SUPERVISOR OF ASSESSMENTS AND
PLANNING & ZONING COMMITTEE
of the
OGLE COUNTY BOARD

SUPERVISOR OF ASSESSMENTS AND
PLANNING & ZONING COMMITTEE REPORT
SEPTEMBER 15, 2010

The regular monthly meeting of the Supervisor of Assessments and Planning & Zoning Committee of the Ogle County Board was held on September 15, 2010 at 1:00 P.M. at the Old Ogle County Courthouse, Third Floor County Board Room #317, 105 S. Fifth St., Oregon, IL .

The Order of Business is as follows:

1. ROLL CALL AND DECLARATION OF A QUORUM

   Chairman Lyle Hopkins called the meeting to order at 1:00 P.M. Roll call indicated six members of the Committee were present; Chairman Hopkins, Jim Barnes, Ben Marcia Heuer, Larry Boes, Mel Messer, and Dennis Williams. Ben Diehl was absent. Mr. Hopkins declared a quorum present.

2. READING AND APPROVAL OF REPORT OF AUGUST 11, 2010 MEETING AS MINUTES

   Mr. Boes made a motion to approve the report of August 11, 2010 as minutes; seconded by Mr. Messer. The motion carried by a voice vote.

SUPERVISOR OF ASSESSMENTS PORTION OF MEETING:

3. CONSIDERATION OF MONTHLY BILLS OF SUPERVISOR OF ASSESSMENTS, AND ACTION

   Monthly bills of the Supervisor of Assessments were presented to the Committee for consideration. The bills totaled $580.13. Mrs. Heuer made a motion to approve the payment of the bills in the amount of $580.13; seconded by Mr. Barnes. The motion carried by a voice vote.

4. OLD BUSINESS

   No old business for consideration

5. NEW BUSINESS

Mr. Harrison stated that the Board of Review will be holding a hearing regarding an application for property tax exemption filed by Pinecrest Grove of Mt. Morris. The hearing will be held at 10:00 A.M. Friday, September 17. Since the application involves a property with an assessed value of $100,000, the Board is required to hold a hearing.

PLANNING & ZONING PORTION OF MEETING:

6. UNFINISHED BUSINESS (CONSIDERATION AND POSSIBLE ACTION)

There was no unfinished business for consideration.

7. NEW BUSINESS

A. DECISIONS (CONSIDERATION AND POSSIBLE ACTION)

#6-10 AMENDMENT -- Bushnell Walnut Creek Farm, LLC, %Edwin Bushnell, PO Box 249, Stillman Valley, IL and Valley Evangelical Church of Stillman Valley %Edward Clift, 103 S. Maple St., Stillman Valley, IL for an Amendment to the Zoning District to rezone from AG-1 Agricultural District to R-1 Rural Residence District on property described as follows, owned by Bushnell Walnut Creek Farm, LLC and being purchased by Valley Evangelical Church of Stillman Valley:

Part of G.L.1 of the NW1/4 Fractional Section 3 Marion Township 24N, R11E of the 4th P.M., Ogle County, 6.0 acres, more or less
Property Identification Number: Part of 10-03-300-007
Common Location: 6300 Block of E. IL Rte. 72

Mr. Hopkins stated the intent is to build a church at this site, which would also include a pre-school within the church.

Mrs. Heuer made a motion to approve #6-10 Amendment for Bushnell Walnut Creek Farm, LLC and Valley Evangelical Church of Stillman Valley and noted that this petition was unanimously approved by the Regional Planning Commission and Zoning Board of Appeals and there were no objections from the Township; seconded by Mr. Barnes. The motion carried unanimously by a roll call vote of 6-0.

B. MOBILE HOME APPLICATIONS - (CONSIDERATION AND POSSIBLE ACTION)

Request of Samuel & Mary LeFevre, 17W320 Northwoods Dr., Bensonville, IL for extension of Zoning Certificate #360-07NA issued for Recreational Vehicle for Construction.
Location: 5054 N. River Rd.
Section 10, Rockvale Township

Mr. Reibel stated there has been a recreational vehicle at the site for the last three years. A septic system has been installed and the intent is to get started on the house soon. Mr. & Mrs. LeFevre were present and stated we hope to have the foundation in by the Spring. We are doing all the work ourselves. Mr. Hopkins stated there was a delay in getting started due to the water hook-up issues with Byron. Mr. LeFevre confirmed the delay in extending water lines and

added that the City of Byron is now requesting $4,000.00 to hook up to the water system. Mr. Messer asked if this be your permanent residence. Mr. LeFevre answered yes.

Mr. Messer made a motion to approve a one year extension of Zoning Certificate #360-07NA; seconded by Boes. The motion carried unanimously by a roll call vote of 6-0.

8. SUBDIVISION PLATS (CONSIDERATION AND POSSIBLE ACTION)

There were no subdivision plats for consideration.

9. CONSIDERATION OF MONTHLY BILLS OF PLANNING & ZONING DEPARTMENT, AND ACTION

Monthly bills of the Planning & Zoning Department were presented to the Committee for consideration. The bills totaled $314.86. Mr. Messer made a motion to approve the payment of the bills in the amount of $314.86; seconded by Mrs. Heuer. The motion carried by a voice vote.

10. REFERRAL OF NEW PETITIONS TO THE ZONING BOARD OF APPEALS FOR PUBLIC HEARING

#10-10 VARIATION -- Greg & Lisa Crull, 8697 N. Hilltop Dr., Byron, IL for a Variation to allow the construction of an accessory building (detached garage) 1) to be located 15' from the right-of-way line of N. Sunset Dr. in lieu of 33'; and 2) to exceed the maximum allowable accessory building area due to parcel size pursuant to Section 6.06 of the *Ogle County Amendatory Zoning Ordinance* on property described as follows and owned by the petitioners:

Lot 85 of Byron Hills Estates #3, located in part of the W1/2 of the NE1/4 of Section 30 Byron Township 25N, R11E of the 4th P.M., Ogle County, IL
Property Identification Number: 05-30-203-001
Common Location: 8697 N. Hilltop Dr.

#11-10 VARIATION -- Jeremy L. Coulthard, 9385 N. Brookville Rd., Shannon, IL for a Variation to allow an accessory building to exceed the maximum allowable accessory building area due to parcel size pursuant to Section 6.06 of the *Ogle County Amendatory Zoning Ordinance* on property described as follows and owned by the petitioners:

Part of the NW1/4 of the SW1/4 of Section 22 Forreston Township 25N, R7E of the 4th P.M., Ogle County, IL, 4.03 acres, more or less
Property Identification Number: 01-22-300-005
Common Location: 9385 N. Brookville Rd.

Mrs. Heuer made a motion to refer the above new requests to the Zoning Board of Appeals for public hearing; seconded by Mr. Barnes. The motion carried by a voice vote.

11. DISCUSSION OF WECS SUB-COMMITTEE PERFORMANCE STANDARDS REPORT AND POSSIBLE ACTION

Mr. Hopkins stated Mr. Reibel has put together some maps for the committee to review. These maps represent what impact the various setbacks would have on wind developmental areas in the county. Mr. Reibel explained that the three maps show address points on tax parcels less than 60 acres with the address points buffered to 1,000', 1/4 mile and ½ mile. Mr. Hopkins asked the Committee members for comments regarding the setbacks that the WECS Subcommittee has recommended. Mr. Barnes

stated the WECS Subcommittee came up with these recommendations. Mr. Hopkins stated they were passed by a vote of 4 to 3, and I want to hear what this Committee has to say. Mr. Hopkins added that he personally feels that ½ mile or 2,640' is way too much. Mr. Barnes stated I spoke with Lee County and they are strongly considering of extending their setback distances. Mr. Hopkins asked what are they now. Mr. Barnes stated I don't know but they are thinking of increasing them to 2000'. Chris Henkel, Lee County Zoning Administrator was present and stated the current Lee County setback is 1,400' from foundation of the tower to dwelling foundation.

Mrs. Heuer stated I believe 2640' would preclude wind development in Ogle County and infringes upon property owner rights. I find it is beyond what other counties have in place and we are setting a bad precedent.

Mr. Messer stated it is my understanding there are two sizes of wind turbines, 200' and 400'. Would we have two different standards based on tower height? Mr. Hopkins answered we only want one set of rules.

Mr. Hopkins stated we have representatives here from the wind development companies to give a presentation and answer some of our questions.

Mr. Williams, referring to page 5 of the WECS Performance Standards documents, stated that it refers to a distance of 3,960 feet and asked what is that referring to. Mr. Reibel stated that refers to information required to be submitted as part of an application for a Special Use Permit for a wind farm. Mr. Reibel stated that the proposed setbacks are on page 10. Mr. Williams asked have we heard from any municipalities? Mr. Reibel answered no - municipalities have siting authority within their 1.5 mile jurisdiction.

Mr. Barnes asked is there any thought to having town hall meetings. Mr. Hopkins answered no. That is what the WECS Subcommittee meetings were for. People had a chance to come and express opinions at that time. Now this Committee is to review the proposed ordinance and make our recommendations for the Zoning Board of Appeals and get sworn testimony at that time. The Zoning Board of Appeals can make changes as they see fit and their recommendations would go to the County Board. Mr. Messer asked were the WECS Subcommittee meetings advertised as public. Mr. Hopkins answered yes.

Mr. Hopkins stated we have representatives from the wind developers here to answer questions.

Brad Lila from RES Americas and Yang Madsen of Gamesa were present to give a power point presentation to the Committee. Copies of the presentation were give to the committee for review during the presentation.

Mr. Boes asked who owns Gamesa. Ms. Madsen answered that Gamesa is not owned by anyone - it is a publicly owned international company based in Spain, with North American headquarters in Philadelphia. Mr. Boes asked the wind industry representatives present if anyone in present lives by a wind farm. Mr. Lila responded that no one present lives near a wind farm. John Meyers from Outland Renewable Energy stated we are a US company owned by farmers in Minnesota and one in New Jersey. Discussion ensued.

Mr. Lila and Ms. Madsen presented their concerns issues with the proposed WECS Performance Standards by providing a multimedia presentation and discussion (copy of presentation attached).

Mr. Lila stated we are not a fly-by-night development company. We are working on six different continents and in all states in the US. We have a great deal of experience and

hope you take our thoughts into consideration. We understand this is a difficult process and appreciate all the time and effort put in by the Committee. We are asking for Ogle County to hold us to the same standards as required by the State for sound. Mr. Meyers From Outland Energy stated the current ordinance works. If you adopt these proposed standards, you will not have wind development in Ogle County. Can you afford to pass on this opportunity?

Mr. Hopkins stated after hearing this, do we want to wait until next month to further discuss or do you want to have a special meeting. Mr. Boes stated there is a lot of information to digest. Mr. Williams stated we need to spend time discussing this information. We have a moratorium that expires in December and there is an election in November. In all fairness to those county board members, I think we need to consider extending the moratorium until we can get an ordinance that is best for our county. Mr. Hopkins stated the Zoning Board of Appeals is where sworn testimony will be taken and who will make the major decision. All we are doing is make a recommendation. Mr. Barnes stated I believe we should put this on hold until next month's meeting. All agreed. Mr. Hopkins stated the consensus is we will hold this discussion over until the October meeting.

Request of Lindenwood Cemetery Association for an indefinite extension of Special Use Permit #2-10SU approved by the Ogle County Board May 19, 2010.

Part of the SW1/4 of the SW1/4 Section 5 and Part of the NW1/4 of the NW1/4 Section 8 Lynnville Township 41N, R2E of the 3rd P.M., Ogle County, IL, 3.72 acres,
Property Identification Number: Part of 19-08-100-011
Common Location: 16000 Block of E. Elevator Rd.

Mr. Fruit, representing the Lindenwood Cemetery Association, was present. He stated we did not know that we had to have the project started within 12 months of approval. We are currently purchasing additional property and will not have a road in until that sale is completed. That will prevent us from getting things started within 12 months of the approval of the Special Use Permit. Mr. Reibel stated this Committee is authorized to extend a Special Use for what whatever length of time they feel is justified. Discussion ensued. Mr. Hopkins stated the land is continued to be used as farm land. I have no problem leaving this open-ended for a cemetery. I would not consider the same for a business or for a house.

Mr. Messer made a motion to extend the Special Use #2-10 indefinitely; seconded by Mr. Barnes. The motion carried unanimously by a roll call vote of 6-0.

13. PUBLIC COMMENT

Mr. Randy Ocken, a member of the WECS sub-committee, stated I want to make a clarification. There is one item in proposed WECS Performance Standards that was not discussed. In regards to the proposed 2,640' and 1,300' setbacks on page 10, items 2 & 5, the developer can negotiate a reduced setback if they wish. We have heard from the wind companies today that turbines cause no adverse impacts so there should be no problem with negotiating a reduction.

Mr. Noel Allison of Rochelle stated Dr. David Loomis recommend an escrow for decommission and that is what the WECS Subcommittee recommended as well.

Mr. Tom Smith of Rochelle stated the Chairman of the WECS Subcommittee should be given an opportunity to answer questions.

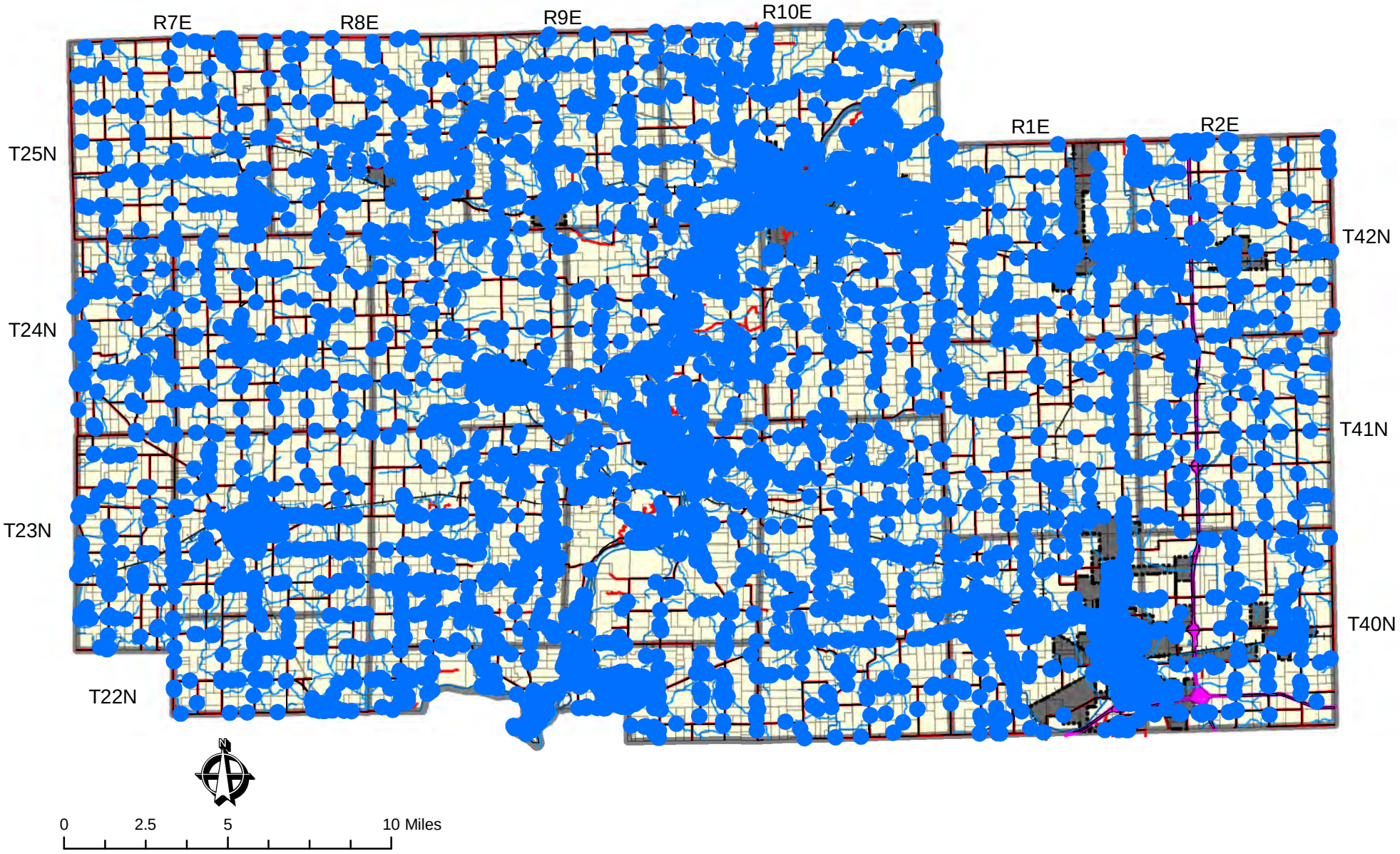
14. ADJOURN (Next meeting October 13, 2010)

The regular monthly meeting of the Supervisor of Assessments and Planning & Zoning Committee of the Ogle County Board adjourned at 2:43 P.M. The next meeting of the Supervisor of Assessments and Planning & Zoning Committee is scheduled for Wednesday, October 13, 2010 at 1:00 P.M. at the Old Ogle County Courthouse, Third Floor County Board Room #317, 105 S. Fifth St. Oregon, IL.

Respectfully submitted,

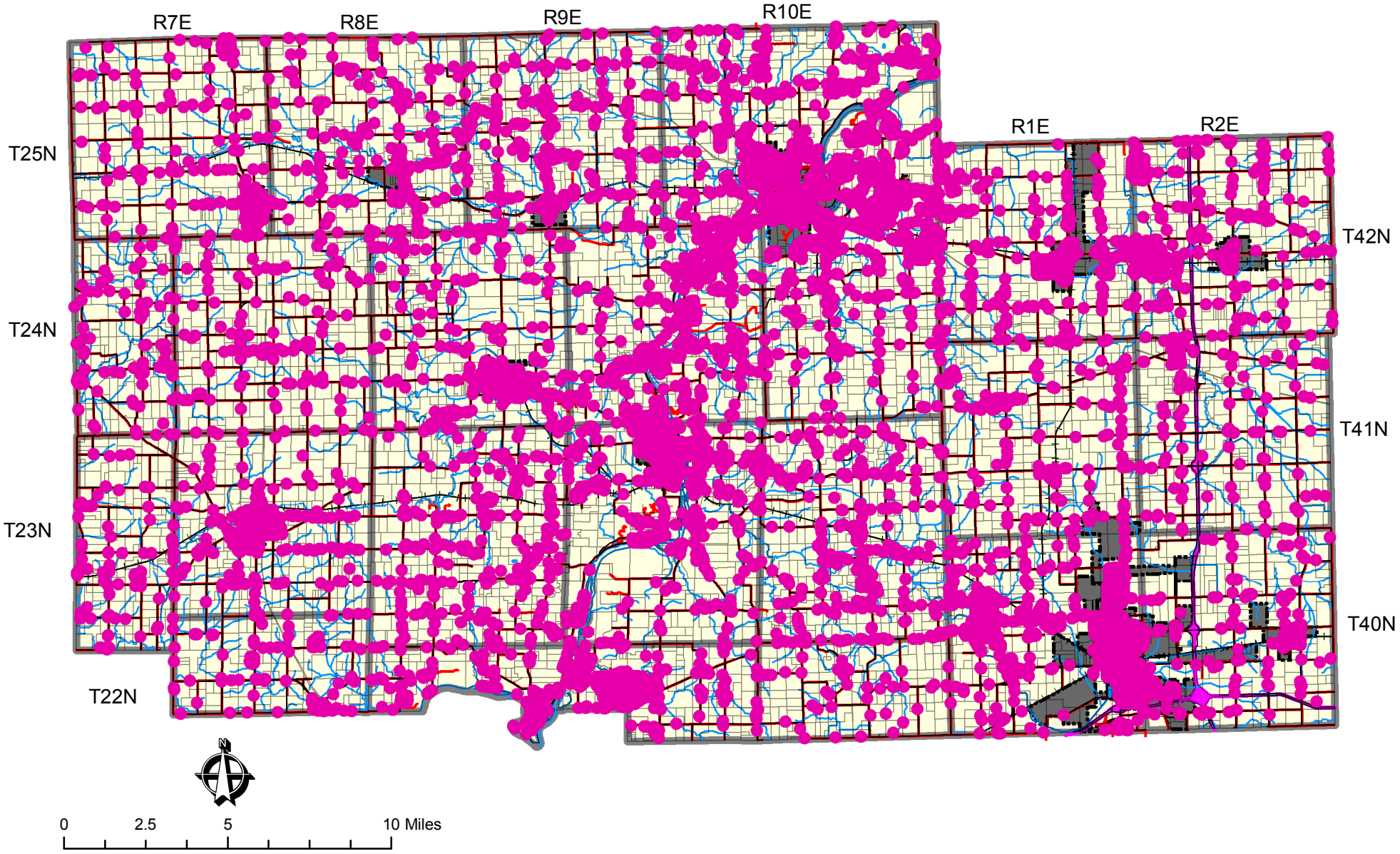
Michael Reibel
Planning & Zoning Administrator

1,320' (1/4 Mile) Buffer from Address Points on Tax Parcels <60 Acres
Ogle County, Illinois



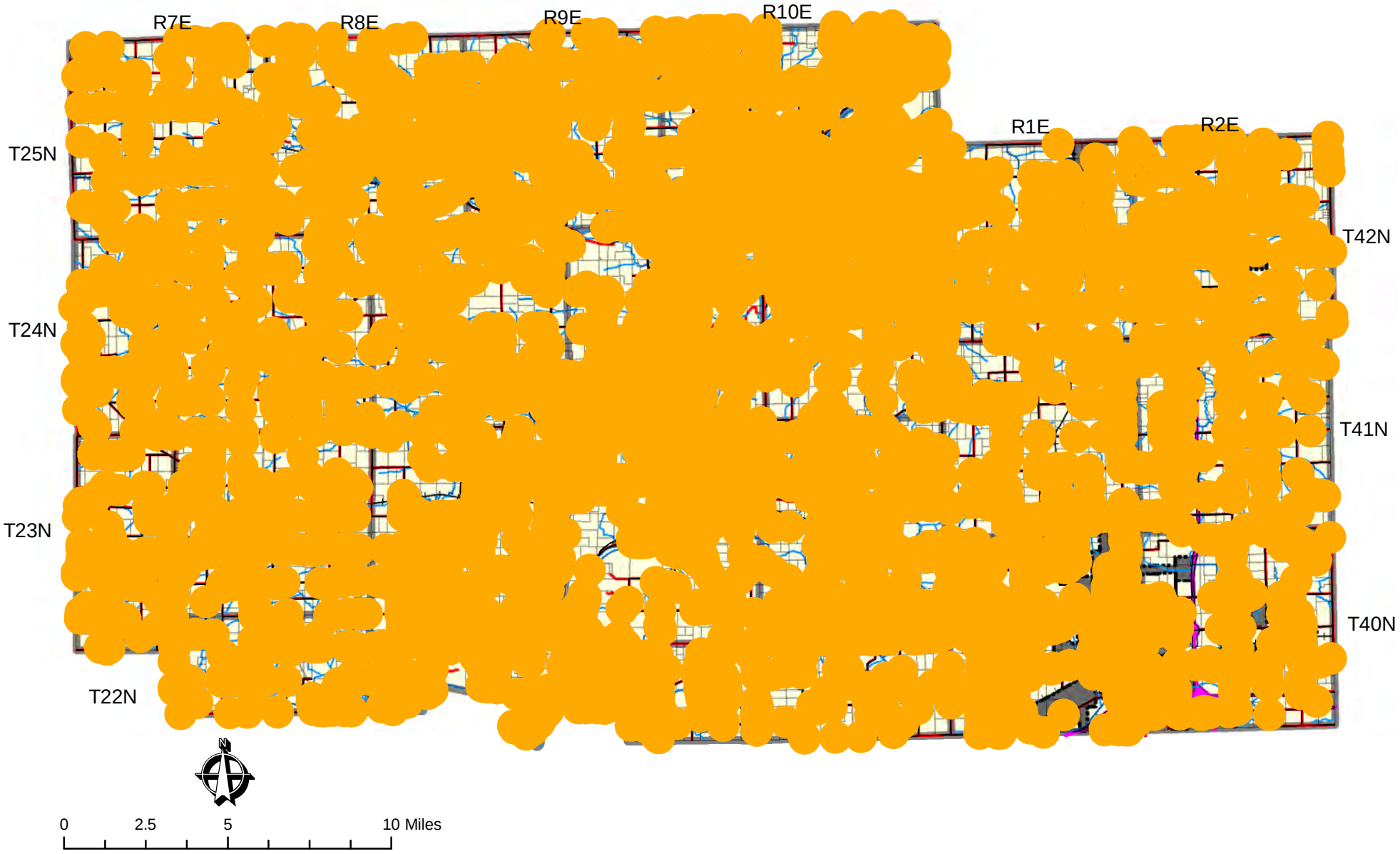
Ogle County Planning & Zoning Department, July 2010

1,000' Buffer from Address Points on Tax Parcels <60 Acres
Ogle County, Illinois



Ogle County Planning & Zoning Department, July 2010

2,640' (1/24 Mile) Buffer from Address Points on Tax Parcels <60 Acres
Ogle County, Illinois



Ogle County Planning & Zoning Department, July 2010

Brad Lila
Development Manager
RES America Developments Inc.
Brad.Lila@res-americas.com

Yang Madsen
Project Manager
Gamesa Energy
Ymadsen@gamesacorp.com

Intent of Zoning Code

- “Laws….supply ethical standards and expectations, while providing rules of conduct, measures to enforce those rules, and a means for settling disputes. Other functions of law include: peacekeeping; checking government power and promoting personal freedom; facilitating planning and the realization of reasonable expectations; promoting economic growth through free competition; promoting social justice; and protecting the environment.” (Mallor, Barnes, Bowers, and Langvardt).

