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Subject: Siting of Wind Turbines With Respect to Noise Emissions and their Health and Welfare Effects on Humans

Reference: RDH Project No. 210004

Dear Mr. Marion,

Per your request, this letter presents an overview of the effects of large-scale wind turbines (greater than one megawatt) on people. It particularly addresses these effects with respect to residents living in the vicinity of wind turbine developments (often referred to as "wind farms").

Preface.

Of particular concern is the ability of the May 2010 Public Service Commission of Wisconsin (PSCW) sound and vibration guidelines[1] to protect the public health and welfare, and to do so with an adequate margin of safety[2]. The three operative terms important to this discussion are:

- Welfare,
- Health, and
- Margin of Safety

In the present context the term welfare refers to the potential annoyance or nuisance effect of the noise. The word health refers to potential health effects of the noise having to do with sound level, frequency content, or temporal character. The term margin of safety relates specifically to the many unknown factors involved in predicting the health and welfare effects of wind turbine related sound. At present the A-weighted sound level is widely used in guidelines and regulations to place limits on residential sound exposure from industrial sources, and it has been

[1] Public Service Commission of Wisconsin, "Measurement Protocol for Sound and Vibration Assessment of Proposed and Existing Wind Electric Generation Plans," May 2010.
[2] Environmental Protection Agency (EPA), Office Of Noise Abatement And Control (ONAC), "Information On Levels of Environmental Noise Requisite To Protect Public Health and Welfare with an Adequate Margin of Safety," March 1974.

used in wind turbine documents as well. The A-weighted sound level is a measure of a sound's relative loudness. In the case of wind turbine sound it is not at all clear that many of the reported effects on humans can be explained by loudness alone. In fact, it is safe to say the scientific community does not know the exact sound exposure attributes that are causative to the health and welfare concerns of wind turbine sound. Until such time as a better scientific understanding of the cause / effect relationship becomes available, the margin of safety must include an uncertainty of estimation factor when using the A-weighted sound level, the C-weighted sound level, or combinations thereof.

A recent submittal to PSCW identifying concerns regarding the proposed PSCW May 2010 wind siting rules provides a good overview of the issues[3]. A number of points are raised, and rather than restate those relating to wind turbine sound emissions here I will say that I am in general agreement with:

- II.13 Siting Criteria, Items 1-4, 6-9, and
- II.14 Noise Criteria, Items 1-5.

Items not included above do not mean I am in disagreement with them. They simply contain language in whole or in part that exceeds my area of expertise.

The remainder of this report presents comments on the following topics:

1) The nature of wind turbine noise compared with other noise sources heard in residential communities.
2) Community noise standards and how they apply to wind turbine environments.
3) The reported effects of wind turbine noise on people in residential settings.
4) The paucity of information regarding why people respond as they do to wind turbine noise.
5) The sound levels above which residents appear to begin experiencing these effects.
6) The setback distances from wind turbines below which residents appear to begin experiencing these effects.
7) Policy Question.
8) Some concluding remarks.

Throughout my presentation my focus will be on the health and welfare of those who may be exposed to varying degrees of wind turbine noise. This emphasis is consistent with the seminal 1974 Environmental Protection Agency (EPA) document, "Information On Levels of Environmental Noise Requisite To Protect Public Health and Welfare with an Adequate Margin of Safety."

[3] PSC REF#:133746, "Comments by the Towns of Morrison, Wrightstown and Glenmore Brown County, Wisconsin, June 24, 2010." Submitted to: Public Service Commission of Wisconsin, Docket No. 1-AC-231 Draft Chapter 128—Wind Energy Systems.

1. The nature of wind turbine noise compared with other noise sources heard in residential communities

Different sound sources vary in their sound level, frequency content and temporal character. These differences are most easily described by example. First, there are steady state noise sources. A good example would be an active highway. The sound level at a listener location away from the highway may vary somewhat from moment to moment, but by small amounts. But by and large human observers perceive highway sound as near constant in amplitude.

Second, there are transient sources. These are sources present only for brief periods of time. Good examples are passing trains or aircraft. These sources rise gradually in amplitude as they approach the listener and then decay as they depart.

A third class of sound source is the impulsive one. These sources can be repetitive or random in nature. Repetitive impulse sources would be jackhammers and pile drivers. The basic difference between the two examples is the rate at which the impulses occur. A random impulsive source would be the operations in a machine shop where hammering or metal fabrication takes place. In all of these examples any one impulse lasts for only a very small fraction of a second, and the onset and offset of the impulse is very rapid.

Finally, we come to the wind turbine source. Unlike any of the previous sources described, it is neither steady state in the classic sense, nor is it transient, nor is it impulsive. Instead, it produces a distinctive broadband "swoosh-boom" sound[4] with each passing blade of the turbine. Each whoosh effectively modulates the sound level, with a more gradual onset than an impulsive sound, and a less gradual one than the transient sources I mentioned. For the typical three-bladed turbine in the 1-megawatt output range the blade passage rate is nominally one per second. One can sound out the observed sound in the typical second-counting style … "whoosh" one thousand, "whoosh" two thousand, "whoosh" three thousand, and so on. So long as the wind is blowing at sufficient speed to drive the turbine the sound will be generate for lengthy periods of time without interruption.

The hours of operation of wind turbines are not dictated by diurnal patterns of human activity like many other anthropogenic sources. They are able to operate when wind conditions are favorable, day or night. This means they may become a factor during both waking and sleeping hours.

The repetitive sound character is unique and unlike any other source found in residential communities. As such it is easily identifiable. It does not blend in to other background sources that are continuous in nature.

Wind turbine noise is most prevalent in rural areas. By their very nature, large-scale wind turbine installations require vast areas of open land. Hence, any potential sound masking effect from urban and suburban sources is unlikely to be present. This means that their sound will be audible a lower levels in the rural environment. It further means that rural noise standards

[4] Kamperman, G. and James, R. "The 'How To' Guide To Siting Wind Turbines To Prevent Health Risks From Sound," Version 2.1, October 28, 2008.

should be applied to these installations as opposed to suburban or urban ones where nighttime sound levels, for example, can be 15 to 20 decibels higher.

2. Community noise standards and how they apply to wind turbine environments.

I have enumerated the various types of noise sources because noise emission guidelines and standards traditionally evolve over time to address new types of sources as they emerge as technological advances and enter our environment. For example, some of the first community noise standards only used average or percentile sound levels, quantities that were relatively easy to measure with a simple sound level meter. They were universally applied to all non-airborne sources. In time, penalty factors were added for sources with audible pure tone components, and for those with an impulsive character. Time of day of the occurrence was also incorporated to recognize the need for lower sound levels at night. The important point is that standards and guideline evolution is a natural, ongoing process as new noise sources with unique characteristics are introduced.

This evolutionary process generally begins with anecdotal evidence being presented. This evidence takes the form of some new source's health and welfare effects not being accounted for by existing regulations. Scientific inquiry then begins and research is conducted until a consensus is reached regarding the cause / effect relationship. Next, appropriate national and international standards committees develop new standards to be applied, or existing ones are modified for source specificity. These new standards eventually find their way into guidelines and regulations.

From the time a new source is brought to the attention of the acoustics community it is not unusual for a period of five to ten years to elapse between the onset of literature review and research and the promulgation of an agreed upon noise standard for the source. This has been true for highways, for aircraft, for railroads, industry, and many other sources.

Before proceeding to the next topic, let me provide an example of how a new acoustic phenomenon was addressed. My example is the introduction of jet aircraft into the commercial air transport fleet in the early 1960s. Up until that time, piston-engine, propeller-driven aircraft comprised the entire fleet. The sound consisted primarily of droning lower frequency tones and a little broadband noise. The introduction of jet aircraft brought significant changes to the character of aircraft noise. First, it was found there were much higher levels of high-frequency noise generated by the jet exhaust. Second, there were high-frequency tones coming from the front of the engine that originated from the compressor turbine blades.

Initial measurements were made and the overall sound levels were not that different between the aircraft types. But people felt the jet aircraft were considerably more annoying. In short, existing methods of measuring aircraft sound levels were not adequately predicting community response to the new generation of aircraft. Let me summarize what happened next.

First, laboratory and field studies were performed to understand how people rated the different frequencies contained in a broadband noise. Second, further laboratory studies were undertaken to understand the additional perceived "noisiness" of the high-frequency pure tones. Third, additional studies were conducted to understand how people rated sounds of differing durations, essentially determining how people were willing to trade sound intensity for sound duration for a constant level of annoyance. It should be noted that the commonly used A-weighted sound level did not adequately address any of these phenomena.

As the research drew to a close standards committees began to evaluate the data and they determined that a new noise level metric was needed to adequately correlate measurements with observed human response. The end result was a new metric called the equivalent perceived noise level that embodied the findings regarding sound amplitude, frequency content, duration, and pure tone content found in varying degrees in both propeller and jet aircraft. This metric is now used to certify noise level compliance of new or modified aircraft, and is currently embodied in both our "Federal Aviation Regulation (FAR) Part 36 – Noise Standards, Aircraft Type and Airworthiness Certification" and the "International Civil Aviation Organization (ICAO) Annex 16, Environmental Protection, Volume 1, Aircraft Noise." Aircraft are not certificated for flight unless they meet these specific noise standards.

This is an example of *the process*. These processes take time. During the interim period existing measures of sound, with appropriate adjustments, must be used for regulatory purposes. It is probably safe to say we are on the leading edge of such a process regarding the sounds emitted from wind turbines and their effects on residential neighbors. In the meantime some regulatory language taking advantage of A-weighted and C-weighted sound levels should be used to protect the health and welfare of neighbors with the adequate margin of safety.

3. The reported effects of wind turbine noise on people in residential settings

At the present time there is fairly consistent anecdotal evidence that at sound levels consistent with existing standards of acceptability for the other sources residents express higher degrees of annoyance than expected, and also report new physiological symptoms (in addition to sleep interference) when living near wind turbine installations. Stated another way, residents appear to become sensitive to wind turbine noise at lower sound levels than they would to other sources. The physiological symptoms include (but are certainly not limited to)

- Feelings of uneasiness,
- Dizziness,
- Nausea,
- Headache,
- Inability to concentrate, and
- Sleep disruption

Hence, it seems doubtful we can simply apply existing noise standards and guidelines to wind turbine environments. One reason postulated by more than one researcher is the modulated character of wind turbine noise. This is the repetitive short-term variability in sound level created with each blade passage (approximately once per second).

4. The paucity of information regarding why people respond as they do to wind turbine noise.

At the present time it is my professional opinion that there is a significant lack of understanding regarding the extent of observed effects across affected populations, the intensity of these effects, and their relationship to the frequency content, sound level amplitude and temporal dynamics unique to wind turbines. Most of the pioneering work has been performed abroad, in the Netherlands, Sweden, Denmark and Britan. Examples include work by Pedersen[5]. But more investigation is needed to fully understand and document the effects and the sound conditions that elicit them.

A number of reports have been prepared in recent years purporting that symptoms reported by wind farm neighbors should not be attributed to wind turbine noise since such symptoms are not supported by existing literature. This is particularly the case regarding the controversy regarding the issue of low-frequency wind turbine noise. However, it is safe to say that the existing peer-reviewed literature does not address the specific attributes of wind turbine temporal patterns and long-term exposure to them. Hence, an important body of information by which standards might be set has simply not yet been developed. It is important to remain mindful that the absence of research and reported findings does not prove the absence of an effect.

5. The sound levels at which residents appear to begin experiencing these effects.

A number of privately sponsored reports, white papers, government investigations, peer-reviewed papers, and professional society presentations shed light on the A-weighted sound levels at which the observed phenomena begin to be observed. However, the evidence is far from consistent. One of the main issues for consideration is the relation of the wind turbine sound levels with that of the ambient. In rural areas the ambient is often controlled by wind-induced noise in foliage. If the surface winds are high then the ambient will be elevated accordingly. If the surface winds are low, then the A-weighted ambient sound levels can easily drop into the 20 dB range (or even lower). Wind turbines can still operate under such conditions because the winds aloft will almost always be higher and may be sufficient for turbine operation. A worst-case condition is when the winds aloft are blowing in the direction of turbine to residence, and the surface winds are calm. Under these conditions the ambient sound levels are likely to be at their lowest, and the sound propagation conditions the most favorable (least attenuation) between source and residence.

Sound levels from a specific source that are in this same range as that of the ambient have a high likelihood of being detectable, and if source sound levels are10 dB above the ambient then they will almost certainly be detected. If the audibility of this unique modulated sound is an important issue leading to the observed attitudinal and physiological effects, then assuming the night time ambient can drop to 20 dB(A) suggests that turbine sound levels of 30 dB(A) may become a problem on quiet nights. This number is consistent with the findings of Pedersen and Person Waye[5] who found that 40 percent of respondents exposed to turbine sound levels on the order of 30 to 32.5 dB(A) gave a "noticeable" response during administration of their

[5] Pedersen E and Persson Waye K. (2004). "Perceptions and annoyance due to wind turbine noise - a dose-response relationship," J Acoust Soc Am 116(6): 3460- 3470.

questionnaire (see Figure 1) Existing regulations, on the other hand, aim at a sound level of approximately 40 dB(A), ten decibels higher, that elicited 80 to 90 percent noticeability response.

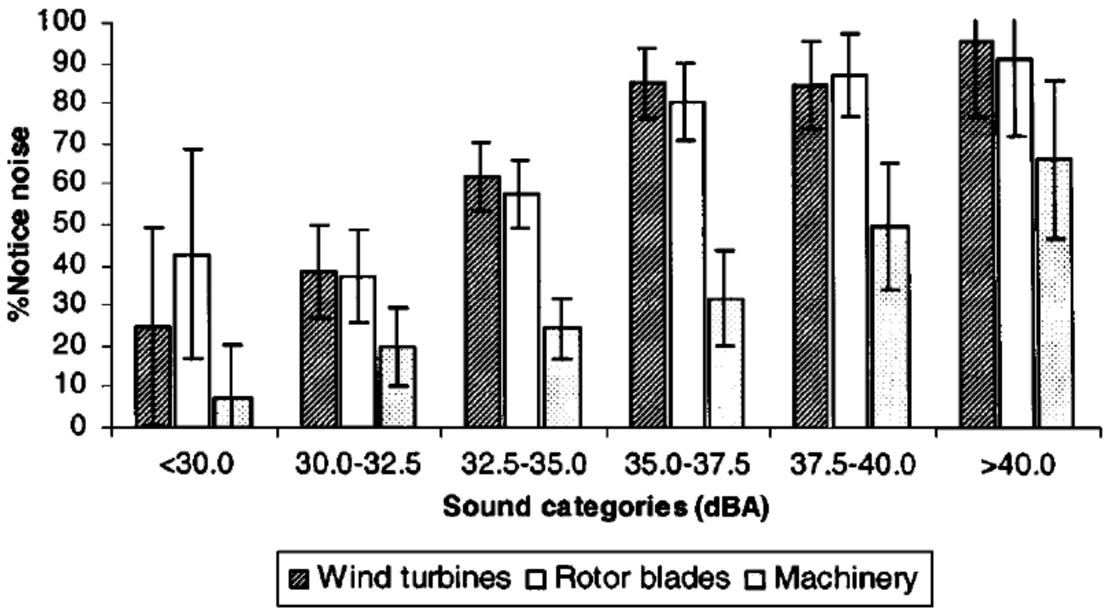


Figure 1. Percent of respondents reporting noticeability of wind turbine noise for various categories of continuous A-weighted equivalent sound level ($L_{eq, A}$). Source: Pedersen and Person Waye (2004), Figure 2.

In terms of annoyance, the same researchers found that the percentage of respondents (from the same subject pool as above) who reported themselves "highly annoyed" occurred at substantially lower sound levels than for other sources (see Figure 2). For example, at an Leq of 40 dB approximately 30 percent of respondents reported high annoyance. This number compares with 12 percent used by the Federal Aviation Administration and other federal agencies as their criterion for a sufficient proportion of the affected population to consider (and fund) remedial sound treatment for homes. At approximately 37 dB(A) 12 percent of the turbine-exposed study participants reported high annoyance. For road traffic noise 12 percent of respondents report high annoyance at approximately 62 dB, a 25 dB difference from wind turbine noise. The source of the transportation-related curves in this figure is Miedema and Vos (1998)[6].

oops

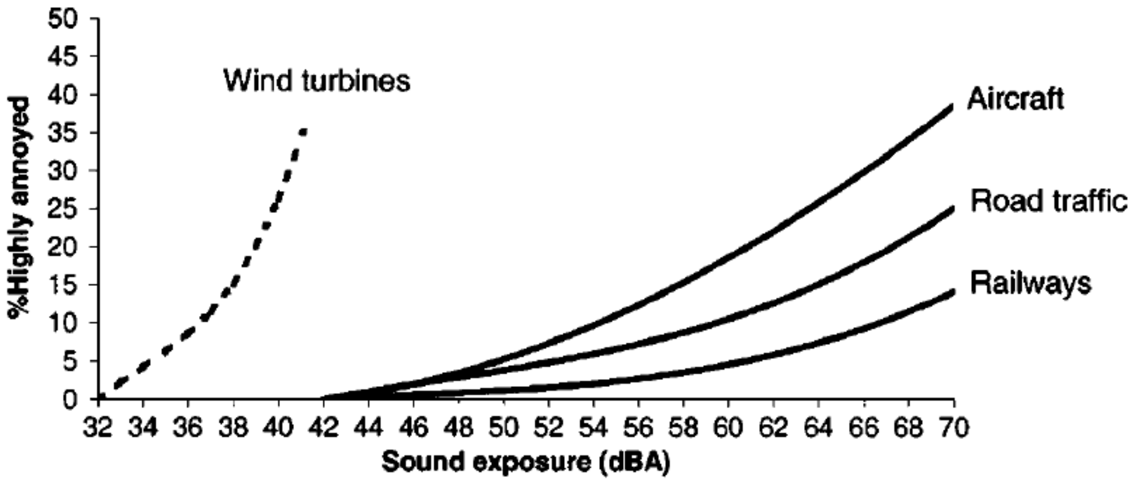
no

see note next page

On simply an A-weighted sound level basis, people are reporting moderate levels of annoyance at sound levels 25 dB lower than for a continuous source such as a highway. This finding is highly suggestive that other factors besides the loudness rating approximations of the A-weighted sound level are influencing people's response to wind turbine noise, and that research is needed to explain the differences and suggested alternative noise metrics to be used for wind turbine siting.

[6] Miedema, H. M. E., and Vos, H. (1998). "Exposure–response relationships for transportation noise," J. Acoust. Soc. Am. 104, 3432–3445.

wrong use of graph: this one is illustrative only, not data



Sound exposure is for wind turbines calculated A-weighted L_{eq} for a hypothetical time period and for transportation DNL.

Figure 2. Percent of respondents reported high annoyance attitude as a function of sound level (Day-night average sound level for aircraft, road traffic, and railways; Leq for wind turbines). Source: Pedersen and Person Waye (2004), Figure 3.

Part of the reason for the disparity between the transportation source and wind turbine curves in Figure 2 may lie in two conditions identified in Appendix D of the EPA Levels Document. Table D-7 is reproduced below. In the first two columns the “special conditions” are identified. These conditions are spelled out along with appropriate sound level adjustment factors to compensate for the fact that virtually all of the data available to the writers for setting criteria originated from urban and suburban settings where the sound sources were familiar ones to the residents. The writers were cognizant of the fact that not all situations of concern would arise under these conditions. Thus, they provided recommended adjustments to measured ambient sound levels before comparing those numbers with urban and suburban criteria, such as dosage effect curves the predict levels of high annoyance from the Day-Night Average Sound Level.

Another way to look at these adjustments is to think of the residents as more or less sensitive to the newly introduced noise source depending on situational circumstances.

Two of the circumstances identified in the table are relevant to the proposed wind turbine facility. They are highlighted in the table in orange, and they specifically address:

- Quiet, rural settings, and
- Unfamiliar noise sources.

Taken together the increased sensitivity of residents affected by wind turbines is 15 decibels. This means that the guidelines of the table are recommending that criterion levels of acceptability be set 15 dB lower than for urban and suburban applications where increases or decreases in existing sound levels will be occurring with familiar noise sources. This could be a partial explanation for the lateral shift in the wind turbine curve from the remaining curves in Figure 2. The remaining 10 dB of the offset could be due to the sound level modulation inherent in wind turbines (a technological factor not present in 1974 at the time the report was written.

Table D-7
Corrections To Be Added To The Measured Day-Night Sound Level (L_{dn}) Of Intruding Noise To Obtain Normalized L_{dn}[d-3]

Type of Correction	Description	Amount of Correction to be Added to Measured L_{dn} in dB
Seasonal Correction	Summer (or year-round operation)	0
	Winter only (or windows always closed)	-5
Correction for Outdoor Noise Level Measured in Absence of Intruding Noise	Quiet suburban or rural community (remote from large cities and from industrial activity and trucking)	+10
	Normal suburban community (not located near industrial activity)	+5
	Urban residential community (not immediately adjacent to heavily traveled roads and industrial areas)	0
	Noisy urban residential community (near relatively busy roads or industrial areas)	-5
	Very noisy urban residential community	-10
Correction for Previous Exposure & Community Attitudes	No prior experience with the intruding noise	+5
	Community has had some previous exposure to intruding noise but little effort is being made to control the noise. This correction may also be applied in a situation where the community has not been exposed to the noise previously, but the people are aware that bona fide efforts are being made to control the noise.	0
	Community has had considerable previous exposure to the intruding noise and the noise maker's relations with the community are good	-5
	Community aware that operation causing noise is very necessary and it will not continue indefinitely. This correction can be applied for an operation of limited duration and under emergency circumstances.	-10

The word "correction" as it appears in the above table caption means the quantity in decibels that should be arithmetically added to measured ambient sound levels (e.g. ambient sound levels with or without the influence of a modifying noise source) in order to normalize conditions to a typical urban / suburban setting. Once the sound levels are normalized they may be used to determine annoyance. By the same token it could be argued these same "corrections should be used in interpreting impact or criterion level exceedances found in urban- and suburban-based noise guidelines. The table contains both positive and negative numbers (and zero) to determine the value of this "correction," and the corrections are additive.

For example, let us suppose the measured sound level of a new sound source in a rural area is 40 dB(A). The "correction" for a new source is +5 dB. The "correction" for rural communities is +10 dB. Together they total +15 dB, and when that total correction is added to the measured 40 dB(A) the adjusted value is 55 dB(A). If an urban / suburban based noise regulation or guideline says the limit should be 50 dB(A), then the adjusted measurement value of 55 would represent an exceedance. The table essentially says that it is inappropriate to compare the measured value of 40 dB with the criterion of 50 dB because the conditions under which 50 dB criterion was developed are not those where the 40 was measured.

Obviously this procedure is to be used only when guidelines and regulations do not explicitly account for these situational factors. Conversely, guidelines and regulations that contain criteria specific to these situations obviate the need for making such adjustments. However, one would expect such situation-specific criteria to differ from urban and suburban criteria by the amount of the correction(s) found in the table. For example, in the example cited in the previous paragraph, if an existing criterion for an urban / suburban setting were 50 dB(A), then all other things being equal the expected criterion for the rural / new source situation should be 15 dB lower, or 35 dB(A). Note that the absolute number of 50 dB(A) was chosen to serve as an example for computational illustration purposes. It should not be construed as a recommendation of any kind.

