Excerpts from the Final Report of the Township of Lincoln Wind Turbine Moratorium Committee

[Prepared by Elise Bittner-Mackin for presentation to the Bureau County, Illinois, Zoning Board of Appeals regarding the 54.5-MW 33-turbine Crescent Ridge wind facility proposed for Indiantown and Milo by Stefan Noe (Illinois Wind Energy)]

After the wind turbines went online in Kewaunee County, Wisconsin, the Lincoln Township Board of Supervisors approved a moratorium on new turbine construction. The purpose of the moratorium was to delay new construction of wind turbines for eighteen months, giving the township the opportunity to assess the impacts of the 22 turbines installed by Wisconsin Public Service Corporation (WPSC) and Madison Gas and Electric (MG&E), which went online in June 1999.

The following document summarizes some of the problems the Moratorium Committee faced in trying to address problems the township hadn't faced prior to turbine construction and some of the resulting changes the committee proposed as a result of its study. Verification of this information can be obtained from Lincoln Township officials.

Agenda. The Moratorium Committee met 39 times between January 17, 2000, and January 20, 2002, to (1) study the impact of wind factories on land, (2) study the impact on residents, and (3) review conditional use permits used to build two existing wind factories in Lincoln Township.

Survey. The committee conducted a survey on the perceived impacts of the wind turbines that was sent out to all property owners residing in the township. Each household received one vote. The results were presented on July 2, 2001, to the town board, two years after the wind factory construction.

Question: Are any of the following wind turbine issues currently causing problems in your household?

residents w/i	800 ft. - 1/4 mi.	1/4 mi. - 1/2 mi.
a. Shadows from the blades	33% yes	41% yes

Here are additional write-in comments from the survey:

- We get a 'strobe effect' throughout our house and over our entire property (40 acres).
- Shadows are cast over the ground and affect my balance.
- We installed vertical blinds but still have some problems.
- They catch my eye and I look at them instead of the road. They are dangerous.
- Strobe light, headaches, sick to the stomach, can't shut everything up enough to stop the strobe coming into the house.

An additional comment from Lincoln Township Supervisor John Yunk:

- The strobing effect is so terrible that turbines should not be any closer than 1 mile from schools, roads and residences ... They should never be set on East-West.

Dr. Jay Pettegrew, researcher, neurologist, and professor for the University of Pittsburgh, testified before the Bureau County Zoning Board of Appeals that strobe effect could cause drivers to have seizures, which could result in fatal traffic accidents. At the very least, drivers could become disoriented and confused, he said. He testified that the turbine spacing (sited on top of hills instead of in a single field in orderly rows) would increase the likelihood of seizures.

It is important to note that according to Lincoln Township Chairperson Arlin Monfils, the wind developers publicly stated that strobe and shadow effect would not occur once the turbines were operating. In reality, strobe and shadow effects were problem enough that residents vehemently complained and the power company anted up for awnings, window treatment blinds and small trees to block the light at certain times of the day. Strobe and shadow effects take place for about 40 minutes during sunrise or sunset if the angle of the sun and the light intensity create the right conditions. Mr. Jeff Peacock, Bureau County highway engineer, has recommended denying permits for 8 turbines due to safety concerns, including strobe effect.

Diane Heling, whose property is adjacent to the WPSC turbines, said the utility purchased blinds for her home, but especially in the spring and fall when there are no leaves on the trees, the strobing is at its worst in her home. It's like a constant camera-flashing in the house. I can't stand to be in the room, Mrs. Heling said. Her neighbor, Linda Yunk, whose property is adjacent to the WPSC turbines, describes the strobe effect as unsettling. It's like somebody turning something on and off, on and off, on and off ... It's not a small thing when it happens in your house and when it affects your quality of life to that extent, Mrs. Yunk said.

residents w/i	800 ft. - 1/4 mi.	1/4 mi. - 1/2 mi.
b. TV reception	33% yes	37% yes

Additional write-in comments from survey:

- Ever since they went up our reception is bad.
- At times you can see shadowing on the TV that imitates the blades' moves, also poor reception.
- Minimum of 50' antenna tower proposed but no guarantee that would be high enough. Such a tower is unacceptable.
- At times we get black and white TV. Two channels come in hazy!!

residents w/i	800 ft. - 1/4 mi.	1/4 mi. - 1/2 mi.
c. Blinking lights from on top of the towers	9% yes	15% yes

Additional write-in comments from survey:

- Blinking red lights disrupt the night sky. They make it seem like we're living in a city or near a factory.
- At night it is very irritating because they flash in the windows.

- We have to keep drapes closed at night.
- Looks like a circus, live in the country for peace and quiet.

residents w/i	800 ft. - 1/4 mi.	1/4 mi. - 1/2 mi.
d. Noise	44% yes	52% yes

Additional write-in comments from survey:

- Sounds like a gravel pit crushing rock nearby.
- Sometimes so loud it makes it seem like we live in an industrial park. The noise dominates the 'sound scape.' It's very unsettling/disturbing especially since it had been so peaceful here. It is an ongoing source of irritation. Can be heard throughout our house even with all the windows and doors closed.
- The noise can make it impossible to fall asleep. It makes an uneven pitch not like the white noise of a fan. Can be heard through closed windows making it hard to fall asleep anytime of the year.
- You can hear them at times as far as two miles away.
- It is the annoyance of never having a quiet evening outdoors. When the blades occasionally stop it's like pressure being removed from my ears. You actually hear the quiet, which is a relief.

The most illustrative description of turbine noise was that of reverberating bass notes from a neighbor's stereo that penetrate the walls and windows of a home. Now imagine having no recourse for asking anyone to turn down that noise, whether it's during the day or in the middle of the night.

As the result of so many noise complaints, The Moratorium Committee ordered WPS to conduct a noise study. However, residents are still upset that the study was inadequate in that it measured decibel levels for only one to five days per season, sometimes only for a few minutes at some sites, and included days when rain and high winds blotted out the noise from the turbines. In addition, many measurements were taken when the turbines were not running. WPSC claimed it did not have the funds for a more comprehensive study, according to resident Mike Washechek, whose home is victim to some of the worst noise caused by the turbines, due to its location downhill and downwind from the WPSC turbines.

Nonetheless, the study established that the turbines added 5-20 dB(A) to the ambient sound. A 10-dB increase is perceived as a doubling of noise level. As soon as the noise study was published in 2001, WPS conceded that these homes were rendered uninhabitable by the noise of the turbines and made buyout offers for the neigboring homes (see below).

e. Other problems -- lightning

On the survey, several residents showed concern over the perceived problem of increased lightning strikes in the area.

Additional write-in comments from survey:

- ... bring lightning strikes closer to our home.
- More concern over seeing more lightning than in the past -- before generators were

erected.

According to Township Chairperson Monfils, the wind developers declared prior to construction that lightning would not affect the turbines; however, lightning later struck and broke a blade that had to be replaced.

In addition, Mrs. Yunk said that one month after the turbines went online, in July 1999, a lightning and thunderstorm sent enough electricity through the power grid that Mrs. Yunk and Mrs. Heling both lost their computers to what the service technician called a fried electrical system -- even though both computers were surge protected. The reason that Mrs. Yunk attributes the electrical surge to lightning striking a turbine on that particular night is that on the night of the storm, her relative, Joseph Yunk, whose television set was also fried that same evening, reported seeing lightning move from one of the turbines along the power grid to the nearby homes, which is a common occurrence with wind factories since nearby strikes to either turbines, external power systems, or the ground can send several tens of kilovolts along telephone and power lines. Replacements for the computers and television were paid by the residents.

e. Other problems -- traffic

On the survey, several residents showed concern over hazardous traffic conditions during and after construction of the turbines.

Additional write-in comments from survey:

- People driving and stopping.
- While they were being installed the destroying of the roads, noise, and extra traffic have been negative.
- More traffic and have to back out of driveways (live on hill, hard to see).
- More traffic. I used to feel safe walking or riding bike.

In addition, Mrs. Yunk said that especially when the turbines first went up, other drivers would be looking up at them and they would dead stop in front of you. She said she narrowly avoided colliding with a car that had stopped abruptly in front of her.

Question: In the last year, have you been awakened by sound coming from the wind turbines?

residents w/i	800 ft. - 1/4 mi.	1/4 mi. - 1/2 mi.
	67% yes	35% yes

Additional write-in comments from survey:

- Enough to go to the doctor because I need sleeping pills. Sometimes it absolutely drives you 'nuts.'
- I wake up with headaches every morning because of noise. Causes me to have very restless sleep at night!
- We have no way of knowing long-term effects. Growing concerns with stray voltage and its effect on health. We've had frequent headaches, which we didn't have before. Especially in the morning, after sleeping at night. We need answers!
- Not awakened but found it hard to fall asleep!!!

Question: How close to the wind turbines would you consider buying or building a home?

The results for all survey respondents in the study, including those living over 2 miles away are as follows:

- 61% would not build or buy within 1/2 mile of turbines
- 41% would have to be 2 or more miles away from turbines in order for them to build or buy
- 74% would not build or buy within 1/4 mile of turbines

These are people who know first-hand about the problems caused by the wind factories. They have lived with the turbines for three years. Again, 74% responded that they would not build or buy within 1/4 mile of turbines. Common sense dictates that if a 38-story skyscraper is built next to any home and it obstructs the view, that home would not be as valuable on the market as an equivalent home sited away from such an obstruction. Common sense also dictates that if the skyscraper had moving parts that contribute to or have the potential to contribute to blinking lights, strobing, noise, stray voltage, ice throws, and health problems, that home would not be as valuable as it had been previously. The above numbers from Lincoln Township corroborate that common sense.

Additional write-in comments from surveys:

- Ugly, would not buy in this area again.
- 25+ miles. They can been seen from this distance.
- Would never consider it. Plan on moving if we can sell our house.
- Nowhere near them never ever!! Not for a million dollars.

A sampling of some of the overall write-in comments from the survey is as follows:

- I live approximately 1 1/2 miles from the windmills. On a quiet night with the right wind direction, I can hear the windmill noise. People living within a 1/4 mile should probably be compensated for the noise and the nuisance.
- The noise, flashing lights, interrupted TV reception, strobe effect, and possible effect of stray voltage has created a level of stress and anxiety in our lives that was not present before the turbines' installation. From the beginning there has been a lack of honesty and responsibility.
- Let other counties or communities be the guinea pigs with the long-term effects or disadvantages of having the windmills. All the landowners who put the windmills up have them on property away from their own homes but on the fence lines and land near all other homeowners.
- Our whole family has been affected. My husband just went to the doctor because of his stomach. He hates them. We have fights all the time about them. It's terrible. Why did you put them so close to our new home and expect us to live a normal life? If it isn't the shadows it's the damn noise. The only people that think they are so great and wonderful are those who really don't know.
- When we were dating back in the 1970's we always said that someday we were going to build a home here. It was great and then you guys did this ... This should have never happened. If only you would have taken the time and study this more. Everyone was thinking about themselves and money. No one cared about anything else.

WPSC's buyout offer. During the two years of the Moratorium Committee work, Wisconsin Public Service Corporation made offers to buy houses and property to six property owners around the WPSC wind factory site. Offers were made to property owners who vocalized complaints about the wind factory's effects on their quality of life after construction. According to Lincoln Township Supervisor John Yunk, some of these residents were identified on the Noise Complaint Log record kept by the township. Over 90 complaints were logged in one year.

According to the Moratorium Committee report, WPSC publicly stated the buyout was to establish a buffer zone around the wind factory. The Noise Complaint Log was discontinued by WPSC after the buyout offer.

According to the Moratorium Committee report, WPSC's intention was to bulldoze the houses and subsequently keep the property from being developed for rural residences. Owners were allowed only one month to consider the offer.

According to the Moratorium Committee report, This tactic did not sit well with the Committee. In response the Committee drafted and approved a resolution condemning the WPSC ploy, and requesting that WPSC meet with the town board to develop a better solution for the township.

WPSC officials met with the town board and concerned citizens at the August 6, 2001, regular board meeting, reiterated their policy to purchase property and destroy the homes, and stated that they had no intention of meeting with the town board or changing their policies at the request of the town board.

Mrs. Heling was offered the buyout, but she said she and her family were allowed only one month to make the decision and only six months to move. In addition, the buyout offer was based solely on an appraisal by someone hired by WPSC. Mrs. Heling said WPSC refused to consider independent appraisals. Mrs. Heling said she couldn't obtain another property within six months, so she and her family rejected the buyout.

- The Gabriel household was set back 1,000 feet from the nearest turbine. The family took the buyout. The county no longer receives property taxes on that razed homestead. The family no longer lives in the area.
- The Kostichka household was set back 1,200 feet from the nearest turbine. The family took the buyout. The county no longer receives property taxes on that razed homestead. The family no longer lives in the area.
- Four remaining homeowners are suing WPSC.

The most recent development is that one homeowner contacted Township Supervisor Yunk during the week of September 11, 2002, and asked what the process would be to request MG&E to buy out her home. She said she has a new baby and two other young children and that she does not want to live in her house any longer because she is too scared about the effects on her family by electronic radiation, stray voltage, and other electricity associated with the turbines.

Property values. The following information will directly refute the Market Analysis: Crescent Ridge Project, Indiantown & Milo Townships, Bureau County, Illinois report submitted by Michael Crowley to this board.

Mr. Crowley, a paid consultant to the Crescent Ridge developers, alleges in his report that property values won't be affected in Bureau County, based on his analysis, in part, of property values in Kewaunee County.

However, Town of Lincoln zoning administrator Joe Jerabek compiled a list of properties that have been sold in the township and their selling prices. The list compared the properties' selling prices as a function of the distance to the wind factories, using real estate transfer returns and the year 2001 assessment roll. Conclusions were as follows:

- Sales within 1 mile of the windmills prior to their construction were 104 percent of the assessed values, and properties selling in the same area after construction were at 78 percent, a decrease of 26 points.
- Sales more than 1 mile away prior to construction were 105 percent of the assessed values, and sales of properties 1 mile or more after the construction of the turbines declined to 87 percent of the assessed value, an 18 point decline.

Furthermore, not taken into account in Mr. Jerabek's conclusion are the homes that were bought out and bulldozed by WPSC.

Also not taken into account is the fact that of the homes that sold within one mile of the turbines since their construction, four of them were owned within the Pelnar family as the family members shuffled houses. One brother sold to another brother. One brother purchased his father's home. The father built a new home. And a sister purchased land from one brother and built a home. It is important to note that two of the family members are turbine owners themselves.

Subsequent to the zoning administrator's report, homes have gone on the market that are still for sale.

- 1 home, sited across the road from the wind factory, was constructed after the turbines were built and has been on the market for over 2 years.
- 2 homeowners adjacent to the turbines are contemplating selling to WPSC, which may bulldoze the homes, according to neighbor Scott Srnka.
- 1 homeowner is in the process of finding out if MG&E will buy out her home.
- 1 homeowner, Mrs. Heling, who previously was offered the WPSC buyout, said she would sell if she thought she could get fair value for her home and if it would sell quickly enough that she wouldn't be paying on two properties at once. She said she doesn't believe that can happen, so she has not put up her home for sale.
- 1 homeowner, Mrs. Yunk, who lives across from the WPSC turbines, said she and her husband have decided that after having lived in their home for 28 years, they will be putting it up for sale to move to property farther away from the turbines. She said they are worried about selling their current property because of its proximity to the turbines. They will have to find a buyer who doesn't mind the turbines, she said.

Stray voltage. Another issue addressed by the Moratorium Committee is that of stray voltage and earth-current problems that may be exacerbated by the wind factories. This issue was brought to the attention of the Lincoln Town Board by the committee and concerned residents. An ordinance was passed by the Town Board to study the potential effects and to declare a moratorium on any further turbine development. The Committee agreed that any study of earth currents and stray voltage issues must include an analysis of the distribution system, analysis of the wiring from the utility's grid to the wind turbines, and an analysis of the grounding system used for the wind turbines. They also drafted a request for proposals to identify an expert that could help pinpoint the issues surrounding stray voltage and earth currents. The issue has yet to be resolved.

In the meantime, farmers and their livestock in Lincoln Township have been suffering. There are over four farms that are battling -- among other problems -- herd decline due to diseases that were not present in the herds prior to turbine construction, but are present now, according to farmer Scott Srnka. These problems are not limited to nonparticipating leaseholders. Farms with turbines have been affected as well, as evidenced by the trucks, which have grown more and more frequent, hauling away animal carcasses, Mr. Srnka said.

Mr. Srnka is a former supporter of the WPSC wind power project that is across the road from his family farm. His dairy herd is about 175 cows on 800 acres of land. Mr. Srnka said, Thirteen turbines were proposed for my land, but we decided to wait. Thank goodness we did or we'd be out of farming.

Mr. Srnka has traced the decline of milk production and increase of cancer and deformities in his formerly award-winning herd to an increase of electrical pollution on his farm after turbine construction. He also has seen the same chronic symptoms that are in his herd in his family.

Animal health problems in the Srnkas' formerly award-winning herd include cancer deaths, ringworm, mange, lice, parasites, cows not calving properly, dehydration, mutations such as no eyeballs or tails, cows holding pregnancy only 1 to 2 weeks and then aborting, blood from nostrils, black and white hair coats turning brown, mastitis, kidney and liver failure.

Within a few months in the first year after the turbines were erected, 8 cows died of cancer. No previous cases of cancer were detected ever before in the Srnka herd, which is a closed herd, according to Mr. Srnka.

Mr. Srnka also detected a change in well water on his property, and there has been a definite change in taste, he said, which has contributed to the decrease in water consumption by his herd. In the past his cows consumed 30 gallons of water a day, but that figure declined to 18 to 22 gallons of water a day after turbine construction. As a result, cows became dehydrated and terminally ill.

At the time of his testimony before the Bureau County Zoning Board of Appeals in October, Mr. Srnka said he had spent upwards of $50,000 of his own money to try to remedy the electrical pollution in his home and on his farm. Mr. Srnka stated that in his opinion, there were three other farms in the area facing enough problems with their herds in the aftermath of the turbines going online that those three farms are almost ready to sell out.

The ZBA members saw a brief unedited video interview with Mr. Srnka in his dairy barn, taken this spring. In it there were some of the cows in his herd and Mr. Srnka talking about some of the rewiring that he has had to install to try to combat problems of electrical pollution. Mr. Srnka said that he has had to resort to insulating the farm through electrical wiring to put his farm, in effect, on what he calls its own island.

Dr. Pettegrew, testifying before the Bureau County Zoning Board of Appeals, said he would be remiss as a doctor if he didn't tell the board that he thought the weaknesses and illness he saw in the cows in the video were most likely caused by EMFs or electrical pollution. Dr. Pettegrew also said the risk would be greater in Indiantown and Milo for animals and humans to become ill than in Wisconsin because the proposed turbines would be taller and would produce more electricity.

Mr. Srnka and neighbors report serious health effects on not just dairy cows. Health problems in residents include

- sleep loss
- diarrhea
- headaches
- frequent urination
- 4 to 5 menstrual periods per month
- bloody noses: Mr. Srnka had cows bleed to death from uncontrollable bleeding from the nostrils
- inability to conceive

Sometimes even short-term visitors to the farms or homes contract the symptoms, including construction workers on the Srnka property who broke out in nosebleeds after only a few hours. One of the workers left and refused to return.

The Srnkas are so concerned with health effects that they aren't going to have kids anymore because we're so afraid.

Representatives of WPSC have denied that there are stray voltage or earth currents affecting Mr. Srnka's family or livestock and will not compensate him for his family health bills, electrical system upgrades, loss of herd or decrease in milk production.

How did the situation become so grave when wind factory developers swore there would be no problems?

Even if a wind developer may claim that the wind factories, substations and power grids will not contribute to stray voltage or electrical pollution because (1) insulated cable will be used, (2) all cable will be buried several feet beneath the surface, and (3) cables are laid in thick beds of sand -- these statements should be viewed with suspicion because of poor project track records, according to Larry Neubauer, a master electrician with Concept Electric in Appleton, Wisconsin. Mr. Neubauer, who has customers who are dairy producers, homeowners with stray voltage problems, and farmers with turbines on their property, said that currents from each ground on the cables and project substations, as well as the regional transmission lines that receive electrical energy and that are electrically tied together, do not harmlessly dissipate into the soil. Energy disperses in all directions through the soil and these currents seek out other grounded facilities, such as barns, mobile homes and nearby residences. Only in California is it illegal to use the ground as an electricity conductor. In the rest of the country, including Wisconsin and Illinois, power companies are allowed to dump currents into the ground, according to Mr. Neubauer.

Residential properties that are in a direct line between substations and the ground conduits are particularly at high risk since electricity takes the path of least resistance. Mr. Neubauer said that burying the cables, as the Illinois Wind Energy project intends to do, makes it worse, citing the short lifespans of buried cables, frosts that wreak havoc on the cables, and the problems of locating trouble spots that cannot be seen without digging up the cables.

Two of Mr. Neubauer's clients, who were interviewed in October, are dairy farmers who have spent over $250,000 and $300,000 trying to rewire their farms to reduce stray voltage. That cost does not included herd loss or losses from diminished milk production. Mr. Russ Allen owns 550 dairy cows in DePere, Wisconsin. His farm is in a direct line between nearby WPSC turbines and a substation. Mr. Russ said he was losing one or two cows a day during the three years prior to his installing electrical equipment to help reduce currents on his farm. About 600 cows died, he said. Mr. Russ said he has so much electrical current on his farm that he laid a No. 4 copper wire around his farm for 5,000 feet. The wire is not attached to any building or additional wires; yet it can light up a lightbulb from contact with the soil alone. Mr. Russ has scheduled a media day on October 24 to draw awareness to the problems of stray voltage and he said to encourage everyone in Bureau County to attend.

What scares me more is that I know ... they're pumping current through people. They're pumping current through kids, Mr. Allen said.

It is important to note that Mr. Noe and his electrical engineer, Mr. Pasley, deny that there will ever be EMFs or stray voltage resulting from the proposed Indiantown/Milo turbines. Just as WPSC has dismissed any problems in the face of mounting evidence, Mr. Noe testified that he will never implement electrical pollution studies and that he thinks they would be a waste of money.

Moratorium Committee findings. As a result of the aforementioned concerns and problems with wind factories in Lincoln Township, the Moratorium Committee recommended, in brief, the following changes from the original conditional use permit:

- *Insurance*. The town is named as an additional insured and the town is held harmless in any litigation.

- *Fees*. Wind developers pay for all costs associated with the permitting process, including hearing costs plus attorney fees -- up front.

- *Wells*. Residents' wells are protected against damage from any type of foundation construction, not only blasting, within a 1-mile radius of each turbine. This includes the requirement that wind developers will pay for independent testing of wells within 1 mile of the project for flow rate and water quality. Developers also must pay for remediation and fix problems within 30 days of complaints.

- *TV reception*. Wind developers will pay for testing of television reception prior to construction and pay to correct degradation of TV signals. Wind developers will expand the potential problem area to a 1-mile radius for all complaints -- period.

  Despite claims that television reception would not be affected, the wind factory developers in Lincoln Township had to pay for power boosters and reception equipment to counteract the effects of the turbines. The residents also had to fight with the utilities when an additional local station was added and the utilities refused to pay for any more TV reception improvements for the duration of the 30-year turbine contract. Residents had to fight to get the power company to add the station. Three years later, residents are still unhappy about how the turbines continue to interfere with their reception, in many cases observable in unclear stations and in the color flashes that coincide with the turning of the blades, according to Mrs. Heling.

- *Noise*. 50 decibels for noise is too great. Noise shall not exceed 40 to 45 decibels, though

35 decibels was recommended unless there is written consent from affected property owners.

It is important to note that the noise study submitted by Illinois Wind Energy uses theoretical generalizations about topography and noise conduction and does not use the same height or turbine models proposed for Indiantown and Milo.

As a side note, according to the Walgreens Drug Store web site, the most sensitive earplugs they sell only block out noise up to 30 decibels.

- *Tower removal*. Turbines and all relegated above-ground equipment shall be removed within 120 days after the date the generators reach the end of their useful lives, the date the turbines are abandoned, the termination of the landowner lease, or revocation of the permit. An escrow account will be established or bonding provided by the wind developers to ensure tower removal.

- *Tourism*. Wind developers are banned from promoting the project as a tourist destination, will not provide bus or tourist parking, and will not provide promotional signs located at the projects or elsewhere.

  Despite the ordinance prohibiting promotion of the wind turbine project, WPSC was caught red-handed by Township Supervisor Yunk last month in August filming a promotional video with child actors riding bicycles in front of the turbines. Mr. Yunk ordered the film crew to leave, but they refused and continued filming. The township has found that once the turbines were constructed, it has been practically impossible to enforce the ordinance or gain cooperation from WPSC or MG&E.

- *Road damage*. Wind developers will pay for the total cost to return the towns' roads to town standards, not just pay for damaged areas. Any road damage caused by the wind developers during the repair, replacement, or decommissioning of any wind turbines will be paid for by the wind developers. An independent third party will be paid by the wind developers to pre-inspect roadways prior to construction.

  Township Chairperson Monfils said that it's not a matter of if there will be road damage. There will be road damage. The wind factory developers in Lincoln Township said originally that they would fix the roads if there were damage. But when it came time to fix the roads, the township had to scrap with them to get it done, according to Mr. Monfils. He said the developers disputed the costs and he had to battle with them two or three times to get repairs paid.

- *Periodic review*. Every year the project will undergo a periodic review for the purpose of determining whether wind developers have complied with the permit and whether wind projects have had any unforeseen adverse impacts. Any condition modified or added following the review will be of the same force and effect as if originally imposed. Wind developers will send a representative at least once a year to report the operating status of the projects and to receive questions and comments from the governing body and township residents.

  Even with the review, Lincoln Township residents reported being dissatisfied with the developers' response to their complaints. Mrs. Yunk said the developers were readily available prior to construction, but afterward were scarce. She said she fielded calls from residents who could not reach developers and residents who were given the run-around, being told they needed to contact other people within the organization. She said residents' concerns and problems were deflected by the developers, who said residents had to prove that problems did not exist previously and that the problems were without a doubt the result of the turbines.

- *Health and safety*. If a serious adverse unforeseen material impact develops due to the operation of any of the turbines that has a serious detrimental effect on the township or a particular resident, the township has a right to request the cessation of those turbines in question until the situation has been corrected.

- *Setbacks*. The minimum suggested setback from the nearest residences or public buildings is 1,000 feet, though 1,500 feet was recommended. Setbacks from adjacent property lines will be no less than the tower height plus the length of an extended blade. Minimum distance between turbines will never be less than 800 feet.

- Strobing effect, blade shadows, and stray voltage earth currents are some other issues to be addressed.

In effect, with these guidelines, Lincoln Township is making construction of new turbines unattractive to further development. They are finding it almost impossible to remedy problems with the current turbines and restore a former quality of life to residents. However, they are trying to ensure no more mistakes will be made.

As Mrs. Yunk plainly said, Anyone that thinks there aren't going to be problems resulting from the turbines has got another guess coming. She said that she and other residents felt like the bad guys for opposing the turbine project and warning other residents that the project would spell disaster. She said she hates now that what they feared has come true: There isn't any satisfaction in being able to say, I told you so.

The board must weigh heavily the situation of Kewaunee County and the voices and experiences of residents who have no vested interest in wind development in Bureau County. They have no vested interest in telling anything but the truth. They are telling it like it is, and unfortunately, like it was.

back to "A Problem With Wind Power"

[www.aweo.org]

Community reactions and Criteria Wind turbine noise

Robert W. Rand, INCE
Rand Acoustics
Brunswick, Maine

Community reactions and Criteria
Wind turbine noise

EPA Case Studies

Annoyance

Health Effects

Community Response

Increase in Noise	Estimated Community Response
5 dB	Sporadic Complaints
10 dB	Widespread Complaints
15 dB	Threats of Community Action
20 dB	Vigorous Community Action

EPA Levels Document 1974. Similar method in ANSI S1.9 Part 4.

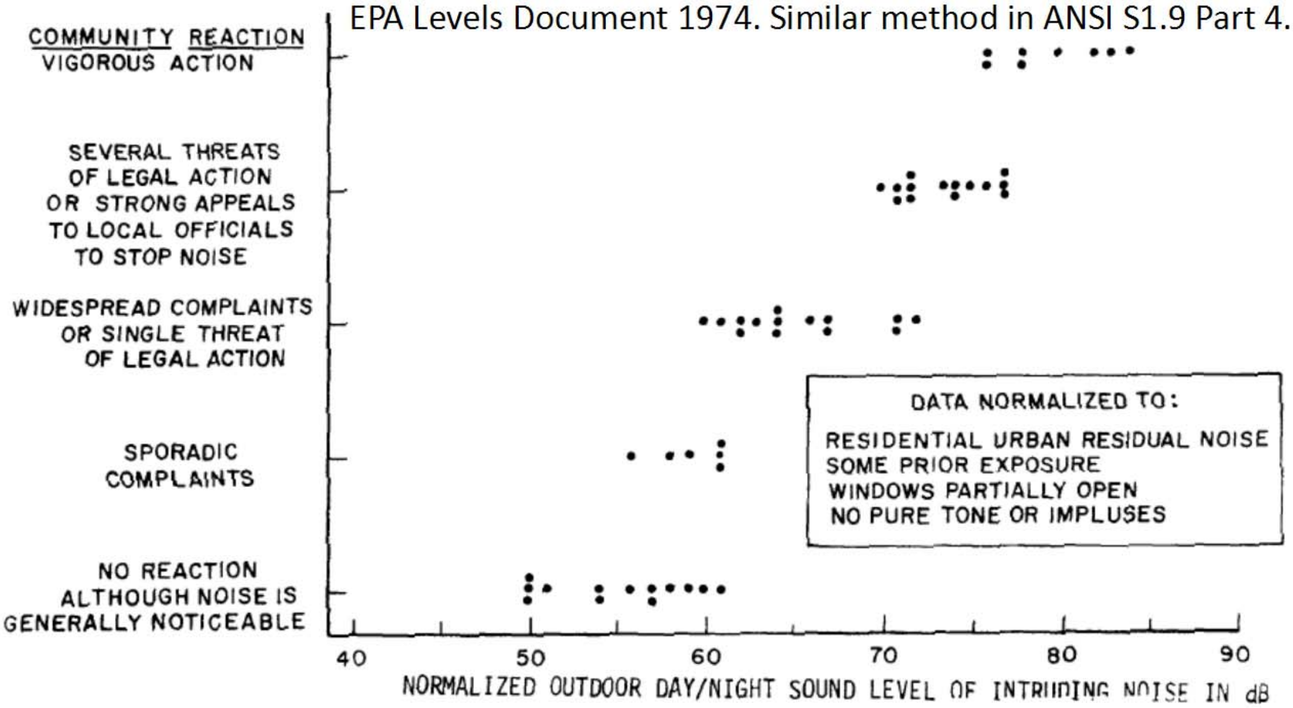
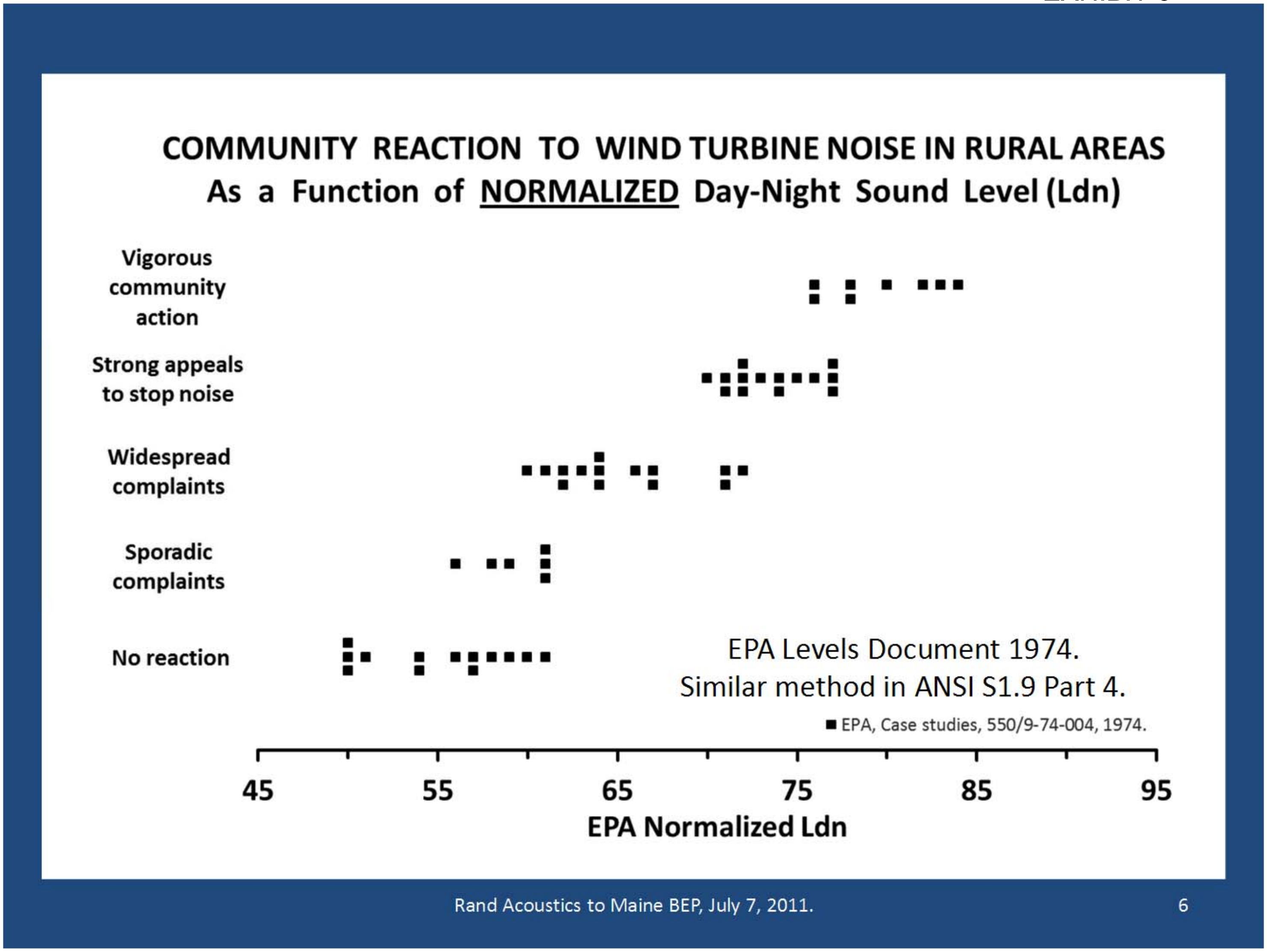


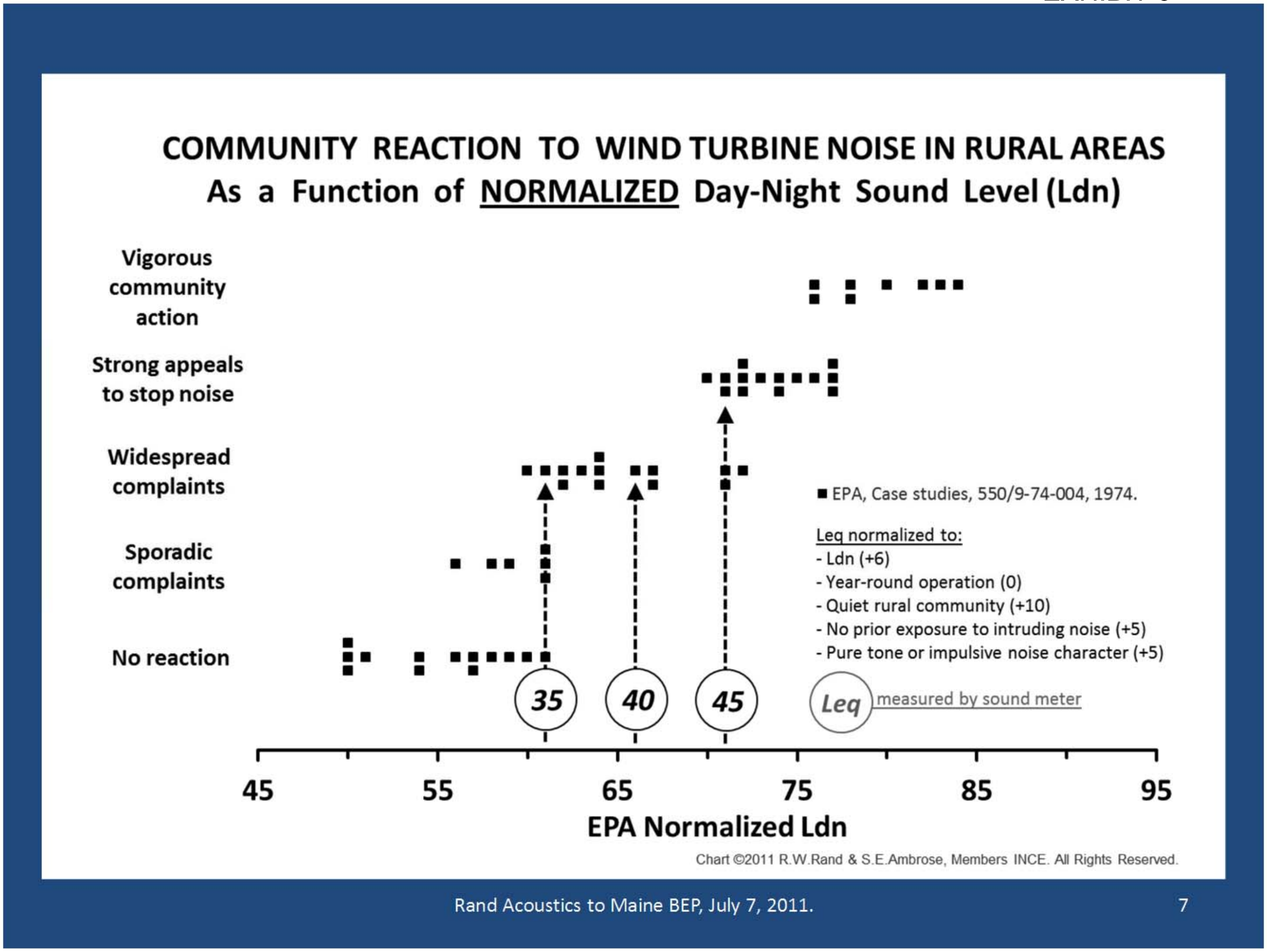
Figure D-7. Community Reaction to Intensive Noises of Many Types as a Function of the Normalized Outdoor Day Night Sound Level of the Intruding Noise D-3

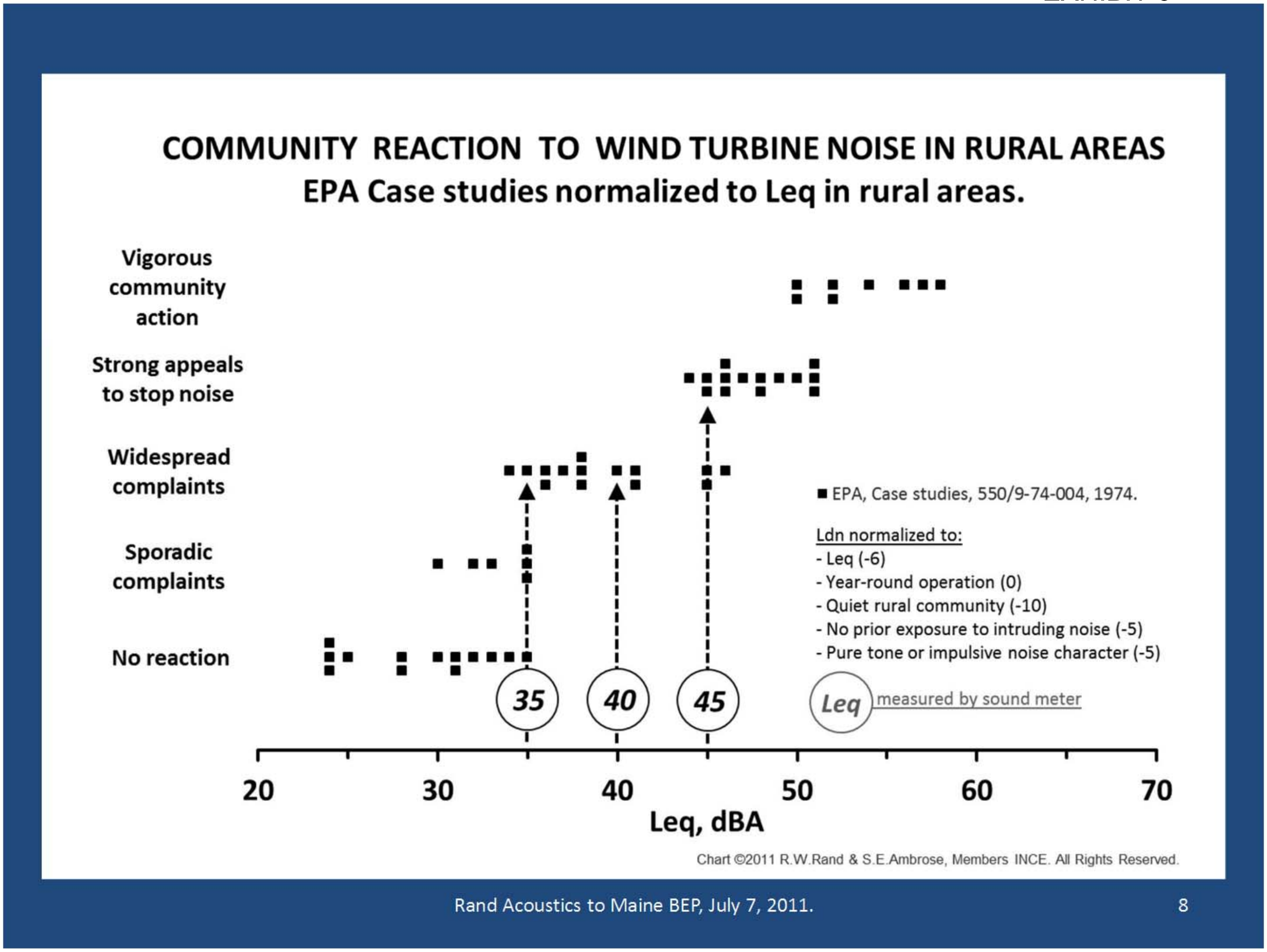
Table D-7

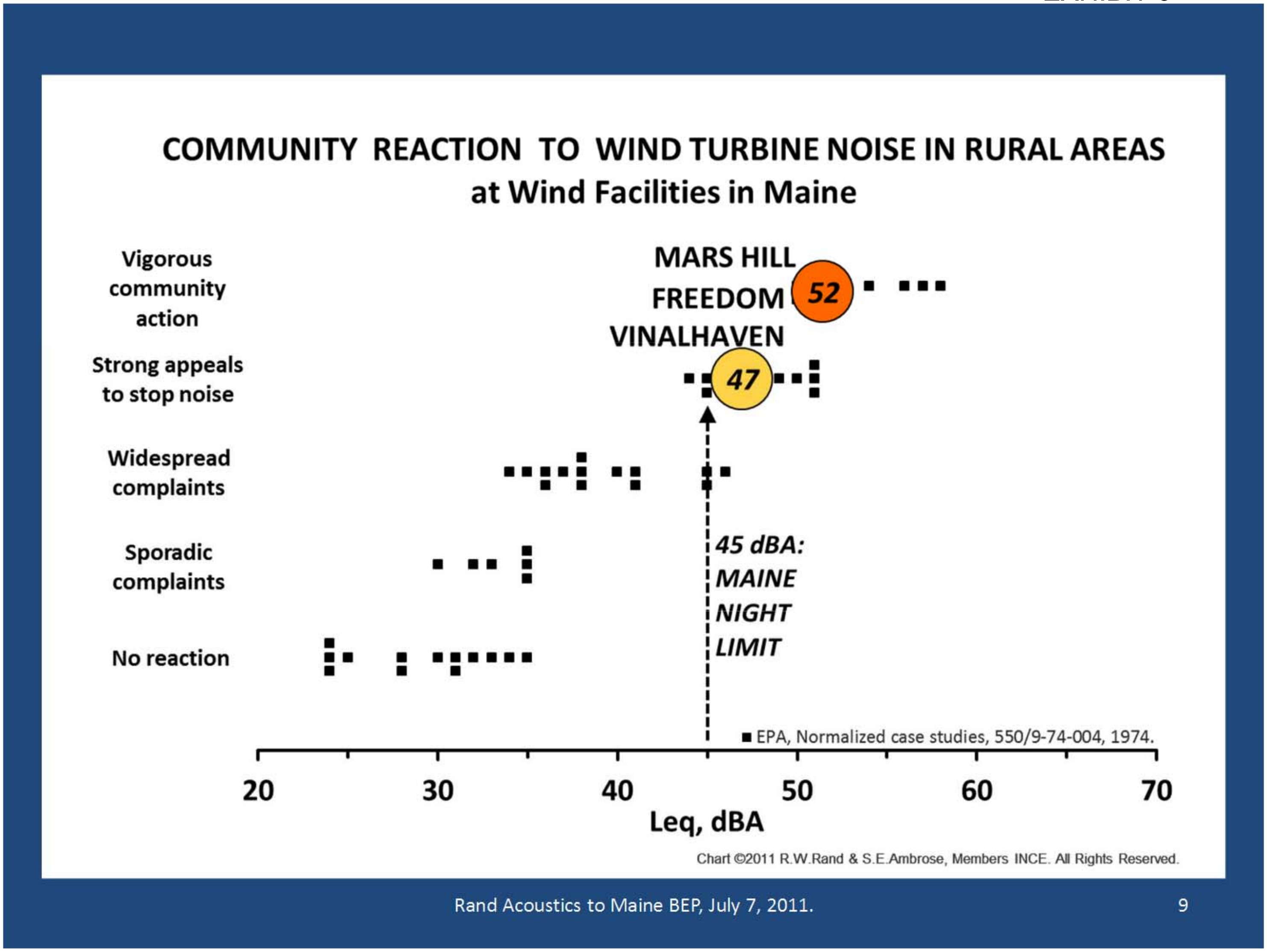
CORRECTIONS TO BE ADDED TO THE MEASURED DAY-NIGHT SOUND LEVEL (Ldn) OF INTRUDING NOISE TO OBTAIN NORMALIZED Ldn[1]

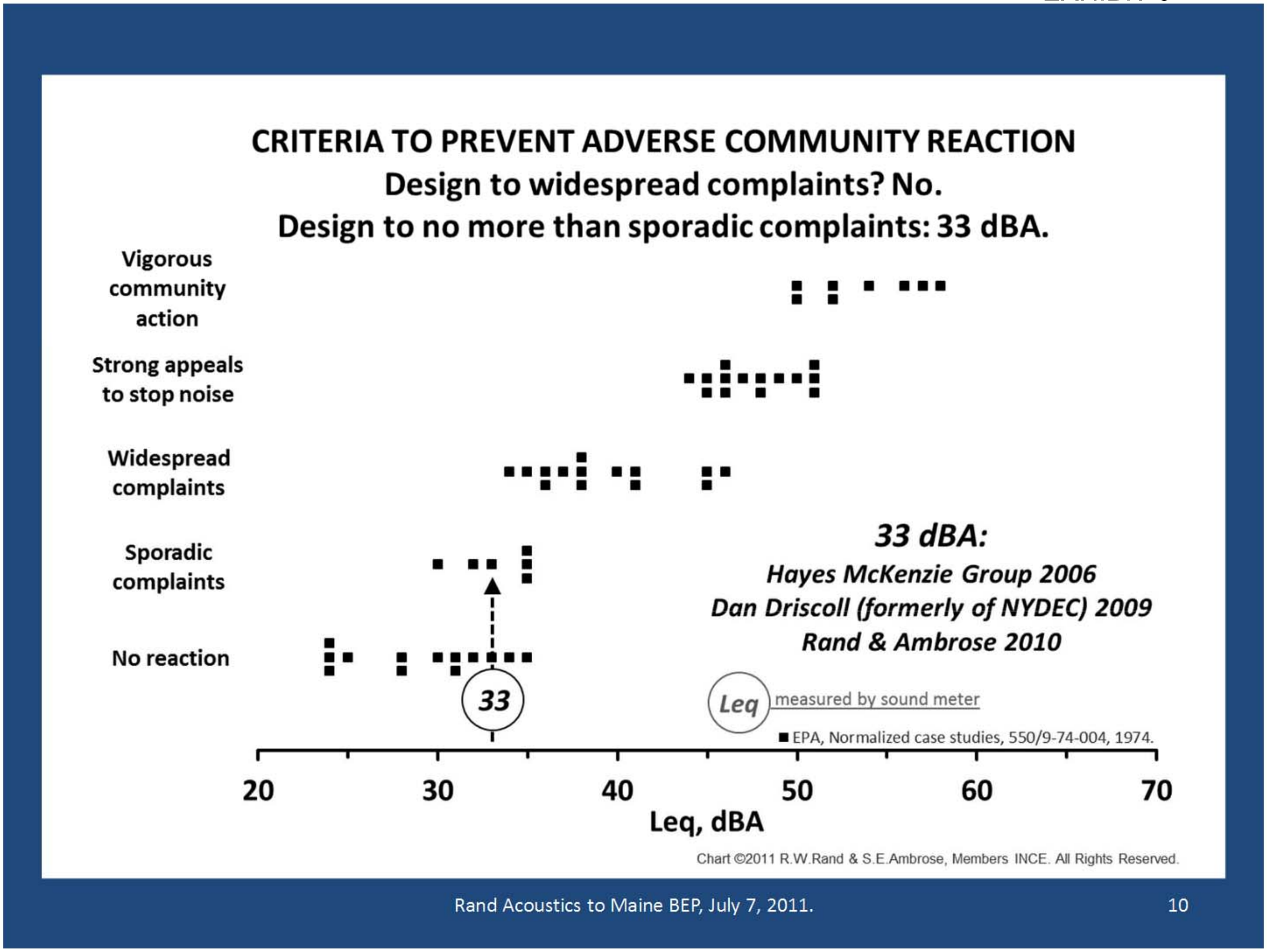
Type of Correction	Description	Amount of Correction to be Added to Measured L_{dn} in dB
Seasonal Correction	Summer (or year-round operation)	0
	Winter only (or windows always closed)	-5
Correction for Outdoor Noise Level Measured in Absence of Intruding Noise	Quiet suburban or rural community (remote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


COMMUNITY REACTION TO WIND TURBINE NOISE IN RURAL AREAS
As a Function of NORMALIZED Day-Night Sound Level (Ldn)
Vigorous community action
Strong appeals to stop noise
Widespread complaints
Sporadic complaints
No reaction
EPA Levels Document 1974.
Similar method in ANSI S1.9 Part 4.
EPA, Case studies, 550/9-74-004, 1974.
45
55
65
75
85
95
EPA Normalized Ldn
Rand Acoustics to Maine BEP, July 7, 2011.
6

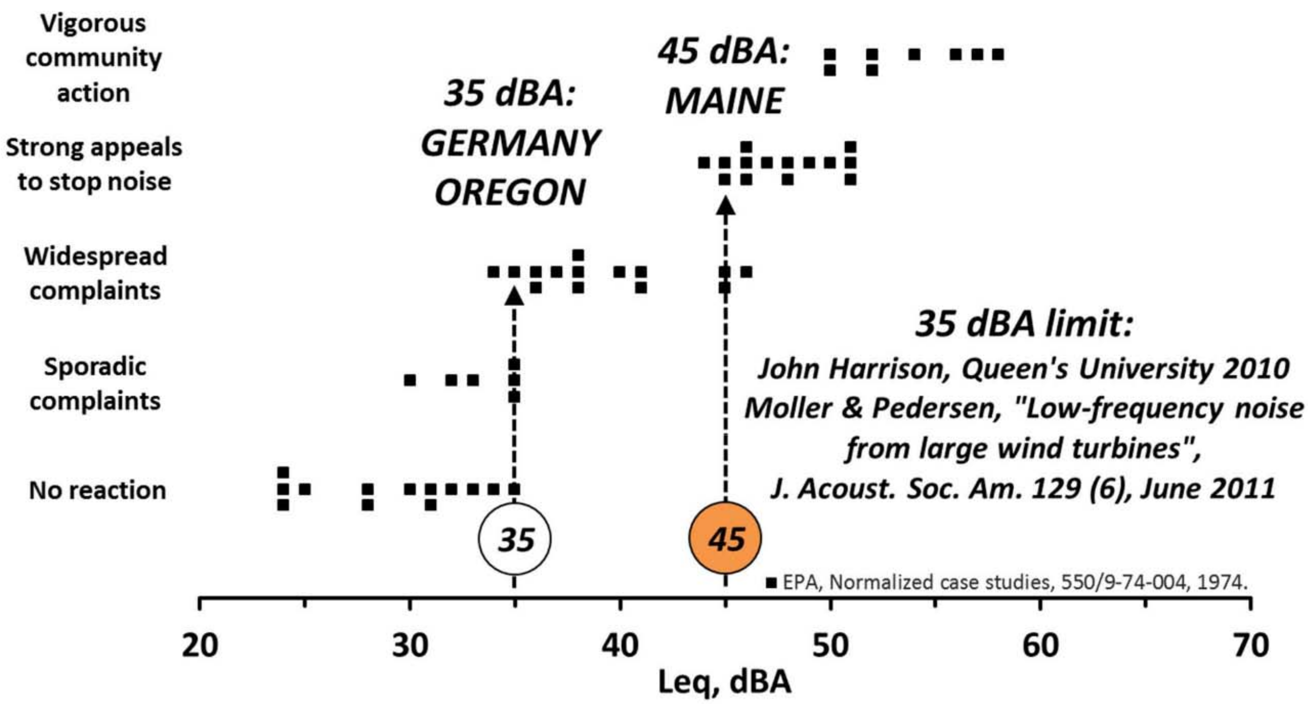

COMMUNITY REACTION TO WIND TURBINE NOISE IN RURAL AREAS
As a Function of NORMALIZED Day-Night Sound Level (Ldn)
Vigorous community action
Strong appeals to stop noise
Widespread complaints
Sporadic complaints
No reaction
EPA, Case studies, 550/9-74-004, 1974.
Leq normalized to:
- Ldn (+6)
- Year-round operation (0)
- Quiet rural community (+10)
- No prior exposure to intruding noise (+5)
- Pure tone or impulsive noise character (+5)
35
40
45
Leq
measured by sound meter
45
55
65
75
85
95
EPA Normalized Ldn
Chart ©2011 R.W.Rand & S.E.Ambrose, Members INCE. All Rights Reserved.
Rand Acoustics to Maine BEP, July 7, 2011.
7


COMMUNITY REACTION TO WIND TURBINE NOISE IN RURAL AREAS
EPA Case studies normalized to Leq in rural areas.
Vigorous community action
Strong appeals to stop noise
Widespread complaints
Sporadic complaints
No reaction
■ EPA, Case studies, 550/9-74-004, 1974.
Ldn normalized to:
- Leq (-6)
- Year-round operation (0)
- Quiet rural community (-10)
- No prior exposure to intruding noise (-5)
- Pure tone or impulsive noise character (-5)
35
40
45
Leq
measured by sound meter
20
30
40
50
60
70
Leq, dBA
Chart ©2011 R.W.Rand & S.E.Ambrose, Members INCE. All Rights Reserved.
Rand Acoustics to Maine BEP, July 7, 2011.
8


COMMUNITY REACTION TO WIND TURBINE NOISE IN RURAL AREAS
at Wind Facilities in Maine
Vigorous community action
Strong appeals to stop noise
Widespread complaints
Sporadic complaints
No reaction
MARS HILL
FREEDOM
VINALHAVEN
52
47
45 dBA: MAINE NIGHT LIMIT
EPA, Normalized case studies, 550/9-74-004, 1974.
20
30
40
50
60
70
Leq, dBA
Chart ©2011 R.W.Rand & S.E.Ambrose, Members INCE. All Rights Reserved.
Rand Acoustics to Maine BEP, July 7, 2011.
9

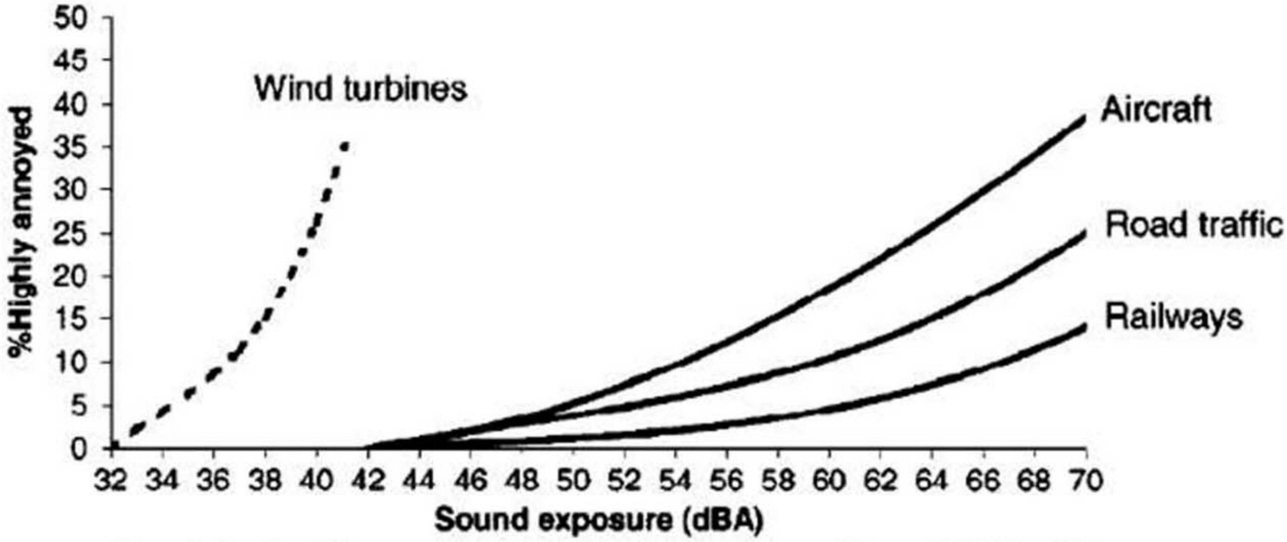

CRITERIA TO PREVENT ADVERSE COMMUNITY REACTION
Design to widespread complaints? No.
Design to no more than sporadic complaints: 33 dBA.
Vigorous community action
Strong appeals to stop noise
Widespread complaints
Sporadic complaints
No reaction
33 dBA:
Hayes McKenzie Group 2006
Dan Driscoll (formerly of NYDEC) 2009
Rand & Ambrose 2010
33
Leq
measured by sound meter
EPA, Normalized case studies, 550/9-74-004, 1974.
20
30
40
50
60
70
Leq, dBA
Chart ©2011 R.W.Rand & S.E.Ambrose, Members INCE. All Rights Reserved.
Rand Acoustics to Maine BEP, July 7, 2011.
10

Wind power development works in other locales with 35 dBA limit. Surely wind power can work in Maine with 35 dBA limit.



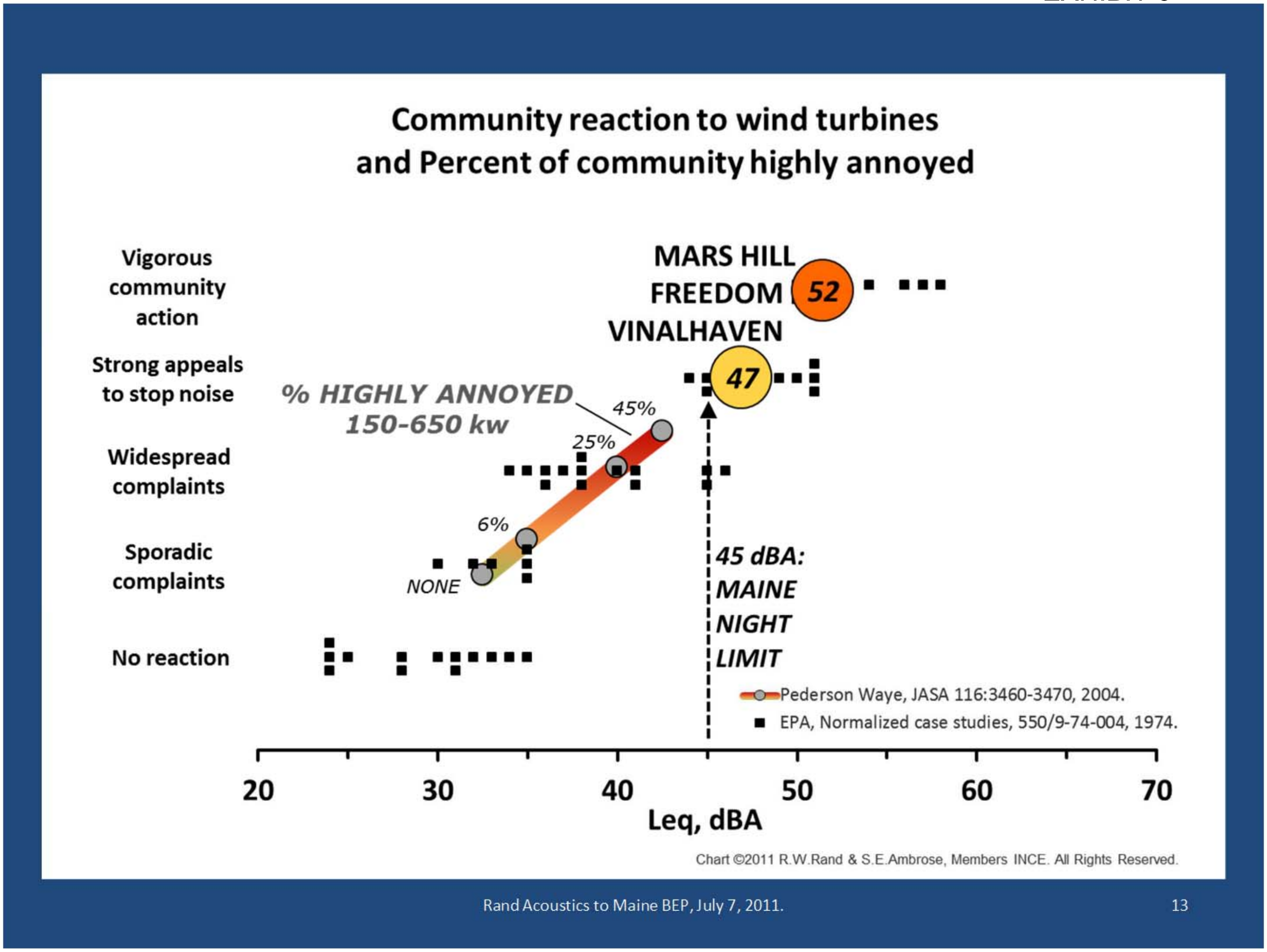
Community reaction to wind turbine noise

Annoyance



Reprinted with permission from Pedersen, E. and K.P. Waye (2004). Perception and annoyance due to wind turbine noise—a dose-response relationship. The Journal of the Acoustical Society of America 116: 3460. Copyright 2004, Acoustical Society of America.

EXHIBIT 6



Community reaction to wind turbines
and Percent of community highly annoyed
Vigorous community action
Strong appeals to stop noise
Widespread complaints
Sporadic complaints
No reaction
MARS HILL
FREEDOM
VINALHAVEN
52
47
% HIGHLY ANNOYED
150-650 kw
45%
25%
6%
NONE
45 dBA:
MAINE
NIGHT
LIMIT
Pederson Waye, JASA 116:3460-3470, 2004.
EPA, Normalized case studies, 550/9-74-004, 1974.
20
30
40
50
60
70
Leq, dBA
Chart ©2011 R.W.Rand & S.E.Ambrose, Members INCE. All Rights Reserved.
Rand Acoustics to Maine BEP, July 7, 2011.
13

Community reaction to wind turbine noise

Health Effects (WHO 2009)

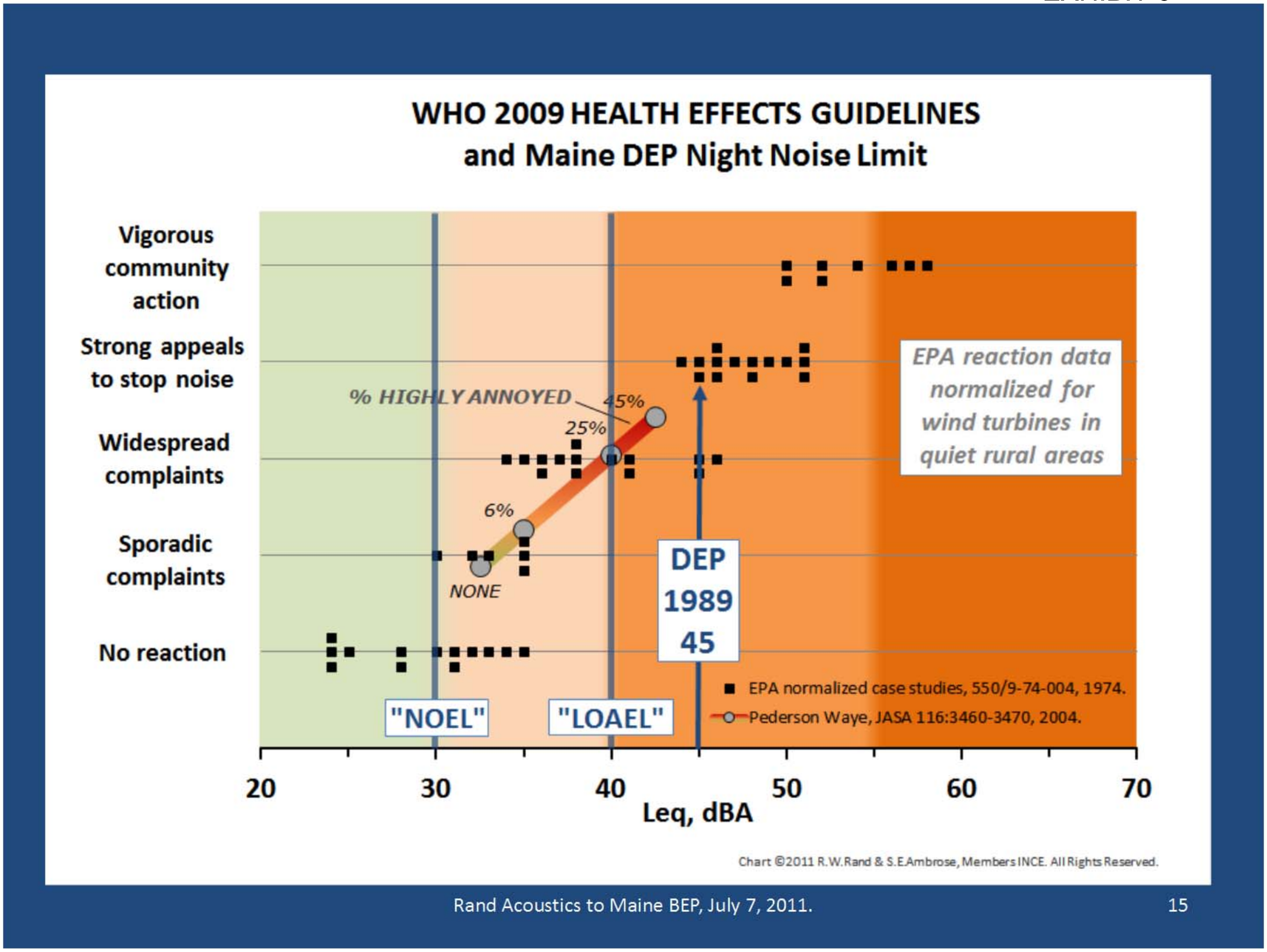
Average night noise level over a year $L_{night,outside}$	Health effects observed in the population
Up to 30 dB	Although individual sensitivities and circumstances may differ, it appears that up to this level no substantial biological effects are observed. $L_{night,outside}$ of 30 dB is equivalent to the no observed effect level (NOEL) for night noise.
30 to 40 dB	A number of effects on sleep are observed from this range: body movements, awakening, self-reported sleep disturbance, arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (for example children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest. $L_{night,outside}$ of 40 dB is equivalent to the lowest observed adverse effect level (LOAEL) for night noise.
40 to 55 dB	Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
Above 55 dB	The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed. There is evidence that the risk of cardiovascular disease increases.

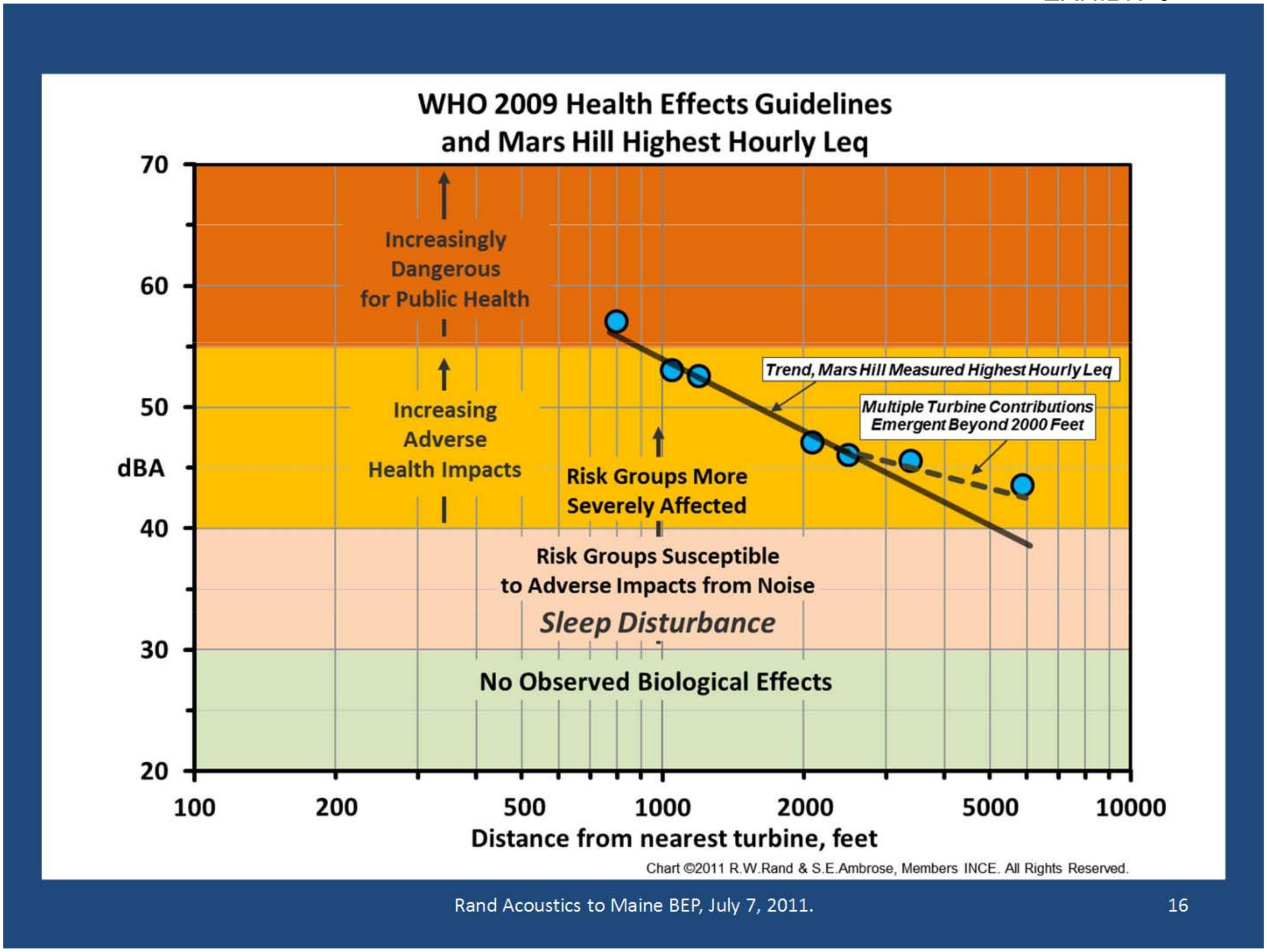
"NOEL"

Table 3
Effects of different levels of night noise on the population's health

"LOAEL"

Rand Acoustics to Maine BEP, July 7, 2011.


WHO 2009 HEALTH EFFECTS GUIDELINES
and Maine DEP Night Noise Limit
Vigorous community action
Strong appeals to stop noise
Widespread complaints
Sporadic complaints
No reaction
% HIGHLY ANNOYED
45%
25%
6%
NONE
EPA reaction data normalized for wind turbines in quiet rural areas
DEP 1989 45
"NOEL"
"LOAEL"
EPA normalized case studies, 550/9-74-004, 1974.
Pederson Waye, JASA 116:3460-3470, 2004.
20
30
40
50
60
70
Leq, dBA
Chart ©2011 R.W.Rand & S.E.Ambrose, Members INCE. All Rights Reserved.
Rand Acoustics to Maine BEP, July 7, 2011.
15


WHO 2009 Health Effects Guidelines
and Mars Hill Highest Hourly Leq
70
60
50
40
30
20
dBA
Increasingly
Dangerous
for Public Health
Increasing
Adverse
Health Impacts
Risk Groups More
Severely Affected
Risk Groups Susceptible
to Adverse Impacts from Noise
Sleep Disturbance
No Observed Biological Effects
Trend, Mars Hill Measured Highest Hourly Leq
Multiple Turbine Contributions
Emergent Beyond 2000 Feet
100
200
500
1000
2000
5000
10000
Distance from nearest turbine, feet
Chart ©2011 R.W.Rand & S.E.Ambrose, Members INCE. All Rights Reserved.
Rand Acoustics to Maine BEP, July 7, 2011.
16

Robert W. Rand, INCE
RAND ACOUSTICS
65 Mere Point Road
Brunswick, Maine 04011

rrand@randacoustics.com
207.632.1215
FAX 206.339.3441

February 5, 2011

Mr. Reg Karg, Chairman
Riga Township Planning Commission
12164 Riga Hwy.
Ottawa Lake, MI 49267

Mr. Karg,

On request of interested parties in Riga Township, I am writing to provide important information about siting wind turbines to protect public health with an adequate margin of safety. I am a Member of the Institute of Noise Control Engineering with over thirty years of experience in acoustics including many years working in industrial power generation noise control. I have conducted independent studies of wind turbine noise including actual field measurements of operating wind turbines in the State of Maine over the last year, where significant community reaction has occurred near wind turbine facilities equipped with smaller wind turbines than proposed for the Riga Township.

I understand that there have been suggestions of using a wind turbine noise limit of 45 dBA at a distance of 1300 feet or so in Riga Township. Experience in New England has proven that these noise levels at these distances for wind turbines sited in rural areas are associated with significant adverse community reactions, widespread complaints, appeals to stop the noise, and legal action. When siting large industrial wind turbines in quiet rural areas, lower maximum noise levels and farther distances are recommended to prevent adverse community reaction and protect public health and welfare with an adequate margin of safety.

This letter presents a discussion of community reactions to noise, guidelines for appropriate maximum permissible noise limits in rural areas, measured noise levels versus distance and observed community responses. I appreciate your consideration of this letter and believe you will find this information useful in your determinations of how to protect the health and welfare of Riga Township.

Please call me if you have any questions.

Respectfully submitted,

Community reactions to noise

People react to changes in noise level and to unusual or unpredictable noise character. People respond to the change in the sound level from the background to which they are accustomed, as follows:

Figure 1. Estimated Community Response to Noise Increase

Community Response

Increase in Noise	Estimated Community Response
5 dB	Sporadic Complaints
10 dB	Widespread Complaints
15 dB	Threats of Community Action
20 dB	Vigorous Community Action

In *rural* areas (such as Riga Township) it is generally found that background sound levels *in the absence of industrial noise, traffic or insects* falls in around 35 dBA or lower during the day and 25 dBA or lower at night. An adverse community response could occur if a new and unfamiliar noise source was introduced at night at levels of 35 dBA or higher in a quiet rural area.

In contrast for example, consider Hull Massachusetts, a city that experiences pervasive noise from auto traffic and aircraft flyovers from Logan Airport, with typical background sound levels of 40 to 55 dBA at night [1]. With two large industrial wind turbines operating in Hull and sited close to residential neighborhoods, there are few or no complaints from the wind turbine noise there. Does this make sense? Actually, it does. Hull experiences *urban and aircraft* sound levels that are *much higher* than those found in rural areas.

Let's say that a wind turbine produces a sound level of 45 dBA at 1300 feet. In a *rural* area with a nighttime background sound level of 25 dBA or less, the increase is 20 dBA and the expected community reaction is strong, with "Vigorous Community Action" ranging to "Threats of Community Action" and "Widespread Complaints" with farther distances from the wind turbine. In contrast, in an *urban residential* area like Hull, Massachusetts, with background sound levels similar to or higher than the wind turbines (depending on distance) and a sound signature similar to jet aircraft, there may be no perceptible noise change at nearby residential neighborhoods due to the wind turbine and thus, no reaction.

Noise criteria for noise-producing facilities

Noise-producing facilities are usually required to meet certain noise limits or "criteria" when operating in order to protect the welfare of nearby residents. In many cases criteria are taken directly from local ordinances or State regulations that specify noise limits at specific locations such as property lot lines. However "just meeting" these limits may not prevent an adverse community reaction, depending on the apparent loudness of the noise source when compared to the existing expected background sound levels.

By now most people are aware of the reports of adverse community reactions near some wind turbine facilities. From investigations made around New England, adverse community reactions appear to occur mostly when there are residential homes in quiet rural areas within a mile or so of a wind turbine facility. The noise limits for these sites are always above 35 dBA. Coincidence? No.

Many ordinances and regulations in the United States developed in the last thirty years took their guidance from the EPA's 1974 "Levels Document" [2] and used the EPA's "guideline" of the *Ldn55* (55 dBA day, 45 dBA night), maximum permissible sound level (for urban residential areas) as a noise limit or criterion, whether the ordinance or regulation was applied to urban residential, rural, or wilderness areas. In developing its guidelines, the EPA's primary focus (as expressed in the Levels Document) was on preventing hearing loss and speech interference, writing that "*The level of 55 dB [note: Ldn- 55 dBA day, 45 dBA night] is identified as maximum level compatible with adequate speech* *communication indoors and outdoors. With respect to complaints and long-term annoyance, this level is clearly a maximum serving a large majority of the population. However specific local situations, attitudes and conditions may make lower levels desirable for some locations."*

The "large majority" that the EPA wrote of can be seen below in Figure 2. Of the roughly 214 million people living in the US in 1974, some *100 million* lived in areas with existing background sound levels *above* Ldn 55. Over *10 million* lived with background sound levels above *Ldn 70.*

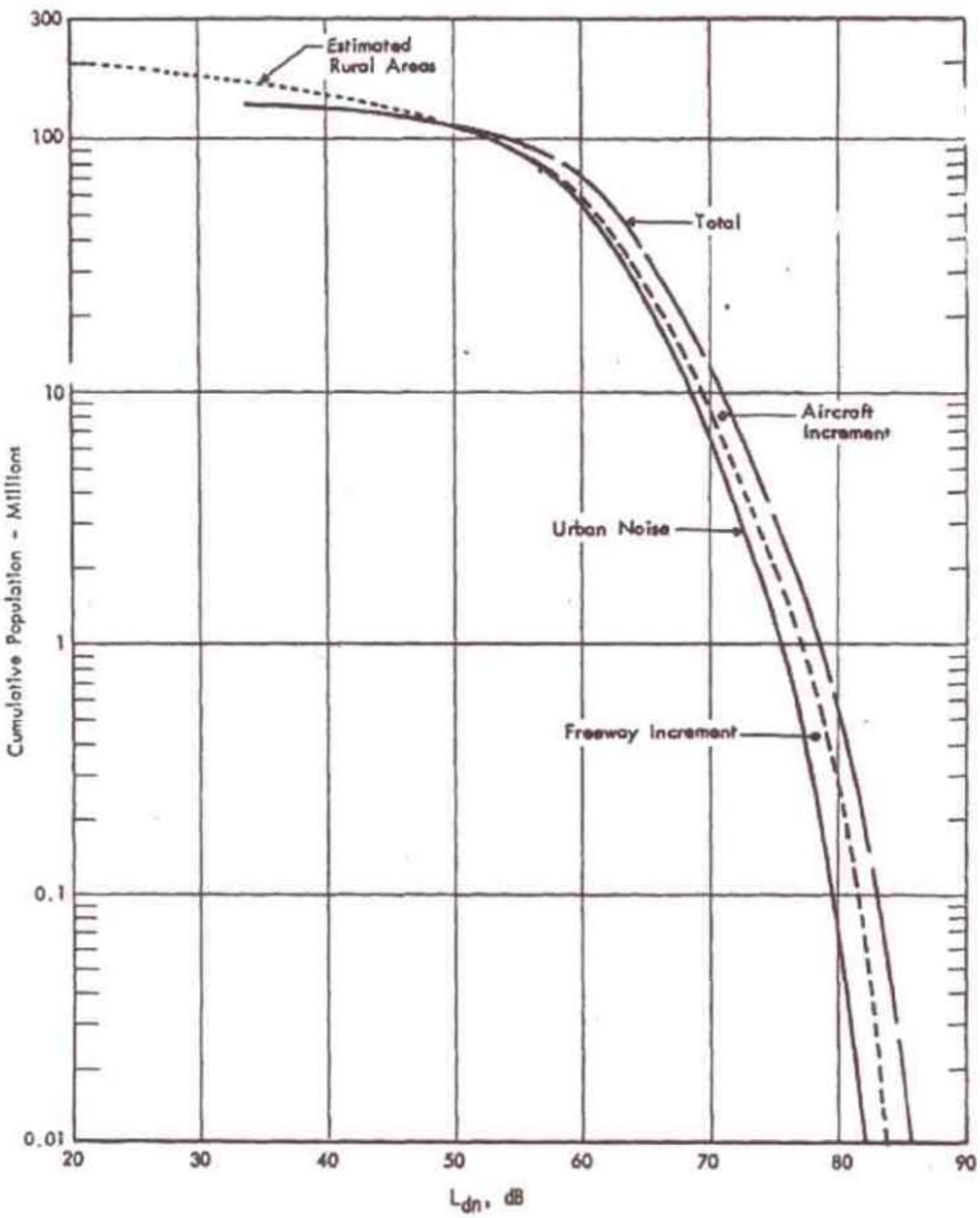


Figure 2 Residential Noise Environment of the National Population As A Function of Exterior Day-Night Average Sound Level (Ref B.5)

For those living with elevated background sound levels in urban areas, the EPA's guideline of a maximum Ldn 55 was well positioned to assure no hearing loss, nor any speech interference within a reasonable speaking distance. However, for the some 100 million people living *outside* urban areas, with existing background sound levels *below* Ldn 55, the EPA's guideline has no protective effect. Indeed, the use of Ldn 55 as a "permitted" maximum level can serve to *degrade* the acoustic environment in quiet rural and wilderness areas by allowing *much higher* intrusive sound levels where existing background sound levels were much lower. *This was never the EPA's intent.*

For an *urban residential* area like Hull, a 45-dBA nightime limit (the nightime limit in Ldn55) *could* be effective at producing a "No Reaction" community response. However, if a criteria of 45 dBA were selected for a *rural* area with minimum background sound levels of 25 dBA or less, that allows a *20 dB increase* over the pre-existing night time levels. The predicted community reaction would be strong and adverse, and the ordinance would not be experienced as a protection to well-being in the much quieter rural setting.

With this general framework now presented to you, how can community reactions to wind turbine sound levels be assessed and appropriate criteria developed for rural areas such as Riga Township? Fortunately there is an established method for determining community reaction to noise.

<u>Noise impact assessment: EPA</u>

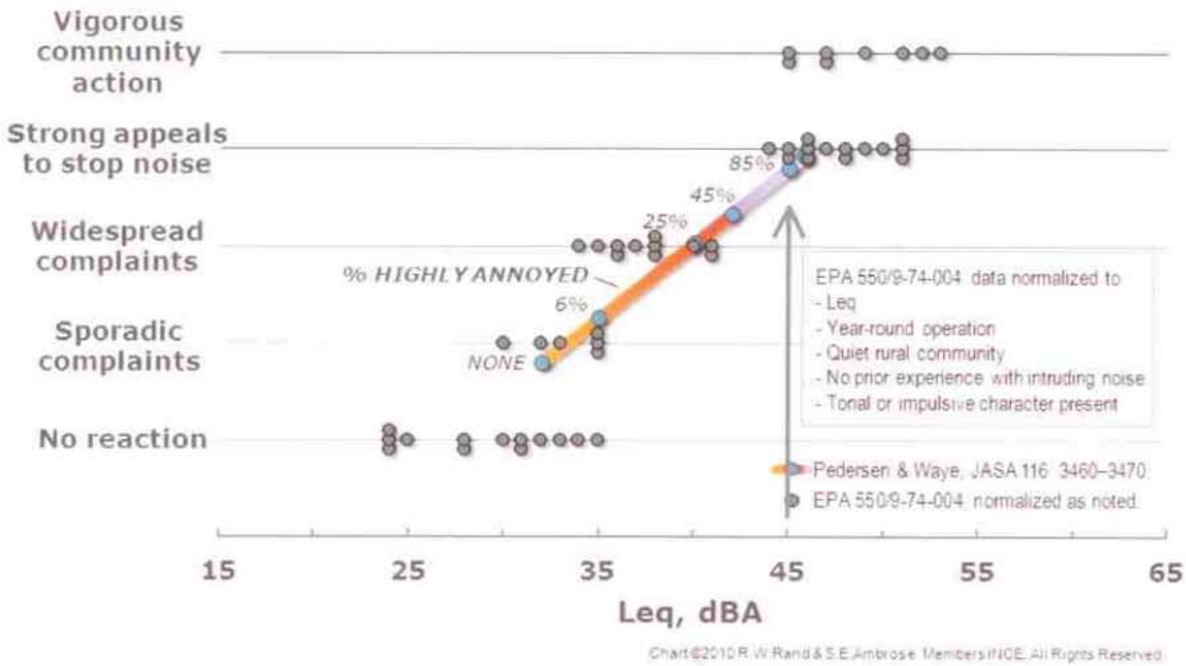
The USEPA's 1974 "Levels Document" recognized the range of community reactions in different areas and presented a well-researched community reaction prediction methodology, sometimes referred to as the "Normalized Ldn" method for noise impact assessment. The EPA noise impact assessment method includes correction factors for background sound level, previous experience to the noise and sound character in terms of impulsive noise (Attachment 1). The community impact reaction can be predicted for wind turbines located in quiet areas with the EPA methodology. Using the EPA's modeling corrections allow the reviewer to account for the features of wind turbine noise that distinguish it from other noise sources.

Figure D-7 in Attachment 1 shows the EPA normalized Ldn values with no corrections. The process used for this review analysis starts with converting the EPA's Ldn data to Leq (the *energy-average* sound level). To convert the EPA data from Ldn to Leq, a 6 dB factor is employed assuming steady operation day and night. For example, Ldn 51 equals an Leq of 45 dBA for a steady-state noise source. Then, the community noise impact assessment for a wind turbine facility uses the following normalizing correction factors to the EPA's data to bring them into an Leq chart:

0 dB for year round operation,
10 dB for being located in a quiet or rural area,
5 dB for no prior experience and,
5 dB for tonal or impulsive character.

With the conversion to Leq and the correction factors applied, the EPA data now appear at the normalized Leq values shown in Figure 3. Now, the predicted wind turbine Leq can be assessed directly with the EPA's normalized data, which is now expressed in a normalized Leq with associated normalized community reactions. Figure 3 shows the Leq noise level on the 'X-axis' and normalized EPA community reactions on the 'Y-axis'. The community reaction is determined by finding, as an example, the proposed 45 dBA on the figure as shown and moving straight up the chart to find the occurrences of community reaction. The Leq 45 value actually intersects the normalized community reactions at two reaction levels: "Strong appeals to stop the noise" and the highest level "Vigorous action".

Figure 3 – Community Impact Assessment



The EPA method indicates that the 45-dBA limit suggested for nearest neighbors in the quiet areas of Riga Township is associated with the EPA-based normalized community impact reactions of "Strong Appeals To Stop Noise" to "Vigorous Community Action." The proper way to design noise-producing facilities is to perform a community noise impact assessment to ensure that noise emissions result in "No Reaction" or no more than "Sporadic Complaints."

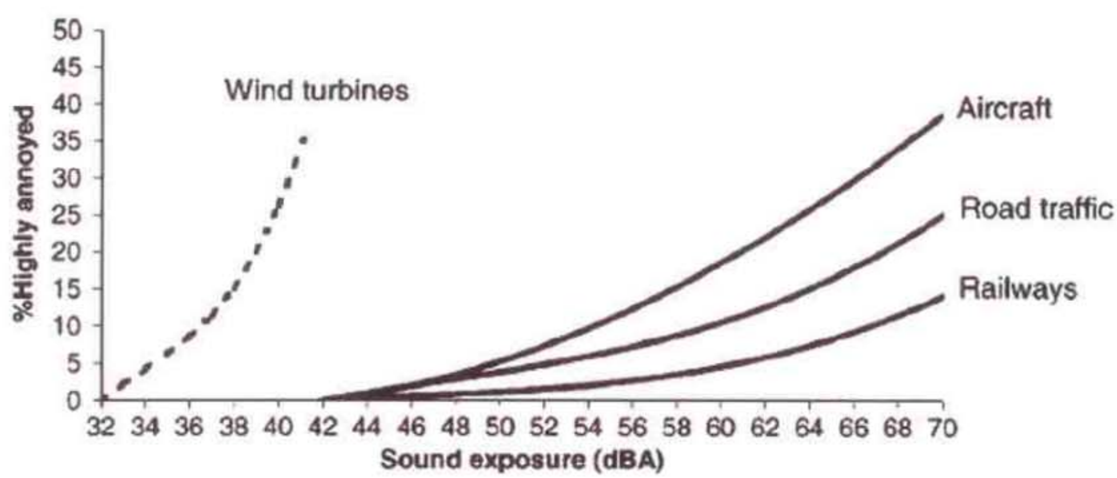
How can the EPA's guideline of Ldn 55 (55 dBA day, 45 dBA night) be adjusted for noise impacts from wind turbines in the quiet, rural setting? Accounting for ALL the correction factors in the EPA's community reaction assessment method as discussed above, the resulting total correction of 20 dB leads to the conclusion that the EPA's maximum permissible noise limits should be adjusted downward from their urban residential guideline of Ldn 55 to a *rural* Ldn 35, or 35 dBA, day and 25 dBA, night. These levels are consistent with background sound levels normally found in rural areas and would be expected to produce "No Reaction."

If a criterion were developed by making EPA's 10 dB correction from urban residential to *rural*, without considering the impact of 1) a new noise and 2) the impulsive, low-frequency sound character, it follows that the EPA's Ldn 55 (55 day, 45 night) maximum permissible noise limits would be corrected to Ldn 45, with a night limit *not to exceed 35 dBA*. The predicted community reaction at the nearest neighbors could be "Sporadic Complaints" to "Widespread Complaints".

Does a maximum permissible limit of 45 dBA provide adequate provision to prevent an adverse noise impact from the wind turbines on public welfare (well-being) in *rural* areas? The answer is clearly, no, and this is why.

Figure 3 includes the results of independent wind turbine noise research by Pedersen & Waye in 2004 [3]. Their data confirm that there can be an adverse community reaction, with associated *activity interference*, including and especially *sleep interference*, for wind turbine noise levels above 32 dBA in rural areas. It should be noted that Pedersen & Waye data included on Figure 3 were obtained around multiple wind turbine sites with sizes ranging from 150kw to 600kw, much smaller than the Vestas V100 wind turbines proposed for Riga Township. The original Pedersen & Waye chart is provided as Figure 4 below showing the adverse community response ramping up quickly starting around 32 dBA, a full *10 dB below* the level where an adverse response from transportation noise starts up.

Figure 4 – Wind turbine noise compared to transportation



When the wind turbine sound level increases from 35 to 42 dBA, Pedersen & Waye found that increasingly, 6 to 45 percent of the community were highly annoyed, with the associated adverse health effects of *"psychological distress, stress, difficulties to fall asleep and sleep interruption."*[4]. Their 2004 best-fit equation suggests the *potential* for most of the community to be highly annoyed for noise levels around 45 dBA. This inference is noted in this letter's Figure 2 as a light extension through 45 dBA. The Pedersen & Waye research strongly suggests that wind turbine noise levels at 45 dBA in the *quiet rural* areas will result in the highest possible negative community response, with essentially all who can be affected highly annoyed, and the associated adverse health effects and activity interferences noted.

When the EPA and Pedersen & Waye assessments are taken together, there is strong evidence that the state of *well-being* (welfare) and being in a state of "*highly annoyed*" cannot coexist.

Have such adverse community noise reactions been observed near wind turbine facilities in quiet rural areas? *Yes.* Operating sound levels compiled for Mars Hill, Maine as well as field data acquired at Freedom, Maine and Vinalhaven, Maine have been charted for community reaction with sound level versus distance and, these clearly illustrate community reactions to those sites well known from news reports as correlated with the predicted community reactions from the EPA method. The charts are provided in Attachment 2.

<u>What criteria to use?</u>

A 45-dBA noise limit at 1/4 mile or so appears to be ineffective to prevent an adverse community reaction or protect public welfare at nearest neighbors from wind turbine noise in quiet rural areas. As a Member of INCE, I am pledged to protect public health as outlined in the INCE Canon of Ethics. The first Fundamental Canon reads as follows.

1. Hold paramount the safety, health and welfare of the public.

Therefore, suitable criteria should be sought.

The US defunded its Office of Noise Abatement in the early 1980s and has had marginal oversight on noise issues since then, primarily aircraft noise. However it is a member of the World Health Organization and we may look to the WHO and its concerted work over the last fifteen years to establish noise guidelines for public health. In 2009 the WHO-Europe published guidelines for outdoor noise levels in residential areas, based on comprehensive peer review of medical evidence of health effects from noise [5]. WHO-Europe published a yearly average sound level of 30 dBA, night, outdoors is the level below which there are no observed health effects, the "No Observed Effects Level" or NOEL. Above the 30 dBA NOEL, health effects including sleep disturbance were found, mild at lower levels for healthy individuals and more adverse with higher levels for "vulnerable groups"; children, the elderly, and people with disease or pre-existing health conditions. Above 40 dBA, the "No Observed Adverse Effects Level" (NOAEL), adverse health impacts are clearly evident and more severe for vulnerable groups.

While there has been debate among acousticians as to how to correlate WHO's 2009 yearly-averaged noise level guidelines to a wind turbine noise level and unique sound character that fluctuates minute to minute depending on wind speed, wind shear, and other factors, there can be little question that adverse health impacts are certain for average noise levels above 40 dBA and health effects including sleep disturbance are possible with average noise levels above 30 dBA.

It doesn't take a year to decide if recurring sleep loss is a problem. Most people have experienced fatigue and other health effects from one poor night's sleep, or perhaps a few nights of interrupted sleep. Some living near wind turbines have to leave their homes and go to another location to get a good night's sleep, and are unable to sell their homes to move away (Mars Hill, Freedom, Vinalhaven).

The night noise guidelines are summarized in Figure 4 shown below.

Figure 4. WHO 2009 Night Noise Guidelines Summary

Average night noise level over a year $L_{night,outside}$	Health effects observed in the population
Up to 30 dB	Although individual sensitivities and circumstances may differ, it appears that up to this level no substantial biological effects are observed. $L_{night,outside}$ of 30 dB is equivalent to the NOEL for night noise.
30 to 40 dB	A number of effects on sleep are observed from this range: body movements, awakening, self-reported sleep disturbance, arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (for example children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest. $L_{night,outside}$ of 40 dB is equivalent to the LOAEL for night noise.
40 to 55 dB	Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
Above 55 dB	The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed. There is evidence that the risk of cardiovascular disease increases.

Others advocate for lower noise limit criteria than 45 dBA

Other researchers have recommended quieter wind turbine noise levels than the 45 dBA suggested for nearest neighbors in Riga Township. In 2006 the Hayes McKenzie Group, UK recommended a maximum of 33 dBA when the impulsive character is audible [6]. Dan Driscoll, a recognized acoustic professional formerly with the NYDEC recommended 33 dBA in 2009 [7]. Dr. Michael Nissenbaum of Fort Kent, Maine conducted an independent medical control study for residents living near the Mars Hill wind turbines, with a medical recommendation in 2010 for a minimum separation distance of 2200 meters [8], which roughly correlates to wind turbine noise levels in the mid- to high 30s dBA, depending on number of wind turbines, alignment and other factors.

Because there are no reliable engineering noise controls at the source, the use of separation distance may be needed to meet noise criteria. In field measurements at operating facilities in rural Maine (see Appendix 3), distances of one to two miles were found for wind turbine noise levels of 35 dBA or lower. In noisier areas such as Hull, Massachusetts or near an interstate highway that is busy day and night, adverse community reaction would emerge at higher sound levels, and separation distances to prevent adverse reactions would be reduced.

Conclusions

1. A 45-dBA noise limit at 1/4 mile or so appears to be ineffective to prevent an adverse community reaction or protect public welfare at nearest neighbors from wind turbine noise in *quiet rural* areas, and could allow much higher sound levels than existing, potentially provoking adverse community reaction and complaints.

2. The predicted community reaction to wind turbine noise in *quiet rural* areas based on the EPA normalized community reaction assessment method is "Widespread Complaints" or stronger at 34 dBA or higher.

3. When the EPA community reaction and Pedersen & Waye assessments are taken together, there is strong evidence that the state of *well-being* (welfare) and being in a state of "*highly annoyed*" cannot coexist.

4. Long-term average intrusive noise levels over 40 dBA outside at night are linked to adverse health effects (WHO 2009). Intrusive noise levels between 30 and 40 dBA outside at night *may* produce sleep interference or health effects, especially for health risk groups. The LOAEL of 40 dBA yearly average is the WHO guideline for preventing for preventing adverse health effects from noise. The NOEL of 30 dBA yearly average is the WHO guideline below which there are no observed health effects from noise.

5. A recommended criteria for siting wind turbines in quiet rural areas would be a maximum permissible noise level of 30 to 35 dBA at nearest neighbors properties to prevent adverse community reactions and protect public health and welfare.

This range is consistent with a) the WHO 2009 LOAEL of 40 dBA with a conservative 5 dB design safety factor, b) the recommendations of other professionals, c) a design to approximately no more than "Sporadic Complaints" in quiet rural areas based on the EPA community reaction assessment method, and d) protecting vulnerable groups (children, elderly, those with pre-existing conditions) who may be more susceptible to sleep interference or other health effects between 35 and 40 dBA.

6. Because there are no reliable engineering noise controls at the source, the use of adequate separation distance during facility planning is needed.

7. Distances of one to two miles are needed to meet quiet rural noise criteria of 35 dBA or less (based on actual sites, Attachment 3). Shorter distances can be adequate if wind turbine facilities are located in noisy areas such as urban areas, industrial areas or near busy highways.

1. Assessment Of Airport Noise Monitoring At Hull, Ma, Paul Schomer, May 31, 2001.
2. Information On Levels Of Environmental Noise Requisite To Protect Public Health And Welfare With An Adequate Margin Of Safety, 550/9-74-004, March 1974.
3. Pedersen, E. and K. Pedersson Waye, Perception and annoyance due to wind turbine noise: A dose–response relationship, Journal of the Acoustical Society of America 116, 2004.
4. As described in the conclusions of the Pedersen & Waye 2008 report, Project WindFarmPerception (FP6-2005-Science-and-Society-20, Specific Support Action, Project no. 044628).
5. Night Noise Guidelines For Europe, 2009. ISBN 978 92 890 4173 7.
6. "Officials cover up wind farm noise report", J. Leake and H. Byford, The Sunday Times, December 13, 2009, http://www.timesonline.co.uk/tol/news/environment/article6954565.ece.
7. Dan Driscoll, Environmental Stakeholder Roundtable on Wind Power, June 16, 2009. http://www.powernaturally.org/programs/wind/Daniel%20A.%20Driscoll_Wind%20Roundtable%20Presentation%20w%20Figs.pdf.
8. Prefiled Testimony Of Dr. Michael Nissenbaum, On Behalf Of Albany, Vermont, State of Vermont Public Service Board, Docket No. 7628. http://www.kingdomcommunitywind.com/filemanager/download/21431/.

ATTACHMENT 1

COMMUNITY REACTION TO ENVIRONMENTAL NOISE

Excerpt From: Information On Levels Of Environmental Noise Requisite To Protect Public Health And Welfare With An Adequate Margin Of Safety, 550/9-74-004, March 1974.

There are two methods of indirectly assessing the cumulative effects of environmental noise on people. These are examining the reactions of individuals or groups of individuals to specific intruding noises, either (a) with respect to actions taken (complaints, suits, etc.), or (b) in terms of responses made to social survey questionnaires. The first category, involving overt action by individuals or groups, is summarized in this section, and key data regarding the second category, involving responses indicating annoyance, is summarized in the next section.

In the last 25 years, many new types of noise sources have been introduced into suburban and urban residential communities. These sources, such a jet aircraft, urban freeways, new industrial plants, and homeowner equipment, have created numerous community problems with environmental noise. These problems have provided significant data and insight relating to community reaction and annoyance and stimulated the development of several indices for measurement of the magnitude of intruding noises.

Various U.S. Governmental agencies began to investigate the relationships between aircraft noise and its effect on people in communities in the early 1950's. This early research resulted in the proposal of a model by Bolt, Rosenblith and Stevens for relating aircraft noise intrusion and the probable community reaction. This model, first published by the Air Force, accounted for the following seven factors:

1. Magnitude of the noise with a frequency weighting relating to human response.
2. Duration of the intruding noise.
3. Time of year (windows open or closed).
4. Time of day noise occurs.
5. Outdoor noise level in community when the intruding noise is not present.
6. History of prior exposure to the noise source and attitude toward its owner.
7. Existence of pure-tone or impulsive character in the noise.

Correction for these factors were initially made in 5 dB intervals since the magnitudes of many of the corrections were based solely on the intuition of the authors, and it was considered difficult to assess the response to any greater degree of accuracy. This model was incorporated in the first Air Force Land Use Planning Guide in 1957 and was later simplified for ease of application by the Air Force and the Federal Aviation Administration.

Recently the day-night sound level has been derived for a series of 55 community noise problems to relate the normalized measured Ldn with the observed community reaction. The normalization procedure followed the Bolt, Rosenblith and Stevens method with a few minor modifications. The correction factors which were added to the measured Ldn to obtain the normalized Ldn are given in Table D-7. The distribution of the cases among the various noise sources having impact on the community are listed in Table D-8. The results are summarized in Figure D-7.

The "no reaction" response in Figure D-7 corresponds to a normalized outdoor day-night sound level which ranges between 50 and 61 dB with a mean of 55 dB. This mean value is 5 dB below the value that was utilized for categorizing the day-night sound level for a "residential urban community," which is the baseline category for the data in the figure. Consequently, from these results, it appears that no community reaction to an intruding noise is expected, on the average, when the normalized day-night sound level of an identifiable intruding noise is approximately 5 dB less than the day-night sound level that exists in the absence of the identifiable intruding noise. This conclusion is not surprising; it simply suggests that people tend to judge the magnitude of an intrusion with reference to the noise environment that exists without the presence of the intruding noise source.

The data in Figure D-7 indicate that widespread complaints may be expected when the normalized value of the outdoor day-night sound level of the intruding noise exceeds that existing without the intruding noise by approximately 5 dB, and vigorous community reaction may be expected when the excess approaches 20 dB. The standard deviation of these data is 3.3 dB about their means and an envelope of +5 dB encloses approximately 90 percent of the cases. Hence, this relationship between the normalized outdoor day-night sound level and community reaction appears to be a reasonably accurate and useful tool in assessing the probable reaction of a community to an intruding noise and in obtaining one type of measure of the impact of an intruding noise on a community.

The methodology applied to arrive at the correlation between normalized Ldn and community complaint behavior illustrated in Figure D-7 is probably the best available at present to predict the most likely community reaction in the U.S. Unfortunately, readiness to complain and to take action is not necessarily an early indicator of interference with activities and annoyance that the noise creates. The fact that correction for the normal background noise level without intruding noise results in better correlation of the data points might be interpreted to mean that urban communities have adapted to somewhat higher residual noise levels that are not perceived as interfering or annoying. On the other hand, it is more likely that the higher threshold for complaining is caused by the feeling that higher residual noise is unavoidable in an urban community and that complaining about "normal" noise would be useless.

Table D-7

CORRECTIONS TO BE ADDED TO THE MEASURED DAY-NIGHT SOUND LEVEL (Ldn) OF INTRUDING NOISE TO OBTAIN NORMALIZED Ldn[1]

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

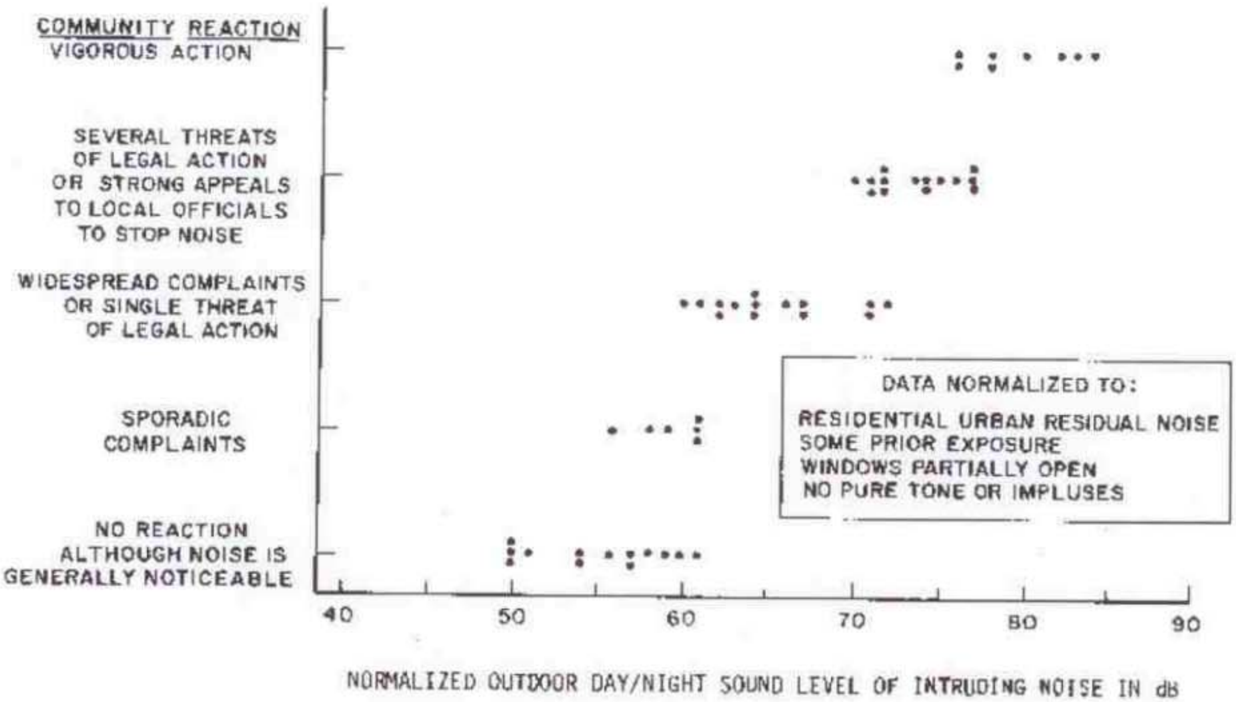
Table D-8

NUMBER OF COMMUNITY NOISE REACTION CASES AS A FUNCTION OF NOISE SOURCE TYPE AND REACTION CATEGORY

Type of Source	Community Reaction Categories			Total Cases
	Vigorous Threats of Legal Action	Wide Spread Complaints	No Reaction or Sporadic Complaints	
Transportation vehicles, including:	6	2	4	12
Aircraft operations			3	3
Local traffic	1			1
Freeway		1		1
Rail	2			2
Auto race track				
Total Transportation	9	3	7	19
Other single-event or intermittent operations, including circuit breaker testing, target shooting, rocket testing and body shop	5			
Steady state neighborhood sources, including transformer substations, residential air conditioning	1	4	2	7
Steady state industrial operations, including blowers, general manufacturing, chemical, oil refineries, et cetera	7	7	10	24
Total Cases	22	14	19	55

Figure D-7

Community Reaction to Intensive Noises of Many Types as a Function of the Normalized Outdoor Day Night Sound Level of the Intruding Noise[1]



1. Eldred, K. M., "Community Noise", Environmental Protection Agency NTID 300.3, December 1971.

ATTACHMENT 2

COMMUNITY REACTIONS TO WIND TURBINE NOISE FACILITIES IN MAINE

Currently in December 2010, neighbors living near Mars Hill, Freedom, and Vinalhaven wind facilities are complaining vigorously about wind turbine noise and have been doing so since facility operation commenced. Data compiled for Mars Hill as well as data acquired at Freedom and Vinalhaven have been charted for community reaction with sound level versus distance using the EPA's community noise impact assessment method provided in the 1974 Levels Document [A.2-1] and are provided in this attachment for comparison with community reactions from nearby neighbors at the three facilities.

The process used for this review analysis starts with converting the EPA's Ldn data to Leq. To convert the EPA data from Ldn to Leq, which is used by the Maine DEP, a 6 dB factor is employed assuming steady operation day and night. For example, Ldn 55 equals an Leq of 49 dBA for a steady-state noise source. Then, the community noise impact assessment for this wind turbine site uses the following normalizing correction factors to the EPA's data to bring them into an analysis for Leq from wind turbines sited in rural areas:

0 dB for year round operation,
10 dB for being located in a quiet area,
5 dB for no prior experience and,
5 dB for impulsive character.

The resulting ranges of sound level for the normalized community noise reactions to wind turbines sited in rural areas were as follows. The Levels Document [A.3-1] indicates that the standard deviation of these data is 3.3 dB about their means and an envelope of +5 dB encloses approximately 90 percent of the cases.

"Vigorous action"	45 to 53 dBA
"Strong appeals to stop the noise"	44 to 51 dBA
"Widespread complaints"	34 to 41 dBA
"Sporadic complaints"	30 to 35 dBA
"No reaction"	24 to 35 dBA

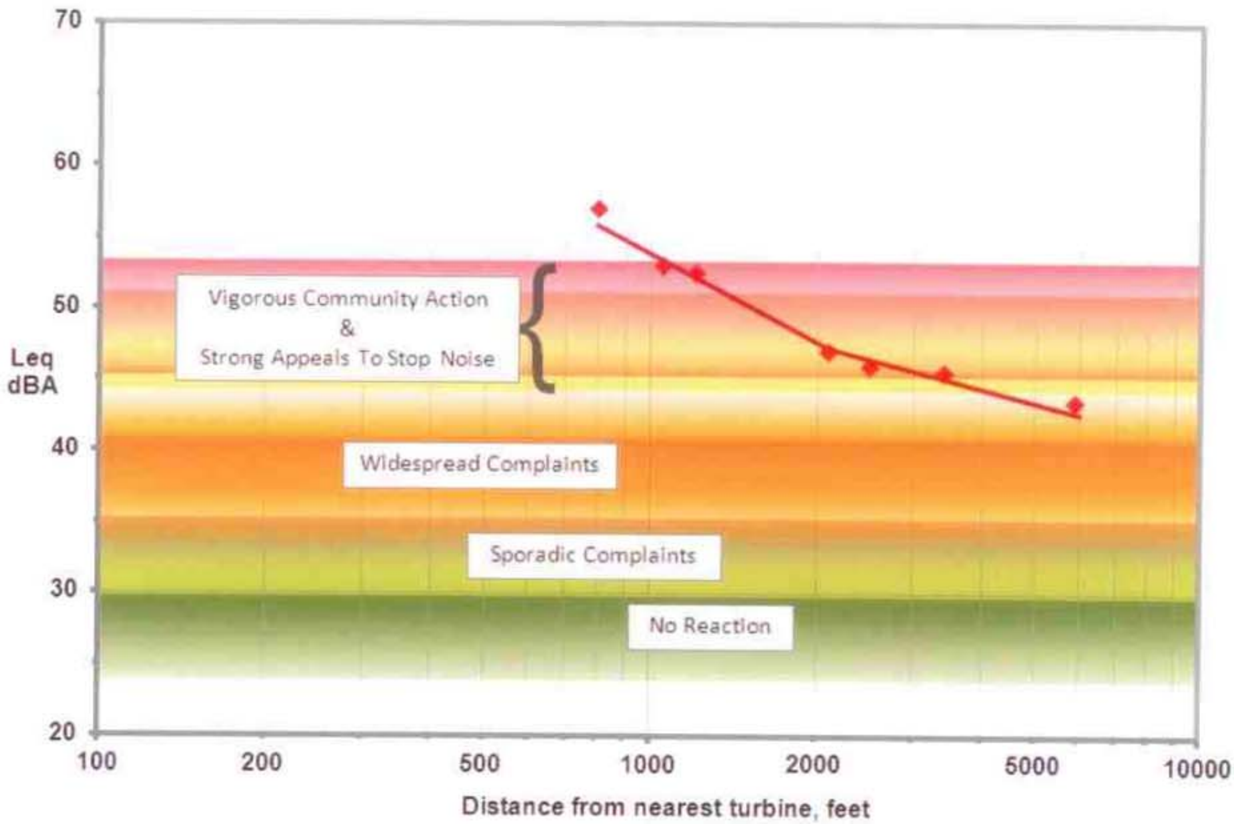
Then, the resulting community reactions were graphed by ranges of noise level listed above, and correlated to the measured sound levels versus distance, in the charts below for Mars Hill, Freedom, and Vinalhaven. The charts clearly illustrate the community reactions to those sites that are now well known from news coverage.

A.2-1. Information On Levels Of Environmental Noise Requisite To Protect Public Health And Welfare With An Adequate Margin Of Safety, 550/9-74-004, March 1974.

MARS HILL

Data for Mars Hill were obtained from the Sound Level Study, Compilation Of Ambient & Quarterly Operations Sound Testing, Maine Department of Environmental Protection Order No. L-21635-26-A-N. Highest measured hourly Leq levels are charted in Figure A.3-1 below as sound level versus distance from the nearest turbine. Nearby neighbors live as close as 800 feet out to several thousand feet from the turbine line.

Figure A.3-1. – Noise Impact By Predicted Community Reaction, Mars Hill.

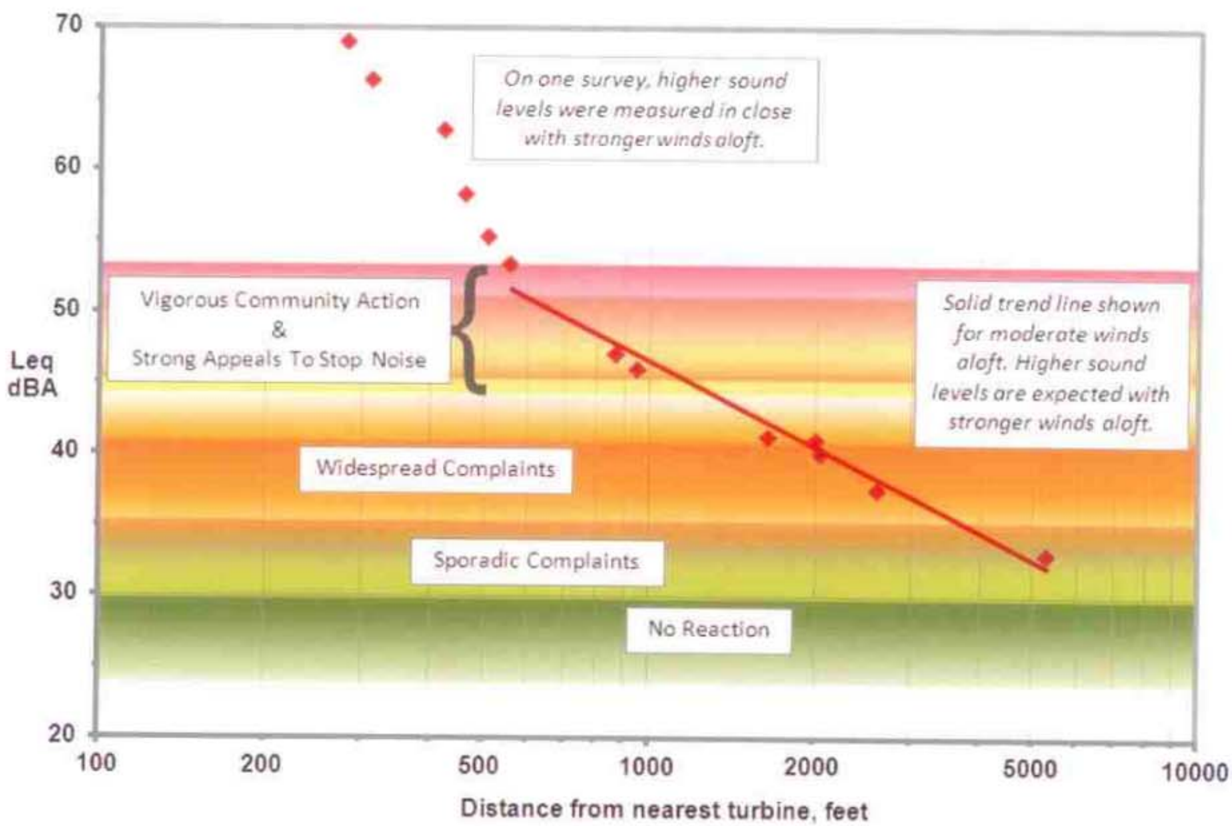


DEP permitted wind turbine noise levels of 50 dBA at nearby neighbors, and with an administrative letter, then allowed noise levels above 50 dBA, which elicited the highest negative community responses, "Strong appeals" and "Vigorous community action". Neighbors launched a lawsuit in March 2009 that is still underway as of the date of this report.

FREEDOM

Data for Freedom were acquired in 2010 during several independent field surveys by the authors. Field measurements were made with Type 1 instrumentation with calibration traceable to NIST, and all measurements were attended, with winds light or non-existent at the sound meter and in trees nearby, but with *moderate* winds aloft turning the wind turbines. Sound levels are expected to be higher with stronger winds aloft. The wind turbine noise was dominant in the levels reported in the Figure 3-2 below.

Figure 3-2. – Noise Impact By Predicted Community Reaction, Freedom.

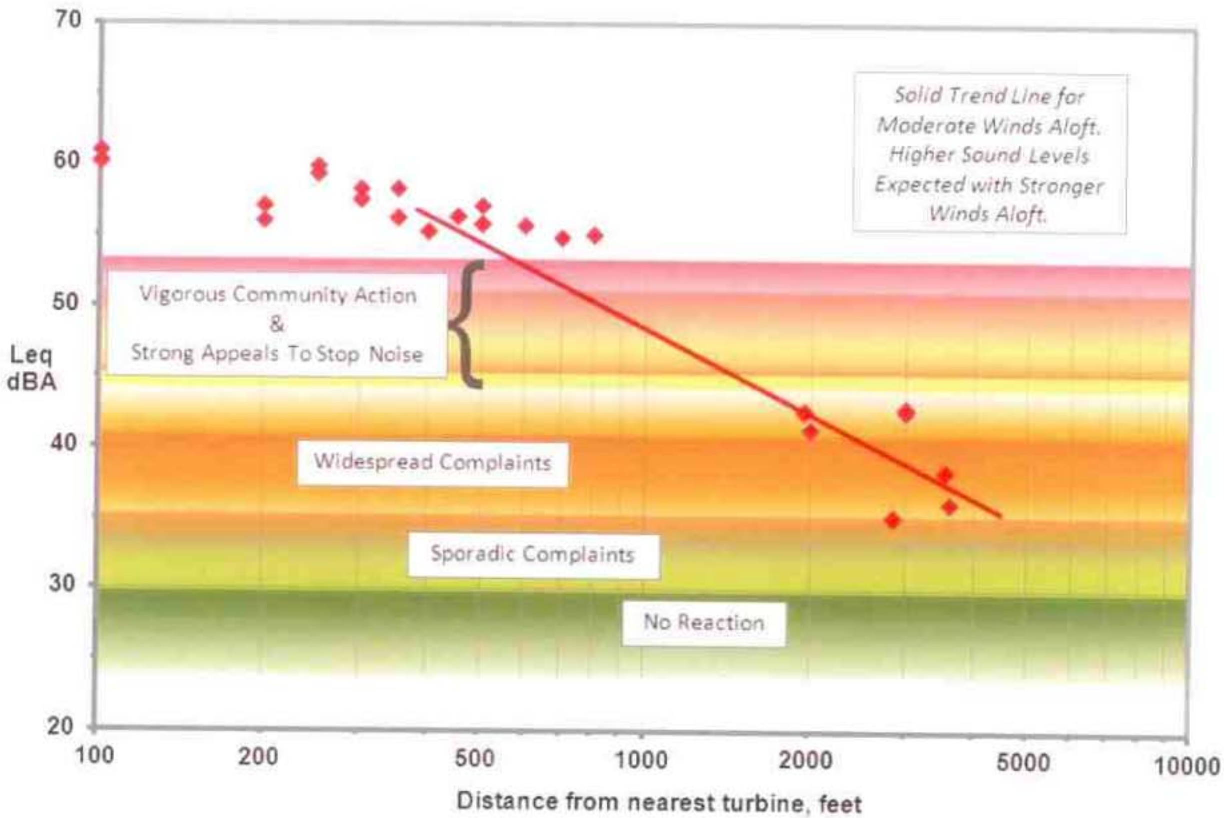


Counter to the Legislature's intent, the DEP chose not to regulate the Beaver Ridge Wind facility at all. Sound levels exceed 34 dBA within 4000 feet, resulting in "Widespread complaints" for those neighbors living within that range. For neighbors experiencing noise levels above 44 dBA, "Strong appeals" and "Vigorous community action" ensued with very expensive litigation borne by the residents from their own savings, and no relief to date.

VINALHAVEN

Data for Freedom were acquired in February 2010 during an independent field survey by the authors. Field measurements were made with Type 1 instrumentation with calibration traceable to NIST, and all measurements were attended, with winds light or non-existent at the sound meter and in trees nearby, but with *moderate* winds aloft turning the wind turbines. Sound levels are expected to be higher with stronger winds aloft. The wind turbine noise was dominant in the levels reported in the Figure 3-3 below.

Figure 3-3. – Noise Impact By Predicted Community Reaction, Vinalhaven.



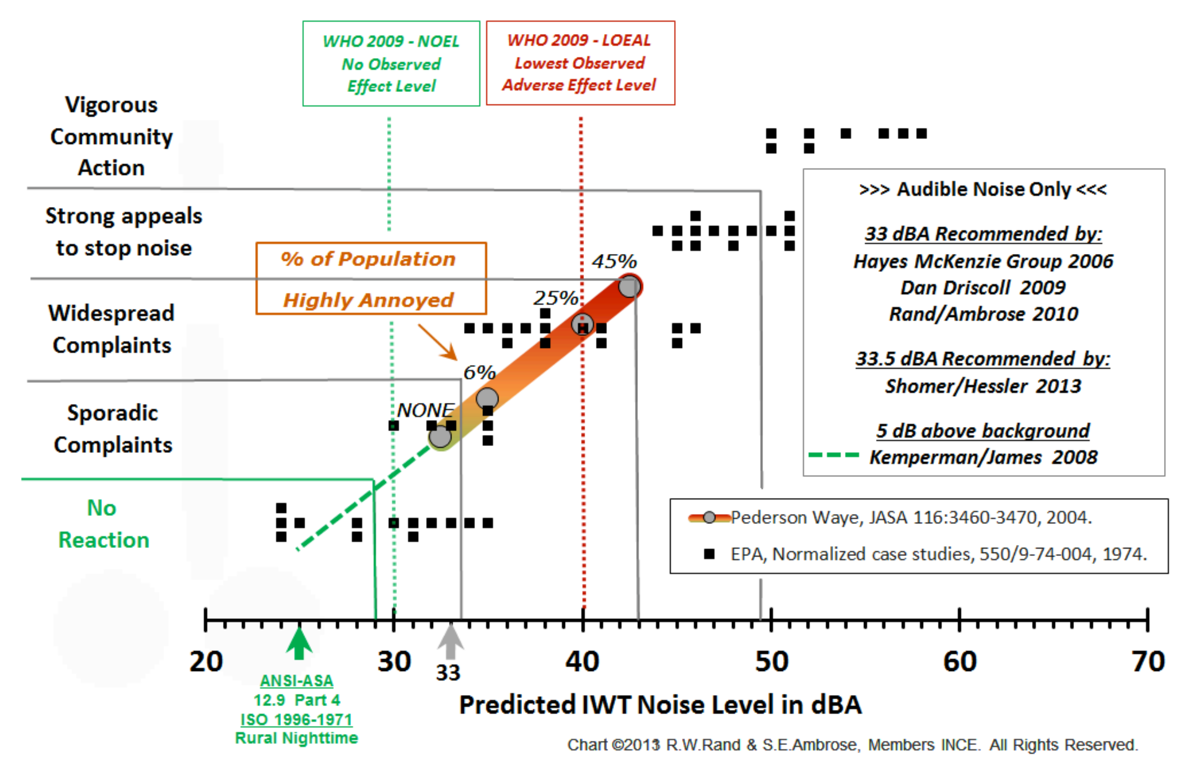
Sound levels exceed 34 dBA within several thousand feet, resulting in "Widespread complaints" for nearby neighbors living within that range. DEP permitted noise levels of 45 dBA at nearest neighbors (900 feet), who have also experienced noise levels exceeding 45 dBA, exhibiting reactions including "Strong appeals to stop the noise" and "Vigorous community action." retaining counsel, acquiring sound levels at their own expense and filing complaints to the DEP. It should be noted that Vinalhaven residents living *more than a couple of miles away* would have a predicted "No reaction" to the wind turbine facility noise emissions, and *that has been the case.*

Wind Turbine Noise Complaint Predictions Made Easy - Part 1

Acousticians have known for decades how to predict the community reaction to a new noise source. Wind turbine consultants have chosen not to predict the community reaction as they have previously done for other community noise sources. If they had, there would be far fewer wind turbine sites with neighbors complaining loudly about excessive noise and adverse health impacts.

In 1974, the USEPA published a methodology that can predict the community reaction to a new noise. A simple chart can be used that shows the community reactions (y-axis) versus noise level (x-axis). This chart was developed from 55 community noise case studies (black squares). The baseline noise levels include adjustments for the existing ambient, prior noise experience, and sound character. The predicted wind turbine noise level is plotted on the 'x-axis' and the predicted community reaction is determined by the highest reaction, indicated by the black squares. Here are some examples: 32 dBA <u>*no reaction*</u> and <u>*sporadic complaints*</u>, 37 dBA <u>*widespread complaints*</u>, 45 dBA <u>*strong appeals to stop noise*</u> and 54 dBA <u>*vigorous community action*</u>, the highest.

Predicted Community Reaction For Wind Turbines in a Quiet Area



The International Standards Organization (ISO) determined that 25 dBA represents a rural nighttime environment. The World Health Organization (WHO) found that noise below 30 dBA had <u>*no observed effect level*</u> (NOEL) and 40 dBA represented the <u>*lowest observed adverse effect level*</u> (NOAEL) for noise sources that excluded wind turbines. Wind turbines produce strong low frequency energy that may reduce the WHO cautionary levels by 5 dB, thereby showing closer agreement with the 33 dBA recommendations.

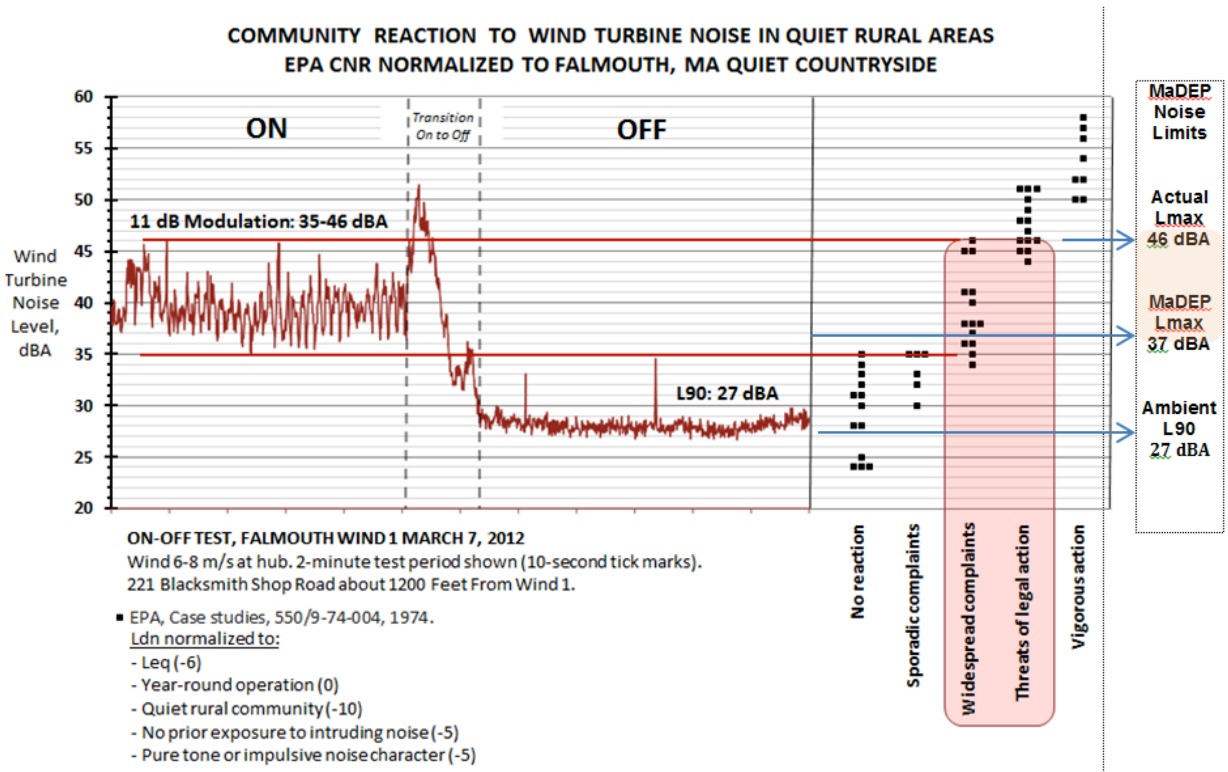
Pederson & Waye (2004) research found that when wind turbine noise levels reached 35 dBA, 6% of the population was *highly annoyed*, and this rapidly increased to 25% at 40 dBA. Independent researchers recommend that noise levels should not exceed 33 dBA, which is near the upper limit for <u>*sporadic complaints*</u>, or a maximum increase of 5 dB, whichever is more stringent.

15 Great Falls Road -- Windham, Maine 04062 -- Tel: 207-892-6691 -- Email: sea@myfairpoint.net -- 43.8033498, -70.4488508

Wind Turbine Noise Complaint Predictions Made Easy - Part 2

People react in a predictable manner to changes in sound level and frequency content caused by a new noise source. Wind turbines are the cause for numerous complaints about excessive noise and adverse health effects. These complaints will continue to be a public health hazard as long as modern acoustic instruments are used without a person listening to identify the sound sources or by manipulating computer prediction models to provide acceptable results. Wind turbine predictions are based on meeting a specific noise level. Regulatory boards and agencies are not assessing noise levels consistent with how people hear.

The wind turbines at Falmouth Massachusetts clearly show why there are so many neighbors complaining. An effective way to evaluate a sound source is by comparing the ON operation to OFF. The graph below shows wind turbine ON fluctuates from 35 to 46 dBA and when OFF decreases to 27 dBA.



Using the USEPA (1974) community noise assessment methodology adjusted for a quiet area, the predicted public reaction for wind turbine noise indicates *widespread complaints* and *threats of legal action*, as shown by the shaded box. Massachusetts DEP noise regulation limits the wind turbine ON maximum levels to no more than 10 dB above the ambient background (L90, exceeded 90% of the time) when OFF. The sound level increase is 19 dB for wind turbine operation.

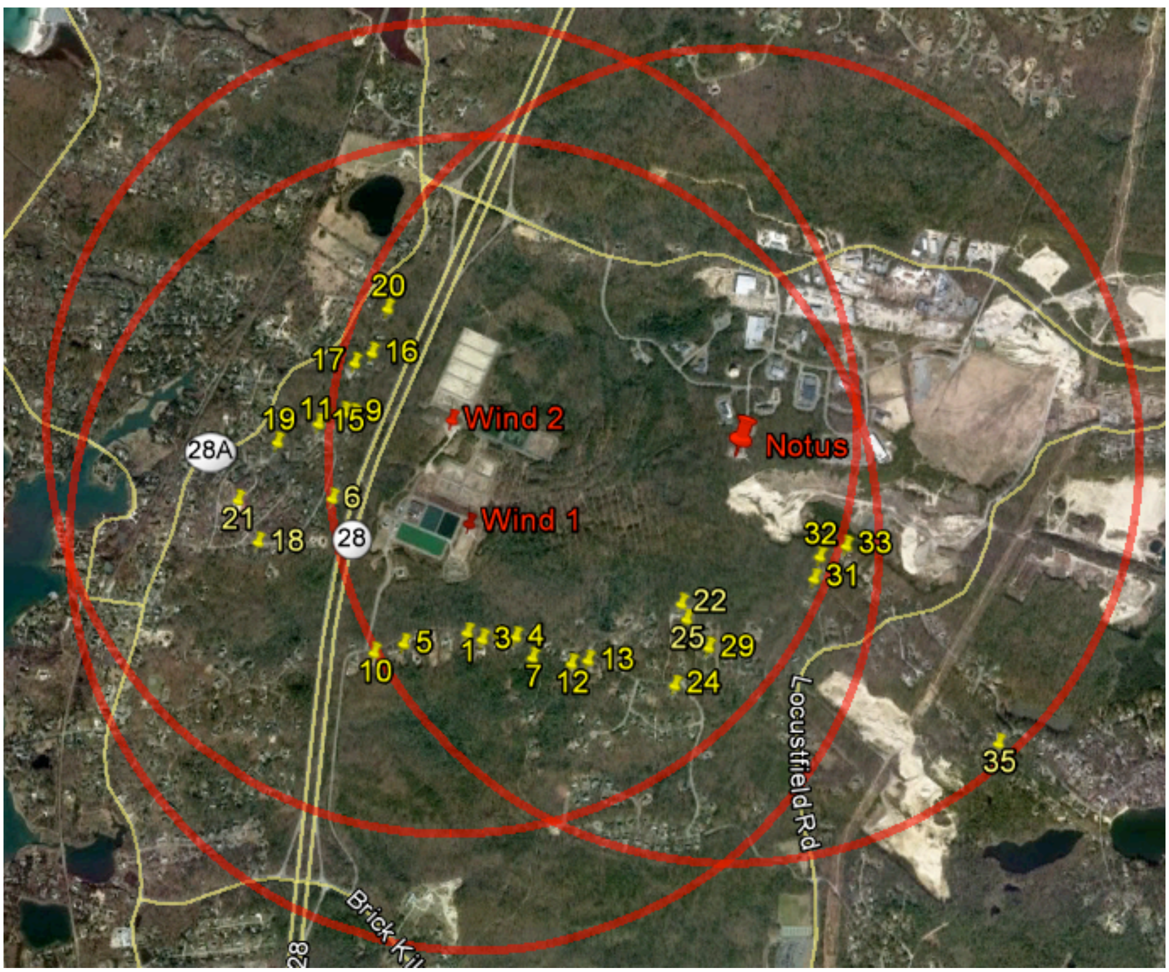
Stephen E. Ambrose, INCE, Bd Cert. - Specializing in Acoustics, Environmental Sound and Industrial Noise Control
15 Great Falls Road -- Windham, Maine 04062 -- Tel: 207-892-6691 -- Email: sea@myfairpoint.net -- 43.8033498, -70.4488508
15 Great Falls Road -- Windham, Maine 04062 -- Tel: 207-892-6691 -- Email: sea@myfairpoint.net -- 43.8033498, -70.4488508

Wind Turbine Noise Complaint Predictions Made Easy - Part 3

Sleep interruption and disturbance indicates the real potential for causing significant public harm from nearby wind turbines. A peer-reviewed research paper has investigated residents living near GE 1.5 MW wind turbines. Dr. Michael Nissenbaum, Jeffrey Aramini and Christopher Hanning published “Effects of industrial wind turbine noise on sleep and health” in the peer-reviewed bi-monthly journal *Noise & Health,* September-October 2012.

The study focused on sleep quality as defined by the *Pittsburg Sleep Quality Index* (PSQI), daytime sleepiness by *Epworth Sleepiness Score* (ESS), and general health according to SF36 ver2; *Mental Component Score* (MSC) and *Physical Component Score* (PSC). Residents received questionnaires based on participant-inclusion criteria for individuals living within 1.5-km (4921-ft) of the nearest 1.5 MW wind turbine(s). Baseline random samples were collected from residents living 3 to 7 km (9840 to 22,965-ft) away. The study conclusion has a strong recommendation for a separation distance of 1.4-km (4593-ft) away from a 1.5 MW wind turbine. This would be especially true for wind turbines located in quiet environments.

An aerial photo shows the locations of Falmouth’s Wind 1, 2 and NOTUS turbines as red pins. The above sleep study-recommended separation distance of nearly 4600 ft is shown as red circles. The Falmouth Board of Health’s health study (June 11, 2012) confirms the sleep study’s conclusion for complaints inside the red circles with yellow pins inside.



15 Great Falls Road -- Windham, Maine 04062 -- Tel: 207-892-6691 -- Email: sea@myfairpoint.net -- 43.803349°, -70.448850°

Wind Turbine Noise Complaint Predictions Made Easy - Part 4

Wind turbine developers promote wind energy for financial benefit for communities when they are built on municipally-owned properties as in Falmouth, Kingston, Scituate and Fairhaven. In return, towns relax their bylaw restrictions to permit loud industrial-type noise sources on municipal land often near quiet residential areas. Town planners approve wind turbine development without performing proper reviews as required in the bylaws. Towns understand they can build a municipal project in any land use zone. However, these projects still need to comply with the zoning bylaws.

Zoning bylaws are enacted to control community development to minimize conflicts between abutting land uses. Industrial and commercial development often produces more traffic, noise, smoke, odors, etc. than residential use. Industrial and commercial facilities are limited to districts with large lots and setback distances. Residential district restrictions protect neighbors' expectations for peace, tranquility and protection of public health and wellbeing.

Bylaws are implemented to provide guidance to town officials and regulatory boards. Public officials are required to perform their duties in a consistent manner. Boards review new developments for appropriate economics, engineering and environmental impacts. Decisions can become emotional when there are disputed considerations for public good versus public harm. Boards are required to enforce their bylaws and should not alter rules, grant waivers or create amendments to benefit a project under consideration.

Too many towns have adopted changes to encourage wind turbine development, changes which were later proven detrimental to public health, safety and wellbeing. Large wind turbines produce loud noise levels that travel thousands of feet and could not comply with existing town bylaw noise limits.

Stephen E. Ambrose, INCE, Bd Cert. - Specializing in Acoustics, Environmental Sound and Industrial Noise Control
15 Great Falls Road -- Windham, Maine 04062 -- Tel: 207-892-6691 -- Email: sea@myfairpoint.net -- 43.803349[8], -70.448850[8]
15 Great Falls Road -- Windham, Maine 04062 -- Tel: 207-892-6691 -- Email: sea@myfairpoint.net -- 43.803349[8], -70.448850[8]

EXHIBIT 9

Perception and annoyance due to wind turbine noise—a dose–response relationship

Eja Pedersen[a)] and Kerstin Persson Waye
Department of Environmental Medicine, Göteborg University, P.O. Box 414, SE-405 30 Göteborg, Sweden

(Received 14 November 2003; revised 1 September 2004; accepted 18 September 2004)

Installed global wind power increased by 26% during 2003, with U.S and Europe accounting for 90% of the cumulative capacity. Little is known about wind turbines' impact on people living in their vicinity. The aims of this study were to evaluate the prevalence of annoyance due to wind turbine noise and to study dose–response relationships. Interrelationships between noise annoyance and sound characteristics, as well as the influence of subjective variables such as attitude and noise sensitivity, were also assessed. A cross-sectional study was performed in Sweden in 2000. Responses were obtained through questionnaires ($n=351$; response rate 68.4%), and doses were calculated as A-weighted sound pressure levels for each respondent. A statistically significant dose–response relationship was found, showing higher proportion of people reporting perception and annoyance than expected from the present dose–response relationships for transportation noise. The unexpected high proportion of annoyance could be due to visual interference, influencing noise annoyance, as well as the presence of intrusive sound characteristics. The respondents' attitude to the visual impact of wind turbines on the landscape scenery was found to influence noise annoyance.
 [DOI: 10.1121/1.1815091]

PACS numbers: 43.50.Qp, 43.50.Sr [LCS] Pages: 3460–3470

I. INTRODUCTION

Wind turbines generate renewable energy and thus contribute to sustainable development. However, disturbance from wind turbines may be an obstacle for large-scale production (Rand and Clarke, 1990; Ackerman and Söder, 2000). Few studies have so far been directed to the prevalence of disturbance, and existing knowledge of annoyance due to wind turbines is mainly based on studies of smaller turbines of less than 500 kW (Wolsink *et al.*, 1993; Pedersen and Nielsen, 1994).

Global wind power installed at the end of 2003 reached 39 GW according to American Wind Energy Association (2004), an increase of 26% in just one year. United States (7 GW) and Europe (29 GW) account for 90% of the cumulative capacity. In Sweden, more than 600 wind turbines are operating today with a total installed capacity of 0.4 GW, producing 600 GWh per year. They are placed in 84 of Sweden's 290 municipalities both along the coasts and in rural inland areas, concerning a number of people. The goal set up by the Swedish government for 2015 is 10 TWh, leading to an increase of 1600% from today. Most of these new turbines will probably be situated off shore, but as the cost for building on land is considerably lower, the development on land is expected to continue. Already, turbines are being erected near densely populated areas. Preliminary interviews conducted among 12 respondents living within 800 m of a wind turbine, and a register study of the nature of complaints to local health and environments authorities, indicated that the main disturbances from wind turbines were due to noise, shadows, reflections from rotor blades, and spoiled views (Pedersen, 2000).

All wind turbines in Sweden are upwind devices. The most common type is a 600 or 660 kW turbine with three rotor blades, rotor diameter 42–47 m, constant rotor speed 28 rpm (84 blade passages per minute, a blade passage frequency of 1.4 Hz), and hub height of 40–50 m. They often operate singly or in multiple units of 2 to 10. The noise emission at the hub is 98–102 dBA measured at wind velocity 8 m/s at 10 m height. Earlier turbines were often downwind devices and contained low-frequency noise (Hubbard *et al.*, 1983). In contrast to these, modern machines have the rotor blades upwind and the noise is typically broadband in nature (Fig. 1), (Persson Waye and Öhrström, 2002; Björkman, 2004). There are two main types of noise sources from an upwind turbine: mechanical noise and aerodynamic noise. Mechanical noise is mainly generated by the gearbox, but also by other parts such as the generator (Lowson, 1996). Mechanical noise has a dominant energy within the frequencies below 1000 Hz and may contain discrete tone components. Tones are known to be more annoying than noise without tones, but both mechanical noise and tones can be reduced efficiently (Wagner *et al.*, 1996). Aerodynamic noise from wind turbines has a broadband character. It originates mainly from the flow of air around the blades; therefore the sound pressure levels (SPLs) increase with tip speed. Aerodynamic noise is typically the dominant component of wind turbine noise today, as manufacturers have been able to reduce the mechanical noise to a level below the aerodynamic noise. The latter will become even more dominant as the size of wind turbines increase, because mechanical noise does not increase with the dimensions of turbine as rapidly as aerodynamic noise (Wagner *et al.*, 1996).

Previous international field studies of annoyance from wind turbines have generally found a weak relationship between annoyance and the equivalent A-weighted SPL (Rand

[a)]Electronic mail: eja.pedersen@set.hh.se

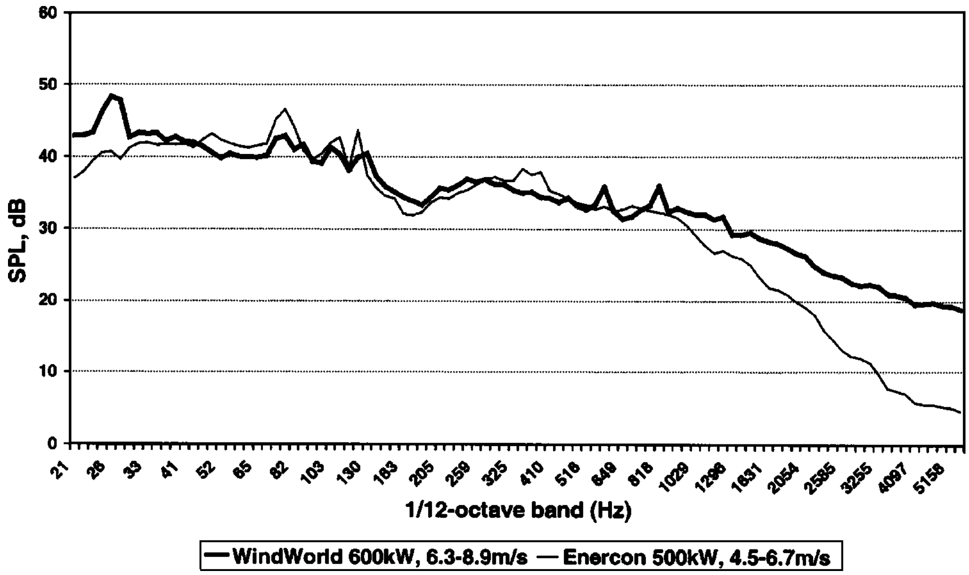


FIG. 1. Frequency spectra of two upwind three-bladed wind turbines recorded at down wind conditions; WindWorld 600 kW and Enercon 500 kW.

and Clarke, 1990; Wolsink *et al.*, 1993; Pedersen and Nielsen, 1994). It is possible that different sound properties, not fully described by the equivalent A-weighted level, are of importance for perception and annoyance for wind turbine noise. Support for such a hypothesis was given in a previous experimental study where reported perception and annoyance for five recorded wind turbine noises were different, although the equivalent A-weighted SPL were the same (Persson Waye and Öhrström, 2002). The results from that study and subsequent experiments suggested that the presence of sound characteristics subjectively described as lapping, swishing, and whistling was responsible for the differences in perception and annoyance between the sounds (Persson Waye and Agge, 2000). The descriptions swishing and whistling were found to be related to the frequency content in the range of 2000 to 4000 Hz (Persson Waye *et al.*, 1998) while the description lapping probably referred to aerodynamically induced fluctuations and was found to best be described by specific loudness over time (Persson Waye *et al.*, 2000). Sound characteristics such as described here could be of relevance for perception and annoyance, especially at low background levels.

It has been suggested that the perception of wind turbine noise could be masked by wind-generated noise. However, most of the wind turbines operating today have a stable rotor speed, and, as a consequence, the rotor blades will generate an aerodynamic noise even if the wind speed is slow and the ambient noise is low. Furthermore, noise from wind turbines comprises modulations with a frequency that corresponds to the blade passage frequency (Hubbard *et al.*, 1983) and is usually poorly masked by ambient noise in rural areas (Arlinger and Gustafsson, 1988).

It has also been shown in previous field studies that attitude to wind turbines is relevant to perceived annoyance (Wolsink *et al.*, 1993; Pedersen and Nielsen, 1994). Such a relationship, however, was not found in an experimental study where the participants were exposed to wind turbine noise (Persson Waye and Öhrström, 2002). The difference could be due to the fact that the subjects in the latter study had very little personal experience of wind turbines generally, or to their lack of visual impression during the noise exposure.

There is clearly a need for field studies to investigate the impact of wind turbines on people living in their vicinity and to further explore the presence of disturbances. In particular, dose–response relationships should be investigated to achieve a more precise knowledge of acceptable exposure levels. As noise annoyance may be interrelated to the presence of intrusive sound characteristics, ambient sound pressure level, and visual intrusion as well as individual variables, all these factors should be taken into account and their relative importance evaluated.

The aims of this study were to evaluate the prevalence of annoyance due to wind turbine noise and to study dose–response relationships. The intention was also to look at interrelationships between noise annoyance and sound characteristics, as well as the influence of subjective variables such as attitude and noise sensitivity.

II. METHOD

A. General outline

The investigation was a cross-sectional study comprising respondents exposed to different A-weighted sound pressure levels (SPL) from wind turbines. Five areas totaling 22 km^2 comprising in total 16 wind turbines and 627 households were chosen within a total area of 30 km^2 (Table I). Subjective responses were obtained through questionnaires delivered at each household and collected a week later in May and June 2000. The response rate was 68.4%. A-weighted SPLs due to wind turbines were calculated for each respondent's dwelling. Comparisons were made of the extent of annoyance between respondents living at different A-weighted SPLs.

B. Study area and study sample

The criteria for the selection of the study areas were that they should comprise a large enough number of dwellings at varying distances from operating wind turbines within a

TABLE I. Description of study areas.

Area	Square km	Wind turbines	Households	Study population	Responses	Response rate (%)
A	3.7	2	89	75	54	72.0
B	4.7	3	44	33	23	69.7
C	8.3	8	70	59	49	83.1
D	3.3	2	393	325	210	64.6
E	2.0	1	31	21	15	71.4
Total	22.0	16	627	513	351	68.4

comparable geographical, cultural, and topographical structure. Suitable areas were found in a municipality in the south of Sweden. More than 40 wind turbines are located in this region, either in small groups with two to five turbines or as single objects. The landscape is flat and mainly agricultural but small industries, roads, and railroads are also present. Most people live in privately owned detached houses in the countryside or in small villages. The wind turbines are visible from many directions. To define the study area, preliminary calculations of sound distribution were made so that the area would include dwellings exposed to similar A-weighted SPL irrespective of the number of wind turbines. Of the 16 wind turbines in the selected five areas, 14 had a power of 600–650 kW, the other two turbines having 500 kW and 150 kW. The towers were between 47 and 50 m in height. Of the turbines, 13 were WindWorld machines, 2 were Enercon, and 1 was a Vestas turbine. Figure 1 shows a $\frac{1}{12}$-octave band spectra of a WindWorld turbine sound recorded 320 m from a turbine in area A at 6.3–8.9 m/s and a spectra of an Enercon turbine sound recorded 370 m from the turbine in area E at 4.5–6.7 m/s. Both recordings were done under downwind conditions.

The study sample comprised one selected subject between the ages of 18 and 75 in each household in the area within a calculated wind turbine A-weighted SPL of more than 30 dB ($n=513$). The subject with birth date closest to May 20 was asked to answer a questionnaire.

C. Questionnaire

The purpose of the study was masked in the questionnaire; the questions on living conditions in the countryside also included questions directly related to wind turbines. The response of most questions was rated on 5-point or 4-point verbal rating scales. The key questions relevant for this paper were translated into English and are presented in the Appendix. The questionnaire was divided into four sections. The first section comprised questions regarding housing and satisfaction with the living environment, including questions on the degree of annoyance experienced outdoors and indoors from several sources of annoyance, wind turbines included. The respondent was also asked to rate his/her sensitivity to environmental factors, one being noise.

The second section of the questionnaire comprised questions on wind turbines, related to the respondent by the recent development of wind turbines in the community. The response to different visual and auditory aspects of wind turbines as noise and shadows were asked for, followed by questions on frequency of disturbances and experiences during certain activities and weather conditions. Respondents were also asked to describe their level of perception and annoyance related to the wind turbine sounds they could hear, using verbal descriptors of sound and perceptual characteristics. These descriptors were obtained from previous experimental studies were subjects initially verbally described their perception of annoying sound properties for five recorded wind turbine sounds (Persson Waye and Öhrström, 2002). This, together with some given adjectives, resulted in a total of 14 adjectives that were rated on unipolar scales with regard to annoyance. In this field study, the original descriptors were complemented with regionally used phrases. Several questions on attitude to wind turbines were also included.

The third section of the questionnaire concerned health aspects such as chronic illnesses (diabetes, tinnitus, cardiovascular diseases, hearing impairment) and general well-being (headache, undue tiredness, pain and stiffness in the back, neck or shoulders, feeling tensed/stressed, irritable). Respondents were asked questions about their normal sleep habits: quality of sleep, whether sleep was disturbed by any noise source, and whether they normally slept with the window open. The last section comprised questions on employment and working hours.

D. Calculations and measurements of noise exposure

For each respondent, A-weighted SPLs (dB) were calculated as the sum of contributions from the wind power plants in the specific area. The calculations were made with calculation points every fifth meter. The calculations followed the sound propagation model for wind power plants adopted by the Swedish Environmental Protection Agency (2001) and used as a basis for granting of building permission. The model assumes downward wind of 8 m/s at 10-m height. The calculation model is slightly different depending on the distance between the source and the receiver. For the cases in this study the following equation was used:

$$L_A = L_{WA,corr} - 8 - 20\lg(r) - 0.005r, \qquad (1)$$

where r is the distance from the source to the receiver in meters. The atmospheric absorption coefficient is estimated to be 0.005 dB/m. $L_{WA,corr}$ is a modified sound power level of the wind power:

$$L_{WA,corr} = L_{WA} + k \cdot \Delta v_h. \qquad (2)$$

TABLE II. Study sample, study population, and response rate related to sound category (dBA).

Sound category	<30.0	30.0–32.5	32.5–35.0	35.0–37.5	37.5–40.0	>40.0	Total
Study sample	25	103	200	100	53	32	513
Study population	15	71	137	63	40	25	351
Response rate	60.0%	68.9%	68.5%	63.0%	75.5%	78.1%	68.4%

L_{WA} is the A-weighted sound power level of the wind power plant, which in this study was given by the manufacturer; k describes how the sound power level varies with the wind speed at 10 m height and

$$\Delta v_h = v_h \left(\frac{\ln(H/z_0)}{\ln(h/z_0)} \frac{\ln(h/0.05)}{\ln(H/0.05)} - 1 \right), \tag{3}$$

where v_h is the wind speed at 10-m height, H the height of the hub, h is 10 m, and z_0 the surface roughness length. In these calculations, $z_0 = 0.05$ m (fields with few buildings) was used and therefore no value of k was needed. The SPL calculated this way is an estimate for the equivalent level for a hypothetical time period with continuous performance at downwind conditions 8 m/s at 10-m height.

To verify the calculations, to record frequency spectra, and to study background sound, a mobile caravan equipped with a sound level meter (Larson & Davis type 820), digital audio tape recorder (Sony TCD-D8 DAT), and meteorological instruments (Davis Weather Monitor type II) was used. The mobile station was placed on different sites of the study area. Both the meteorological instruments and the noise recording instruments were computer controlled and directed remotely via a cellular phone. The microphone was attached on a vertical hardboard facing the noise source. The equipment and procedures are thoroughly described by Björkman (2004). The sound pressure levels measured on the reflecting plane were corrected by −6 dB to present the free field value. The ambient sound pressure level varied from 33 dB $L_{\mathrm{Aeq,5\,min}}$ to 44 dB $L_{\mathrm{Aeq,5\,min}}$. The variations were mainly due to the amount of traffic within a 24-h time period. The lower background levels typically occurred during evening and nights.

The respondents were classified into six sound categories according to the calculated wind turbine A-weighted SPL at their dwelling. Table II shows the number of respondents living within each sound category and also the study sample and response rate for each sound category.

Data for the distance between the dwelling of the respondent and the nearest wind turbine were obtained from property maps, scale 1:10 000. The distance differed within each sound category, depending on the number of wind turbines in the area—the larger number of wind turbines, the shorter distance at the same A-weighted SPL. Table III shows the relationship between distance and A-weighted SPL. Two values are given for each category: the range and the median interval.

E. Statistical treatment of data

Due to the fact that most of the data were categorical (ordered or nonordered) and not continuos data, and therefore no assumptions on probability distribution could be made, nonparametric statistical methods were used, all described by Altman (1991). Data from verbal rating scales were calculated as proportions with 95% confidence intervals. When relevant, the two highest ratings of annoyance (rather annoyed and very annoyed) were classified as annoyed and the three lower ones as not annoyed (do not notice, notice but not annoyed, and slightly annoyed). In the analysis of attitude, negative and very negative were classified as negative; in the analysis of sensitivity, rather sensitive and very sensitive were classified as sensitive. More advanced statistical analyses were carried out using SPSS version 11.0. Relationships between variables were evaluated using Spearman's nonparametric rank correlation (r_s). Pearson's chi-square (chi2) was used to test that all sound categories contained the same proportion of observations. To evaluate differences between two unmatched samples of observations on an ordinal scale (e.g., comparing men and women's answers on a 5-graded verbal rating scale), the Mann–Whitney test was used (z_{MW}); a nonparametric test equivalent to the t test, but based on ranks (Altman, 1991). All significance tests were two-sided and p-values below 0.05 were considered statistically significant. When exploring several relationships at the same time, 1 out of 20 calculations would be classified as statistically significant by chance. This risk of mass significance was avoided using Bonferroni's method when appropriate, reducing the p-value considered statistically significant by dividing it with the number of correlations calculated at the same time (Altman, 1991).

Binary logistic multiple regression was used to study the impact of different variables on annoyance of wind turbine noise (annoyed–not annoyed). Sound category was used as the dose variable. Logistic regression is a method used to make a nonlinear function into a linear equation, using odds rather than straightforward probability. The equation is

TABLE III. Distance between dwelling and nearest wind turbine related to sound category (dBA).

Sound category	<30.0	30.0–32.5	32.5–35.0	35.0–37.5	37.5–40.0	>40.0
Range (m)	650–1049	550–1199	450–1099	300–799	300–749	150–549
Median interval (m)	850–899	750–799	550–599	450–499	350–399	300–349

TABLE IV. Characteristics of the respondents given as proportions of respondents in each sound category (dBA) and in total.

Sound category	<30.0	30.0–32.5	32.5–35.0	35.0–37.5	37.5–40.0	>40.0	Total
n	15	71	137	63	40	25	351
Gender: Male (%)	27	35	39	50	50	48	42
Residence: Detached houses/farms (%)	100	83	61	100	97	96	81
Occupation: Employed (%)	67	59	58	53	69	67	60
Sensitive[a] to noise (%)	62	44	49	53	58	50	50
Negative[b] to wind turbines (%)	8	10	11	18	20	8	13
Negative[b] to visual impact (%)	43	33	38	41	40	58	40
Long-term illness (%)	20	29	28	16	30	24	26
Age: Mean	46	47	47	50	48	48	48
(SD)	(13.3)	(13.7)	(14.3)	(14.6)	(13.1)	(14.3)	(14.0)

[a]Sensitive consists of the two ratings: rather sensitive and very sensitive.
[b]Negative consists of the two ratings: rather negative and very negative.

$$\ln\left(\frac{p}{1-p}\right)=b_0+b_1x_1+b_2x_2+\cdots, \qquad (4)$$

where, in this case, p is the probability of being annoyed by noise from wind turbines, x_1–x_n are the variables put into the model, and b_1–b_n are the logarithmic value of the odds ratio for one unit change in the respective variable (Altman, 1991). A relevant measurement of explained variance using nonparametric statistics is Nagelkerke pseudo-R^2 (Nagelkerke, 1991).

To estimate how consistently the respondents answered to questions measuring similar response, Cronbach's alpha (Miller, 1995) was calculated as a testing of the internal consistency reliability of the questionnaire. Five of the questions regarding wind turbine noise were compared: annoyance outdoors, annoyance indoors, annoyance of rotor blades, annoyance of machinery, annoyance as a describing adjective. Demographic data on age and gender of the population in the four parishes in the study area were collected from local authorities. The study population was compared to these demographical data, parish-by-parish, and divided into 10-year categories for age and gender, as well as in total.

III. RESULTS

A. Study population

The overall response rate was 68.4%, ranging from 60.0% to 78.1% in the six sound categories (Table II). No statistically significant differences in variables related to age, gender, or employment were found among sound categories (Table IV). A statistically significant difference was found between sound categories as to whether respondents lived in apartments or detached houses (chi2=62.99, df=5, $p<0.001$). Overall, most of the respondents (80%) lived in privately owned detached houses or on farms. The remaining lived in tenant-owned or rented apartments. The latter were more frequent in sound category 32.5–35.0 dBA (Table IV). However, there was no statistically significant difference between the respondents living in privately owned detached houses or on farms, on one hand, and those living in tenant-owned or rented apartments, on the other hand, regarding subjective factors, when correcting for requirements to avoid mass significance. Most of the respondents did not own a wind turbine or share of a wind turbine (95%, $n=335$). No statistically significant differences in variables related to noise sensitivity, attitude, or health were found between the different sound categories.

The mean age in the study population was 48 years (SD =14.0) (Table IV) which did not differ statistically significantly from the demographic data (45 years, SD=15.2). The proportion of women in the study population was slightly higher than in the demographic data; in the study population, 58% women and 42% men (Table IV), compared to 49% women and 51% men in the demographic data. However, no statistically significant differences were found between men and women regarding perception and annoyance due to wind turbine noise, noise sensitivity, or attitude to wind turbines. Differences between genders were found regarding well-being. Women suffered more often from headache ($z_{MW}=-3.243$, $n=328$, $p<0.001$), undue tiredness ($z_{MW}=-3.549$, $n=327$, $p<0.05$), pain and stiffness in back, neck or shoulders ($z_{MW}=-3.312$, $n=331$, $p<0.001$), and tension/stress ($z_{MW}=-3.446$, $n=328$, $p<0.001$).

B. Main results

The proportion of respondents who noticed noise from wind turbines outdoors increased sharply from 39% ($n=27$, 95%CI: 27%–50%) at sound category 30.0–32.5 dBA to 85% ($n=53$, 95%CI: 77%–94%) at sound category 35.0–37.5 dBA (Table V). The proportion of those annoyed by wind turbine noise outdoors also increased with higher sound category, at sound categories exceeding 35.0 dBA. The correlation between sound category and outdoor annoyance due to wind turbine noise (scale 1–5) was statistically significant ($r_s=0.421$, $n=341$, $p<0.001$). No respondent self-reported as annoyed at sound categories below 32.5 dBA, but at sound category 37.5–40.0 dBA, 20% of the 40 respondents living within this exposure were very annoyed and above 40 dBA, 36% of the 25 respondents (Table V).

To explore the influence of the subjective factors on noise annoyance, binary multiple logistic regression was used (Table VI). Eight models were created, all containing sound category as the prime variable assumed to predict noise annoyance. The three subjective factors of attitude to visual impact, attitude to wind turbines in general, and sensitivity to noise were forced into the model one-by-one, two-by-two, and finally all together. In the first model only noise

TABLE V. Perception and annoyance outdoors from wind turbine noise related to sound exposure.

	<30.0 $n=12$ %(95%CI)	30.0–32.5 $n=70$ %(95%CI)	32.5–35.0 $n=132$ %(95%CI)	35.0–37.5 $n=62$ %(95%CI)	37.5–40.0 $n=40$ %(95%CI)	>40.0 $n=25$ %(95%CI)
Do not notice	75 (51–100)	61(50–73)	38(30–46)	15(3–23)	15(4–26)	4(19–57)
Notice, but not annoyed	25(1–50)	24(14–34)	28(20–36)	47(34–59)	35(20–50)	40(19–57)
Slightly annoyed	0	14(6–22)	17(10–23)	26(15–37)	23(10–35)	12(19–57)
Rather annoyed	0	0	10(5–15)	6(0–13)	8(−1–16)	8(19–57)
Very annoyed	0	0	8(3–12)	6(0–13)	20(8–32)	36(17–55)

exposure was used as the independent variable. The Exp(b) was 1.87, i.e., the odds for being annoyed by noise from wind turbines would increase 1.87 times from one sound category to the next. When adding the subjective factor of attitude to visual impact as an independent variable, the influence of the noise exposure decreased, but was still statistically significant. The pseudo-R^2 increased from 0.13 to 0.46, indicating that the new model explained 46% of the variance in annoyance. Adding the two remaining subjective factors did not improve the model as the coefficients did not reach statistical significance.

Noise from rotor blades was reported as the most annoying aspect of wind turbines. Of the respondents, 16% ($n=54$, 95%CI: 12%–20%) were annoyed by noise from rotor blades. Changed view (14%, $n=48$, 95%CI: 10%–18%), noise from machinery (9%, $n=33$, 95%CI: 6%–12%), shadows from rotor blades (9%, $n=29$, 95%CI: 6%–11%), and reflections from rotor blades (7%, $n=22$, 95%CI: 4%–9%) were also reported.

C. Attitude and sensitivity

Almost all respondents (93%, $n=327$, 95%CI: 91%–96%) could see one or more wind turbines from their dwelling or garden. When asked for judgments on wind turbines, the adjectives that were agreed on by most respondents were "environmentally friendly" (79%), "necessary" (37%), "ugly" (36%), and "effective" (30%). Only the word "annoying" (25%) was judged higher among those in higher sound categories than among those in lower sound categories ($z_{MW}=-3.613$, $n=351$, $p<0.001$).

The high judgment of the word "ugly" corresponds to the outcome of the attitude questions. Of the respondents, only 13% ($n=44$, 95%CI: 9%–16%) reported that they were negative or very negative to wind turbines in general, but 40% ($n=137$, 95%CI: 34%–44%) that they were negative or very negative to the visual impact of wind turbines on the landscape scenery (Table IV).

All correlations between sound category, noise annoyance, and subjective factors are shown in Table VII. Noise annoyance was correlated to both sound category and the three subjective factors, strongest to attitude to the wind turbines' visual impact on the landscape. The subjective factors were also correlated to each other, except for general attitude and sensitivity to noise. Of all the respondents, 50% ($n=169$, 95%CI: 45%–55%) regarded themselves as rather sensitive or very sensitive to noise (Table IV).

When comparing those annoyed by wind turbine noise and those not, no differences were found regarding the judgments of the local authorities, with the exception of perceived opportunity to influence local government ($z_{MW}=-2.753$, $n=300$, $p<0.005$). Those annoyed reported negative changes to a higher degree ($z_{MW}=-5.993$, $n=307$, p

TABLE VI. Results of multiple logistic regression analyses with 95% confidence intervals.

	Variables	b	p-value	Exp(b) (95%CI)	Pseudo-R^{2}[a]
1	Noise exposure	0.63	<0.001	1.87(1.47–2.38)	0.13
2	Noise exposure	0.55	<0.001	1.74(1.29–2.34)	0.46
	Attitude to visual impact	1.62	<0.001	5.05(3.22–7.92)	
3	Noise exposure	0.62	<0.001	1.86(1.45–2.40)	0.20
	Attitude to wind turbines	0.56	<0.001	1.74(1.30–2.33)	
4	Noise exposure	0.63	<0.001	1.88(1.46–2.42)	0.18
	Sensitivity to noise	0.56	<0.005	1.75(1.19–2.57)	
5	Noise exposure	0.55	<0.001	1.73(1.28–2.33)	0.46
	Attitude to visual impact	1.66	<0.001	5.28(3.26–8.56)	
	Attitude to wind turbines	−0.10	0.319	0.91(0.64–1.28)	
6	Noise exposure	0.57	<0.001	1.77(1.30–2.40)	0.47
	Attitude to visual impact	1.59	<0.001	4.88(3.08–7.72)	
	Sensitivity to noise	0.22	0.344	1.25(0.79–1.96)	
7	Noise exposure	0.63	<0.001	1.88(1.45–2.45)	0.24
	Attitude to wind turbines	0.58	<0.001	1.78(1.32–2.41)	
	Sensitivity to noise	0.59	<0.005	1.80(1.22–2.67)	
8	Noise exposure	0.56	<0.001	1.76(1.29–2.39)	0.47
	Attitude to visual impact	1.63	<0.001	5.11(3.10–8.41)	
	Attitude to wind turbines	−0.10	0.597	0.91(0.64–1.29)	
	Sensitivity to noise	0.21	0.373	1.23(0.78–1.94)	

[a]Nagelkerke (1991).

TABLE VII. Correlation between noise annoyance, sound category (dBA) and the subjective variables. Statistically significant correlations in boldface. To avoid the risk of mass significance $p<0.008$ were required for statistical significance.

	Sound category	Attitude to visual impact	Attitude to wind turbines	Sensitivity to noise
Noise annoyance	**0.421**	**0.512**	**0.334**	**0.197**
Sound category	⋯	**0.145**	0.074	0.069
Attitude to visual impact		⋯	**0.568**	**0.194**
Attitude to wind turbines			⋯	0.023
Sensitivity to noise				⋯

<0.001); 83% compared to 37% among those not annoyed. Of the 138 respondents who reported negative changes overall, 41% ($n=57$, 95%CI: 33%–50%) specified wind turbines in the response to an open question.

D. The occurrence of noise annoyance

Among those who noticed wind turbine noise ($n=223$), 25% ($n=47$, 95%CI: 18%–31%) reported that they were disturbed every day or almost every day and 17% ($n=33$, 95%CI: 12%–23%) once or twice a week. Annoyance was most frequently reported when relaxing outdoors and at barbecue nights.

Perception of wind turbine noise was influenced by weather conditions. Of the respondents who noticed wind turbine noise, 54% stated that they could hear the noise more clearly than usual when the wind was blowing from the turbines towards their dwelling. Only 9% reported that the noise was heard more clearly when the wind was from the opposite direction. The noise was also more clearly noticed when a rather strong wind was blowing (39%), but 18% reported that the noise was more clearly noticed in low wind. For warm summer nights, 26% noticed the noise more clearly than usual.

E. Sound characteristics

There was a statistically significant correlation between sound category and annoyance due to noise from rotor blades ($r_s=0.431$, $n=339$, $p<0.001$) and from the machinery ($r_s=0.294$, $n=333$, $p<0.001$). In all sound categories, a higher proportion of respondents noticed noise from rotor blades than from the machinery (Fig. 2). The proportion who noticed noise from rotor blades was similar to the proportion of respondents who noticed wind turbine noise in general. Noise from rotor blades was noticed in lower sound categories than noise from the machinery, i.e., it could be heard at a greater distance. However, comparing the numbers of annoyed with the numbers of those who could hear noise from the two sources, respectively, both noises were almost equally annoying. Of the 215 respondents who noticed noise from rotor blades, 25% ($n=54$, 95%CI: 19%–31%) were annoyed. Of the 101 respondents who noticed noise from the machinery, 30% ($n=30$, 95%CI: 21%–39%) were annoyed.

Among those who noticed noise from wind turbines, swishing, whistling, pulsating/throbbing, and resounding were the most common sources of annoyance according to verbal descriptors of sound characteristics (Table VIII). These descriptors were all highly correlated to noise annoyance. All other verbal descriptors of sound characteristics were also statistically significantly correlated to noise annoyance, but to a lower degree. When analyzing annoyance due to noise from rotor blades, the strongest correlated verbal descriptor of sound characteristics was swishing ($r_s=0.807$, $n=185$, $p<0.001$), which can be compared to noise annoyance due to noise from the machinery—which had the highest correlation with scratching/squeaking ($r_s=0.571$, $n=133$, $p<0.001$).

F. Indoor noise annoyance and sleep disturbance

A total of 7% of respondents ($n=25$, 95%CI: 5%–10%) were annoyed by noise from wind turbines indoors. Forty-five percent ($n=24$, 95%CI: 32%–59%) of those who were annoyed by noise from wind turbines outdoors were also

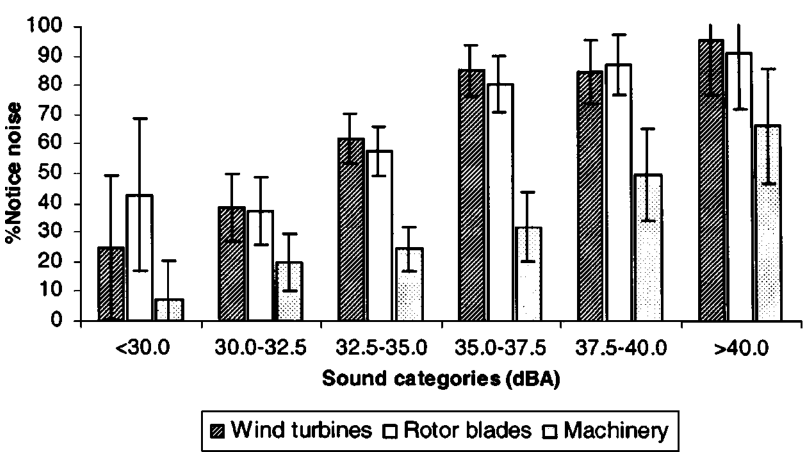


FIG. 2. Proportions with 95% confidence intervals of perception outdoors due to noise (notice but not annoyed, slightly annoyed, rather annoyed, very annoyed) from wind turbines, from rotor blades, and from machinery, related to sound categories.

TABLE VIII. Verbal descriptors of sound characteristics of wind turbine noise, based on those who noticed wind turbine sound ($n=223$). Statistically significant correlations in boldface. To avoid the risk of mass significance $p<0.0062$ were required for statistical significance.

	Annoyed by the specified sound character	Correlation to noise annoyance
Swishing	33%(27%–40%)	**0.718**
Whistling	26%(18%–33%)	**0.642**
Pulsating/throbbing	20%(14%–27%)	**0.450**
Resounding	16%(10%–23%)	**0.485**
Low frequency	13% (7%–18%)	**0.292**
Scratching/squeaking	12% (6%–17%)	**0.398**
Tonal	7% (3%–12%)	**0.335**
Lapping	5% (1%–8%)	**0.262**

annoyed indoors. There was a statistically significant correlation between indoor annoyance and sound category ($r_s=0.348$, $n=340$, $p<0.001$).

Regarding sleep disturbance, 23% ($n=80$, 95%CI: 18%–27%) of respondents stated that they were disturbed in their sleep by noise. Several sources of sleep disturbance, such as road traffic, rail traffic, neighbors, and wind turbines, were reported in an open question. At lower sound categories, no respondents were disturbed in their sleep by wind turbine noise, but 16% ($n=20$, 95%CI: 11%–20%) of the 128 respondents living at sound exposure above 35.0 dBA stated that they were disturbed in their sleep by wind turbine noise. Of those, all except two slept with an open window in the summer. No statistically significant correlations were found between sleep quality in general and outdoor noise annoyance, indoor noise annoyance, attitude to visual impact, attitude to wind turbines in general, or sensitivity to noise.

IV. DISCUSSION

A. Method

The results were based on the questionnaire survey and calculated A-weighted SPL. The purpose of the study was masked in order to avoid other factors such as attitude and ownership influencing the answers. The survey method is well established and has been used in several previous studies exploring annoyance due to community noise (e.g., Öhrström, 2004).

The results indicate a high validity for the questionnaire. The questions detected annoyance by odor from industrial plants in the area where the biogas plant is located [of those annoyed by odor from industrial plants, 83% ($n=19$) lived close to the biogas plant]; it also detected annoyance by noise from trains in the areas where the train passes [all of the respondents who reported that they were annoyed by noise from railway traffic ($n=12$) lived in areas where the railway passed]. There was a high correspondence between the responses to the general question of noise from wind turbines at the beginning of the questionnaire and the more specific questions later (alpha: 0.8850, $n=326$), also indicating high reliability of results.

The response rate at the different sound categories ranged from 60.0% to 78.1%, with the overall mean 68.4% and the dropout fairly equally distributed over sound categories. The distribution of age in the study population was similar to that of the demographic data for the area, but the proportions of women were somewhat higher than expected, especially in the lower sound categories. It has previously been shown that annoyance is not related to gender (Miedema and Vos, 1999) and as this study found no differences between men and women regarding noise annoyance and attitude to wind turbines, the higher proportion of women in the study population presumably had no impact on the results. A rather high proportion, 50%, of respondents self-reported as rather or very sensitive to noise. Other field studies in Sweden on annoyance due to road traffic noise in urban areas have found a lower proportion of noise-sensitive persons; for example, Matsumura and Rylander (1991) reported 25% of the respondents as noise sensitive in a road traffic survey ($n=805$). The difference might reflect preference of living environment, indicating that noise sensitive individuals prefer a more rural surrounding or that people living in areas with low background noise levels might develop a higher sensitivity to noise.

The calculated A-weighted SPL reflected downwind conditions assuming a wind speed of 8 m/s. Over a larger period of time, the direction and speed of the wind will vary and hence affect the actual SPL at the respondent's dwelling. It is likely that these variations, seen as an average over a longer period of time, in most cases will result in lower levels than the calculated SPL. Several unreliabilities related to the calculations might have led to an over- or underestimation of the dose levels. However, this error would not invalidate the comparison between respondents living at different SPL. Another source of error is that no account was taken of the physical environment around the respondent's house (e.g., location of patio or veranda, presence of bushes and trees in the garden). The actual SPL that the respondent experienced in daily life might therefore differ from the calculated, leading in most cases to an overestimation of the calculated dose.

B. Results

The results suggest that the proportions of respondents annoyed by wind turbine noise are higher than for other community noise sources at the same A-weighted SPL and that the proportion annoyed increases more rapidly. A comparison between established estimations of dose–response relationships for annoyance of transportation noise (Schultz, 1978; Fidell *et al.*, 1991; Miedema and Voss, 1998; Miedema and Oudshoorn, 2001; Fidell, 2003) and an estimation of a dose–response relationship for wind turbine noise, based on the findings in this study, are shown in Fig. 3. All curves are third order polynomials. The established curves describing annoyance from transportation noise are based on a large amount of data, and the wind turbine curve on only one study, so interpretations should be done with care. An important difference between studies of transportation noises and wind turbine noise is however where the main annoyance reaction is formed. For most studies of transportation noises

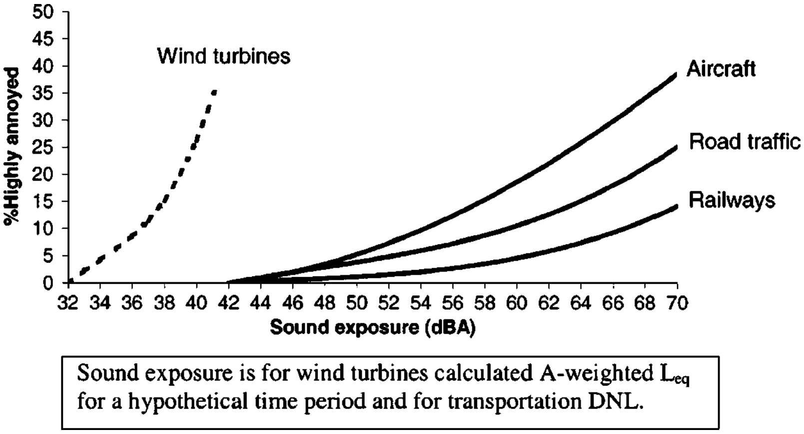


FIG. 3. A comparison between the dose–response relationship for transportation noise estimated by third order polynomials suggested by Miedema and Oudshoorn (2001) and wind turbine noise (dotted line). The latter $(\%HA = 4.38*10^{-2}(LEQ-32)^3 - 2.413*10^{-1}(LEQ-32)^2 + 2.4073(LEQ-32))$ were derived using regression based on five points interpolated from sound categories used in this study and the assumption that ‘‘very annoyed’’ in this study equals ‘‘highly annoyed’’ (Miedema and Voss, 1998).

it can be assumed that annoyance is formed mainly as a reaction to the sound pressure levels perceived indoors, and hence the actual noise dose should be reduced by the attenuation of the façade. For wind turbine noise the main annoyance reaction is formed when spending time outdoors. The actual difference in noise dose could therefore, at least partly, explain the comparatively higher prevalence of noise annoyance due to wind turbines. However, this factor does not explain the steep gradient.

Another factor that could be of importance for explaining the seemingly different dose–response relationships is that the wind turbine study was performed in a rural environment, where a low background level allows perception of noise sources even if the A-weighted SPL are low. Wind turbine noise was perceived by about 85% of the respondents even when the calculated A-weighted SPL were as low as 35.0–37.5 dB. This could be due to the presence of amplitude modulation in the noise, making it easy to detect and difficult to mask by ambient noise. This is also confirmed by the fact that the aerodynamic sounds were perceived at a longer distance than machinery noise.

Data obtained in this study also suggest that visual and/or aesthetic interference influenced noise annoyance. Support for this hypothesis can be found in studies evaluating auditory-visual interactions (Viollon *et al.*, 2002). In one field-laboratory study, subjects evaluating annoyance due to traffic noise were less annoyed if a slide of a visually attractive street was presented together with the noise, as compared to the same noise level presented together with a visually unattractive street. The difference in noise annoyance amounted to as much as 5 dBA (Kastka and Hangartner, 1986). The hypothesis was also supported by the logistic multiple regression analyses in the present study, where the visual variable attitude to visual impact had a significant impact on the model. However, although the inclusion of the variable increased the pseudo-R^2, the influence of noise exposure was still a significant factor for noise annoyance. A general prediction of the visual influence on noise annoyance, however, can not yet be made with any certainty as both attenuating (Kastka and Hangartner, 1986) and amplifying effects (e.g., Watts *et al.*, 1999) have been detected.

The high prevalence of noise annoyance could also be due to the intrusive characteristics of the aerodynamic sound. The verbal descriptors of sound characteristics related to the aerodynamic sounds of swishing, whistling, pulsating/throbbing, and resounding were—in agreement with this hypothesis—also reported to be most annoying. The results for the sounds of swishing and whistling agree well with results from previous experimental studies (Persson Waye *et al.*, 2000; Persson Waye and Agge, 2000; Persson Waye and Öhrström, 2002), while pulsating/throbbing in those studies was not significantly related to annoyance.

Most respondents who were annoyed by wind turbine noise stated that they were annoyed often, i.e., every day or almost every day. The high occurrence of noise annoyance indicates that the noise intrudes on people’s daily life. The survey was performed during May and June when people could be expected to spend time outdoors, and the results therefore reflect the period that is expected to be most sensitive for annoyance due to wind turbine noise.

A low number of respondents were annoyed indoors by wind turbine noise. Some of the respondents also stated that they were disturbed in their sleep by wind turbine noise, and the proportions seemed to increase with higher SPL. The number of respondents disturbed in their sleep, however, was too small for meaningful statistical analysis, but the probability of sleep disturbances due to wind turbine noise can not be neglected at this stage.

Noise annoyance was also related to other subjective factors such as attitude and sensitivity. These results correspond well with the results from other studies regarding community noise (e.g., noise from aircraft, railways, road traffic, and rifle ranges). In a summary of 39 surveys performed in ten different countries, the correlation was 0.42 between dose and response, 0.15 between exposure and attitude, 0.41 between annoyance and attitude, −0.01 between exposure and sensitivity, and 0.30 between annoyance and sensitivity (Job, 1988). Corresponding numbers from this study are presented in Table VII and show a noteworthy similarity.

Two aspects of attitude were explored in the present study. Attitude to the visual impact of wind turbines on the landscape scenery was more strongly correlated to annoyance than the general attitude to wind turbines. The four most supported adjectives queried in the survey were environmentally friendly, necessary, ugly, and effective, thus giving the picture of a phenomenon that is accepted, but not regarded as a positive contribution to the landscape.

Previous studies of community noise have found that people who tend to be consistently negative could be predicted to be more annoyed by a new source of noise (Weinsten, 1980). More recent studies on community noise have included additional aspects and suggest conceptual models describing individual differences in the terms of stress, appraisal, and coping (Lercher, 1996). In the case of annoyance due to wind turbine noise, the findings suggest that individual differences others than attitude and sensitivity could influence the variation of noise annoyance. Respondents annoyed by wind turbine reported negative changes in their neighborhood to a higher degree than those not annoyed and stated that they had little perceived opportunity to influence local government. The importance of these parameters for noise annoyance due to wind turbines should be further studied.

C. Conclusions

A significant dose–response relationship between calculated A-weighted SPL from wind turbines and noise annoyance was found. The prevalence of noise annoyance was higher than what was expected from the calculated dose. It is possible that the presence of intrusive sound characteristics and/or attitudinal visual impacts have an influence on noise annoyance. Further studies are needed, including a larger number of respondents especially at the upper end of the dose curve, before firm conclusions could be drawn. To explore attitude with regard to visual impact, some of these studies should be performed in areas of different topography where the turbines are less visible. There is also a need to further explore the influence of individual and contextual parameters.

ACKNOWLEDGMENTS

We gratefully acknowledge the assistance of Agneta Agge; we also thank the Swedish Energy Agency P13644-1 and the Adlerbertska Research Foundation for funding the study. This article has benefited greatly from comments provided by Associate Editor Lou Sutherland and two anonymous reviewers.

APPENDIX: QUESTIONNAIRE

Key questions from the questionnaire used in the study. Questions with the main purpose to mask the intention of the questionnaire and standard questions on socio-economic status and health are not shown here. Translated from Swedish.

Section I

—How satisfied are you with your living environment? (very satisfied, satisfied, not so satisfied, not satisfied, not at all satisfied)

—Have there been any changes to the *better* in your living environment/municipality during the last years? (no, yes) State which changes.

—Have there been any changes to the *worse* in your living environment/municipality during the last years? (no, yes) State which changes.

—State for each nuisance below if you notice or are annoyed when you spend time *outdoors* at your dwelling: odor from industries, odor from manure, flies, noise from hay fans, noise from wind turbines, railway noise, road traffic noise, lawn mowers. (do not notice, notice but not annoyed, slightly annoyed, rather annoyed, very annoyed)

—State for each nuisance below if you notice or are annoyed when you spend time *indoors* in your dwelling: odor from industries, odor from manure, flies, noise from hay fans, noise from wind turbines, railway noise, road traffic noise, lawn mowers. (do not notice, notice but not annoyed, slightly annoyed, rather annoyed, very annoyed)

—How would you describe your sensitivity to the following environmental factors: air pollution, odors, noise, littering? (not sensitive at all, slightly sensitive, rather sensitive, very sensitive)

Section II

—Can you see any wind turbine from your dwelling or your garden? (yes, no)

—What is your opinion on the wind turbines' impact on the landscape scenery? (very positive, positive, neither positive nor negative, negative, very negative)

—Are you affected by wind turbines in your living environment with regard to: shadows from rotor blades, reflections from rotor blades, sound from rotor blades, sound from machinery, changed view? (do not notice, notice but not annoyed, slightly annoyed, rather annoyed, very annoyed)

—If you are annoyed by noise, shadows and/or reflections from wind turbines, how often does this happen? (never/almost never, some/a few times per year, some/a few times per month, some/a few times per week, daily/almost daily)

—If you hear sound from wind turbines, how would you describe the sound: tonal, pulsating/throbbing, swishing, whistling, lapping, scratching/squeaking, low frequency, resounding? (do not notice, notice but not annoyed, slightly annoyed, rather annoyed, very annoyed)

—Have you noticed if sounds from wind turbines sound different at special occasions: when the wind blows from the turbine towards my dwelling, when the wind blows from my dwelling towards the turbine, when the wind is low, when the wind is rather strong, warm summer nights? (less clearly heard, more clearly heard, no differences, do not know)

—Are you annoyed by sound from wind turbines during any of the following activities: relaxing outdoors, barbecue nights, taking a walk, gardening, other outdoor activity? (do not notice, notice but not annoyed, slightly annoyed, rather annoyed, very annoyed)

—Do you own any wind turbines? (no, yes I own one or more turbines, yes I own shares of wind turbines)

—What is your general opinion on wind turbines? (very positive, positive, neither positive nor negative, negative, very negative)

—Please mark the adjectives that you think are adequate for wind turbines: efficient, inefficient, environmentally friendly, harmful to the environment, unnecessary, necessary, ugly, beautiful, inviting, threatening, natural, unnatural, annoying, blends in.[1]

EXHIBIT 9

[1]Developed by Karin Hammarlund, Department of Human and Economic Geography, Göteborg University, Sweden, and used with her permission.

Ackermann, T., and Söder, L. (**2000**). ''Wind energy technology and current status—a review,'' Renew. Sustain. Energy Rev. **4**, 315–374.

Altman, D. G. (**1991**). *Practical Statistics for Medical Research* (Chapman & Hall, London).

American Wind Energy Association (**2004**). *Global wind energy market report 2004*, http://www.awea.org/pubs/documents/globalmarket2004.pdf (last viewed online 15 June, 2004).

Arlinger, S., and Gustafsson, H.-Å. (**1988**). ''Hur ett ljudband med konstant ljudnivå maskerar ett brusband med periodiskt varierande ljudnivå'' (''How a broadband noise with constant sound pressure level masks a broadband with periodically varying sound pressure levels''), Department of Technical Audiology, Linköping University, Sweden.

Björkman, M. (**2004**). ''Long time measurements of noise from wind turbines,'' J. Sound Vib. **277**, 567–572

Fidell, S. (**2003**). ''The Schultz curve 25 years later: A research perspective,'' J. Acoust. Soc. Am. **144**, 3007–3015.

Fidell, S., Barber, D. S., and Schultz, T. J. (**1991**). ''Updating a dosage-effect relationship for the prevalence of annoyance due to general transportation noise,'' J. Acoust. Soc. Am. **89**, 221–233.

Hubbard, H. H., Grosveld, F. W., and Shepherd, K. P. (**1983**). ''Noise characteristics of large wind turbine generators,'' Noise Control Eng. J. **21**, 21–29.

Job, R. F. S. (**1988**). ''Community response to noise: a review of factors influencing the relationship between noise exposure and reaction,'' J. Acoust. Soc. Am. **83**, 991–1001.

Kastka, J., and Hangartner, M. (**1986**). ''Machen hässlichen Strassen den Verkehrlärm lästiger'' (''Do ugly streets make traffic noise more annoying?''), Arcus **1**, 23–29.

Lercher, P. (**1996**). ''Environmental noise and health: an integrated research perspective,'' Environ. Int. **22**, 117–128.

Lowson, M. V. (**1996**). ''Aerodynamic noise of wind turbines,'' in *Proceedings of Internoise*, 30 July–2 August, Liverpool, England, pp. 479–484.

Matsumura, Y., and Rylander, R. (**1991**). ''Noise sensitivity and road traffic annoyance in a population sample,'' J. Sound Vib. **151**, 415–419.

Miedema, H. M. E., and Oudshoorn, C. G. M. (**2001**). ''Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals,'' Environ. Health Perspect. **109**, 409–416.

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

Miedema, H. M. E., and Vos, H. (**1999**). ''Demographic and attitudinal factors that modify annoyance from transportation noise,'' J. Acoust. Soc. Am. **105**, 3336–3344.

Miller, M. B. (**1995**). ''Coefficient alpha: a basic introduction from the perspectives of classical test theory and structural equation modeling,'' Struct. Eq. Model. **2**, 255–273.

Nagelkerke, N. J. D. (**1991**). ''A note on the general definition of the coefficient of determination,'' Biometrika **78**, 691–692.

Öhrström, E. (**2004**). ''Longitudinal surveys on effects of changes in road traffic noise-annoyance, activity disturbances, and psycho-social well-being,'' J. Acoust. Soc. Am. **145**, 719–729.

Pedersen, E. (**2000**). ''Störningsupplevelser från vindkraft, förstudie'' (''Experience of annoyance from wind turbines, a pilot study''), Halmstad University, Sweden.

Pedersen, T. H., and Nielsen, K. S. (**1994**). ''Genvirkning af støj fra vindmøller'' (''Annoyance by noise from wind turbines''), Report 150, DELTA Acoustic & Vibration, Lydtekniske Institut, Copenhagen, Denmark.

Persson Waye, K., and Agge, A. (**2000**). ''Experimental quantification of annoyance to unpleasant and pleasant wind turbine sounds,'' in *Proceedings of Internoise*, 27–30 August, Nice, France, pp. 3994–3997.

Persson Waye, K., and Öhrström, E. (**2002**). ''Psycho-acoustic characters of relevance for annoyance of wind turbine noise,'' J. Sound Vib. **250**, 65–73.

Persson Waye, K., Öhrström, E., and Björkman, M. (**1998**). ''Sounds from wind turbines–can they be made more pleasant?'' in *Proceedings of 7th International Congress on Noise as a Public Health Problem*, 22–26 November, Sydney, Australia, pp. 531–534.

Persson Waye K., Agge, A., and Björkman M. (**2000**). ''Pleasant and unpleasant characteristics in wind turbine sounds,'' in *Proceedings of Internoise*, 27–30 August, Nice, France, pp. 2327–2330.

Rand, M., and Clarke, A. (**1990**). ''The environmental and community impacts of wind energy in the UK,'' Wind Eng. **14**, 319–330.

Schultz, T. J. (**1978**). ''Synthesis of social surveys on noise annoyance,'' J. Acoust. Soc. Am. **64**, 377–405.

Swedish Environmental Protection Agency (**2001**). ''Ljud från vindkraftverk'' (''Noise from wind turbines''), Report 6241, Stockholm, Sweden.

Viollon, S., Lavandier, C., and Drake, C. (**2002**). ''Influence of visual setting on sound ratings in an urban environment,'' Appl. Acoust. **63**, 493–511.

Wagner, S., Bareiss, R., and Guidati, G. (**1996**). ''Wind turbine noise,'' EUR 16823 (Springer).

Watts, G., Chinn, L., and Godfrey, N. (**1999**). ''The effects of vegetation on the perception of traffic noise,'' Appl. Acoust. **56**, 39–56.

Weinsten, N. D. (**1980**). ''Individual differences in critical tendencies and noise annoyance,'' J. Sound Vib. **68**, 241–248.

Wolsink, M., Sprengers, M., Keuper, A., Pedersen, T. H., and Westra, C. A. (**1993**). ''Annoyance from wind turbine noise on sixteen sites in three countries,'' European Community Wind Energy Conference, 8–12 March, Lübeck, Travemünde, Germany, pp. 273–276.

3. Community Reaction to Environmental Noise

There are two methods of indirectly assessing the cumulative effects of environmental noise on people. These are examining the reactions of individuals or groups of individuals to specific intruding noises, either (a) with respect to actions taken (complaints, suits, etc.), or (b) in terms of responses made to social survey questionnaires. The first category, involving overt action by individuals or groups, is summarized in this section,and key data regarding the second category, involving responses indicating annoyance, is summarized in the next section.

In the last 25 years, many new types of noise sources have been introduced into surburban and urban residential communities. These sources, such as jet aircraft, urban freeways, new industrial plants, and homeowner equipment, have created numerous community problems with environmental noise. These problems have provided significant data and insight relating to community reaction and annoyance and stimulated the development of several indices for measurement of the magnitude of intruding noises.

Various U.S. Governmental agencies began to investigate the relationships between aircraft noise and its effect on people in communities in the early 1950's. This early research resulted in the proposal of a model by Bolt, Rosenblith and Stevens[D-10] for relating aircraft noise intrusion and the probable community reaction. This model, first published by the Air Force, accounted for the following seven factors:

1. Magnitude of the noise with a frequency weighting relating to human response.
2. Duration of the intruding noise.
3. Time of year (windows open or closed).
4. Time of day noise occurs.
5. Outdoor noise level in community when the intruding noise is not present.
6. History of prior exposure to the noise source and attitude toward its owner.
7. Existence of pure-tone or impulsive character in the noise.

Correction for these factors were initially made in 5 dB intervals since the magnitudes of many of the corrections were based solely on the intuition of the authors, and it was considered difficult to assess the response to any greater degree of accuracy.[D11-13] This model was incorporated in the first Air Force Land Use Planning Guide[D-14] in 1957 and was later simplified for ease of application by the Air Force and the Federal Aviation Administration.

Recently the day-night sound level has been derived for a series of 55 community noise problems[D-3] to relate the normalized measured L_{dn} with the observed community reaction. The normalization procedure followed the Bolt, Rosenblith and Stevens method with a few minor modifications. The correction factors which were added to the measured L_{dn} to obtain the normalized L_{dn} are given in Table D-7.

Table D-7

CORRECTIONS TO BE ADDED TO THE MEASURED DAY-NIGHT SOUND LEVEL (L_{dn}) OF INTRUDING NOISE TO OBTAIN NORMALIZED L_{dn} D-3

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

The distribution of the cases among the various noise sources having impact on the community are listed in Table D-8. The results are summarized in Figure D-7.

The "no reaction" response in Figure D-7 corresponds to a normalized outdoor day-night sound level which ranges between 50 and 61 dB with a mean of 55 dB. This mean value is 5 dB below the value that was utilized for categorizing the day-night sound level for a "residential urban community," which is the baseline category for the data in the figure. Consequently, from these results, it appears that no community reaction to an intruding noise is expected, on the average, when the normalized day-night sound level of an identifiable intruding noise is approximately 5 dB less than the day-night sound level that exists in the absence of the identifiable intruding noise. This conclusion is not surprising; it simply suggests that people tend to judge the magnitude of an intrusion with reference to the noise environment that exists without the presence of the intruding noise source.

The data in Figure D-7 indicate that widespread complaints may be expected when the normalized value of the outdoor day-night sound level of the intruding noise exceeds that existing without the intruding noise by approximately 5 dB, and vigorous community reaction may be expected when the excess approaches 20 dB. The standard deviation of these data is 3.3 dB about their means and an envelope of

± 5 dB encloses approximately 90 percent of the cases. Hence, this relationship between the normalized outdoor day-night sound level and community reaction appears to be a reasonably accurate and useful tool in assessing the probable reaction of a community to an intruding noise and in obtaining one type of measure of the impact of an intruding noise on a community.

Table D-8

NUMBER OF COMMUNITY NOISE REACTION CASES AS A FUNCTION OF NOISE SOURCE TYPE AND REACTION CATEGORY

Type of Source	Community Reaction Categories: Vigorous Threats of Legal Action	Community Reaction Categories: Wide Spread Complaints	Community Reaction Categories: No Reaction or Sporadic Complaints	Total Cases
Transportation vehicles, including:				
Aircraft operations	6	2	4	12
Local traffic			3	3
Freeway	1			1
Rail		1		1
Auto race track	2			2
Total Transportation	9	3	7	19
Other single-event or intermittent operations, including circuit breaker testing, target shooting, rocket testing and body shop	5			
Steady state neighborhood sources, including transformer substations, residential air conditioning	1	4	2	7
Steady state industrial operations, including blowers, general manufacturing, chemical, oil refineries, et cetera	7	7	10	24
Total Cases	22	14	19	55

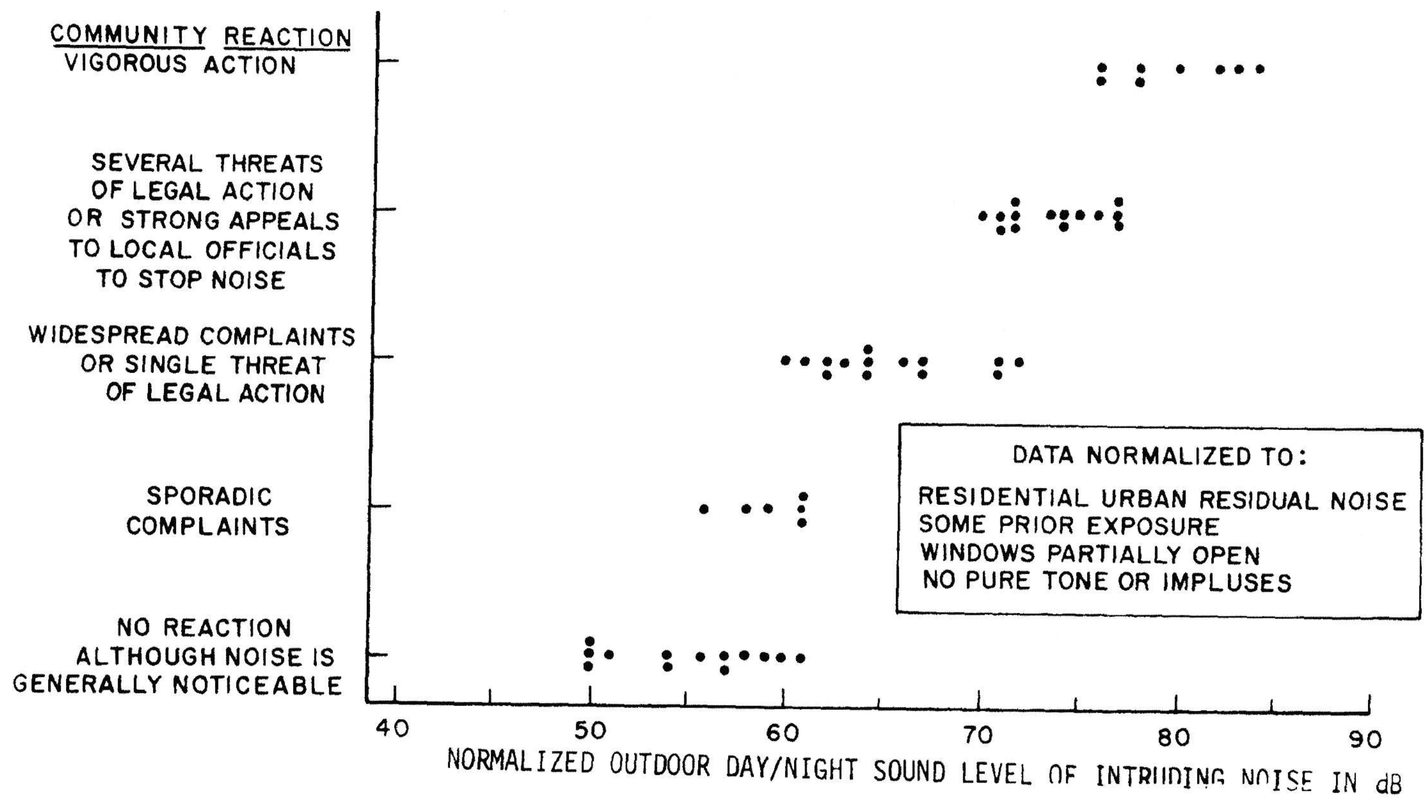


Figure D-7. Community Reaction to Intensive Noises of Many Types as a Function of the Normalized Outdoor Day Night Sound Level of the Intruding Noise D-3

The methodology applied to arrive at the correlation between normalized L_{dn} and community complaint behavior illustrated in Figure D-7 is probably the best available at present to predict the most likely community reaction in the U.S. Unfortunately, readiness to complain and to take action is not necessarily an early indicator of interference with activities and annoyance that the noise creates. The fact that correction for the normal background noise level without intruding noise results in better correlation of the data points might be interpreted to mean that urban communities have adapted to somewhat higher residual noise levels that are not perceived as interfering or annoying. On the other hand, it is more likely that the higher threshold for complaining is caused by the feeling that higher residual noise is unavoidable in an urban community and that complaining about "normal" noise would be useless. For the present analysis, it might therefore be more useful to look at the same data without any corrections for background noise, attitude, and other subjective attributes of the intruding noise. Figure D-8 gives these data for the same 55 cases.

The increase in spread of the data is apparent in comparing Figures D-7 and D-8, and the standard deviation of the data about the mean value for each reaction is increased from 3.3 dB for the normalized data to 7.9 dB. The mean value of the outdoor day-night sound level associated with "no reaction" is 55 dB; with vigorous reaction, 72 dB; and, for the three intermediate degrees of reaction, 62 dB.

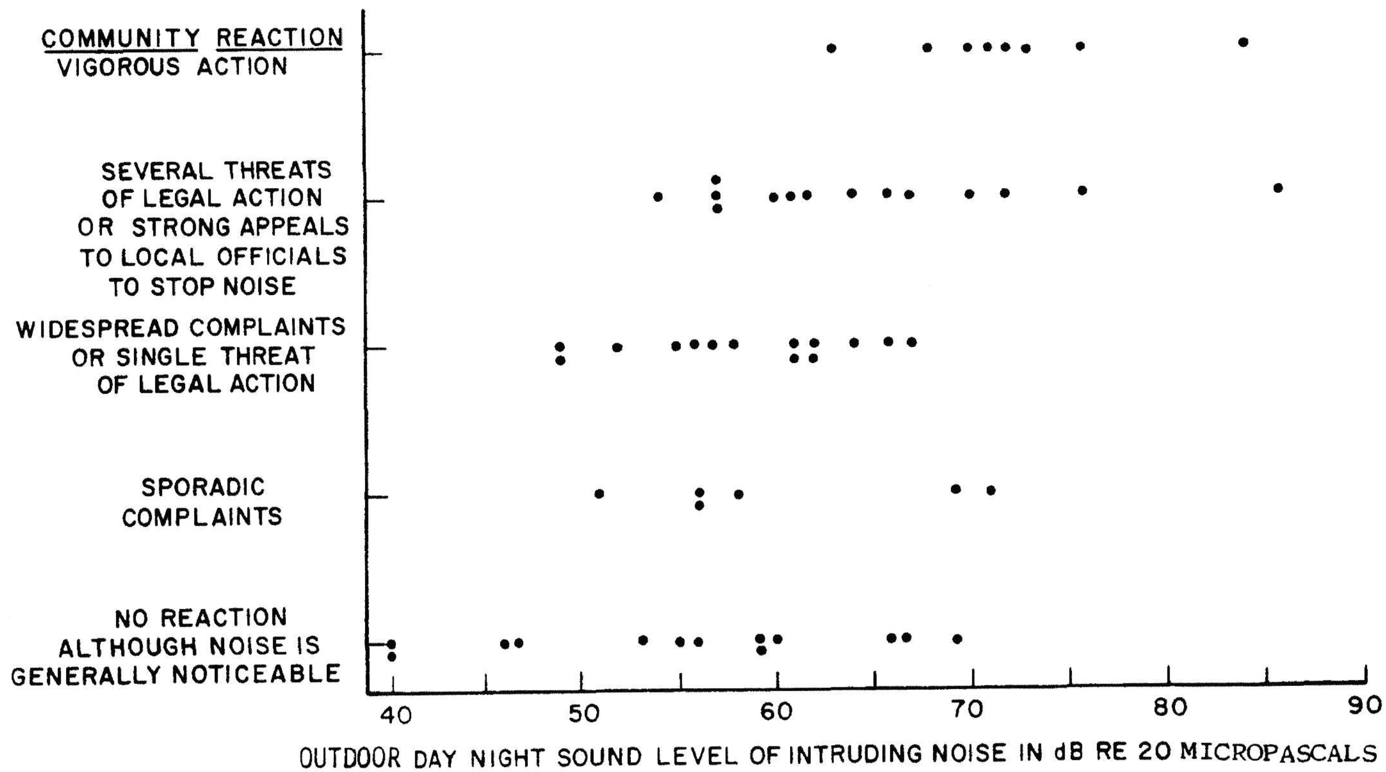


Figure D-8. Community Reaction to Intensive Noises of Many Types As A Function of the Outdoor Day/Night Sound Level of the Intruding Noise D-3

There is no evidence in these 55 cases of even sporadic complaints if the L_{dn} is less than 50 dB.

4. Annoyance

Annoyance discussed in this report is limited to the long-term integrated adverse responses of people to environmental noise. Studies of annoyance in this context are largely based on the results of sociological surveys. Such surveys have been conducted among residents of a number of countries including the United States.[D-6, D-7, D-15, D-16]

The short-term annoyance reaction to individual noise events, which can be studied in the field as well as in the laboratory, is not explicitly considered, since only the accumulating effects of repeated annoyance by environmental stimuli can lead to environmental effects on public health and welfare. Although it is known that the long-term annoyance reaction to a certain environment can be influenced to some extent by the experience of recent individual annoying events, the sociological surveys are designed to reflect, as much as possible, the integrated response to living in a certain environment and not the response to isolated events.

The results of sociological surveys are generally stated in terms of the percentage of respondents expressing differing degrees of disturbance or dissatisfaction due to the noisiness of their environments. Some of the surveys go into a complex procedure to construct a scale of annoyance. Others report responses to the direct question of "how annoying

45 Cougar Canyon Santa Fe NM 87508 505.466.1879
acousticecology.org jim@acousticecology.org

Acoustic Ecology Institute Fact Sheet: Wind Energy Noise Impacts

Excerpted from a 25-page AEI Special Report: Wind Energy Noise Impacts, available at: AcousticEcology.org/srwind.html *Visit this page for links to sources mentioned below*

Introduction

This AEI Fact Sheet is not intended to over-emphasize noise complaints, but rather to provide information that can foster informed conversation about any specific wind farm proposal. As you'll read below, it appears that noise can be a significant issue in at least some situations when turbines are within about a half mile of homes, with impacts occasionally occurring up to a mile away. Some acousticians and health professionals are encouraging setbacks of 1.5 miles (roughly 2km) or even a bit more. In the US, it is quite common to have setbacks defined as a multiple of turbine height; for example, 5 times the turbine height from a home (which would equate to 500m for a 100m turbine). It appears to AEI that a half-mile (800m) setback is marginally acceptable if the goal is to minimize impacts on residents, though we would prefer a one-mile (1.5km) setback, which would offer near assurance of avoiding noise issues.

Each proposed wind farm site is unique and must be evaluated based on local topographic, atmospheric, and land use patterns. Prevailing wind direction is a key factor, as is topography. **A recent UK government survey suggests that about 20% of wind farms tend to generate noise complaints; the question is, what are the factors in *those* wind farms that may be problematic, and how can we avoid replicating these situations elsewhere?**

Noise impacts are not necessarily deal-killers for wind energy, as long as developers are honest about what is likely to be heard and continue to work diligently to investigate the aspects of wind turbine noise that are still not fully understood. The Altamont Wind Farm in California, built on a major raptor flyway in the early years of industrial wind development, has continued to be a poster child for the bird-killing power of wind turbines, despite widespread understanding that it was an exceedingly bad siting decision, one not likely to be repeated. Similarly, many noise complaints today seem to be coming from people whose homes are on the near edge of fairly lax setback guidelines (within 1500 feet in many cases). Will a few ill-considered siting choices similarly poison attitudes about noise issues?

Resistance to wind farms is often belittled as NIMBY-ism (Not In My Backyard); but at the same time, proponents often slip into oversimplified WARYDU rhetoric (We Are Right; You Don't Understand). If we are to forge a reliable energy future that is respectful of both the environment and the rights of neighbors, we'll need to move past knee-jerk reactions on both sides, and develop best practices that can ensure that the landscape and local residents don't become long-term casualties of today's "Klondike Wind Rush."

How Noisy Are Wind Turbines?

The US National Wind Coordinating Collaborative, a multi-stakeholder group that aims to facilitate wind development, summarizes the situation in fairly straightforward terms:

> *By and large, those affected by the noise generated by wind turbines live within a few miles of a large wind power plant or within several hundred feet of a small plant or individual turbine. Although the noise at these distances is not great, it nevertheless is sufficient to be heard indoors and may be especially disturbing in the middle of the night when traffic and household sounds are diminished.*

In a similar vein, the American Wind Energy Association's fact sheet on noise notes that "Today, an operating wind farm at a distance of 750 to 1,000 feet is no noisier than a kitchen refrigerator." **This raises a question: how many of us sleep in the kitchen?**

The bottom line is that most modern industrial wind turbines are designed to keep noise levels at or below 45dB at 1000 feet (350 meters), which should drop to 35-40dB at a bit over a half mile (1000m); commercial turbines are quite often built this close to homes. Some are rated at lower sound levels. However, as is noted below, atmospheric conditions can wreak havoc with nice clean sound propagation models, especially at night. And, as turbines get bigger, their noise can be deceptively hard to predict; certainly, they can be quieter at their bases than some distance away, and temperature inversions, wind layers, and other atmospheric effects can lead to surprisingly distant sound impacts.

It appears that turbine noise travels farther in calm night air; one widely-respected study (van den Berg, see below) found that sound levels were 5-15dB louder than predicted in some night-time atmospheric conditions, and noted that residents as far as 1.9km away were disturbed by noise. In nearly all cases, those downwind bear the brunt of the sound; if you live upwind of a wind farm, noise problems will likely be far less severe.

It is important to recognize that night-time ambient noise levels in rural areas are often 35dB or lower; so, it is not that hard for wind farms to become a new and dominant acoustic presence. All too often, wind developers tell local planning boards that the turbines will be inaudible, which is rarely the case. Similarly, some investigations of noise complaints come to the conclusion that anomalously high noise levels occur so infrequently that they are insignificant. But if temperature inversions or other atmospheric stability effects that cause excessive noise occur just 10% of the nights, that means that nearby residents may find their sleep disturbed 35 nights a year. Is this insignificant? Such questions need to be considered directly, not shunted aside.

While in many situations, the sound from turbines is drowned out by nearby wind noise, or is perceived as a gentle whooshing noise that is quite easy to accommodate, in some wind or atmospheric conditions, a pulsing noise can arise, which is much harder to ignore or acclimate to, making it a major source of complaints. Perceptually, the problem is that any pulsed or irregular sound (this rhythmic thumping tends to wax and wane over the course of a night) will tend to cause more disturbance. These pulses, sometimes termed Amplitude Modulation, are usually loudest in one or two specific directions, depending on the wind direction.

When considering noise predictions, **beware of overly simplistic comparisons of sound levels**. Acousticians, as well as advocacy organizations on both sides of the issue, will often say a turbine's noise is "equal to" or "the same as" a familiar sound (distant traffic, quiet conversation), or is "twice as loud" as something else (perhaps the background noise level). While these comparisons have a basis in physics and our anatomical responses, the fact is that humans do not perceive and compare sounds as neatly as they perceive, say, height or weight. Certainly, "twice as loud" is an indefinite value for most people; and, equivalent dB value sounds are experienced very differently depending on the nature of the sound itself and the situation in which we hear it.

Low-Frequency Noise

In some cases, low-frequency noise can become an issue with wind turbines. These sounds may be inaudible to the human ear, yet still cause physiological responses in the body. Such low-frequency noise can be transmitted through the ground from towers, or be part of the broadband noise field generated by spinning turbine blades. Low-frequency noise travels greater distances with less loss of intensity than higher-frequency sound.

It is important to measure the noise from turbines using a dbC scale, sometimes written db(C), which is weighted to accentuate low-frequency components of a sound. Most noise standards are weighted to the dBA/dB(A) scale, which accentuates frequencies heard best by the human ear. It is becoming a standard procedure in dealing with industrial and machine noise to compare dBC and dBA readings; when dBC is 20dB more than dBA, or when dBC is 60dB or higher, it is considered an indicator that low-frequency noise is at problematic levels, and the need for special low-frequency mitigation is then generally called for.

Health Effects

The World Health Organization has found that to protect children's health **sound levels should be less than 30 dBA during sleeping periods**. They note that a child's autonomous nervous system is 10 to 15 dB more sensitive to noise than adults (WHO night time recommendations for the general public are 30dB inside bedrooms, and 45dB outside open bedroom windows). Even for adults, health effects are first noted in some studies when the sound levels exceed 32 dBA, 10-20 dBA lower than the levels needed to cause awakening. The WHO researchers found that sound levels of 50 dBA or more strongly disrupted hormone secretion cycles. For sounds that contain a strong low frequency component, which is typical of wind turbines, WHO says that the limits may need to be even lower than 30 dBA to not put people at risk.

In early 2009, New York physician Nina Pierpont will release a book that summarizes her preliminary research into the health effects of wind farms, centering on a "case series" study of people with similar physical responses in different locations. She proposes a new term, **Wind Turbine Syndrome**, to describe what she suspects is a vestibular system (inner ear/balance) disturbance. *(It should be clearly noted that only a small proportion of people living near turbines are strongly affected; Pierpont's work focuses on those few and is a first step at moving past a simplistic "it's all in their heads" response to these cases.)* While industry sources object to this focus on the few with special sensitivity, Pierpont is undertaking the first step in standard medical research: case series studies describe a new health issue, and provide a basis for design of more detailed field and clinical studies. Her work is generating a surprising amount of enthusiastic praise from fellow doctors, and marks an important new threshold in our consideration of the impacts of wind farms on people living within a mile or so.

Noise Measurement

When the "experts" begin talking about noise, they throw around terms that can make most people's eyes glaze over. A key factor is that noise is generally measured over a period of time, stated in decibels (usually in dBA; weighted to match human hearing), and then characterized in various statistical shorthands, to clarify different aspects of sound fluctuations. These include: L_{eq}/LA_{eq} (sound level averaged over a given period of time; will be lower than the loudest sounds and higher than the quietest times); L_{90}/LA_{90} (sound is louder than this 90% of the time; represents the generally quietest times); L_{10}/LA_{10} (sound is louder than this only 10% of the time; represents generally loudest times, excluding extreme transient noises). A crucial decision when writing regulations meant to protect citizens from noise during quiet times of day or night is what period either turbine noise or existing "ambient" background noise is averaged over; day-long averages or 12-hour averages (both of which are preferred by industry noise consultants), can lead to noise standards that do not represent the quietest ambient or loudest turbine conditions, which is exactly when turbine noise can be an issue. A better approach is hourly (or three-hour) averages throughout the day or night, with regulated limits being tied to the quietest ambient period.

What Some Neighbors Are Hearing

Complaints from wind farm neighbors about noise are often discounted as the griping of a tiny but very vocal minority. **Are we simply hearing from the most sensitive or the most crotchety people? A recent research paper suggests not.** Christopher Bajdek's paper focused on creating realistic expectations about noise (and in so doing, countered both over-reactions of some websites and overly sanguine projections by industry reps). Presented at NOISECON 2007, a noise control industry conference, it included two key maps that charted dB measurements and the percentage of residents who were "highly annoyed" by the noise: **44-50% of people under a half mile away were "highly annoyed" (over a third within a half mile had been awakened by turbine noise)**; only as sound levels drop below 40dB do annoyance levels drop substantially; as sound drops below 35dB (a bit under a mile from nearest turbines), annoyance drops to 4% and less. Bajdek noted higher annoyance responses to wind farms than to other similarly loud industrial noises, such as roads and railroads, with the supposition that visual impacts elevate reported annoyance. However, that cannot account for the many people awakened by the noise; the irregularity of turbine noise may be a more important factor in making wind farms more annoying than other industrial sounds.

Here are a few of the most compelling "real world" reports from people affected by wind farm noise:

Juniata Township, Altoona, PA: 2000-3300 feet from wind farm with 40 turbines
Resident Jill Stull (turbines 2000ft/600m from her house) said, "You know when you're standing outside and you hear a plane coming about 30,000 feet overhead, then it goes off in the distance? It sounds like those planes are 5,000 feet above your house and circling and never land." The Stulls said they could move, but they aren't going to. "We're not going anywhere. I just want them to be quiet. I'm not going to jump on the 'I hate windmills' bandwagon because I don't," Jill Stull said. "I'm just tired of nobody listening. My point is what is your peace of mind worth? I can't play outside with my kids back at the pond in the woods because it gives me a headache."

"On a calm day, you come outside and try to enjoy a nice peaceful day, and all you hear is the noise all the time and you can't get away from it," said Bob Castel, who has two turbines behind his house. "The first time they started them up, I didn't know what it was. I was like man, that's a weird noise. It was that loud," said Castel.

Elmira, Prince Edward Island: 1km (3300 feet) from wind farm with ten 120m turbines
Problems began within weeks after the turbines started operating. Downwind from the turbines, when the air was moving just enough to turn them (12-15 knots from the northeast), the noise was loud. It was a repetitive modulated drone of sound. Dwayne Bailey and his father Kevin both claimed it sometimes was loud enough to rattle the windows of their homes on the family farmstead. The sound was even worse in the field behind their homes. Distances from 1 to 1.5 kilometers were the areas of the most annoying sounds. This spring the winds created constant misery.

"My idea of noise is a horn blowing or a tractor - it disappears," said Sheila Bailey. "This doesn't disappear. Your ears ring. That goes on continuously." Dwayne developed headaches, popping and ringing ears, and could not sleep. He tried new glasses, prescription sleep aids and earplugs, to no avail. Dwayne's two year old was sleeping well prior to the wind farm, but began waking up, 5- 6 times a night.

Freedom, Maine: 1000 and 1400 feet from wind turbines
Local resident Phil Bloomstein used a sound meter to record decibel levels at his home. The results, which Bloomstein captures on a laptop, show a mean sound level of over 52 decibels, never dropping below 48 and peaking at 59 decibels. "When the turbines were being proposed to be put up," he says, "we were told that 45 decibels would be as loud as it would get except for ... no more than eight days a year." Neighbor Jeff Keating, a bit further from the closest turbine, said, to date, the noise has woken him up three times at night. He likened the experience to hearing the furnace kick on, then lying awake mad about having been woken. "It's not just a physical thing," he said, "there's an emotional side." Keating's neighbor Steve Bennett said he hears the turbines at all times of day. "It's like a jet plane flying overhead that just stays there," he said.

From a distance, the jet plane analogy fits the sound produced by the turbines - a white noise suggestive of a plane that never entirely passes. Closer to the turbines the sound quality changes. Each turbine rotates to face the wind and the sound varies in relation to one's orientation to the blades. At close range, facing the turbine head on, the sound is low and pulsing like a clothes dryer. From the side the blades cut the air with a sipping sound. Either way, when the wind is blowing, there is noise. "They simply do not belong this close to people's homes," Bennett said. "Our property values have been diminished, and our quality of life has been diminished." YouTube videos from Bloomstein: http://tinyurl.com/7gpvlc

Mars Hill, ME: 2600+ feet from turbine

Mars Hill resident Wendy Todd (house is 2600 feet from the nearest turbine): Unfortunately for us, the very mountain that has provided the wind facility with a class 3-wind resource often acts like a fence protecting us from the upper level winds that push the turbines. There are many times when winds are high on the ridgeline but are near calm at our homes. The noise and vibrations from the turbines penetrate our homes. At times there is no escape from it, no matter which room you go to. The noise ranges from the sound of a high range jet to a fleet of planes that are approaching but never arrive. When it's really bad it takes on a repetitive, pulsating, thumping noise that can go on for hours or even days. It has been described as a freight train that never arrives, sneakers in a dryer, a washing machine agitating, a giant heartbeat; a submariner describes it as a large ship passing overhead.

People think that we are crazy. They drive out around the mountain, stop and listen, and wonder why anyone would complain about noise emissions. But, believe me when we are having noise problems you can most assuredly hear the justification of our complaint. We have had people come into our yard get out of their vehicles and have watched their mouth drop. We have had company stop in mid conversation inside our home to ask, "What is that noise?" or say "I can't believe you can hear those like that inside your house."


Two views of the Mars Hill wind farm, showing proximity of rural landowners. It is not hard to imagine noise blanketing the fields, especially when the hill is sheltering the lowlands from wind.
Images from National Wind Watch

(Wendy Todd, continued): 18 families, each with homes less than 3000 feet from the nearest turbine, are experiencing disturbing noise levels; the next closest home is about 5200 feet away, and are only occasionally bothered when inside their homes.

Nick Archer, our Regional Director with the Maine Department of Environmental Protection, thought we were all crazy, too. But he finally made it to our homes and heard what we were talking about. I don't believe he has ever heard a 50+decibel day but he has heard close to that on more than one occasion and has made statements like these: "This is a problem," "We need to figure out what is going on with these things before we go putting anymore of them up," "I thought you were crazy at first but you are not crazy," "The quality of life behind the mountain is changed." Did he say these things just to appease us? I don't believe so.

Possible Factors in Noise Complaints

Why do neighbors sometimes experience noise levels beyond what industry noise models presume will be created by their wind farms?

One reason is that predicted noise levels can be based on unrealistically optimized lab conditions and perfectly new machines; thus the predicted noise output is likely to be the lowest that could occur. In addition, the idealized "spherical spreading" model generally used does not take into account terrain, vegetation, or atmospheric effects, each of which can either increase or decrease sound propagation. One useful approach to sound modeling is to assume a "worst case" ground cover (hard ground, which reflects, rather than absorbs, sound); such models often come closer to matching real, recorded sound levels than ones using "mixed cover" factors.

Topographical effects are very important to consider. Gently sloping terrain rising from a plain can sometimes cause sound levels to actually rise with increasing distance: Near the Vancouver Airport, hills rising from a flat plain caused sound levels to be 20dB higher at 5500m than at 4000m, because of the way the increasing ground angles caused sounds to combine, more than nullifying what, in a standard model, would be expected to be a 3dB decrease over that distance. A different topographical effect is the one reported at Mars Hill, Maine, where noise from turbines atop a ridgeline is made "worse" by the fact that the ridge blocks the wind at homes along its foot, eliminating the masking effect that is often assumed to drown out the sound of turbines in high wind conditions.

Increasingly, though, **researchers are discovering that atmospheric effects can cause the most troubling noise issues over larger areas than expected**. In the daytime, warming air rises, both carrying sound aloft and creating turbulence that scatters turbine noise; in addition, more ground-based ambient noise during the day masks turbine sounds. At night, however, when the air stabilizes it appears that noise from wind turbines can carry much farther than expected. This effect can occur with light winds at turbine height and the ground, or with light winds at turbine height and very little or no wind at ground level. With light and steady breezes capable of spinning the turbines, but not stirring up much ambient noise, sound levels measured at homes 400m to nearly two km away are often 5-15dB higher than models would suggest.

The effect of inversion layers on sound levels has not been systematically studied, though many opportunistic reports suggest the obvious: when an inversion layer forms above the height of turbines, it can facilitate longer-range sound transmission by reflecting some of the sound back toward the ground, and forming a channel for sound propagation. In many locations, this will be a relatively rare occurrence, but in areas with frequent inversion layer formation, it should be considered.

Possible solutions: **It is hard to escape the implication that setback distances may need to be increased in places where the prevalence of such topographic or night time effects suggest sound will often remain at annoying levels for larger distances.** Certainly, noise modeling studies should include calculations based on night time stable atmospheres; G.P. van den Berg, whose 2006 Ph.D. thesis is a comprehensive study of these effects, concludes that "With current knowledge, the effects of stability on the wind profile over flat ground can be modeled satisfactorily." (his measurements indicate that more sophisticated sound models were accurate to within 1.5dB, while simpler models missed the mark by up to 15dB) He goes on to note: "In mountainous areas terrain induced changes on the wind profile influence the stability-related changes and the outcome is less easily predicted: such terrain can weaken as well as amplify the effect of atmospheric stability."

There are certainly many suitable sites for wind farms that are remote enough to avoid even the possibility of noise issues in people's homes. At this crucial stage in the development of the wind power industry, it would be sadly short-sighted to insist on placement of turbines in the "grey area" between what noise models suggest is enough (perhaps 1500 feet) and the zone in which complaints have cropped up (up to a mile or so). Taking a big-picture view, the power generating potential in areas that are marginally close to people's homes is a very small proportion of the nation's wind power capacity. **Let's start where we know turbines will not disturb neighbors, rather than risk a generation of vocal complaints that may impede future development as turbines become quieter.**

Current Approaches to Regulating Wind Farm Noise

While the United States does not have national noise standards, many European countries do. These countries, and many state or county regulations in the US, typically set an absolute sound level that any industrial facility must meet. Commonly, 45dB is used as the night-time limit, and 55dB as the daytime limit; higher thresholds are sometimes allowed, but rarely does the night-time limit drop below 40dB. The problem comes in rural areas, where night-time ambient noise (wind, distant traffic, etc.) is often 35dB, and sometimes as low as 25dB. Given that 10dB is perceived as twice as loud, the problem is obvious.

It should be noted that the majority of wind farms do not trigger noise complaints. These are likely sited far enough away to work well for nearby residents. A 2007 report from the UK found that roughly 20% of wind farms (27 of 133) had received complaints about noise. While noise modeling (predicting the noise levels around wind turbines) tends to indicate that noise impacts should be insignificant beyond several hundred meters, the French National Academy of Medicine has called for a halt of all large-scale wind development within 1.5 kilometers (roughly 1 mile) of any residence, and the U.K. Noise Association recommends a 1km separation distance. In the US, there is no overall recommendation; setback decisions are made locally, and often are based on a 45dB night-time noise limit, so that turbines are sited no closer than 350m (roughly 1100 feet); 350-700m is often considered a reasonable setback in the US, based on simple sound propagation modeling. Though it is not uncommon for larger setbacks to be used, 1000m (1km) or 1500m (1 mile) setbacks are rarely required.

The International Standards Organization (which sets recommendations for all manner of human impacts) and the World Health Organization both recommend noise levels markedly lower than those used in most places, especially at night. WHO recommends a night-time average noise level of no more than 30dB inside bedrooms, and the ISO sets its limit even lower in rural areas, down to 25dB from 11pm-7am.

Local Regulatory Challenges

Small town governing bodies are generally ill equipped to address the questions before them when wind energy companies apply for local permits. In many cases, the proposed wind farm is the first outside industrial facility to be proposed in the town; it is almost always the first 24/7 noise source to appear in the local rural landscape and soundscape.

Energy company experts attend town council or selectmen meetings, often submitting comprehensive documentation that is rarely fully comprehensible to the lay members of the town's governing body. While these documents don't generally promise anything quieter than 45dB, the outside experts too often assure local officials that the wind farms will be inaudible—relying on flawed assumptions that high winds will always create enough increase in ambient noise to drown out the turbines. The use of comparisons, such as "a kitchen refrigerator" or "traffic 100 yards away" is likewise a common way of reassuring locals—one such expert went so far as to assure a council that the 45dB drone of turbine noise was "comparable to" bird song on a summer afternoon!

"There are no rules and regulations on windmills," Paul Cheverie, chairman of the Eastern Kings Community Council (Prince Edward Island, Canada) says. "The more we get into it, the more we realize we jumped the gun." **Wisconsin towns and counties have been especially proactive in implementing wind farm ordinances.** Calumet County limits turbine noise to be no more than 5dB louder than the background ambient levels at the quietest time of night, and Trempealeau County adopted a one-mile setback requirement. See some Wisconsin wind ordinances at http://betterplan.squarespace.com/wind-ordinances-wisconsin-stat

The statistical measures used by acousticians can read like Greek to most laymen (dBA_{90} anyone?). See the brief note on page 3, and be sure to seek out a good primer on these terms before agreeing to any ordinance language.

Detailed Documents Of Note

This AEI Fact Sheet draws on several detailed reports by others. Those wishing to learn more, or to inform themselves so as to discuss these issues in depth with regulatory authorities, company representatives, acousticians, or neighbors, will benefit from reading the source material below.

The full AEI Special Report on Wind Turbine Noise Impacts includes comprehensive resource lists, including links to download the following papers and many others, along with links to websites of wind industry organizations, government regulators, wind advocates, landowner support groups, and organizations concerned with wind turbine noise. See AcousticEcology.org/srwind.html

- G.P. van der Berg's 200-page Ph.D. thesis, published as **The sounds of high winds: the effect of atmospheric stability on wind turbine sound and microphone noise**, is a treasure-trove of detailed acoustic analysis and clear lay summaries, regarding both atmospheric stability issues and the challenges of recording effectively in high-wind conditions (i.e., avoiding wind noise on mics so as to more accurately capture ambient noise levels). http://tinyurl.com/78baby
- Soysal and Soysal, **Wind Farm Noise and Regulations in the Eastern United States**. Paper presented at the Second International Meeting on Wind Turbine Noise, Lyon, France, September 2007. A well-done and concise (12p) summary of wind farm noise sources, sound levels measured at one typical wind farm in Pennsylvania, and noise regulation challenges.
- Kamperman and James, **How To Guide to Wind Turbine Siting**, August 2008. Two acousticians who have become roaming expert witnesses for rural towns addressing wind development submitted these proposed limits at the July 2008 national Noise Control conference. In brief, they suggest limiting turbine noise to 5dB above night-time ambient noise levels at any neighboring property boundary, or a maximum of 35dB within 30 meters of any occupied building.
- Nina Pierpont, M.D. **Wind Turbine Syndrome**. Book to be released in 2009. Pierpont's short book-length summation of research into the health effects of low-frequency noise, and more specifically of audible as well as low-frequency noise emitted by wind turbines, is garnering impressive praise from fellow physicians. windturbinesyndrome.com
- Champaign County, Ohio, **Wind Turbine Study Group Report** - Pages 21-33 cover noise issues, including lots of back and forth (point/rebuttal) comments from study group members

---

The Acoustic Ecology Institute works to increase personal and social awareness of our sound environment, through education programs in schools, regional events, and our internationally recognized website, AcousticEcology.org, a comprehensive clearinghouse for information on sound-related environmental issues and scientific research. Our over-arching goal is to help find pragmatic ways to bridge the gaps between extreme positions voiced by advocacy-oriented organizations, and so to contribute toward the development of ethical public policies regarding sound.

AcousticEcology.org is an unparalleled resource for issue updates and reliable background information. The site features a News Digest, science summaries, Special Reports, and extensive lists of research labs and advocacy organizations on all sides of sound-related environmental issues, including ocean noise, motorized recreation in wildlands, oil and gas development, wind turbines, and more.

Contact Jim Cummings at 505-466-1879 or AcousticEcology.org

THE acoustic ecology INSTITUTE
. . . listen . . .

Wind Farm Noise 2011

Science and policy overview

Compiled by Jim Cummings

Contents

Preface: About this Report

It's been over two years now since wind farm noise issues showed up on my radar here at the Acoustic Ecology Institute. In early 2010, I published AEI's first annual report on the issue, in which I tried to make sense of the wildly incongruous perspectives that seem to dominate our discourse: on the one hand, wind boosters minimize the extent and effect of noise near wind farms, insisting there's nothing to bother ourselves over, while on the other hand, increasing numbers of apparently clear-headed citizens say their quality of life is destroyed by the incessant noise of nearby turbines. A few cranks harping on their latest pet peeve, or brave souls speaking truth to power? Is wind energy a benign key to our energy future, or a scourge in our communities that we'll live to regret?

In typical AEI fashion, the Wind Farm Noise 2009 report came down somewhere in the middle on these questions. It's clear that wind turbines are often audible in the surrounding landscape – often audible to a half mile, sometimes to a mile or more. They may not be loud, but they can be heard; several aspects of the nature of wind turbine noise seems to makes their sound more noticeable and more disturbing than other noise sources. In some communities, a significant minority (a quarter to half) of those hearing the turbines are upset about the new noise in their local soundscape; we're definitely hearing from far more than a few local naysayers. At the same time, most wind farms are built in areas distant from concentrations of homes, and so create few if any noise problems. In the wide-open spaces of the US west and in receptive farm and ranch communities in states like Iowa and Texas where the income is welcome and/or homes are few and far between, noise has been only an occasional problem.

The issue of wind farm noise has exploded in importance over the past few years as wind developers set their sights on rural communities in the upper Midwest and northeast, where individual parcels are smaller and a significant proportion of the population holds strong to a passion for the peace and quiet of rural living. In July 2010, I was asked to take part in a DOE-funded webinar to provide some perspective on community responses to wind farms; the resulting research review opened up fascinating new perspectives on the dichotomy of responses we hear in wind farm communities, which will be summarized in this report as well. Sneak preview: working farmers and ranchers are far less bothered by low and moderate noise levels from wind turbines than are those who live in the country for peace and refuge from the urban and suburban life. This isn't surprising, but it's central to the challenges at the heart of community siting decisions. One of the recurring themes you'll find here is the idea that what's right for one community or region may not be right for another; what I am trying to offer is a set of resources that will help community, county, or state planners to understand likely noise impacts, and to make choices about setbacks that they feel are appropriate for their citizens.

This report attempts to share the most useful new information that I've garnered over the past year or so. For some, it will seem long; I encourage them to scan the text using the underlined and colored sections as skimming aids, and dive in where they wish. For others, it may seem that I gloss over important points; I will make more detailed source material available on the AEI website.

If you don't have time to digest the full report, another approach would be to focus on the first several pages, where I introduce the main themes of the report and offer a sense of my emerging perspective on the issue. Reading or scanning the rest will obviously help you understand why I have come to the perspectives I hold, and will introduce you to some of the key aspects of emerging research.

The bulk of the report focuses on what I see as the most important – and also the least controversial – of the emerging new information on wind farm noise, the idea that existing community noise standards may not protect all types of towns from unacceptable levels of negative community reaction to wind turbine noise. Over the past couple years a growing cadre of extremely experienced acousticians has begun to examine the question of why we are seeing unexpectedly high levels of complaints in some wind farm communities. Most of these acousticians have long worked as industry and military consultants (not wild-eyed radicals by any means), and each offers interesting and important insights that can help us to address the question. These acoustics and community noise experts are responding to their professional obligation to investigate noise issues, and deserve to be heard. Their work reinforces my long-held belief that the clearly audible noise around wind farms is the central issue, and that addressing this issue is the clearest, most easily understood and justifiable, approach to dealing with community acceptance of wind energy.

I will also address, far more briefly, the two other noise-related policy questions being pressed in many communities: low-frequency noise and infrasound as it relates to health effects, and property values. Both of these topics are far harder to assess than the audible noise impacts being primarily addressed by most of the acousticians featured in the report's first section. While there is clearly more to learn about both topics, they also can become quite a quagmire for folks like me trying to understand what's known, and for community groups relying on these as foundations for their efforts for more protective setbacks. Perhaps another year will find AEI fleshing these themes out in more detail, but for now, I'll do my best to give you a sense of what I've learned so far about these hot-button topics.

Of course, no summary can be all-inclusive, and because of this, any report bears some editorial selection in its author(s) choices of themes to stress. In an appendix, I offer a sense of my history as an editor on similar topics, and my choices of what to include here, so you can judge for yourself to what degree you can place your faith in me as an honest broker of the information presented here about this complex and controversial topic. I hope that what I've gathered here is useful to most of you.

Introduction: AEI's Perspective

Since the beginning of 2011, as I continue to watch and listen to the content and tenor of the public policy debate around wind farm noise, I'm increasingly struck by two key thoughts:

> Most wind advocates, including both industry players and regional renewable energy organizations, appear to continue to be in a state of disbelief that the noise of turbines could possibly be a significant issue for nearby neighbors. While they do increasingly acknowledge that turbines will be audible much of the time, they consistently paint complaints about noise as being unworthy of serious consideration, either because turbines are not all that loud, or because they believe all noise complaints are bogus surrogates for a broader opposition to wind energy that is "really" based on visual impacts or economic arguments (driven in some cases by climate change denial). While there is some overlap between people who are disturbed by seeing turbines and by hearing them, this connection is often overstated as wind advocates seek to discount noise issues. Perhaps most crucially, wind advocates rarely acknowledge that turbine noise is often 10dB louder than background sound levels (sometimes even 20dB or more); acousticians have long known that any increase over 6dB begins to trigger complaints, with 10dB the threshold for widespread problems.
>
> Most community groups are over-reaching in their approach to raising the issue of noise, by focusing too much of their argument on possible health impacts of wind turbine noise exposure. While there are numerous reliable anecdotal examples of people having physical reactions to nearby turbines, the mechanisms behind these reactions remain obscure, as to other possible factors that may contribute; evidence for direct health impacts caused by the noise itself is not yet solid enough to win legal arguments, and making the case for indirect impacts (due to sleep disruption or annoyance) is difficult at best. In addition, even the accumulating number of reports of health reactions to new turbines represents a small minority of people within a mile or so of turbines. Much more convincing are community response rates that affirm that – in some types of rural communities – large proportions of people hearing turbines feel that their quality of life is severely impacted. While it may seem harder to push for larger setbacks without relying on the dire possibilities of health impacts, I believe that in many rural towns, counties, and states, the rural quality of life argument would be a far more defensible foundation from which to obtain more protective and flexible setback requirements that could minimize or eliminate nearly all noise issues (including whatever health effects may be occurring) – right now, without arguing about research techniques that few understand.

This new annual report aims to frame the current state of research and policy in a way that can help those trying to find a constructive middle ground that protects rural residents from an intrusive new 24/7 noise source while also encouraging wind development as part of our renewable energy future. Most of the emphasis here will be on giving communities the information they need in order to make their own choices about what degree of new noise makes sense in their particular situation.

There are still plenty of locations in the US and Canada where wind farms can be built without causing undue impacts on the sense of place that rural residents so treasure. In ten years, as an ever wider array of renewable energy sources become part of our electricity mix, we'll look back and wonder what we were thinking when we erected giant wind turbines in and amongst homes, with such little regard for the fact that these machines irrevocably change the nature of rural life. We can avoid the surprisingly invasive effect of moderate or even faint wind farm noise in otherwise pastoral landscapes without causing wind development to grind to a halt; such scare talk is unwarranted, based on what we can easily see is possible in the many, many locations where wind farms have been built with little or no noise issues in their local communities. All it takes is not building *quite* so close to unwilling neighbors – just being a bit more neighborly as we plan new wind farms.

Noise issues in context:
Anti-wind smokescreen? Undue fear? Unacknowledged plague? Shocking surprise?

It may be worth a moment's pause from the focus of this report—the effects of audible noise on the quality of life of wind farm neighbors—in order to note the several larger contexts within which the realities of the noise issue is sometimes lost or confused.

Too often, noise complaints are discounted altogether as merely an easy excuse for those who are simply anti-wind, or who don't like wind turbines in their view. There's no doubt that some people who are more broadly resisting wind development latch onto the noise issue as one part of their argument, but it's clearly false to imply that all those with noise concerns are anti-wind. Over and over again, the most compelling testimonies from wind farm neighbors who are struggling with noise issues come from those who were actually in favor of their local wind farm and excited about renewable energy in their communities. For most of these folks, the impact of 40-45db turbine noise comes as a total surprise, and it is this shock, as well as the ways the noise intrudes on their sense of place and rural quiet, that they most want to share, so that others can make decisions with this awareness about the perceptual intrusion of moderate noise that they lacked.

There is some research that shows correlations between noise annoyance and dislike of the wind farm itself. However, most such research took place after wind farms were in place, so it's hard to know whether the negative attitude toward the wind farm is *because of* the noise issues, or *contributes to* the noise complaints. It's entirely plausible that the experience of struggling with noise would lead to a negative attitude toward the wind farm. In addition, none of these studies show anything close to a one-to-one correlation; there are always neighbors for whom the noise is the primary problem, or the aspect of the wind farm that they find hardest to get used to.

In small rural communities, many people report that tensions run high between those hosting or supporting wind development and others who are having problems with the noise or their health. It can be hard to know exactly how many people are struggling with noise issues, since some people shy away from making waves. It's commonly reported by those in communities with noise issues that there are others either struggling with noise or trying to adjust to it who are not speaking out. These folks tend to question AEI's generalization, based on the few formal surveys that have been published, that annoyance rises only to around half of those hearing turbines; they often suggest that most people hearing the noise are bothered, unless they've got some hearing loss. This may well be, though I am content with the idea that a strongly negative impact on a quarter to half of those exposed to turbine noise is enough to justify considering changes in current setback standards.

Both the discounting of noise issues, and the belief that they must be nearly universal, are natural consequences of differences in noise sensitivity (see Appendix A). Those who are sensitive to noise have a hard time imaging how anyone could tolerate the intrusion, while those who are tolerant of noise can't see why it would bother anyone.

Finally, the objection is often voiced that community groups raising noise concerns are creating excessive fear about proposed wind developments, and that this fear itself may amplify or even create the negative reactions that are reported. This is a hard one to grapple with, because it does seem that some of the risks raised by community groups are presented as more definite or widespread than they actually are around active wind farms, while other concerns are clearly based on solid evidence. My observation is that the pre-construction level of fear *is* likely being amplified somewhat out of proportion, but that once wind farms are operating, those who report struggling with audible noise impacts are *not* delusional, and are reporting actual experiences. Suffice to say that just because some people highlight relatively rare cases of serious health impacts or people driven from their homes by lack of sleep, that doesn't mean either that these examples are irrelevant, *or* that they will occur everywhere. And most centrally, even if these most dire experiences are rare and unlikely to happen to most wind farm neighbors, that doesn't change the fact that high proportions of nearby neighbors in many communities say that the turbine noise has been an unpleasant and disruptive intrusion into their lives. It is this simpler yet perhaps more fundamental and universal value that I think is the most important thing to keep in mind.

But then, I'm someone who by vocational and personal experience is especially interested in, and connected to, the quality of the natural and human soundscape and the ways that new sounds change our experience of place. The arrival of spring migrant songbirds, the gradual fading away of night insects in the fall, the subtle play of breezes on trees nearby and hills in the distance, and the seasonal coming and going of the hum of the highway a mile away—these sounds all inform my sense of place. While I may be more focused on this than many people thanks to my line of work, such experiences are very common among a large segment of the rural population. This is the reason that AEI feels it's important and worthwhile to keep emphasizing the extent of audible wind farm noise, and to encourage communities to make decisions based on some clear appreciation for how this may play out for their friends and neighbors.

Problems grow when turbines are close enough to be easily heard by neighbors

While wind farms in the wide-open spaces of the west operate with few if any complaints, many towns and counties around the US and Canada are finding that the noise levels commonly allowed around wind farms (40-50dB) are triggering strong negative responses in a high proportion of neighbors close enough to hear these levels—often 25-50% of those living within a quarter of mile to three-quarters of a mile or so. These proportions closely match those found in the rare peer-reviewed studies of community responses. Not every close neighbor is disturbed, which leads some to think the problem is not with the noise, but with the people complaining. However, we'll see that it's entirely normal to see a range of noise sensitivity in a population, with around half being unlikely to be bothered by any but the loudest noises.

Likewise, when surveying the entire town (including those far from turbines), noise issues seem to affect only a small proportion of people. It's when we look at those living close enough to experience clearly audible noise levels on a regular basis that the problem comes more clearly into focus. The problem is not building wind farms; the problem is placing turbines close enough to homes that they are clearly audible much of the time. So the real nut of the question for towns preparing to host wind farms is to consider the impact on those closest, within a half-mile to mile or so. If all turbines were a mile or two from homes (as is the case in many wind farms), we'd have virtually no noise issues. However, since current setback limits are often a quarter mile or less, shifting to mile or more setbacks can seem to be going to far; in recent months, some places (including the county next door to mine) have adopted half-mile setbacks in an attempt to find a new middle ground. This will clearly reduce noise issues by keeping peak sound levels closer to 40dB at the nearest neighbors, though they will still sometimes creep higher, and in many rural areas it's likely that a quarter or more of those between a half mile and three-quarters of a mile to a mile will continue to be negatively impacted.

This becomes the concrete community decision point: should we put the turbines close enough to rob a significant proportion of these neighbors of the peace and quiet around their home that all of us living here enjoy? What is an acceptable level of disruption? While it may be considered acceptable to set a noise limit that will bother a small proportion of those hearing it, I think that few would feel that they've found the right noise limit if it triggers complaints in a quarter to half of those who hear the allowable noise. According to the research we have to work with, as well as reports from several recent towns where noise has become an issue, there are real questions about whether wind farm noise limits of 40-50dB actually provide the kind of protection that we expect from our noise ordinances.

Again, these "real questions" do not have universal answers—what works in one community may not work in another. Some communities may want to provide near absolute protection from non-household noise (including wind turbines), while others may easily accept routinely audible noise from turbines, motorized equipment, or industry; many will likely fall somewhere in between. It may be appropriate to look at programs that either compensate or buy out neighbors whose quality of life is being "sacrificed" in the name of the greater public good; some wind developers have done so[1], though this option is more often seen as introducing unacceptable levels of uncertainty into project budgets. This report won't attempt to assess such options, but they are certainly being discussed by many citizens and other observers.

Where wind farms make sense

Over the past year, I've been fortunate to find myself driving across several different regions in the U.S., and have often come upon wind farms. Every single time I encountered a wind farm in the wide open spaces of the west and midwest (in NM, TX, Iowa, Nebraska, Kansas, and Wyoming), they seemed to be totally *right* for their place; ranging in size from a dozen turbines to sixty or so, to many hundreds or thousands spread over tens of miles, these wind farms were rarely within a mile, or even several miles, of homes. Sometimes there would be one or two homes on the edges of the wind farm, likely owned by the lessees. Even these homes, several hundred feet to a half-mile from the nearest turbines, somehow made sense in the larger context of the place and the landowner's commitment to wind.

Conversely, when visiting wind farms in Wisconsin it was downright unsettling to enter a wind farm filled with small homes and farms, all surrounded by turbines; these folks are living *in* a wind farm, rather than near one. Similarly, neighbors in places like Vinalhaven, Maine, and Falmouth, Massachusetts who were excited about renewable energy in their communities have found that living within half to three-quarters of a mile of even one or a few turbines can be shockingly disruptive to their enjoyment of backyards and to their sleep. My experience in wind farms has been very consistent: I have always been able to clearly hear any turbines that were within a half mile of me (faintly, but clearly there); at a quarter to third of a mile, the sound stood out, and as I approached three-quarters of a mile, the sound faded into the background sounds of distant roads or ground breeze.

Occasionally in my travels, the turbines would be close to the road or highway I was driving on. Once, in Kansas, I pulled off the road to take a look and listen. The nearest turbines towered above me; I guessed they must be within a quarter mile. Once I moved away from the two-lane federal highway and crossed the nearby railroad tracks, several turbines were clearly audible between passing cars from my upwind location, despite ongoing faint background road noise. Then I drove out the dirt road that ran perpendicular to the turbine arrays, and was surprised to find that the closest turbine was in fact four-tenths of a mile from the tracks.

This is a recurring experience when exploring in wind farms: they always seem much closer than they really are. Driving toward my first wind farm, I was *sure* I must be within a couple miles when I was still between three and four miles away, and likewise, was certain they were within a mile when I was still nearly two miles away. Similar distortions of perception occur at close range, even now that I should know better: turbines a half mile away seem *incredibly* close, and ones a mile away seem to be just far enough away to minimize that sense of looming closeness.

Stated simply: building close to neighbors is just plain rude

While this may come off as ridiculously fuzzy-wuzzy, it seems to me that the best argument for larger setbacks in populated rural areas is that it's simply *impolite* to put a 400-foot turbine closer than around a mile to someone's home without their agreement. Or to put a sharper edge on it, it's just plain rude.

It's easy to make a less subjective/emotional version of this point: noise control and community noise specialists have long known that a new noise source will become noticeable when it is 5dB louder than existing sounds, and will cause widespread complaints at 10db louder. Wind turbines making 40-50dB of noise will often be 10dB louder than background ambient, and sometimes as much as 20dB or more. Some states (notably New York) attempt to avoid noise intrusions by limiting turbines to 6dB louder than existing ambient; this leads, predictably, to arguments about how low existing ambient really is when turbines are operating. But the emerging consensus is that in some fairly common situations, ambient can be as low as 20-25db. So, unless you keep the turbine noise to 30-35db, they are likely to be rudely loud.

At the same time, a setback of a half-mile (with the accompanying noise levels of around 40dB) could well be enough for some non-participating neighbors, especially if they don't spend a lot of time outside their homes, or are old enough to have some hearing loss. Indeed, many people would probably not mind a turbine a quarter mile away or closer, especially if it offers some supplemental income, as is clearly evident in some farm and ranch areas where noise has not become much of a community issue.

A possible route forward: larger setbacks, with simple easements for closer siting[1]

My experiences around wind farms – walking, driving, looking and listening – as well as taking in both the reports of neighbors affected by unexpectedly intrusive levels of noise from turbines a half mile away and of industry experience that suggests noise levels of 45-50dB are often tolerable, lead me to my current perspective that the most constructive and

[1] **A note on the word "siting":** some readers of previous AEI reports have said this word confused them. I think they saw it as a variation on sit or sitting, and weren't sure how it applied. It is a variation on the word "site," with an "-ing" suffix: i.e., choosing where to place turbines.

widely beneficial path forward would be a shift toward larger setback requirements (in effect, lowering the maximum noise levels at homes nearly to quiet night time ambient noise levels), combined with easily crafted easement provisions that allow turbines to be built closer to landowners who agree to allow it. This would protect communities and individuals who have invested their life savings in a quiet rural lifestyle, while acknowledging that there are many in rural areas who are ready and willing to support wind energy development, even near their homes.

Fortunately for the rest of you, I'm not the boss of the world, so what I think doesn't really matter. However, in towns, counties, states, and provinces across the continent, groups of diligent citizens are trying to make sense of confusing information and starkly opposite yet adamantly stated opinions. I hope that this report can help to clarify some of the reasons that such differing views exist, and give some support to efforts to find a workable path forward for both the wind industry and rural lifestyles.

Three key themes

This year's report will focus on three key themes that have become the central pillars of local resistance to current wind farm siting standards. None of these three need to be obstacles to wind development, *if* the industry and local and state regulators can move beyond simplistic denial, and forge a way forward that acknowledges the validity of community concerns about the changes that industrial wind farms inevitably bring with them. Indeed, the continued growth of the wind industry in the US and Canada may depend upon a fundamental shift of attitude, centered on providing communities with assurances that the negative impacts they fear will be incorporated into project planning—and more importantly, addressed if they occur.

1. Community Noise Standards: Are standards used for other noise sources sufficient, or is wind farm noise unique enough to need lower noise standards? Are "one size fits all" noise standards essential to foster wind development, or is it acceptable for different communities to choose different standards, based on local land use patterns and lifestyles?

2. Infrasound and health effects: Always inconsequential, or worthy of serious study?

3. Property values: How should we make sense of studies that counter-intuitively conclude that the presence of wind turbines has no effect on property values? Is there any practical need, or community-relations role, for property value guarantees and/or buyout provisions?

The need for respectful engagement with differing opinions

Cutting through all three of these themes is an underlying dynamic that is truly poisoning the waters of general public discourse as well as attempts by countless county commissions and statewide task forces to make sense of the controversies: there is a growing tendency for professionals (acoustical engineers, physicians, assessors) to vilify their peers who have a different view of the extent of problems with current wind farm regulation and siting. The "truth" about physical acoustics (sound levels around wind farms, frequencies of concern), health impacts (how prevalent or how severe), and property values are not as cut-and-dried as advocates for either side suggest. Most importantly, it's clear to me as an outside observer that well-educated, experienced experts in each of these fields are coming to diverse interpretations of the data we have to work with. I see professional disagreement after diligent assessment, not wayward acousticians or doctors or assessors who are biased anti-wind crusaders or shills for industry. This is a very important point, and is in some ways the central theme of this report.

If we frankly engage these three issues, and cultivate an underlying tone of respect and openness to each other – building a bridge over the current chasm that separates those who interpret the research differently – it seems likely that we can craft siting guidelines that protect local citizens from drastic quality of life impacts while providing clear and flexible avenues for future expansion of the wind industry as part of our future energy mix. That is the underlying goal of AEI's efforts to help both sides understand the other, and to help regulatory authorities to find their way to a balanced perspective on the contentious issues they are trying to address.

A huge business upside awaits for flexible wind developers

It's becoming increasingly clear is that communities *do* differ in their tolerance for noise, and in their willingness to accept the obvious (as well as the uncertain) trade-offs that come with wind farm development in their midst. There is no reason that we need a one-size-fits-all approach to wind farm siting. Some communities may decide (as the Roscoe TX area has) that wind farms are a positive addition to their communities. Others may seek to keep noise levels relatively low, as is the case in rural Oregon, which has an effective 36dB upper limit. Some may want to ensure that residents rarely if ever even hear turbine noise, adopting setbacks of a mile or more. A wind industry that is committed to being a good social citizen will accept these differences, and focus their development efforts accordingly, rather than trying to convince regulators that noise standards that work for the most noise-tolerant communities are the standards that should be adopted in all communities. There will often be some higher costs imposed by stricter siting standards (most commonly, the need to build extra miles of transmission lines to link to the grid), but such costs are often modest in the context of a large wind farm project.

Yes, some locations – in fact many locations in rural areas with relatively small lot sizes – may be hard or impossible to build in, but these are exactly the locations where the social tradeoffs, and the resulting balancing of costs and benefits, are least clearly favorable to wind development anyway. If the industry can accept that it doesn't have the *right* to build anywhere the noise can be kept to 50dB (which is becoming the preferred target standard for industry advocates), and that its future development will be taking place within the fabric of a diverse society, then there is a clear business opportunity emerging for those companies that take the lead by crafting truly responsive community relations programs. These companies will commit to working with the standards set by local tolerance for industrial wind development, rather than pushing local or state authorities to make it easy for them by adopting minimal siting standards. These leading edge wind companies may also put their money where their mouth is on property values by establishing programs that compensate landowners for moderate changes in property value, and helping create programs that buy and sell homes, so residents who wish to sell their homes can do so quickly at fair market value. These companies will develop reputations as companies that are ready to be good local citizens, and will find that the increases in some costs and a willingness to forsake some locations altogether leads to dramatic benefits in terms of long-term stability and acceptance in the communities where they work, and especially, in communities where they propose new projects.

Community Noise Standards

At the heart of the debate that's raging in communities around the world is the question of how far wind turbines need to be from homes. Beyond the basic safety buffers of 1.5 to 3 times turbine height that protect people from the rare occasions when a turbine falls down or breaks apart, the question of the proper setback from neighboring homes boils down to noise impacts. Some regulations set a maximum noise limit, while others define a minimum distance between turbines and homes. In practice, though, the distance-based standards are also generally based on an assessment of the likely maximum noise levels at the regulated distance.

The way it's "always" been

In recent years, it's been common for US and Canadian regulations to require setbacks of 1200-1700 feet, which roughly correspond to noise limits of 40-50dB. In most of the communities that have become "poster children" for wind farm noise issues, the residents living just beyond these distances (from 1200 to 3000 feet) are finding that noise levels in the range of 45dB, or even 40dB, are perceived as quite loud in quiet rural landscapes. This has led many in those communities to seek operational changes in the turbines to reduce noise; however, in most cases, the turbines are operating within the legal noise limits. In a few cases, recordings made by residents or hired acoustics consultants have found noise levels in violation of limits, but only by a few decibels (almost always just 1-3dB). Such small differences are effectively inaudible (it takes 3-5dB to be perceptible as a difference in loudness), which suggests that legal noise limits of 40-45dB may not be low enough to minimize impacts. In apparent response to some cases of turbines in existing wind farms slightly exceeding limits of 45dB, the industry has more recently been advocating noise limits of 50dB.

At the same time, the wind industry can point to many wind farms where residents are living 800-1500 feet from turbines, with very few if any noise complaints arising from received levels of 45dB or even 50dB. Indeed, I've searched in vain for reports of noise problems at wind farms in Iowa, which generates more wind energy than any state other than Texas (I don't doubt there are some homeowners who dislike the local turbines, but they appear to be few and far between, compared to other areas that spawn pages of Google results in simple searches). And in Texas, with a quarter of the nation's wind power output, nearly three times more than Iowa[2], there have been a couple of high-profile cases, but no widespread uprising over noise such as we see in Wisconsin, New York, and Maine. These past experiences are what lie behind the industry's insistence that current standards are sufficient.

Likewise, decades of experience have led to the adoption of community noise standards of 45-55dB for many kinds of industrial noise. Based on research into annoyance responses, effect on sleep and health, and general community acceptance of noise, when a new factory, or office building with its ventilation systems, or even a new road, is proposed it must meet community noise standards that virtually always allow noise at nearby residents to be 45dB, and often 50dB or more. These noise standards are not designed to reduce complaints or even displacement of the more sensitive residents to absolutely zero; but experience suggests that negative impacts should affect no more than a very small minority of nearby residents. Based on this long history of community tolerance for such noise levels, the wind industry strongly encourages local wind regulations to conform with these "generally accepted" community noise standards.

So how are these noise standards working?
(see Appendix A)

This leads naturally to the simple question: how are the generally accepted community noise standards working near wind farms? Do people hearing 40-50dB turbine noise find it is an acceptable presence in their lives, in the same way that these levels of road noise are easily tolerated? This was the topic of my presentation to the New England Wind Energy Education Project (NEWEEP) webinar in the summer of 2010. Funded by the DOE as part of its wind advocacy Wind Powering America program, this NEWEEP webinar was one of the first pro-wind events to take a direct look at community responses to wind farm noise. The presentation takes a close look at the Scandinavian research into annoyance rates at varying sound levels, as well as two lines of research that seek to explain why some people (and communities) react more strongly than others to wind farm noise. I had initially included a several-page overview of this research in the body of this report, as it offers a concrete picture of why many acousticians are questioning whether current community noise standards are sufficient for wind farm noise. However, it seemed to interrupt the flow of this section, so I moved it to Appendix A. If you have not seen the NEWEEP presentation, I do encourage you to flip to Appendix A now or later. The key points that inform what follows are:

- In rural areas, turbine noise levels of 40dB or more trigger a rapidly increasing level of annoyance in 25-50% of those who live close enough to hear these levels. Initial increases in annoyance rates occur as soon as turbines are audible, at 30-35dB.
- Individual differences in reactions to wind farm noise may be largely explained by referring to forty years of research into noise sensitivity.
- Community-wide differences in acceptable noise levels may reflect differing "place identities": those who work the land are far more tolerant of wind farm noise than those living in a rural area for peace and restoration.

Does wind turbine noise require tighter noise standards?

The crux of the current controversy is the suggestion that – at least in deeply quiet rural areas – wind turbine noise can cause problems at lower sound levels than other industrial noise sources, so that lower noise limits may be justified or necessary. This suggestion is based on the experience of communities where noise is an issue, and on some new (and old) ways of assessing noise annoyance potential.

A growing number of acoustical engineers have come to the conclusion that "generally accepted" community noise standards are clearly not protecting communities from wind turbine noise to the degree that 40-50dB limits would protect them from other noise sources. These acousticians have begun to suggest that noise limits of 35dB, or even 30dB, at nearby homes are more apt to lower annoyance levels to those that we have come to expect from other sources of community noise; aiming for lower noise exposure leads to setback recommendations that seem to be coalescing around distances of between a mile and a mile and a half (2km, or 1.25 miles, is a common recommendation).

Unfortunately, as these more cautionary acousticians have come to more prominence, submitting testimony to local and state wind ordinance task forces and generating detailed reports and recommendations that are cited by community groups, they've <u>often been vilified by industry advocates. I heard the reputations of some of these acousticians directly attacked</u> in a county commission meeting I attended, suggesting that their assessments are based on fundamentally faulty understanding of basic acoustics literature. (Equally unfortunately, acousticians that write environmental assessments for wind projects implying that the status quo is acceptable are often characterized by community activists, and sometimes even by their more cautious acoustician peers, as scientifically suspect yes-men for wind development.)

The fact is that nearly all of the acousticians who question the effectiveness of current community noise standards for wind farms are just as experienced in their field as the acousticians that are cited by the industry to support the status quo. <u>Most of those recommending larger – sometimes much larger – setbacks and/or much lower noise limits have worked for decades as fully credentialed acoustical engineers, and have turned their attention to wind farm noise over the past few years after hearing of the experiences of some neighbors, or being asked for their professional opinion by people who don't fully understand the noise reports being generated by the industry</u>.

When these more cautionary acousticians present their findings and recommendations before local commissions or in legal challenges, they are <u>often accused of being biased, with the suggestion that their opinions should be disregarded</u>. This charge appears to be based on the idea that anyone who recommends lower sound levels or larger setback is fundamentally opposed to wind power development. In my reading of the various reports and testimony submitted by these acousticians, I don't see evidence of bias. There are, in many cases, clear opinions presented as to the effectiveness of various proposed noise limits as community noise standards, and clear recommendations about what noise levels or setback distances the particular acoustician feels is likely to provide the level of acceptance of turbine noise that communities generally seek in their noise standards for other sound sources.

By contrast, noise studies and noise models included in industry-generated environmental assessments and project planning documents present the projected noise levels around the turbines, and <u>do not directly assess whether these noise levels are likely to be acceptable to</u>

residents. