we use a default of 10 degrees C and 70% relative humidity, as this generally yields the lowest attenuation (from ISO 9613-1). Other combinations of humidity and temperature yield lower sound levels due to increased atmospheric absorption. The graph above shows the additional attenuation one would get for a single wind turbine at 1 km, relative to the absorption at 10 degrees C and 70% humidity. As shown, the lowest sound levels would occur around freezing temperatures and dry conditions. The results show higher attenuation at very hot and dry conditions, but these are not typical of most landscapes.

Refraction due to wind

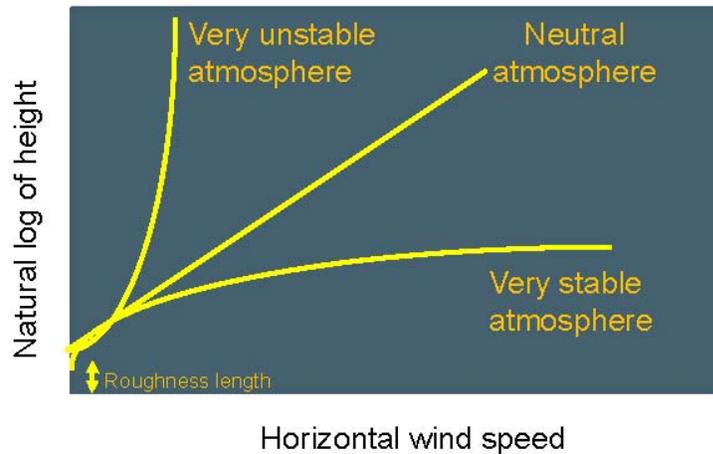


Not to scale

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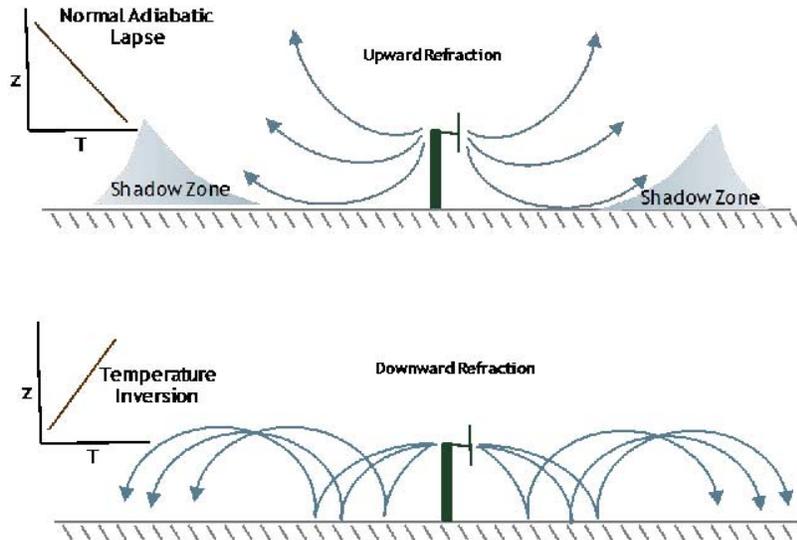
Sound refracts due to a vertical wind gradient. With winds increasing with height, as is most often the case, sound will refract downward downwind of the source and upward upwind of the source. In the upwind direction, this can lead to a shadow zone with low sound levels. Downwind, increases or decreases can be found depending on ground absorption and distance. (Crocker 2007)

Wind profiles under various stabilities



Wind affects atmospheric stability. Very unstable atmospheres have a lot of vertical mixing and are characterized by very little layering and relatively constant wind speeds with height. At the other extreme, very stable atmospheres tend to allow layering with a higher degree of wind shear, that is, increasing wind speed with height.

Refraction from Temperature Profile

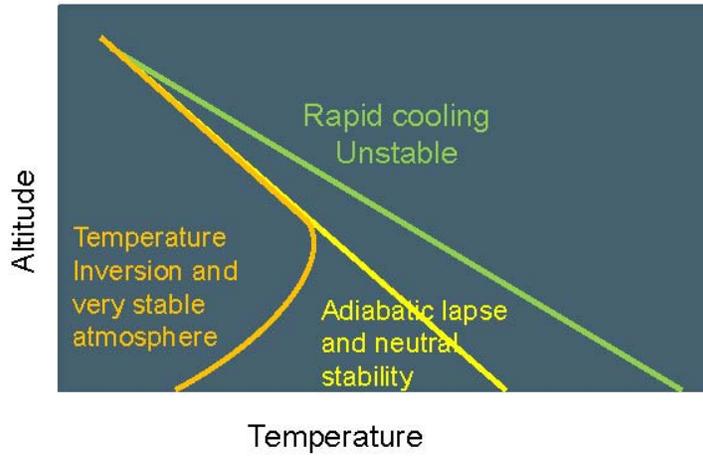


Not to scale

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Temperature also affects propagation. With a normal adiabatic lapse (decreasing temperature with height), sound refracts upward, creating shadow zones on both sides of the source. With a temperature inversion, which typically only occurs at night, temperature increases with height up to a point, and downward refraction occurs. (Crocker 2007)

Vertical Temperature Profiles



An unstable atmosphere is characterized by rapid cooling, or cooling greater than the adiabatic rate. Very stable atmospheres can be created by inversions.

Atmospheric stability

Wind Speed (m/s)	Daytime insolation (mW/cm ²)				1 hr before sunset or after sunrise	Nighttime cloud cover (in eighths)		
	>60	30 to 60	<30	Overcast		0-3	4-7	8
≤ 1.5	A	A-B	B	C	D	F or G	F	D
2.0 to 2.5	A-B	B	C	C	D	F	E	D
3.0 to 4.5	B	B-C	C	C	D	E	D	D
5.0 to 6.0	C	C-D	D	D	D	D	D	D
> 6.0	D	D	D	D	D	D	D	D

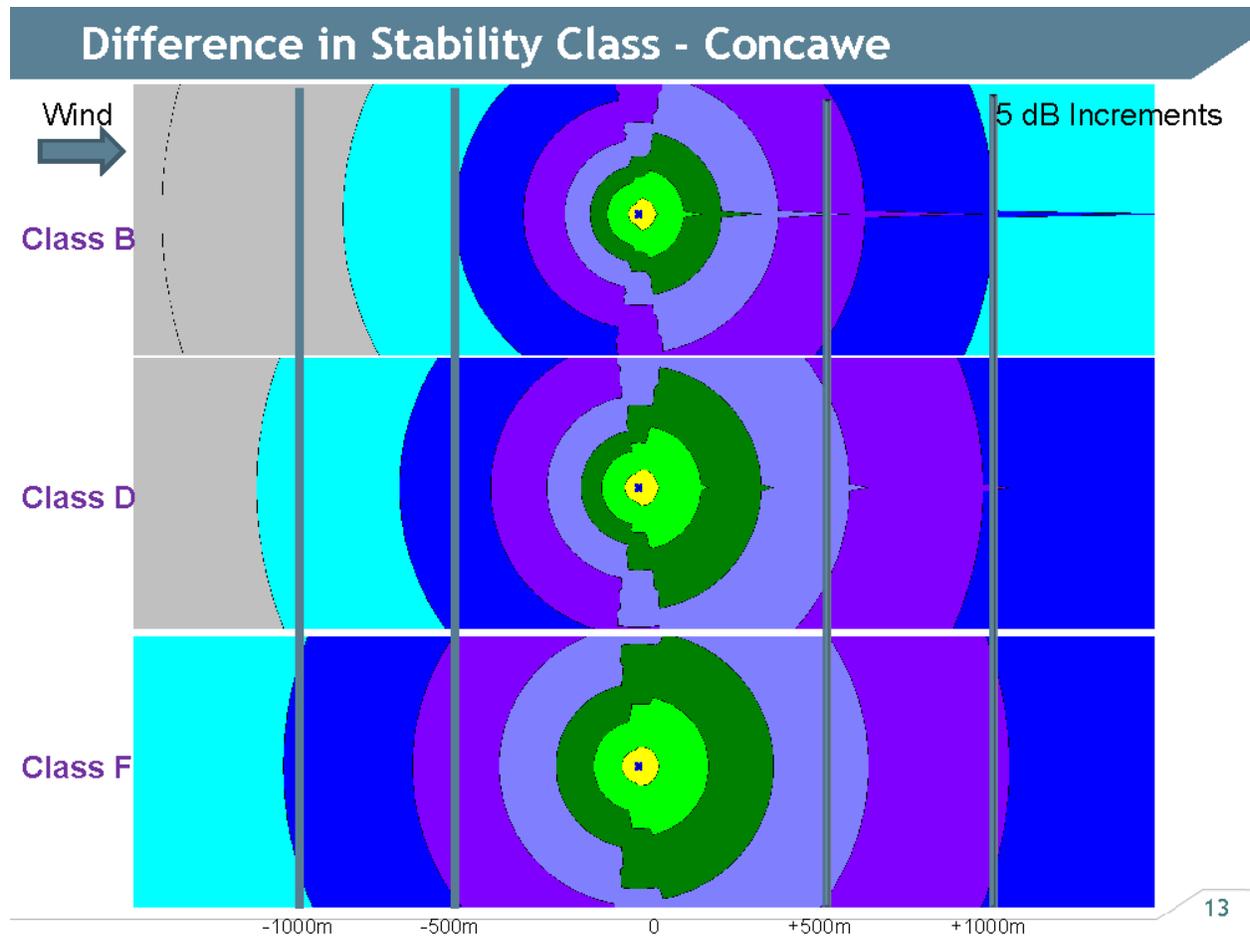
- Pasquill Gifford stability categories
 - Class A is highly unstable
 - Class D is neutral
 - Class F and G are highly stable
- This allows us to combine various meteorological parameters to estimate the turbulence affecting propagation

Pasquill Gifford stability categories have been commonly used by the U.S. EPA to characterize stability. Classes range from A to G, with A being a highly unstable atmosphere and G being very stable. The above table shows the Concawe method for categorizing different insolation levels, cloud cover, time of day, and wind speed into stability classes. (Concawe 1981)

Stability Class

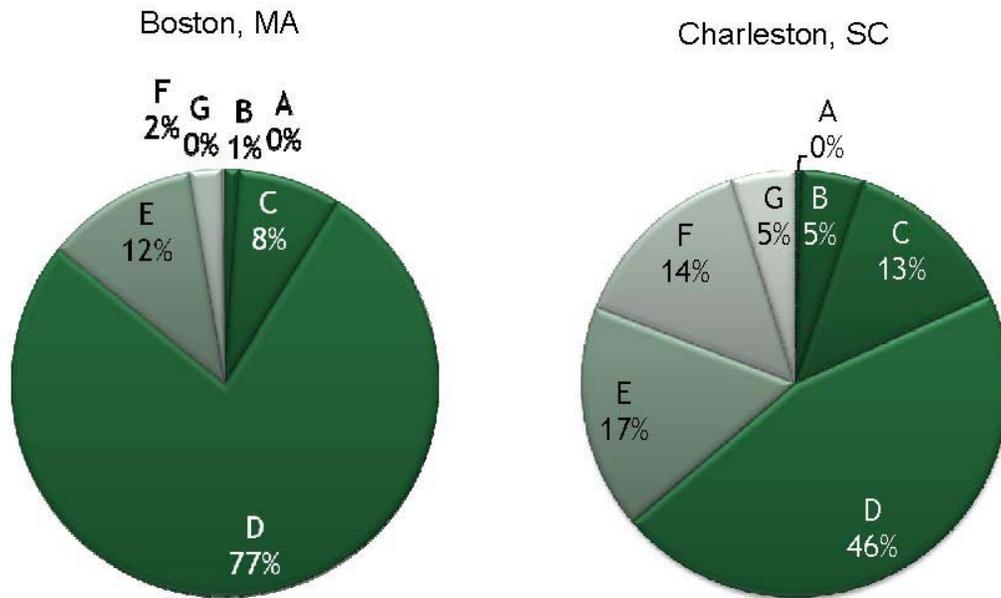
- **Unstable atmospheres are generally unfavorable to propagation**
- **Stable atmospheres are generally favorable to downwind propagation**
- **Concawe and Harmonoise give specific adjustments due to atmospheric stability**
- **ISO 9613-2 assumes a moderate nighttime inversion or downwind propagation**

According to Concawe, unstable atmospheres are generally unfavorable to propagation, while stable atmospheres are favorable. (Concawe 1981). Harmonoise, currently being developed in Europe, uses different stability characteristics developed specifically around sound propagation. (Nota, Barelds, van Maercke 2005)



The chart above shows the change in sound level according to Concawe, as modeled in Cadna A, for a wind turbine modeled as a point source with an 80 meter height, with a 3 m/s wind. As shown, increasing stability from B to D increases downwind propagation by about 5 dB. There is little change downwind from Class D to F downwind. However, upwind propagation increases more as we change from Class D to F.

Frequency of Stability Categories



Meteorology is very site specific. If we compare Boston to Charleston, SC, we see that Boston spends most of its time in a neutral stability. However Charleston is much more varied, with both unstable and stable meteorological conditions. (Source data from US EPA Support Center for Regulatory Air Models)

Process to annualize sound level impacts

- 1) Obtain local hourly wind speed at two or more heights, wind direction, and temperature.
- 2) Obtain cloud cover and ceiling height from the closest National Weather Service station

Now, we are ready to calculate the hourly sound levels. First, met data from the project met tower is obtained. This usually includes hourly wind speeds at multiple heights, wind direction, standard deviations, and temperature. Regional data, such as cloud cover and humidity can be obtained from the closest National Weather Service Station.

- 
- 3) **Calculate Stability Class following the procedure in the U.S. EPA’s “On-site meteorological program guidance for regulatory modeling applications.”**

Stability Class a function of

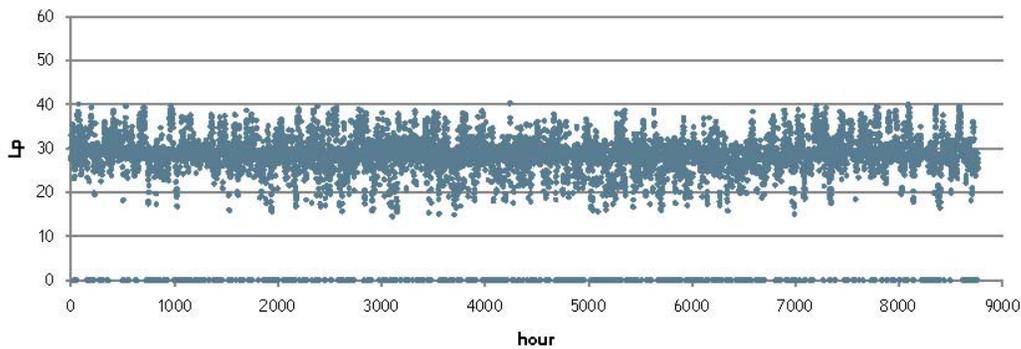
- wind speed,
- cloud cover,
- solar angle,
- daytime/nighttime, and
- ceiling height.

Step 3 is to calculate the P/G stability class. The best method is to use the US EPA’s method which takes into account wind speed, cloud cover, solar angle, daytime/nighttime, and ceiling height (EPA 1987). Other methods are available, such as looking at the standard deviation of wind direction, but these are generally less reliable.

- 4) **Run sound propagation model for 64 different combinations of wind speed, wind direction, and atmospheric stability, with Concawe meteorological adjustments**
- 5) **Match each hour's wind speed, wind direction, and stability class to those used in the model runs.**

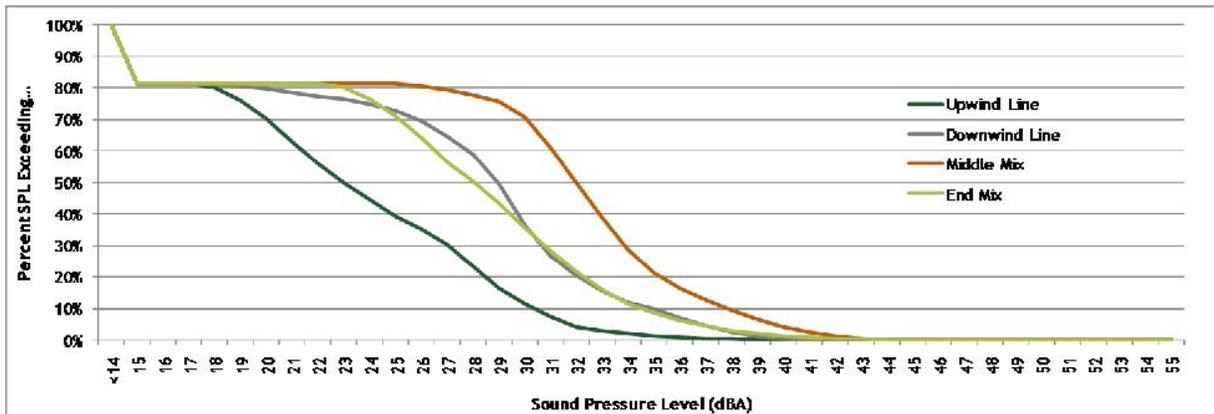
We then run the Cadna model using Concawe meteorological adjustments for 64 different combinations of wind speed, wind direction, and P/G stability class. We then look up the sound level results for each hour by matching these parameters.

- 6) Adjust sound level by wind turbine sound emissions relative to wind speed.
- 7) Account for a random normalized distribution about the mean sound power level.
- 8) Adjust for atmospheric absorption (optional)



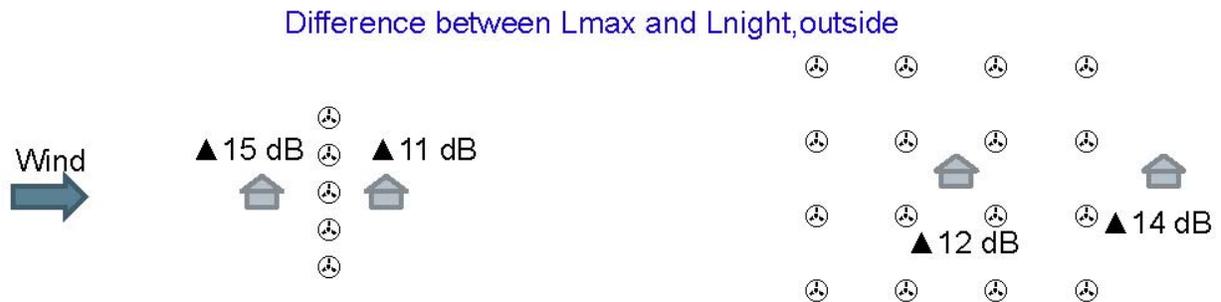
Next, we adjust the modeled sound level if the wind speed is anything other than that creating the maximum sound power. For example, if the wind speed is below the 3 m/s cut-in, the sound level is set to zero. Given that sound emissions are not fixed, but have a confidence interval, we can then randomly adjust the sound emissions using a normal distribution about the mean. In the end, we get hourly sound levels. As shown in the graph above, we see the maximum, but, in this case, sound levels are concentrated at levels that are roughly 10 dB lower than the maximum. Note that while the meteorological data used is real and the modeling results are real, we have combined the model and met data from different sites such that this example does not represent a specific place.

■ Cumulative frequency distribution of SPLs



The next step is to show how this data can be used. Cumulative frequency distributions can be drawn to visualize the percent of time spent at different sound levels. The steeper the curve, the less varying the sound levels. The steepest curves tend to be where the wind farm surrounds a home, with the most shallow curves from a situation where the home is upwind of the wind farm (on a prevailing basis).

- WHO Europe has new guideline of 40 dB $L_{night, outside}$
- 40 dBA outside the home, at night, averaged over the year



- Differences are dependent of meteorology, but generally range from 5 to 15 dB.

We can also look at the difference between the L_{max} and the WHO Europe $L_{night, outside}$ parameter (annual average nighttime sound level outside). As shown, this difference is also depending on the configuration of the home with respect to the wind farm. The differences are dependent of meteorology, but generally range from 5 to 15 dB. That is, if the modeled L_{max} is 40 dB for example, the $L_{night, outside}$ will usually be in the range of 25 to 35 dB.

Conclusions

- Impacts for sources such as wind turbines cannot be defined solely using L_{max}
- Hourly SPLs can be estimated knowing various meteorological parameters
- The distribution of SPLs over the year can then be estimated
- Multi-hour levels can be estimated
 - L_n
 - $L_{night, outside}$
 - Annual L_{dn}



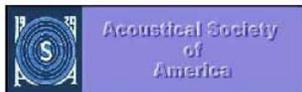
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We conclude by noting that using this technique, we can make an estimate of impacts for sources not just over one condition, but over the variety of conditions that occur over the year. With hourly sound levels, we can calculate how much time a receiver will spend at different sound levels, and calculate impacts relative to multi-hour guideline levels such as the WHO Leq for an 8-hour night, WHO Europe's 40 dB $L_{night, outside}$ annual average, and U.S. EPA's 45 dB L_{dn} .



Questions?

Kenneth Kaliski, P.E., INCE Bd. Cert.
Eddie Duncan, INCE Bd. Cert.
Resource Systems Group, Inc.
55 Railroad Row
White River Junction, VT 05001
kkaliski@rsginc.com



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REFERENCES

- Berglund, B, Lindvall, T, Schwela, D, "Guidelines for Community Noise," World Health Organization, 1999
- Nota, Barelds, van Maercke, "Harmonoise WP 3 Engineering method for road traffic and railway noise after validation and fine-tuning", Technical Report HAR32TR- 040922-DGMR20 of Harmonoise WP3 working group, 2005
- Crocker, M, "Handbook of Noise and Vibration Control," John Wiley & Sons, 2007
- Manning, C. J., "The Propagation of Noise from Petroleum and Petrochemical Complexes to Neighbouring Communities," Report no. 4/81, Concawe, 1981
- U.S. EPA, "Information of Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margine of Safety," EPA 440/9-74-004, 1974
- U.S. EPA, "On-Site Meteorological Program Guidance for Regulatory Modeling Applications," EPA-450/4-87-013, 1987
- WHO Europe, "Night Noise Guidelines for Europe," World Health Organization, 2009

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Noise

Session 3aNSa: Wind Turbine Noise I

3aNSa4. Prevalence of complaints related to wind turbines in northern New England

Kenneth Kaliski* and Gurpreet Neeraj

***Corresponding author's address: RSG, 55 Railroad Row, White River Junction, VT 05001, ken.kaliski@rsginc.com**

As of the end of December 2012, there were over a dozen large operating wind projects with a total capacity exceeding 600 MW in northern New England. This paper evaluates the prevalence of noise complaints to regulatory authorities from those wind projects. A comparison of the distance of complainants and non-complainants from wind farms is made with the goal of assessing the prevalence of complaints at various distances from the wind projects.

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INTRODUCTION AND BACKGROUND

In 2012, Hessler and Hessler^[1] investigated serious noise complaints from five wind farms. They found that between 2% and 7% of households, with an average of 4%, within about 2,000 feet of these wind farms registered noise complaints. Overall, they found that the level of complaints was far lower than predicted by others, particularly in the dose-response studies done in Europe by Pederson and Persson Waye^{[2][3][4]}.

In this study, we investigated official reports of noise complaints in 15 of the 16 large wind farms that are currently active in the northern New England, specifically the states of Maine, New Hampshire, and Vermont. We then evaluated the location of those complaints with respect to the distance from the wind farm.

METHODOLOGY

A list of wind farms greater than 1 MW in total capacity active in Maine, New Hampshire, and Vermont were obtained from various sources. Because in each of these states, the siting of large wind farms is regulated by the state, state officials were contacted to determine which projects had noise complaints and where those complainant households were located. In addition, some project operators were also contacted to fill in any gaps. In all but one case, the number of complaints, and locations or approximate distances of complainants to the nearest turbine could be identified.

The turbines of each wind farm were mapped, and then buffers of 1 km (0.6 mi), 1.6 km (1 mi), 2 km (1.2 mi), and 3.2 km (2 mi) were extended from the project. These buffer distances were chosen because they are commonly cited in the literature and press. For locations in Maine and New Hampshire, households were then identified via aerial photography. Each identified household was assumed as a single family residence. For locations in Vermont, the state's E911 residential GIS database was used to identify households. The numbers of households in each buffer distance was then counted. An example of the buffer and residence mapping is shown in Figure 1.

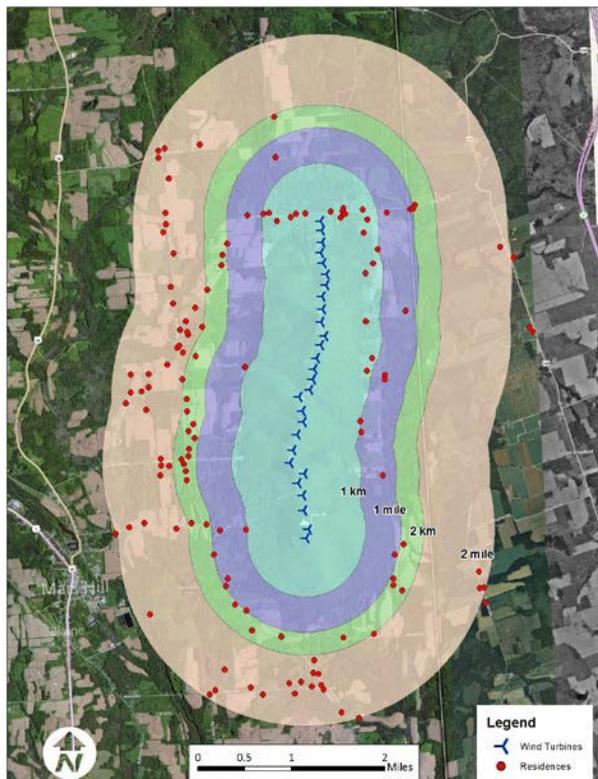


FIGURE 1. Example analysis showing wind turbines, identified households, and 1 kilometer, 1 mile, 2 kilometer, and 2 mile buffers around the wind farm

RESULTS

We were able to identify turbine locations, residential locations, and complainant setback distances from 16 wind farms, accounting for 329 wind turbines and 674 MW of total capacity.

The number of households within each distance band registering at least one noise complaint is shown in Table 1. A total of 29 complaints were noted. As indicated, the percentage of complaints within 1 km (3,280 ft) is 5% similar to the 4% found in Hessler and Hessler^[1]. In the five wind farms they analyzed, they found 764 residences within 2,000 feet, whereas our 16 New England wind farms combined had fewer than 150 residences within 3,280 feet. This is a notable characteristic of New England wind farms since the most common standard is 45 dBA, the turbines are generally arrayed in a ridgeline configuration, and the rural nature leads to somewhat larger setbacks than found in other environments.

Of the complaints, 48% occurred at wind farms where a noise violation was found or where a variance from the noise standard existing at the time was obtained during permitting. 14% of the complaints were where subsequent noise testing found the projects to be in compliance with their noise standards (45 dBA in each case), and in the remaining 38%, the results of compliance testing has not yet been reported. About 1/3 of all complaints were registered from a single wind farm.

TABLE 1. Number of residences, number of noise complaints, and percent of noise complaints within various distance bands from the closest wind turbines.

	Distance				
	< 1 km	1 km to 1.6 km	1.6 km to 2 km	2 km to 3.2 km	> 3.2 km
Number of residences within band	147	497	816	2214	n/a
Official noise complaints within band	8	11	1	6	3
Noise complaints as a percent of residences	5%	2%	0.1%	0.3%	n/a

TABLE 2. Number of residences, number of noise complaints, and percent of noise complaints within various distances from the closest wind turbines. This is similar to Table 1, but the values are cumulative for each successive distance band. The three complaints beyond 3.2 km are not included here.

	Distance			
	< 1 km	< 1.6 km	< 2 km	< 3.2 km
Number of total residences within each distance	147	644	1460	3674
Official noise complaints within each distance	8	19	20	26
Noise complaints as a percent of residences	5%	3%	1%	0.7%

CONCLUSIONS

The findings from this study identified 5% of households registering at least one noise complaint within 1 km (0.6 mi) of wind turbine projects in northern New England. It should be noted that about half of these complaints are located at wind farms that were either found to be in violation of their applicable noise standard or obtained a variance from the noise standard at the time of permitting.

Beyond 1 km, the frequency of complaints drops off quickly, with a rate of 3% for homes between 1 km (0.6 mi) and 1.6 km (1 mi), and 0.2% from 1.6 km (1 mi) to 3.2 km (2 mi).

We recognize that distance from wind turbines is not a reliable indicator of noise exposure. The projects evaluated here range from 3 turbines to 44 turbines, and thus would have remarkably different sound levels as a function of distance along this range. In addition, there are non-acoustic factors that relate to noise annoyance, as well^[5] that have not been identified here. The next step in this research is to change the independent variable to modeled sound levels. Combined with a statistical correlation analysis, this would help identify how and whether noise complaints can be characterized as a function of overall modeled sound levels.

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REFERENCES

1. D. M. Hessler and G. F. Hessler, "Recommended noise level design goals and limits at residential receptors for wind turbine developments in the United States," *Noise Control Eng. J.* **59** (1), (Jan-Feb 2011).
2. E. Pedersen and K. Persson Waye, "Perception and annoyance due to wind turbine noise—a dose-response relationship", *J. Acoust. Soc. Am.*, **116**(6), 3460–3470, (2004).
3. K. Persson Waye, "Perception and environmental impact of wind turbine noise", *InterNoise09*, (2009).
4. E. Pedersen, et al., "Response to noise from modern wind farms in the Netherlands", *J. Acoust. Soc. Am.*, **126**(2), 634–643, (2009).
5. F. van den Berg, E. Pedersen, J. Bouma, R. Bakker, "WINDFARMperception: Visual and acoustic impact of wind turbine farms on residents, FP6-2005-Science-and-Society-20 Specific Support Action, Project no. 044628, University of Groningen (2008)