JOINT STUDY SESSION of the Environment and Land Use Committee and the Zoning Board of Appeals

County of Champaign, Urbana, Illinois

Thursday, June 30, 2022 - 6:30 p.m.

Shields-Carter Meeting Room

Brookens Administrative Center, 1776 E. Washington St., Urbana

AGENDA

I. Call to Order
   A. ELUC
   B. ZBA

II. Roll Call
   A. ELUC
   B. ZBA

III. Suspension of ZBA Bylaws

IV. Approval of Agenda

V. Public Participation

VI. Discussion of authorization for a Public Hearing on Proposed Zoning Ordinance Text Amendment to revise select wind farm ordinance sections as follows:
   a. Increase the minimum separation to principal structures to 3,250 feet to the non-participating property line

   b. Change the noise limit to 39dBA

   c. Add a noise limit of 80 dBC for infrasound

VII. Adjournment

All meetings are at Brookens Administrative Center – 1776 E Washington Street in Urbana – unless otherwise noted. To enter Brookens after 4:30 p.m., enter at the north (rear) entrance located off Lierman Avenue. Champaign County will generally, upon request, provide appropriate aids and services leading to effective communication for qualified persons with disabilities. Please contact Administrative Services, 217-384-3776, as soon as possible but no later than 48 hours before the scheduled meeting.

Champaign County
Department of
PLANNING & ZONING

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Urbana, Illinois 61802

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TO: **Environment and Land Use Committee and Zoning Board of Appeals**

FROM: **John Hall, Zoning Administrator**
Susan Burgstrom, Senior Planner

DATE: **June 21, 2022**

RE: **Discussion of proposed Text Amendment to revise minimum separations and noise limits for wind farms in the Zoning Ordinance**

BACKGROUND

The ZBA took final action on Zoning Case 037-AT-22 at their meeting on Thursday, May 26, 2022. During this meeting, they provided three statements as part of their recommendation for denial of the height and setback proposed for wind farms:

21. The ZBA is convinced that the existing minimum required separation to a principal structure is inadequate and should be increased to at least 3,250 feet from property lines.

22. The ZBA is convinced that the existing Illinois Pollution Control Board noise limit is inadequate and a noise limit of 39 dB(A) (audible) at the property line would better protect Champaign County residents.

23. The ZBA is convinced that the existing Illinois Pollution Control Board noise limit is inadequate and a noise limit of 80dB (for infrasound) at the property line would better protect Champaign County residents.

The purpose of this joint meeting of ELUC and the ZBA is to begin the discussion of how the Zoning Ordinance might be amended to address the concerns of the ZBA related to minimum separations and noise limits. Moving forward, ELUC and ZBA will be asked to balance the rights of those who choose to participate in the wind farms and those who do not.

3,250 FOOT RECOMMENDED SETBACK FROM PROPERTY LINES

The current Zoning Ordinance requirements for wind turbine setbacks are in Section 6.1.4 C. as follows:

1. At least 1,000 feet separation from the exterior above-ground base of a WIND FARM TOWER to any PARTICIPATING DWELLING OR PRINCIPAL BUILDING provided that the noise level caused by the WIND FARM at the particular building complies with the applicable Illinois Pollution Control Board regulations.

2. At least 1,200 feet separation from the exterior above-ground base of a WIND FARM TOWER to any existing NON-PARTICIPATING DWELLING OR PRINCIPAL BUILDING provided that the noise level caused by the WIND FARM at the particular building complies with the applicable Illinois Pollution

Control Board regulations and provided that the separation distance meets or exceeds any separation recommendations of the manufacturer of the wind turbine used on the WIND FARM TOWER.

3. The above separations may be reduced to a distance no less than 1.10 times the total WIND FARM TOWER height (measured to the tip of the highest rotor blade) upon submission of a PRIVATE WAIVER signed by the owner of said DWELLING or BUILDING or adjacent property. The PRIVATE WAIVER must specify the agreed minimum separation and specifically acknowledge that the grantor accepts the resulting noise level caused by the WIND FARM.

4. A separation distance equal to 1.10 times the total WIND FARM TOWER height (measured to the tip of the highest rotor blade) from the exterior above-ground base of a WIND FARM TOWER to the nearest adjacent property line for property that is also part of the WIND FARM County Board SPECIAL USE Permit. This separation may be reduced upon submission of a PRIVATE WAIVER signed by the owner of the adjacent property. The PRIVATE WAIVER must specify the agreed minimum separation.

The origins of a 3,250 foot setback were two reports that were distributed to the ZBA by Brian Armstrong, attorney with Luetkehans, Brady, Garner & Armstrong at the March 17, 2022 meeting:

- The Health Canada publication titled *Wind Turbine Noise and Health Study: Summary of Results* published November 6, 2014 (Attachment A) was undertaken in two Canadian provinces, Ontario and Prince Edward Island, and included responses from 1,283 households in the vicinity of 18 wind turbine developments with a total of 399 wind turbines. The study consisted of three primary components:
    - An in-person questionnaire to randomly selected participants living at varying distances from wind turbine installations regarding self-reported sleep; self-reported illnesses and chronic diseases; self-reported stress; quality of life indicators; and annoyance. Wind turbine noise exposure was not found to be associated with self-reported sleep quality or with self-reported illnesses or self-reported stress or with any significant change in quality of life. Annoyance towards several wind turbine features (i.e. noise, shadow flicker, blinking lights, vibrations, and visual impacts) were statistically associated with increasing levels of wind turbine noise.

    - Collection of objectively measured outcomes that assessed hair cortisol, blood pressure, and sleep quality. Exposure to wind turbine noise was not observed to be related to hair cortisol concentrations, blood pressure, resting heart rate, or measured sleep.

    - More than 4,000 hours of wind turbine noise measurement that supported the calculation of wind turbine noise at the residences in the study. The 1,238 residences were grouped into different categories of calculated outdoor A-weighted wind turbine noise levels of less than 25 dB(A); 25 to <30 dB(A); 30 to <35 dB(A); 35 to < 40 dB(A); and greater than 40 dB(A) (but an inadequate sample size above 46 dB(A)). The report did not come to a conclusion regarding a recommended distance from wind turbines.

- *Proposed minimum siting distances for Livingston County Wind Farms*, undated, was prepared by Schomer and Associates, Inc. (Attachment B). The paper is an analysis of separation distances and calculated noise levels from existing wind turbines for the 1,283 dwellings in the Health Canada publication titled *Wind Turbine Noise and Health Study: Summary of Results* published November 6, 2014. The report divides the separations for 745 dwellings in the Health Canada study into nine separation categories from 1,500 feet to 3,750 feet. 493 dwellings in the Health Canada study were located further than 3,750 feet from a turbine and those dwellings are not included in this analysis. The 745 dwellings in this analysis were divided into 6 noise levels from 35 dB(A) to 40 dB(A). The report also included the results of a study by Minnesota Department of Commerce regarding international wind turbine noise limits for residences and the requirements of the American National Standards Institute (ANSI). The report concludes with a recommendation for a noise limit of 38 dB(A) and a minimum separation of 3,250 feet.

Virtually all of the public testimony during the recent wind farm case claimed that the current setbacks are insufficient and cause issues such as: adverse health impacts; annoyance due to noise, shadow flicker from the blade rotation, and blinking lights; and inability to enjoy one's entire property due to these concerns.

A summary of public testimony from the Case 037-AT-22 hearing can be found in Attachment C. No complaints have been received by P&Z Staff related to Champaign County's only wind farm, California Ridge, since its construction 10 years ago in the northeast part of the county.

P&Z Staff prepared a map (Attachment D) showing what areas of the county would be available for wind farm development only taking into account if a distance of 3,250 feet was established between turbines and the property lines of residential lots. There are few areas in the County that could be developed as wind farms with that setback.

Attachment E includes 4 maps showing the existing California Ridge turbine locations. P&Z Staff marked a red X on those turbines that would not have been built under the following conditions:

- At 39 dB(A), a separation distance of greater than 3,250 feet to non-participating dwellings would have resulted in 11 of the 30 turbines being built.
- At 39 dB(A), a separation distance of greater than 3,250 feet to non-participating property lines would have resulted in 6 of the 30 turbines being built.
- At 40 dB(A), a separation distance of 2,360 feet to non-participating dwellings would have resulted in 16 of the 30 turbines being built.
- At 40 dB(A), a separation distance of 2,360 feet to non-participating property lines would have resulted in 10 of the 30 turbines being built.

In the public hearing for Case 037-AT-22, testimony was received indicating that landowners who are otherwise non-participating might be interested in receiving private waivers from a wind farm company to allow a reduced separation distance to their property.

39 DB(A) NOISE LIMIT FOR AUDIBLE NOISE

The current Zoning Ordinance requirement for wind turbine noise is in Section 6.1.4 I. as follows:

1. Noise levels from each WIND FARM TOWER or WIND FARM shall be in compliance with the applicable Illinois Pollution Control Board (IPCB) regulations (35 *Illinois Administrative Code* Subtitle H: Noise Parts 900, 901, 910).

The IPCB regulations can be found in Attachment F. Testimony received during the recent public hearings suggested that the IPCB regulations should not be used for wind turbines because these regulations did not anticipate the complex nature of wind turbines that did not even exist when the regulations were created.

Studies presented as part of testimony suggested that a high majority of people could avoid adverse health impacts and annoyance if sound from turbines was limited to 39 dB(A) rather than IPCB's maximum limit of 51 dB(A). Dr. Paul Schomer, an acoustician from Champaign, Illinois, testified at numerous public hearings that 39 dB(A) should be the maximum limit to avoid annoyance and health impacts from wind turbine noise, and a distance of 3,250 feet would ensure that 39 dB(A) would not be exceeded.

In a paper titled *A possible criterion for wind farms* from the 173rd Meeting of the Acoustical Society of America in June 2017 (Attachment G), Dr. Schomer and Pranav Pamidighantam studied four distinct methodologies for determining noise criterion for wind farms. In summary, the four sets of data from these independent studies "result in criteria recommendations that are remarkably close to one another, lending support to a 24-hour A-weighted Leq wind turbine noise criterion in or around the range of 36-38 dB(A)." The report does not suggest a certain distance that would be associated with that noise level range.

John Hall, Zoning Administrator, compiled a list of A-weighted decibel ratings (dB(A)) and associated setbacks from testimony and studies received during the public hearings for Case 037-AT-22. Only those citations that showed a noise level with associated setback were included. Also included are modeled noise levels from the existing California Ridge wind farm turbines in Champaign County.

Table Comparing Selected Wind Farm Tower Separations and Corresponding Wind Farm Noise Case 037-AT-22

June 21, 2022

Separation distance	**Source**	**Corresponding noise level**
1,217 feet	Turbine #22 California Ridge Wind Farm (Champaign County)	44.6 dB(A) modeled [1]
1,550 feet	Turbine #10 California Ridge Wind Farm (Champaign County)	43.1 dB(A) modeled [1]
1,665 feet[2]	Former Hartke residence in Vermilion County	Exceeded IPCB limit during onsite measurement in some situations; 43 dB(A) modeled[1] in Vermilion County California Ridge Wind Farm
1,900 feet	Turbine #23 California Ridge Wind Farm (Champaign County)	41.0 dB(A) modeled [1]
2,360 feet	Turbine #28 California Ridge Wind Farm (Champaign County)	40 dB(A) modeled [1]
2,500 feet	Health Canada study	40 dB(A) modeled (12.3% unprotected)
2,580 feet	Ted Hartke handout of 3/31/22	34 dB(A) "design level"

	(based on turbine noise of 102dB(A))	(maximum of 39 dB(A); from Steven Ambrose)
Separation distance	**Source**	**Corresponding noise level**
2,750 feet	Health Canada study	40 dB(A) modeled (4.5% unprotected)
2,820 feet ±	California Ridge Wind Farm (Champaign County)	39 dB(A) modeled [1] (estimated)
3,000 feet	Health Canada study	40 dB(A) modeled (.9% unprotected)
3,000 feet	Health Canada study	39 dB(A) modeled [1] (4.7% unprotected)
3,250 feet	Dr. Paul Schomer recommendation to Livingston County	38 dB(A) modeled [1] (2.8% unprotected; based on data from Health Canada study)
1.25 miles [3]	Dr. Jerry Punch PowerPoint [3]	38 to 40 dB LAeq [3]

Notes

1. ”Modeled” means the noise level was the result of computer modeling.
2. The Hartke residence was also within 2,225 feet of a second wind turbine and within 3,147 feet of a third wind turbine and 3,454 feet of a fourth wind turbine.
3. In his PowerPoint slides Dr. Jerry Punch does not actually recommend any minimum separation distance or any noise limit.

80 DB NOISE LIMIT FOR INFRASOUND

Infrasound is defined as sound with frequencies below 20 Hertz. IPCB regulations do not go below 31.5 Hertz, and therefore the Champaign County Zoning Ordinance does not regulate infrasound.

ZBA member Tom Anderson appreciated the handout titled *Wind Turbine Noise: Effects on Human Health* by Jerry Punch that was distributed by Attorney Brian Armstrong at the March 17, 2022 ZBA meeting (Attachment H). In particular, slide 32 stated: “Low-frequency noise levels are typically not masked by wind or other noises and cannot be controlled effectively by barriers so that distance is the only practical means of achieving acceptable noise levels.” Mr. Anderson made the motion to recommend regulating for infrasound at a limit of 80 decibels, which was approved.

Testimony received during the recent public hearings suggested that infrasound can be measured and should be regulated due to the adverse health impacts that some experience with this type of sound. However, a study presented by Attorney Brian Armstrong at the March 17, 2022 ZBA meeting concluded that limiting audible noise levels would be sufficient (Attachment I). A January 2017 paper in the journal Sound & Vibration titled *Health Effects from Wind Turbine Low Frequency Noise & Infrasound* by authors George Hessler (George Hessler Associates, Inc., Haymarket VA), Geoff Leventhall (consultant, Ashtead, Surrey, UK), Paul Schomer (Schomer and Associates, Inc., Champaign IL), and Bruce Walker (Channel Islands Acoustics, Camarillo, CA) concluded that infrasound (0 to 20 Hz) can almost be ruled as a potential mechanism for stimulating motion sickness symptoms but some additional research was recommended. Pending those results, the four authors recommended that an acceptable A-weighted noise level is all that should be required. In the paper the four authors also share their recommended noise limits for wind farms which are 35 to 39 dB(A) (Schomer) and 40 dB(A) (Leventhall and Hessler with Hessler having a 45 dB(A) maximum) and 45dB(A) (Walker).

Further study is therefore needed to determine the desirable limit for infrasound noise.

ATTACHMENTS

A *Proposed minimum siting distances for Livingston County Wind Farms*, prepared by Schomer and Associates, Inc. (undated)

B *Wind Turbine Noise and Health Study: Summary of Results* published by Health Canada on November 6, 2014

C Summary of public testimony from the Case 037-AT-22 public hearings

D Map of 3,250 setback to property line of residential lots prepared by P&Z Staff on June 2, 2022

E P&Z Staff markup of California Ridge wind turbines maps

F Illinois Pollution Control Board noise regulations *(35 IAC 901.102)*

G *A possible criterion for wind farms* from the 173rd Meeting of the Acoustical Society of America, Dr. Schomer and Pranav Pamidighantam, June 2017

H *Wind Turbine Noise: Effects on Human Health* presentation by Dr. Jerry Punch at Christian County ZBA, June 23, 2020

I *Health Effects from Wind Turbine Low Frequency Noise & Infrasound* by George Hessler (George Hessler Associates, Inc., Haymarket VA), Geoff Leventhall (consultant, Ashtead, Surrey, UK), Paul Schomer (Schomer and Associates, Inc., Champaign IL), and Bruce Walker (Channel Islands Acoustics, Camarillo, CA), January 2017

Proposed minimum siting distances for Livingston County Wind Farms

Schomer and Associates, Inc.

LBGA
EXHIBIT
6

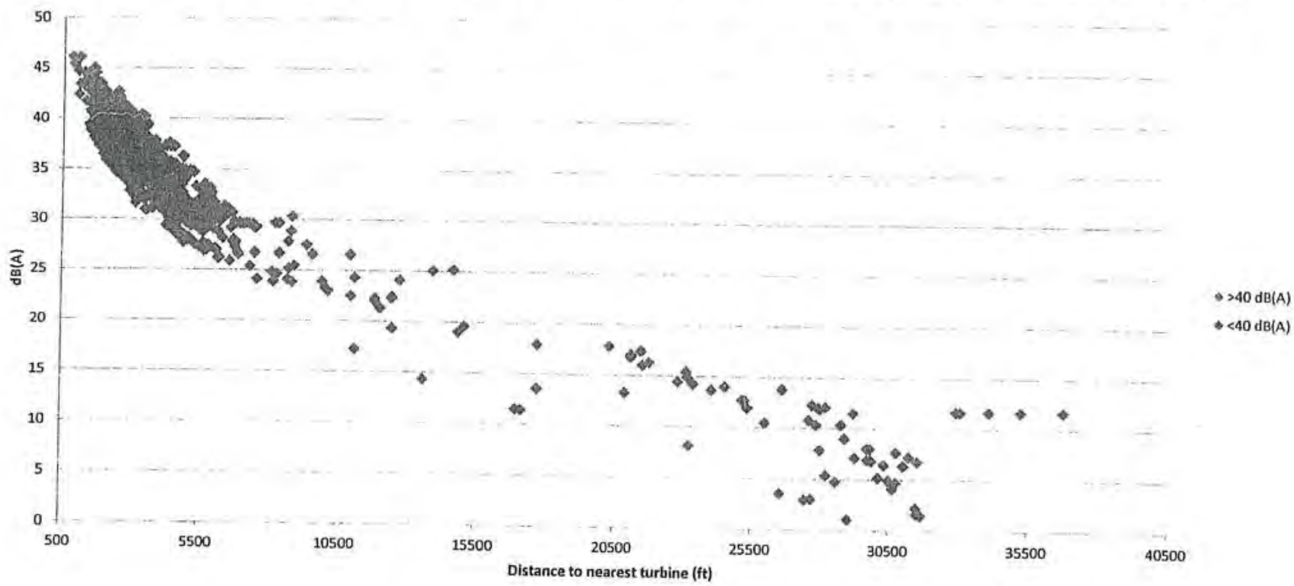
Health Canada Study

- 6 papers in the Journal of the Acoustical Society of America special Issue on Wind Turbine effects:
  - **Wind turbine sound power measurements**
  - **Wind turbine sound pressure level calculations at dwellings**
  - **Exposure to wind turbine noise: Perceptual responses and reported health effects**
  - **Personal and situational variables associated with wind turbine noise annoyance**
  - **Self-reported and measured stress related responses associated with exposure to wind turbine noise**
  - **Estimating annoyance to calculated wind turbine shadow flicker is improved when variables associated with wind turbine noise exposure are considered**
- 3 Papers in other journals
  - "Self-reported and Objectively Measured Health Indicators among a Sample of Canadians Living within the Vicinity of Industrial Wind Turbines: Social Survey and Sound Level Modelling Methodology." in *Noise News International*
  - "An assessment of quality of life using the WHOQOL-BREF among participants living in the vicinity of wind turbines." in *Environmental Research*
  - "Effects of Wind Turbine Noise on Self-Reported and Objective" in *Sleep*

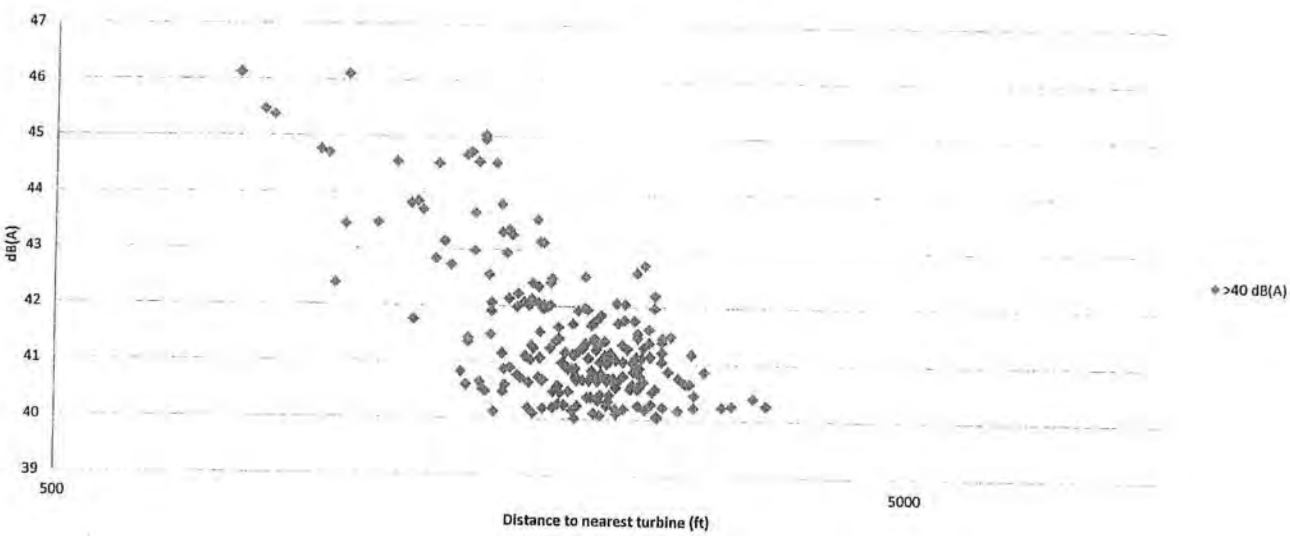
Health Canada Study

- More than 20 on the expert committee with 5 coming from the international community; about 10 Ph.Ds and 4 M.Ds
- About 20 researchers named on the papers
- Comprehensive and thorough with extensive credentials for all involved parties

Distribution of Health Canada Data, 1238 houses



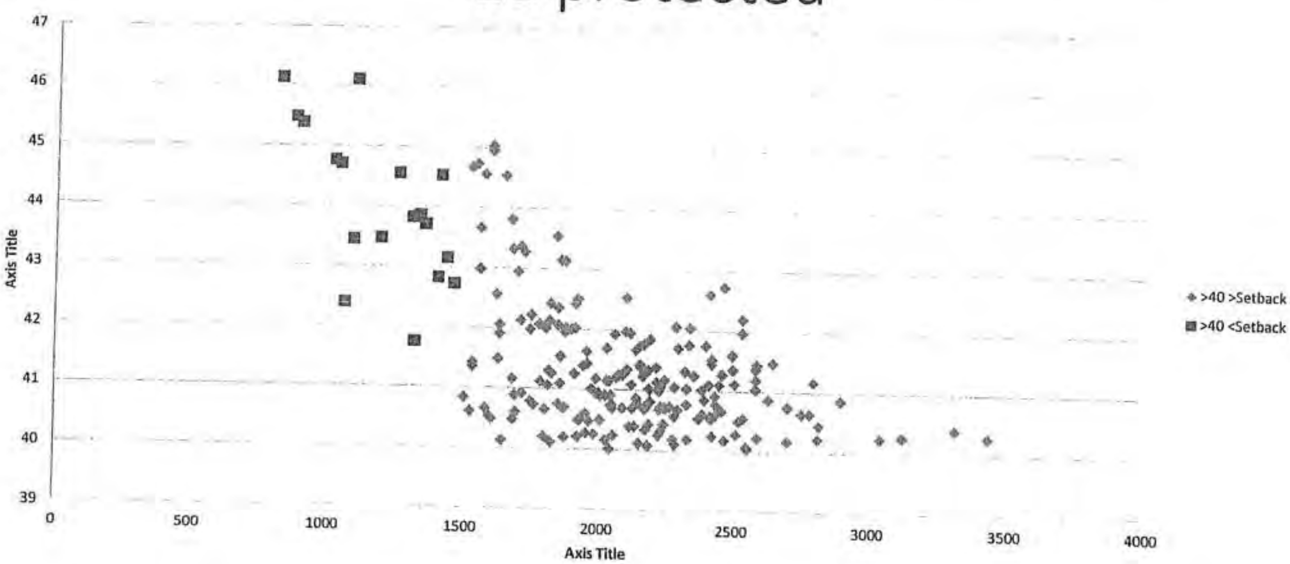
Only data above 40 dB(A) shown, 220 houses
No Setback



Number of houses exceeding limits per setback distance

SETBACKS	Kilometers	--	0.46	0.61	0.69	0.76	0.84	0.91	0.99	1.07	1.14
	Feet	--	1500	2000	2250	2500	2750	3000	3250	3500	3750
40 dB(A)		220									
39 dB(A)											
38 dB(A)											
37 dB(A)											
36 dB(A)											
35 dB(A)											

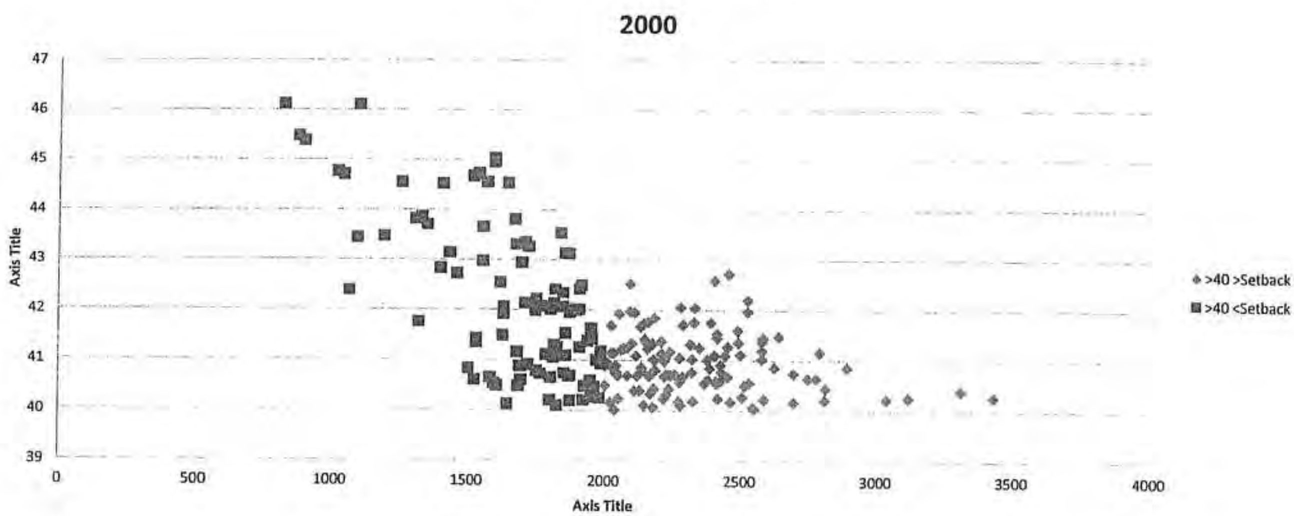
With 1500 ft setback, 202 of 220 remain
18 protected



Number of houses exceeding limits per setback distance

SETBACKS											
	Kilometers	--	0.46	0.61	0.69	0.76	0.84	0.91	0.99	1.07	1.14
	Feet	--	1500	2000	2250	2500	2750	3000	3250	3500	3750
40 dB(A)		220	202								
39 dB(A)											
38 dB(A)											
37 dB(A)											
36 dB(A)											
35 dB(A)											

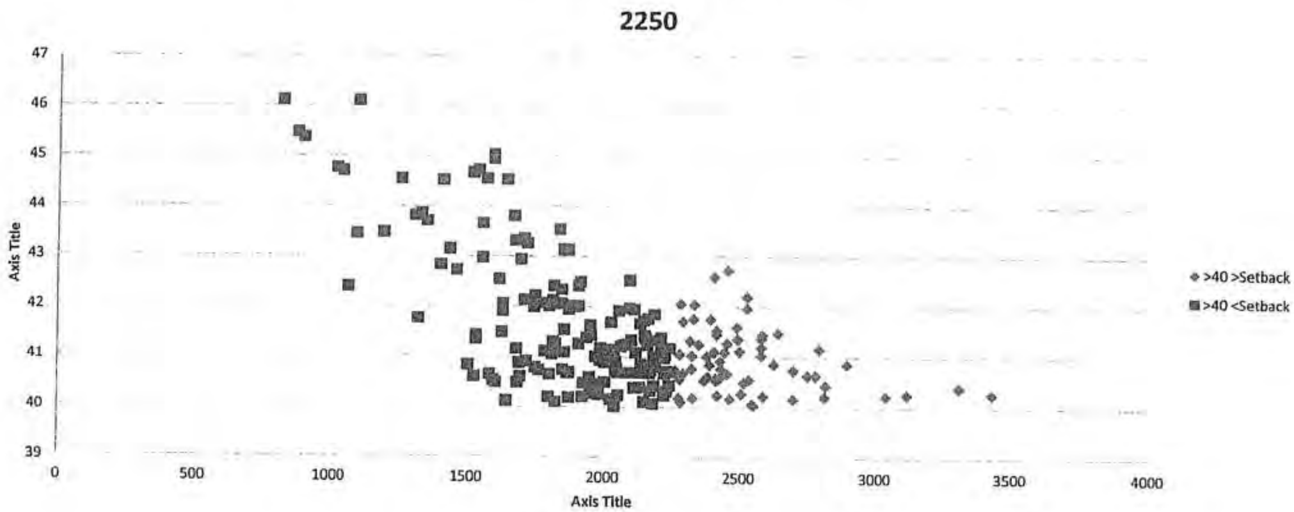
With 2000 ft setback, 124 of 220 remain 96 protected



Number of houses exceeding limits per setback distance

SETBACKS	Kilometers	--	0.46	0.61	0.69	0.76	0.84	0.91	0.99	1.07	1.14
	Feet	--	1500	2000	2250	2500	2750	3000	3250	3500	3750
40 dB(A)		220	202	124							
39 dB(A)											
38 dB(A)											
37 dB(A)											
36 dB(A)											
35 dB(A)											

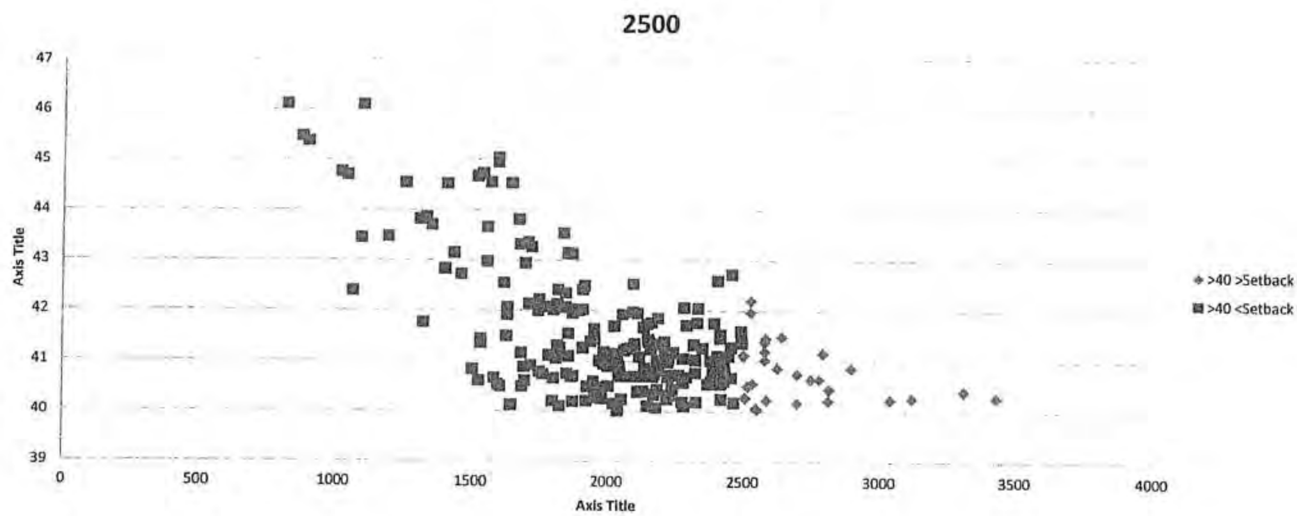
With 2250 ft setback, 66 of 220 remain 154 protected



Number of houses exceeding limits per setback distance

SETBACKS	Kilometers	--	0.46	0.61	0.69	0.76	0.84	0.91	0.99	1.07	1.14
	Feet	--	1500	2000	2250	2500	2750	3000	3250	3500	3750
40 dB(A)		220	202	124	66						
39 dB(A)											
38 dB(A)											
37 dB(A)											
36 dB(A)											
35 dB(A)											

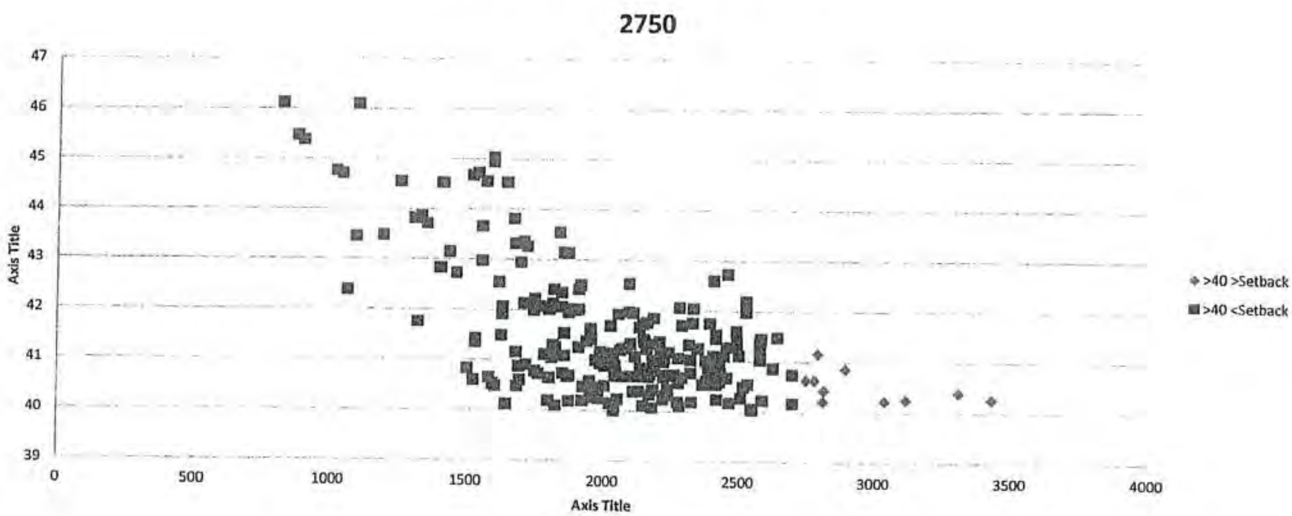
With 2500 ft setback, 27 of 220 remain 193 protected



Number of houses exceeding limits per setback distance

SETBACKS										
Kilometers	--	0.46	0.61	0.69	0.76	0.84	0.91	0.99	1.07	1.14
Feet	--	1500	2000	2250	2500	2750	3000	3250	3500	3750
40 dB(A)	220	202	124	66	27					
39 dB(A)										
38 dB(A)										
37 dB(A)										
36 dB(A)										
35 dB(A)										

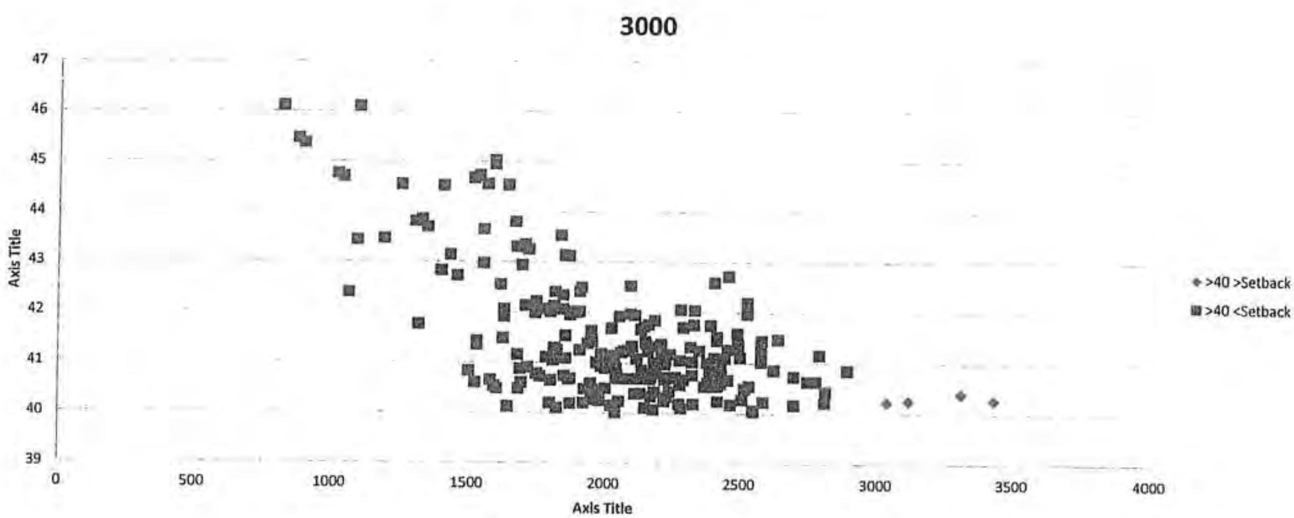
With 2750 ft setback, 10 of 220 remain 210 protected



Number of houses exceeding limits per setback distance

SETBACKS	Kilometers	--	0.46	0.61	0.69	0.76	0.84	0.91	0.99	1.07	1.14
	Feet	--	1500	2000	2250	2500	2750	3000	3250	3500	3750
40 dB(A)		220	202	124	66	27	10				
39 dB(A)											
38 dB(A)											
37 dB(A)											
36 dB(A)											
35 dB(A)											

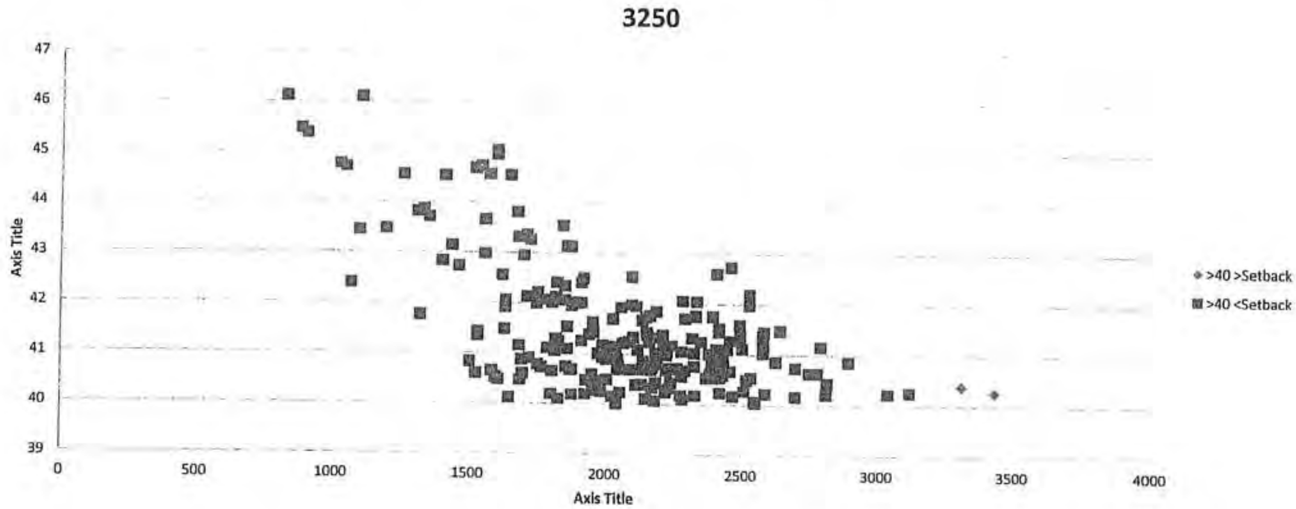
With 3000 ft setback, 4 of 220 remain 216 protected



Number of houses exceeding limits per setback distance

SETBACKS	Kilometers	--	0.46	0.61	0.69	0.76	0.84	0.91	0.99	1.07	1.14
	Feet	--	1500	2000	2250	2500	2750	3000	3250	3500	3750
40 dB(A)		220	202	124	66	27	10	4			
39 dB(A)											
38 dB(A)											
37 dB(A)											
36 dB(A)											
35 dB(A)											

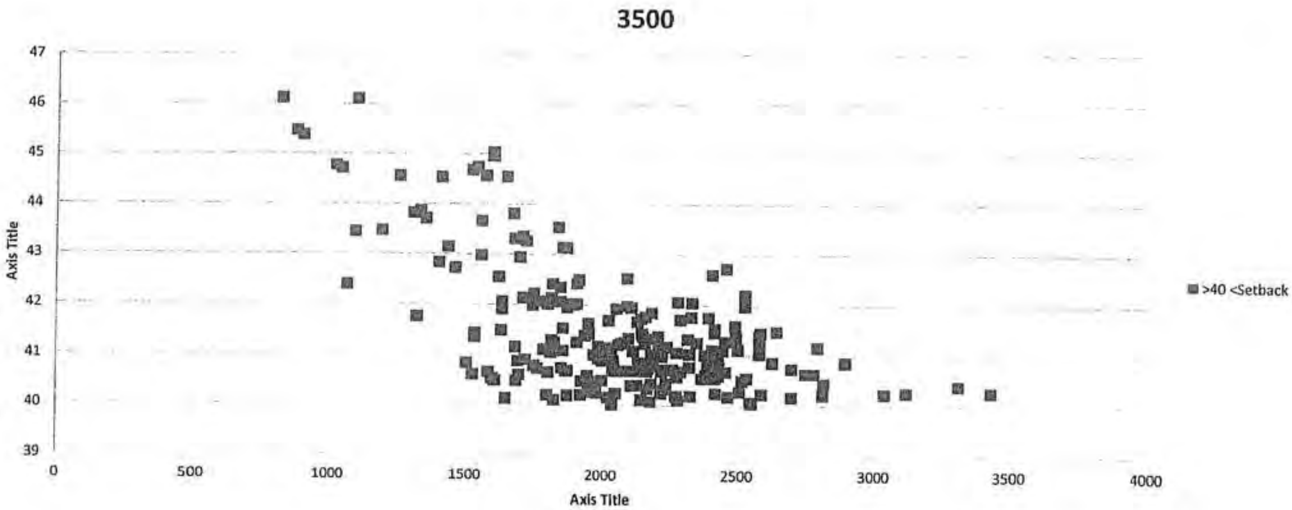
With 3250 ft setback, 2 of 220 remain 218 protected



Number of houses exceeding limits per setback distance

SETBACKS											
	Kilometers	--	0.46	0.61	0.69	0.76	0.84	0.91	0.99	1.07	1.14
	Feet	--	1500	2000	2250	2500	2750	3000	3250	3500	3750
40 dB(A)		220	202	124	66	27	10	4	2		
39 dB(A)											
38 dB(A)											
37 dB(A)											
36 dB(A)											
35 dB(A)											

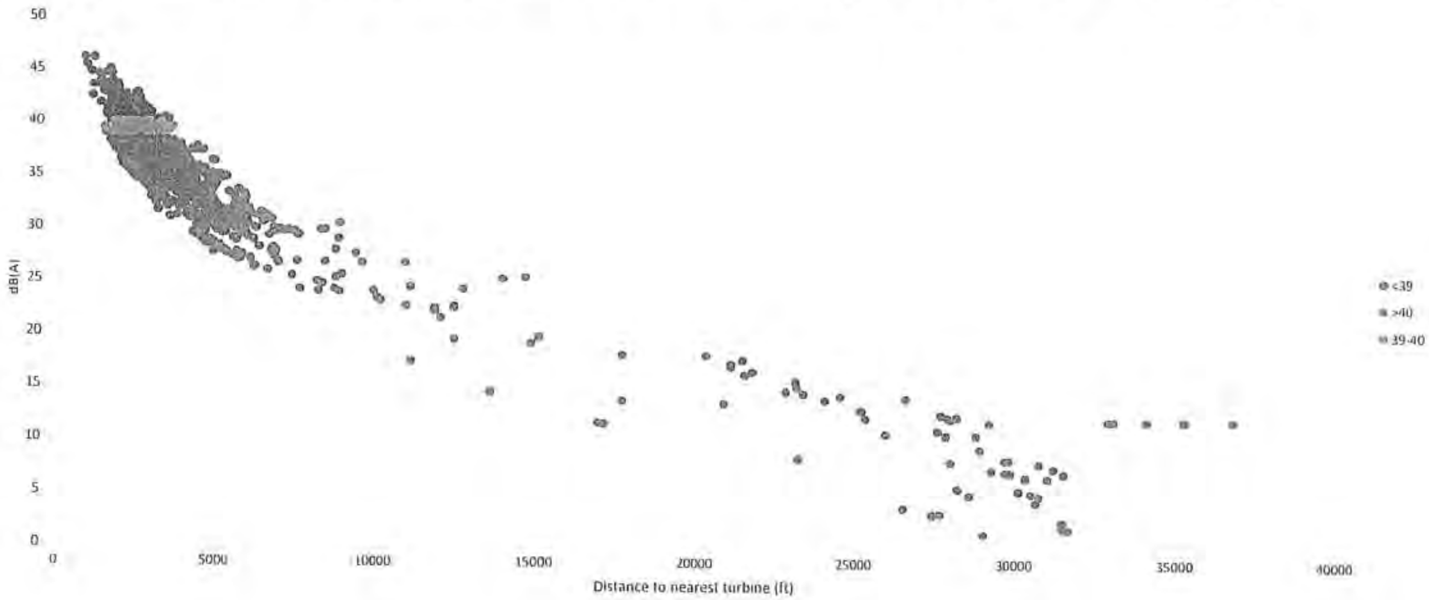
With 3500 ft setback, 0 of 220 remain
220 protected



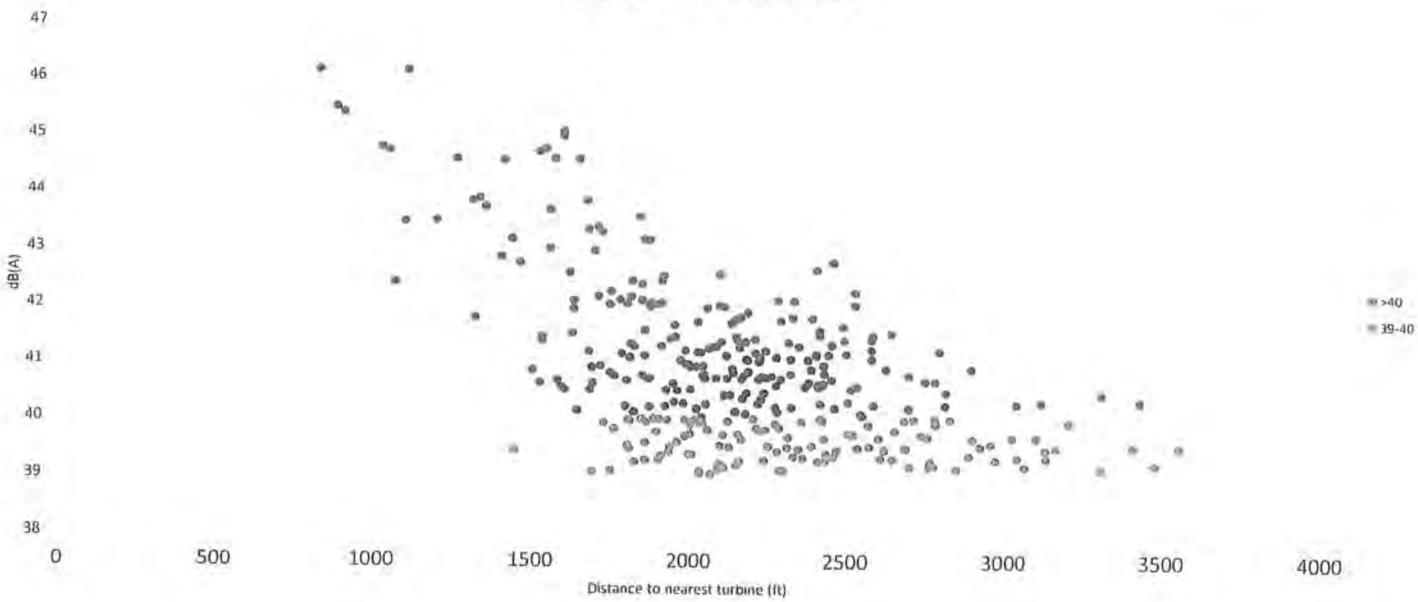
Number of houses exceeding limits per setback distance

SETBACKS											
	Kilometers	--	0.46	0.61	0.69	0.76	0.84	0.91	0.99	1.07	1.14
	Feet	--	1500	2000	2250	2500	2750	3000	3250	3500	3750
	40 dB(A)	220	202	124	66	27	10	4	2	0	0
	39 dB(A)										
	38 dB(A)										
	37 dB(A)										
	36 dB(A)										
	35 dB(A)										

Number of houses exceeding limit, 39 dB(A)



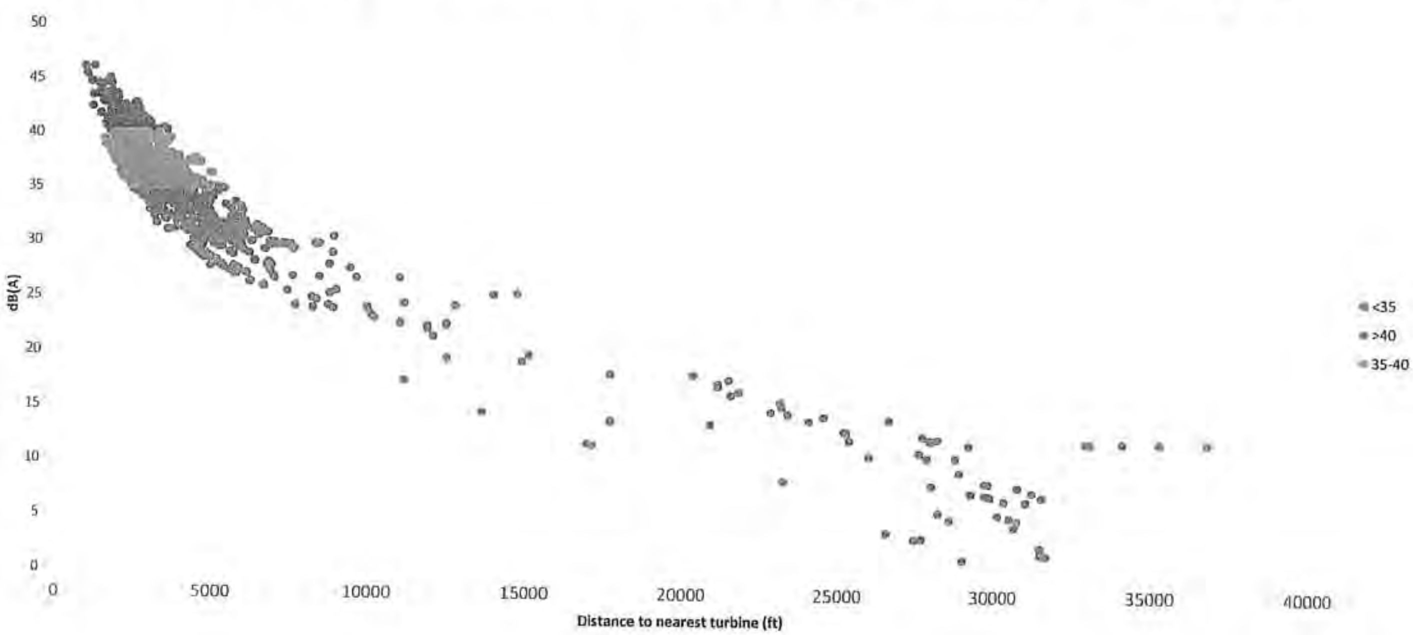
Only data above 39 dB(A) shown, 335 houses
No Setback



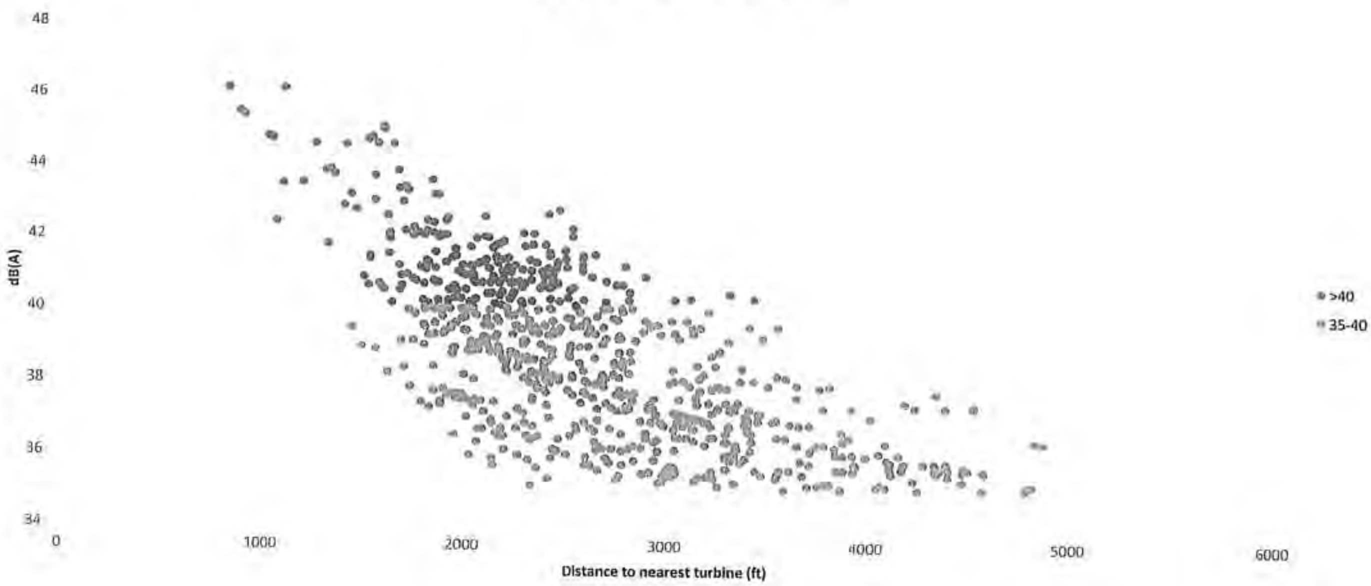
Number of houses exceeding limits per setback distance

SETBACKS											
	Kilometers	--	0.46	0.61	0.69	0.76	0.84	0.91	0.99	1.07	1.14
	Feet	--	1500	2000	2250	2500	2750	3000	3250	3500	3750
40 dB(A)		220	202	124	66	27	10	4	2	0	0
39 dB(A)		335	316	214	128	68	35	16	6	1	0
38 dB(A)											
37 dB(A)											
36 dB(A)											
35 dB(A)											

Number of houses exceeding limit, 35 dB(A)



Only data above 39 dB(A) shown,745 houses
No Setback



Number of houses exceeding limits per setback distance

SETBACKS										
Kilometers	--	0.46	0.61	0.69	0.76	0.84	0.91	0.99	1.07	1.14
Feet	--	1500	2000	2250	2500	2750	3000	3250	3500	3750
40 dB(A)	220	202	124	66	27	10	4	2	0	0
39 dB(A)	335	316	214	128	68	35	16	6	1	0
38 dB(A)	430	410	300	193	107	56	30	12	3	0
37 dB(A)	534	514	390	277	178	113	72	38	16	10
36 dB(A)	643	623	498	373	263	184	129	74	36	21
35 dB(A)	745	725	600	472	356	270	204	139	89	65

Number of houses exceeding limits per setback distance

SETBACKS	Kilometers	--	0.46	0.61	0.69	0.76	0.84	0.91	0.99	1.07	1.14
	Feet	--	1500	2000	2250	2500	2750	3000	3250	3500	3750
40 dB(A)		220	202	124	66	27	10	4	2	0	0
39 dB(A)		335	316	214	128	68	35	16	6	1	0
38 dB(A)		430	410	300	193	107	56	30	12	3	0
37 dB(A)		534	514	390	277	178	113	72	38	16	10
36 dB(A)		643	623	498	373	263	184	129	74	36	21
35 dB(A)		745	725	600	472	356	270	204	139	89	65

dB(A) and Setback Criterion

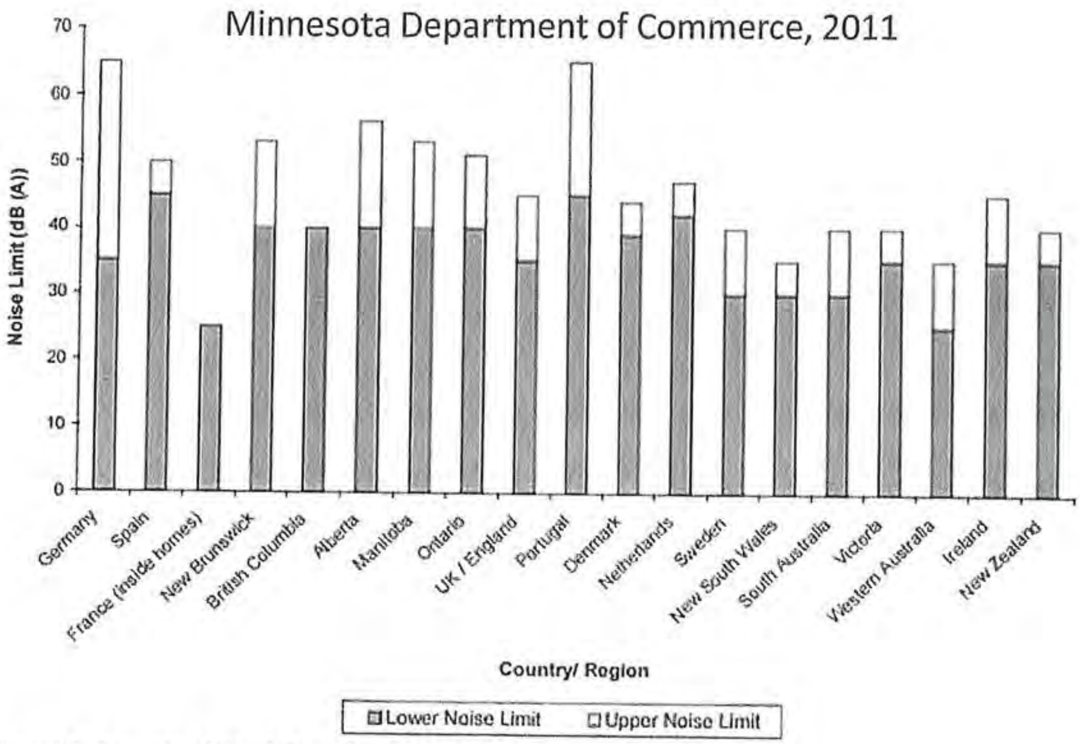


Figure 3: Country Wind Turbine Noise Limits at Residences

Example of Land use designations

- South Australia limit based on highest applicable:
  - Rural: 35 dB(A), or
  - Non-rural: 40 dB(A), or
  - 5 dB(A) above background measured as L90, 10 min
    - Note: USA background measurement standards includes the use of I-weighting when bird and/or insect noise is a problem and substantially longer measurement times

Recommended dB(A) limits, Health Canada Study

- "Consistent with Pedersen et al. (2009), the increase in WTN annoyance was clearly evident when moving from [30–35) dB to [35–40) dB, where the prevalence of WTN annoyance increased from 1% to 10%. This continued to increase to 13.7% for areas where WTN levels were [40–46] dB. The prevalence of WTN annoyance was higher outdoors, during the summer, and during evening and nighttime hours. Pedersen et al. (2009) also found that annoyance with WTN was greater outdoors compared to indoors."
- **The limit should be around 5-6%** Highly annoyed (FAA, DoD)
- The dB(A) limit based upon Health Canada data should be between 36-39 dB(A)

ANSI S 12.9 Part 4

- Basic Limit: 55 DNL
- Quiet Rural areas: -10 dB(A); so 55-10= 45 DNL
- 45 DNL is 35-39 dB(A) at night

Recommended dB(A) limit and corresponding setback

- Based on the Minnesota report, ANSI S 12.9 Part 4, and the Health Canada Study, I recommend that the dB(A) limit should be **38 dB(A)**

SETBACKS										
Kilometers	--	0.46	0.61	0.69	0.76	0.84	0.91	0.99	1.07	1.14
Feet	--	1500	2000	2250	2500	2750	3000	3250	3500	3750
40 dB(A)										
39 dB(A)										
38 dB(A)	430	410	300	193	107	56	30	12	3	0
37 dB(A)										
36 dB(A)										
35 dB(A)										

References

- Minnesota Department of Commerce, Energy Facility Permitting. (2011). International Review of Policies and Recommendations for Wind Turbine Setbacks from Residences: Setbacks, Noise, Shadow Flicker, and Other Concerns. Retrieved from http://mn.gov/ commerce/energyfacilities/documents/International_Review_of_Wind_Policies_and_Recommendations.pdf
- "Exposure to wind turbine noise: Perceptual responses and reported health effects." Michaud, David S., Feder, Katya, Keith, Stephen E., Voicescu, Sonia A.,Marro, L. ,Than, J., Guay, M., Denning, A., McGuire, D., Bower, T., Lavigne, E., Murray, Brian J., Weiss, Shelly K., van den Berg, F,. The Journal of the Acoustical Society of America, 139, 1443-1454 (2016), DOI:http://dx.doi.org/10.1121/1.4942391

Environmental and Workplace Health

Wind Turbine Noise and Health Study: Summary of Results

Background and Rationale

The Government of Canada is committed to protecting the health and well-being of Canadians. Jurisdiction for the regulation of noise is shared across many levels of government in Canada. Health Canada's mandate with respect to wind power includes providing science-based advice, upon request, to federal departments, provinces, territories and other stakeholders on the potential impacts of wind turbine noise (WTN) on community health and well-being. Provinces and territories, through the legislation they have enacted, make decisions in relation to areas including installation, placement, sound levels and mitigation measures for wind turbines.

Globally, wind energy is relied upon as an alternative source of renewable energy. In Canada wind energy capacity has grown from approximately 137 Megawatts (MW) in 2000 to just over 8.5 Gigawatts (GW) in 2014 (CANWEA, 2014). At the same time, there has been concern from some Canadians living within the vicinity of wind turbine installations that their health and well-being are negatively affected from exposure to WTN.

The scientific evidence base in relation to WTN exposure and health is limited, which includes uncertainty as to whether or not low frequency noise (LFN) and infrasound from wind turbines contributes to the observed community response and potential health impacts. Studies that are available differ in many important areas including methodological design, the evaluated health effects, and strength of the conclusions offered.

In July 2012, Health Canada announced its intention to undertake a large scale epidemiology study in collaboration with Statistics Canada (*Statistics Canada Official Title: Community Noise and Health Study*). The study was launched to support a broader evidence base on which to provide federal advice and in acknowledgement of the community health concerns expressed in relation to wind turbines.

Research Objectives and Methodology

The objectives of the study were to:

- Investigate the prevalence of health effects or health indicators among a sample of Canadians exposed to WTN using both self-reported and objectively measured health outcomes;
- Apply statistical modeling in order to derive exposure response relationships between WTN levels and self-reported and objectively measured health outcomes; and,
- Investigate the contribution of LFN and infrasound from wind turbines as a potential contributing factor towards adverse community reaction.

The study was undertaken in two Canadian provinces, Ontario (ON) and Prince Edward Island (PEI), where there were a sufficient number of homes within the vicinity of wind turbine installations. The study consisted of three primary components: an in-person questionnaire, administered by Statistics Canada to randomly selected participants living at varying distances from wind turbine installations;

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EXHIBIT
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collection of objectively measured outcomes that assess hair cortisol, blood pressure and sleep quality; and, more than 4000 hours of WTN measurements conducted by Health Canada to support the calculation of WTN levels at residences captured in the study scope. To support the assessment and reporting of data, and permit comparisons to other studies, residences were grouped into different categories of calculated outdoor A-weighted WTN levels as follows: less than 25 dB; 25-<30dB; 30-<35dB; 35-<40dB; and greater than or equal to 40 dB[1].

Detailed information on Health Canada's *Wind Turbine Noise and Health Study* methodology, including the 60-day public consultation and peer review process is available on the Health Canada website. The detailed methodology for the study is also available in the peer reviewed literature (*Michaud et al., Noise News International, 21(4): 14-23, 2013*).

Preliminary Research Findings[2]

Health Canada has completed its preliminary analysis of the data obtained. Research findings are presented below in accordance with the study component in which they were obtained i.e. in-person, self-report questionnaire findings, objectively measured responses, and noise measurements and calculations. As with other studies of this nature, a number of limitations and considerations apply to the study findings including:

- results may not be generalized to areas beyond the sample as the wind turbine locations in this study were not randomly selected from all possible sites operating in Canada;
- results do not permit any conclusions about causality; and,
- results should be considered in the context of all published peer-reviewed literature on the subject.

A. *Study Population and Participation*

The study locations were drawn from areas in ON and PEI where there were a sufficient number of homes within the vicinity of wind turbine installations. Twelve (12) and six wind turbine developments were sampled in ON and PEI, representing 315 and 84 wind turbines respectively. All potential homes within approximately 600 m of a wind turbine were selected, as well as a random selection of homes between 600 m and 10 km. From these, one person between the ages of 18 and 79 years from each household was randomly selected to participate.

The final sample size consisted of 2004 potential households. Of the 2004 locations sampled, 1570 were found to be valid dwellings[3] of which a total of 1238 households with similar demographics[4] participated, resulting in an overall participation rate of 78.9%. Participation rate was similar regardless of one's proximity to wind turbines and equally high in both provinces. The high response rates in this study help to reduce, but not eliminate, non-response bias[5].

B. *Self-Reported Questionnaire Results*

Results are presented in relation to WTN levels. For findings related to WTN annoyance, results are also provided in relation to distance to allow for comparisons with other studies. WTN is a more sensitive measure of exposure level and allows for consideration of topography, wind turbine characteristics and the number of wind turbines at any given distance. To illustrate, two similar homes may exist in similar environments located at the same distance from the nearest turbine operating in areas with 1 small and 75 large wind turbines respectively. These homes would be treated the same if the analysis was conducted using only distance to the nearest wind turbine, however they would be completely different in terms of their WTN exposure levels.

The following were not found to be associated with WTN exposure:

- self-reported sleep (e.g., general disturbance, use of sleep medication, diagnosed sleep disorders);
- self-reported illnesses (e.g., dizziness, tinnitus, prevalence of frequent migraines and headaches) and chronic health conditions (e.g., heart disease, high blood pressure and diabetes); and
- self-reported perceived stress and quality of life.

While some individuals reported some of the health conditions above, the prevalence was not found to change in relation to WTN levels.

1. Self-reported Sleep

Long-term sleep disturbance can have adverse impacts on health and disturbed sleep is one of the more commonly reported complaints documented in the community noise literature. Self-reported sleep disturbance has been shown in some, but not all, studies to be related to exposure to wind turbines.

The Pittsburgh Sleep Quality Index (PSQI) is a frequently used questionnaire for providing a validated measure of reported sleep pathology where scores can range from 0-21 and a global score of greater than 5 is considered to reflect poor sleep quality. The PSQI was administered as part of the overall questionnaire, which was supplemented with questions about the use of sleep medication, prevalence of sleep disorders diagnosed by a healthcare professional and how sleep disturbed people were in general over the last year.

Results of self-reported measures of sleep, that relate to aspects including, but not limited to general disturbance, use of sleep medication, diagnosed sleep disorders and scores on the PSQI, did not support an association between sleep quality and WTN levels.

2. Self-reported Illnesses and Chronic Diseases

Self-reports of having been diagnosed with a number of health conditions were not found to be associated with exposure to WTN levels. These conditions included, but were not limited to chronic pain, high blood pressure, diabetes, heart disease, dizziness, migraines, ringing, buzzing or whistling sounds in the ear (i.e., tinnitus).

3. Self-reported Stress

Exposure to stressors and how people cope with these stressors has long been considered by health professionals to represent a potential risk factor to health, particularly to cardiovascular health and mental well-being. The Perceived Stress Scale is a validated questionnaire that provides an assessment of the degree to which situations in one's life are appraised as stressful.

Self-reported stress, as measured by scores on the Perceived Stress Scale, was not found to be related to exposure to WTN levels.

4. Quality of Life

Impact on quality of life was assessed through the abbreviated version of the World Health Organization's Quality of Life scale; a validated questionnaire that has been used extensively in social studies to assess quality of life across the following four domains: Physical; Environmental; Social and Psychological.

Exposure to WTN was not found to be associated with any significant changes in reported quality of life for any of the four domains, nor with overall quality of life and satisfaction with health.

The following was found to be statistically associated with increasing levels of WTN:

- annoyance towards several wind turbine features (i.e. noise, shadow flicker, blinking lights, vibrations, and visual impacts).

5 Annoyance

5.1 Community Annoyance as a Measure of Well-being

The questionnaire, administered by Statistics Canada, included themes that were intended to capture both the participants' perceptions of wind turbines and reported prevalence of effects related to health and well-being. In this regard, one of the most widely studied responses to environmental noise is community annoyance. There has been more than 50 years of social and socio-acoustical research related to the impact that noise has on community annoyance. Studies have consistently shown that an increase in noise level was associated with an increase in the percentage of the community indicating that they are "highly annoyed" on social surveys. The literature shows that in comparison to the scientific literature on noise annoyance to transportation noise sources such as rail or road traffic, community annoyance with WTN begins at a lower sound level and increases more rapidly with increasing WTN.

Annoyance is defined as a long-term response (approximately 12 months) of being "very or extremely annoyed" as determined by means of surveys. Reference to the last year or so is intended to distinguish a long term response from one's annoyance on any given day. The relationship between noise and community annoyance is stronger than any other self-reported measure, including complaints and reported sleep disturbance.

5.2 Community Annoyance Findings

Statistically significant exposure-response relationships were found between increasing WTN levels and the prevalence of reporting high annoyance. These associations were found with annoyance due to noise, vibrations, blinking lights, shadow and visual impacts from wind turbines. In all cases, annoyance increased with increasing exposure to WTN levels.

The following additional findings in relation to WTN annoyance were obtained:

- At the highest WTN levels (≥ 40 dBA in both provinces), the following percentages of respondents were highly annoyed by wind turbine noise: ON-16.5%; PEI-6.3%. While overall a similar pattern of response was observed, the prevalence of WTN annoyance was 3.29 times higher in ON versus PEI (95% confidence interval, 1.47 - 8.68).
- A statistically significant increase in annoyance was found when WTN levels exceeded 35 dBA.
- Reported WTN annoyance was statistically higher in the summer, outdoors and during evening and night time.
- Community annoyance was observed to drop at distances between 1-2km in ON, compared to PEI where almost all of the participants who were highly annoyed by WTN lived within 550m of a wind turbine. Investigating the reasons for provincial differences is outside the scope of the current study.
- WTN annoyance significantly dropped in areas where calculated nighttime background noise

exceeded WTN by 10dB or more.

- Annoyance was significantly lower among the 110 participants who received personal benefit, which could include rent, payments or other indirect benefits of having wind turbines in the area e.g., community improvements. However, there were other factors that were found to be more strongly associated with annoyance, such as the visual appearance, concern for physical safety due to the presence of wind turbines and reporting to be sensitive to noise in general.

5.3 Annoyance and Health

- WTN annoyance was found to be statistically related to several self-reported health effects including, but not limited to, blood pressure, migraines, tinnitus, dizziness, scores on the PSQI, and perceived stress.
- WTN annoyance was found to be statistically related to measured hair cortisol, systolic and diastolic blood pressure.
- The above associations for self-reported and measured health endpoints were not dependent on the particular levels of noise, or particular distances from the turbines, and were also observed in many cases for road traffic noise annoyance.
- Although Health Canada has no way of knowing whether these conditions may have either pre-dated, and/or are possibly exacerbated by, exposure to wind turbines, the findings support a potential link between long term high annoyance and health.
- Findings suggest that health and well-being effects may be partially related to activities that influence community annoyance, over and above exposure to wind turbines.

C. *Objectively Measured Results*

Objectively measured health outcomes were found to be consistent and statistically related to corresponding self-reported results. WTN was not observed to be related to hair cortisol concentrations, blood pressure, resting heart rate or measured sleep (e.g., sleep latency, awakenings, sleep efficiency) following the application of multiple regression models[6].

1. Measures Associated with Stress

Hair cortisol, blood pressure and resting heart rate measures were applied in addition to the Perceived Stress Scale to provide a more complete assessment of the possibility that exposure to WTN may be associated with physiological changes that are known to be related to stress.

Cortisol is a well-establish biomarker of stress, which is traditionally measured from blood and/or saliva. However, measures from blood and saliva reflect short term fluctuations in cortisol and are influenced by many variables including time of day, food consumption, body position, brief stress, etc., that are very difficult to control for in an epidemiology study. To a large extent, such concerns are eliminated through measurement of cortisol in hair samples as cortisol incorporates into hair as it grows. With a predictable average growth rate of 1 cm per month, measurement of cortisol in hair makes it possible to retrospectively examine months of stressor exposure. Therefore cortisol is particularly useful in evaluating the potential impact that long term exposure to WTN has on one of the primary biomarkers linked to stress.

The results from multiple linear regression analysis reveal consistency between hair cortisol concentrations and scores on the Perceived Stress Scale (i.e., higher scores on this scale were associated with higher concentrations of hair cortisol) with neither measure found to be significantly affected by exposure to WTN. Similarly, while self-reported high blood pressure (hypertension) was associated with higher measured blood pressure, no statistically significant association was observed between measured blood pressure, or resting heart rate, and WTN exposure.

2. Sleep Quality

Sleep was measured using the Actiwatch2™, which is a compact wrist-worn activity monitor that resembles a watch. This device has advanced sensing capabilities to accurately and objectively measure activity and sleep information over a period of several days. This device is considered to be a reliable and valid method of assessing sleep in non-clinical situations. The following measured sleep impacts were considered: sleep latency (how long it took to fall asleep); wake time after sleep onset (the total duration of awakenings); total sleep time; the rate of awakening bouts (calculates how many awakenings occur as a function of time spent in bed); and sleep efficiency (total sleep time divided by time in bed).

Sleep efficiency is especially important because it provides a good indication of overall sleep quality. Sleep efficiency was found to very high at 85% and statistically influenced by gender, body mass index (BMI), education and caffeine consumption.

The rates of awakening bouts, total sleep time or sleep latency were further found in some cases to be related to: age, marital status, closing bedroom windows, BMI, physical pain, having a stand-alone air conditioner in the bedroom, self-reports of restless leg syndrome and being highly annoyed by the blinking lights on wind turbines.

While it can be seen that many variables had a significant impact on measured sleep, calculated outdoor WTN levels near the participants' home was not found to be associated with sleep efficiency, the rate of awakenings, duration of awakenings, total sleep time, or how long it took to fall asleep.

D. *Wind Turbine Noise Measures Results*

Note - To support a greater understanding of the concepts included in this section, Health Canada has developed a short Primer on Noise.

Scientists that study the community response to noise typically measure different sounds levels with a unit called the A-weighted decibel (dBA). The A-weighting reflects how people respond to the loudness of common sounds; that is, it places less importance on the frequencies to which the ear is less sensitive. For most community noise sources this is an acceptable practice. However, when a source contains a significant amount of low frequencies, an A-weighted filter may not fully reflect the intrusiveness or the effect that the sound may have (e.g. annoyance). In these cases, the use of a C-weighted filter (dBC) may be more appropriate because it is similar to the A-weighting except that it includes more of the contribution from the lower frequencies than the A-weighted filter.

1. A- Weighted

More than 4000 hours of WTN measurements conducted by Health Canada supported the calculations of A-weighted WTN levels at all 1238 homes captured in the study sample.

- Calculated outdoor A-weighted WTN levels for the homes participating in the study reached 46 dBA for wind speeds of 8m/s. This approach is the most appropriate to quantify the potential adverse effects of WTN. The calculated WTN levels are likely to be representative of yearly averages with an uncertainty of about +/- 5dB and therefore can be compared to World Health Organization (WHO) guidelines. The WHO identifies an annual outdoor night time average of 40 dBA as the level below which no health effects associated with sleep disturbance are expected to occur even among the most vulnerable people (WHO (2009) *Night Noise Guidelines for Europe*).

2. Low Frequency Noise

Wind turbines emit LFN, which can enter the home with little or no reduction in energy potentially resulting in rattles in light weight structures and annoyance. Although the limits of LFN are not fixed, it generally includes frequencies from between 20Hz and 200Hz. C-weighted sound levels can be a better indicator of LFN in comparison to A-weighted levels, and were calculated in order to assess the potential LFN impacts.

- Calculated outdoor dBC levels for homes ranged from 24 dBC and reached 63 dBC.
- Three (3)% of the homes were found to exceed 60 dBC[7].
- No additional benefit was observed in assessing LFN because C- and A-weighted levels were so highly correlated (r=0.94) that they essentially provided the same information. It was therefore not surprising that the relationship between annoyance and WTN levels was predicted with equal strength using dBC or dBA and that there was no association found between dBC levels and any of the self-reported illnesses or chronic health conditions assessed (e.g., migraines, tinnitus, high blood pressure, etc.)
- Sound pressure levels were found to be below the recommended thresholds for reducing perceptible rattle and the annoyance that rattle may cause.

As LFN is generally considered to be an indoor noise problem, it was of interest to better understand how much outdoor LFN makes its way into the home.

- At a selection of representative homes, Health Canada measurements showed an average of 14dB of outdoor WTN is blocked from entering a home at low frequencies (16 Hz - 100 Hz) with closed windows compared to an average reduction of 10dB with windows partially open.

3. Infrasound

Long-term measurements over a period of 1 year were also conducted in relation to infrasound levels.

- Infrasound from wind turbines could sometimes be measured at distances up to 10km from the wind turbines, but was in many cases below background infrasound levels.
- The levels were found to decrease with increasing distance from the wind turbine at a rate of 3dB per doubling of distance beyond 1km, downwind from a wind turbine.
- The levels of infrasound measured near the base of the turbine were around the threshold of audibility that has been reported for about 1% of people that have the most sensitive hearing.

Due to the large volume of acoustical data, including that related to infrasound, analysis will continue over subsequent months with additional results being released at the earliest opportunity throughout 2015.

Data Availability and Application

Detailed descriptions of the above results will be submitted for peer review with open access in scientific journals and should only be considered final following publication. All publications by Health Canada related to the study will be identified on the Health Canada website.

Raw data originating from the study is available to Canadians, other jurisdictions and interested parties through a number of sources: Statistics Canada Federal Research Data Centres, the Health Canada website (noise data), open access to publications in scientific journals and conference presentations. Plain language abstracts outlining the research and identifying the scientific journals where papers can be found will further be published to the Departmental website.

Health Canada's Wind Turbine Noise and Health Study included both self-reported and physically measured health effects as together they provide a more complete overall assessment of the potential impact that exposure to wind turbines may have on health and well-being.

Study results will support decision makers by strengthening the peer-reviewed scientific evidence base that supports decisions, advice and policies regarding wind turbine development proposals, installations and operations. The data obtained will also contribute to the global knowledge of the relationship between WTN and health.

1 Categories are mutually exclusive. Only six out of 1238 dwellings in the study were above 45dBA; an inadequate sample size to create an additional category.

2 A more detailed presentation of the results will be submitted for publication in scientific journals. Results should only be considered final following peer-review and publication in the scientific literature.

3 434 were not valid dwellings; upon visiting the address Statistics Canada noted that the location was either demolished for unknown reasons, under construction, vacant for unknown reasons, an unoccupied seasonal dwelling, residents were outside the eligible age range, or not a home at all.

4 Some minor differences were found with respect to age, employment, type of home and home ownership.

5 Non-response bias may be a problem depending upon the extent to which non participation is associated with the exposure of interest (in this case wind turbine exposure). This study did not include a non-response survey, however refusing to participate was not related to the distance between the resident and the nearest wind turbine.

6 This type of analysis identifies the personal and situational variables that best explain the variation observed in the objective measures after adjusting for all variables that are known to have an influence on the effects being assessed.

7 For sources that operate at night in rural environments, a dBC limit somewhere between 60 dBC and 65 dBC has been recommended to minimize community complaints/annoyance associated with LFN, See discussion in Broner (2011). A simple outdoor criterion for assessment of low frequency noise emission. Acoustics Australia Vol 39, Issue 1, pp 7-14.

Date Modified: 2014-10-30

Attachment C: Summary of public testimony from Case 037-AT-22

(1) The following is a summary of communications received prior to the March 17, 2022 ZBA public hearing for this case:

a. In an email received March 16, 2022, Shannon Reel asked for clarification on several questions related to the proposed wind farm ordinance revisions. She expressed concerns about ensuring her entire property, not just her residence, would not be infringed upon by insufficient setback from turbines. She also mentioned noise, lights, vibrations, and ice shed. She would like a setback that is 6 times the total height for non-participatory property lines. She would like a moratorium of 18 months on special use wind farm applications in Champaign County.

b. In an email received March 16, 2022, Jennifer Eisenmenger said that she is opposed to industrial wind farms. She said wind Farms are invasive to wild places, damaging to animals and humans, and require so much fossil fuel in the manufacturing, transportation, maintenance, and disposal that they actually do little to offset it's usage. She is against unlimited heights on wind turbines, and in favor of significantly increased setbacks from households. She asked that consideration be given to what happens (as illustrated in Douglas County) when wind farms go out of business, leaving counties and land owners with the health and safety issues that come with deteriorating turbines.

c. In an email received March 17, 2022, Benjamin Rice said he is opposed to having no height restrictions and also to the setback being measured from his home and not his property line. He said his yard would be unenjoyable due to noise and it could be dangerous for his family.

d. In an email received March 17, 2022, Heidi Leerkamp said she is opposed to all changes which increase the height allowed for wind turbines or lessen setbacks from non-participating property or dwellings. She said a wind farm project might be considered a win for economic development but would be a long term drain on the health and welfare of our county. She said these projects greatly impact their daily quality of life and enjoyment of their home property. They negatively affect their ability to operate their family farm as well as the values of their home and farm properties. She mentioned negative impacts on area infrastructure and little benefit for local jobs related to the wind farms. She said that both physical and mental health are negatively impacted by living under and around moving structures of an unprecedented size. She expressed concern about decommissioning of the wind turbines. She asked that no more wind projects be approved in our area and no increases be made to the current wind turbine height limits, and no decreases to the turbine setback limits be made.

e. In an email received March 17, 2022, Justin Leerkamp said that he is against any increase above the current height restriction on wind turbines. He said that further and larger setbacks from property lines, not just occupied dwellings would be welcome, but increases in height will only add to further problems for rural residences, and property values for rural homes. He expressed concern about the decommissioning of wind turbines. He said his biggest objections to increasing height is both noise and shadows from the blades, both during the day and from the lighting systems at night bouncing off the blades. He said he supports the use of new lighting systems that are activated when aircraft are near, but questions how effective this will be when areas south east of Willard airport are in the ILS path of its runways.

Attachment C: Summary of public testimony from Case 037-AT-22

f. In an email received March 17, 2022, David Happ said he supports adding the ADLS lighting requirements to the ordinance. He said he does not support increases to maximum height of the turbines. He said that Champaign County should change their ordinance to specify a separation distance of 3,250 feet from any residence, and one-half mile from any property line, and he does not think a property owner should be allowed to waive these requirements. He said that increasing the maximum tower height and supporting lower separation distances, is exactly the opposite of what people who have lived near windfarms in the past have asked for.

g. In an email received March 17, 2022, Todd Horton said that there is insufficient concern to remedy shadow flicker in the Zoning Ordinance.

h. In an email received March 17, 2022, Darrel and Regina Rice said it makes no sense to them to take ground in this part of the country out of production for a wind farm. They don't want to see it, hear it, farm around it, and they don't want it near their homes or on their land. They asked for reasonable height limits on the turbines, and to increase the setbacks beyond what is currently being considered.

i. In an email received March 17, 2022, Donald Carter expressed concern about health impacts due to insufficient setbacks and noise from the turbines. He is concerned about decreased property values due to wind farms, infrastructure damage and harm to productivity of farm ground where turbines are located, and with ongoing maintenance of turbines as deterioration had been experienced in other nearby windfarms.

j. In an email received March 17, 2022, Cary and Pam Leerkamp said they have concerns about decreasing property values and asked that the ZBA consider the welfare of county residents.

k. In an email received March 17, 2022, Traci Bosch had concerns about Carle hospital helicopter safety as they maneuver around turbines. She is concerned about her water supply, noise, rural infrastructure during and after construction of the turbines, and permanent scarring of the soil and roads due to turbine construction. She asked for consideration of rural taxpayers and decreasing property values.

l. In an email received March 17, 2022, Brandon and Sarah Hastings said they are opposed to having no height restriction on wind turbines. They expressed concern about debris being thrown from turbines, health issues caused by turbines, potential impacts on internet service, reduced property values, damage to fields and drainage tile, and how fee revenues from turbine projects would be used by the County.

m. In an email received March 17, 2022, Michelle and Scott Wiesbrook said they had concerns about traffic during wind farm construction, having an unlimited height for wind turbines, noise, flicker, vibration, constructing wind farms on productive farmland, and decommissioning the turbines.

n. In an email received March 17, 2022, Lynn Rice said the proposed unlimited height and short setback restrictions being proposed at tonight’s meeting should be denied. She mentioned adverse health and sleep effects due to proximity to wind turbines, and said they should have a maximum height of 500 feet and minimum setback of 1.25 miles from homes.

Attachment C: Summary of public testimony from Case 037-AT-22

o. In an email received March 17, 2022, Josh Kamerer asked what would be done to alleviate any broadband/internet service interruptions as many have school age children who depend on internet access.

p. In an email received March 17, 2022, Steven Herriott said that wind turbines are a blight on our beautiful countryside. He said turbine companies should be held to standards of fixing the roads they destroy.

q. In an email received March 17, 2022, Tiffany Byrne said she had concerns about health impacts due to proximity to wind turbines. She also mentioned impacts on wildlife and livestock. She asked that the height limit not exceed the current 500 feet and that homes should be at least 1.25 miles away from wind turbines.

r. In an email received March 17, 2022, Adam Watson said that he is in complete opposition of changing the wind tower height limit to unlimited and changing the setbacks.

s. In an email received March 17, 2022, Natalie Thomas said she had concerns about noise from the turbines, having sufficient setbacks from the turbines, impacts on area communities, sleep deprivation and other health issues, travel safety and making sure roads are in good repair, decommissioning of wind turbines, impacts on wildlife, and public welfare.

t. In an email received March 17, 2022, Jan Niccum said that she had concerns about decommissioning, road conditions, financial benefits to local communities from the wind farms, and reducing flicker and hum from the turbines.

u. In an email received March 17, 2022, Aaron Fenter said he had concerns about unlimited height and insufficient setbacks from wind turbines. He said the zoning department has a responsibility to the many rural residents to not allow anything that would detract from their quality of life, their comfort in their homes or the value of their properties.

v. In an email received March 17, 2022, Kate Boyer said she opposes wind farms, especially due to concerns with her health and that of her children. She said noise and flickering are major triggers for her seizures and for her children's autistic episodes, and living in the peaceful country has improved their health.

w. In an email received March 17, 2022, Stephen Smith said he opposes putting a wind farm in the area. He expressed concerns about road conditions, damaged field tiles, the hazard of wind turbines to agricultural air applications of seeds and chemicals, noise, strobe effect/lighting, blade breakage, and traffic increases from turbine construction.

x. In an email received March 17, 2022, Jennifer Miller, DVM, said she had concerns about the impacts of wind farms on livestock. She said that chronic stress may impact egg laying, rate of gain, milk production, fertility and stereotypies (cribbing and weaving). She said this can impact families raising the livestock. She asked for consideration of setback to property lines and not just to homes, and for noise levels below 39 decibels. She would like the height capped at 500 feet.

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(2) The following is a summary of testimony received at the March 17, 2022 ZBA public hearing for this case:

a. Stephen Smith stated that he is against putting wind farms in and has several concerns: roads being destroyed during wind farm construction and not being repaired after, broken drainage tiles that are not always repaired, the hazard of wind turbines to agricultural air applications of seeds and chemicals, noise, turbine blade breakage, shadow flicker, and ice/snow shed. He said the turbines should be set back farther and setback should be measured from the property line.

b. William Boyer spoke on behalf of his mother, Kate Boyer. He said they have health concerns related to the wind turbines. She suffers from temporal lobe epilepsy, and several of her children are on the autism spectrum. One of the main reasons they purchased an isolated country house was to bring relief to their health. Noise and flickering lights are major triggers for both her epileptic seizures and her children's autistic episodes. She said moving to the peaceful country was such an amazing transformation of mental and physical health. She asked that the County not allow wind turbines in the area.

c. Dirk Rice said that the setback for non-participating residences should be at least twice that of participating residences. He spoke in favor of the Aircraft Detection Lighting System. He recommended against the proposed setbacks and said the turbines need to be much farther away from residences.

d. Sarah Hastings said she opposed the unlimited height restriction. She provided articles, one of which said that a 300-foot wind turbine could throw debris 1,200 feet. She said that another article stated that wind turbines can cause health issues and interfere with radio, TV, satellite and radar signals. She also expressed concern about decreased property values.

e. Kirk Allen said he was with Edgar County Watchdogs, expressed concern about property rights, and how the Zoning Act in the Illinois County Code stipulates the "authority to regulate and restrict location and use of structures for the purpose of promoting the public health, safety, morals, comfort, general welfare, conserving the value of property throughout the County." He suggested that the Board review Zoning Ordinances from Christian County and Edgar County.

f. Brian Armstrong, Attorney with the firm of Luetkehans, Brady, Garner & Armstrong, said he was speaking on behalf of numerous people in the audience and some who could not attend the meeting. He expressed concerns about noise, the insufficient setbacks proposed, and how turbine height should have a limit. He provided eight exhibits for the Board. He provided data from noise analyses done by Dr. Paul Schomer, acoustician. He encouraged the Board to adopt a setback of no less than 3,250 feet from a wind turbine. The following is a synopsis of those exhibits:

(a) Exhibit 1 was a publication by Health Canada (the department of the Government of Canada responsible for health policy) titled *Wind Turbine Noise and Health Study: Summary of Results* published 11/6/2014. The study was undertaken in two Canadian provinces, Ontario and Prince Edward Island, and included responses from 1,283 households in the vicinity of 18 wind turbine developments with a total of 399 wind turbines. The study consisted of three primary components which were as follows and with the following results:

i. An in-person questionnaire to randomly selected participants living at varying distances from wind turbine installations regarding self-reported sleep; self-reported illnesses and chronic diseases; self-reported stress; quality of life indicators; and annoyance. Wind turbine noise exposure was not found to be associated with self-reported sleep quality or with self-reported illnesses or self-reported stress or with any significant change in quality of life. Annoyance towards several wind turbine features (i.e. noise, shadow flicker, blinking lights, vibrations, and visual impacts) were statistically associated with increasing levels of wind turbine noise

ii. Collection of objectively measured outcomes that assessed hair cortisol, blood pressure, and sleep quality. Exposure to wind turbine noise was not observed to be related to hair cortisol concentrations, blood pressure, resting heart rate, or measured sleep.

iii. More than 4,000 hours of wind turbine noise measurement that supported the calculation of wind turbine noise at the residences in the study. The 1,283 residences were grouped into different categories of calculated outdoor A-weighted wind turbine noise levels of less than 25 dBA; 25 to <30DBA; 30 to <35dBA; 35 to < 40 dBA; and greater than 40dBA (but an inadequate sample size above 46dBA).

(b) Exhibit 2 was a January 2017 paper in the journal Sound & Vibration titled *Health Effects from Wind Turbine Low Frequency Noise & Infrasound* by authors George Hessler (George Hessler Associates, Inc., Haymarket VA), Geoff Leventhall (consultant, Ashtead, Surrey, UK), Paul Schomer (Schomer and Associates, Inc., Champaign IL), and Bruce Walker (Channel Islands Acoustics, Camarillo, CA). This study by four experts concluded that infrasound (0 to 20 Hz) can almost be ruled as a potential mechanism for stimulating motion sickness symptoms but some additional research was recommended. Pending those results, the four authors recommended that an acceptable A-weighted noise level is all that should be required. In the paper the four authors also share their recommended noise limits for wind farms which are 35 to 39 dBA (Schomer) and 40 dBA (Leventhall and Hessler with Hessler having a 45 dBA maximum) and 45dBA (Walker).

(c) Exhibit 3 was a paper titled *The Results of an Acoustic Testing Program, Cape Bridgewater Wind Farm Prepared for Energy Pacific by Steve Cooper, The Acoustic Group, A Review of this Study and Where it is Leading* by Paul D. Schomer, PhD., P.E.; Schomer and Associates, Inc.; Standards Director, Acoustical Society of America, and George Hessler, Hessler Associates, Inc. The paper is dated 10 February 2015. This paper reviewed a very limited study regarding the perceived effects of noise on three couples who lived between 650 meters and 1600 meters from the Cape Bridgewater wind farm in Australia. The Cape Bridgewater study found that the three couples could sense the operation of wind turbines in the wind farm even when there was no acoustical or visual stimulus from wind turbine operation and their reactions were correlated with the power output of the wind turbines. One of the couples was so affected by the wind farm emissions that they abandoned their home. The Cape Bridgewater study was too limited for the results to be generalized to the population, but the study did demonstrate a cause and effect relation at these locations.

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(d) Exhibit 4 was an excerpt of McLean County Zoning Board of Appeals minutes from 1/24/2018. The excerpt is the questioning of Dr. Schomer by Attorney Luetkehans and members of the Zoning Board of Appeals. The questioning focused on the various wind farm noise limits and the Cape Bridgewater study. Dr. Schomer stated his recommended noise limit for wind farm noise to be 38 to 40 dB.

(e) Exhibit 5 is a report titled *A Cooperative Measurement Survey and Analysis of Low Frequency and Infrasound at the Shirley Wind Farm in Brown County, Wisconsin* that was partially funded by the Wisconsin Public Service Commission and by Clean Wisconsin, a nonprofit environmental advocacy organization. Although the study was about the Shirley Wind Farm the results of the study were to be used in a pending wind farm proposed for St. Croix County, WI. The report was issued on 12/24/2012. Four acoustical consulting firms jointly conducted the study. The firms were Channel Islands Acoustics (principal Dr. Bruce Walker); Hessler Associates, Inc. (principals George and David Hessler); Rand Acoustics (principal Robert Rand); and Schomer and Associates, Inc, (principal Dr. Paul Schomer). Each consultant presented their individual findings in a separate Appendix but all agreed that in regards to the Shirley Wind Farm there was "…enough evidence and hypotheses given to classify low frequency noise and infrasound as a serious issue…it should be addressed beyond the present practice of showing that wind turbine levels are magnitudes below the threshold of hearing at low frequencies." Hessler Associates, Inc. recommended a noise limit of 39.5 dBA or less for the proposed St. Croix wind farm. Schomer and Associates recommended additional testing and if that was not possible they recommended a noise limit of 33.5 dBA or less for the proposed St. Croix wind farm, based on a 6 dB decrease in noise that the Navy used when dealing with severe noise induced nausea. Neither Channel Islands Acoustic nor Rand Acoustics made recommendations for the proposed St. Croix wind farm.

(f) Exhibit 6 is an undated report titled *Proposed minimum siting distances for Livingston County Wind Farms* prepared by Schomer and Associates, Inc. The paper is an analysis of separation distances and calculated noise levels from existing wind turbines for the 1,283 dwellings in the Health Canada publication titled *Wind Turbine Noise and Health Study: Summary of Results* published 11/6/2014. The report divides the separations for 745 dwellings in the Health Canada study into nine separation categories from 1,500 feet to 3,750 feet. 493 dwellings in the Health Canada study were located further than 3,750 feet from a turbine and those dwellings are not included in this analysis. The 745 dwellings in this analysis were divided into 6 noise levels from 35 dB(A) to 40 dB(A). The report also included the results of a study by Minnesota Department of Commerce regarding international wind turbine noise limits for residences and the requirements of the American National Standards Institute (ANSI). The report concludes with a recommendation for a noise limit of 38dB(A) and a minimum separation of 3,250 feet.

(g) Exhibit 7 is a report titled *Alta Farm Wind Project II, LLC, Dewitt County, Illinois, Property Value Impact Analysis: Residential improved and vacant agricultural land properties* by Kurt C. Kielisch of Forensic Appraisal Group of Neenah, Wisconsin, dated February 18, 2019. The report is a summary of a study contracted by DeWitt County Residents Against Wind Turbines group, represented by Atty.

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Phillip A. Luetkehans, Schirott, Luetkehans & Garner, LLC, Itasca, Illinois, to study the impacts that the proposed Alta Farms Wind Project II, LLC, would have on improved residential and vacant agricultural land values. The report has four parts: a literature study regarding wind farms and land use; a summary of wind farm value impact studies; an analysis of how residential property values are being impacted by a wind farm using paired sales analysis in the Twin Groves II wind farm in McLean, Illinois; and a multiple regression analysis on the impact of agricultural land values being impacted by the Twin Groves II wind farm. The impact studies found little to no evidence of an impact in wind industry and government supported studies, but found a “significant impact” from independent studies using a variety of valuation methods from paired sales analysis to multi-regression analysis. Losses amongst the nine independent studies that were completed between 2007 and 2015 ranged from 7.7% to 50% in value, with distances ranging from adjacent to a wind farm to within 3 miles of a wind farm. The report also indicated that “Agricultural land also is impacted by the presence of a wind farm losing -6.3% to -8.5% of its overall value if located within a wind farm.” For the proposed wind farm, the report concluded that “the presence of wind turbines in close proximity to residential properties and agricultural land will have a negative impact on property value and this impact is permanent. The magnitude of that impact will be dependent on the proximity of the wind turbines to the property, the disruption of the viewshed and disruption of the land use.”

(h) Exhibit 8 is a PowerPoint presentation authored by Jerry Punch, Ph.D., titled “Wind Turbine Noise: Effects on Human Health” that was given to the Christian County, Illinois Zoning Board of Appeals on June 23, 2020. The presentation covered the following topics:

- Physical nature of wind turbine noise
- Common health effects of wind turbine noise exposure
- Research evidence that wind turbine noise causes adverse health effects
- Methods of limiting wind turbine noise
- Standards and guidelines relevant to wind turbine noise

Recommendations included maximizing setback distance and minimizing noise levels. Dr. Punch provided numerous citations for recommended setback and noise levels, but did not make recommendations himself.

g. Ted Hartke communicated his personal experience with how turbine noise caused him and his family to move from a perfectly good home in Vermilion County. He recommended that Champaign County adopt a setback of no less than 3,250 feet from a wind turbine based on Dr. Schomer’s noise analyses. He said he supports a 500 foot limit on the turbine height.

h. Darrell Rice said that it makes no sense to them to take ground in this part of the country out of production for a wind farm; they don't want to see it, hear it, farm around it, have it near their homes or on their land. He asked the Board to place reasonable height limits on turbines and increase the setbacks beyond what is being considered.

i. Benjamin Rice said that he wants his family to be able to enjoy their entire seven acres of land. He expressed concerns about noise, safety from turbines breaking apart and throwing ice, and the height of the turbines. He asked for consideration of their rights and getting to enjoy peace and quiet in the country.

j. Brad Shotton asked the Board to give them a voice in order to preserve the properties they have. He would like increased setbacks, a limit on the wind turbine height, and asked the Board not to accept the proposal before them. He expressed concern about noise, vibrations, and shadow flicker.

k. Ed Decker said it would be totally irresponsible to give the wind turbine an unlimited height, and he would like the Board to keep it at the 500 feet height limit. He said he thinks the 3,250 feet has come up several times tonight for the setback, and he thinks that would be a reasonable setback, and he thinks that needs to be from each property line as well as each dwelling. He expressed concern about noise and property values.

l. Kelly Vetter said that she thinks there is a conflict of interest that the wind company's engineer oversees the decommissioning estimates for the existing wind farm. She asked that Champaign County do what other counties have done, which is to make ordinances that prevent a wind farm from even coming in.

m. Todd Horton said that he is really concerned that an incompatible land use would be something, that creates flickering lights coming through the windows of their homes. He said when it comes to shadow flicker, there is no standard for what an acceptable reduction of shadow flicker is, but they don't have anything in the current Zoning Ordinance that says anything is enforceable, other than the wind farm project developer provides a shadow flicker study, but it doesn't say the wind farm project developer has to follow the study. He said that he hopes the wind turbines are not allowed to be taller.

n. Don Carter said that there is a company, NextEra Energy, that is planning a wind farm on 50,000 acres south of Philo, Sidney and Homer. He said the Board members are the residents' champions; the Board is the one that stands between the residents and people that many of the residents feel would ill-use that land out there. He asked the Board to take up their case, take up their cause by passing responsible aspects of this ordinance that is before them.

o. Charlie Mitsdarfer said he is really worried about the height, and even more concerned about the setbacks. He said these are an eyesore, and he is worried about property values and mitigating existing land problems caused by wind farm construction. He said roads are in poor shape and there are broken field tiles, and the land will never be what it was before that construction. He said he has heard of issues with well water. He questioned the unlimited height proposed, and asked for a one-mile setback from turbines.

p. Justin Leerkamp said he farms in the Douglas County area adjacent to many of these windmills, and he feels that the setback multiplier is not large enough having worked under these 600 foot towers. He said if we do use a multiplier, to increase the height, it should not be linear, it should be exponential as the height increases. He said the purpose of that would be to reduce the shadow flicker. He said he really doesn't feel that the height increase is warranted at this time; he feels that the 500 foot limit has worked for this county. He said he is in favor of lighting mitigation.

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q. William Mitsdarfer said he hears people complain about the railroad a lot, or living next to a grain elevator. He said he understands that it's probably noisy and dirty or whatever, but that elevator or railroad were there before the house was or the town, so people knew that when they moved there. He said their homes are there now and there's no windmills. He saw no good in having windmills.

r. Traci Bosch said she is just 3-3/4 miles from the Douglas County windmills. She said they sound like a constant blowtorch, and urged the Board to drive out to a windmill and listen before making any decisions. She said that the Board should talk to residents of northern Champaign County about what it is like when a turbine blows apart. She expressed concerns about road conditions, property values, and impacts on school and fire station revenues.

s. Daniel Herriott asked the Board to consider Dekalb County's wind farm ordinance, which has a setback that is six times the turbine height and allows zero flicker on non-participating neighbors. He said the height limit should be kept at 500 feet.

(3) The following is a summary of communications received between March 18 and April 1, 2022 for this case:

a. In an email received March 18, 2022, Mick & Mary Schumacher said they had concerns about the height of the towers, designed setbacks, and setbacks from neighboring property owners.

b. In an email received March 29, 2022, Ted Hartke provided citations supporting a 39 dBA maximum noise limit because 40 dBA begins adverse health impacts.

c. In an email received March 29, 2022, Don Carter stated he is opposed to the proposed changes in turbine heights and setbacks. He would like to maintain the current 500 foot height limitation in the ordinance, and increase the setback to the property line of non-participating land owners to 3,250 feet. He agrees with the adoption of county-level AIMA standards and adding aircraft detection lighting systems for wind turbines. He agrees with the proposed increase in turbine fees, and thinks the fee should be even higher.

d. In an email received March 29, 2022, Michael Mooney is opposed to having more wind farms in the county. He expressed concerns about damage to field tiles and ruined roads due to wind farm construction.

e. In an email received March 29, 2022, Gary Place expressed concerns about wind farms effects on safety and quality of life. He would like to keep the current 500 foot height limit, would like to have a 3,250 foot setback to non-participating landowners' property lines, and have a noise limit of 38 dBA.

f. In an email received March 30, 2022, Shannon Reel expressed concerns about noise, sleep deprivation, loss of home value, and flicker from the wind turbines. She is against removing the 500 foot height restriction and in favor of setback to a non-participating property line of 6 times the height of a turbine.

g. In a second email received March 30, 2022, Shannon Reel expressed concerns about roads not getting repaired and the County not having enough money to repair the roads once wind farm construction has occurred. She urged the County to deny the proposed changes.

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h. In an email received March 30, 2022, Drs. Andrew & Jennifer Miller stated they are opposed to changing the setbacks and the height of wind turbines. They feel the setback from property lines should be 3,250 feet and the height of turbines limited to 500 feet.

i. In an email received March 30, 2022, Darrel Rice expressed concern about water quality related to bedrock damage caused by wind turbine installation and underground vibrations from turbines. He also mentioned concerns about shadow flicker, effects on bats and honeybees, adverse health impacts of wind turbines. He asked that the 500 foot height limit be maintained and that the setback requirements be extended to the property lines and be extended in distance.

j. In an email received March 31, 2022, Justin Leerkamp said he does not support an unlimited height for turbines. He thinks setbacks should increase in distance and also be measured from property lines, not residences. He supports the adoption of the Agricultural Impact Mitigation Agreement, and suggested that the proposed fee increases be increased even more. He said he supports the adoption of the ADLS lighting system.

k. In an email received March 31, 2022, Todd and Sharon Herbert said they would like the 500 foot wind turbine height maintained, and the setback to be increased to 3,250 feet from the neighboring property lines. They are also in favor of the aircraft detection system. They expressed concerns about broken drainage tiles and roads caused by wind farm construction.

l. In an email received March 31, 2022, Michelle and Scott Wiesbrook asked to maintain the current wind turbine height limit at 500 feet. She supports the adoption of the county-level Agricultural Impact Mitigation Agreement and aircraft lighting detection systems. She thinks the fees should be increased even higher than what is currently proposed. She expressed concern about groundwater quality.

m. In an email received March 31, 2022, David Happ said he supports the Right to Farm Resolution. He does not support changing the maximum allowable wind turbine height of 500 feet. He does not think that the minimum required separation should be a factor of tower height; it should be 3,250 feet. He said he supports aircraft lighting detection systems and Agricultural Impact Mitigation Agreements. He supports the proposed fee increase.

n. In an email received March 31, 2022, Tiffany Byrne said that she supports a setback of 6,600 feet from non-participating dwellings. She said that the height limit should remain unchanged.

o. In an email received March 31, 2022, Brandon and Sarah Hastings asked that the height limit for wind turbines be kept at 500 feet. They expressed concern about groundwater quality, ice throw, noise, and flicker. They support aircraft lighting detection systems and Agricultural Impact Mitigation Agreements. They support the proposed increase in fees and think they could be even higher.

p. In an email received March 31, 2022, Traci Bosch expressed concern about safety of pilots who spray crops and fly emergency helicopters in wind turbine areas.

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q. In an email received March 31, 2022, Stephen Smith asked that height of turbines be limited to 200 feet. He supports an increase in the setback to the non-participating landowners' property lines. He expressed concern about shadow flicker.

r. In an email received March 31, 2022, Doug Downs said he opposes changing the height limitation. He would like to see the setback increased to 3,250 feet.

s. In an email received March 31, 2022, Kris Petersen described flying conditions and the dangers wind turbines impose on their aerial application service. He said allowing the turbines to be taller will make their jobs more dangerous and less efficient. He said he had concerns about the aircraft lighting detection systems and how they might impact pilot safety.

t. In an email received March 31, 2022, Mike Lockwood expressed concern about possibly being surrounded by wind turbines, light pollution, and impacts on his quality of life. He favors longer setbacks than those proposed, and favors keeping the current 500 foot height limitation.

u. In an email received April 1, 2022, Heidi Leerkamp asked that the ZBA abandon the proposed changes to special use permits for industrial wind energy complexes. She asked that wildlife and best prime farmland be more thoroughly studied before allowing any more wind turbines in the County.

(4) The following is a summary of testimony received at the March 31, 2022 ZBA public hearing for this case:

a. Jed Gerdes stated he is opposed to having wind farms in Champaign County, and that our area's prime farmland should be protected from that kind of development. He said he supports a 1.25 to 1.5 mile setback. He expressed concern about broken drainage tiles, noise, and decreased property values.

b. Michael Mooney said that he does not think it prudent to put wind farms on prime farmland. He expressed concern about broken drainage tiles and bad roads caused by wind farm construction.

c. Kelly Vetter offered to put together a citizen's taskforce to assist the County Board with their decision making regarding wind turbines.

d. Dennis Riggs said that the 500 foot height limit should be maintained, and a setback of at least 3,250 feet from property lines should be established to protect against the problem of unsightliness, noise, air pressure fluctuations, and light flicker. He expressed concerns for broken drainage tiles and bad roads, and supports strong Agricultural Impact Mitigation Agreements and decommissioning agreements.

e. David Reel asked for a moratorium on any new wind turbines for at least 18 months in order to ensure that any revisions to the wind ordinance are not hastily done without due diligence as to what is in the best interest of the county. He said he does not feel the current setback requirements are sufficient.

f. Kris Petersen said he is a pilot and expressed concerns for pilot safety in wind farms and more so if taller turbines are allowed.

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g. Roger Negangard expressed concerns about decommissioning and letting the wind companies keep anything in the ground below 46 inches; he thinks they should remove all they put into the ground. He said there needs to be a longer setback and that the height of the turbines needs to be limited.

h. Jennifer Eisenmenger said she is very concerned about the environment. She asked what would happen to mitigation plans when wind farms go out of business.

i. Heidi Leerkamp asked that the ZBA abandon the proposed changes to special use permits for industrial wind energy complexes. She asked that wildlife and best prime farmland be more thoroughly studied before allowing any more wind turbines in the County.

j. Brian Schluter said he is the Compromise Township Road Commissioner. He expressed concern about sufficient setbacks and height, and he does not favor a blanket ordinance.

k. Aaron Fenter said that height limitations should be reviewed periodically rather than allowing an unlimited height. He believes that property values will decrease for residences in a wind farm area. He believes that Champaign County should look at Livingston County's ordinance as an example if they are going to change the current requirements.

l. Adam Watson said he believes changing to an unlimited height would be irresponsible. He said that he feels their county should be the most concerned about the health and safety of its residents. He said he is in agreement with needing to use aircraft detection lighting systems.

m. Stephen Smith said he would like to recommend would be keeping these windmills under 200 feet if they do put them in the area, which would reduce harmful, environmental, and aesthetic impact, and it would also keep from the shadow flicker occurring.

n. Dirk Rice said that as he looks at the proposal for these changes in the regulation and there is no science behind it. He expressed concern for property values, setback and height requirements.

o. Charlie Mitsdarfer said that he has a couple concerns with the Agriculture Impact Mitigation Agreement, and he agrees that it is important, but he has a lot of reservations about how it is going to get enforced. He expressed concerns about returning the soil to its prior condition once wind turbines are removed. He also was concerned about drainage and about crop productivity if the wind turbines affect his ability to spray, and about declining property values due to wind turbines.

p. Justin Leerkamp said he generally supports the Agricultural Impact Mitigation Agreement, but was concerned about its ability to be enforced. He suggested increasing the fees even more and to use part of those fees to enforce the AIMA. He expressed concern for having enough money in the escrow for decommissioning wind turbines. He said that he doesn't support an increase in height, and he doesn't feel their current setbacks are large enough. He said he would like to see more studies on property values.

q. Darrell Rice asked the Board to give them the best possible restrictions to ensure their lives are the most pleasant they could have living within a wind farm footprint, including lower

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height limits and larger setbacks. He expressed concern for shadow flicker, road conditions and drainage related to construction of wind turbines.

r. Ted Hartke began a presentation, but due to time limits, he agreed to do his presentation at the next meeting on April 14th.

(5) The following is a summary of communications received between April 2, 2022 and April 14, 2022 for this case:

a. In an email received April 12, 2022, Kim Decker provided a list of some locations, sources, or reports that have or are recommending more than one mile setbacks from wind turbines.

b. In an email received April 14, 2022, Matthew Herriott said he was opposed to wind turbine height limits above 500 feet. He said the proposed setback is insufficient to protect the safety and wellbeing of residents. He suggested using Livingston County's ordinance as an example. He said he supported the aircraft lighting detection system, but wondered how well it would work due to the airport. He suggested that the proposed fee increase could be higher and could be used to ensure complaints are addressed. He said he supports the Agricultural Impact Mitigation Agreement if the guidelines are enforced.

(6) The following is a summary of testimony received at the April 14, 2022 ZBA public hearing for this case:

a. Ted Hartke said the ICPB noise limits don't address health issues, only annoyance. He said Dr. Schomer, who helped make these standards, said the ICPB noise levels do not protect health and he said the maximum noise limit from wind turbines should be 39 dB or less. Mr. Hartke gave a presentation citing various sources and testified about his family's negative experience with noise from wind turbines that forced them out of their home. He said that if the Board put the setback at 3,250 feet away and the wind company would want to make the setback at 2,500 or 3,000 feet away, this would put the citizens who live in the wind farm in control, and they would get to decide if they would want to sign off on noise, shadow flicker, and property value loss – the citizens could negotiate that themselves.

Regarding turbine height limits, Mr. Hartke said the taller wind turbines have a longer blade and the blade would flex more causing the low frequency increase along with the thumping and pulsation noise, which is going to be more disturbing.

b. Margie Kolter recommended that people go out to a wind farm area and listen to the noise and feel the vibration that turbines cause. She expressed concern about decommissioning costs and the possibility that the wind companies will go bankrupt and leave the equipment behind. She said that the wind farms are taking prime farm ground and putting concrete in, affecting the drainage, and then they are affecting these peoples' lives.

c. Phil Luetkehans stressed the importance of having sufficient setbacks to protect the health, safety, and welfare of residents and their property values. He said that he thinks anywhere in that setback range of 3,000 feet to 3,250 feet they would probably give a significant protection to residents. He spoke of the probable decrease in property values attributable to proximity to wind turbines. He made a few recommendations for changing the County wind farm ordinance to better protect the County and its residents.

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d. Steve Littlefield, a real estate agent, provided five examples of property values for lots that had sold between 2012 and the present in the California Ridge wind farm area. His overall takeaway was that property values are negatively impacted by proximity to wind turbines.

e. Kim Decker said that she would like to have a longer setback, and that the setback should be measured between the turbine and the property line, not to the residence. She provided a list of several dozen setbacks that have been adopted in the US and abroad. She said she is asking the Board to do the responsible thing and in her opinion that is to vote down the proposition they have before them and hopefully revamp this whole process of setbacks and wind height.

f. Matthew Herriott said he is opposed to a tower height taller than 500 feet and suggested that Champaign County take a closer look at Livingston County's ordinance for height and setback. He expressed support for the ALDS lighting, but questioned how often the lights would actually be off given airport traffic. He suggested that the fee increase should be even higher, and that the higher amount be used in part to have an enforcement officer dealing with complaints about wind and solar farms. He said he supports the Agricultural Impact Mitigation Agreement if it is correctly enforced. He recommended that the Champaign County Zoning Board deny the current proposed changes to the ordinance regarding turbine height and setback distance.

g. Brandon Hastings said the height restriction should stay at 500 feet, setbacks should be 3,250 feet or six times the height, whichever is greater to match Livingston County regulations, but it should measure setback from the property line rather than from the residence. He said he thinks the zoning should eliminate the chance of shadow flicker for non-participating parcels. He expressed concern about how big an issue drainage is, and that the Agricultural Impact Mitigation Agreement should include that. He said that fees should be huge, and escrow accounts should be established not only for decommissioning, but for drainage issues and road repair.

h. Kelly Vetter urged the Board to consider the possibilities of the unintended consequence as related to protecting water resources from wind farm development.

i. Steven Herriott said he thinks the height needs to be maintained at 500 feet. He said he feels that sometimes we are doing things to encourage or bend over backwards to help these wind companies, and he doesn't think it is our responsibility to encourage them to come but to let them conform to what we need out there in the country. He said if by chance the turbines get higher, we need to go with six times the height in setback, and measure from the property line and not the residence.

(7) The following is a summary of communications received between April 15, 2022 and May 26, 2022 for this case:

a. In an email received May 2, 2022, Ted Hartke provided four documents that he asked to be distributed to the ZBA and ELUC members. The documents were distributed and added to the Documents of Record.

b. At the May 5, 2022 ELUC meeting, Mary King distributed three handouts, which have been distributed to the ZBA and added to the Documents of Record.

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c. In an email received May 26, 2022, Mike Lockwood said he favored significantly increased setback distances. He said he was opposed to increasing the allowed height of wind turbines. He asked for more power for homeowners in the approval process and less power for those landowners who do not live in the area.

(8) The following is a summary of testimony received at the May 26, 2022 ZBA public hearing for this case:

a. Stephen R. Smith read a statement on behalf of his neighbor, Kelly Vetter, who said it is time to slow down the current monstrosities of wind turbines trying to come into their backyard and think this through. She supported taking a legacy view that fits the landscape, their values, and generations to come. Mr. Smith said he supports a minimum separation of 3,250 feet from the property line and keeping the 500 foot maximum height for wind turbines.

b. Randy Wells shared his experience with the Douglas County windmills that are as close as .75 mile from his home. He talked about construction issues and bad road conditions due to the wind turbine development. He is concerned that money will not be there for decommissioning when the time comes. While he has not experienced adverse health impacts, he has experienced the noise and flashing lights from the turbines.

c. Lisa Ellis said she is an Edgar County Board member, and offered advice about revising the wind ordinance. She said that Edgar County adopted a 3,250 foot setback to the structure, but the wind company can negotiate with individual landowners to have a reduced separation that cannot be less than 1,000 feet. She said the ordinance should consider local roads, drainage tile, and emergency services. She said Edgar County does not have a height restriction on wind turbines. She said she lives about 25 miles from the nearest turbine, and can hear it and see it from her home.

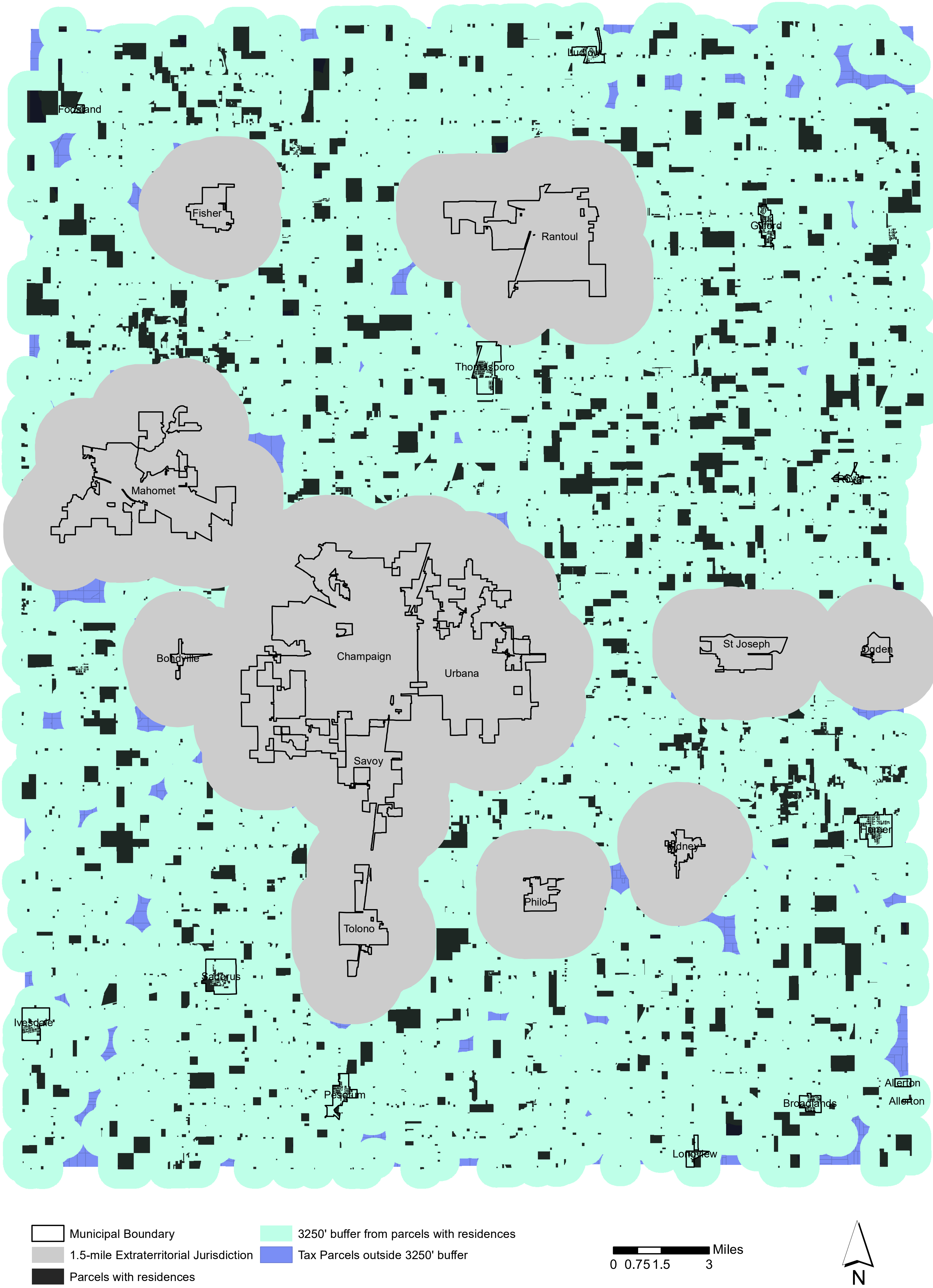
d. Ted Hartke reviewed the four documents he submitted that were distributed as part of Supplemental Memo #2 dated May 17, 2022. He referred to testimony by Dr. Schomer that a limit of 39 dba is needed to mitigate adverse health effects. He said that Dr. Schomer testified that taller turbines will cause more infrasound, and that turbines are louder at night than during the day, with a difference of 3 to 6 dba. He testified about his own story of having to leave his home due to the wind turbines built near his home. He summarized by saying he supports a noise level of less than 39 dba, supports setbacks at 3,250 feet or 6.5 times the blade tip height, supports waivers for setbacks for individual landowners, and wants more consideration for infrasound.

e. Roger Henning Jr said that he supports a setback of 3,250 feet. He has bought property for future development by family members, and wants them to be able to build on any part of the property, so he supports the setback being to the property line and not the structure.

f. Todd Herbert supports maintaining a less than 500 foot height maximum, and supports a setback of 3250 feet or 6 times the height measured from the property line. He thinks it is a bad decision to allow individual waivers to allow a setback of 1,000 feet. He agrees that a setback of 1.25 miles would be best. He supports the aircraft lighting detection system. He expressed concern about drainage tile and supports a setback from the very fragile Drainage District tiles. He said there would be no farming if there was no tile.

3,250 feet separation from property line

June 30, 2022



N

1,000 0 1,000

Feet

≥ 3,250' SEPARATION TO DWELLING, 39dBA
(11 TURBINES)

Legend

- Proposed Turbine Location

Principal Dwelling Structure

- Not Participating
- Participating
- 125' Turbine Buffer
- County Boundary

Landowner Status

- Participating
- No Information

Separation distances between wind farm structures and non-participating dwellings or principal buildings are greater than minimum setbacks.

Dimensions indicated are from non-participating buildings or principal buildings to turbine buffer. Turbine buffer is 125' from current turbine centerpoint in order to account for field adjustments and micrositing issues.

Champaign County Non-Participating Dwelling Separation Summary

California Ridge Wind Energy Project, Champaign and Vermilion Counties, Illinois

Rev. 01

July 29, 2011

Invenergy

One South Wacker Drive Suite 1900
Chicago, Illinois 60606
(312) 224-1400

N

1,000 0 1,000
Feet

≥3,250' SEPARATION TO PL, 39dBA
(6 TURBINES)

Legend

Proposed Turbine Location

Principal Dwelling Structure

Not Participating

Participating

125' Turbine Buffer

County Boundary

Landowner Status

Participating

No Information

Separation distances between wind farm structures and non-participating dwellings or principal buildings are greater than minimum setbacks.

Dimensions indicated are from non-participating buildings or principal buildings to turbine buffer. Turbine buffer is 125' from current turbine centerpoint in order to account for field adjustments and micrositing issues.

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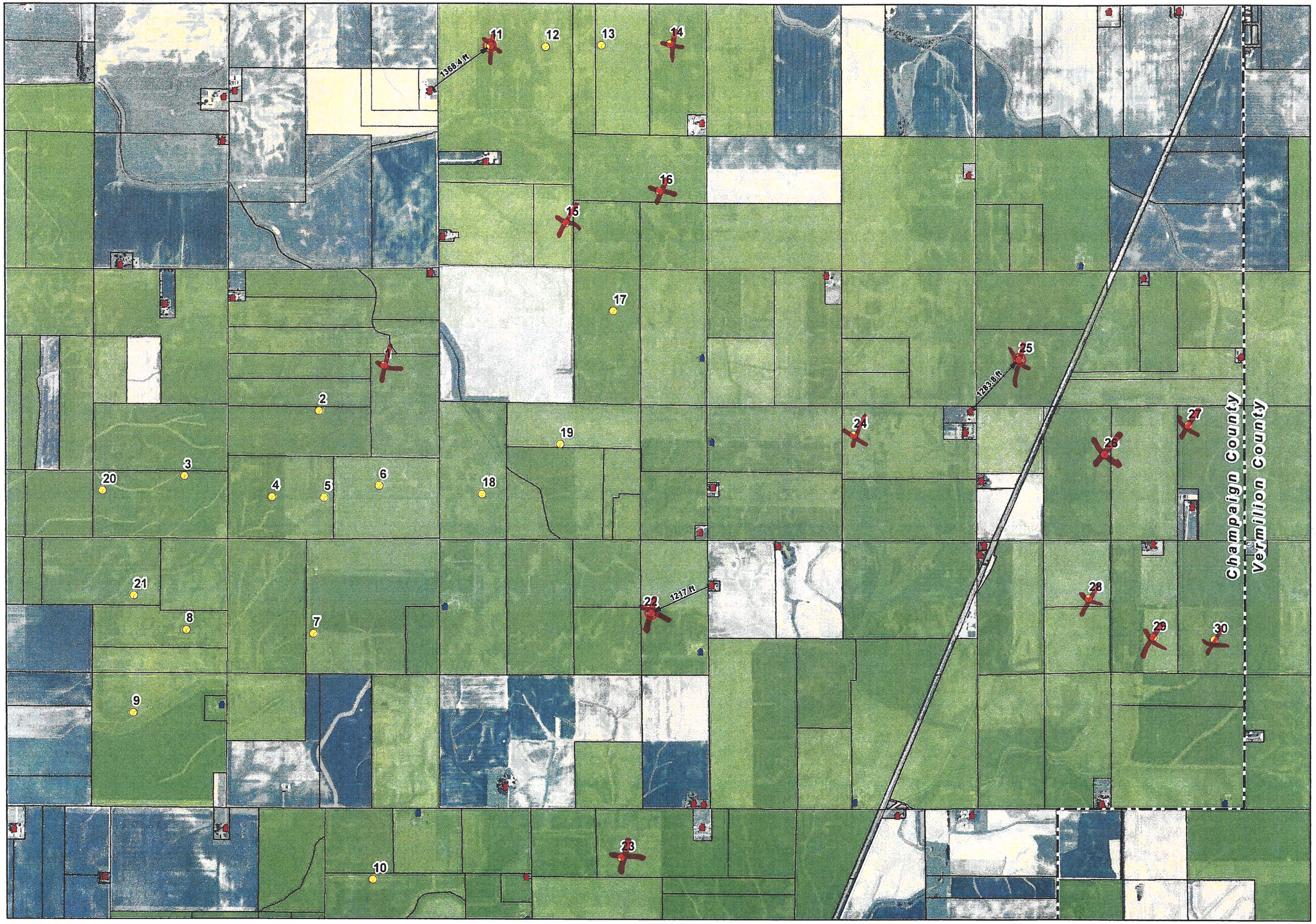

N

1,000 0 1,000

Feet

≥ 2,360' separation to Dwelling (16 turbines) & 40dBA

Legend

- Proposed Turbine Location

Principal Dwelling Structure

- Not Participating
- Participating
- 125' Turbine Buffer
- County Boundary

Landowner Status

- Participating
- No Information

Separation distances between wind farm structures and non-participating dwellings or principal buildings are greater than minimum setbacks.

Dimensions indicated are from non-participating buildings or principal buildings to turbine buffer. Turbine buffer is 125' from current turbine centerpoint in order to account for field adjustments and micrositing issues.

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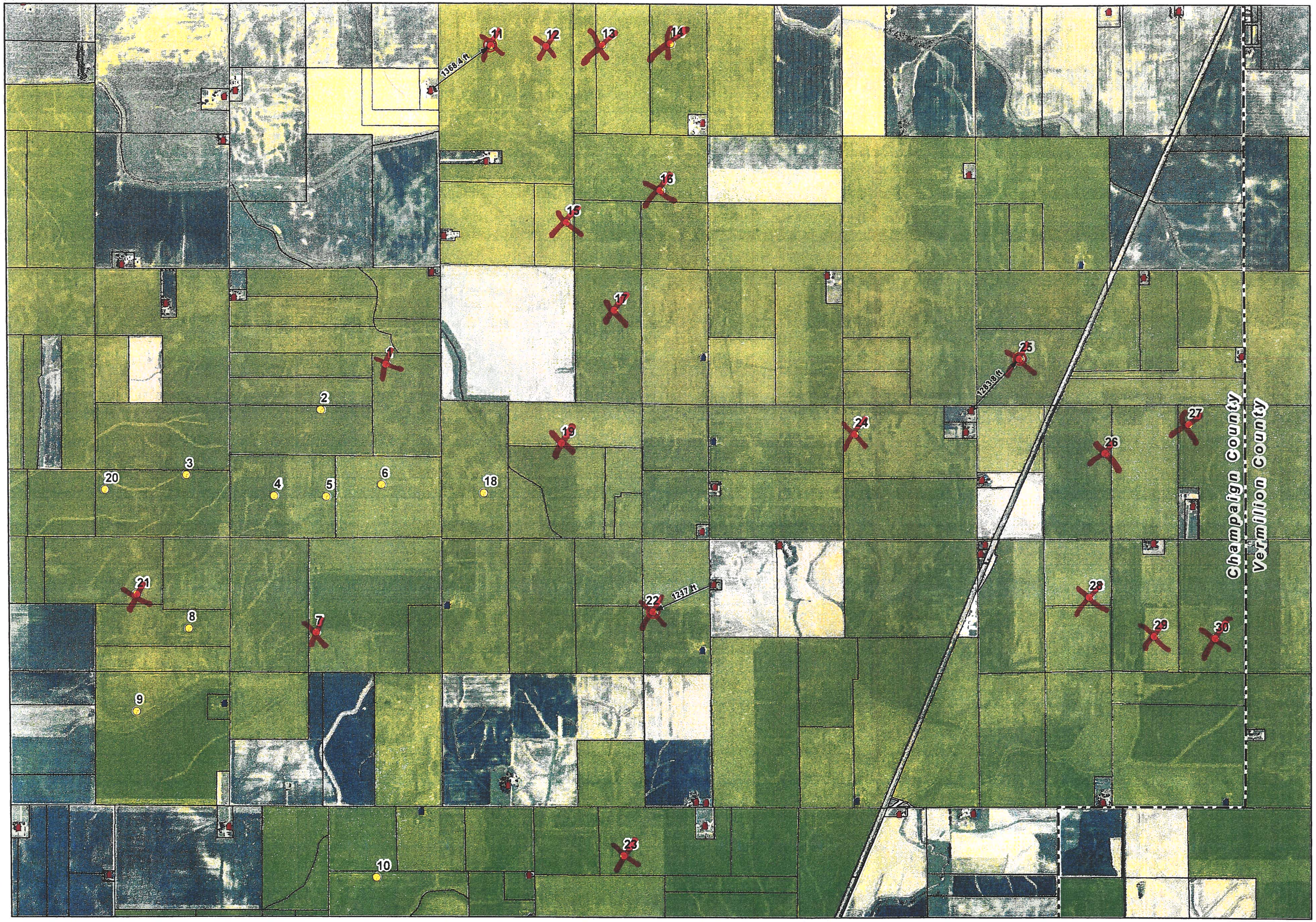

N

1,000 0 1,000

Feet

≥ 2,360' SEPARATION TO PL, 40dBA

(10 TURBINES)

Legend

- Proposed Turbine Location

Principal Dwelling Structure

- Not Participating
- Participating
- 125' Turbine Buffer
- County Boundary

Landowner Status

- Participating
- No Information

Separation distances between wind farm structures and non-participating dwellings or principal buildings are greater than minimum setbacks.

Dimensions indicated are from non-participating buildings or principal buildings to turbine buffer. Turbine buffer is 125' from current turbine centerpoint in order to account for field adjustments and micrositing issues.

Champaign County Non-Participating Dwelling Separation Summary

California Ridge Wind Energy Project, Champaign and Vermilion Counties, Illinois

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July 29, 2011

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TITLE 35: ENVIRONMENTAL PROTECTION
SUBTITLE H: NOISE
CHAPTER I: POLLUTION CONTROL BOARD
PART 901 SOUND EMISSION STANDARDS AND LIMITATIONS FOR PROPERTY-LINE-NOISE-SOURCES
SECTION 901.102 SOUND EMITTED TO CLASS A LAND

Section 901.102 Sound Emitted to Class A Land

a) Except as elsewhere provided in this Part, a person must not cause or allow the emission of sound during daytime hours from any property-line noise source located on any Class A, B or C land to any receiving Class A land that exceeds any allowable octave band sound pressure level specified in the following table, when measured at any point within the receiving Class A land. Sound pressure levels must be measured at least 25 feet from the property-line noise source.

Octave Band Center Frequency (Hertz)	Allowable Octave Band Sound Pressure Levels (dB) of Sound Emitted to any Receiving Class A Land from		
	Class C Land	Class B Land	Class A Land
31.5	75	72	72
63	74	71	71
125	69	65	65
250	64	57	57
500	58	51	51
1000	52	45	45
2000	47	39	39
4000	43	34	34
8000	40	32	32

b) Except as provided elsewhere in this Part, person must not cause or allow the emission of sound during nighttime hours from any property-line noise source located on any Class A, B or C land to any receiving Class A land that exceeds any allowable octave band sound pressure level specified in the following table, when measured at any point within the receiving Class A land. Sound pressure levels must be measured at least 25 feet from the property-line noise source.

Octave Band Center Frequency (Hertz)	Allowable Octave Band Sound Pressure Levels (dB) of Sound Emitted to any Receiving Class A Land from		
	Class C Land	Class B Land	Class A Land
31.5	69	63	63
63	67	61	61
125	62	55	55
250	54	47	47
500	47	40	40
1000	41	35	35
2000	36	30	30
4000	32	25	25
8000	32	25	25

(Source: Amended at 42 Ill. Reg. 20453, effective November 1, 2018)

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Noise: Paper 4aNSb3

A possible criterion for wind farms

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Opposition to wind farm noise is not abating and shows no sign of doing so in the future. In a January 2017 paper in Sound and Vibration, Hessler, Leventhal, Walker and Schomer come together to report that independently they have come to about the same conclusion for a proper threshold of wind turbine noise. The same A-Weighted criterion has shown to come up in a variety of independent ways. This paper is not for pie in the sky desires for no sound. Rather, it attempts to recommend a criterion to use for determining the limits of wind turbine noise. This criterion is based off of the data of four independent sources: (1) CTL, (2) ANSI S12.9 Part 4, (3) Michaud et al. (2016), and (4) a State of Minnesota Department of Commerce survey of criteria set in various foreign countries and provinces. This paper recommends the use of A-weighting and a 24-hour Leq as the metric. 36-38 dB is recommended for the criterion.

RECEIVED

APR 14 2022

CHAMPAIGN CO. P & Z DEPARTMENT

Case SU-17-11

SLG EXHIBIT 5

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1. INTRODUCTION

A. BACKGROUND

Like most other industries or sources of transportation, noise and noise criteria are a matter of consternation to all sides involved in the siting and development of wind farms. Industry wants the permitted acoustical levels as high as possible, the community wants them as low as possible, and the municipality or county wants to maximize the dollars in their budget. For the past 10 or 15 years there has been an evolution towards developing a metric and criterion for wind turbine noise. Many turbines were built with what turns out to be rather high levels. They were designed with the community level being set at 50 or even 55 dB (A). Gradually, these levels have decreased, but friction between the community groups, the developers of the wind farms, and local government continues to this day.

B. PURPOSE

The purpose of this paper is to explain and evaluate the metric by which the community response to wind turbine noise is gauged and the limits appropriate to that response function. Chapter II deals with selection of the metric, and Chapter III presents the data and methods used to establish criteria and a criterion, based on the metric selected.

C. APPROACH

The approach to the selection of a metric is pragmatic. When looking at the present situation, A-weighting is the only appropriate metric for most noise sources. Based on all that we know, it could well be that C-weighting is preferred, or even Z-weighting or lower would be an improvement. But pragmatically, what is in use today and has corresponding response functions is A-weighting. These issues are dealt with in Chapter II.

In the second and more major part of the paper, various *independent* references and their procedures are used to find data on which to base the selection of a recommended criterion. These data come from four very independent sources. The use of four totally independent sources of data, independent from each other and independent from the issues at hand cannot be stressed enough. For example, the community tolerance level (CTL) was developed based on road traffic and airport noise, totally independent of wind turbine noise (WTN), totally independent of American National Standards Institute (ANSI) S12.9 Part 4, totally independent of the Health Canada study, and totally independent of the Minnesota Department of Commerce study. Similar statements can be made of each of the four sources, and these four sources are equally independent from the parties concerned (industry, community, and local government). They are totally independent of the results from the ANSI S12.9 Part 4 calculation, because these results were developed without having wind turbines mentioned or included in any way, as this was just a general procedure for environmental noise. Any assessment here is certainly independent from the Minnesota Department of Commerce existing criteria levels. The average and extremes of those data are what they are; nothing we do here can influence that. CTL is derived for other sources and other places, and not constructed for WTN, so its application is totally independent from wind turbine noise sources. The Health Canada data are not totally independent of the issues at hand, but the authors argue that the Health Canada data are equally independent for all three parties. In the same test with the same subjects, the Health Canada study finds that there are no health effects that can be found at the resolution that one gets with about 1200 subjects, but that there are substantial annoyance effects with these same subjects in the same study. One finding for industry, one finding for the community. That is, with the same sampling, the same noise measurements, the same noise predictions, the same surveyors, the same survey instrument, the same subjects, one gets half of the results that in some sense support industry, and half of the results that in some sense support the community. At least to this authors' mind, Health

Canada represents an independent government entity not aligned with any of the three parties. The four sources are as follows:

1.data inherent to community tolerance level (CTL);

2.ANSI S12.9 Part 4

3.data from Health Canada, used to establish the equivalency between wind turbine noise and other noise;

4.the Minnesota Department of Commerce

Note: None of the data was developed by these authors and each of the sources is independent from any of the three primary groups involved: community, developer/operator, and local government. Thus, our approach is to present and explain these sets of data or procedures, and to show how they relate to the general method and the criterion that is ultimately selected.

1. CTL provides a one-number assessment of a set of cluster data from an attitudinal survey. Depending on what is held constant, almost any situation can be compared in decibel units of day-night level (DNL). Keeping with current practice, road traffic noise is used as the baseline. The difference in CTL between a data set under study and road traffic noise is the decibel difference between the two CTL values, respectively.
2. ANSI S12.9 Part 4 is directly used to form a small range of levels for potential development of a criterion.
3. Direct use of the Michaud *et al.* data and other similar international data to set a criterion.
4. Data from a State of Minnesota Department of Commerce survey of criteria set in various foreign countries and provinces.

2. SELECTION OF A METRIC

A. DISCUSSION OF WEIGHTING

As is well known, most sources are assessed using A-weighting with perhaps an adjustment for sound character (e.g. tonal or impulsive). A basic version of this assessment metric has been used since at least 1971 when the first version of ISO 1996 (International Organization for Standardization) was approved. The only source for which A-weighting is not used is high-energy impulsive noise, e.g. sound from demolition, open pit mining and quarrying, sonic booms, and noise from military training. For these sources, C-weighted data are collected, and these data are transformed to equivalent A-weighted levels in terms of equal annoyance (ANSI S12-9, ISO 1996-1).

There is no function that relates C-weighted wind turbine noise to an equivalent A-weighted level, nor is there a function that relates Z-weighting to an equivalent A-weighted level. The C-weighting procedure for high-energy impulsive noise took about 25 years to validate and get into use. Correlation between A-weighting and C-weighting in response to turbine noise has been shown, but this does not show that either of the weightings is correct. There is no conversion tool upon which to develop equivalent A-weighted levels. A response function is required. But it can be observed that a high degree of correlation between A- and C-weighting exists; so high that there is virtually no difference between using C-weighting or A-weighting. When one has a class of sources that all have the same spectrum, then the difference between different linear filters that all measure at least some part of the sound will all be highly correlated with one another. The difference between A-weighting and other weightings is that response functions have been created and scrutinized for A-weighting.

A constant, 24-hour A-weighted equivalent level (Leq) computed over the day and night periods, is the recommended metric, and in nearly all cases, the metric of interest is the nighttime Leq resulting from wind farm operations. So, as with aircraft and other noise categories that are dominated by one kind of source, comparisons can be made from one situation to another because the spectral content has not changed from one situation to another. For example, if one is measuring traffic noise, then the Leq for the hour beginning at 1500 measured on Tuesday should be similar to the hour measured at 1500 on Wednesday.

If the appropriate computational procedures are chosen, then one can install a barrier, have a reasonable chance at predicting a reduction, and subsequently produce a meaningful reduction for the community. That is not the situation with wind farm noise. It has been shown that the correlation from one type of wind turbine to another, and from one size to another, results in a set of numbers that properly order different situations because there is no change to the spectrum from one wind turbine to another. But this is not the case if one performs mitigation and predicts the benefit based on A-weighting. A barrier can be built alongside a highway and the reduction can be predicted. The corresponding decrease in community annoyance can also be predicted, at least to a reasonable degree. We cannot make the same statement about wind farm noise.

The reader should be cautioned not to believe that A-weighting is the correct weighting function for wind farm noise assessment. This simply has not been shown. Currently, however, the A-weighted levels assigned to different community responses seem to fit current wind farms in terms of response and level, at least in terms of annoyance based on attitudinal survey data. A-weighting is not chosen because it has been shown scientifically to be better than other metrics. Rather, it is chosen because at the current state of development, to date, no one has shown any metric to be superior. Even if it were available today, it would still take quite a while to gain acceptance for such a metric.

B. METRIC

The choice of a metric is limited. In principle, all of the readily available noise metrics are those built into sound level meters and other similar devices. The non-time integrating metrics are very limited in the data provided. Lmax and Lmin are two non-integrated choices, but it is clear that Lmax may be something that occurs for a short time every once in a while (e.g., once an hour or once a day). In the class of time-integrated metrics, there are three prominent choices: Leq, Ldn, and Lden. These three are not significantly independent; rather, there are very clear and consistent differences among them. Leq 24-hour is predicated on the assumption that wind farm noise emissions from a given turbine throughout the 24-hour day are more or less constant (read ±1 dB). The question is: how far above Leq must the DNL be such that the calculation of Leq during daytime added to (Leq+10) dB at night equals to DNL? The difference between the numerical value for Leq and DNL when the Leq is held constant is about 6-7 dB. A similar number exists for DENL. DNL or DENL provide no additional information as compared to the simpler, constant 24-hour Leq. Were Leq not a constant, and Ld and Ln are not constant, then a more complicated difference between DNL and 24-hour Leq would be required.

3. METHODS AND PROCEDURES BY WHICH A CRITERION FOR WIND TURBINE NOISE CAN BE SELECTED

A. DIFFERENCES IN COMMUNITY TOLERANCE LEVEL (CTL) BETWEEN ROAD TRAFFIC AND WIND TURBINE NOISE

At this point, it is proposed that a relationship between percent highly annoyed and various nighttime Leq levels be established. However, the recent papers by Fidell et al. and Schomer et al. relate percent highly annoyed to DNL. These two papers also introduce the concept of community tolerance level (CTL). This paper will establish the relationship between nighttime Leq, CTL, and DNL for wind turbine noise. Once that is done, we will compare various DNL and CTL levels with wind farm levels. As a part of this comparison, we will include the transformation of CTL or DNL data to nighttime Leq in order to have valid comparisons. First, DNL will be discussed, followed by CTL.

Up until the introduction of CTL, all community attitudinal survey data were analyzed by using linear regression analysis. There was no underlying functional relation. With CTL, it is hypothesized that the community response to environmental noise is similar to the basic human loudness function where loudness is proportional to the independent variable raised to the 0.3 power. Secondly, it is hypothesized that the functional form of a relationship is a transition function, and for the sake of simplicity, the simplest form of a transition function is used: e^{-v}. It becomes:

$$\%HA = 100 * e^{-1/(10^{\left(\frac{Ldn-Lct+5.306}{10}\right)^{0.3}})} \quad (1)$$

where 5.306 is an arbitrary constant K. The property of K is such that when Ldn=Lct, then Lct corresponds to the 50th percentile for %HA. That is, for purposes of convenience, the value of CTL for a given community is standardized at the midpoint of the exponential function. A CTL value thus corresponds to the DNL value at which half of the people in a community describe themselves as highly annoyed by transportation noise exposure. As Fidell *et al.* (2011) show, the constant 5.306 follows from the definition of CTL as the midpoint of the exponential function. That is, when DNL = CTL, the %HA = 50%. (Definition of CTL at a point other than 50% on the exponential function would merely result in a change to the constant 5.306, with no loss of generality.)

Fidell *et al.* (2011) gives the percent highly annoyed as a function of DNL for all noise caused by airport operations. Schomer *et al.* (2012) does the same for highway and railroad noise. The convention is that all noises are compared to road traffic noise. The difference in the value of K between any source and road traffic yields the numerical difference in dB between the two situations. For example, the CTL for all road traffic is 78 dB and the CTL for all aircraft is 73 dB. So, aircraft is 5 dB less tolerable than road traffic noise. CTL can quantify the difference between any two situations one wants to consider. For example, one could look at the difference between nighttime and daytime, the difference between hilly country and flat country, the difference between urban, suburban, and rural, or the difference between communities on the ocean and those landlocked.

Michaud *et al.* (2016) calculates the CTL for wind turbine noise to be 62 DNL. That is, 16 dB must be added to the DNL of road traffic noise to make it equivalent to that of wind turbine noise. Michaud et al. also calculate the CTL for each of his two study areas, Prince Edward Island and Ontario, independently. In addition, they calculate the CTL for other surveys that provide the necessary data to calculate the CTL (Pedersen et al. 2004, 2007, 2009; Yano et al. 2013). Michaud shows that the CTL for Ontario is very similar to the CTL for Pederson et al., 2004 and Yano et al. 2013. The CTL for PEI is shown to be very similar to the CTL for Pederson et al 2007 and 2009. The CTL for Ontario is about 7.5 dB lower than the CTL for PEI. They also compute the average CTL for windfarms and that is what is used herein.

B.USE THE DIRECT HEALTH CANADA AND THER COMPARABLE INTERNATIONAL SURVEY DATA OF %HA AT VARIOUS TURBINE NOISE LEVELS

This method is the simplest, it says that the %HA at a certain dB(A) is exactly what is measured. There are three data points provided by the Health Canada analysis: the ranges are from [30-35) dB, [35-40) dB, and [40-46) dB. The corresponding %HA are 1%, 10%, and 14%.

In this paper, several primary sources of data are used to develop the functional relationship and select the criteria. Once a DNL is chosen as the metric, the second step is to establish percent highly-annoyed as a function of DNL. This %HA can then be compared to the results from Michaud *et al.* to form a criterion.

C. USE THE S12.9 TO DIRECTLY DEVELOP A CRITERION

ANSI S12.9 Part 4 uses DNL as its primary metric. ANSI S12.9 Part 6 establishes 55 DNL as the criterion for start of impact from noise. Part 4 also establishes the adjustment of 10 dB for quiet rural areas, i.e. the criterion drops to 45 DNL. In terms of a 24-hour A-Leq, this criterion drops to 39 dB. So, we find 39 dB to be a criterion, independent of the noise source. This derivation never mentions wind turbine noise.

D. USE THE MINNESOTA DEPARTMENT OF COMMERCE FINDINGS

Minnesota, like 29 other states (reference 2 from Haugen 2011), has a state renewable energy objective that calls for "25% of the state's electrical energy to come from renewable sources including wind energy by 2025 (reference 3 from Haugen 2011)." "While many people support wind energy, some have become concerned about possible impacts to their quality of life due to wind turbines, including noise, shadow flicker, and visual impacts…" Because of these concerns surrounding wind power, the state set out to survey a variety of players in the wind energy industry, from many foreign regions and countries. "For this report, a variety of professionals working on renewable energy issues within national and regional governments, wind energy associations, wind energy development companies, and other areas were contacted by email."

The Minnesota findings are shown in Figure 1. This figure shows national and regional wind farm limits in two different kinds of areas: (1) residential and other noise sensitive areas, and (2) all other areas. These are represented in the figure as a solid blue bar for the sensitive areas, and a solid green bar going above the blue for the other areas. Only 3 of the 19 jurisdictions are above 40 dB: Spain, Portugal, and the Netherlands, and the average is 36 dB.

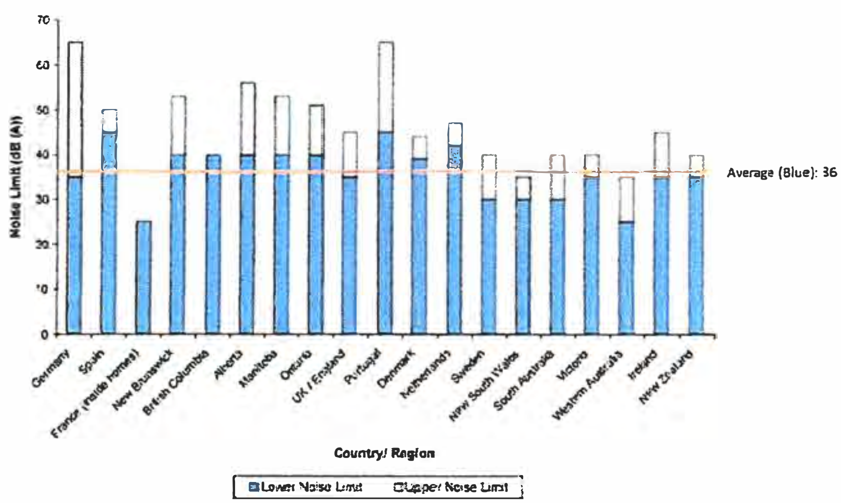

Figure 3: Country Wind Turbine Noise Limits at Residences

Figure 1: International wind turbine noise limits obtained by the Minnesota Department of Commerce

4. EVALUATION OF CURVES EQUATING DNL TO %HA

In this report, data from six different sources are examined in an attempt to develop a %HA criterion for wind turbine noise (and most other noises): Schultz, the Committee on Hearing, Bioacoustics, and Biomechanics (CHABA), the Federal Interagency Committee on Noise (FICON), CTL (Fidell *et. al.*, Schomer *et. al.*), Miedema and Oudshoorn (2003), and Miedema and Vos (1997). Schultz, CHABA, and FICON are all based on the Schultz's 1978 synthesis of social surveys on noise annoyance, with the CHABA curve being virtually identical, and FICON being mysteriously low in the relevant DNL interval (60-75 DNL). Miedema and Oudshoorn is an improved version of Miedema and Vos, and along with CTL is used in the current version of ISO 1996-1. Schultz, CHABA, and FICON use data from a combination of aircraft and road traffic noise sources to arrive at their %HA values, whereas CTL, Miedema and Vos, and Miedema and Oudshoorn all make a distinction between aircraft and road traffic. The curve given by Miedema and Vos is shown in the figure for reference as a dashed blue line, but is not included in the analysis that follows because they are two variant data fits to the same data base by the same organization, and using both of them could bias the calculations that follow.

These five sources and their %HA from 50 to 70 DNL in 5 dB increments are shown in Table 1. In this table, Miedema and Oudshoorn and CTL both have separate equations for road traffic and air traffic. CHABA and FICON each use their own single equation for all modes of transportation; planes, trains, and automobiles. Research has conclusively shown that aircraft sound is more annoying than other sound for the same numerical value, which implies that the DNL values Schultz, CHABA, and FICON attribute to a corresponding percentage of high annoyance must be biased high for use with road traffic. And conversely, the %HA for aircraft noise must be biased low. Part A of Figure 2 shows the five functions described for road traffic noise, and Part B shows the five functions described for aircraft noise. From the figures, it would seem that the biased low is a much stronger factor than the biased high. In fact, from the data, one would be tempted to say there is no bias high, but from the logic, this seems to be impossible. As shown in Figure 2A, the Schultz, CHABA, and FICON curves fit somewhat closely to the road traffic curves, but understates the %HA value. For aircraft noise (Figure 2B), %HA values are understated by a very large amount, nominally 15%.

ROAD:

Group	**M&O**	**CTL**	**CHABA**	**FICON**	**SCHULTZ**
50	3.8	0.7	2.3	1.7	1.3
55	6.6	3.1	4.6	3.3	3.9
60	10.6	8.6	8.7	6.5	8.5
65	16.5	17.6	15.2	12.3	15.2
70	25.1	29.2	24.5	22.1	24.6

AIR:

Group	**M&O**	**CTL**	**CHABA**	**FICON**	**SCHULTZ**
50	5.3	3.1	2.3	1.7	1.3
55	11	8.6	4.6	3.3	3.9
60	18.6	17.6	8.7	6.5	8.5
65	27.8	29.2	15.2	12.3	15.2
70	38.5	41.9	24.5	22.1	24.6

Table 1: %HA values at different DNL levels for 5 sources

There is no doubt that both Schultz and CHABA represent excellent researchers and excellent organizations. Their results differ from more recent results by Miedema and Oudshoorn, Fidell, and

Schomer. The only conclusion one could come to is that the two databases being analyzed are not the same, and that is known to be the case. The database used by Schultz contained 11 clustering surveys, of which six were aircraft, four were road traffic, and one was railroad. In contrast, the three more recent curves are based on a much larger database. Fidell used 43 aircraft surveys for his work, and Schomer used 39 road traffic surveys and 11 railroad surveys, totaling 93 surveys used to create the CTL method. Miedema and Oudshoorn is based upon a similar quantity of data. A large quantity of the data is used both for CTL and Miedema and Oudshoorn. For a variety of reasons, the authors of this paper will use the methods based on the larger database, Miedema and Oudshoorn, CTL, and CHABA.

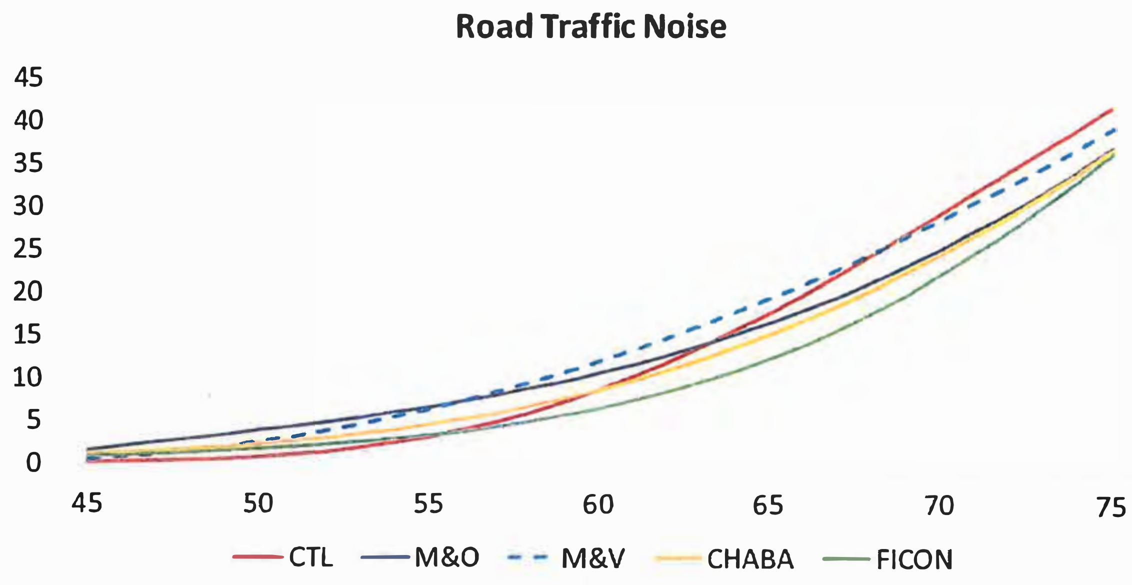

Figure 2A: 5 curves for determining %HA for road traffic noise

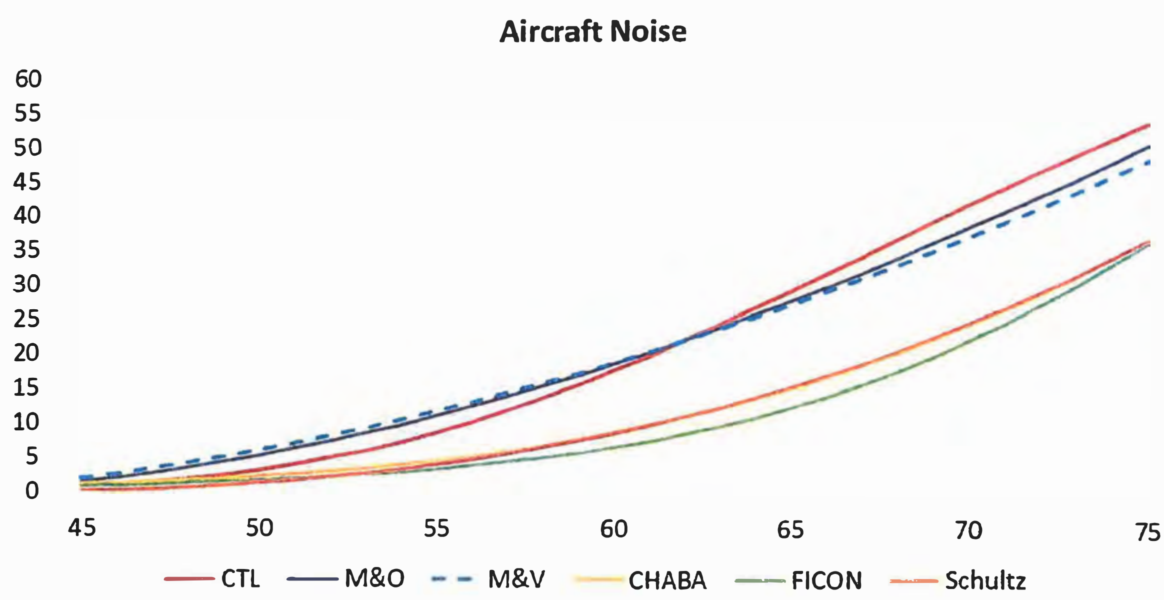

Figure 2B: 6 curves for determining %HA for aircraft noise

5.WHAT IS THE ACCEPTABLE LIMIT FOR PERCENT HIGHLY ANNOYED (%HA)?

A. ESTABLISHING A FUNCTION FOR %HA vs DNL

Since the purpose of this report is to establish data and relations for the selection of a wind turbine noise criterion. In this section, four independent methods are given with which to establish a relation by which to judge wind turbine noise annoyance. During at least the last several years, it has been common to use road traffic noise as the "yardstick" by which other noises are measured. Miedema and Vos (1997), Miedema and Oudshoorn (2003), Fidell *et al.* and Schomer *et al.*, as well as ISO 1996-1 all use road traffic noise for this purpose.

In 2005, Schomer examined the metrics and criterions used by nearly every federal agency and board, by recommendations in national standards, and by international recommendations such as those made by the World Health Organization. These, and multiple other sources agree to 55 DNL as an acceptable criterion for road traffic noise. Therefore, we will use 55 DNL as our intermediate criterion. The term "intermediate" is used because the real issue is annoyance and not decibels. It is very common to relate %HA to decibels, but it is almost always decibels that are measured and not annoyance. For a DNL of 55 dB, 4 different estimates of %HA were found in the literature. CTL equates 55 DNL with about 3% HA, Miedema and Oudshoorn equates 55 DNL with about 7% HA, for road traffic and aircraft noise separately, and CHABA predicts about 5% for a DNL of 55, for both air and road traffic combined. Herein, we will be using the average of these four estimates, which is 5%.

B. CHOOSING A CRITERIA

1. The first method, the method that is dependent on %HA, relates the data from Health Canada to the 5% value established above. Michaud *et al.* (2013) writes that "Consistent with Pedersen et al. (2009), the increase in wind turbine annoyance was clearly evident when moving from [30–35) dB to [35–40) dB, where the prevalence of wind turbine annoyance increased from 1% to 10%. This continued to increase to 13.7% for areas where WTN levels were [40–46] dB." Michaud relates 3 different values for %HA values with 3 corresponding decibel levels: 1%HA is related to 32.5 dB(A), and 10%HA is related to 37.5 dB(A). Therefore, 5%HA would be related to a value between 32.5 and 37.5 dB(A), most likely around 35 dB(A). With this method, a 5%HA criterion is related to 35 dB(A). A more conservative criterion is given by the doubling of the %HA from 5 to 10%. For this second %HA limit, the corresponding dB(A) level is 37.5 dB(A).

2. The second method compares CTL for road traffic noise to CTL for wind turbine noise. The average CTL for road traffic noise (Schomer *et al.* 2012) is 78.3 dB. In comparison, the average CTL for wind turbine noise is 62 dB. So, a 16 dB difference is found between wind turbine noise and the traffic noise "yardstick." To complete this comparison, one must have a value for an acceptable DNL for road traffic noise. Here, a range of DNL is considered: 55-60 dB. Subtracting 16 yields a range of 39-44 dB for wind turbine noise. As per section II-B above, 6-7 dB is subtracted from DNL in order to calculate Leq. This subtraction yields a range of 32-38 dB as a limit for wind turbine noise.

3. A third method to develop a criterion is to directly apply ANSI S12.9 Parts 4 and 5. Part 5 recommends a DNL of 55 dB for residential areas as a limit based on the start of impact. Part 4 recommends a 10 dB

penalty on the limits for quiet rural areas. Most wind farms are built in quiet rural areas, so this penalty is applicable in this case. In a quiet rural area, the DNL limit becomes 45 dB. But this is DNL, to get to Leq we must subtract 6-7 dB, so that the recommendation becomes an Leq of 38-39 dB.

4. Data published by the Minnesota Department of Commerce, shown in Figure 1, give noise limits for sensitive rural areas and non-sensitive areas. As an example of land use designations, wind turbine noise limits in South Australia are based on the highest level applicable between: rural areas at 35 dB(A), non-rural areas at 40 dB(A), or 5 dB(A) above background measured as L90. The average value of the noise limits for sensitive areas given by the Minnesota report is about 36 dB(A).

6. ANALYSIS AND CONCLUSIONS

Four independent data sources are used to create four estimates of an acceptable 24-hour A-weighted Leq criterion for wind turbine noise. Two methods use 5% highly annoyed as the estimated start of impact for a receiving person. The remaining methods examine both adjustments to a recommended DNL indicating start of impact, and an analysis of existing wind turbine noise limits. The four estimates of a criterion are listed below:

1. 5% HA is shown to be a very approximate average to a criterion for %HA. In order to be conservative, the range from 5 to 10% is considered herein. Applying a 5% HA value to the Health Canada data gives a limit between 32.5 dB and 37.5 dB, or about 35 dB(A). Applying a 10% HA value to the Health Canada data gives a limit of 37.5 dB(A) (Michaud *et al.* 2016b).

2. A 16 dB difference is found between the CTL for road traffic noise and WTN, and if the metric is Leq, then the difference between WTN and Leq is another 6-7 dB, for a total of 22-23 dB difference. Comparing the CTL for wind turbine noise to the CTL for road traffic at the lower limit of 55 DNL for road traffic suggests a limit of 32-33 dB(A). Comparing the CTL for wind turbine noise to the CTL for road traffic at the upper limit of 60 DNL for road traffic suggests a limit of 37-38 dB(A).

3. Applying ANSI S12.9 Parts 4 and 6 to determine the level at which impact will start in a quiet, rural area gives a limit of 38-39 dB(A).

4. The average of existing worldwide limits found in the Minnesota Department of Commerce report for sensitive areas is about 36 dB.

As applicable, Table 2 lists the minimum, average, and maximum Leq criteria for wind turbine noise for each of the four methods above:

	Minimum (dB)	Average (dB)	Maximum (dB)
1-%HA		35	37.5
2-CTL	32		38
3-ANSI		38	39
4-MN DoC		36	
AVERAGE	**32**	**36.3**	**38.2**

Table 2: Minimum, average, and maximum Leq criteria

The average of the top-end values is about 38 dB(A) and the average of the middle values is about 36 dB(A). The minimum level, 32 dB, is not emphasized. These four sets of independent data result in criteria recommendations that are remarkably close to one another, lending support to a 24-hour A-weighted Leq wind turbine noise criterion in or around the range of 36-38 dB(A).

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Wind Turbine Noise: Effects on Human Health

Zoning Board of Appeals
Christian County, Illinois
June 23, 2020

Jerry Punch, Ph.D., Professor Emeritus
Michigan State University
East Lansing, Michigan

LBGA
EXHIBIT
8

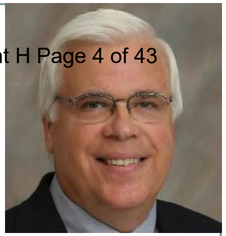
Abbreviations

AHEs: Adverse health effects
IWTs: Industrial wind turbines
WHO: World Health Organization
WTN: Wind turbine noise

Topic Outline

- Physical nature of WTN
- Common health effects of WTN exposure
- Research evidence that WTN causes AHEs
- Methods of limiting WTN
- Standards and guidelines relevant to WTN

Professional Background



- Educational background
  - BA, Wake Forest University, Psychology
  - MS, Vanderbilt University, Hearing and Speech Sciences
  - PhD, Northwestern University, Audiology
- Clinically certified in Audiology (American Speech-Language-Hearing Association)
- 50+ years experience as audiology clinician, researcher, teacher, and administrator in academic, clinical, professional association, hospital, and industrial settings (last 30 years at MSU); retired from MSU faculty (2011)
- Numerous research publications and conference presentations, including several recent papers on wind turbine noise
- Chair of Technical Work Group to revise Michigan guidelines for siting onshore wind turbines
- Legal consultant as expert witness on matters of health in variety of cases in multiple states
- (Details in CV; available on request)

Wind Turbine Noise: Professional Experience

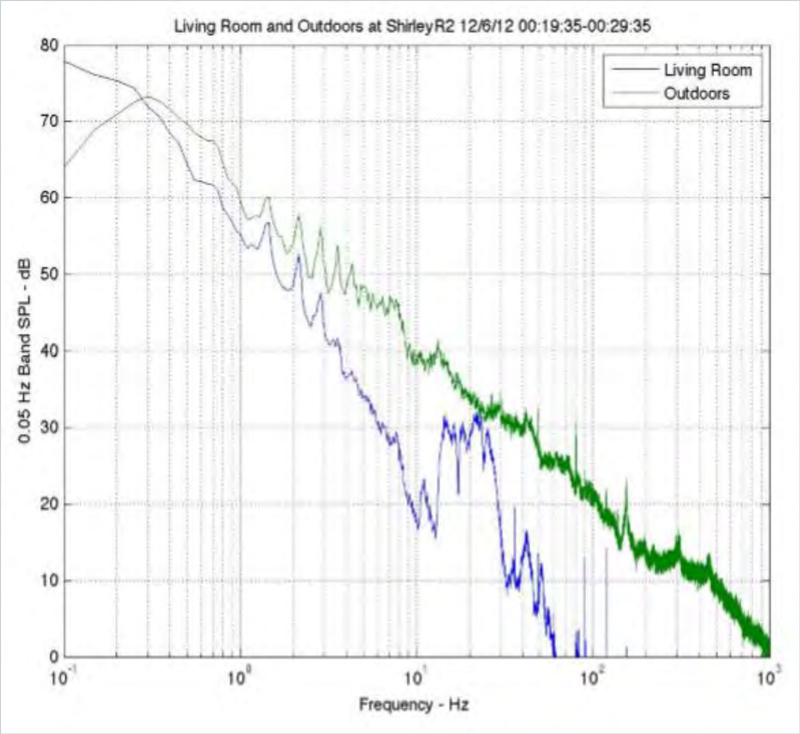
- Visited wind project in Huron County, MI (2009)
- Read book by Paul Gipe, *Wind Energy Comes of Age*
- Published literature review article in *Audiology Today* in 2010
- Chaired Wind and Health Technical Work Group, MI Department of Energy
- Presented invited comments in public meetings and hearings of zoning boards and commissions in several states (MI, IL, IN, NY)
- Co-authored three-part, invited article (hearinghealthmatters.org)
- Qualified legally as health expert in Daubert hearing (MI)
- Served or serving as witness, as health expert, in legal cases (OH, WI, MI, IA, IL, OR, IN, NY, SD), before or after turbine construction
- Interviewed individuals and families who had abandoned, or about to abandon, their homes (MI, IA, OR)
- Co-authored 2016 literature review (with R. James): *Wind turbine noise and human health: a four-decade history of evidence that wind turbines pose risks*

My First View of IWTs (Huron County, Michigan)

Family Home in Huron County, Michigan

This family was sleeping in a motel during nights when the turbines were fully operational.

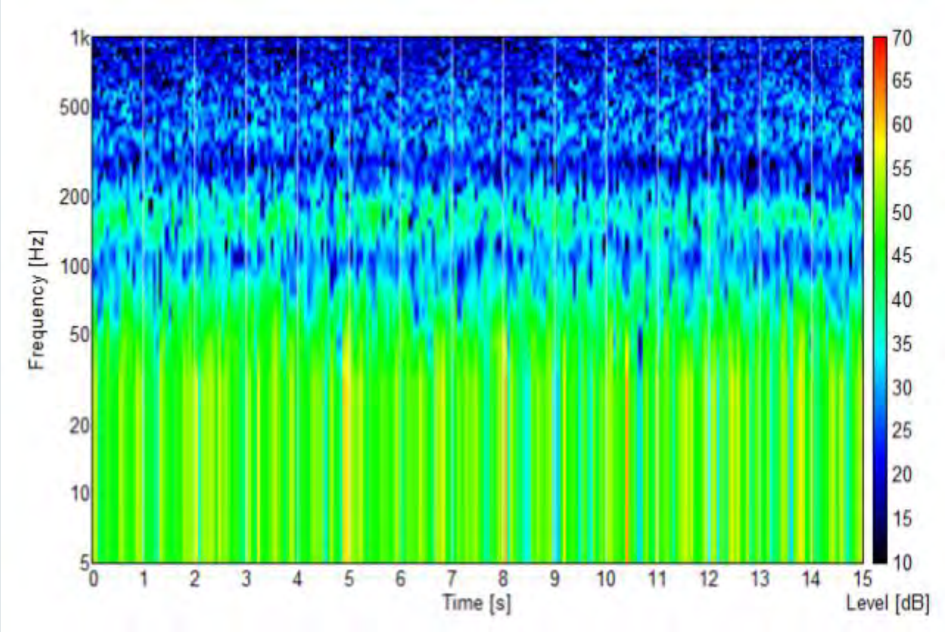
Physical Nature of WTN



Acoustical measurements taken at a home in proximity to Shirley Wind Project, Brown County, Wisconsin.

- The frequency response of WTN consists of extremely high levels of low-frequency energy.
- Due to room resonance effects, WTN can often be more intense indoors than outdoors.
- Because IWTs operate mostly at night, WTN can be especially bothersome in a closed bedroom.

Physical Nature of WTN (Continued)



Spectrogram of WTN at Shirley Wind Project, Brown County, Wisconsin (James & Bray, 2010).

- WTN is amplitude modulated over very short periods of time. In that respect, it is different from other industrial noises and transportation noises.
- Interactions of the blades with the air and tower result in blade-pass energy that produces intermittent tonal energy that often 10 dB or more higher than average values.
- These high levels of pulsating energy occur at infrasonic rates, typically 1/sec or less, making it more disturbing than most other noises.
- These characteristics result in both auditory and non-auditory sensations. A whooshing sound can usually be heard, along with a perception of vibration, either of which can disrupt sleep.

Nuisance, Annoyance, and Health

- A term used mainly in state and local noise-control regulations to protect the use and enjoyment of personal property; a nuisance can be annoying but carries a stronger connotation of being legally actionable.
- The WHO treats nuisance and annoyance as essentially the same thing, defining *annoyance* as "any sound that is perceived as irritating or a nuisance."
- The WHO defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." It considers long-term annoyance induced by noise to be an AHE.
- Many scientific studies, along with the WHO, have described WTN to be annoying to a substantial percentage of the population.

Numerous research studies link annoyance and low-frequency noise

- Kelley et al (1982)*
- Kelley et al (1985)*
- Kelley (1987)*
- Bradley (1994); HVAC systems
- Leventhall (2004); occupational settings
- Pedersen & Waye (2004)*
- van den Berg (2004)*
- Pedersen & Waye (2007)*
- Pedersen et al (2009)*
- Janssen et al (2010)*
- Harrison (2011)*
- Shepherd et al (2011)*
- Palmer (2013)*

*Study dealt specifically with low-frequency noise from wind turbines. See Punch & James, 2016, for full references.

IWTs have many annoying characteristics

- *Industrial wind turbines produce pulsed, amplitude-modulated, tonal sounds that are unpredictable, uncontrollable (by receptors), and sleep-disturbing.*
- *Amplitude-modulated* and *impulsive* noises are more easily perceived and more annoying than constant-level noise (Sutherland & Burke, 1979; Bradley, 1994).
- *Tonal sounds* are more annoying than sounds containing energy across a broad range of frequencies (Moorhouse et al, 2005; Bray, 2007; Swinbanks, 2012).
- Sounds that are *unpredictable* and *uncontrollable* increase noise annoyance (Geen & McCown, 1984; Hatfield et al, 2002).
- *Nighttime noise* is more annoying than daytime noise (Berger et al, 2015; Berglund et al, 1999; WHO, 2009).
- *Rural noise* is more annoying than urban noise (Pedersen & Waye, 2007).

Annoyance from Wind Turbines

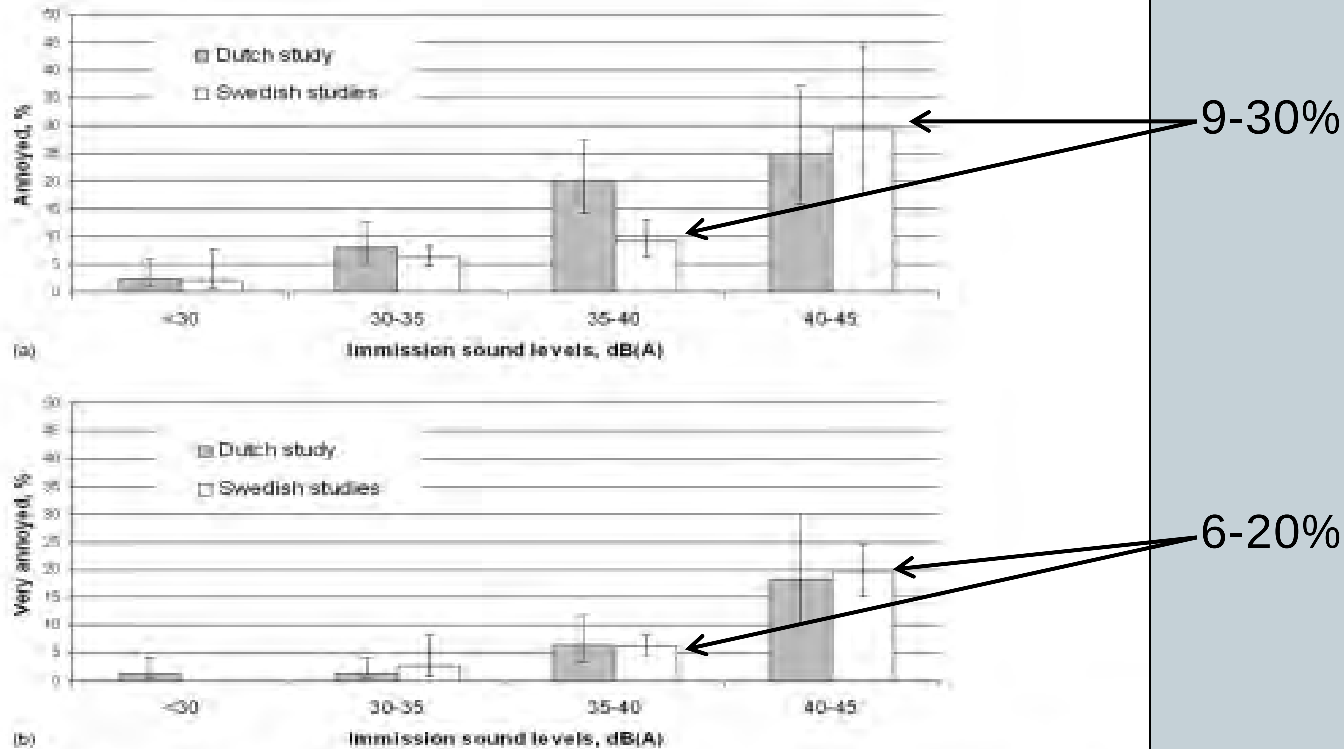


FIG. 2. Proportions of respondents annoyed (a) and very annoyed (b) by wind turbine noise outside their dwellings in four sound level intervals in the Dutch study (only respondents who did not benefit economically, n=586) and the Swedish studies (n=1095), with 95% confidence intervals.

Source: Pedersen, E. et al (2009). Response to noise from modern wind farms in The Netherlands. *Journal of the Acoustical Society of America*, *126*, 634-643.

IWT noise is much more annoying than aircraft, traffic, or rail noise

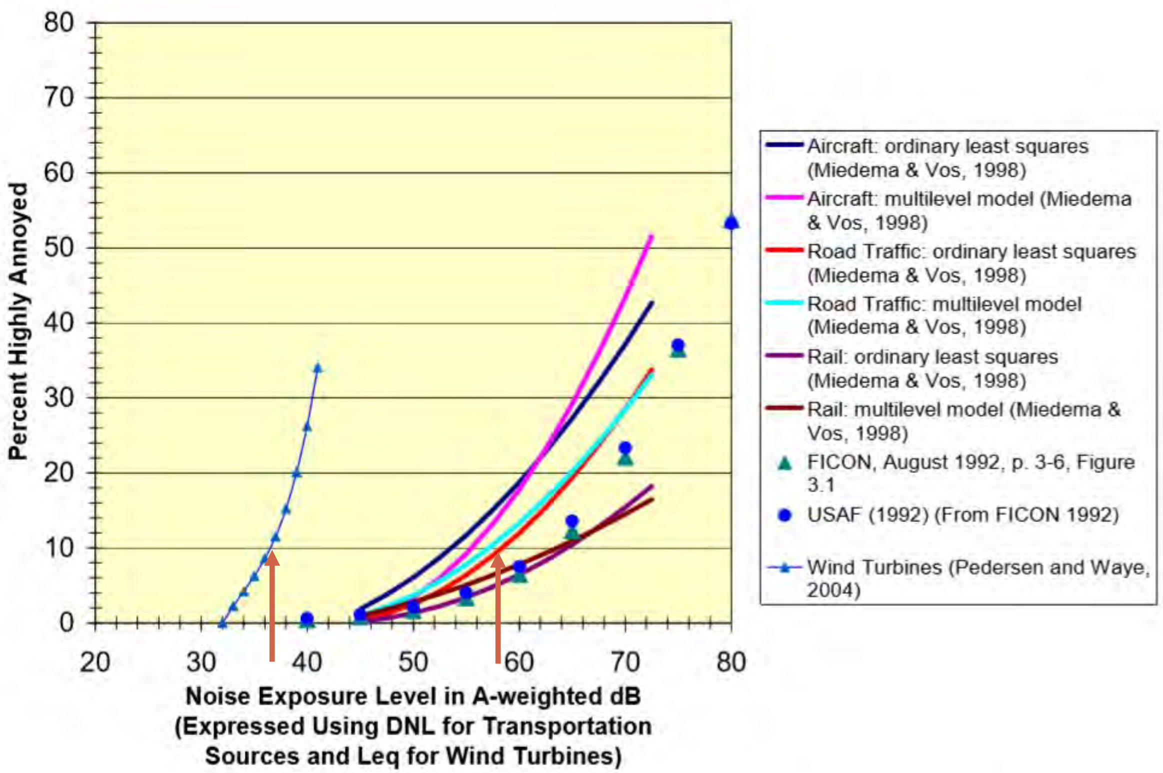
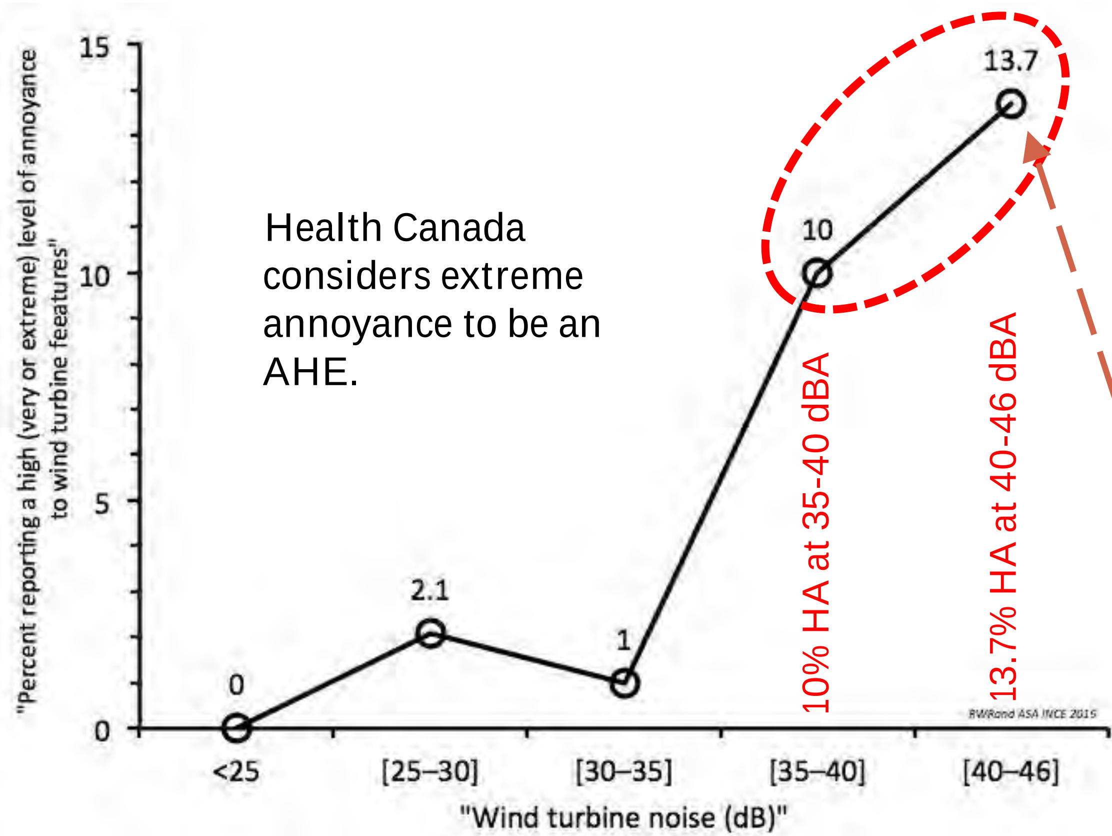


Figure 1: Dose-response relationships for transportation sources and wind turbines

Source: Graph replotted from Pedersen, E., & Persson Waye, K. P. (2004). Perception and annoyance due to wind turbine noise—a dose-response relationship. Journal of the Acoustical Society of America, 116, 3460-3470.

The Health Canada study found IWT noise highly annoying in a substantial number of people



Data source: "Exposure to wind turbine noise: Perceptual responses and reported health effects", TABLE IV. Perception of community noise and related variables, Variable "Reporting a high (very or extreme) level of annoyance to wind turbine features: Noise", D.S. Michaud et al, Health Canada, J. Acoust. Soc. Am. 139 (3), March 2016.

At least 1 out of 10 people in project area who were exposed to levels >35 dBA were highly annoyed.

Almost 14% of people who are exposed to levels between 40-46 dBA will experience high annoyance.

Common Human Reactions to IWT Exposure

Nina Pierpont, M.D., Ph.D., and a pediatric neurologist, described 10 symptoms, labeled *Wind Turbine Syndrome*, in a 2009 book by the same name; many other researchers have since observed similar symptoms.

- Sleep disturbance
- Headache
- Visceral Vibratory Vestibular Disturbance (VVVD)
- Dizziness, vertigo, unsteadiness
- Tinnitus
- Ear pressure or pain
- External auditory canal sensation
- Memory and concentration deficits
- Irritability and anger
- Fatigue and loss of motivation

Sleep disturbance is the most well-documented symptom*

- Leventhall (2003)
- Minnesota Department of Health (2009)
- Pedersen (2009, 2011)
- Masotti & Hodgetts (2011)
- Shepherd & Billington (2011)
- Shepherd et al. (2011)
- Thorne (2011, 2013)
- Krogh et al. (2012)
- Nissenbaum et al. (2012)
- Jeffery et al. (2013)
- Nissenbaum (2013)
- Paller et al. (2013)
- Palmer (2013)
- Taylor (2013)
- Kasprzak (2014)

*See Punch & James, 2016, for full references.

Sleep disturbance adversely affects health: National Institutes of Health

- Hypertension
- Negative effects on memory, temperament, heart rate, heart health, and hormones
- Reduced capacity to learn new information, concentrate, and recall information
- Lowered immunity to disease, weight gain; negative effects on childhood growth and development, muscle growth and tissue repair in children and adults
- Negative effects on puberty and fertility

Cape Bridgewater Study: Australia

- In a controlled, visually blinded field study and a separate laboratory study, Australians Steven Cooper and Chris Chan showed that inaudible sound pulsations of wind turbines, occurring at infrasonic rates, caused unpleasant perceptible "sensations" that were synchronized with wind turbine operation.
- Sensations included headache; pressure in the head, ears, or chest; ringing in the ears; heart racing; or a sensation of heaviness.
- Alternative explanations, such as the so-called *nocebo effect*, have been refuted by finding a direct cause-effect relationship between infrasound and AHEs.

Additional Documented Reactions to IWT Noise

- Anxiety
- Migraine headaches
- Motion sickness
- Reduced quality of life
- Visual blurring
- Vomiting, nausea

✓

Observations from Personal Interviews: Michigan Family Residents

Comparison with Pierpont's Wind Turbine Syndrome Criteria

(Information obtained based on checklist of 72 health-related conditions)

Symptom	*Mother*	*Father*	*Son*
Sleep disturbance	✓	✓	✓
Headache			✓
Visceral Vibratory Vestibular Disturbance (VVVD)	✓		✓
Dizziness, vertigo, unsteadiness	✓		
Tinnitus		✓	
Ear pressure or pain	✓	✓	✓
External auditory canal sensation	✓	✓	
Memory and concentration deficits	✓		✓
Irritability, anger	✓	✓	
Fatigue, loss of motivation	✓	✓	✓

✓

Observations from Personal Interviews: Individual Oregon Resident

Comparison with Pierpont's Wind Turbine Syndrome Criteria

Symptom	*Adult Male*
Sleep disturbance	✓
Headache	✓
Visceral Vibratory Vestibular Disturbance (VVVD)	✓
Dizziness, vertigo, unsteadiness	✓
Tinnitus	
Ear pressure or pain	
External auditory canal sensation	
Memory and concentration deficits	✓
Irritability, anger	✓
Fatigue, loss of motivation	✓

An Additional Concern

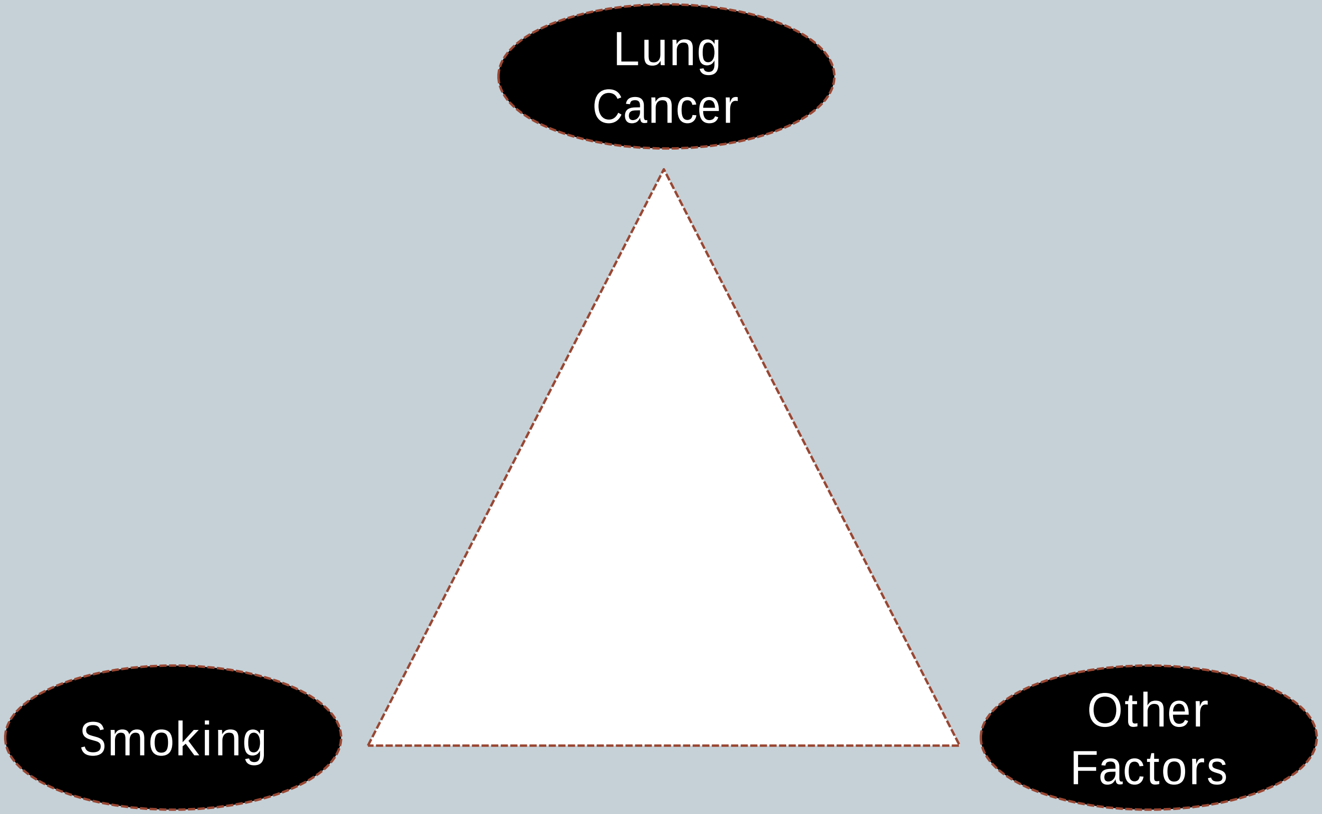
- Alves-Pereira and colleagues: "Airborne pressure waves are ubiquitous in all human environments and have played vital roles in the survival, evolution, and development of the human species. Under certain conditions, airborne pressure waves can be perceived as "sound" by the human auditory system. Under other conditions, they may be perceived as a whole-body or partial-body vibration." (p. 1)
- Based on a series of laboratory and field studies of lower animals: "Exposure to infrasonic and lower frequency airborne pressure waves can cause cellular and tissue damage depending on frequency, dB-level, and exposure time…." (p. 17)
- Biological systems affected include these organs, tissues, and systems:
  - Fascia
  - Connective tissue
  - Inflammatory processes
  - Vascular systems throughout body, including eye, liver, lungs, tracheae, coronary arteries
  - Cognitive deficits (probably due to brain damage and sleep deprivation)
  - Focal collagenous growths and hemorrhagic events
  - Changes in immune response, reproductive system, inner ear (vestibular and cochlear)
  - Genotoxicity

Source: Mariana Alves-Pereira, Bruce Rapley, Huub Bakker and Rachel Summers (January 9th 2019). Acoustics and Biological Structures, Acoustics of Materials, Zine El Abiddine Fellah and Erick Ogam, IntechOpen, DOI: 10.5772/intechopen.82761. Available from: https://www.intechopen.com/books/acoustics-of-materials/acoustics-and-biological-structures.

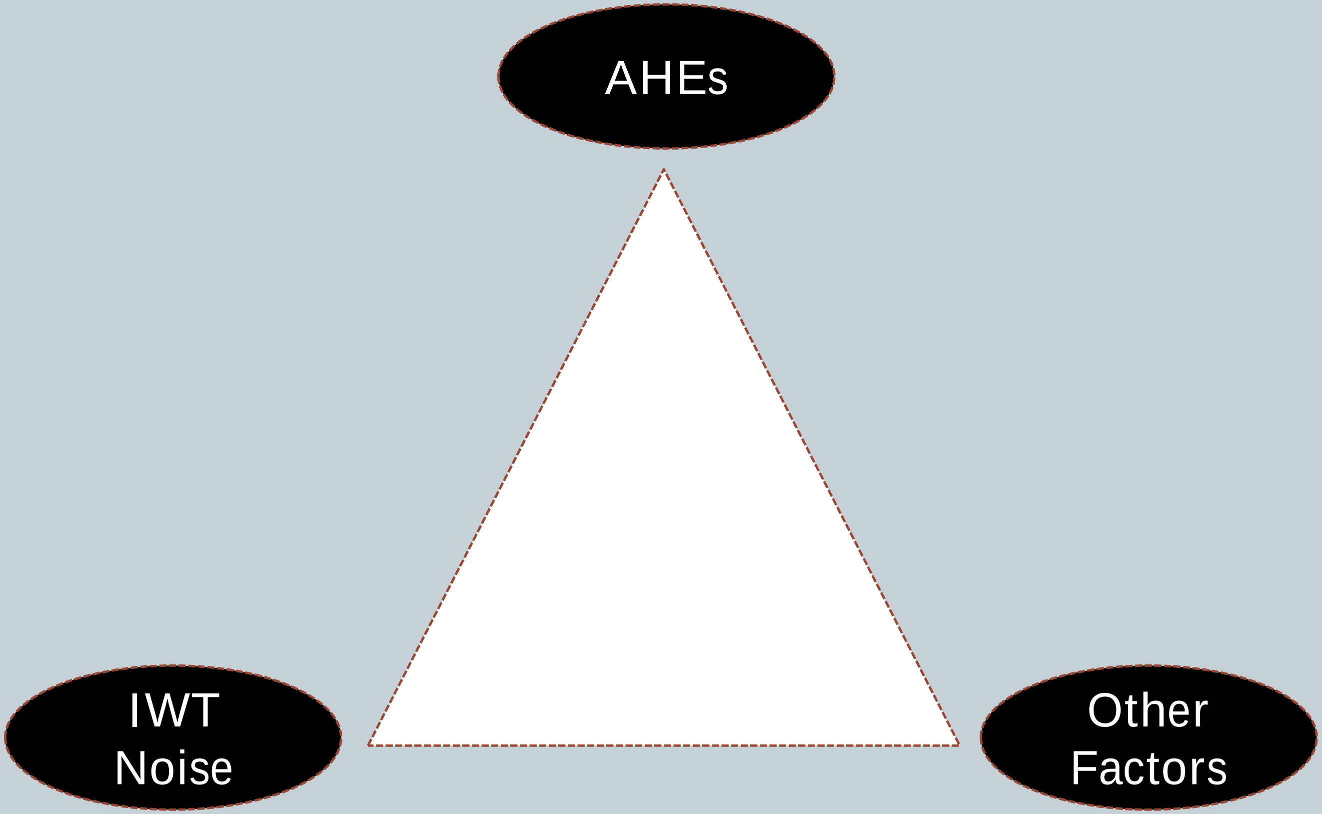
Specific vs. General Causation

- *Specific causation* usually requires that a physician determine what is causing the symptoms of an individual patient (e.g., abdominal pain is caused by a gall bladder attack).
  - Minimum requirements (IWT cases): Medical education, patient contact, knowledge of acoustics and its effects on people
- *General causation* usually requires that a scientist (or other expert) determine what is causing symptoms of people in a particular population (e.g., cigarette smoking causes lung cancer in a significant number of people).
  - Minimum requirements (IWT cases): Education in epidemiology or other health-related field, research background, site visits, resident interviews, knowledge of acoustics and its effects on people

Correlation vs. Causation



Correlation vs. Causation



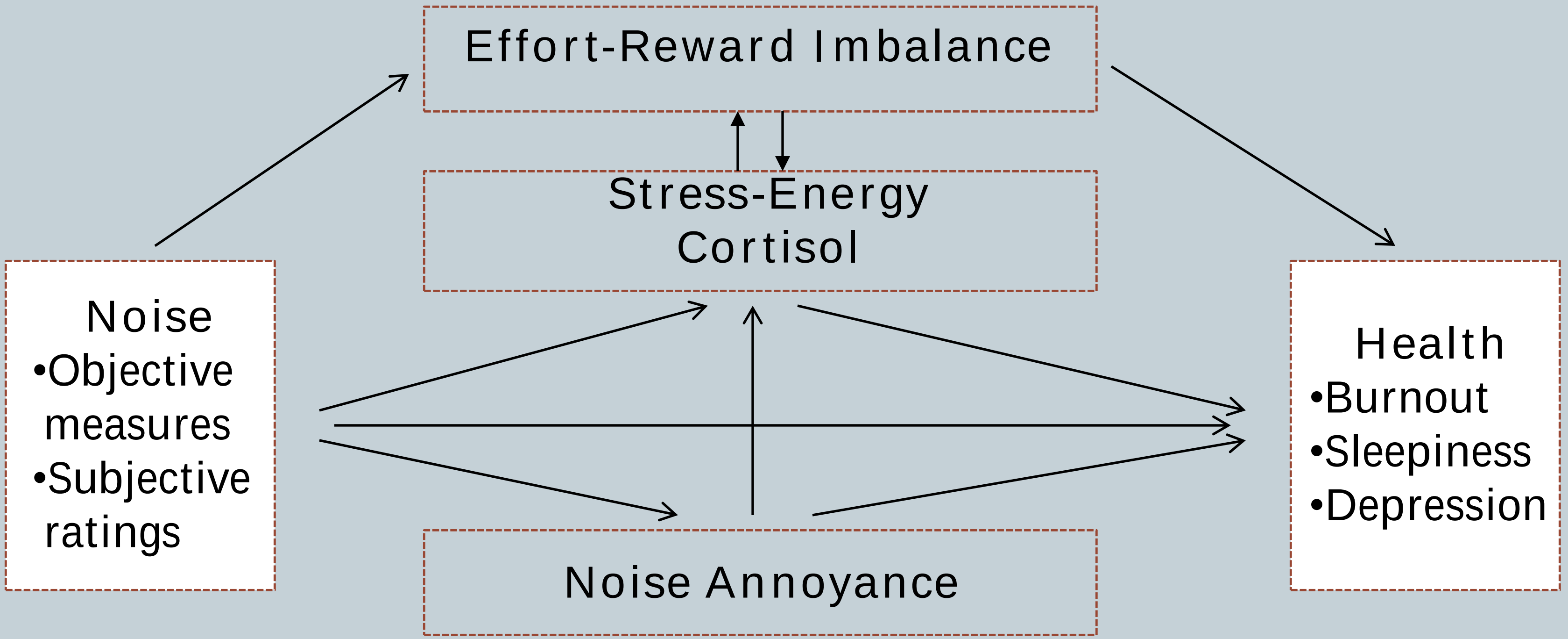
Bradford Hill Criteria (1965)

- These criteria are widely used to establish a causal link between environmental factors and disease (relevant WTN conditions in parentheses):

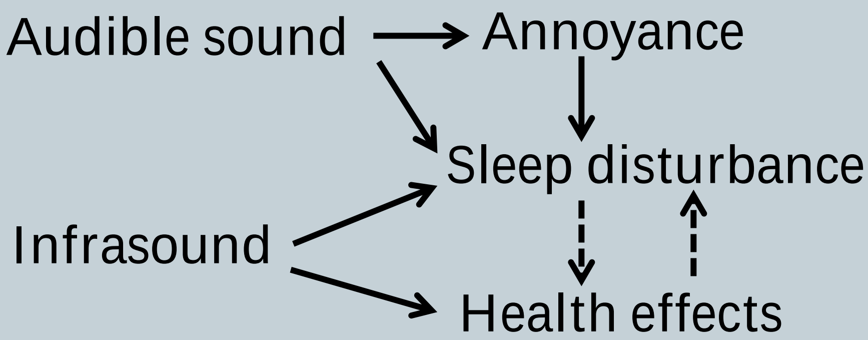
(1) Strength of association (widespread reports of complaints)
(2) Consistency (consistency of reported symptoms across individuals)
(3) Specificity (consistency of symptoms across individuals and sites, without other known linkages)
(4) Temporality (concurrence of symptoms with IWT operation)
(5) Biological gradient (dose-response relationship between symptoms and exposure levels or distance)
(6) Biological plausibility (identification of role of hearing and balance mechanisms of inner ear in causing specific symptoms)
(7) coherence (coherence with WHO, U.S., and some state noise guidelines)
(8) experimentation (cross-sectional studies, as well as multiple observations that symptoms subside when individuals leave area and recur when they return to area)
(9) analogy (noise-induced Sick Building Syndrome)

- All these factors have been shown, to various degrees, to link WTN and AHEs.

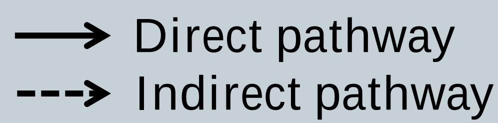
Noise and health are linked directly and indirectly



Schomer classifies the effects of audible noise and infrasound on health (modified)



Example: Wind turbine noise can cause awakenings, and chronic awakenings can lead to AHEs.



How *can* WTN be limited?

- Setback Distance: To protect human health, recommendations in the literature include minimum distances ranging from 0.5-2.5 miles. The distance recommended most often by researchers is 1.25 mi (2 km), but some now recommend longer setbacks.
- Noise levels: Recommendations in the literature typically limit noise levels to 30-40 dBA Leq. Some regulatory agencies and local zoning ordinances support limiting noise levels to 5-10 dB above prevailing background noise levels.

How *should* WTN be limited?

- Maximizing setback distance
  - Noise levels vary based on distance, but not in a predictable dose-response relationship.
  - Noise levels also depend on terrain, number and size of turbines, weather patterns, and turbine array. Turbine size and distance from the receiver are two of the most influential factors.
  - Typical setbacks of a half mile or less, intended to protect physical safety from mechanical failure or ice throw, are NOT adequate to protect general health and well-being.
- Minimizing noise levels
  - This approach is generally more effective than using a specific setback distance, but regulations based on noise levels are somewhat more difficult to implement.
  - Prior to project construction, *noise modeling* is often used to predict noise levels; after project construction, *direct noise measurements* are used. Because modeling is imprecise and often underestimates noise levels, the levels should always be verified post-construction.

Additional Considerations

- Infrasound and low-frequency noise levels are typically not masked by wind or other noises, and *cannot* be controlled effectively by erecting barriers, insulating homes, or wearing earplugs, so distance is the only practical means of achieving acceptable sound levels.
- WTN easily crosses property lines, so setback distances should be based on the acceptable noise levels at property lines, not residences (i.e., enjoyment of property, with waiver an option).

Physicians advocate for longer IWT setbacks, but ....

- Dr. Nina Pierpont and many others have recommended a setback distance of 1.25 miles (2 km).
- Dr. Ben Johnson, a cardiologist, recently advocated for a 1.5 mile setback in Madison County, Iowa:

"Resolved that the Madison County Board of Health determines that there is the potential for negative health (e)ffects associated with commercial wind turbines and that current setbacks are inadequate to protect the public health. The Board encourages those entities with jurisdiction within the County to require a one and one-half (1-1/2) mile setback for future wind turbine projects."

Madison County, Iowa
August 8, 2019

A comprehensive list of recommended setbacks in the U.S. and other countries is available at: http://www.wiseenergy.org/Energy/Wind_Ordinance/Setbacks.pdf.

Some major U.S. and international guidelines are used to limit noise exposure

- U. S. Environmental Protection Agency (EPA)

Noise Control Act (1972) and Quiet Communities Act (1978)

Not updated, but link noise to stress-related illnesses and other AHEs

- ISO 1996-1 and ANSI S12.9 Part 4 Standards

Recommend 15-dB penalty for new noise sources in quiet, rural communities

- National Association of Regulatory Utility Commissioners (NARUC, 2011) and NY Department of Environmental Conservation (DEC, 2001)

Recommend limiting noise levels to 5 or 6 dB above background levels; given rural background levels of ≤30 dBA (1-hr. Leq) at night, nighttime IWT noise often exceeds guidelines

- WHO (1999, 2009, 2018)

Developed in Europe and used worldwide to limit noise levels for the purpose of limiting annoyance and AHEs

- Schomer and Pamidighantam (2017)

Recommend maximum permissible levels averaging 36-38 dBA, measured over a 24-hour period, to protect against substantial annoyance and AHEs from WTN (based on four independent studies)

The WHO noise guidelines limit community, transportation, and industrial noise levels

- WHO (Berglund et al., 1999; community noise)
  - For continuous nighttime noise, indoor levels should not exceed 30 dB LAeq, and outdoor levels should not exceed 45 dB LAeq. Single noise events should not exceed 45 dB LAmax.
  - Special attention should be given to noise when background noise is low, when noise is combined with vibrations, and when noise consists of low-frequency components.
- WHO (2009; nighttime transportation noise)
  - Outside night noise levels should be limited to 40 dB LAeq, and night, inside noise should be limited to 35-42 dB LAmax (based on transportation noises).
- WHO (2018; environmental noise, including IWT noise)
  - Wind turbine noise level should be limited to 45 dB Lden, which equates to ~38 dB LAeq.
  - This guideline does not provide a specific LAmax recommendation.

The 2009 WHO noise guidelines recommend minimizing sleep disturbance and AHEs

Leq(night,outside)	Health Effects
<30 dBA	No substantial biological effects
30-40 dBA	Affects sleep: body movements, awakening, self-reported sleep disturbance, arousals; vulnerable groups (young children, elderly adults, persons with chronic health conditions) more susceptible
40-55 dBA	AHEs observed (with vulnerable groups more severely affected)

The above levels are long-term averages and are not based specifically on wind turbine noise, which contains more low-frequency noise than most other industrial and transportation sources, on which these levels are based.

IPCB Regulations

- Developed in the late 1960s and early 1970s to regulate levels of non-transportation noise sources in Illinois, with emphasis on nighttime noise
- Based on limiting noise levels in narrow (octave) bands of the frequency spectrum (1 hr, Leq)
- If levels are at allowable limits in all bands, overall level equates to 51.2 dBA
- Dr. Paul Schomer, former Director of Standards for the Acoustical Society of America, contributed directly to development of IPCB (900-901) regulations
- Schomer has described the IPCB noise limits as a never-to-exceed regulation, applicable to each octave band, and has indicated they should not be applied to WTN

IPCB Regulations (Continued)

“The state regulations are these octave band limits that were created 60 years ago. If I were creating them today, I wouldn't use them.”

Paul Schomer, Ph.D.
Emeritus Director of Standards
Acoustical Society of America

Source: McLean County Zoning Board of Appeals, February 22, 2018, McLean County Government Center, 115 East Washington Street, Bloomington, Illinois, Case Number SU-18-02, p. 508.

Illinois Case Example: Post-Construction

- The acoustician for the wind company indicated compliance with IPCB noise regulations at all frequencies *except* at 2000 Hz at 10 residences that would be exposed to the loudest levels.
- My analysis indicated that, at one or more frequencies, IPCB regulations were exceeded at 178 of 228 (78%) residences.
- Noise levels at residences of 17 plaintiffs who filed a post-construction lawsuit ranged from 41-47 dBA.

Kansas Case Example: Pre-Construction

	40 dBA Leq	38 dBA Leq/45 dBA Lden	36 dBA Leq
Non-Participants	186 (41.8%)	300 (67.4%)	337 (75.7%)
Participants	62 (88.6%)	66 (94.3%)	66 (94.3%)
Total	248 (48.2%)	366 (71.1%)	403 (78.3%)

Number and percentage of 445 non-participating residences and 70 participating residences at which noise limits established by three authoritative sources will be exceeded.

40 dBA Leq (WHO 2009)	38 dBA Leq/45 dBA Lden (Schomer & Pamidighantam, 2017; WHO, 2018)	36 dBA Leq (Schomer & Pamidighantam, 2017)
13 (46.4%)	22 (78.6%)	24 (85.7%)

Number and percentage of residences of 28 plaintiffs at which noise limits established by three authoritative sources will be exceeded.

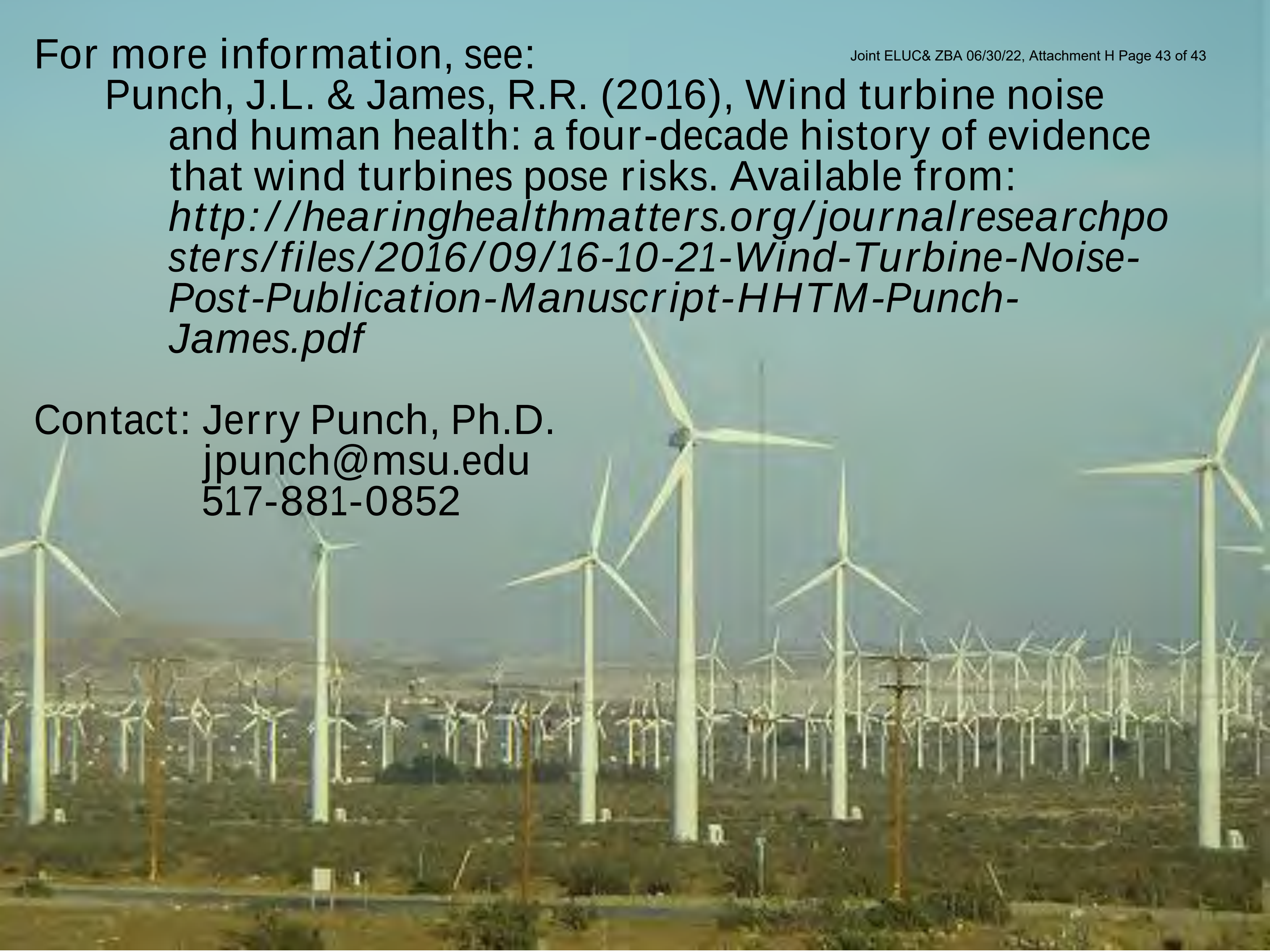
A highly substantial percentage of residents overall, as well as plaintiffs in this case, would be exposed to noise levels that exceed any of the three limits recommended by national and international authorities.

Conclusions

1. WTN is a unique source of low-frequency noise that can lead directly or indirectly to a variety of AHEs.
2. Infrasound has been linked directly to negative sensations and AHEs.
3. Noise limits and setbacks advocated by the wind industry are harmful to the health of a substantial percentage of people.
4. Researchers have most often recommended a setback of 1.25 mile (2 km) to minimize annoyance and AHEs; some scientists and regulatory authorities now recommend longer setbacks.
5. WHO guidelines (2009, 2018) recommend limiting noise levels to 38-40 dB LAeq; the 2009 WHO guidelines recommend limiting nighttime low-frequency noise to 42 dB LAmax (inside) to protect against sleep disturbance, the most common complaint.
6. While maximizing setback distance can effectively reduce noise levels, limiting noise levels to those recommended by authoritative sources is the most effective way to protect public health.

Punch & James (2016): Summary Statements

- "The available literature, which includes research reported by scientists and other reputable professionals in peer-reviewed journals, government documents, print and web-based media, and in scientific and professional papers presented at society meetings, is sufficient to establish a general causal link between a variety of commonly observed AHEs and noise emitted by IWTs." (p. 54)
- "A pro-health view is that there is enough anecdotal and scientific evidence to indicate that ILFN from IWTs causes annoyance, sleep disturbance, stress, and a variety of other AHEs to warrant siting the turbines at distances sufficient to avoid such harmful effects, which, without proper siting, occur in a substantial percentage of the population."(p. 55)



For more information, see:

Punch, J.L. & James, R.R. (2016), Wind turbine noise and human health: a four-decade history of evidence that wind turbines pose risks. Available from: *http://hearinghealthmatters.org/journalresearchposters/files/2016/09/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf*

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Health Effects from Wind Turbine Low Frequency Noise & Infrasound

Do Wind Turbines Make People Sick? That is the Issue.

LBGA
EXHIBIT
2

George Hessler, George Hessler Associates, Inc., Haymarket, Virginia
Goeff Leventhall, Consultant., Ashtead, Surrey, United Kingdom
Paul Schomer, Schomer and Associates, Inc., Champaign, Illinois
Bruce Walker, Channel Islands Acoustics, Camarillo, California

Do wind turbines make people sick? That is a contentious issue in licensing wind farms. In particular, low frequency sound emissions (infrasound and "pulsed" and steady low frequency sound) from wind turbines are blamed by opponents but vigorously denied by project proponents. This leads to an impasse of testifying "experts," and regulators must decide on the basis of witness credibility for each project, leading to inconsistent findings. This article presents the opinions of four very experienced independent investigators with wind turbine acoustics over the past four decades. The latest Threshold-of-Hearing research down to 2 Hz is compared to today's modern wind turbine emissions. It is jointly concluded that infrasound (0-20 Hz) can almost be ruled out, subject to completion of recommended practical research, and that no new low frequency limit is required, provided adequate "A"- weighted levels are mandated.

Claims of adverse health effects are made by individuals and organized community groups at some operating wind turbine sites located around the world. Adverse publicity is intense at about a dozen operating sites in the United States, the United Kingdom, Canada, Scandinavia and Australia. Health effects attributed to wind turbines include symptoms similar to those of motion sickness, such as, dizziness, nausea, vomiting and a general feeling of discomfort or not feeling well. Sea sickness (a form of motion sickness) is well understood as a disturbance of the inner ear, and the cause is both obvious and indisputable. Motion sickness is more subtle and is caused by the brain receiving conflicting messages about what is seen by the eye as opposed to what is felt or sensed.[1] For example, air sickness can result from plane motion caused by invisible turbulence in the air. To date, no such similar connection has been found at wind turbine sites, although some residents claim they can sense when wind turbines become operational without benefit of sight or hearing.

It has now been demonstrated by multiple independent researchers that wind turbines, like any other rotating fan, emit measurable tones at the blade-passing frequency (BPF) and up to about the fifth harmonic plus broadband noise. For a typical large three-bladed wind turbine rotating at 16 RPM, the BPF and harmonic tones are at frequencies of 0.8, 1.6, 2.4, 3.2, 4 and 4.8 Hz. These very-low-frequency tones are commonly called infrasound, defined as low-frequency noise in the 0-20 Hz frequency range. A better definition used by one of the authors is "pulsed LFN," since the tones result from analysis of pulses produced by tower blade interaction. The 0-20 Hz measurements are all well below the threshold of hearing, as established by the latest research at frequencies down to about 2 Hz. But it might at least be asked: Are the pulses the invisible source of conflicting messages to the brain? Reference 1 states that messages "are delivered from your inner ear, your eyes (what you see), your skin receptors (what you feel) and muscle and joint receptors," but there is the open question of whether the low levels of pulsed LFN or infrasound from wind turbines excite any of these receptors.

Permitting authorities for new projects must evaluate adverse health effect claims presented as proven factual data by opposition forces, countered by project advocates that state no physical link to health effects has ever been demonstrated at wind turbine sites. This debate has now raged for at least a decade and is now at an impasse.

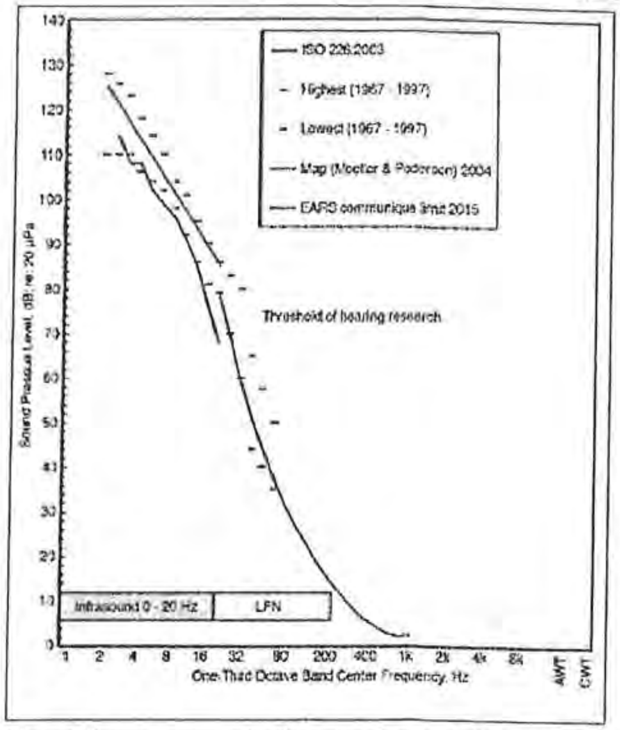

Figure 1. Research summary for determining threshold of hearing at low frequencies.

It has been the first author's privilege and pleasure to associate and collaborate with three prominent co-author scientists in the wind turbine acoustical field. All four authors do not doubt for a moment the sincerity and suffering of some residents close to wind farms and other low-frequency sources, and this is the reason all four would like to conduct, contribute or participate in some studies that would shed some light on this issue. It must also be said that it is human nature to exaggerate grievances and that some qualitative measure must be made available to compensate affected residences.

The first author has asked each co-author to independently summarize their opinions and recommendations on how the current impasse can be broken.

Current Research on the Threshold of Hearing

Research to measure the threshold of hearing at low frequencies can be summarized in one graphic (see Figure 1). The highest and lowest gray bars encompass the results of 10 studies over the listed 30-year period that is nicely shown in the Noise & Health Journal.[2] These are the min. and max. at each 1/3-octave-band frequency for any of the 10 studies. The graphic also plots ISO 226:2003(E) that covers the entire audible range from 20 Hz to 12,500 Hz (plotted to 1000 Hz). The green line comes from Project EARS funded by the

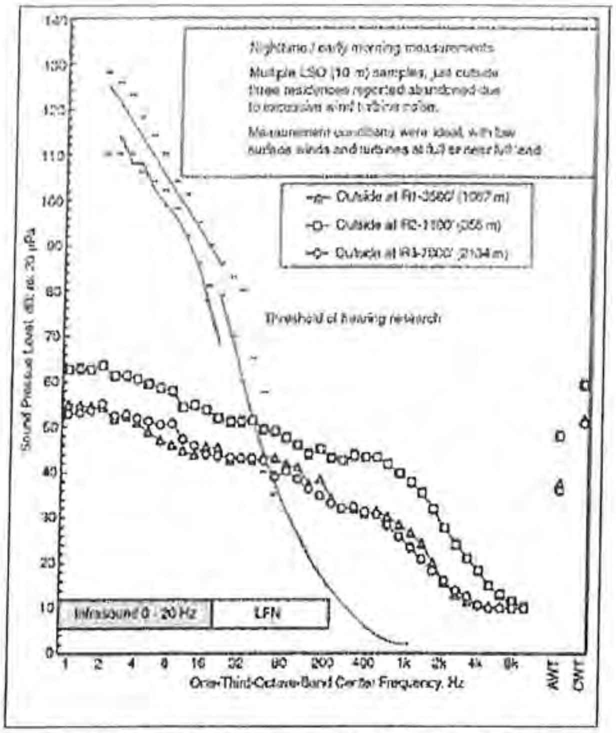

Figure 2. Typical wind turbine spectra and levels compared to threshold of hearing at low frequencies.

European Union[3] and represents "acceptance levels" based on the 10% percentile hearing threshold values determined in the EARS Project and is the latest research on the subject.

Defining the Problem

How does ILFN from a modern wind farm compare to the above summary? Figure 2 replots the contents of Figure 1, all in blue, and adds the measured spectra and overall levels at three locations from a study[4] funded by Clean Wisconsin (an environmental organization) and the state of Wisconsin. This study was carried out at a wind farm located among residences in a quiet environment of residences and farmland, typical of wind farm sites in the American midwest and northeast. Response at this site has been adverse, to say the very least. The three plots are near residences reported to be abandoned due to adverse health effects. Several things may be deduced form this plot.

First, the wind farm was designed to a standard of 50 dBA at nonparticipating residences, and that level is not endorsed by any of these four authors. All of us have been at or near 40 dBA for many years. Had 40 dBA been used, there would not be a wind turbine as close as 1100 feet at R2, where a level of 48 dBA was measured. Wind turbine sound was readily detectable by the test engineers at R2, but not at R1 and R3 where levels are less than 40 dBA.

Second, the levels at all the residences in the infrasound range (0-20 Hz) are far below perceptible levels in this range. This strongly suggests the source of any message to the brain is not from wind turbine infrasound directly but may occur as audible LFN or pulsing LFN at the blade-passing frequency well inside the infrasound range.

Third, a wind turbine is not a classic LFN noise source – a source heavily weighted with LFN. Such sources typically have C-weighted levels 15 or 20 dB above A-weighted levels. Observe from the plot that C-weighted levels are both relatively low (<60 dBC) based on typical C-weighted guidelines, and the C-A differential is less than 15 dB.

To understand just how difficult this issue is, consider that the residents (husband, wife and young baby) at R2 experienced their child awakening at night screaming, but not on nights away from home. The wife was highly annoyed, and the husband had "no problem at all" with wind turbine sound. Add to this that there is a home across the street, the same distance and direction from the turbine, but the owners accept "good neighbor" payments. Could any payment be enough if suffering serious health effects?

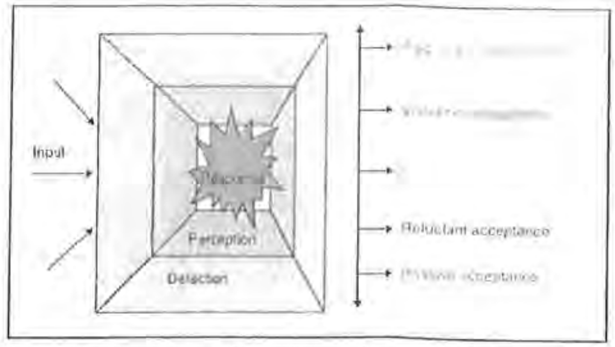

Figure 3. Response process (left) and range of responses (right).

And last, there are thousands of landowners that lease their land for wind turbines and live very close to turbines. It is hard to abandon the notion that higher levels closer to the source should produce higher levels of affected residents, but a recent large-scale, long-term measurement survey in Australia showed no correlation between complaint locations and measured levels.

It would seem one promising direction of a study could be extensive interviews of such folks exposed to high levels of wind turbine noise that could reveal common symptoms and/or the number of folks seriously affected.

Opinions and Recommendations of Geoff Leventhall

Wind Turbine Noise and Health. Wind turbine noise spans a range from below 1 Hz up to 10 kHz or more. A one-third-octave spectrum typically drops off at between 4 dB/octave and 6 dB/octave. Blade-passing tones are added into the falling spectrum in the range from about 1 Hz to 7 or 8 Hz and have normally disappeared from the spectrum by 10 Hz, although they may reappear at a low level at higher frequencies. (Zajamšek, Hansen *et al.* 2016). The high correlation between wind turbine dBA and dBC, (Keith, Feder *et al.*, 2016) is explained by this generalized falling spectrum from infrasound to high frequencies, also described by Tachibana *et al.*, who found 4 dBA per octave fall-off (Tachibana, Yanob *et al.*, 2014).

Sound level at nearest residential distances of, say 500 m, may be around 60 dB at 10 Hz, while the hearing threshold is close to 100 dB at this frequency. A falling spectrum of 6 dB/octave (20 dB/decade) gives 80 dB at 1 Hz for a level of 60 dB at 10 Hz. The hearing threshold is not well known at 1 Hz but is likely to be about 130 dB, since measurements have shown a threshold of 120 dB at 2.5 Hz (Kuehler, Fedtke *et al.*, 2015)

Levels of wind turbine infrasonic blade tones are well below our normal hearing threshold, while at higher frequencies, say 30-50 Hz, the blade harmonics, if present, may approach median threshold. (Zajamšek, Hansen *et al.*, 2016).

Wind turbine sound fluctuates due to short-term variations in propagation, with typical maximum fluctuations of about 15 dB (Bray and James 2011). Wind turbine low-frequency noise normally becomes just audible to the average listener at frequencies above 40-50 Hz. Higher audible frequencies, 250-1000 Hz from aerodynamic noise may vary in level at the blade-passing frequency, giving amplitude modulation (swish) of about once per second. Frequencies in the higher kilohertz range are heavily attenuated by air absorption and are not normally a factor in wind turbine noise at residences.

Does wind turbine noise, as experienced at typical residential distances, affect health through either direct or indirect mechanisms? There is wide variation in human response to audible noise, especially to low levels of noise like that produced by wind turbines, but these low levels are not known to have direct and adverse physiological effects on the body. The term "physiological effects" must be used carefully, since any response to a stimulus is a physiological effect. The great majority of these responses are harmless, beneficial or essential to our proper functioning.

Figure 3 shows a simplified diagram of the hearing process, leading to perception and response to a noise (Leventhall 1998). Input noise is detected, stimulating perception via the auditory cortex. Response, the reaction to perception, is very variable, as in Figure 1, depending on many personal and situational factors and conditioned by both previous experiences and current expectations. Response to the same noise from within a large group might range from passive acceptance (I can hear it, but it does not bother me) to aggressive resentment (I can't stand this noise – it's ruining my life).

Daytime disturbance by noise leads to irritation and aversion, while sleep disturbance may be an additional night effect, although investigations have shown similar numbers of poor sleepers and good sleepers both close to and remote from wind turbines (Nissenbaum, Aramini *et al.* 2012) (Jalali, Nezhad-Ahmadi *et al.* 2016) (Michaud, Feder *et al.*, 2016). Cognitive behavioral therapy reduces disturbance from noise through a process of desensitization and can improve sleep and quality of life (Leventhall, Robertson *et al.*, 2012).

The main effect of low levels of unwanted audible sound is creation of hostile reactions and negative thoughts, leading to stress and to the adverse health effects that might follow. Stress has different intensities, ranging from cataclysmic events (war and earthquakes), to acute personal stress (bereavement), and to chronic low level stress (long-term illness or persistent personal problems) (Benton and Leventhall, 1994). Stress from wind turbines, if it arises, is normally low level but, in a very small number of people, it may become intense and overpowering so that opposition to wind turbines is the dominating emotion in their lives. Unfortunately, concentrating attention on an unwanted noise aggravates any problems. Anticipatory stress also occurs following approval of a wind farm, although it has not yet been built, and a few anxious residents may experience similar symptoms to those that they believe to be associated with an active wind farm (Mroczek, Banas *et al.*, 2015).

Reaction to noise, especially low-level noise, is largely conditioned by attitudes to the noise and its source. Noise level contributes only about 20-30% of the total annoyance from noise (Job, 1988), while feelings, fear and opinions shape many of our responses, influencing tolerance levels. Negative emotions give an additional impact to an unwanted stimulus. The attitudes of nearby residents toward wind turbines is a major factor in the effects that turbines may have on their health (Rubin, Burns *et al.*, 2014). It has been shown that sham exposures to infrasound, (Crichton, Dodd *et al.*, 2014) or to sham electric fields (Witthoft and Rubin, 2013) produce symptoms in those who have been primed to expect an effect from exposure. The human being is clearly very complex in its reactions to physical and psychological stimuli.

Infrasound has a special place in discussions of the health effects of wind turbines, with many claims centered on direct pathological interactions, initially fostered by media scare stories originating in the 1960s and still continuing (Leventhall, 2013a).

In his 1974 popular science book *Supernature*, Lyall Watson described infrasound as causing deaths ("fell down dead on the spot"), while focused infrasound "can knock a building down as effectively as a major earthquake." This is unfounded, but an aura of mystery and danger persists around infrasound deep in the minds of many people, where it waits for a trigger to bring it to the surface. A recent trigger, heavily manipulated by objectors and media, has been wind turbines (Deignan, Harvey *et al.*, 2013).

A concept from psychology is the "truth effect," which explains how we can develop belief in false statements through their repetition by others (Henkel and Mattson, 2011).

- We believe statements that are repeated, especially by different sources.
- The path to our belief is made easier by each previous repetition.

Advertising and political propaganda are clear examples of the operation of the truth effect, which is also known as "illusory truth."

We all also have our preferred beliefs. When there is a choice, we tend to believe what we wish to believe. We feel comfortable when our existing beliefs are confirmed, and if we have become antagonistic to wind turbines we readily absorb negative statements about them.

Some objectors to wind turbines further their cause by generating anxiety on effects on health, particularly from infrasound and low-frequency noise, in populations close to proposed wind farms. Persistent repetition that infrasound from wind turbines will cause illness develops stressful concerns in residents, but repetition is neither evidence nor proof. However, a nocebo effect may occur, by which expectation of an outcome may lead to realization of that outcome (Chapman, Joshi *et al.*, 2014).

There are a large number of coordinated objector groups working internationally. A web page (https://quixoteslaststand.com/) gives links to more than 2000 groups that share information on wind turbines, while some make unsubstantiated, anecdotal claims about their effects. However, there is no doubt that when stress is persistent it may result in somatic effects in a small number of people who have a low-coping capacity, although the ability to cope can be enhanced (Leventhall , Robertson *et al.*, 2012).

In considering infrasound and other sound from wind turbines, it is necessary to take a very analytical, critical, unemotional view of the topic and to remain free of the influence of incorrect, but frequently repeated, statements.

There is no evidence that inaudible infrasound from wind turbines affects health, but there are indications from exposure tests that it does not (Tonin, Brett *et al.*, 2016). Inaudible infrasound has not been shown to affect those exposed, but just audible infrasound has a sleep-inducing effect (Landström, Lundström *et al.*, 1983).

Comparisons have been made of levels of infrasound from wind turbines at dwellings with the levels of infrasound that occur from man-made sources in urban and industrial areas and also levels that occur naturally in coastal and other regions. The infrasound exposure levels are similar (Turnbull, Turner *et al.*, 2012).

There is a persistent microbarom frequency of about 0.2 Hz caused by interacting sea waves, which goes to high levels during storms, propagating long distances over land. Microbarom six-hour averages have been measured in the region of 60-70 dB, while power spectral densities as high as 120 dB at 0.2 Hz have been observed (Shams, Zuckerwar *et al.*, 2013). We are not affected by this infrasound, which is at higher sound pressure levels than wind turbine infrasound at 0.2 Hz.

Investigations to find a link between infrasound from wind turbines and adverse physiological effects include work by Salt, who used high-level 5-Hz infrasound to bias the hearing of guinea pigs and noted that the outer hair cells (OHC) responded to this stimulus. The response threshold was lower than the hearing threshold, which is determined by the inner hair cells. Salt used the single measurement as a point on an OHC threshold curve and deduced an OHC threshold for humans by considering the low-frequency mechanics of the ear and comparison of human sensitivity with guinea pig hearing sensitivity. The human OHC threshold was determined as 100 dB at 1.0 Hz, falling by 40 dB/decade, so that it meets the inner-hair-cell threshold at about 100 Hz (Salt and Hullar, 2010). They conclude: "The fact that some inner ear components (such as the OHC) may respond to infrasound at the frequencies and levels generated by wind turbines does not necessarily mean that they will be perceived or disturb function in any way. On the contrary though, if infrasound is affecting cells and structures at levels that cannot be heard, this leads to the possibility that wind turbine noise could be influencing function or causing unfamiliar sensations."

Wind turbine emissions are generally below the OHC threshold so that, under these circumstances, the threshold is not relevant to wind turbine infrasound. The effects of stimulation of the OHCs remain unknown. The OHCs are the main component of the cochlear amplifier and are continuously active, being the source of otoacoustic emissions (Ashmore, Avon *et al.*, 2010). But wind farms at which nausea and similar effects are reported, may have a spectrum that is entirely below the Salt OHC threshold, so that it is not exceedance of this threshold that is the cause of distress.

Salt's further publications, seeking to support the adverse effects of infrasound, use examples in which the frequencies and levels are higher than those from wind turbines (Salt and Lichtenhan, 2014). As pointed out by Dobie, Salt and Lichtenhan, quote effects resulting from 30 Hz at 100 dB and 120 dB and from 50 Hz at 85-95 dB (Dobie, 2014). These low-frequency pure tones are not directly relevant to wind turbine noise, which does not contain such high-level tones. Salt's connection of his work to wind turbine infrasound is not yet convincing.

Over the past 45 years, popular culture has attributed a number of unpleasant, even fatal, effects to infrasound, but none has been sustained by evidence. Concerns on inaudible infrasound from current designs of wind turbines commenced 10-15 years ago, linked to objections to the growth of wind farms, and have accelerated over the past 5-10 years. It is inevitable that, in the absence of good supporting evidence, these speculative claims will become discredited over the next 5-10 years.

At the present time, conclusions are:

- Audible wind turbine noise acts through annoyance and stress, which may lead to poor sleep quality, especially in hostile people. Hostility is heightened by the actions of objector groups. There is no known direct effect on health from the low levels of audible wind turbine noise. However, stress may develop from an individual's reaction to the turbines.
- There is no established evidence that the inaudible infrasound from wind turbines affects health, but there are indications that it does not.

Opinions and Recommendations of Paul Schomer

Currently, I think this group of four find ourselves in the following situation: We all agree that sound flowing through the cochlea is not the source of problems below the threshold of hearing. That statement leaves two of what I will call technical possibilities. One possibility is that there are pathways other than through the cochlea for the infrasound to get to the brain. A second possibility is that to date we have missed something in the audible sound range that is the source of problems or that both of these situations exist.

Are There Noncochlear Paths for Infrasound to Reach the Brain? The following is a relatively simple study that could test whether individuals who claim they can detect the turning on and off of turbines can actually do this without visual or audible clues. There are at least a few small groups in the United States, Australia, and Canada that claim to have this ability. The results could be that none of these people could detect the turning on and off, or it could be the reverse and everyone would be able to detect the turning on or turning off. It is likely that the result will be somewhere in between.

In Shirley, Wisconsin, there are residents who say they have this ability. This study could be readily performed in Shirley; however, it requires the cooperation of the energy company.

Suggested Test 1

Consider the two houses in Shirley where there is no audible sound; the R-1 house and the R-3 house. The residents of the houses, and others, who would be subjects, would arrive at the house with the wind turbines off. The test itself would likely take 0.5 to 2.5 hours to perform.

Sometime during the first 2 hours, the wind turbines(s) that had been designated by the residents as the turbines they could detect, might or might not be turned on. It would be the residents' task to sense this "turn on" within some reasonable time designated by the residents – say 10 or 30 minutes. Correct responses, "hits," would be correctly sensing the turbines being turned on, or sensing no change if they were not turned on. Incorrect responses, "misses," would be failure to sense a turn on when the turbines were turned on, or "false alarms" would be sensing a turn on when the turbines were not turned on. Similar tests could not necessarily be done starting with the turbines initially on because the subjects, when sensitized, find it more difficult to sense a turn off. More information about this test can be found in Schomer *et al.*, 2015.

Possible Overlooked Audible Path. This pathway is predicated on several key facts described below. The main hypothesis is that the electric power being generated changes the acoustic signal without changing the A-weighted level. If the electric power correlates better than A-weighted level to subject response, then this would indicate that the electric power being generated controls some aspect of the sound that the subjects are sensing. This is important for two reasons:

- The subjects are incapable of having detailed knowledge of the electric power.
- If this is all true, it is something that is potentially correctable.

Facts:

- *Discussion with Geoff Leventhall.* At one point when I suggested to Leventhall that 30 and 40 years ago, the reported effects were very similar to today's reported effects and that we had much the same problem, he remarked that the sound at that time period was low-frequency audible sound at around 40-50 Hz. The problems with infrasound and low-frequency noise that occurred 30 and 40 years ago is that they produce the same symptoms as today, but were for frequencies in the 40-50 Hz range – not infrasound.
- *Steven Cooper.* Cooper finds and reports in his Cape Bridge Water Study that the subject's response correlated better to the electric power being generated, to turbine operations hovering around cut in speed, and to large changes in the electric power being generated rather than to the acoustic signal.
- *Bruce Walker.* "I did a lot of work with Hansen's cleanest data set. When the extremely narrow band spectrum was plotted on a linear frequency scale, it conformed pretty well to sin(x)/x envelope with lobes at ZF, 30 and 45 Hz (more or less) and lines every blade-passing frequency. The lines in the 45 Hz lobe would combine into a wave packet that exceeded the audible threshold briefly once every blade pass. Walker added, "One thing I've observed with modern 100-meter rotors is that when producing power, the blades deflect axially to pass pretty close to the tower near the tip, into a region where the upstream flow deficit could be significant, though not separated as in downwind designs. Overly aggressive pitch programming could cause periodic brief stalls that might produce the requisite steep edge on the pulses."
- *Discussions at the ASA meeting in Salt Lake City.* Discussions at the meeting made it clear that the frequency may not be limited to 45 Hz but may be based on the manufacturer and the specifics of the blades. It was also suggested that these frequencies might interact with chest cavity resonances. Rainford and Gradwell (2012) find, using their procedure outlined in Rainford (2006) that the typical chest cavity has a resonance at about 50 Hz. This does not seem to be a factor, since Leventhall reports that below 80 dBA, at 50 Hz there is no chest cavity response.
- *George Hessler.* The measurements at Shirely show a relatively constant noise being generated during the day and time of the R2 measurements. However, the measured acoustic level was 1.5 dB below the expected level for full power with a Nordex N-100/2500 wind turbine, the turbine used at Shirley. Nordex literature reports that the acoustic output of the N-100/2500 is a constant for wind speeds measured at a height of 10 meters. At a wind speed of 4 m/s, the Nordex sound level is down about 1.0 dB from the maximum. Wind turbine noise vs. wind speed plots are unusual. As the wind speed increases from 0, it reaches a speed where the rotors of the turbine can start to turn. From this point, the noise from the turbine begins and goes up rather rapidly with increasing wind speed until it reaches a transition plateau where the sound level no longer increases with wind speed. However, the power generated by a wind turbine goes up much more gradually in power as a function of wind speed and only reaches its maximum several meters per second above the acoustic limit. The result is that for a very small change in sound level generated by the wind turbine, there can be a very large change in the electric power generated. This is true for the Nordex N-100/2500. Table 1 is compiled from Nordex literature and gives the relationship shown between acoustic power emitted and electrical power generated as a function of wind speed.
- *Geoff Leventhall.* Leventhall reports that the highest reaction to low-frequency sound occurs in the 40 to 50 Hz range. However, his data (Figure 4) show almost equal responses in the 30 to 40 Hz range and the 70-80 and 80-90 Hz ranges.
- *Shirley Report.* The Shirley report shows levels of 25-30 dB in the 40-50 Hz range, and it shows room resonances and possibly some wall resonances. Room resonances are in the 35-100 Hz

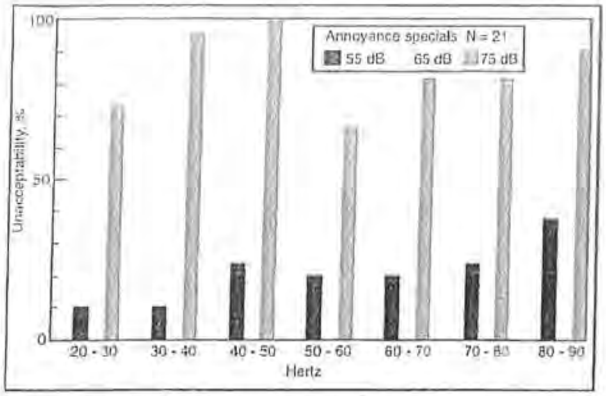

Figure 4. Unacceptability ratings for group of "specials" to noise stimuli.

range. Wall resonances are typically in the 10-30 Hz range.

- *Threshold of Hearing.* The pulses, roughly one per second, that result from the blades passing the support tower, appear to have about a 10% duty cycle and would drop the threshold of audibility by about 8 to 10 dB. Figure 1 shows threshold of audibility based on several sources along with the lowest and highest levels of audibility at a given frequency. These levels are for continuous sinusoidal signals. With a 10% duty cycle, the thresholds go down by about 9 dB. For the most sensitive subjects, this indicates a threshold of hearing of about 31 dB at 50 Hz to 35 dB at 40 Hz.
- *Bruce Walker.* Bruce Walker's findings that the tone at 45 Hz was above the threshold of hearing stands in support of the theory that low-frequency audible sound exists in the vicinity of wind turbines and could be the source of problems. There is a possibility that these offensive signals can only be found using narrow-band analysis as Walker used. Constant bandwidth filters may be too broad.
- *Steven Cooper.* It is somewhat amazing that Cooper's findings fit this situation so well. He found that the peoples' responses correlated to large changes in electric power, turbine operations hovering around a cut in speed, and the absolute level of the electric power being generated better than to the acoustic level. Table 1 supports Cooper's findings. The electric power changes gradually until full power is reached; the acoustic signature rises quickly and then becomes a constant. Please note that the subjects could know when the turbine was on or off, but the data in Table 1 clearly shows that there is no way to know what percent of the maximum electric power is being generated from any data available to the subjects. So the fact that the subjects' responses correlated with the electric power, which is something the subjects could have no way of knowing, lends strong support to Cooper's findings. The acoustic data during "large" transitions in percent of full electric power should be analyzed, since it could be a potential source of problems.
- *The Energy Company.* Clearly, it would be nice to have trustworthy confirmation of this analysis. To date, the power company at Shirley has not given any clear data on the actual power generated (or any other physical parameters, such as blade rpm, wind speed, or direction) for any time during our measurements. So we are limited to the indirect analysis of estimating a large change on the basis of a 1 dB acoustic change.

Table 1. Electric power (kW) and acoustic A-weighted power level (dB) both as functions of WS (m/s).

Wind Speed 10 m m/s	Electricity Generated, kW	Percent of Full Power	Acoustical Power Level, A-weighted dB
3*	34	1	95.5
4	83	4	100.5
5	237	9	103.0
6	448	18	106.5
7	738	30	107.5
8	1123	45	107.5
9	1604	64	107.5
10	2043	82	107.5
11	2321	93	107.5
12	2467	99	107.5
13	2500	100	107.5
14	2500	100	107.5

*3.5 m/s for electric power; 3.0 m/s for acoustic power.

This all suggests that the Shirley signals would be slightly too low to trigger this chain of reactions. There are at least two possibilities. One possibility is that there are other undiscovered mechanisms and pathways. Another possibility is that the acoustic level is higher than we measured, because we measured on a quieter day. We do not know, because we do not have the physical parameters. Bruce Walker suggests that sufficiently high levels exist at some wind farms. Hessler's relatively constant measured data suggests we are not at a low power. So it seems this is another conundrum, but again this is a needless problem that the power company could sort out.

Analysis and Hypothesis Development

Point 1: Suggests looking for something in the 40-50 Hz range as our possible "culprit."

Point 2: Suggests that the electric power being generated is a very important parameter to a person's response. As Table 1 shows, the acoustic output is more or less constant over a wide range of wind speeds, but the electrical power being generated is changing with wind speed. It is true that the subjects in Cooper's study could have known when the sound, hence the wind farms, were turning on and off, but they would have no way of knowing the electric power from the acoustical signal. This lends strong support to Cooper's results.

Point 3: Suggests that there is a source of low-frequency audible sound that is produced each time a blade passes the support tower (or the low point of each blade during each revolution). The wind turbine blades flex so that the blade tips come closer to the support tower (the flex increases) as the electric power being generated increases. The reverse occurs as the power being generated decreases; the flex decreases and the minimum distance between the support pole and the blade tip increases. So, this particular sound increases and decreases in step with changes in the electric power being generated.

The physical mechanism that is at work here is the same as a stick or pole placed in a river. The pole represents an object that can disrupt the regular flow. There is a big wake downstream as everybody knows, but if one examines the situation a little more closely, you realize that there has to be pressure reflected upstream off this pole in the river, and that causes some disturbance upstream. The closer one is to the pole, the stronger the upstream reflection effect is. Much the same is happening with the wind turbine. As the blade gets closer to the support tower, it gets into more of this upstream disturbance.

In summary, there is a sound source that produces low-frequency pulses at the blade passage frequency, and the sound level of the source goes up and down in accordance with the amount of electric power being generated. The facts in this analysis indicate that this should be studied further, since this may be an important factor in the community response – both annoyance and other physiological effects. Moreover, the fact that this sound source can be controlled by the operator, to some degree, gives some promise to our ability to mitigate or eliminate this problem.

The hypothesis is that there is a frequency that will be characteristic of a specific blade and manufacturer that based on the discussion at ASA appears to be in the 25-60 Hz range. This tone modulated at 1 Hz causes a reaction in at least some people. This potential phenomenon should be able to be tested in a variety of ways, most of them quickly and inexpensively.

Suggested Test 1

Diary Test. Using a diary study, one could ask respondents to keep the following information:

- When they are at home and awake.
- The times when they feel a sensation caused by the wind turbines.

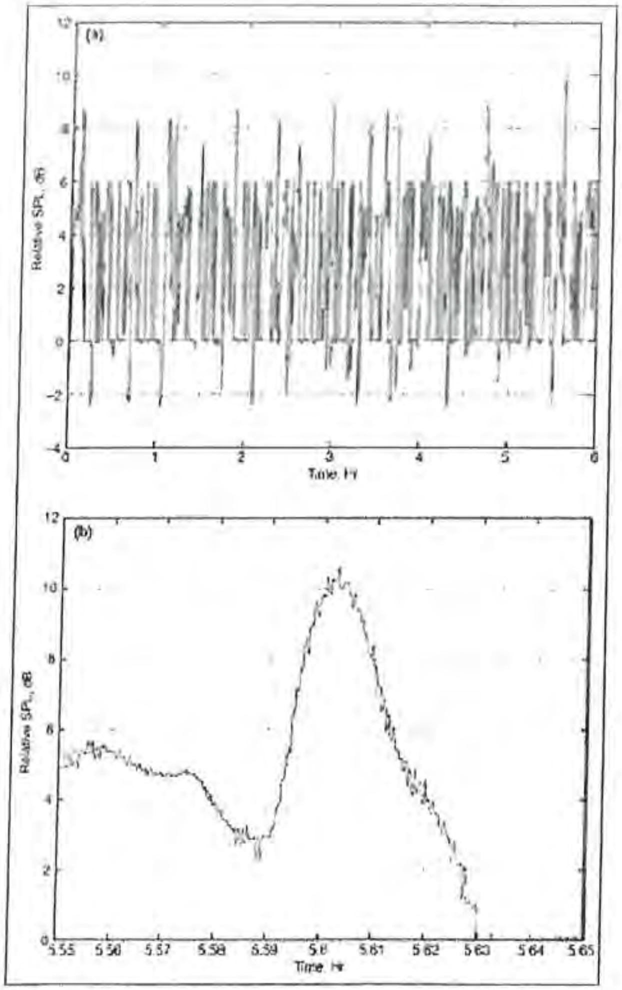

Figure 5. (a) Computed variations in SPL from a five-turbine array with unequal rotation rates relative to incoherent result; (b) expansion of largest peak.

- If so, how strong is the sensation?

This information could be related with electric power generated and other physical parameters.

Suggested Test 2

Response Comparison. There are certainly some data that can be examined that were gathered in conjunction with peoples' responses. Hopefully, the Cooper data will show if specific tones in this region are present, how strong they are, and how they compare with the peoples' responses.

General Tests

The two following tests are more general and would aid in understanding the phenomenon we are dealing with.

- *Direct Human Testing.* Direct human testing could be done in laboratory and field settings but, as has been testified to, there may be a period of time for the symptoms to incubate. A good start on this is underway at the University of Minnesota.
- *Direct Animal Testing.* A cat or guinea pig's ear could be used to test for reaction to wind turbine noise. Monitoring could be done on the nerve that emanates from the otolith and from the nerves emanating from the cochlea as a function of wind turbine sound amplitude both above and below the threshold of hearing.

Opinions and Recommendations of Bruce Walker

Modern large wind turbines produce pressure fluctuations as the result of a variety of mechanisms. The time scales of these fluctuations range from minutes to milliseconds (conversely the frequency scales range from millihertz to kilohertz). Two aspects of wind turbine noise that have received significant attention over the past decade are amplitude-modulated broadband noise and quasi-periodic "thumps" generated by interaction between rotor blades and support towers. The focus of this review is the latter, which is most commonly identified as wind turbine infrasound (WTIS). In modern turbines, the time scale of this disturbance is on the order 1 second. However, the details of the individual disturbance events appear to hold the key to whether or not WTIS results in human response.

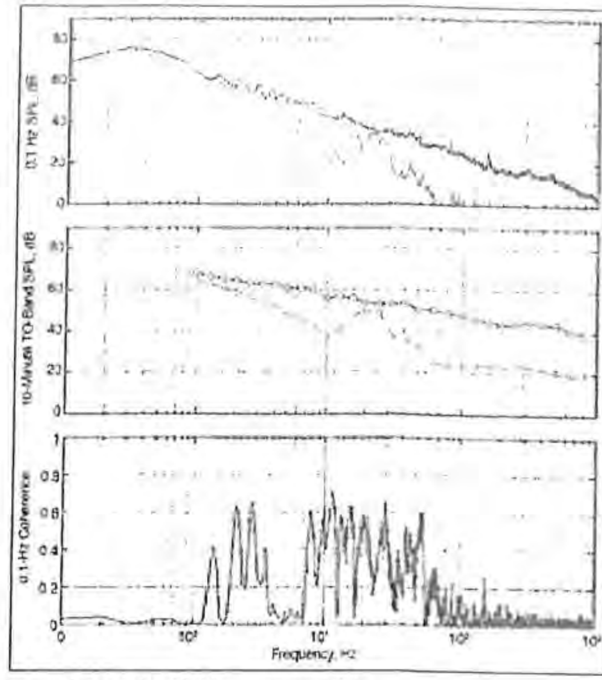

Figure 6. Example of field measurement data.

Modeling

There has been a temptation to model WTIS using the same techniques as for modeling audible sound: summation of spectral sound pressure squared from multiple point sources. At Wind Turbine Noise 2011,[5] the modeling issue was addressed by observation that the waveforms of WTIS were likely to be deterministic and therefore add coherently, so that the more correct modeling would be summation of time-domain sound pressures and subsequent computation of peak and average sound pressure levels.

For multiple turbine installations, this would produce a wide range of potential outcomes, depending on the relative synchronization of the turbines. Figure 5 shows a hypothetical result for five turbines turning at random speeds over a narrow range. For a few minutes over a six-hour simulation period, peak levels over 10 dB above the SPL predicted from pressure-squared summing were encountered. Receptors exposed to this momentary period of enhanced pulsation levels could be highly annoyed or awakened by it, while enforcement personnel might measure for hours and never witness it.

Measurement

There has been a temptation to measure WTIS using the same techniques as for measuring audible sound: time-averaged weighted levels and power spectra. Typical field measurement results are similar to those shown in Figure 6 acquired a few hundred meters from a 2-3 MW range turbine. Spectral peaks are seen at several multiples of the 0.75-Hz blade-passing frequency. The sound pressure levels at each of these peaks is far below the generally accepted sensation threshold.

However, the putative blade/tower interaction genesis of the WTIS would suggest that the actual acoustic signal would be a sequence of relatively narrow pulses. Further, the unsteadiness of rotation speed would cause higher harmonic content of the signal to migrate among conventional PSD analysis bins and appear as broadband noise.

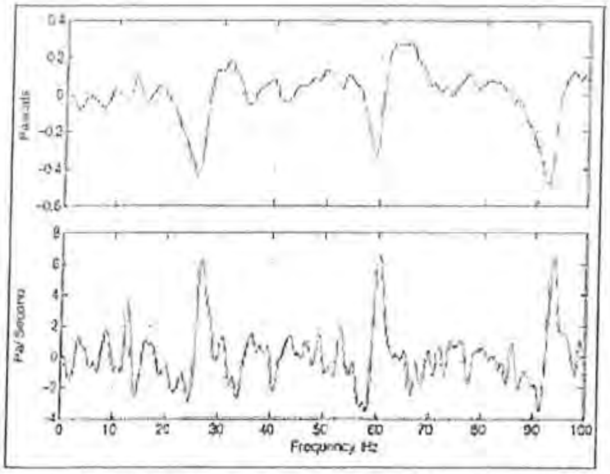

Figure 7. Example ensemble average waveform and time derivative with wind direction 140° re mic orientation.

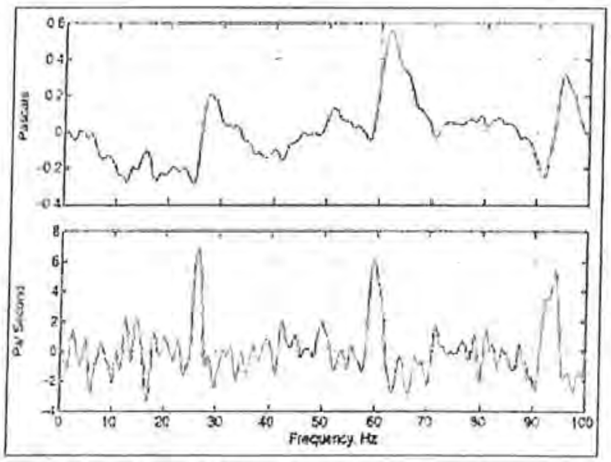

Figure 8. Example ensemble average waveform and time derivative with wind direction 60° re mic orientation.

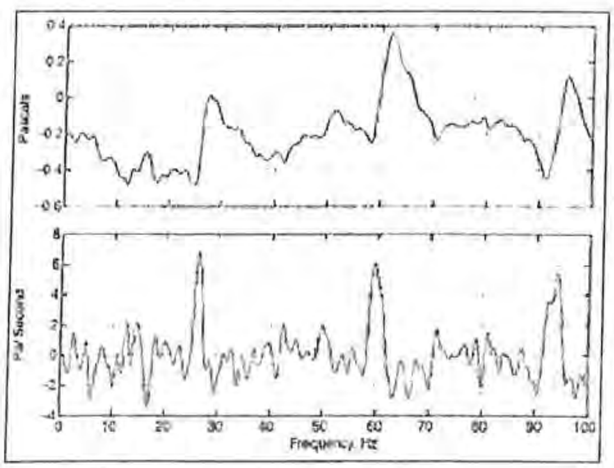

Figure 9. Shaft-order spectrum for wave shown in Figure 8.

At Low Frequency Noise 2012,[6] Wind Turbine Noise 2013[7] and ASA 2014,[8] methods were described for capturing the wave form emitted by large wind turbines by synchronous sampling and ensemble averaging several-minute recorded samples from a three- and four-microphone array. These measurements confirmed that the emitted infrasound was confined to less than 10% of the blade-pass period, as shown in Figure 7. One set of measurements suggested that the phase of the BPF signal component depended on azimuth, as shown in Figure 8. The algorithms used to simulate synchronous sampling left too much residual jitter to retain time resolution better than approximately 50 ms.

Figure 10. Loudspeakers for WTIS synthesis in 43 m³ test room.

Synthesis

An electro-acoustic system was assembled starting in 2012 to synthesize periodic signals with fundamental frequency 0.8 Hz and up to 65 harmonics in a residential bedroom. A photo of the system is shown in Figure 10, and a schematic of the test facility is shown in Figure 11. Three 18-inch "woofers" are driven by a DC-coupled, 300-watt amplifier, excited by Fourier-synthesized waves from 16-bit, D-to-A converters. A second loudspeaker can provide synchronized amplitude-modulated, Dopplerized, audible sound if desired. An infrasound microphone is suspended above the evaluator's head. The system was described in detail at Wind Turbine Noise, 2015.[9]

Spectra corresponding to variations on that shown in Figure 12 were presented to a variety of volunteers at levels extending to approximately 15 dB above those reported from field measurements. Harmonic phases were adjusted to maximize or minimize signal crest factor and signal peak slope. If the upper limit of spectral content was 20 Hz or below, no evaluator reported any sensation. With the upper limit extended to 32 Hz and the level above 20 Hz spectrally uniform, one evaluator reported significant unease after a few minutes exposure. Subsequently, this evaluator reported unease when exposed only to amplitude-modulated audible sound.

In 2014, Hansen *et al.*,[10] obtained field measurement data that displayed periodic spectral detail that extended to above 50 Hz, as shown in Figure 13. At ASA 2014 and Wind Turbine Noise 2015, Palmer[11] showed correlations of resident response to nearby operations of turbines that depended on resident positions inside rooms. This suggested the possibility that the residents were affected by sound of frequency high enough to excite room resonances, typically 30-40 Hz and above.

The Hansen data were analyzed extensively and results presented in Wind Turbine Noise 2015.[12] All spectral lines were separated by the turbine BPF, but in some ranges, the actual frequencies were not exact multiples of BPF. The mechanism for generating such a spectrum could be brief bursts of mechanical resonance once per blade pass or the effect of multiple turbines at slightly different speeds. The spectra were forced into a harmonic series and synthesized for evaluation. Because the reported power spectra lacked phase information, all harmonics were assumed to be at zero phase simultaneously.

Response

Threshold, annoyance and sleep interference were informally investigated using the full Hansen spectrum, then with high-pass filtering at 20 and 30 Hz and finally with low-pass filtering at 20 Hz. In summary, high-pass filtering had no effect on any parameter, and low-pass filtering resulted in no response, even with 10 dB exaggerated levels.

The results of these informal tests were presented at Wind Turbine Noise 2015, with admonition that they represent small samples and relatively brief (10 minutes to 2 hours) exposure. It was recommended that more extensive similar investigations be undertaken.

Follow-Up

During Wind Turbine Noise 2015, and discussions with co-authors, it appeared that the Hansen spectrum could be approximated by a uniform BPF harmonic series, weighted by a $\sin(\pi f/18)/(\pi f/18)$ shape function.

The resulting waves and spectra are shown in Figures 14-16. Figure 16 demonstrates that once each blade-pass period, the signal harmonics from the third spectrum lobe may constructively combine, producing a periodic "thud" that at levels just slightly above hearing threshold, produces an illusion of infrasound that is devoid of actual infrasonic energy. Note that near 45 Hz, the

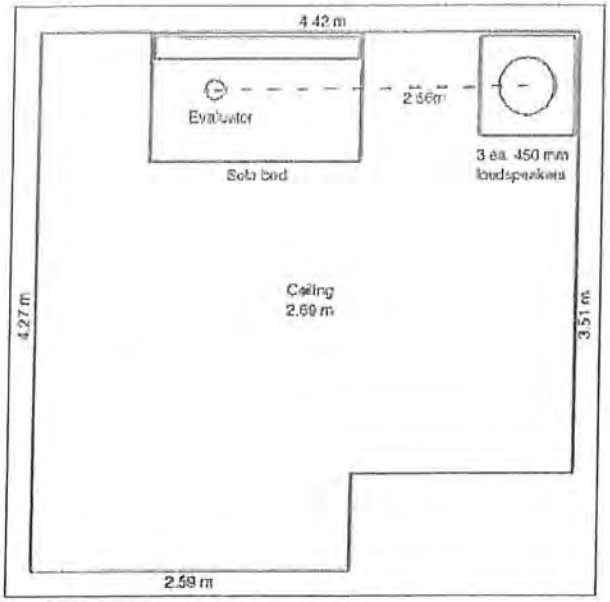

Figure 11. Layout of WTIS evaluation test room.

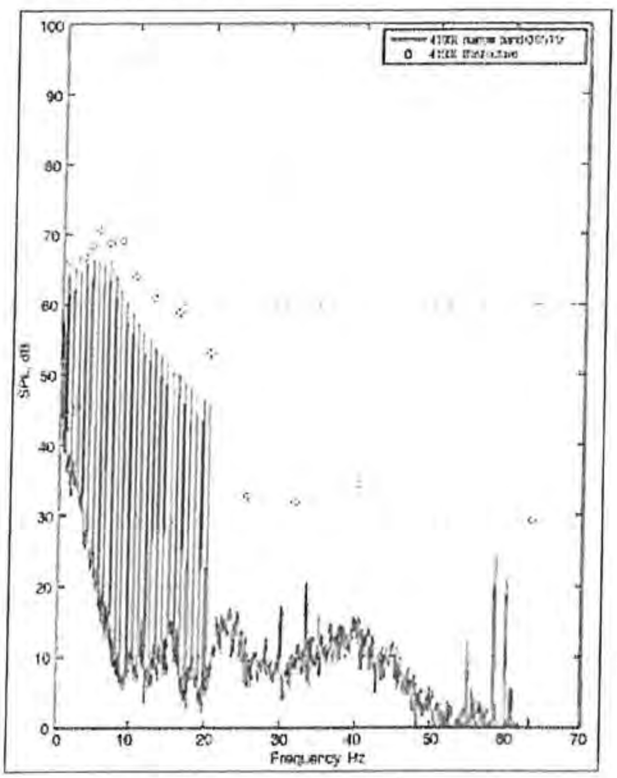

Figure 12. Generic WTIS spectrum used for initial evaluations.

maximum SPL is 13 dB above L_{eq}, so a measured spectral "hump" that appeared to be well below threshold could easily produce audible "thumps" that would be mistaken for infrasound. The time between the negative and positive peaks in the full-spectrum wave is 0.055 seconds, in which time the rotor blade tip would travel 4.6 meters at 84 mps tip speed. This seems reasonable for the approximate width of the support tower or its bow wake, supporting blade/tower interaction as a genesis mechanism.

An observation from the idealized spectrum shown in Figure 14 is that the phases of the components in the second lobe would be reversed relative to the first and third lobes. This detail was not followed in perception testing. In Figure 15, the effect of the phase reversal on the composite waveform is displayed. The crest factor and wave "sharpness" are clearly increased with the second lobe phase properly reversed. When reproduced at 10× frequency

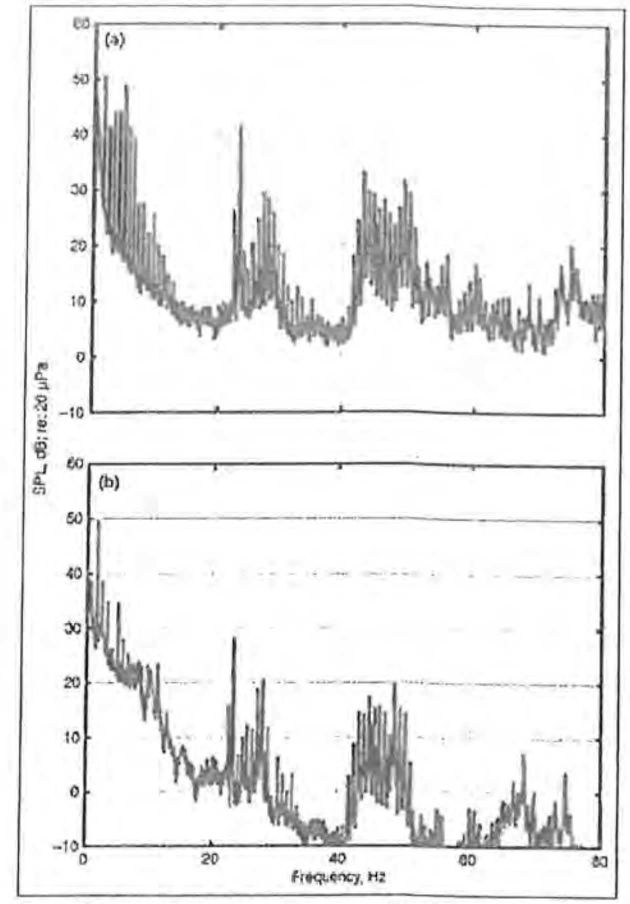

Figure 13. Outdoor (a) and indoor (b) spectra of WTN measured by Hansen.

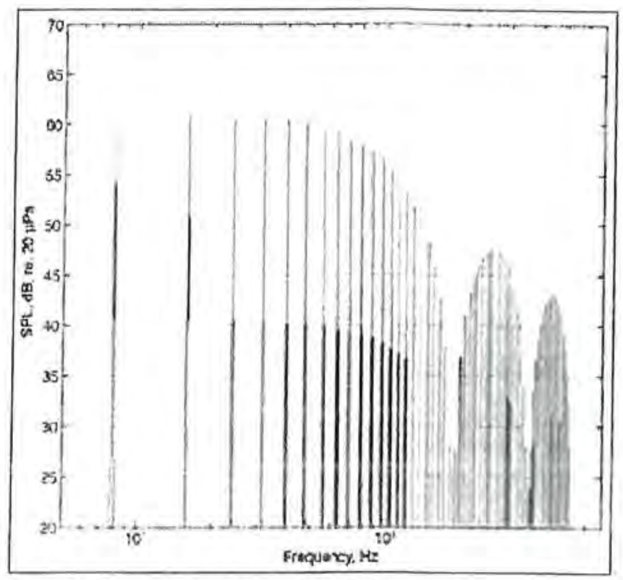

Figure 14. Spectrum of sin(x)/x-weighted BPF harmonics.

on loudspeakers, the properly phase-reversed signal is distinctly more impulsive sounding. The effect on perception at full-scale frequency is currently being explored.

Summary and Collective Recommendations

Disclaimer. The preceding sections are the sole and exclusive work of each author. There has been no attempt at editing or reaching agreement among authors.

Areas Identified for Needed Practical Research

Simulation. Walker has demonstrated that wind turbine infra-

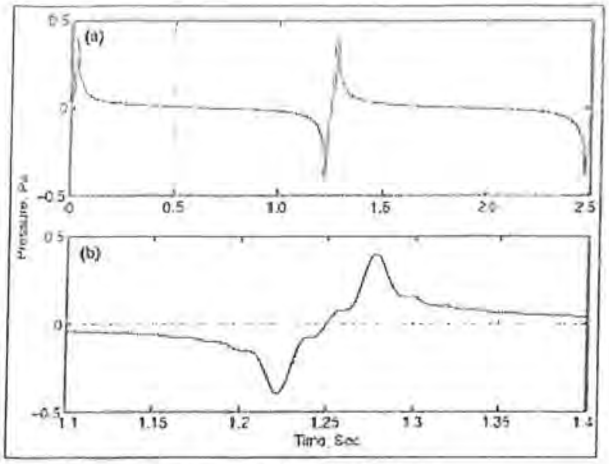

Figure 15. Waveform of spectrum shown in Figure 14.

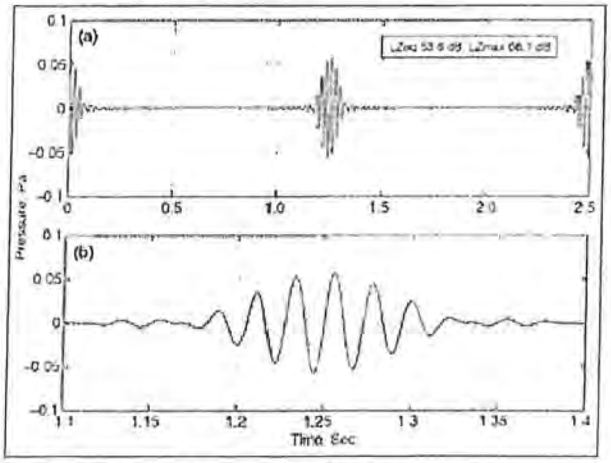

Figure 16. Wave-packet representation of third-spectrum lobe components.

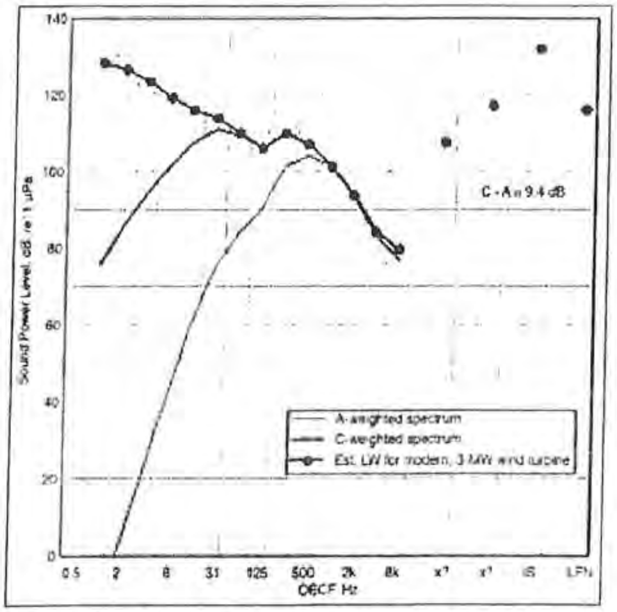

Figure 17. Typical spectrum from a large, modern, , 3-MW wind turbine.

sound and pulsed LFN, which may be upper harmonics of the Infrasound pulsations, can be mathematically defined, duplicated and simulated with loudspeakers for subject evaluator testing. A more formal and expanded set-up, perhaps at a university using student volunteers exposed to both low and high levels could establish the threshold of perception for both steady and pulsed LFN for the particular and unique source of environmental noise from

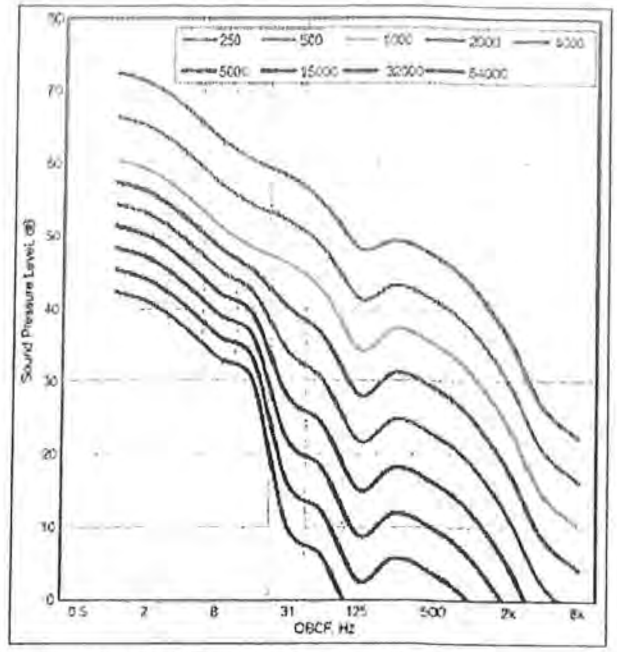

Figure 18. Calculated Lp spectra as function of distance.

wind turbines. Studies in this area are progressing in Australia.

Survey of Wind Turbine Projects Participating Residents. Landowners who lease their land for wind turbine installations may experience sound levels well in excess of proposed limits for normal siting practices and experience higher levels than nonparticipating neighbors. There should be an absolute wealth of information to be learned from these residents collected by a well-designed national survey. Such a survey must have the complete cooperation and possible sponsorship from the industries' national representative, AWEA (American Wind Energy Association) in America and others throughout the world. The authors would like to suggest questions to any study team.

Noise Source Reduction. The designers and suppliers of wind turbines must make a continued and concerted effort to reduce noise emissions from their turbine designs. Reductions can be accomplished by a combination of blade design and operational software. A universal design goal based on measurable established standards (IEC-61400) for sound power level would encourage these efforts.

Perception Testing. Schomer suggests pathways that could support some test findings in America and Australia that suggest from statistical correlation that some residents could perceive wind turbine operation and/or operational changes without benefit of sight or audibility. A detailed discussion is offered on practical perception testing that could discover something unknown to us at this time and is highly recommended for implementation.

Discussion and Collective Conclusion

None of these opinions and recommendations answers the posed question: does ILFN from wind turbines make people sick? It is abundantly obvious that intense adverse response occurs at certain sites. Realistically, it is not even possible to answer the posed question to all parties' satisfaction with practical research. For examples, a direct link to adverse health effects from yesterday's tobacco and today's excess sugar can be denied forever, because any research that could actually prove a link to all parties would take longer than forever and would be totally impractical. The wind farm industry must accept that there are enough worldwide sites that emit excessive wind turbine noise resulting in severe adverse community response to adopt and adhere to a reasonable sound level limit policy. Likewise, wind farm opponents must accept reasonable sound limits or buffer distance to the nearest turbine – not pie-in-the-sky limits to destroy the industry.

The A-weighted sound level is commonly used for assessing noise from wind farms as well as most all other large power genera-

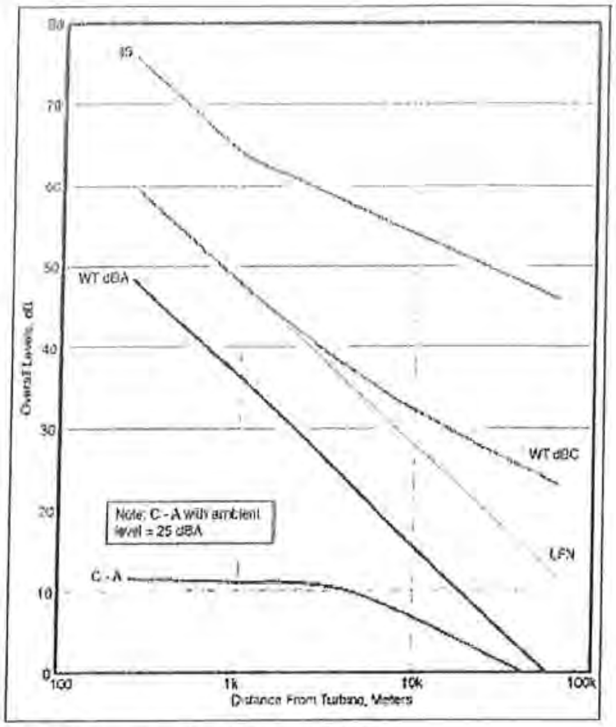

Figure 19. Overall levels as function of distance.

tion facilities. Each author has been recommending the following limits for wind farm noise emissions for years: Hessler[13] – 40 dBA design goal, 45 dBA max limit; Leventhall – 40 dBA; Schomer – 35-39 dBA; and Walker – 45 dBA in high ambient areas but lower in lower area ambient locales. The authors have generally found that wind farms designed to a level of 40 dBA or a bit lower at nonparticipating residential receptors have an acceptable community response. Surveys at wind farm sites for a decade have consistently shown good statistical correlation between wind farm noise level emissions and the percentage of highly annoyed residential receptors (% HA).

The question arises if an A-weighted criterion alone is adequate to protect receptors from infrasound (IS), LFN and pulsed LFN shown to be present in large wind turbines. Figure 17 plots the measured spectrum from a typical, nominal, 3-MW wind turbine plus the most commonly used overall levels. Infrasound (IS), the highest overall level, is calculated by summing the bands 1-16 Hz (0.7-22 Hz) and LFN by summing the bands 31.5-125 Hz for a frequency band of 22-177 Hz. Note that the overall C-weighted level and LFN levels are quite close together. Notice also that C-weighting filters out IS and would not be a good metric for assessing wind turbine IS but would be excellent for assessing LFN from wind turbines.

Hessler[14] and Broner[15] have recommended C-weighting limits for low-frequency industrial sources based principally on extensive experience with open-cycle combustion turbines. Both have concluded independently that a level of 60 dBC is a desirable criterion to minimize adverse response from neighboring communities as shown in Table 2[14] and Table 3.[15] the C-weighted level from wind turbines will always be comfortably below 60 dBC when emitting 40 dBA or less.

Figure 18 illustrates the computed pressure spectra from 250 m (820 feet) to 64,000 m (40 miles). The calculation uses ISO-9613 algorithms for hemispherical divergence, air absorption and ground effects assuming a 100-m hub height. Note that 3 dB/doubling distance in lieu of 6 dB is used for IS beyond 1 km as measured in the recent extensive Health Canada study. The reason for doing this calculation is to determine the overall levels with distance that is shown in Figure 19.

Looking at the octave-band spectra, it is apparent that the indicator of a potential low-frequency noise problem, C-A level, should increase with distance, since the A-weighting level is reduced by excess attenuation while low frequency noise is not. The result is 11 increasing to 24 dB if the ambient is not considered in the calculation. However, when a macro residual ambient of 25 dBA is assumed, the quantity starts at 11 dB and actually decreases to zero, as shown on Figure 19. This classic indicator of a potential low-frequency problem when C-A reaches 15 to 20 dBC will not occur when assessing LFN at wind turbine sites.

Table 2. Maximum allowable C-weighted sound level, LCeq, at residential areas to minimize infrasound noise and vibration problems.

	Normal Suburban/Urban Residential Areas, Daytime Residual Level, $L^{90} > 40$ dBA	Very Quiet Suburban or Rural Residential Areas, Daytime Residual Level, $L^{90} > 40$ dBA
Intermittent day-only or seasonal source operation	70	66
Extensive or 24 / 7 source operation	65	60

Table 3. Criteria for assessment of LFN.

Sensitive Receiver / Operation		Range	Critera Leq, dBC
Residential	Nighttime / plant ops 24 /7	Desirable Maximum	60 65
	Daytime / intermittent 1 - 2 hours	Desirable Maximum	65 70
Commercial / office	Nighttime or plant ops. 24 / 7	Desirable Maximum	70 75
Industrial	Daytime or intermittent 1 - 2 hours	Desirable Maximum	75 80

Collective Conclusions

Our analysis illustrates that a wind turbine is not a classic LFN source; that is, one with excessive low-frequency spectral content. But a wind turbine is a unique power-generating source with spectral content down to the 1-Hz octave band, emitting measurable IS in addition to LFN. Infrasound (IS, 0-20 Hz) from wind turbines can almost be ruled out as a potential mechanism for stimulating motion sickness symptoms. But to be thorough and complete, we recommend that one or two relatively simple and relatively inexpensive studies be conducted to be sure no infrasound pathways to the brain exist other than through the cochlea. Pending the results of these studies, we feel that no other IS or LFN criteria are required beyond an acceptable A-weighted level.

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