Goals and Principles

We seek to provide feedback based on the following principles and goals:

- Protect landowner rights
- Provide adequate protection for safety and health
- Create jobs and stimulate economic development
- Increase local tax base
- Provide clean renewable energy
- Allow reasonable wind energy (WECS) development in primarily agricultural areas

Wind Turbine Height Restrictions

Sec. III, D - WECS Turbine Height shall not exceed 425 feet for any WECS Project

- Turbine height restrictions of this nature limit development to the use of old technology.

- Use of outdated technology can result in the need for additional turbines to produce the desired amount of energy, additional collection lines and more access roads.

- Proposed height limit: 500 feet

Wind Turbine Placement

Sec. III, D, WECS Turbines should be placed in an irregular (no more than 3 in a straight line) pattern to mitigate compounding effect of noise and low frequency vibrations.

- The existing Illinois noise ordinance accomplishes the objective proposed.
- Results in lower energy production, promotes the use of more land and turbines and is an overall inefficient use of the wind resource.
- No credible scientific data supporting idea that there is a compounding effect of low frequency vibrations.
- **Overwhelming majority** of participating Ogle County landowners and farmers are strongly in favor of linear placement.
- Propose deletion of this requirement

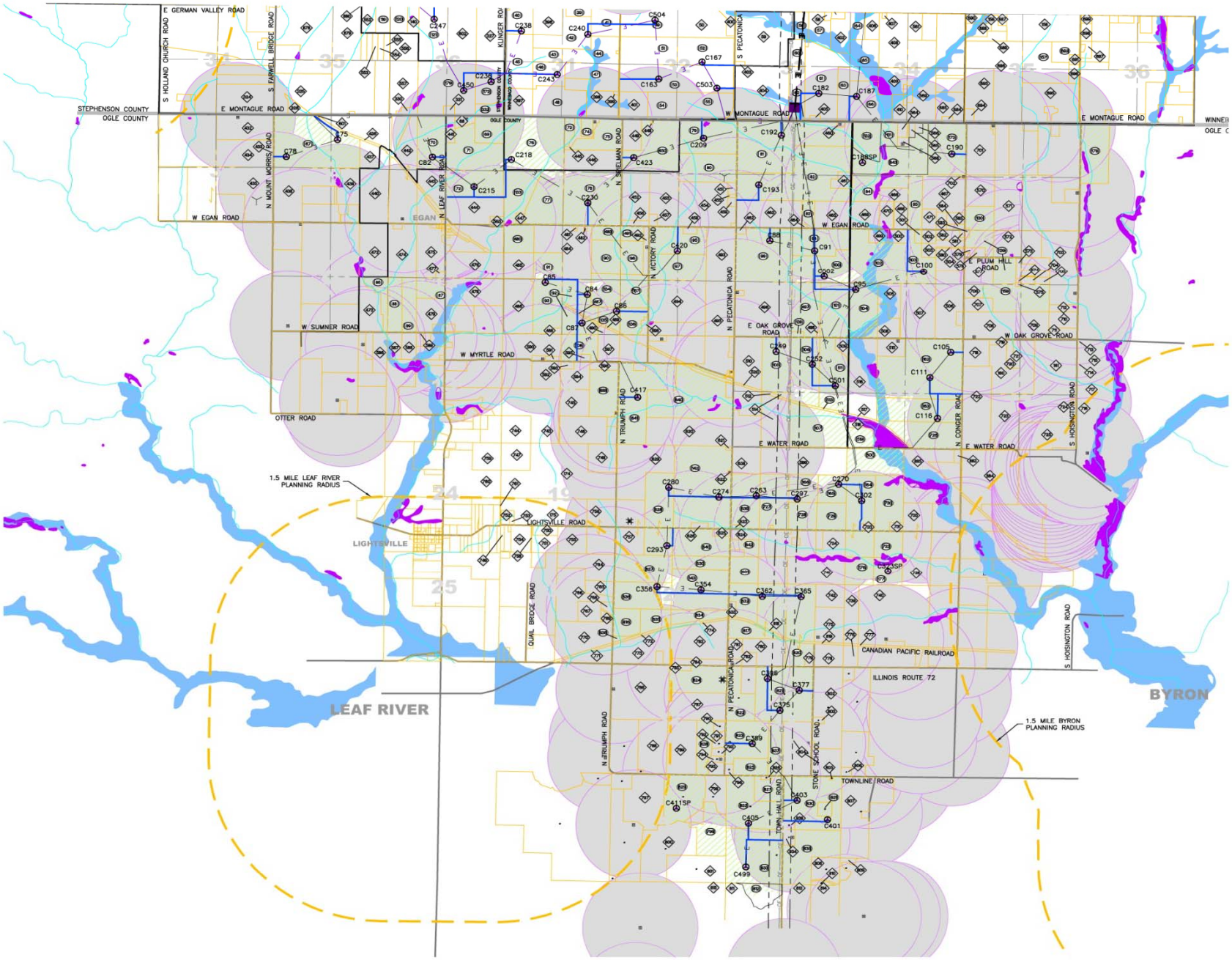
Setback Distances From Dwellings

Sec. 3, K. (Page 10) WECS Turbines shall be setback at least one half mile, (2,640 feet) from a residence located on a non-participating parcel.

This provision alone will prohibit wind energy in Ogle County.

- One homeowner who is opposed to wind energy can effectively "control" a 1 mile diameter around their residence (over 500 acres for one house).
- Balance of landowner rights between owners of homes and farms
- Typical setback in IL is 1,000 to 1,200 feet
- Half-mile setback requirement is higher than that of quarries and livestock plants

Proposed setback: 1,000 – 1,200 feet from non-participating residences


E GERMAN VALLEY ROAD
S HOLLAND CHURCH ROAD
S FARWELL BRIDGE ROAD
KLINGER ROAD
S PECATONICA
STEPHENSON COUNTY
OGLE COUNTY
E MONTAGUE ROAD
W MONTAGUE ROAD
WINNEBAGO COUNTY
N MOUNT MORRIS ROAD
N LEAF RIVER ROAD
N SHELMAN ROAD
N VICTORY ROAD
N PECATONICA ROAD
W EGAN ROAD
EGAN
E PLUM HILL ROAD
W SUMNER ROAD
W MYRTLE ROAD
E OAK GROVE ROAD
W OAK GROVE ROAD
N TRIUMPH ROAD
N CONGER ROAD
S HOSINGTON ROAD
OTTER ROAD
E WATER ROAD
1.5 MILE LEAF RIVER PLANNING RADIUS
LIGHTSVILLE ROAD
LIGHTSVILLE
QUAIL BROOK ROAD
CANADIAN PACIFIC RAILROAD
ILLINOIS ROUTE 72
LEAF RIVER
BYRON
1.5 MILE BYRON PLANNING RADIUS
STONE SCHOOL ROAD
TOWNLINE ROAD
TOWN HALL ROAD

Setback Distances From Property Lines

- Proposed 1,300’ setback from adjoining property lines is nearly triple the average distance typically required.

  - By Example: A 425’ blade tip height would typically require a 467’ property line setback (1.1 times max height).
  - Current proposal would exceed setback example by 833 feet.
  - What is the intent of this setback? Is it reasonable and fair?
  - Proposed setback from property lines: 1.1 times tip height

Shadow-Flicker Guideline For Dwellings

Sec. IV, F.1-3 (Page 16). Paragraph 1 allows for up to 30 hours of shadow flicker effect on an adjoining non-participating property owner, while Paragraph 2 mandates the curtailment of any "flicker" effect.

- These two paragraphs conflict and suggest two different standards for working with shadow flicker.
- Very ambiguous language
- We propose: A 45 hour/calendar year measurement of shadow flicker on an adjoining non-participating residence.

Shadow Flicker on Roads and Intersections

Sec IV F, Paragraph 3. (Page 16). "Shadow flicker shall not be allowed to occur on any road or street intersection."

- Measured by human eye or light metering device, this could make it physically impossible to locate a turbine anywhere within the county.
- A sensitive light meter could detect changing shadow levels far below that of any human eye.
- "In summary, the evidence on shadow flicker does not support a health concern." (Chatham-Kent Public Health Unit, 2008)
- We are asking for a standard of reasonableness and fairness
- We suggest removing this requirement due to the lack of scientific evidence that flicker causes safety or health risks

Sound Standard Requirements

The State of Illinois currently has a very restrictive noise standard.

- Comprehensive standard which applies equally to all sound sources without discrimination.
- This rule has proven to be an effective mechanism for regulating sound sources in Illinois for many years.
- The proposed WECS standards are significantly more restrictive than the state limits that apply to all other sound sources in the state.
- We are not asking to exceed state standards or preferential treatment, we are only asking to be held to the same standards of every other person, business or entity in Illinois.
- We propose adopting the State of Illinois sound standard for Ogle County

Low Frequency Sound Standards (Cont.)

IV. L. 5 b,(6) (Page 22 (6)) Proposal states "Low frequency sound can impact neighbors over a longer distance than more tonal sounds and is possibly perceived indoors."

- This statement assumes impact, which is not based on science.

Geoff Leventhall, Ph.D. a world renowned authority on noise, vibration and acoustics, has participated in recent detailed studies entitled "Wind Turbine Sound and Health Effects", December 2009, along with a diverse team of experts, and collectively concluded the following in summary:

- There is no evidence that the audible or sub-audible sounds emitted by wind turbines have any direct adverse physiological effects.
- The ground-borne vibrations from wind turbines are too weak to be detected by, or to affect, humans.
- The sounds emitted by wind turbines are not unique…and there is no reason to believe…the sounds from wind turbines could plausibly have direct adverse health consequences.

Home Seller Protection Program

Section VIII. stipulates that the Owner and/or Operator of the WECS purchase a home if the home has been unsuccessfully marketed for 150 days.

- Studies have shown that WECSs do not have a significant impact on home values
- No home seller protection programs are required for other land use in the county
- There is no requirement in the proposed ordinance to demonstrate that the failure to sell has anything to do with the WECS
- Given current market conditions, the average home takes 6 to 12 months to sell
- We propose removing this section

Decommissioning Plan

Section VI C requires a cash escrow account for decommissioning, site restoration and road repairs

- The cash escrow requirement is too high for upfront cost
- There are many other ways to ensure payment in the event of WECS' failure to decommission
- We propose an engineering study after 10 years of WECS operation to determine decommission cost, and require a surety at that point. The decommissioning plan may be updated every 3 to 5 years to account for pricing changes
- For surety, we propose using a letter of credit, bonds, or other financial surety to allow for new financial vehicles in the next 10 years

Wildlife Study

Section III L2. and III R provide standards on wildlife and bird/bat migration , including requiring the applicant to pay for the County to hire a wildlife expert to review studies and plans.

- The review is not tied to standards in applicable state or federal law. The Applicant is essentially regulated by the personal opinion of the wildlife expert.
- A half-mile setback from “natural resource areas” is much higher than required for other land uses such as mineral and other energy production activities
- There is no scientific evidence supporting the half-mile setback
- There is no mechanism to manage costs of the wildlife expert
- There are existing agencies ensuring wildlife safety: IL DNR already has a review process for wildlife consultation and review, and US Fish & Wildlife Service also monitors any potential harm to threatened or endangered species

Conclusion

- This presentation provides highlights of our concerns
- We appreciate the opportunity to comment on the draft ordinance
- We look forward to working closely with Ogle County on these and other issues

Questions?

Brad Lila, RES Americas

Yang Madsen, Gamesa Energy USA

Wind Turbine Neuro-Acoustical Issues

Dora Anne Mills, MD, MPH Maine CDC/DHHS

June, 2009

1. What protections are in Maine law regarding excessive noise and vibrations?

Maine DEP has rules that apply to all developments in unorganized areas of the state and in all municipalities without a more restrictive noise ordinance. The rules recognize in its text that excessive noise can degrade health and welfare of nearby neighbors, and they provide limits based on the type of development in the area surrounding the noise. For instance, they limit noise levels for routine operation of a proposed development: to 75 dBA at any time; to 60 dBA during the daytime and 50 dBA during the nighttime for non-commercial and non-industrial areas; and to 55 dBA daytime and 45 dBA nighttime for areas in which ambient sounds are 45 dBA or less daytime or 35 dBA or less nighttime.

Maine DEP also has retained the services of a noise expert to review noise study submissions as part of wind turbine applications and compliance evaluations.

DEP's ambient, post development monitoring at the Mars Hill wind farm shows dBA levels higher than 45, sometimes exceeding 60 when there are windy conditions both at ground level and at turbine height. This presents an example of how ambient noise from wind at these locations (which is why turbines are placed there) is in excess of the optimal nighttime 45 dBA. The DEP rules and compliance monitoring provide for distinguishing between the ambient contribution to noise and that from turbines at wind farms.

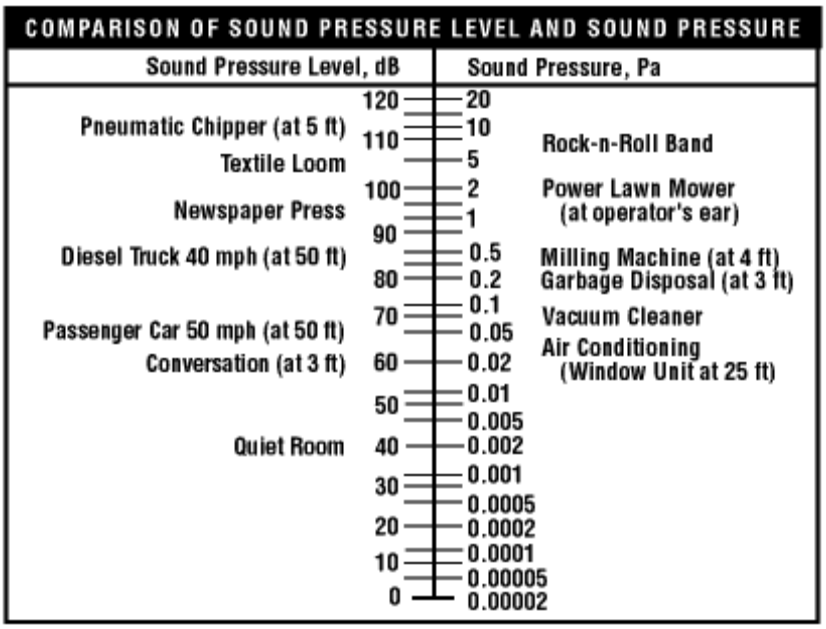
In summary: Maine law appears to essentially place a 45 dBA noise limit on most wind turbine projects in Maine. A 5 dBA variance to limits may be granted upon specific findings that concern pre-development existing ambient noises that are in excess of a particular standard. For compliance with the rule, noise levels are measured at the boundary of the property owned by the proposed developer.

Sources:

- Maine DEP rule-making authority on noise is in Title 38 Section 343
  Rules are in Chapter 375, Section 10:
  http://www.maine.gov/sos/cec/rules/06/096/096c375.doc
- Maine SPO Noise Technical Assistance Bulletin
  http://www.maine.gov/spo/landuse/docs/techassist/techassistbulletins/noisetabulletin.pdf

2. What do different noise levels compare to?

40 dBA is comparable to a quiet room. 55 dBA is comparable to a household room or office in which there is normal background vibration and sounds such as is commonly found from household appliances.



Canadian Centre for Occupational Health and Safety
(see www.ccohs.ca/oshanswers/phys_agents/noise_basic.html).

3. What kinds of noises are expected from wind turbines?

According to several resources, new wind turbines are relatively quiet, and meet federal and international standards and regulations for noise, including Maine's regulations. According to the US Department of Energy, a modern wind farm at a distance of 750 – 1,000' is no louder than a kitchen refrigerator or a moderately quiet room.

However, there are people who live about these distances from wind turbines who disagree with this federal agency statement. It appears from the research that distance from the wind turbine, height of the wind turbine relative to the surrounding topography, the quality of the sound (repetitive low frequency sound), wind conditions, and wind direction all affect how the wind turbine noise affects people. Research done on wind turbines, airport and other sources of noise indicates that annoyance levels are difficult to assess. However, taking in account the above factors as well as careful measurements need to be considered when siting wind turbines near residential properties.

Sources:

- US Dept of Energy's Wind Energy Guide for County Commissioners: http://www.nrel.gov/wind/pdfs/40403.pdf
  Page 6: An operating modern wind farm at a distance of 750'-1,000' is no louder than a kitchen refrigerator or moderately quiet room.
- University of Massachusetts Renewable Research Energy Laboratory: http://www.windpoweringamerica.gov/pdfs/workshops/mwwg_turbine_noise.pdf
  Contains a number of resources on sounds emitted from wind turbines
- Noise levels of small residential wind turbines:

Dept of Energy's Consumer Guide on Small Wind Turbines
http://apps1.eere.energy.gov/consumer/your_home/electricity/index.cfm/mytopic=10930
Comparable sounds to wind turbines

- Wind Turbine Noise Issues: A white paper prepared by Renewable Energy Research Laboratory, U of Massachusetts, 2004:
http://www.town.manchester.vt.us/windforum/aesthetics/WindTurbineNoiseIssues.pdf

4. Are there health effects to the levels of sound heard by wind turbines?
According to a 2003 Swedish EPA review of noise and wind turbines:
"Interference with communication and noise-induced hearing loss is not an issue when studying effects of noise from wind turbines as the exposure levels are too low."

In my review I found no evidence in peer-reviewed medical and public health literature of adverse health effects from the kinds of noise and vibrations heard by wind turbines other than occasional reports of annoyances, and these are mitigated or disappear with proper placement of the turbines from nearby residences. Most studies showing some health effects of noise have been done using thresholds of 70 dBA or higher outdoors, much higher than what is seen in wind turbines.

Sleep disturbance is another commonly raised concern, and the WHO guidelines for community noise recommend that nighttime outdoor noise levels in residential areas not exceed 45 dBA, which is consistent with Maine law.

Sources:

- Noise Annoyance from Wind Turbines – A Review 2003 Sweden Environmental Protection Agency
http://www.barrhill.org.uk/windfarm/noise/10%20pederson.pdf
This study found no evidence of health problems, reviews the variety of noise regulation laws in place in Europe
- British Medical Journal 2007 Swedish Study (Eja Pedersen)
http://oem.bmj.com/cgi/content/full/64/7/480?ijkey=b1a1ae4a98c9453315a90941395e0a05262aca53
Survey in Sweden of residents near wind turbines found annoyance increased with increased sound pressure levels (SPLs), and increased annoyance was associated with lower sleep quality and negative emotions.
- Noise Pollution: Non-Auditory Effects on Health, 2003
http://bmb.oxfordjournals.org/cgi/content/full/68/1/243
- World Health Organization Community and Occupational Noise
http://www.who.int/mediacentre/factsheets/fs258/en/
- World Health Organization 2002 Technical Meeting on Relationship Between Noise and Health
http://www.euro.who.int/document/NOH/exposerespnoise.pdf Page 52 says that WHO standard is for nighttime noise not to exceed 45 dB.

5. What about low frequency noises (LFN)?

Some have pointed to LFN emitted from wind turbines as a possible source of adverse health effects. The reasons LFN are focused on include: LFN encounter less absorption as they travel through air than higher frequency sound, so they persist for a longer distance; the amount of sound transmitted from the outside to the inside of a building is higher with LFN; and some models for assessing impact of noise do not adequately include LFN.

Low frequency and infrasound (lower than what is perceptible) vibrations are very common in our background, and known to be emitted from many household appliances and vehicles as well as in neighborhoods near airports and trains. Exposure to very intense LFN can be annoying and may adversely affect overall health, though these levels appear to be more intense than what is measured from modern wind turbines.

The DEP noise regulations are based on the "A" frequency range of noise, which measures the higher frequency end of the noise spectrum, and is denoted with the term dbA. Because the dbA measurement deemphasizes noises from the lower end of the frequency spectrum (or "C" weighted noise, dbC), Maine DEP has been evaluating noise models and predicted noise levels from proposed wind power facilities using a handicapping system that requires an applicant to prove that dbA noise levels will be at such a level at property boundaries that they are effectively controlling for low frequency noises in the dbC range. The Land Use Regulation Commission has required monitoring for dbC noise at one of its recently permitted wind turbine facilities in order to evaluate dbC noise levels at property boundaries.

One recent study commonly cited by proponents of the belief of the physiological impacts of LFN is: "Tuning and sensitivity of the human vestibular system to low-frequency vibration", Todd, et al. Neuroscience Letters, 2008, which can be found at: http://www.ncbi.nlm.nih.gov/pubmed/18706484. This study indicates that the human vestibular system is sensitive, which means it shows a physiological response, to low-frequency and infrasound vibrations of -70 dB, indicating that human seismic receptor sensitivity of the vestibular system may possibly be on par with the frog ear. However, sensitivity, i.e. showing a physiological response, does not mean there are adverse effects.

Summary:

Reviews found in peer reviewed journals of the possible health effects of low frequency noise have not found evidence of significant health effects (several references are listed below).

Sources:

- Infrasound from Wind Turbines: Fact, Fiction, or Deception? Journal of Canadian Acoustics, Volume 34, no 2, 2006. http://www.wind.appstate.edu/reports/06-06Leventhall-Infras-WT-CanAcoustics2.pdf

"Infrasound from wind turbines is below the audible threshold and of no consequence. Low frequency noise is normally not a problem, except under conditions of unusually turbulent in flow air. The problem noise from wind turbines is the fluctuating swish. This may be mistakenly referred to as infrasound by those with a limited knowledge of acoustics, but it is entirely in the normal audio range and is typically 500Hz to 1000Hz. It is difficult to have a useful discourse with objectors whilst they continue to use acoustical terms incorrectly. This is unfortunate, as there are wind turbine installations which may have noise problems. It is the swish noise on which attention should be focused, in order to reduce it and to obtain a proper estimate of its effects. It will then be the responsibility of legislators to fi x the criterion levels, However, although the needs of sensitive persons may influence decisions, limits are not normally set to satisfy the most sensitive."

- Sources and Effects of Low-Frequency Noise 1996
  http://scitation.aip.org/getabs/servlet/GetabsServlet?prog=normal&id=JASMAN000099000005002985000001&idtype=cvips&gifs=yes
  J. Acoust. Soc. Am. Volume 99, Issue 5, pp. 2985-3002 (May 1996)
- Characteristics of low frequency signals emitted from home electric appliances: http://sciencelinks.jp/j-east/article/200507/000020050705A0229983.php,
- Magnetic Emission Ranking of Electrical Appliances: http://rpd.oxfordjournals.org/cgi/content/abstract/ncm460v1)
- International Meeting on Low Frequency Noise and Vibration and Its Control, the Netherlands, 2004
  http://www.viewsofscotland.org/library/docs/LF_turbine_sound_Van_Den_Berg_Sep04.pdf

6. What are the health benefits to wind turbines?

- There are tremendous potential health benefits to wind turbines, including reductions in deaths, disability, and disease due to asthma, other lung diseases, heart disease, and cancer. Maine has among the highest rates in the country of asthma and cancer.
- Wind turbines mean less dependency on foreign oil and coal that contribute to global warming and pollution (coal produces carbon dioxide, acid rain, smog, particulate pollution, carbon monoxide, and mercury), which in turn contribute to the diseases above.
- According to the Maine DEP, if Maine generated 5% of its electricity from wind power, there would be significant pollution cuts:
  - 464,520 tons per year of CO2
  - 252 tons per year of SO2
  - 147 tons per year of NOx

7.What about a moratorium on wind turbine projects?

- I do not find evidence to support a moratorium on wind turbine projects at this time. The articles cited by those who are in favor of a moratorium are either from non-peer reviewed journals (though some are labeled as "peer reviewed") or are misinterpreted analyses from peer reviewed journals.

- If there is any evidence for a moratorium, it is most likely on further use of fossil fuels, given their known and common effects on the health of our population.

Basic Wind Turbine Noise-Related Resources:

- US Dept of Energy's New England Wind Power Website on Wind Turbine Sound – this has a good summary and links to references
  http://www.windpoweringamerica.gov/ne_issues_sound.asp
- Massachusetts DEP Regulations
  http://www.nonoise.org/lawlib/states/mass/mass.htm
  "A source of sound will be considered to be violating the Department's noise regulation (310 CMR 7.10) if the source: Increases the broadband sound level by more than 10 dB(A) above ambient, or Produces a "pure tone" condition - when any octave band center frequency sound pressure level exceeds the two adjacent center frequency sound pressure levels by 3 decibels or more. These criteria are measured both at the property line and at the nearest inhabited residence. Ambient is defined as the background A-weighted sound level that is exceeded 90% of the time measured during equipment operating hours. The ambient may also be established by other means with the consent of the Department."
- Ongoing Research is being done by the US Dept of Energy Wind Turbine Aeroacoustic Research:
  http://www1.eere.energy.gov/windandhydro/wind_research_enable.html#research
  "Turbine noise can be caused by rotor speed, blade shape, tower shadow, and other factors. The program is sponsoring both wind tunnel and field tests to develop a noise prediction code that turbine manufacturers can use to ensure that new rotor designs and full systems aren't too noisy. This is especially true for high-growth U.S. markets for small wind turbines that will demand quieter rotors, especially when turbines are sited in residential neighborhoods. Small turbines operate at high rotational speeds and tend to spin even if they are furled (pointed out of the wind).
- **Background Information on Noise:**
  http://www.osha.gov/dts/osta/otm/noise/health_effects/physics.html
  http://www.ccohs.ca/oshanswers/phys_agents/noise_basic.html
  http://www.phys.unsw.edu.au/jw/dB.html
  The decibel (**dB**) is used to measure the intensity of sound. It uses a logarithmic scale and describes a ratio where 0 is at the threshold of human hearing. When measuring sound, filters are usually used. The A scale filter results in sound level meters called dBA that are less sensitive to very high or very low frequencies. The C filter provides more of a measurement of low frequency noise.

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Public Service Commission of Wisconsin
RECEIVED: 08/06/10, 9:11:27 AM

Jim Doyle
Governor

Karen E. Timberlake
Secretary

State of Wisconsin
Department of Health Services

July 19, 2010

Edward S. Marion
716 Ottawa Trail
Madison, WI 53711

Dear Mr. Marion:

Thank you for your July 12, 2010, letter to Secretary Karen E. Timberlake regarding the possible health effects of wind turbine noise. Secretary Timberlake has asked me to respond to you on her behalf, and I welcome the opportunity to do so. In your letter of May 13, you asked for confirmation of the Division of Public Health's views regarding the health effects of wind turbine noise. You shared additional information with us, and requested that the Division of Public Health (DPH) conduct a formal epidemiological study of the health effects of wind turbine noise in Wisconsin.

The presentation "Wind Turbines, a Brief Health Overview" by Dr. Jevon McFadden to the Wisconsin Wind Siting Council on May 17, 2010, was not a statement about the position of the Wisconsin Division of Public Health.

DPH recognizes that wind turbines create certain exposures; audible sound, low-frequency sound, infrasound and vibration, and shadow flicker. Certain ranges of intensity or frequency of audible sound, low frequency sound, vibration, and flicker have been associated with some objectively-verifiable human health conditions. Our review of the scientific literature concludes that exposure levels measured from contemporary wind turbines at current setback distances do not reach those associated with objective physical conditions, such as hearing loss, high blood pressure, or flicker-induced epilepsy.

Your letter also cites information that many symptoms are reported by some who live near wind turbines. This information is difficult to interpret for a few reasons.

First, symptoms such as sleep disturbance and headache are common, and caused by a wide variety of conditions. For example, sleep disturbance is a common problem in the general population, and may also be a sign of an underlying medical disorder. The same is true for symptoms like nausea, headache, problems with equilibrium, and others mentioned in your letter. Neither individuals, nor investigators should assume that they originate from exposure to wind turbines. Persistent symptoms, or those that interfere with daily functions, should be evaluated by a medical professional.

Second, as your letter describes, some people experience annoyance at wind turbines, and annoyance has been associated with some of the symptoms you cite. Annoyance is a psychological reaction with a wide range of individual variability, and is influenced by multiple personal and situational factors. Annoyance, per se, is not considered a physical or mental health disorder, but it may influence perception or interpretation of health-related complaints. This makes it more difficult in an observational study to objectively assess whether or not reported symptoms are indicative of actual physical conditions caused by exposures from wind turbines.

DPH staff previously reviewed the five reports you referenced in your letter. They also reviewed over 150 reports from the scientific and medical literature (published and unpublished) pertinent to the issue of wind turbines and health. DPH has also taken time to listen to, and respond to concerns voiced by local residents, municipalities, and local health department officials from across the State of Wisconsin. We have discussed this issue with colleagues at UW School of Medicine and Public Health, the Minnesota and Maine state health departments, and the Centers for Disease Control and Prevention. From this, we conclude that current scientific evidence is not sufficient to support a conclusion that contemporary wind turbines cause adverse health outcomes in those living at distances consistent with current draft rules being considered by the Public Service Commission.

This is different from saying that future evidence about harms may not emerge, or that wind turbines will not change over time, or that annoyance and other quality-of-life considerations are irrelevant. DPH does not endorse a specific setback distance or noise threshold level relating to wind turbines. Nevertheless, in keeping with standard public health practice, DPH favors a conservative approach to setbacks and noise limits that provides more-than-minimum protection to those who live or work near wind turbines. These will help minimize local impacts on quality of life and serve as a buffer against possible unrecognized health effects.

Current draft siting rules limit noise exposures from wind turbines to very low levels, and we anticipate that the final siting rules will be at least equally protective. For this reason, we do not believe there is a compelling reason to perform an epidemiologic investigation in Wisconsin. To the extent that gaps remain in current science, DPH favors continued investigations to help advance knowledge and guide future policy development. The most valuable studies would assess subjective complaints and objective clinical measurements in the setting of controlled or known environmental exposures. Such clinical studies fall outside the scope of standard public health investigations.

As additional scientific evidence becomes available, DPH will continue to appraise its relative strength, credibility, and applicability to the issue of wind turbine development in Wisconsin.

As is the case with any major development undertaking in the State of Wisconsin, it is important that we continue to look for ways to maximize positive impacts and minimize negative impacts to residents. To the extent that these impacts fall into the public health realm, DPH will continue to seek data and information to guide public policy on this matter.

Sincerely,

Seth Foldy, MD, MPH, FAAFP
State Health Officer and Administrator
Wisconsin Department of Health Services
Division of Public Health

Australian Government

National Health and Medical Research Council

NHMRC

Wind Turbines and Health

A Rapid Review of the Evidence

July 2010

Wind Turbines and Health – A Rapid Review of the Evidence

The purpose of this paper is to present findings from a rapid review of the evidence from current literature on the issue of wind turbines and potential impacts on human health. In particular the paper seeks to ascertain if the following statement can be supported by the evidence: *There are no direct pathological effects from wind farms and that any potential impact on humans can be minimised by following existing planning guidelines.* This statement is supported by the 2009 expert review commissioned by the American and Canadian Wind Energy Associations (Colby et al. 2009).

Context

In Australia, since the legislation of the *Renewable Energy (Electricity) Act* in 2000, wind power has been gaining prominence as a viable sustainable alternative to more traditional forms of energy production. Studies have found that there is increasing population demand for 'green' energy and that people are willing to pay a premium for renewable energy (Chatham-Kent Public Health Unit, 2008; Pedersen & Persson Waye, 2007). However as with any shift in technology, the emergence of wind farms is not without controversy.

There are two opposing viewpoints regarding wind turbines and their potential effect on human health. It is important to note that these views are frequently presented by groups or people with vested interests. For example, wind energy associations purport that there is no evidence linking wind turbines to human health concerns. Conversely, individuals or groups who oppose the development of wind farms contend that wind turbines can adversely impact the health of individuals living in proximity to wind farms.

Concerns regarding the adverse health impacts of wind turbines focus on the effects of infrasound, noise, electromagnetic interference, shadow flicker and blade glint produced by wind turbines. Does the evidence support these concerns?

Sound and Noise from Wind Turbines

Sound is composed of frequency expressed as hertz (Hz) and pressure expressed as decibels (dB). In terms of frequency sound can be categorised as audible and inaudible. Infrasound is commonly defined as sound which is inaudible to the human ear (below 16 Hz). Despite this commonly used definition, infrasound can be audible (EPHC, 2009). There is often confusion regarding the boundary between infrasound and low frequency noise (Leventhall, 2006). Human sensitivity to sound, especially to low frequency sound, is variable and people will exhibit variable levels of tolerance to different frequencies (Minnesota Department of Health, 2009).

Noise can be defined as any undesirable or unwanted sound. The perception of the noise is also influenced by the attitude of the hearer towards the sound source. This is sometimes called the nocebo effect, which is the opposite of the better known placebo effect. If people have been preconditioned to hold negative opinions about a noise source, they are more likely to be affected by it (AusWEA, 2004).

Wind turbines produce noise that can be classified into the following categories:

1. Mechanical noise which is produced from the motor or gearbox; if functioning correctly, mechanical noise from modern wind turbines should not be an issue.
2. Aerodynamic noise which is produced by wind passing over the blade of the wind turbine (Minnesota Department of Health, 2009).

As well as the general audible range of sound emissions, wind turbines also produce noise that includes a range of Special Audible Characteristics (SACs) such as amplitude modulation, impulsivity, low frequency noise and tonality (EPHC, 2009).

Table 1 compares the noise produced by a ten turbine wind farm compared to noise levels from some selected activities.

Activity	**Sound pressure level (dBA)**[1]
Jet aircraft at 250m	105
Noise in a busy office	60
Car travelling at 64kph at 100m	55
Wind farm (10 turbines) at 350m	**35-45**
Quiet bedroom	35
Background noise in rural area at night	20-40

Table 1: Noise levels compared to ten turbine wind farm (SDC, 2005).

Macintosh and Downie (2006) conclude that based on these figures "noise pollution generated by wind turbines is negligible".

One of the most common assertions regarding potential adverse noise impacts of wind turbines is concerned with low frequency noise and infrasound. It should be noted that infrasound is constantly present in the environment and is caused by various sources such as ambient air turbulence, ventilation units, ocean waves, distant explosions, volcanic eruptions, traffic, aircraft and other machinery (Rogers, Manwell & Wright, 2006). In relation to wind turbines, Leventhall (2006) concludes that there is insignificant infrasound generated by wind turbines and that there is normally little low frequency noise. A survey of all known published results of infrasound from wind turbines found that wind turbines of contemporary design, where rotor blades are in front of the tower, produce very low levels of infrasound (Jakobsen, 2005). Another recent report concludes that wind farm noise does not have significant low-frequency or infrasound components (Ministry of the Environment, 2007). As discussed in further detail below the principal human response to audible infrasound is annoyance (Rogers, 2006).

Effects of Noise from Wind Turbines on Human Health

The health and well-being effects of noise on people can be classified into three broad categories:

[1] The "A" represents a weighting of measured sound to mimic that discernable by the human ear, which does not perceive sound at low and high frequencies to be as loud as mid range frequencies (AusWEA, nd. a).

1. subjective effects including annoyance, nuisance and dissatisfaction;
2. interference with activities such as speech, sleep and learning; and
3. physiological effects such as anxiety, tinnitus or hearing loss (Rogers, Manwell & Wright, 2006).

Several commentators argue that noise from wind turbines only produces effects in the first two categories (Rogers, 2006; Pedersen & Persson Waye, 2007).

Various studies of wind turbine effects on health have concentrated on the self-reported perception of annoyance. There are difficulties with measuring and quantifying subjective effects of noise such as annoyance. According to the World Health Organization (WHO) (1999) annoyance is an adverse health effect, though this is not universally accepted. Kalveram proposes that annoyance is not a direct health effect but an indication that a person's capacity to cope is under threat. The person has to resolve the threat or their coping capacity is undermined, leading to stress related health effects (Kalveram 2000). Some people are very annoyed at quite low levels of noise, whilst other are not annoyed by high levels.

It has been suggested that if people are worried about their health they may become anxious, causing stress related illnesses. These are genuine health effects arising from their worry, which arises from the wind turbine, even though the turbine may not objectively be a risk to health (Chapman 2010). The measurement of health effects attributable to wind turbines is therefore very complex.

One study of wind turbine noise and annoyance found that no adverse health effects other than annoyance could be directly correlated with noise from wind turbines. The authors concluded that reported sleep difficulties, as well as feelings of uneasiness, associated with noise annoyance could be an effect of the exposure to noise, although it could just as well be that respondents with sleeping difficulties more easily appraised the noise as annoying (Pedersen & Persson Waye, 2007).

Many factors can influence the way noise from wind turbines is perceived. The aforementioned study also found that being able to see wind turbines from one's residence increased not just the odds of perceiving the sound, but also the odds of being annoyed, suggesting a multimodal effect of the audible and visual exposure from the same source leading to an enhancement of the negative appraisal of the noise by the visual stimuli (Pedersen & Persson Waye, 2007). Another study of residents living in the vicinity of wind farms in the Netherlands found that annoyance was strongly correlated with a negative attitude toward the visual impact of wind turbines on the landscape. The study also concluded that people who benefit economically from wind turbines were less likely to report noise annoyance, despite exposure to similar sound levels as those people who were not economically benefiting (Pedersen et al, 2009).

In addition to audible noise, concerns have been raised about infrasound from wind farms and health effects. It has been noted that the effects of low frequency infrasound (less than 20Hz) on humans are not well understood (NRC, 2007). However, as discussed above, several authors have suggested that low level frequency noise or infrasound emitted by wind turbines is minimal and of no consequence (Leventhall, 2006; Jakobsen, 2005). Further, numerous reports have concluded that there is no evidence of health effects arising from infrasound or low frequency noise

generated by wind turbines (DTI, 2006; CanWEA, 2009; Chatham-Kent Public Health Unit, 2008; WHO, 2004; EPHC, 2009; HGC Engineering, 2007). In summary:

- ‘There is no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects’ (Berglund & Lindvall 1995).

- Infrasound associated with modern wind turbines is not a source which will result in noise levels which may be injurious to the health of a wind farm neighbour (DTI, 2006).

- Findings clearly show that there is no peer-reviewed scientific evidence indicating that wind turbines have an adverse impact on human health (CanWEA, 2009).

- Sound from wind turbines does not pose a risk of hearing loss or any other adverse health effects in humans. Subaudible, low frequency sounds and infrasound from wind turbines do not present a risk to human health (Colby, et al 2009).

- The Chatham-Kent Public Health Unit (Ontario, Canada) reviewed the current literature regarding the known health impacts of wind turbines in order to make an evidence-based decision. Their report concluded that current evidence failed to demonstrate a health concern associated with wind turbines. ‘In summary, as long as the Ministry of Environment Guidelines for location criteria of wind farms are followed … there will be negligible adverse health impacts on Chatham-Kent citizens. Although opposition to wind farms on aesthetic grounds is a legitimate point of view, opposition to wind farms on the basis of potential adverse health consequences is not justified by the evidence’ (Chatham-Kent Public Health Unit, 2008).

- Wind energy is associated with fewer health effects than other forms of traditional energy generation and in fact will have positive health benefits (WHO, 2004).

- ‘There are, at present, very few published and scientifically-validated cases of an SACs of wind farm noise emission being problematic … the extent of reliable published material does not, at this stage, warrant inclusion of SACs … into the noise impact assessment planning stage (EPHC, 2009).

- While a great deal of discussion about infrasound in connection with wind turbine generators exists in the media there is no verifiable evidence for infrasound and production by modern turbines (HGC Engineering, 2007).

The opposing view is that noise from wind turbines produces a cluster of symptoms which has been termed Wind Turbine Syndrome (WTS). The main proponent of WTS is a US based paediatrician, Dr Pierpont, who has released a book ‘Wind Turbine Syndrome: A report on a Natural Experiment, presents case studies explaining WTS symptoms in relation to infrasound and low frequency noise. Dr Pierpont’s assertions are yet to be published in a peer-reviewed journal, and have been heavily criticised by

acoustic specialists. Based on current evidence, it can be concluded that wind turbines do not pose a threat to health if planning guidelines are followed.

Shadow Flicker and Blade Glint

Shadow flicker occurs when the sun is located behind a wind turbine casting a shadow that appears to flick on and off as the wind turbine blades rotate (Chatham-Kent Public health Unit, 2008). It is possible to use modelling software to model shadow flicker before the finalisation of a wind farm layout and siting.

Blade glint occurs when the surface of wind turbine blades reflect the sun's light and has the potential to annoy people (EPHC, 2009).

Effects of Shadow Flicker and Blade Glint on Human Health

Shadow flicker from wind turbines that interrupts sunlight at flash frequencies greater than 3Hz has the potential to provoke photosensitive seizures (Harding, Harding & Wilkins, 2008). As such it is recommended that to circumvent potential health effects of shadow flicker wind turbines should only be installed if flicker frequency remains below 2.5 Hz under all conditions (Harding, Harding & Wilkins, 2008).

According to the EPHC (2009) there is negligible risk of seizures being caused by modern wind turbines for the following reasons:

- less than 0.5% of the population are subject to epilepsy at any one time, and of these, approximately 5% are susceptible to strobing light;
- Most commonly (96% of the time), those that are susceptible to strobe lighting are affected by frequencies in excess of 8 Hz and the remainder are affected by frequencies in excess of 2.5 Hz. Conventional horizontal axis wind turbines cause shadow flicker at frequencies of around 1 Hz or less;
- alignment of three or more conventional horizontal axis wind turbines could cause shadow flicker frequencies in excess of 2.5 Hz; however, this would require a particularly unlikely turbine configuration.

In summary, the evidence on shadow flicker does not support a health concern (Chatham-Kent Public Health Unit, 2008) as the chance of conventional horizontal axis wind turbines causing an epileptic seizure for an individual experiencing shadow flicker is less than 1 in 10 million (EPHC, 2009). As with noise, the main impact associated with shadow flicker from wind turbines is annoyance.

In regards to blade glint, manufacturers of all major wind turbine blades coat their blades with a low reflectivity treatment which prevents reflective glint from the surface of the blade. According to the Environment Protection and Heritage Council (EPHC) the risk of blade glint from modern wind turbines is considered to be very low (EPHC, 2009).

Electromagnetic Radiation and Interference

Electromagnetic radiation (EMR) is a wavelike pattern of electric and magnetic energy moving together. Types of EMR include X-rays, ultraviolet, visible light, infrared and radio waves (AusWEA, nd. b).

Electromagnetic interference (EMI) from wind turbines may affect electromagnetic or radiocommunication signals including broadcast radio and television, mobile phones and radar (EPHC, 2009).

As high and exposed sites are best from a wind resource perspective, it is not unusual for any of a range of telecommunications installations, radio and television masts, mobile phone base stations or emergency service radio masts to be located nearby. Care must be taken to ensure that wind turbines do not passively interfere with these facilities by directly obstructing, reflecting or refracting their radio frequency EMR signals.

Effects of Electromagnetic Radiation and Interference from Wind Turbines on Human Health

Electromagnetic Fields (EMF) emanate from any wire carrying electricity and Australians are routinely exposed to these fields in their everyday lives. The electromagnetic fields produced by the generation and export of electricity from a wind farm do not pose a threat to public health (Windrush Energy 2004). The closeness of the electrical cables between wind turbine generators to each other, and shielding with metal armour effectively eliminate any EMF (AusWEA, nd. b).

Measures to Mitigate Potential Impacts of Wind Turbines

As with the introduction of any new technology, some communities are against wind farms being located in their area. Some factors which may increase community concern include coerced or unequal exposure, industrial, exotic and/or memorable nature of the turbine, dreaded, unknown or catastrophic consequences, substantial media attention, potential for collective action and a process which is unresponsive to the community. Voluntary exposure, for example choosing to house the turbine on community land, reduces concern (Adapted by Professor Chapman from Covello et al. methodology 1986).

One review of wind turbines and noise recommends that best practice guidelines such as those identifying potential receptors of turbine noise, following established setbacks and dispelling rumours regarding infrasound which have not been supported by research, are followed in order to mitigate any potential noise issues associated with wind turbines (Howe, 2007).

Sustainable Energy Authority Victoria (2003) also recommend that complying with standards relating to turbine design and manufacturing, site evaluation and final siting of wind turbines will minimise any potential impacts on the surrounding area.

The recently released Draft National Wind Farm Development Guidelines (EPHC, 2009) include detailed methodologies at different stages of the planning and development process to assess such issues as noise and shadow flicker to mitigate any potential impact. Such processes include a range of measures such as high-level risk assessment, data collection, impact assessment, detailed technical studies and public consultation.

Therefore if planning guidelines are followed and communities are consulted with in a meaningful way, resistance to wind farms is likely to be reduced and annoyance and related health effects avoided.

Conclusion

The health effects of many forms of renewable energy generation, such as wind farms, have not been assessed to the same extent as those from traditional sources. However, renewable energy generation is associated with few adverse health effects compared with the well documented health burdens of polluting forms of electricity generation (Markandya & Wilkinson, 2007).

This review of the available evidence, including journal articles, surveys, literature reviews and government reports, supports the statement that: *There are no direct pathological effects from wind farms and that any potential impact on humans can be minimised by following existing planning guidelines.*

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Wind Turbine Sound and Health Effects
An Expert Panel Review

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Acronyms and Abbreviations

μPa	microPascal
ACOEM	American College of Occupational and Environmental Medicine
ANSI	American National Standards Institute
AWEA	American Wind Energy Association
ASHA	American Speech-Language-Hearing Association
CanWEA	Canadian Wind Energy Association
dB	decibel
dBA	decibel (on an A-weighted scale)
DNL	day-night-level
DSM-IV-TR	*Diagnostic and Statistical Manual of Mental Disorders*, Fourth Edition
EPA	U.S. Environmental Protection Agency
FDA	Food and Drug Administration
FFT	Fast Fourier Transform
GI	gastrointestinal
HPA	Health Protection Agency
Hz	Hertz
IARC	International Agency for Research on Cancer
ICD-10	International Statistical Classification of Diseases and Related Health Problems, 10th Revision
IEC	International Engineering Consortium
ISO	International Organization for Standardization
Km	kilometer
kW	kilowatt
L_{eq}	equivalent level
LPALF	large pressure amplitude and low frequency
m/s	meters per second
m/s^2	meters per second squared
NIESH	National Institute of Environmental Health Sciences
NIHL	noise-induced hearing loss
NIOSH	National Institute for Occupational Safety and Health
N/m^2	Newtons per square meter
NRC	National Research Council
NTP	National Toxicology Program
ONAC	Office of Noise Abatement and Control
OSHA	Occupational Safety and Health Administration
Pa	Pascal
UK	United Kingdom
VAD	vibroacoustic disease
VVVD	vibratory vestibular disturbance
VEMP	vestibular evoked myogenic potential response
WHO	World Health Organization

Executive Summary

People have been harnessing the power of the wind for more than 5,000 years. Initially used widely for farm irrigation and millworks, today's modern wind turbines produce electricity in more than 70 countries. As of the end of 2008, there were approximately 120,800 megawatts of wind energy capacity installed around the world (Global Wind Energy Council, 2009).

Wind energy enjoys considerable public support, but it also has its detractors, who have publicized their concerns that the sounds emitted from wind turbines cause adverse health consequences.

In response to those concerns, the American and Canadian Wind Energy Associations (AWEA and CanWEA) established a scientific advisory panel in early 2009 to conduct a review of current literature available on the issue of perceived health effects of wind turbines. This multidisciplinary panel is comprised of medical doctors, audiologists, and acoustical professionals from the United States, Canada, Denmark, and the United Kingdom. The objective of the panel was to provide an authoritative reference document for legislators, regulators, and anyone who wants to make sense of the conflicting information about wind turbine sound.

The panel undertook extensive review, analysis, and discussion of the large body of peer-reviewed literature on sound and health effects in general, and on sound produced by wind turbines. Each panel member contributed a unique expertise in audiology, acoustics, otolaryngology, occupational/ environmental medicine, or public health. With a diversity of perspectives represented, the panel assessed the plausible biological effects of exposure to wind turbine sound.

Following review, analysis, and discussion of current knowledge, the panel reached consensus on the following conclusions:

- There is no evidence that the audible or sub-audible sounds emitted by wind turbines have any direct adverse physiological effects.
- The ground-borne vibrations from wind turbines are too weak to be detected by, or to affect, humans.
- The sounds emitted by wind turbines are not unique. There is no reason to believe, based on the levels and frequencies of the sounds and the panel's experience with sound exposures in occupational settings, that the sounds from wind turbines could plausibly have direct adverse health consequences.

SECTION 1

Introduction

The mission of the American Wind Energy Association (AWEA) is to promote the growth of wind power through advocacy, communication, and education. Similarly, the mission of the Canadian Wind Energy Association (CanWEA) is to promote the responsible and sustainable growth of wind power in Canada. Both organizations wish to take a proactive role in ensuring that wind energy projects are good neighbors to the communities that have embraced wind energy.

Together AWEA and CanWEA proposed to a number of independent groups that they examine the scientific validity of recent reports on the adverse health effects of wind turbine proximity. Such reports have raised public concern about wind turbine exposure. In the absence of declared commitment to such an effort from independent groups, the wind industry decided to be proactive and address the issue itself. In 2009, AWEA and CanWEA commissioned this report. They asked the authors to examine published scientific literature on possible adverse health effects resulting from exposure to wind turbines.

The objective of this report is to address health concerns associated with sounds from industrial-scale wind turbines. Inevitably, a report funded by an industry association will be subject to charges of bias and conflicts of interest. AWEA and CanWEA have minimized bias and conflicts of interest to the greatest possible extent through selection of a distinguished panel of independent experts in acoustics, audiology, medicine, and public health. This report is the result of their efforts.

1.1 Expert Panelists

The experts listed below were asked to investigate and analyze existing literature and publish their findings in this report; their current positions and/or qualifications for inclusion are also provided.

- W. David Colby, M.D.**:** Chatham-Kent Medical Officer of Health (Acting); Associate Professor, Schulich School of Medicine & Dentistry, University of Western Ontario
- Robert Dobie, M.D.**:** Clinical Professor, University of Texas, San Antonio; Clinical Professor, University of California, Davis
- Geoff Leventhall, Ph.D**.:** Consultant in Noise Vibration and Acoustics, UK
- David M. Lipscomb, Ph.D**.:** President, Correct Service, Inc.
- Robert J. McCunney, M.D.**:** Research Scientist, Massachusetts Institute of Technology Department of Biological Engineering; Staff Physician, Massachusetts General Hospital Pulmonary Division; Harvard Medical School
- Michael T. Seilo, Ph.D**.:** Professor of Audiology, Western Washington University

- Bo Søndergaard, M.Sc. (Physics**):** Senior Consultant, Danish Electronics Light and Acoustics (DELTA)

Mark Bastasch, an acoustical engineer with the consulting firm of CH2M HILL, acted as technical advisor to the panel.

1.2 Report Terminology

Certain terms are used frequently throughout this report. Table 1-1 defines these terms. An understanding of the distinction between "sound" and "noise" may be particularly useful to the reader.

TABLE 1-1
Definitions of Acoustical Terms

Term	Definitions
Sound	Describes wave-like variations in air pressure that occur at frequencies that can stimulate receptors in the inner ear and, if sufficiently powerful, be appreciated at a conscious level.
Noise	Implies the presence of sound but also implies a response to sound: noise is often defined as unwanted sound.
Ambient noise level	The composite of noise from all sources near and far. The normal or existing level of environmental noise at a given location.
Decibel (dB)	A unit describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the measured pressure to the reference pressure, which is 20 micropascals (µPa).
A-weighted sound pressure level (dBA)	The sound pressure level in decibels as measured on a sound level meter using the A-weighted filter network. The A-weighted filter de-emphasizes the very low and very high frequency components of the sound in a manner similar to the frequency response of the human ear and correlates well with subjective reactions to noise.
Hertz (Hz)	A unit of measurement of frequency; the number of cycles per second of a periodic waveform.
Infrasound	According to the International Electrotechnical Commission's (IEC's) IEC 1994, infrasound is: Acoustic oscillations whose frequency is below the low-frequency limit of audible sound (about 16 Hz). However this definition is incomplete as infrasound at high enough levels is audible at frequencies below 16 Hz. (IEC (1994): 60050-801:1994 International Electrotechnical Vocabulary - Chapter 801: Acoustics and electroacoustics).
Low-frequency sound	Sound in the frequency range that overlaps the higher infrasound frequencies and the lower audible frequencies, and is typically considered as 10 Hz to 200 Hz, but is not closely defined.

Source: HPA, 2009.

SECTION 2

Methodology

Three steps form the basis for this report: formation of an expert panel, review of literature directly related to wind turbines, and review of potential environmental exposures.

2.1 Formation of Expert Panel

The American and Canadian wind energy associations, AWEA and CanWEA, assembled a distinguished panel of independent experts to address concerns that the sounds emitted from wind turbines cause adverse health consequences.

The objective of the panel was to provide an authoritative reference document for the use of legislators, regulators, and people simply wanting to make sense of the conflicting information about wind turbine sound.

The panel represented expertise in audiology, acoustics, otolaryngology, occupational/ environmental medicine, and public health. A series of conference calls were held among panel members to discuss literature and key health concerns that have been raised about wind turbines. The calls were followed by the development of a draft that was reviewed by other panel members. Throughout the follow-up period, literature was critically addressed.

2.2 Review of Literature Directly Related to Wind Turbines

The panel conducted a search of Pub Med under the heading "Wind Turbines and Health Effects" to research and address peer-reviewed literature. In addition, the panel conducted a search on "vibroacoustic disease." The reference section identifies the peer and non-peer reviewed sources that were consulted by the panel.

2.3 Review of Potential Environmental Exposures

The panel conducted a review of potential environmental exposures associated with wind turbine operations, with a focus on low frequency sound, infrasound, and vibration.

SECTION 3

Overview and Discussion

This section summarizes the results of the review and analysis conducted by the expert panel and responds to a number of key questions:

- How do wind turbine operations affect human auditory response?
- How do we determine the loudness and frequency of sound and its effects on the human ear?
- How do wind turbines produce sound?
- How is sound measured and tested?
- What is vibration?
- **W**hat type of exposure to wind turbines is more likely to be perceived by humans (low frequency sound, infrasound or vibration)?
- Can sounds in the low frequency range, most notably the infrasonic range, adversely affect human health? Even when such levels are below the average person's ability to hear them?
- How does the human vestibular system respond to sound?
- What are the potential adverse effects and health implications of sound exposure?
- What does scientific literature say about wind turbines, low frequency sound, and infrasound?

3.1 Wind Turbine Operation and Human Auditory Response to Sound

3.1.1 Overview

The normal operation of a wind turbine produces sound and vibration, arousing concern about potential health implications. This section addresses the fundamental principles associated with sound and vibration, sound measurement, and potential adverse health implications. Sound from a wind turbine arises from its mechanical operation and the turning of the blades.

3.1.2 The Human Ear and Sound

The human ear is capable of perceiving a wide range of sounds, from the high-pitched sounds of a bird song to the low-pitched sound of a bass guitar. Sounds are perceived based on their loudness (i.e., volume or sound pressure level) or pitch (i.e., tonal or frequency content). The standard unit of measure for sound pressure levels is the decibel (dB). The standard unit used to describe the tonal or frequency content is the Hertz (Hz), measured in cycles per second)—Appendix A provides more information on the fundamentals of sound. Customarily, the young, non-pathological ear can perceive sounds ranging from 20 Hz to 20,000 Hz. Appendix B provides more information on the human ear.

Frequencies below 20 Hz are commonly called "infrasound," although the boundary between infrasound and low frequency sound is not rigid. Infrasound, at certain frequencies and at high levels, can be audible to some people. Low frequency sound is customarily referred to as that between 10 Hz and 200 Hz, but any definition is arbitrary to some degree. Low frequency sound is the subject of concern to some with respect to potential health implications.

TABLE 3-1
TYPICAL SOUND PRESSURE LEVELS MEASURED IN THE ENVIRONMENT AND INDUSTRY

Noise Source At a Given Distance	A-Weighted Sound Level in Decibels	Qualitative Description
Carrier deck jet operation	140	
	130	Pain threshold
Jet takeoff (200 feet)	120	
Auto horn (3 feet)	110	Maximum vocal effort
Jet takeoff (1000 feet) Shout (0.5 feet)	100	
N.Y. subway station Heavy truck (50 feet)	90	Very annoying Hearing damage (8-hour, continuous exposure)
Pneumatic drill (50 feet)	80	Annoying
Freight train (50 feet) Freeway traffic (50 feet)	70 to 80	
	70	Intrusive (Telephone use difficult)
Air conditioning unit (20 feet)	60	
Light auto traffic (50 feet)	50	Quiet
Living room Bedroom	40	
Library Soft whisper (5 feet)	30	Very quiet
Broadcasting/Recording studio	20	
	10	Just audible

Adapted from Table E, "Assessing and Mitigating Noise Impacts", NY DEC, February 2001.

Table 3-1 shows sound pressure levels associated with common activities. Typically, environmental and occupational sound pressure levels are measured in decibels on an A-weighted scale (dBA). The A-weighted scale de-emphasizes the very low and very high frequency components of the sound in a manner similar to the frequency response of the human ear. For comparison, the sound from a wind turbine at distances between 1,000 and 2,000 feet is generally within 40 to 50 dBA.

Section 3.2 discusses the effects of exposure to wind turbine sound. Section 3.3 describes the potential adverse effects of sound exposure as well as the health implications.

3.1.3 Sound Produced by Wind Turbines

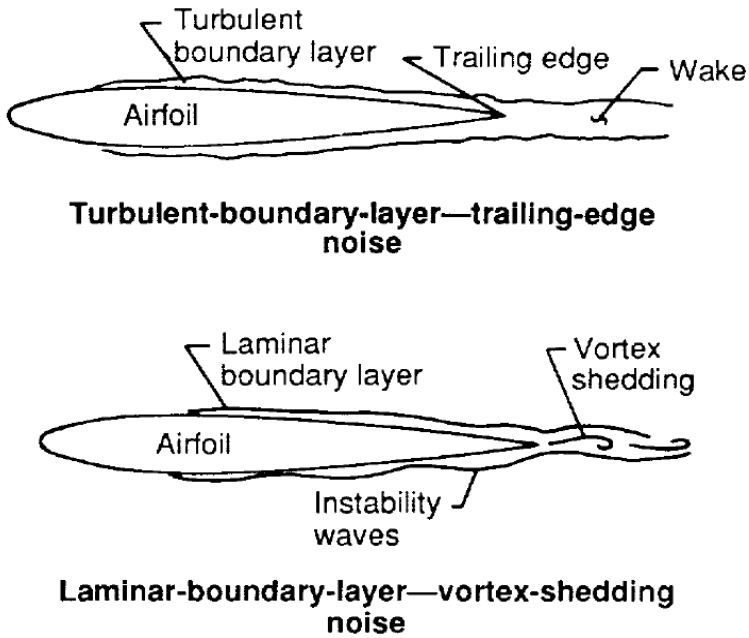
Wind turbine sound originates from either a mechanical or aerodynamic generation mechanism. Mechanical sound originates from the gearbox and control mechanisms. Standard noise control techniques typically are used to reduce mechanical sound. Mechanical noise is not typically the dominant source of noise from modern wind turbines (except for an occasional gear tone).

The aerodynamic noise is present at all frequencies, from the infrasound range over low frequency sound to the normal audible range and is the dominant source. The aerodynamic noise is generated by several mechanisms as is described below. The aerodynamic noise tends to be modulated in the mid frequency range, approximately 500 to 1,000 Hz.

Aerodynamic sound is produced by the rotation of the turbine blades through the air. A turbine blade shape is that of an airfoil. An airfoil is simply a structure with a shape that produces a lift force when air passes over it. Originally developed for aircraft, airfoil shapes have been adapted to provide the turning force for wind turbines by employing a shape which causes the air to travel more rapidly over the top of the airfoil than below it. The designs optimize efficiency by minimizing turbulence, which produces drag and noise. An aerodynamically efficient blade is a quiet one.

The aerodynamic sound from wind turbines is caused by the interaction of the turbine blade with the turbulence produced both adjacent to it (turbulent boundary layer) and in its near wake (see Figure 3-1) (Brooks et al., 1989). Turbulence depends on how fast the blade is moving through the air. A 100-meter-diameter blade, rotating once every three seconds, has a tip velocity of just over 100 meters per second. However, the speed reduces at positions closer to the centre of rotation (the wind turbine hub). The main determinants of the turbulence are the speed of the blade and the shape and dimensions of its cross-section.

FIGURE 3-1
Sound Produced by Wind Turbine Flow



The following conclusions have been derived from the flow conditions shown in Figure 3-1 (Brooks et al., 1989):

- At high velocities for a given blade, turbulent boundary layers develop over much of the airfoil. Sound is produced when the turbulent boundary layer passes over the trailing edge.
- At lower velocities, mainly laminar boundary layers develop, leading to vortex shedding at the trailing edge.

Other factors in the production of aerodynamic sound include the following:

- When the angle of attack is not zero—in other words, the blade is tilted into the wind—flow separation can occur on the suction side near to the trailing edge, producing sound.
- At high angles of attack, large-scale separation may occur in a stall condition, leading to radiation of low frequency sound.
- A blunt trailing edge leads to vortex shedding and additional sound.
- The tip vortex contains highly turbulent flow.

Each of the above factors may contribute to wind turbine sound production. Measurements of the location of the sound source in wind turbines indicate that the dominant sound is produced along the blade—nearer to the tip end than to the hub. Reduction of turbulence sound can be facilitated through airfoil shape and by good maintenance. For example, surface irregularities resulting from damage or to accretion of additional material, may increase the sound.

Aerodynamic sound has been shown to be generated at higher levels during the downward motion of the blade (i.e., the three o'clock position). This results in a rise in level of approximately once per second for a typical three-bladed turbine. This periodic rise in level is also referred to as amplitude modulation, and as described above for a typical wind turbine, the modulation frequency is 1 Hz (once per second). In other words, the sound level rises and falls about once per second. The origin of this amplitude modulation is not fully understood. It was previously assumed that the modulation was caused when the blade went past the tower (given the tower disturbed the airflow), but it is now thought to be related to the difference in wind speed between the top and bottom of the rotation of a blade and directivity of the aerodynamic noise (Oerlemans and Schepers, 2009).

In other words, the result of aerodynamic modulation is a perceivable fluctuation in the sound level of approximately once per second. The frequency content of this fluctuating sound is typically between 500 Hz and 1,000 Hz, but can occur at higher and lower frequencies. That is, the sound pressure levels between approximately 500 and 1,000 Hz will rise and fall approximately once per second. It should be noted, however, that the magnitude of the amplitude modulation that is observed when standing beneath a tower does not always occur at greater separation distances. A study in the United Kingdom (UK) also showed that only four out of about 130 wind farms had a problem with aerodynamic modulation and three of these have been solved (Moorhouse et al., 2007).

In addition to the sound levels generated by the turbines, environmental factors affect the levels received at more distant locations. For example, warm air near the ground causes the turbine sound to curve upwards, away from the ground, which results in reduced sound levels, while warm air in a temperature inversion may cause the sound to curve down to the earth resulting in increased sound levels. Wind may also cause the sound level to be greater downwind of the turbine—that is, if the wind is blowing from the source towards a receiver—or lower, if the wind is blowing from the receiver to the source. Most modeling techniques, when properly implemented, account for moderate inversions and downwind conditions. Attenuation (reduction) of sound can also be influenced by barriers, ground surface conditions, shrubbery and trees, among other things.

Predictions of the sound level at varying distances from the turbine are based on turbine sound power levels. These turbine sound power levels are determined through standardized measurement methods.

3.1.4 Sound Measurement and Audiometric Testing

A sound level meter is a standard tool used in the measurement of sound pressure levels. As described in Section 3.1.2, the standard unit of sound pressure level (i.e., volume) is dB and the standard unit used to describe the pitch or frequency is Hz (cycles per second). A sound level meter may use the A-weighting filter to adjust certain frequency ranges (those that humans detect poorly), resulting in a reading in dBA (decibels, A-weighted). Appendix C provides more information on the measurement of sound. The pitch or frequencies (sometimes referred to as sound level spectrum) can be quantified using a sound level meter that includes a frequency analyzer. Octave band, one-third octave band, and narrow band (such as Fast Fourier Transform, or FFT) are three common types of frequency analyzers.

Consider, for example, a routine audiometric test (hearing test) in which a person sits in a booth and wears headphones, through which sounds are transmitted to evaluate hearing. Outside the booth, a technician turns a dial which yields certain frequencies (for example, 125 Hz, a low-pitched sound, or 4,000 Hz, a high-pitched sound) and then the technician raises the volume of each frequency until the person recognizes the sound of each tone. This is a standard approach used to measure thresholds for many reasons, including noise-induced hearing loss (NIHL). As the technician raises the volume of the designated frequency, the sound level (in dB) is noted. People who need more than 25 dB at more than one frequency to hear the sound (ie loudness of the tone) are considered to have an abnormal test.

The effects of prolonged, high-level sound exposure on hearing have been determined through audiometric tests of workers in certain occupations. The studies have been published in major medical journals and subjected to the peer review process (see, for example, McCunney and Meyer, 2007). Studies of workers have also served as the scientific basis for regulations on noise in industry that are overseen by the Occupational Safety and Health Administration (OSHA). Workers in noise-intensive industries have been evaluated for NIHL and certain industries are known to be associated with high noise levels, such as aviation, construction, and areas of manufacturing such as canning. Multiyear worker studies suggest that prolonged exposure to high noise levels can adversely affect hearing. The levels considered sufficiently high to cause hearing loss are considerably higher than one could experience in the vicinity of wind turbines. For example, prolonged, unprotected high exposure to noise at levels greater than 90 dBA is a risk for hearing loss in occupational settings such that OSHA established this level for hearing protection. Sound levels from wind turbines do not approach these levels (50 dBA at a distance of 1,500 feet would be a conservative estimate for today's turbines). Although the issue of NIHL has rarely been raised in opposition to wind farms, it is important to note that the risk of NIHL is directly dependent on the intensity (sound level) and duration of noise exposure and therefore it is reasonable to conclude that there is no risk of NIHL from wind turbine sound. Such a conclusion is based on studies of workers exposed to noise and among whom risk of NIHL is not apparent at levels less than 75 dBA.

3.2 Sound Exposure from Wind Turbine Operation

This section addresses the questions of (1) whether sounds in the low frequency range, most notably the infrasonic range, adversely affect human health, and whether they do so even when such levels are below the average person's ability to hear them; (2) what we are referring to when we talk about vibration; and (3) how the human vestibular system responds to sound and disturbance.

3.2.1 Infrasound and Low-Frequency Sound

Infrasound and low frequency sound are addressed in some detail to offer perspective on publicized hypotheses that sound from a wind turbine may damage health even if the noise levels are below those associated with noise-induced hearing loss in industry. For example, it has been proposed that sounds that contain low frequency noise, most notably within the infrasonic level, can adversely affect health even when the levels are below the average person's ability to detect or hear them (Alves-Pereira and Branco, 2007b).

Comprehensive reviews of infrasound and its sources and measurement have been published (Berglund and Lindvall, 1995; Leventhall et al., 2003). Table 3-2 shows the sound pressure level, in decibels, of the corresponding frequency of infrasound and low frequency sound necessary for the sound to be heard by the average person (Leventhall et al., 2003).

TABLE 3-2
Hearing Thresholds in the Infrasonic and Low Frequency Range

Frequency (Hz)	4	8	10	16	20	25	40	50	80	100	125	160	200
Sound pressure level (dB)	107	100	97	88	79	69	51	44	32	27	22	18	14

NOTE:
Average hearing thresholds (for young healthy people) in the infrasound (4 to 20 Hz) and low frequency region (10 to 200 Hz).

Source: Leventhall et al., 2003

As Table 3-2 indicates, at low frequencies, a much higher level sound is necessary for a sound to be heard in comparison to higher frequencies. For example, at 10 Hz, the sound must be at 97 dB to be audible. If this level occurred at the mid to high frequencies, which the ear detects effectively, it would be roughly equivalent to standing without hearing protection directly next to a power saw. Decibel for decibel, the low frequencies are much more difficult to detect than the high frequencies, as shown in the hearing threshold levels of Table 3-2.

Table 3-2 also shows that even sounds as low as 4 Hz can be heard if the levels are high enough (107 dB). However, levels from wind turbines at 4 Hz are more likely to be around 70 dB or lower, and therefore inaudible. Studies conducted to assess wind turbine noise have shown that wind turbine sound at typical distances does not exceed the hearing threshold and will not be audible below about 50 Hz (Hayes 2006b; Kamperman and James, 2008). The hearing threshold level at 50 Hz is 44 dB, as shown in Table 3-2. Recent work on evaluating a large number of noise sources between 10 Hz and 160 Hz suggests that wind turbine noise heard indoors at typical separation distances is modest on the scale of low frequency sound sources (Pedersen, 2008). The low levels of infrasound and low frequency sound from wind turbine operations have been confirmed by others (Jakobsen, 2004; van den Berg, 2004).

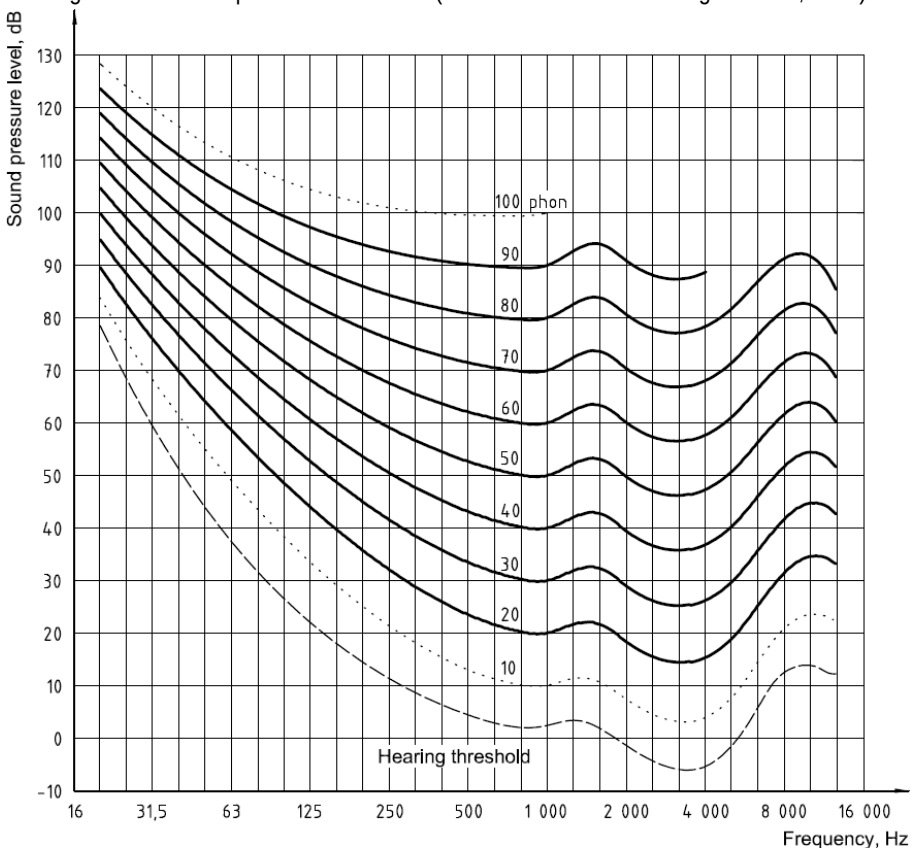
The low frequency sound associated with wind turbines has attracted attention recently since the A-weighting scale that is used for occupational and environmental regulatory compliance does not work well with sounds that have prominently low frequency components. Most environmental low frequency sound problems are caused by discrete tones (pitch or tones that are significantly higher in level (volume) than the neighboring frequencies); from, for example, an engine or compressor, not by continuous broadband sound. The high frequency sounds are assessed by the A-weighted measurement and, given their shorter wavelengths, are controlled more readily. Low frequency sounds may be irritating to some people and, in fact, some low frequency sound complaints prove impossible to resolve (Leventhall et al., 2003). This observation leads to a perception that there is something special, sinister, and harmful about low frequency sound. To the contrary, most external sound when heard indoors is biased towards low frequencies due to the efficient building attenuation of higher frequencies. One may recognize this when noise

from a neighbor's stereo is heard within their home—the bass notes are more pronounced than the higher frequency sounds. Any unwanted sound, whether high frequency or low frequency, can be irritating and stressful to some people.

Differences in how a low frequency sound and high frequency sound are perceived are well documented. Figure 3-2 shows that lower-frequency sounds typically need to be at a high sound pressure level (dB) to be heard. Figure 3-2 also demonstrates that as the frequency lowers, the audible range is compressed leading to a more rapid rise in loudness as the level changes in the lower frequencies. At 1,000 Hz, the whole range covers about 100 dB change in sound pressure level, while at 20 Hz the same range of loudness covers about 50 dB (note the contours displayed in Figure 3-2 are in terms of phons, a measure of equal loudness; for additional explanation on phons, the reader is referred to http://www.sfu.ca/sonic-studio/handbook/Phon.html [Truax, 1999]). As the annoyance of a given sound increases as loudness increases, there is also a more rapid growth of annoyance at low frequencies. However, there is no evidence for direct physiological effects from either infrasound or low frequency sound at the levels generated from wind turbines, indoors or outside. Effects may result from the sounds being audible, but these are similar to the effects from other audible sounds.

Low frequency sound and infrasound are further addressed in Section 3.3, Potential Adverse Effects of Exposure to Sound.

FIGURE 3-2
Hearing Contours for Equal Loudness Level (International Standards Organization, 2003)



3.2.2 Vibration

Vibration, assumed to result from inaudible low frequency sounds, has been postulated to have a potential adverse effect on health. This section defines vibration, describes how it is measured, and cites studies that have addressed the risk of vibration on health.

Vibration refers to the way in which energy travels through solid material, whether steel, concrete in a bridge, the earth, the wall of a house or the human body. Vibration is distinguished from sound, which is energy flowing through gases (like air) or liquids (like water).

As higher frequency vibrations attenuate rapidly, it is low frequencies which are of potential concern to human health. When vibration is detected through the feet or through the seat, the focus of interest is the vibration of the surface with which one is in contact—for example, when travelling in a vehicle.

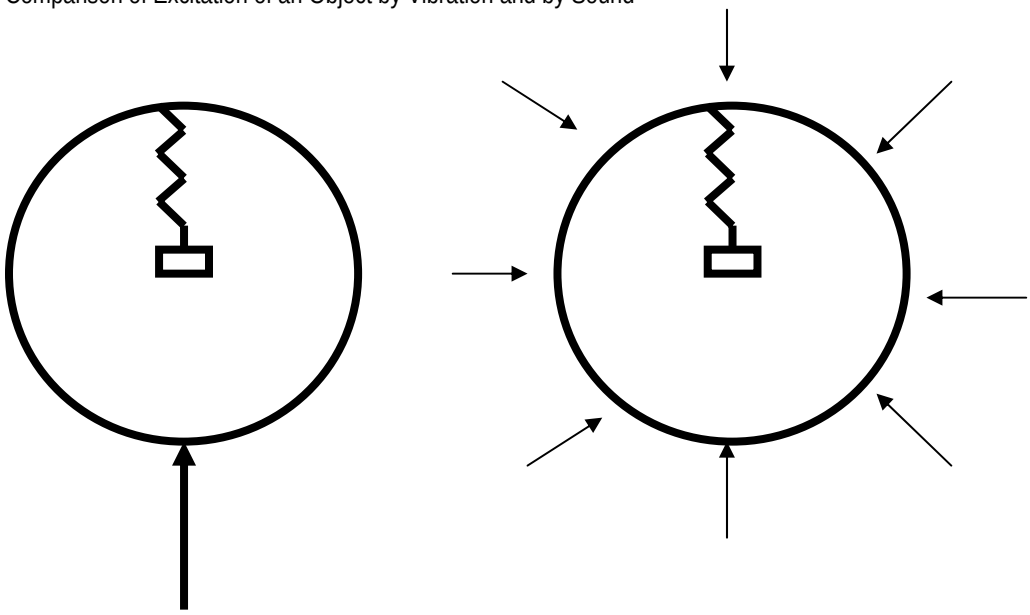
Vibration is often measured by the acceleration of the surface in meters per second, squared (m/s^2), although other related units are used. Vibration can also be expressed in decibels, where the reference excitation level used in buildings is often $10^{-5} m/s^2$ and the vibration level is $20\log (A/10^{-5})$ dB, where A is the acceleration level in m/s^2.

The threshold of perception of vibration by humans is approximately 0.01 m/s^2. If a frequency of excitation (vibration) corresponds with a resonant frequency of a system, then

excitation at the resonant frequency is greater than at other frequencies. However, excitation by sound is not the same as excitation by mechanical excitation applied at, say, the feet.

Figure 3-3 shows an object excited by point mechanical vibration and by sound. The object contains a resiliently suspended system. For example, if the object was the body, the suspended system might be the viscera (internal organs of the body). The left hand of the figure can be interpreted as the body vibrated by input to the feet. The vibration of the viscera will be maximum at the resonant frequency[1] of the suspended system, which, for viscera, is about 4 Hz. When excitation is by long wavelength low frequency sound waves, as shown at the right of the figure, not only is the force acting on the body much smaller than for vibration input, but, as the wavelength is much greater than the dimensions of the body, it is acting around the body in a compressive manner so that there is no resultant force on the suspended system and it does not vibrate or resonate.

FIGURE 3-3
Comparison of Excitation of an Object by Vibration and by Sound



Unfortunately, this lack of effect has not been addressed by those who have suggested the mechanical vibration response of the body instead of the acoustic response as a potential health consequence. This oversight has led to inaccurate conclusions. For example, Dr. Nina Pierpont bases one of her key hypotheses for the cause of "wind turbine syndrome" on such an egregious error (Pierpont, 2009, pre-publication draft). Although not a recognized medical diagnosis, "wind turbine syndrome" has been raised as a concern for proposed projects—refer to Section 4.3 for more information.

Vibration of the body by sound at one of its resonant frequencies occurs only at very high sound levels and is not a factor in the perception of wind turbine noise. As will be discussed

[1] A common example of resonance is pushing a child on a swing in which energy is given to the swing to maximize its oscillation.

below, the sound levels associated with wind turbines do not affect the vestibular or other balance systems.

3.2.3 Vestibular System

The vestibular system of the body plays a major role in maintaining a person's sense of balance and the stabilization of visual images. The vestibular system responds to pressure changes (sound pressure, i.e., decibels) at various frequencies. At high levels of exposure to low frequency sound, nausea and changes in respiration and blood pressure may occur. Studies have shown, however, that for these effects to occur, considerably high noise levels (greater than 140 dB, similar in sound level of a jet aircraft heard 80 feet away) are necessary (Berglund et al., 1996).

Head vibration resulting from low frequency sound has been suggested as a possible cause of a variety of symptoms that some hypothesize as being associated with wind turbines. In order to properly assess this hypothesis, this section addresses the human vestibular system. The "vestibular system" comprises the sense organs in the vestibular labyrinth, in which there are five tiny sensory organs: three semicircular canals that detect head rotation and two chalk-crystal-studded organs called otoliths (literally "ear-stones") that detect tilt and linear motion of the head. All five organs contain hair cells, like those in the cochlea, that convert motion into nerve impulses traveling to the brain in the vestibular nerve.

These organs evolved millions of years before the middle ear. Fish, for example, have no middle ear or cochlea but have a vestibular labyrinth nearly identical to ours (Baloh and Honrubia, 1979). The vestibular organs are specialized for stimulation by head position and movement, not by airborne sound. Each vestibular organ is firmly attached to the skull, to enable them to respond to the slightest head movement. In contrast, the hair cells in the cochlea are not directly attached to the skull; they do not normally respond to head movement, but to movements of the inner ear fluids.

The otolith organs help fish hear low frequency sounds; even in primates, these organs will respond to head vibration (i.e., bone-conducted sound) at frequencies up to 500 Hz (Fernandez and Goldberg, 1976). These vibratory responses of the vestibular system can be elicited by *airborne* sounds, however, only when they are at a much higher level than normal hearing thresholds[2] (and much higher than levels associated with wind turbine exposure). Thus, they do not help us hear but appear to be vestiges of our evolutionary past.

The vestibular nerve sends information about head position and movement to centers in the brain that also receive input from the eyes and from stretch receptors in the neck, trunk, and

[2] Young et al. (1977) found that neurons coming from the vestibular labyrinth of monkeys responded to head vibration at frequencies of 200-400 Hz, and at levels as low as 70 to 80 dB below gravitational force. However, these neurons could not respond to airborne sound at the same frequencies until levels exceeded 76 dB sound pressure level (SPL), which is at least 40 dB higher than the normal threshold of human hearing in this frequency range. Human eye movements respond to 100 Hz head vibration at levels 15 dB below audible levels (Todd et al., 2008a). This does not mean that the vestibular labyrinth is more sensitive than the cochlea to airborne sound, because the impedance-matching function of the middle ear allows the cochlea to respond to sounds that are 50-60 dB less intense than those necessary to cause detectable head vibration. Indeed, the same authors (Todd et al., 2008b) found that for airborne sound, responses from the cochlea could always be elicited by sounds that were below the threshold for vestibular responses. Similarly, Welgampola et al. (2003) found that thresholds for vestibular evoked myogenic potential response (VEMP) were higher than hearing thresholds and stated: "the difference between hearing thresholds and VEMP thresholds is much greater for air conducted sounds than for bone vibration." In other words, the vestigial vestibular response to sound is relatively sensitive to bone conduction, which involves vibration of the whole head, and much less sensitive to air conduction.

legs (these stretch receptors tell which muscles are contracted and which joints are flexed, and provide the "proprioceptive" sense of the body's position and orientation in space). The brain integrates vestibular, visual, and proprioceptive inputs into a comprehensive analysis of the position and movement of the head and body, essential for the sense of balance, avoidance of falls, and keeping the eyes focused on relevant targets, even during movement.

Perception of the body's position in space may also rely in part on input from receptors in abdominal organs (which can shift back and forth as the body tilts) and from pressure receptors in large blood vessels (blood pools in the legs when standing, then shifts back to the trunk when lying down). These "somatic graviceptors" (Mittelstaedt, 1996) could be activated by whole-body movement and possibly by structure-borne vibration, or by the blast of a powerful near explosion, but, as described in Section 4.3.2, it is unlikely that intra-abdominal and intra-thoracic organs and blood vessels could detect airborne sound like that created by wind turbines.

Trauma, toxins, age-related degeneration, and various ear diseases can cause disorders of the vestibular labyrinth. A labyrinth not functioning properly can cause a person to feel unsteady or even to fall. Since the semicircular canals of the ear normally detect head rotation (such as shaking the head to indicate "no"), one of the consequences of a dysfunctional canal is that a person may feel a "spinning" sensation. This reaction is described as vertigo, from the Latin word to turn. In normal conversation, words like vertigo and dizziness can be used in ambiguous ways and thus make careful interpretation of potential health claims problematic. "Dizzy," for example, may mean true vertigo or unsteadiness, both of which may be symptoms of inner ear disease. A person who describes being "dizzy" may actually be experiencing light-headedness, a fainting sensation, blurred vision, disorientation, or almost any other difficult-to-describe sensation in the head. The word "dizziness" can represent different sensations to each person, with a variety of causes. This can make the proper interpretation of research studies in which dizziness is evaluated a challenge to interpret.

Proper diagnostic testing to evaluate dizziness can reduce errors in misclassifying disease. The vestibular labyrinth, for example, can be tested for postural stability. Information from the semicircular canals is fed to the eye muscles to allow us to keep our eyes focused on a target; when the head moves; this "vestibulo-ocular reflex" is easily tested and can be impaired in vestibular disorders (Baloh and Honrubia, 1979).

3.3 Potential Adverse Effects of Exposure to Sound

Adverse effects of sound are directly dependent on the sound level; higher frequency sounds present a greater risk of an adverse effect than lower levels (see Table 3-2). Speech interference, hearing loss, and task interference occur at high sound levels. Softer sounds may be annoying or cause sleep disturbance in some people. At normal separation distances, wind turbines do not produce sound at levels that cause speech interference, but some people may find these sounds to be annoying.

3.3.1 Speech Interference

It is common knowledge that conversation can be difficult in a noisy restaurant; the louder the background noise, the louder we talk and the harder it is to communicate. Average

levels of casual conversation at 1 meter (arm's length) are typically 50 to 60 dBA. People raise their voices—slightly and unconsciously at first—when ambient levels exceed 50 to 55 dBA, in order to keep speech levels slightly above background noise levels. Communication at arm's length requires conscious extra effort when levels exceed about 75 dBA. Above ambient levels of 80 to 85 dBA, people need to shout or get closer to converse (Pearsons et al., 1977; Webster, 1978). Levels below 45 dBA can be considered irrelevant with respect to speech interference.

3.3.2 Noise-Induced Hearing Loss

Very brief and intense sounds (above 130 dBA, such as in explosions) can cause instant cochlear damage and permanent hearing loss, but most occupational NIHL results from prolonged exposure to high noise levels between 90 and 105 dBA (McCunney and Meyer 2007). Regulatory (OSHA, 1983) and advisory (NIOSH, 1998) authorities in the U.S. concur that risk of NIHL begins at about 85 dBA, for an 8-hour day, over a 40-year career. Levels below 75 dBA do not pose a risk of NIHL. Thus, the sound levels associated with wind turbine operations would not cause NIHL because they are not high enough.

3.3.3 Task Interference

Suter (1991) reviewed the effects of noise on performance and behavior. Simple tasks may be unaffected even at levels well above 100 dBA, while more complex tasks can be disrupted by intermittent noise as low as 75 dBA. Speech sounds are usually more disruptive than nonspeech sounds. Levels below 70 dBA do not result in task interference.

3.3.4 Annoyance

Annoyance as a possible "effect" of wind turbine operations is discussed in detail in later sections of this report (Sections 3.4 and 4.1). In summary, annoyance is a subjective response that varies among people to many types of sounds. It is important to note that although annoyance may be a frustrating experience for people, it is not considered an adverse health effect or disease of any kind. Certain everyday sounds, such as a dripping faucet—barely audible—can be annoying. Annoyance cannot be predicted easily with a sound level meter. Noise from airports, road traffic, and other sources (including wind turbines) may annoy some people, and, as described in Section 4.1, the louder the noise, the more people may become annoyed.

3.3.5 Sleep Disturbance

The U.S. Environmental Protection Agency (EPA) document titled *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety* (1974) recommends that indoor day-night-level (DNL) not exceed 45 dBA. DNL is a 24-hour average that gives 10 dB extra weight to sounds occurring between 10p.m. and 7 a.m., on the assumption that during these sleep hours, levels above 35 dBA indoors may be disruptive.

3.3.6 Other Adverse Health Effects of Sound

At extremely high sound levels, such as those associated with explosions, the resulting sound pressure can injure any air-containing organ: not only the middle ear (eardrum

perforations are common) but also the lungs and intestines (Sasser et al., 2006). At the other extreme, any sound that is chronically annoying, including very soft sounds, may, for some people, create chronic stress, which can in turn lead to other health problems. On the other hand, many people become accustomed to regular exposure to noise or other potential stressors, and are no longer annoyed. The hypothesis that chronic noise exposure might lead to chronic health problems such as hypertension and heart disease has been the subject of hundreds of contradictory studies of highly variable quality, which will not be reviewed in this document. Other authors have reviewed this literature, and some of their conclusions are quoted below:

> "It appears not likely that noise in industry can be a direct cause of general health problems…, except that the noise can create conditions of psychological stress…which can in turn cause physiological stress reactions…" (Kryter, 1980)

> "Epidemiological evidence on noise exposure, blood pressure, and ischemic heart disease is still limited." (Babisch, 2004), and "contradictory' (Babisch, 1998), but "there is some evidence…of an increased risk in subjects who live in noisy areas with outdoor noise levels of greater than 65 - 70 dBA." (Babisch, 2000)

> "The present state of the art does not permit any definite conclusion to be drawn about the risk of hypertension." (van Dijk, Ettema, and Zielhuis, 1987)

> "At this point, the relationship between noise induced hearing loss and hypertension must be considered as possible but lacking sufficient evidence to draw causal associations." (McCunney and Meyer, 2007)

3.3.7 Potential Health Effects of Vibration Exposure

People may experience vibration when some part of the body is in direct contact with a vibrating object. One example would be holding a chainsaw or pneumatic hammer in the hands. Another would be sitting in a bus, truck, or on heavy equipment such as a bulldozer. Chronic use of vibrating tools can cause "hand-arm vibration syndrome," a vascular insufficiency condition characterized by numbness and tingling of the fingers, cold intolerance, "white-finger" attacks, and eventually even loss of fingers due to inadequate blood supply. OSHA does not set limits for vibration exposure, but the American National Standards Institute (ANSI) (2006) recommends that 8-hour workday exposures to hand-arm vibration (5 to 1400 Hz, summed over three orthogonal axes of movement) not exceed acceleration values of 2.5 m/s^2.

Excessive whole-body vibration is clearly linked to low back pain (Wilder, Wasserman, and Wasserman, 2002) and may contribute to gastrointestinal and urinary disorders, although these associations are not well established. ANSI (1979) recommends 8-hour limits for whole-body vibration of 0.3 m/s^2, for the body's most sensitive frequency range of 4 to 8 Hz. This is about 30 times more intense than the weakest vibration that people can detect (0.01 m/s^2).

Airborne sound can cause detectable body vibration, but this occurs only at very high levels—usually above sound pressure levels of 100 dB (unweighted) (Smith, 2002; Takahashi et al., 2005; Yamada et al., 1983). There is no scientific evidence to suggest that modern wind turbines cause perceptible vibration in homes or that there is an associated health risk.

3.4 Peer-Reviewed Literature Focusing on Wind Turbines, Low-Frequency Sound, and Infrasound

This section addresses the scientific review of the literature that has evaluated wind turbines, the annoyance effect, low frequency sound, and infrasound.

3.4.1 Evaluation of Annoyance and Dose-Response Relationship of Wind Turbine Sound

To date, three studies in Europe have specifically evaluated potential health effects of people living in proximity to wind turbines (Pedersen and Persson Waye, 2004; Pedersen and Persson Waye, 2007; Pedersen et al., 2009). These studies have been primarily in Sweden and the Netherlands. Customarily, an eligible group of people are selected for possible participation in the study based on their location with respect to a wind turbine. Control groups have not been included in any of these reports.

In an article published in August 2009, investigators reported the results of their evaluation of 725 people in the Netherlands, who lived in the vicinity of wind turbines (Pedersen et al., 2009). The potential study population consisted of approximately 70,000 people living within 2.5 kilometers of a wind turbine at selected sites in the Netherlands. The objective of the study was to (1) assess the relationship between wind turbine sound levels at dwellings and the probability of noise annoyance, taking into account possible moderating factors, and (2) explore the possibility of generalizing a dose response relationship for wind turbine noise by comparing the results of the study with previous studies in Sweden.

Noise impact was quantified based on the relationship between the sound level (dose) and response with the latter measured as the proportion of people annoyed or highly annoyed by sound. Prior to this study, dose response curves had been modeled for wind turbines. Previous studies have noted different degrees of relationships between wind turbine sound levels and annoyance (Wolsink et al., 1993; Pedersen and Persson Waye, 2004; Pedersen and Persson Waye, 2007).

Subjective responses were obtained through a survey. The calculation of the sound levels (dose) in Sweden and the Netherlands were similar. A dose response relationship was observed between calculated A-weighted sound pressure levels and annoyance. Sounds from wind turbines were found to be more annoying than several other environmental sources at comparable sound levels. A strong correlation was also noted between noise annoyance and negative opinion of the impact of wind turbines on the landscape, a finding in earlier studies as well. The dominant quality of the sound was a swishing, the quality previously found to be the most annoying type.

The authors concluded that this study could be used for calculating a dose response curve for wind turbine sound and annoyance. The study results suggest that wind turbine sound is easily perceived and, compared with sound from other sources, is annoying to a small percentage of people (5 percent at 35 to 40 dBA).

In this study, the proportion of people who reported being annoyed by wind turbine noise was similar to merged data from two previous Swedish studies (Pederson and Persson

Waye, 2004; Pedersen and Persson Waye, 2007). About 5 percent of respondents were annoyed at noise levels between 35 to 40 dBA and 18 percent at 40 to 45 dBA.

Pedersen et al. also reported significant dose responses between wind turbine sound and self-reported annoyance (Pedersen and Persson Waye, 2004). High exposed individuals responded more (78 percent) than low exposed individuals (60 percent), which suggests that bias could have played a role in the final results.

An analysis of two cross-sectional socio-acoustic studies—one that addressed flat landscapes in mainly rural settings (Pedersen and Persson Waye, 2004) and another in different terrains (complex or flat) and different levels of urbanization (rural or suburban) (Pedersen and Persson Waye, 2007)—was performed (Pedersen, 2008). Approximately 10 percent of over 1000 people surveyed via a questionnaire reported being very annoyed at sound levels of 40 dB and greater. Attitude toward the visual impact of the wind turbines had the same effect on annoyance. Response to wind turbine noise was significantly related to exposure expressed as A-weighted sound pressure levels dB. Among those who could hear wind turbine sound, annoyance with wind turbine noise was highly correlated to the sound characteristics: swishing, whistling, resounding and pulsating/throbbing (Pedersen, 2008).

A similar study in Sweden evaluated 754 people living near one of seven sites where wind turbine power was greater than 500 kilowatt (kW) (Pedersen and Persson Waye, 2007). Annoyance was correlated with sound level and also with negative attitude toward the visual impact of the wind turbines. Note that none of these studies included a control group. Earlier field studies performed among people living in the vicinity of wind turbines showed a correlation between sound pressure level and noise annoyance; however, annoyance was also influenced by visual factors and attitudes toward the impact of the wind turbines on the landscape. Noise annoyance was noted at lower sound pressure levels than annoyance from traffic noise. Although some people may be affected by annoyance, there is no scientific evidence that noise at levels created by wind turbines could cause health problems (Pedersen and Högskolan, 2003).

3.4.2 Annoyance

A feeling described as "annoyance" can be associated with acoustic factors such as wind turbine noise. There is considerable variability, however, in how people become "annoyed" by environmental factors such as road construction and aviation noise, among others (Leventhall, 2004). Annoyance is clearly a subjective effect that will vary among people and circumstances. In extreme cases, sleep disturbance may occur. Wind speed at the hub height of a wind turbine at night may be up to twice as high as during the day and may lead to annoyance from the amplitude modulated sound of the wind turbine (van den Berg, 2003). However, in a study of 16 sites in 3 European countries, only a weak correlation was noted between sound pressure level and noise annoyance from wind turbines (Pedersen and Högskolan, 2003).

In a detailed comparison of the role of noise sensitivity in response to environmental noise around international airports in Sydney, London, and Amsterdam, it was shown that noise sensitivity increases one's perception of annoyance independently of the level of noise exposure (van Kamp et al., 2004).

In a Swedish study, 84 out of 1,095 people living in the vicinity of a wind turbine in 12 geographical areas reported being fairly or very annoyed by wind turbines (Pedersen, 2008). It is important to note that no differences were reported among people who were "annoyed" in contrast to those who were not annoyed with respect to hearing impairment, diabetes, or cardiovascular disease. An earlier study in Sweden showed that the proportion of people "annoyed" by wind turbine sound is higher than for other sources of environmental noise at the same decibel level (Pedersen and Persson Waye, 2004).

3.4.3 Low-Frequency Sound and Infrasound

No scientific studies have specifically evaluated health effects from exposure to low frequency sound from wind turbines. Natural sources of low frequency sound include wind, rivers, and waterfalls in both audible and non-audible frequencies. Other sources include road traffic, aircraft, and industrial machinery. The most common source of infrasound is vehicular (National Toxicology Program, 2001).

Infrasound at a frequency of 20 Hz (the upper limit of infrasound) is not detectable at levels lower than than 79 dB (Leventhall et al., 2003). Infrasound at 145 dB at 20 Hz and at 165 dB at 2 Hz can stimulate the auditory system and cause severe pain (Leventhall, 2006).These noise levels are substantially higher than any noise generated by wind turbines. The U.S. Food and Drug Administration (FDA) has approved the use of infrasound for therapeutic massage at 70 dB in the 8 to 14 Hz range (National Toxicology Program, 2001). In light of the FDA approval for this type of therapeutic use of infrasound, it is reasonable to conclude that exposure to infrasound in the 70 dB range is safe. According to a report of the National Research Council (NRC), low frequency sound is a concern for older wind turbines but not the modern type (National Research Council, 2007).

SECTION 4

Results

This section discusses the results of the anaylsis presented in Section 3. Potential effects from infrasound, low frequency sound, and the fluctuating aerodynamic "swish" from turbine blades are examined. Proposed hypotheses between wind turbine sound and physiological effects in the form of vibroacoustic disease, "wind turbine syndrome," and visceral vibratory vestibular disturbance are discussed.

4.1 Infrasound, Low-Frequency Sound, and Annoyance

Sound levels from wind turbines pose no risk of hearing loss or any other nonauditory effect. In fact, a recent review concluded that "Occupational noise-induced hearing damage does not occur below levels of 85 dBA." (Ising and Kruppa, 2004) The levels of sound associated with wind turbine operations are considerably lower than industry levels associated with noise induced hearing loss.

However, some people attribute certain health problems to wind turbine exposure. To make sense of these assertions, one must consider not only the sound but the complex factors that may lead to the perception of "annoyance." Most health complaints regarding wind turbines have centered on sound as the cause. There are two types of sounds from wind turbines: mechanical sound, which originates from the gearbox and control mechanisms, and the more dominant aerodynamical sound, which is present at all frequencies from the infrasound range over low frequency sound to the normal audible range.

Infrasound from natural sources (for example, ocean waves and wind) surrounds us and is below the audible threshold. The infrasound emitted from wind turbines is at a level of 50 to 70 dB, sometimes higher, but well below the audible threshold. There is a consensus among acoustic experts that the infrasound from wind turbines is of no consequence to health. One particular problem with many of these assertions about infrasound is that is that the term is often misused when the concerning sound is actually low frequency sound, not infrasound.

Under many conditions, low frequency sound below about 40 Hz cannot be distinguished from environmental background sound from the wind itself. Perceptible (meaning above both the background sound and the hearing threshold), low frequency sound can be produced by wind turbines under conditions of unusually turbulent wind conditions, but the actual sound level depends on the distance of the listener from the turbine, as the sound attenuates (falls off) with distance. The higher the frequency, the greater the sound attenuates with distance—Appendix D provides more information on the propagation of sound. The low frequency sound emitted by spinning wind turbines could possibly be annoying to some when winds are unusually turbulent, but there is no evidence that this level of sound could be harmful to health. If so, city dwelling would be impossible due to the similar levels of ambient sound levels normally present in urban environments. Nevertheless, a small number of people find city sound levels stressful.

It is not usually the low frequency nonfluctuating sound component, however, that provokes complaints about wind turbine sound. The fluctuating aerodynamic sound (swish) in the 500 to 1,000 Hz range occurs from the wind turbine blades disturbing the air, modulated as the blades rotate which changes the sound dispersion characteristics in an audible manner. This fluctuating aerodynamic sound is the cause of most sound complaints regarding wind turbines, as it is harder to become accustomed to fluctuating sound than to sound that does not fluctuate. However, this fluctuation does not always occur and a UK study showed that it had been a problem in only four out of 130 UK wind farms, and had been resolved in three of those (Moorhouse et al., 2007).

4.1.1 Infrasound and Low-Frequency Sound

Infrasound occurs at frequencies less than 20 Hz. At low and inaudible levels, infrasound has been suggested as a cause of "wind turbine syndrome" and vibroacoustic disease (VAD)—refer to Section 4.2.1 for more information on VAD. For infrasound to be heard, high sound levels are necessary (see Section 3, Table 3-2). There is little risk of short term acute exposure to high levels of infrasound. In experiments related to the Apollo space program, subjects were exposed to between 120 and 140 dB without known harmful effects. High level infrasound is less harmful than the same high levels of sound in the normal audible frequency range.

High levels of low frequency sound can excite body vibrations (Leventhall, 2003). Early attention to low frequency sound was directed to the U.S. space program, studies from which suggested that 24-hour exposures to 120 to 130 dB are tolerable below 20 Hz, the upper limit of infrasound. Modern wind turbines produce sound that is assessed as infrasound at typical levels of 50 to 70 dB, below the hearing threshold at those frequencies (Jakobsen, 2004). Jakobsen concluded that infrasound from wind turbines does not present a health concern. Fluctuations of wind turbine sound, most notably the swish-swish sounds, are in the frequency range of 500 to 1,000 Hz, which is neither low frequency sound nor infrasound. The predominant sound from wind turbines, however, is often mischaracterized as infrasound and low frequency sound. Levels of infrasound near modern-scale wind farms are in general not perceptible to people. In the human body, the beat of the heart is at 1 to 2 Hz. Higher-frequency heart sounds measured externally to the body are in the low frequency range (27 to 35 dB at 20 to 40 Hz), although the strongest frequency is that of the heartbeat (Sakai, Feigen, and Luisada, 1971). Lung sounds, measured externally to the body are in the range of 5 to 35 dB at 150 to 600 Hz (Fiz et al., 2008). Schust (2004) has given a comprehensive review of the effects of high level low frequency sound, up to 100 Hz.

4.1.2 Annoyance

Annoyance is a broad topic on which volumes have been written. Annoyance can be caused by constant amplitude and amplitude modulated sounds containing rumble (Bradley, 1994).

As the level of sound rises, an increasing number of those who hear it may become distressed, until eventually nearly everybody is affected, although to different degrees. This is a clear and easily understood process. However, what is not so clearly understood is that when the level of the sound reduces, so that very few people are troubled by it, there remain a small number who may be adversely affected. This occurs at all frequencies, although there seems to be more subjective variability at the lower frequencies. The effect of low

frequency sound on annoyance has recently been reviewed (Leventhall, 2004). The standard deviation of the hearing threshold is approximately 6 dB at low frequencies (Kurakata and Mizunami, 2008), so that about 2.5 percent of the population will have 12 dB more sensitive hearing than the average person. However, hearing sensitivity alone does not appear to be the deciding factor with respect to annoyance. For example, the same type of sound may elicit different reactions among people: one person might say "Yes, I can hear the sound, but it does not bother me," while another may say, "The sound is impossible, it is ruining my life." There is no evidence of harmful effects from the low levels of sound from wind turbines, as experienced by people in their homes. Studies have shown that peoples' attitudes toward wind turbines may affect the level of annoyance that they report (Pedersen et al., 2009).

Some authors emphasize the psychological effects of sounds (Kalveram, 2000; Kalveram et al., 1999). In an evaluation of 25 people exposed to five different wind turbine sounds at 40 dB, ratings of "annoyance" were different among different types of wind turbine noise (Persson Waye and Öhrström, 2002).

None of the psycho-acoustic parameters could explain the difference in annoyance responses. Another study of more than 2,000 people suggested that personality traits play a role in the perception of annoyance to environmental issues such as sound (Persson et al., 2007). Annoyance originates from acoustical signals that are not compatible with, or that disturb, psychological functions, in particular, disturbance of current activities. Kalveram et al. (1999) suggest that the main function of noise annoyance is as a warning that fitness may be affected but that it causes little or no physiological effect. Protracted annoyance, however, may undermine coping and progress to stress related effects. It appears that this is the main mechanism for effects on the health of a small number of people from prolonged exposure to low levels of noise.

The main health effect of noise stress is disturbed sleep, which may lead to other consequences. Work with low frequencies has shown that an audible low frequency sound does not normally become objectionable until it is 10 to 15 dB above hearing threshold (Inukai et al., 2000; Yamada, 1980). An exception is when a listener has developed hostility to the noise source, so that annoyance commences at a lower level.

There is no evidence that sound at the levels from wind turbines as heard in residences will cause direct physiological effects. A small number of sensitive people, however, may be stressed by the sound and suffer sleep disturbances.

4.1.3 Other Aspects of Annoyance

Some people have concluded that they have health problems caused directly by wind turbines. In order to make sense of these complaints, we must consider not only the sound, but the complex factors culminating in annoyance.

There is a large body of medical literature on stress and psychoacoustics. Three factors that may be pertinent to a short discussion of wind turbine annoyance effects are the nocebo effect, sensory integration dysfunction and somatoform disorders.

4.1.4 Nocebo Effect

The nocebo effect is an adverse outcome, a worsening of mental or physical health, based on fear or belief in adverse effects. This is the opposite of the well known placebo effect, where belief in positive effects of an intervention may produce positive results (Spiegel, 1997). Several factors appear to be associated with the nocebo phenomenon: expectations of adverse effects; conditioning from prior experiences; certain psychological characteristics such as anxiety, depression and the tendency to somatize (express psychological factors as physical symptoms; see below), and situational and contextual factors. A large range of reactions include hypervagotonia, manifested by idioventricular heart rhythm (a slow heart rate of 20 to 50 beats per minute resulting from an intrinsic pacemaker within the ventricles which takes over when normal sinoatrial node regulation is lost), drowsiness, nausea, fatigue, insomnia, headache, weakness, dizziness, gastrointestinal (GI) complaints and difficulty concentrating (Sadock and Sadock, 2005, p.2425). This array of symptoms is similar to the so-called "wind turbine syndrome" coined by Pierpont (2009, pre-publication draft). Yet these are all common symptoms in the general population and no evidence has been presented that such symptoms are more common in persons living near wind turbines. Nevertheless, the large volume of media coverage devoted to alleged adverse health effects of wind turbines understandably creates an anticipatory fear in some that they will experience adverse effects from wind turbines. Every person is suggestible to some degree. The resulting stress, fear, and hypervigilance may exacerbate or even create problems which would not otherwise exist. In this way, anti-wind farm activists may be creating with their publicity some of the problems that they describe.

4.1.5 Somatoform Disorders

There are seven somatoform disorders in the Fourth Edition of *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV-TR) (American Psychiatric Association, 2000). Somatoform disorders are physical symptoms which reflect psychological states rather than arising from physical causes. One common somatoform disorder, Conversion Disorder, is the unconscious expression of stress and anxiety as one or more physical symptoms (Escobar and Canino, 1989). Common conversion symptoms are sensations of tingling or discomfort, fatigue, poorly localized abdominal pain, headaches, back or neck pain, weakness, loss of balance, hearing and visual abnormalities. The symptoms are not feigned and must be present for at least six months according to DSM-IV-TR and two years according to the International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10) (WHO, 1993). ICD-10 specifies the symptoms as belonging to four groups: (1) Gastrointestinal (abdominal pain, nausea, bloating/gas/, bad taste in mouth/excessive tongue coating, vomiting/regurgitation, frequent/loose bowel movements); (2) Cardiovascular (breathlessness without exertion, chest pains); (3) Genitourinary (frequency or dysuria, unpleasant genital sensations, vaginal discharge), and (4) Skin and Pain (blotchiness or discoloration of the skin, pain in the limbs, extremities or joints, paresthesias). ICD-10 specifies that at least six symptoms must be present in two or more groups.

One feature of somatoform disorders is *somatosensory amplification*, a process in which a person learns to feel body sensations more acutely and may misinterpret the significance of those sensations by equating them with illness (Barsky, 1979). *Sensory integration dysfunction*

describes abnormal sensitivity to any or all sensory stimuli (sound, touch, light, smell, and taste). There is controversy among researchers and clinicians as to whether sensory integration problems exist as an independent entity or as components of a pervasive developmental disorder (Sadock and Sadock, 2005, p. 3135), but their presence can lead to overestimation of the likelihood of being ill (Sadock and Sadock, 2005, p. 1803). Sensory integration dysfunction as such is not listed in the DSM-IV-TR or in the ICD-10.

Day-to-day stressors and adverse life events provide multiple stimuli to which people respond, and that response is often somatic due to catecholamines and activation of the autonomic nervous system. This stress response can become conditioned as memory. There is some evidence that poor coping mechanisms (anger impulsivity, hostility, isolation, lack of confiding in others) are linked to physiological reactivity, which is associated with somatic sensation and amplification (Sadock and Sadock, 2005, p. 1806).

In summary, the similarities of common human stress responses and conversion symptoms to those described as "wind turbine syndrome" are striking. An annoyance factor to wind turbine sounds undoubtedly exists, to which there is a great deal of individual variability. Stress has multiple causes and is additive. Associated stress from annoyance, exacerbated by the rhetoric, fears, and negative publicity generated by the wind turbine controversy, may contribute to the reported symptoms described by some people living near rural wind turbines.

4.2 Infrasound, Low-frequency Sound and Disease

Some reports have suggested a link between low frequency sound from wind turbines and certain adverse health effects. A careful review of these reports, however, leads a critical reviewer to question the validity of the claims for a number of reasons, most notably (1) the level of sound exposure associated with the putative health effects, (2) the lack of diagnostic specificity associated with the health effects reported, and (3) the lack of a control group in the analysis.

4.2.1 Vibroacoustic Disease

Vibroacoustic disease (VAD) in the context of exposure of aircraft engine technicians to sound was defined by Portuguese researchers as a whole-body, multi-system entity, caused by chronic exposure to large pressure amplitude and low frequency (LPALF) sound (Alves-Pereira and Castelo Branco, 2007a; Alves-Pereira and Castelo Branco, 2007b; Alves-Pereira and Castelo Branco, 2007c; Alves-Pereira and Castelo Branco, 2007d). VAD, the primary feature of which is thickening of cardiovascular structures, such as cardiac muscle and blood vessels, was first noted among airplane technicians, military pilots, and disc jockeys (Maschke, 2004; Castelo Branco, 1999). Workers had been exposed to high levels for more than 10 years. There are no epidemiological studies that have evaluated risk of VAD from exposure to infrasound. The likelihood of such a risk, however, is remote in light of the much lower vibration levels in the body itself. Studies of workers with substantially higher exposure levels have not indicated a risk of VAD. VAD has been described as leading from initial respiratory infections, through pericardial thickening to severe and life-threatening illness such as stroke, myocardial infarction, and risk of malignancy (Alves-Pereira and Castelo Branco, 2007a).

4.2.2 High-Frequency Exposure

All of the exposures of subjects for whom the VAD concept was developed, were dominated by higher frequency sounds, a critical point since the frequency range claimed for VAD-inducing sound is much wider than the frequency range of exposures experienced by the aircraft technicians who were diagnosed with VAD (Castelo Branco, 1999). Originally, proponents of the VAD concept had proposed a "greater than 90 dB" criterion for VAD. However, now some claim that VAD will result from exposure to almost any level of infrasound and low frequency sound at any frequency below 500 Hz. This assertion is an extraordinary extrapolation given that the concept of VAD developed from observations that a technician, working around military aircraft on the ground, with engines operating, displayed disorientation (Castelo Branco, 1999). Sound levels near aircraft were very high. In an evaluation of typical engine spectra of carrier based combat aircraft operating on the ground, the spectra peaked at frequencies above 100 Hz with sound levels from 120 to 135 dB close to the aircraft (Smith, 2002). The levels drop considerably, however, into the low frequency region.

There is an enormous decibel difference between the sound exposure of aircraft technicians and the sound exposure of people who live near wind turbines. Animal experiments indicated that exposure levels necessary to cause VAD were 13 weeks of continuous exposure to approximately 100 dB of low frequency sound (Mendes et al., 2007). The exposure levels were at least 50 to 60 dB higher than wind turbine levels in the same frequency region (Hayes, 2006a).

4.2.3 Residential Exposure: A Case Series

Extrapolation of results from sound levels greater than 90 dB and at predominantly higher frequencies (greater than 100 Hz) to a risk of VAD from inaudible wind turbine sound levels of 40 to 50 dB in the infrasound region, is a new hypothesis. One investigator, for example, has claimed that wind turbines in residential areas produce acoustical environments that can lead to the development of VAD in nearby home-dwellers (Alves-Pereira and Castelo Branco, 2007a).

This claim is based on comparison of only two infrasound exposures. The first is for a family which has experienced a range of health problems and which also complained of disturbances from low frequency sound. The second is for a family which lived near four wind turbines, about which they have become anxious (Alves-Pereira and Castelo Branco, 2007a; Alves-Pereira and Castelo Branco, 2007b).

The first family (Family F), was exposed to low levels of infrasound consisting of about 50 dB at 8 Hz and 10 Hz from a grain terminal about 3 kilometers (km) away and additional sources of low frequency sound, including a nearer railway line and road. The second family (Family R) lives in a rural area and was described as exposed to infrasound levels of about 55 dB to 60 dB at 8 Hz to 16 Hz. These exposures are well below the hearing threshold and not uncommon in urban areas. Neither the frequency nor volume of the sound exposures experienced by Families F or R are unusual. Exposure to infrasound (< 20 Hz) did not exceed 50 dB.

4.2.3.1 Family F—Exposure to Low Levels of Infrasound

Family F has a long history of poor health and a 10-year-old boy was diagnosed with VAD due to exposure to infrasound from the grain terminal (Alves-Pereira and Castelo Branco, 2007a; Castelo Branco et al., 2004). However, the infrasound levels are well below hearing threshold and are typical of urban infrasound, which occurs widely and to which many people are exposed.

According to the authors, the main effect of VAD was demonstrated by the 10-year-old boy in the family, as pericardial thickening.[3] However, the boy has a history of poor health of unknown etiology (Castelo Branco et al., 2004). Castelo Branco (1999) has defined pericardial thickening as an indicator of VAD and assumes that the presence of pericardial thickening in the boy from Family F must be an effect of VAD, caused by exposure to the low-level, low frequency sound from the grain terminal. This assumption excludes other possible causes of pericardial thickening, including viral infection, tuberculosis, irradiation, hemodialysis, neoplasia with pericardial infiltration, bacterial, fungal, or parasitic infections, inflammation after myocardial infarction, asbestosis, and autoimmune diseases. The authors did not exclude these other possible causes of pericardial thickening.

4.2.3.2 Family R—Proximity to Turbines and Anxiety

Family R, living close to the wind turbines, has low frequency sound exposure similar to that of Family F. The family does not have symptoms of VAD, but it was claimed that "Family R. will also develop VAD should they choose to remain in their home." (Alves-Pereira and Castelo Branco, 2007b). In light of the absence of literature of cohort and case control studies, this bold statement seems to be unsubstantiated by available scientific literature.

4.2.4 Critique

It appears that Families F and R were self-selected complainants. Conclusions derived by Alves-Pereira and Castelo Branco (2007b) have been based only on the poor health and the sound exposure of Family F, using this single exposure as a measure of potential harmful effects for others. There has been no attempt at an epidemiological study.

Alves-Pereira and Castelo Branco claim that exposure at home is more significant than exposure at work because of the longer periods of exposure (Alves-Pereira and Castelo Branco, 2007e). Because an approximate 50 dB difference occurs between the exposure from wind turbines and the exposure that induced VAD (Hayes, 2006a), it will take 10^5 years (100,000 years) for the wind turbine dose to equal that of one year of the higher level sound.

Among published scientific literature, this description of the two families is known as a case series, which are of virtually no value in understanding potential ***causal associations*** between exposure to a potential hazard (i.e., low frequency sound) and a potential health effect (i.e., vibroacoustic disease). Case reports have value but primarily in generating hypotheses to test in other studies such as large groups of people or in case control studies. The latter type of study can systematically evaluate people with pericardial thickening who live near wind turbines in comparison to people with pericardial thickening who do not live

[3] Pericardial thickening is unusual thickening of the protective sac (pericardium) which surrounds the heart. For example, see http://www.emedicine.com/radio/topic191.htm.

near wind turbines. Case reports need to be confirmed in larger studies, most notably cohort studies and case-control studies, before definitive cause and effect assertions can be drawn. The reports of the two families do not provide persuasive scientific evidence of a link between wind turbine sound and pericardial thickening.

Wind turbines produce low levels of infrasound and low frequency sound, yet there is no credible scientific evidence that these levels are harmful. If the human body is affected by low, sub-threshold sound levels, a unique and not yet discovered receptor mechanism of extraordinary sensitivity to sound is necessary—a mechanism which can distinguish between the normal, relatively high-level "sound" inherent in the human body[4] and excitation by external, low-level sound. Essential epidemiological studies of the potential effects of exposure at low sound levels at low frequencies have not been conducted. Until the fuzziness is clarified, and a receptor mechanism revealed, no reliance can be placed on the case reports that the low levels of infrasound and low frequency sound are a cause of vibroacoustic disease.[5]

The attribution of dangerous properties to low levels of infrasound continues unproven, as it has been for the past 40 years. No foundation has been demonstrated for the new hypothesis that exposure to sub-threshold, low levels of infrasound will lead to vibroacoustic disease. Indeed, human evolution has occurred in the presence of natural infrasound.

4.3 Wind Turbine Syndrome

"Wind turbine syndrome" as promoted by Pierpont (2009, pre-publication draft) appears to be based on the following two hypotheses:

1. Low levels of airborne infrasound from wind turbines, at 1 to 2 Hz, directly affect the vestibular system.

2. Low levels of airborne infrasound from wind turbines at 4 to 8 Hz enter the lungs via the mouth and then vibrate the diaphragm, which transmits vibration to the viscera, or internal organs of the body.

The combined effect of these infrasound frequencies sends confusing information to the position and motion detectors of the body, which in turn leads to a range of disturbing symptoms.

4.3.1 Evaluation of Infrasound on the Vestibular System

Consider the first hypothesis. The support for this hypothesis is a report apparently misunderstood to mean that the vestibular system is more sensitive than the cochlea to low levels of both sound and vibration (Todd et al., 2008a). The Todd report is concerned with vibration input to the mastoid area of the skull, and the corresponding detection of these vibrations by the cochlea and vestibular system. The lowest frequency used was 100 Hz,

[4] Body sounds are often used for diagnosis. For example see Gross, V., A. Dittmar, T. Penzel, F., Schüttler, and P. von Wichert.. (2000): "The Relationship between Normal Lung Sounds, Age, and Gender. " *American Journal of Respiratory and Critical Care Medicine*. Volume 162, Number 3: 905 - 909.

[5] This statement should not be interpreted as a criticism of the work of the VAD Group with aircraft technicians at high noise levels.

considerably higher than the upper limit of the infrasound frequency (20 Hz). The report does not address air-conducted sound or infrasound, which according to Pierpont excites the vestibular system by airborne sound and by skull vibration. This source does not support Pierpont's hypothesis and does not demonstrate the points that she is trying to make.

There is no credible scientific evidence that low levels of wind turbine sound at 1 to 2 Hz will directly affect the vestibular system. In fact, it is likely that the sound will be lost in the natural infrasonic background sound of the body. The second hypothesis is equally unsupported with appropriate scientific investigations. The body is a noisy system at low frequencies. In addition to the beating heart at a frequency of 1 to 2 Hz, the body emits sounds from blood circulation, bowels, stomach, muscle contraction, and other internal sources. Body sounds can be detected externally to the body by the stethoscope.

4.3.2 Evaluation of Infrasound on Internal organs

It is well known that one source of sound may mask the effect of another similar source. If an external sound is detected within the body in the presence of internally generated sounds, the external sound must produce a greater effect in the body than the internal sounds. The skin is very reflective at higher frequencies, although the reflectivity reduces at lower frequencies (Katz, 2000). Investigations at very low frequencies show a reduction of about 30 dB from external to internal sound in the body of a sheep (Peters et al., 1993). These results suggest an attenuation (reduction) of low frequency sound by the body before the low frequency sound reaches the internal organs.

Low-level sounds from outside the body do not cause a high enough excitation within the body to exceed the internal body sounds. Pierpont refers to papers from Takahashi and colleagues on vibration excitation of the head by high levels of external sound (over 100 dB). However, these papers state that response of the head at frequencies below 20 Hz was not measurable due to the masking effect of internal body vibration (Takahashi et al., 2005; Takahashi et al., 1999). When measuring chest resonant vibration caused by external sounds, the internal vibration masks resonance for external sounds below 80 dB excitation level (Leventhall, 2006). Thus, the second hypothesis also fails.

To recruit subjects for her study, Pierpont sent out a general call for anybody believing their health had been adversely affected by wind turbines. She asked respondents to contact her for a telephone interview. The case series results for ten families (37 subjects) are presented in Pierpont (2009, pre-publication draft). Symptoms included sleep disturbance, headache, tinnitus, ear pressure, vertigo, nausea, visual blurring, tachycardia, irritability, concentration, memory, panic attacks, internal pulsation, and quivering. This type of study is known as a case series. A case series is of limited, if any, value in evaluating causal connections between an environmental exposure (in this case, sound) and a designated health effect (so called "wind turbine syndrome"). This particular case series is substantially limited by selection bias, in which people who already think that they have been affected by wind turbines "self select" to participate in the case series. This approach introduces a significant bias in the results, especially in the absence of a control group who do not live in proximity of a wind turbine. The results of this case series are at best hypothesis-generating activities that do not provide support for a causal link between wind turbine sound and so-called "wind turbine syndrome."

However, these so called "wind turbine syndrome" symptoms are not new and have been published previously in the context of "annoyance" to environmental sounds (Nagai et al., 1989; Møller and Lydolf, 2002; Mirowska and Mroz, 2000). The following symptoms are based on the experience of noise sufferers extending over a number of years: distraction, dizziness, eye strain, fatigue, feeling vibration, headache, insomnia, muscle spasm, nausea, nose bleeds, palpitations, pressure in the ears or head, skin burns, stress, and tension (Leventhall, 2002).

The symptoms are common in cases of extreme and persistent annoyance, leading to stress responses in the affected individual and may also result from severe tinnitus, when there is no external sound. The symptoms are exhibited by a small proportion of sensitive persons and may be alleviated by a course of psychotherapy, aimed at desensitization from the sound (Leventhall et al., 2008). The similarity between the symptoms of noise annoyance and those of "wind turbine syndrome" indicates that this "diagnosis" is not a pathophysiological effect, but is an example of the well-known stress effects of exposure to noise, as displayed by a small proportion of the population. These effects are familiar to environmental noise control officers and other "on the ground" professionals.

"Wind turbine syndrome," not a recognized medical diagnosis, is essentially reflective of symptoms associated with noise annoyance and is an unnecessary and confusing addition to the vocabulary on noise. This syndrome is not a recognized diagnosis in the medical community. There are no unique symptoms or combinations of symptoms that would lead to a specific pattern of this hypothesized disorder. The collective symptoms in some people exposed to wind turbines are more likely associated with annoyance to low sound levels.

4.4 Visceral Vibratory Vestibular Disturbance

4.4.1 Hypothesis

In addition to case reports of symptoms reported by people who live near wind turbines, Pierpont has proposed a hypothesis that purports to explain how some of these symptoms arise: visceral vibratory vestibular disturbance (VVVD) (Pierpont, 2009, pre-publication draft). VVVD has been described as consisting of vibration associated with low frequencies that enters the body and causes a myriad of symptoms. Pierpont considers VVVD to be the most distinctive feature of a nonspecific set of symptoms that she describes as "wind turbine syndrome." As the name VVVD implies, wind turbine sound in the 4 to 8 Hz spectral region is hypothesized to cause vibrations in abdominal viscera (e.g., intestines, liver, and kidneys) that in turn send neural signals to the part of the brain that normally receives information from the vestibular labyrinth. These signals hypothetically conflict with signals from the vestibular labyrinth and other sensory inputs (visual, proprioceptive), leading to unpleasant symptoms, including panic. Unpleasant symptoms (especially nausea) can certainly be caused by sensory conflict; this is how scientists explain motion sickness. However, this hypothesis of VVVD is implausible based on knowledge of sensory systems and the energy needed to stimulate them. Whether implausible or not, there are time-tested scientific methods available to evaluate the legitimacy of any hypothesis and at this stage, VVVD as proposed by Pierpont is an untested hypothesis. A case series of 10 families recruited to participate in a study based on certain symptoms would not be considered evidence of causality by research or policy institutions such as the International Agency for Research on

Cancer (IARC) or EPA. As noted earlier in this report, a case series of self-selected patients does not constitute evidence of a causal connection.

4.4.2 Critique

Receptors capable of sensing vibration are located predominantly in the skin and joints. A clinical neurological examination normally includes assessment of vibration sensitivity. It is highly unlikely, however, that airborne sound at comfortable levels could stimulate these receptors, because most of airborne sound energy is reflected away from the body. Takahashi et al. (2005) used airborne sound to produce chest or abdominal vibration that exceeded ambient body levels. This vibration may or may not have been detectable by the subjects. Takahashi found that levels of 100 dB sound pressure level were required at 20 to 50 Hz (even higher levels would have been required at lower and higher frequencies). Sounds like this would be considered by most people to be very loud, and are well beyond the levels produced by wind turbines at residential distances. Comparison of the responses to low frequency airborne sound by normal hearing and profoundly deaf persons has shown that deaf subjects can detect sound transmitted through their body only when it is well above the normal hearing threshold (Yamada et al., 1983). For example, at 16 Hz, the deaf persons' average threshold was 128 dB sound pressure level, 40 dB higher than that of the hearing subjects. It has also been shown that, at higher frequencies, the body surface is very reflective of sound (Katz, 2000). Similarly, work on transmission of low frequency sound into the bodies of sheep has shown a loss of about 30 dB (Peters et al., 1993)

The visceral receptors invoked as a mechanism for VVVD have been shown to respond to static gravitational position changes, but not to vibration (that is why they are called graviceptors). If there were vibration-sensitive receptors in the abdominal viscera, they would be constantly barraged by low frequency body sounds such as pulsatile blood flow and bowel sounds, while external sounds would be attenuated by both the impedance mismatch and dissipation of energy in the overlying tissues. Finally, wind turbine sound at realistic distances possesses little, if any, acoustic energy, at 4 to 8 Hz.

It has been hypothesized that the vestibular labyrinth may be "abnormally stimulated" by wind turbine sound (Pierpont, 2009, pre-publication draft). As noted in earlier sections of this report, moderately loud airborne sound, at frequencies up to about 500 Hz, can indeed stimulate not only the cochlea (the hearing organ) but also the otolith organs. This is not abnormal, and there is no evidence in the medical literature that it is in any way unpleasant or harmful. In ordinary life, most of us are exposed for hours every day to sounds louder than those experienced at realistic distances from wind turbines, with no adverse effects. This assertion that the vestibular labyrinth is stimulated at levels below hearing threshold is based on a misunderstanding of research that used bone-conducted vibration rather than airborne sound. Indeed, those who wear bone conduction hearing aids experience constant stimulation of their vestibular systems, in addition to the cochlea, without adverse effects.

4.5 Interpreting Studies and Reports

In light of the unproven hypotheses that have been introduced as reflective of adverse health effects attributed to wind turbines, it can be instructive to review the type of research studies that can be used to determine definitive links between exposure to an environmental

hazard (in this case, sound and vibration emissions from wind turbines) and adverse health effects (the so-called "wind turbine syndrome").

How do we know, for example, that cigarettes cause lung cancer and that excessive noise causes hearing loss? Almost always, the first indication that an exposure might be harmful comes from the informal observations of doctors who notice a possible correlation between an exposure and a disease, then communicate their findings to colleagues in case reports, or reports of groups of cases (*case series*). These initial observations are usually uncontrolled; that is, there is no comparison of the people who have both exposure and disease to control groups of people who are either non-exposed or disease-free. There is usually no way to be sure that the apparent association is statistically significant (as opposed to simple coincidence), or that there is a causal relationship between the exposure and the disease in question, without control subjects. For these reasons, case reports and case series cannot prove that an exposure is really harmful, but can only help to develop hypotheses that can then be tested in controlled studies (Levine et al., 1994; Genovese, 2004; McLaughlin, 2003).

Once suspicion of harm has been raised, controlled studies (case-control or cohort) are essential to determine whether or not a causal association is likely, and only after multiple independent-controlled studies show consistent results is the association likely to be broadly accepted (IARC, 2006).

Case-control studies compare people with the disease to people without the disease (ensuring as far as possible that the two groups are well-matched with respect to all other variables that might affect the chance of having the disease, such as age, sex, and other exposures known to cause the disease). If the disease group is found to be much more likely to have had the exposure in question, and if multiple types of error and bias can be excluded (Genovese, 2004), a causal link is likely. Multiple case-control studies were necessary before the link between smoking and lung cancer could be proved.

Cohort studies compare people with the exposure to well-matched control subjects who have not had that exposure. If the exposed group proves to be much more likely to have the disease, assuming error and bias can be excluded, a causal link is likely. After multiple cohort studies, it was clear that excessive noise exposure caused hearing loss (McCunney and Meyer, 2007).

In the case of wind turbine noise and its hypothetical relationships to "wind turbine syndrome" and vibroacoustic disease, the weakest type of evidence—case series—is available, from only a single investigator. These reports can do no more than suggest hypotheses for further research. Nevertheless, if additional and independent investigators begin to report adverse health effects in people exposed to wind turbine noise, in excess of those found in unexposed groups, and if some consistent syndrome or set of symptoms emerges, this advice could change. Thus, at this time, "wind turbine syndrome" and VVVD are unproven hypotheses (essentially unproven ideas) that have not been confirmed by appropriate research studies, most notably cohort and case control studies. However, the weakness of the basic hypotheses makes such studies unlikely to proceed.

4.6 Standards for Siting Wind Turbines

4.6.1 Introduction

While the use of large industrial-scale wind turbines is well established in Europe, the development of comparable wind energy facilities in North America is a more recent occurrence. The growth of wind and other renewable energy sources is expected to continue. Opponents of wind energy development argue that the height and setback regulations established in some jurisdictions are too lenient and that the noise limits which are applied to other sources of noise (either industrial or transportation) are not sufficient for wind turbines for a variety of reasons. Therefore, they are concerned that the health and well-being of some residents who live in the vicinity (or close proximity to) of these facilities is threatened. Critics maintain that wind turbine noise may present more than an annoyance to nearby residents especially at night when ambient levels may be low. Consequently, there are those who advocate for a revision of the existing regulations for noise and setback pertaining to the siting of wind installations (Kamperman and James, 2009). Some have indicated their belief that setbacks of more than 1 mile may be necessary. While the primary purpose of this study was to evaluate the potential for adverse health effects rather than develop public policy, the panel does not find that setbacks of 1 mile are warranted.

4.6.2 Noise Regulations and Ordinances

In 1974, EPA published a report that examined the levels of environmental noise necessary to protect public health and welfare (EPA, 1974). Based on the analysis of available scientific data, EPA specified a range of day-night sound levels necessary to protect the public health and welfare from the effects of environmental noise, with a reasonable margin of safety. Rather than establishing standards or regulations, however, EPA simply identified noise levels below which the general public would not be placed at risk from any of the identified effects of noise. Each federal agency has developed its own noise criteria for sources for which they have jurisdiction (i.e., the Federal Aviation Administration regulates aircraft and airport noise, the Federal Highway Administration regulates highway noise, and the Federal Energy Regulatory Commission regulates interstate pipelines (Bastasch, 2005). State and local governments were provided guidance by EPA on how to develop their own noise regulations, but the establishment of appropriate limits was left to local authorities to determine given each community's differing values and land use priorities (EPA, 1975).

4.6.3 Wind Turbine Siting Guidelines

Establishing appropriate noise limits and setback distances for wind turbines has been a concern of many who are interested in wind energy. There are several approaches to regulating noise, from any source, including wind turbines. They can generally be classified as absolute or relative standards or a combination of absolute and relative standards. Absolute standards establish a fixed limit irrespective of existing noise levels. For wind turbines, a single absolute limit may be established regardless of wind speed (i.e., 50 dBA) or different limits may be established for various wind speeds (i.e., 40 dBA at 5 meters per second [m/s] and 45 dBA at 8 m/s). The Ontario Ministry of Environment (2008) wind turbine noise guidelines is an example of fixed limits for each integer wind speed between 4 and 10 meters per second. Relative standards limit the increase over existing levels and may

also establish either an absolute floor or ceiling beyond which the relative increase is not considered. That is, for example, if a relative increase of 10 dBA with a ceiling of 50 dBA is allowed and the existing level is 45 dBA, a level of 55 dBA would not be allowed. Similarly, if a floor of 40 dBA was established and the existing level is 25 dBA, 40 dBA rather than 35 dBA would be allowed. Fixed distance setbacks have also been discussed. Critics of this approach suggest that fixed setbacks do not take into account the number or size of the turbines nor do they consider other potential sources of noise within the project area. It is clear that like many other sources of noise, a uniform regulator approach for wind turbine noise has not been established either domestically or internationally.

A draft report titled *Environmental Noise and Health in the UK*, published for comment in 2009 by the Health Protection Agency (HPA) on behalf of an ad hoc expert group, provides insightful comments on the World Health Organization's noise guidelines (WHO, 1999). The HPA draft report can be viewed at the following address:

http://www.hpa.org.uk/web/HPAwebFile/HPAweb_C/1246433634856

The HPA report states the following:

It is important to bear in mind that the WHO guideline values, like other WHO guidelines, are offered to policymakers as a contribution to policy development. They are not intended as standards in a formal sense but as a possible basis for the development of standards. By way of overall summary, the 1998 NPL report noted [a British report titled *Health-Based Noise Assessment Methods – A Review and Feasibility Study* (Porter et al., 1998) as quoted in HPA 2009]:

> *The WHO guidelines represent a consensus view of international expert opinion on the lowest noise levels below which the occurrence rates of particular effects can be assumed to be negligible. Exceedances of the WHO guideline values do not necessarily imply significant noise impact and indeed, it may be that significant impacts do not occur until much higher degrees of noise exposure are reached. The guidelines form a starting point for policy development. However, it will clearly be important to consider the costs and benefits of reducing noise levels and, as in other areas, this should inform the setting of objectives.*
> (From: HPA, 2009, p. 77)

The HPA report further states the following:

> *Surveys have shown that about half of the UK population lives in areas where daytime sound levels exceed those recommended in the WHO Community Noise Guidelines. About two-thirds of the population live in areas where the night-time guidelines recommended by WHO are exceeded. (p. 81)*
>
> *That sleep can be affected by noise is common knowledge. Defining a dose-response curve that describes the relationship between exposure to noise and sleep disturbance has, however, proved surprisingly difficult. Laboratory studies and field studies have generated different results. In part this is due to habituation to noise which, in the field, is common in many people. (p. 82)*
>
> *Our examination of the evidence relating to the effects of environmental noise on health has demonstrated that this is a rapidly developing area. Any single report will, therefore, need to be revised within a few years. We conclude and recommend that an*

> *independent expert committee to address these issues on a long-term basis be established. (p. 82)*

The statements cited above from the HPA and WHO documents address general environmental noise concerns rather than concerns focused solely on wind turbine noise.

SECTION 5

Conclusions

Many countries have turned to wind energy as a key strategy to generate power in an environmentally clean manner. Wind energy enjoys considerable public support, but it has its detractors, who have publicized their concerns that the sounds emitted from wind turbines cause adverse health consequences.

The objective of the panel was to develop an authoritative reference document for the use of legislators, regulators, and citizens simply wanting to make sense of the conflicting information about wind turbine sound. To this end, the panel undertook extensive review, analysis, and discussion of the peer-reviewed literature on wind turbine sound and possible health effects. The varied professional backgrounds of panel members (audiology, acoustics, otolaryngology, occupational and environmental medicine, and public health) were highly advantageous in creating a diversity of informed perspectives. Participants were able to examine issues surrounding health effects and discuss plausible biological effects with considerable combined expertise.

Following review, analysis, and discussion, the panel reached agreement on three key points:

- There is nothing unique about the sounds and vibrations emitted by wind turbines.
- The body of accumulated knowledge about sound and health is substantial.
- The body of accumulated knowledge provides no evidence that the audible or subaudible sounds emitted by wind turbines have any direct adverse physiological effects.

The panel appreciated the complexities involved in the varied human reactions to sound, particularly sounds that modulate in intensity or frequency. Most complaints about wind turbine sound relate to the aerodynamic sound component (the swish sound) produced by the turbine blades. The sound levels are similar to the ambient noise levels in urban environments. A small minority of those exposed report annoyance and stress associated with noise perception.

This report summarizes a number of physical and psychological variables that may influence adverse reactions. In particular, the panel considered "wind turbine syndrome" and vibroacoustic disease, which have been claimed as causes of adverse health effects. The evidence indicates that "wind turbine syndrome" is based on misinterpretation of physiologic data and that the features of the so-called syndrome are merely a subset of annoyance reactions. The evidence for vibroacoustic disease (tissue inflammation and fibrosis associated with sound exposure) is extremely dubious at levels of sound associated with wind turbines.

The panel also considered the quality of epidemiologic evidence required to prove harm. In epidemiology, initial case reports and uncontrolled observations of disease associations

need to be confirmed through controlled studies with case-control or cohort methodology before they can be accepted as reflective of casual connections between wind turbine sound and health effects. In the area of wind turbine health effects, no case-control or cohort studies have been conducted as of this date. Accordingly, allegations of adverse health effects from wind turbines are as yet unproven. Panel members agree that the number and uncontrolled nature of existing case reports of adverse health effects alleged to be associated with wind turbines are insufficient to advocate for funding further studies.

In conclusion:

1. Sound from wind turbines does not pose a risk of hearing loss or any other adverse health effect in humans.
2. Subaudible, low frequency sound and infrasound from wind turbines do not present a risk to human health.
3. Some people may be annoyed at the presence of sound from wind turbines. Annoyance is not a pathological entity.
4. A major cause of concern about wind turbine sound is its fluctuating nature. Some may find this sound annoying, a reaction that depends primarily on personal characteristics as opposed to the intensity of the sound level.

SECTION 6

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APPENDIX A
Fundamentals of Sound

APPENDIX A

Fundamentals of Sound

The following appendix provides additional background information on sound and how it is defined.

One atmospheric pressure is given by 100,000 pascals (Pa), where one pascal is one Newton per square meter (N/m^2), and a sound pressure of 94 dB re 20μPa is given by 1 Pa (See later for decibels). The frequency of the fluctuations may be between 20 times a second (20 Hz), and up to 20,000 times a second (20,000 Hz) for the "audible" noise. Frequencies below 20 Hz are commonly called "infrasound," although there is a very fuzzy boundary between infrasound and low frequency noise. Infrasound at high levels is audible. Low frequency noise might be from about 10 Hz to about 200 Hz.

In addition to frequency, the quantities which define a sound wave include:

- Pressure, P
- Wavelength, λ
- Velocity, c = 340m/s approx, depending on temperature

The velocity and wavelength are related by: velocity = wavelength x frequency,

Relating frequency and wavelength by velocity gives

Freq Hz	16	31.5	63	125	250	500	1000	2000	4000
Wavelength m	21	11	5.4	2.7	1.4	0.68	0.34	0.17	0.085

Low frequencies have long wavelengths. It is useful to develop an appreciation of frequencies and related wavelengths, since this helps an understanding of noise propagation and control.

Sound pressure in a wave is force per unit of area of the wave and has units of N/m^2, which is abbreviated to Pa. The sound pressure fluctuates above and below atmospheric pressure by a very small amount.

The sound power is a characteristic of the source, and is its rate of production of energy, expressed in watts. The sound power is the fundamental property of the source, whilst the sound pressure at a measurement location depends on the transmission path from source to receiver. Most sound sources, including wind turbines, are specified in terms of their sound power. The sound power of a wind turbine is typically in the 100-105 dBA range, which is similar to that of a leaf blower. The sound power is used to predict propagation of the sound, where the source is assumed to be at the hub.

Sound Levels

The decibel is the logarithm of the ratio between two values of a quantity such as power, pressure or intensity, with a multiplying constant to give convenient numerical factors. Logarithms are useful for compressing a wide range of quantities into a smaller range. For example:

$\log_{10}10 = 1$
$\log_{10}100 = 2$
$\log_{10}1000 = 3$

The ratio of 1000:10 is compressed into a ratio of 3:1.

This approach is advantageous for handling sound levels, where the ratio of the highest to the lowest sound which we are likely to encounter is as high as 1,000,000 to 1. A useful development, many years ago, was to take the ratios with respect to the quietest sound which we can hear. This is the threshold of hearing at 1,000 Hz, which is 20 microPascals (μPa) ($2x10^{-5}$Pa) of pressure for the average young healthy person. Sound powers in decibels are taken with respect to a reference level of 10^{-12} watts.

When the word "level" is added to the word for a physical quantity, decibel levels are implied, denoted by L_X, where $_X$ is the symbol for the quantity.

$$\text{Pressure level} \quad L_p = 20\log_{10}\left[\frac{P}{P_0}\right] \text{ dB}$$

where P is the measured pressure and P_0 is the reference pressure level of $2x10^{-5}$ Pa

A little calculation allows us to express the sound pressure level at a distance from a source of known sound power level as

Sound pressure level, $L_P = L_w - 20\log[r] - 11$ dB

Where L_p is the sound pressure level
L_w is the sound power level of the source
r is the distance from the source

This is the basic equation for spherical sound propagation. It is used in prediction of wind turbine sound but, in a real calculation, has many additions to it, to take into account the atmospheric, ground and topographic conditions. However, as a simple calculation, the sound level at a distance of 500m from a source of sound power 100 dBA is 35 dBA.

Equivalent level (Leq): This is a steady level over a period of time, which has the same energy as that of the fluctuating level actually occurring during that time. A-weighted equivalent level, designated LAeq, is used for many legislative purposes, including for assessment of wind turbine sound.

Percentiles (LN)L These are a statistical measure of the fluctuations in overall noise level, that is, in the envelope of the noise, which is usually sampled a number of times per second, typically ten times. The most used percentiles are L90 and L10. The L90 is the level exceeded for 90 percent of the time and represents a low level in the noise. It is often used to assess

background noise. The L10 is the level exceeded for 10 percent of the time and is a measure of the higher levels in a noise. Modern computing sound level meters give a range of percentiles. Note that the percentile is a statistical measure over a specified time interval.

Frequency Analysis

This gives more detail of the frequency components of a noise. Frequency analysis normally uses one of three approaches: octave band, one-third octave band or narrow band.

Narrow band analysis is most useful for complex tonal noises. It could be used, for example, to determine a fan tone frequency, to find the frequencies of vibration transmission from machinery or to detect system resonances. All analyses require an averaging over time, so that the detail of fluctuations in the noise is normally lost.

Criteria for assessment of noise are based on dBA, octave bands, or 1/3-octave band measurements. These measures clearly give increasingly detailed information about the noise.

APPENDIX B

The Human Ear

APPENDIX B

The Human Ear

Humans have ears with three general regions:

1. An *outer ear,* including an ear (auditory) canal
2. An air-containing *middle ear* that includes an eardrum and small bones called ossicles (three in mammals, one in other animals)
3. An *inner ear* that includes organs of hearing (in mammals, this is the organ of Corti in the cochlea) and balance (vestibular labyrinth)

Airborne sound passes thorough the ear canal, making the eardrum and ossicles vibrate, and this vibration then sets the fluids of the cochlea into motion. Specialized "hair cells" convert this fluid movement into nerve impulses that travel to the brain along the auditory nerve. The hair cells, nerve cells, and other cells in the cochlea can be damaged by excessive noise, trauma, toxins, ear diseases, and as part of the aging process. Damage to the cochlea causes "sensorineural hearing loss," the most common type of hearing loss in the United States.

It is essential to understand the role of the middle ear, as well as the difference between air conduction and bone conduction. The middle ear performs the essential task of converting airborne sound into inner ear fluid movement, a process known as impedance matching (air is a low-impedance medium, meaning that its molecules move easily in response to sound pressure, while water is a high-impedance medium). Without impedance matching, over 99.9 percent of airborne sound energy is reflected away from the body. The middle ear enables animals living in air to hear very soft sounds that would otherwise be inaudible, but it is unnecessary for animals that live in water, because sound traveling in water passes easily into the body (which is mostly water). When a child has an ear infection, or an adult places earplugs in his ears, a "conductive hearing loss" dramatically reduces the transmission of airborne sound into the inner ear. People with conductive hearing loss can still hear sounds presented directly to the skull by "bone conduction." This is how both humans and fishes hear underwater or when a vibrating tuning fork is applied to the head, but it requires much more acoustic energy than air conduction hearing.

APPENDIX C

Measuring Sound

APPENDIX C

Measuring Sound

A sound level meter is the standard way of measuring sound. Environmental sound is normally assessed by the A-weighting. Although hand-held instruments appear to be easy to use, lack of understanding of their operation and limitations, and the meaning of the varied measurements which they can give, may result in misleading readings.

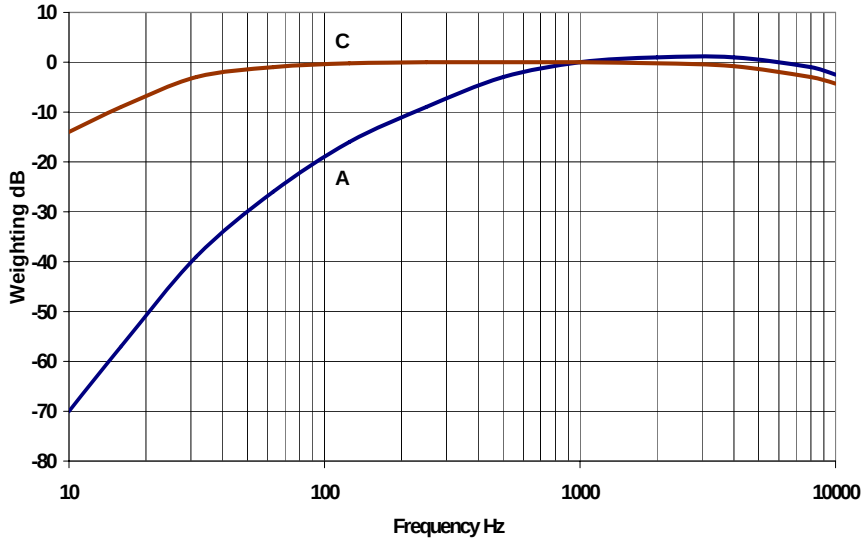
The weighting network and electrical filters are an important part of the sound level meter, as they give an indication of the frequency components of the sound. The filters are as follows:

- A-weighting: on all meters
- C-weighting: on most meters
- Linear (Z-weighting): on many meters
- Octave filters: on some meters
- Third octave filters: on some meters
- Narrow band: on a few meters

Sound level meter weighting networks are shown in Figure C-1. Originally, the A-weighting was intended for low levels of noise. C-weighting was intended for higher levels of noise. The weighting networks were based on human hearing contours at low and high levels and it was hoped that their use would mimic the response of the ear. This concept, which did not work out in practice, has now been abandoned and A- and C-weighting are used at all levels. Linear weighting is used to detect low frequencies. A specialist G-weighting is used for infrasound below 20 Hz.

Figure C-1 shows that the A-weighting depresses the levels of the low frequencies, as the ear is less sensitive to these. There is general consensus that A-weighting is appropriate for estimation of the hazard of NIHL. With respect to other effects, such as annoyance, A-weighting is acceptable if there is largely middle and high frequency noise present, but if the noise is unusually high at low frequencies, or contains prominent low frequency tones, the A-weighting may not give a valid measure. Compared with other noise sources, wind turbine spectra, as heard indoors at typical separation distances, have less low frequency content than most other sources (Pedersen, 2008).

FIGURE C-1
Weighting Networks



APPENDIX D
Propagation of Sound

APPENDIX D

Propagation of Sound

The propagation of noise from wind turbines is determined by a number of factors, including:

- Geometrical spreading, given by K = 20log[r] –11 dB, at a distance r
- Molecular absorption. This is conversion of acoustic energy to heat and is frequency dependent
- Turbulent scattering from local variations in wind velocity and air temperature and is moderately frequency dependent
- Ground effects—reflection, topography and absorption are frequency dependent; their effects increasing as the frequency increases
- Near surface effects—temperature and wind gradients.

The sound pressure at a point, distant from source, is given by

$$L_P = L_W - K - D - A_A - A_G \qquad \text{(dB)}$$

In which:

L_P is the sound pressure at the receiving point

L_W is the sound power of the turbine in decibels re 10^{-12} watts

K is the geometrical spreading term, which is inherent in all sources

D is a directivity index, which takes non-uniform spreading into account

A_A is an atmospheric absorption and other near surface effects term

A_G is a ground absorption and other surface effects term

Near surface meteorological effects are complex, as wind and temperature gradients affect propagation through the air.

APPENDIX E

Expert Panel Members

APPENDIX E

Expert Panel Members

Members of the expert panel are listed below. Biographies of each member are provided following the list.

Expert Panel Members

W. David Colby, M.D.

Chatham-Kent Medical Officer of Health (Acting)
Associate Professor, Schulich School of Medicine & Dentistry, University of Western Ontario

Robert Dobie, M.D.

Clinical Professor, University of Texas, San Antonio
Clinical Professor, University of California, Davis

Geoff Leventhall, Ph.D.

Consultant in Noise Vibration and Acoustics, UK

David M. Lipscomb, Ph.D.

President, Correct Service, Inc.

Robert J. McCunney, M.D.

Research Scientist, Massachusetts Institute of Technology Department of Biological Engineering,
Staff Physician, Massachusetts General Hospital Pulmonary Division; Harvard Medical School

Michael T. Seilo, Ph.D.

Professor of Audiology, Western Washington University

Bo Søndergaard, M.Sc. (Physics)

Senior Consultant, Danish Electronics Light and Acoustics (DELTA)

Technical Advisor

Mark Bastasch

Acoustical Engineer, CH2M HILL

Panel Member Biographies

W. David Colby, M.D.

W. David Colby M.Sc., M.D., FRCPC, is a fellow of the Royal College of Physicians and Surgeons of Canada in Medical Microbiology. Dr Colby is the Acting Medical Officer of Health in Chatham-Kent, Ontario and Associate Professor of Medicine, Microbiology/Immunology and Physiology/Pharmacology at the Schulich School of Medicine and Dentistry at the University of Western Ontario. He received his M.D. from the University of Toronto and completed his residency at University Hospital, London, Ontario. While still a resident he was given a faculty appointment and later was appointed Chief of Microbiology and Consultant in Infectious Diseases at University Hospital. Dr Colby lectures extensively on antimicrobial chemotherapy, resistance and fungal infections in addition to a busy clinical practice in Travel Medicine and is a Coroner for the province of Ontario. He has received numerous awards for his teaching. Dr. Colby has a number of articles in peer-reviewed journals and is the author of the textbook *Optimizing Antimicrobial Therapy: A Pharmacometric Approach.* He is a Past President of the Canadian Association of Medical Microbiologists. On the basis of his expertise in Public Health, Dr Colby was asked by his municipality to assess the health impacts of wind turbines. The report, titled *The Health Impact of Wind Turbines: A Review of the Current White,Grey, and Published Literature* is widely cited internationally.

Robert Dobie, M.D.

Robert Dobie, M.D., is clinical professor of otolaryngology at both the University of Texas Health Science Center at San Antonio and the University of California-Davis. He is also a partner in Dobie Associates, a consulting practice specializing in hearing and balance, hearing conservation, and ear disorders. The author of over 175 publications, his research interests include age-related and noise-induced hearing loss, as well as tinnitus and other inner ear disorders. He is past president of the Association for Research in Otolaryngology, past chair of the Hearing and Equilibrium Committee of the American Academy of Otolaryngology-Head and Neck Surgery, and has served on the boards and councils of many other professional organizations and scholarly journals.

Geoff Leventhall, Ph.D.

Geoff is a UK-based noise and vibration consultant who works internationally. His academic and professional qualifications include Ph.D. in Acoustics, Fellow of the UK Institute of Physics, Honorary Fellow of the UK institute of Acoustics (of which he is a former President), Distinguished International Member of the USA Institute of Noise Control Engineering, Member of the Acoustical Society of America.

He was formerly an academic, during which time he supervised 30 research students to completion of their doctoral studies in acoustics. Much of his academic and consultancy work has been on problems of infrasound and low frequency noise and control of low frequency noise by active attenuation

He has been a member of a number of National and International committees on noise and acoustics and was recently a member of two committees producing reports on effects of noise on health: the UK Health Protection Agency Committee on the Health Effects of

Ultrasound and Infrasound and the UK Department of Health Committee on the Effects of Environmental Noise on Health.

David M. Lipscomb, Ph.D.

Dr. David M. Lipscomb received a Ph. D. in Hearing Science from the University of Washington (Seattle) in 1966. Dr. Lipscomb taught at the University of Tennessee for more than two decades in the Department of Audiology and Speech Pathology. While he was on the faculty, Dr. Lipscomb developed and directed the department's Noise Research Laboratory. During his tenure at Tennessee and after he moved to the Pacific Northwest in 1988, Dr. Lipscomb has served as a consultant to many entities including communities, governmental agencies, industries, and legal organizations.

Dr. Lipscomb has qualified in courts of law as an expert in Audiology since 1966. Currently, he investigates incidents to determine whether an acoustical warning signal provided warning to individuals in harms way, and, if so, at how many seconds before an incident. With his background in clinical and research audiology, he undertakes the evaluation of hearing impairment claims for industrial settings and product liability.

Dr. Lipscomb was a bioacoustical consultant to the U. S. Environmental Protection Agency Office of Noise Abatement and Control (ONAC) at the time the agency was responding to Congressional mandates contained in the Noise Control Act of 1972. He was one of the original authors of the Criteria Document produced by ONAC, and he served as a reviewer for the ONAC document titled *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety*. Dr. Lipscomb's experience in writing and reviewing bioacoustical documentation has been particularly useful in his review of materials for AWEA regarding wind farm noise concerns.

Robert J. McCunney, M.D.

Robert J. McCunney, M.D., M.P.H., M.S., is board certified by the American Board of Preventive Medicine as a specialist in occupational and environmental medicine. Dr. McCunney is a staff physician at Massachusetts General Hospital's pulmonary division, where he evaluates and treats occupational and environmental illnesses, including lung disorders ranging from asbestosis to asthma to mold related health concerns, among others. He is also a clinical faculty member of Harvard Medical School and a research scientist at the Massachusetts Institute of Technology Department of Biological Engineering, where he participates in epidemiological research pertaining to occupational and environmental health hazards.

Dr. McCunney received his B.S. in chemical engineering from Drexel University, his M.S. in environmental health from the University of Minnesota, his M.D. from the Thomas Jefferson University Medical School and his M.P.H. from the Harvard School of Public Health. He completed training in internal medicine at Northwestern University Medical Center in Chicago. Dr. McCunney is past president of the American College of Occupational and Environmental Medicine (ACOEM) and an accomplished author. He has edited numerous occupational and environmental medicine textbooks and over 80 published articles and book chapters. He is the Editor of all three editions of the text book, *A Practical Approach to Occupational and Environmental Medicine*, the most recent edition of which was published in 2003. Dr. McCunney received the Health Achievement Award from ACOEM in 2004.

Dr. McCunney has extensive experience in evaluating the effects of noise on hearing via reviewing audiometric tests. He has written book chapters on the topic and regularly lectures at the Harvard School of Public Health on "Noise and Health."

Michael T. Seilo, Ph.D.

Dr. Michael T. Seilo received his Ph.D. in Audiology from Ohio University in 1970. He is currently a professor of audiology in the Department of Communication Sciences and Disorders at Western Washington University in Bellingham, Washington where he served as department chair for a total of more than twenty years. Dr. Seilo is clinically certified by the American Speech-Language-Hearing Association (ASHA) in both audiology and speech-language pathology and is a long-time member of ASHA, the American Academy of Audiology, and the Washington Speech and Hearing Association.

For many years Dr. Seilo has taught courses in hearing conservation at both the graduate and undergraduate level. His special interest areas include speech perception and the impact of noise on human hearing sensitivity including tinnitus.

Dr. Seilo has consulted with industries on the prevention of NIHL and he has collaborated with other professionals in the assessment of hearing-loss related claims pertaining to noise.

Bo Søndergaard, M.Sc. (Physics)

Bo Søndergaard has more than 20 years of experience in consultancy in environmental noise measurements, predictions and assessment. The last 15 years with an emphasis on wind turbine noise. Mr. Søndergaard is the convenor of the MT11 work group under IEC TC88 working with revision of the measurement standard for wind turbines IEC 61400-11. He has also worked as project manager for the following research projects: Low Frequency Noise from Large Wind Turbines for the Danish Energy Authority, Noise and Energy optimization of Wind Farms, and Noise from Wind Turbines in Wake for Energinet.dk.

Technical Advisor Biography

Mark Bastasch

Mr. Bastasch is a registered acoustical engineer with CH2M HILL. Mr. Bastasch assisted AWEA and CanWEA in the establishment of the panel and provided technical assistance to the panel throughout the review process. Mr. Bastasch's acoustical experience includes preliminary siting studies, regulatory development and assessments, ambient noise measurements, industrial measurements for model development and compliance purposes, mitigation analysis, and modeling of industrial and transportation noise. His wind turbine experience includes some of the first major wind developments including the Stateline project, which when built in 2001 was the largest in the world. He also serves on the organizing committee of the biannual International Wind Turbine Noise Conference, first held in Berlin, Germany, in 2005.

Acknowledgements

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Richard K. Jennings, M.D. —Psychiatrist, Retired

FORECAST RADAR 64° F

Science says wind power safe

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- Discussion

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A Wisconsin State Journal editorial | Posted: Tuesday, August 17, 2010 5:44 pm | (7) Comments

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The Wisconsin Division of Public Health has reviewed more than 150 scientific and medical reports related to wind turbines and public health.

Division staff have listened and responded to concerns about wind turbines from the public, municipal leaders and local health officers. The division has sought the expertise of the University of Wisconsin School of Medicine, the Centers for Disease Control and Prevention, and health departments in states with heavier reliance on wind energy.

So what did the Wisconsin Division of Public Health determine from all of that careful inspection?

"We conclude that current scientific evidence is not sufficient to support a conclusion that contemporary wind turbines cause adverse health outcomes in those living at distances consistent with current draft rules being considered by the Public Service Commission," wrote Dr. Seth Foldy, state health officer and administrator, in a July 19 letter to wind farm critics who claim all manner of ailments from wind turbine noise, vibrations and shadow flicker as the sun sets behind turbines.

Dr. Jevon McFadden, an epidemiologic intelligence service officer with the CDC, offered similar reassurance in May to the Wisconsin Wind Siting Council that he serves on.

"Evidence does not support the conclusion that wind turbines cause or are associated with adverse health outcomes," McFadden wrote in his presentation.

The council, representing diverse interests, just submitted a final report to the Public Service Commission recommending uniform standards for siting small wind farms. The new rules would replace a hodgepodge of local restrictions that, in some cases, make siting wind turbines all but impossible.

The PSC already has uniform rules for siting big wind farms.

Adopting a set of reasonable standards for smaller wind farms - without caving to the overwrought fears of alarmists - is now needed to encourage more production of this clean, home-grown and safe source of energy.

Posted in Editorial on *Tuesday, August 17, 2010 5:44 pm* Updated: 3:53 am. Wind Energy, Wind Power, Wind Turbine, Division Of Public Health, Uw, University Of Wisconsin, Centers For Disease Control, Cdc, Seth Foldy, Jevon Mcfadden, Public Service Commission, Wisconsin

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