The important number to keep in mind is the 15 decibel adjustment. Since this same numeric adjustments of 5 and 10 dB are contained in a current American National Standard (ANSI)[7] the 15 dB total adjustment can be considered as recommended practice. If it is not considered for the rural / new source case, there should be some justification for why it has not.

6. The setback distances from wind turbines at which residents appear to begin experiencing these effects.

The same may be said about setback distances between the nearest wind turbine to the nearest residence as was stated above about sound levels. The setback distance is simply a surrogate for sound level, the farther the distance from the source, the lower the received sound level. A range of setback distances has been recommended based on empirical evidence of varying degrees or reliability. Distances ranging from 0.3 to 2 miles have been suggested between the nearest turbine in a complex and the nearest residential neighbor. This is a large range and each estimate takes into account different factors including the number of turbines near the receptor.

For example, the Province of Ontario, Canada has recently published Ontario Regulation 359/09, Renewable Energy Approvals, that require setback distances of 550 to 950 meters (0.34 to 0.59 miles). These distances are meant to limit the A-weighted sound levels to about 40 dB (perhaps 15 to 20 dB above an ambient of 20 to 25 dB). This allowable increase above ambient far exceeds any existing community noise standard or guidelines of 5 to 10 dB).

[7] ANSI S12.9-2005/Part 4 (Revision of ANSI S12.9-1996/Part 4) “Quantities and Procedures for Description and Measurement of Environmental Sound – Part 4: Noise Assessment and Prediction of Long-term Community Response,” Annex F: Estimated percentage of a population highly annoyed as a function of adjusted day-night sound level.

At the other end of the scale, at least one white paper[4] suggests a review of the evidence would dictate a setback of one mile or more. Recent personal direct experience with a rural wind farm project of only three turbines in Maine shows nearby residents complaining vigorously at distances of approximately 0.5 mile from the nearest turbine. Symptoms described by residents are similar to those identified in Section 3 of this letter report. Setback distances on the order of *at least* one mile are probably in order to protect residents during wind turbine operations at this site under low ambient sound level conditions (turbine type is the GE 1.5 megawatt unit). Based on the evidence, distances of 1.5 to 2 miles would provide the margin of safety called for in the preamble of this report.

7. Policy Question.

Most sound level guidelines and standards (originally designed for suburban or urban areas) allow a new source to raise the ambient sound level by no more than some fixed amount. Increases of 5 to 10 decibels are not uncommon under conditions where the existing ambient is relatively low. If the existing ambient is already moderate to high then lesser increases are allowed. The general philosophy underlying the latter condition is to place a cap on the amount of noise a community should experience.

A policy question not frequently addressed is the extent to which this "increase above ambient" form of regulation is appropriate for rural settings. By its very nature it allows for the acoustic urbanization of rural areas. As each new source is introduced it is allowed to raise the ambient sound level such that the new raised level becomes the criterion for the next source to be introduced. The process can iterate until the cap is reached. The policy question is whether or not this leads to an acceptable or desired outcome regarding quality of life in rural areas.

8. Some concluding remarks.

In conclusion I would like to present the following observations:

1. Wind turbine noise appears to be eliciting annoyance and physiological responses not experienced from other noise sources of similar sound level.
2. Wind turbines are most often sited in rural areas where ambient sound levels are low, resulting in audibility of the turbines at lower sound levels than would be expected in urban or suburban environments.
3. It is not at all clear whether people's responses to wind turbine noise are the result of the absolute loudness (irrespective of the ambient), to the audibility of this unique source, or to some other characteristic such as the periodic modulated nature of the sound and low-frequency content.
4. Under conditions of uncertainty where the stakes of human heath and welfare are high, it would seem prudent to use the best available information available at the moment. Lacking sophisticated epidemiological studies, laboratory listening tests and the like, well-reasoned interpretations of anecdotal information allowing for an adequate margin of safety may have to be used to make these important decisions so that sufficient protections are put in place.

Very truly yours,

Richard D. Horonjeff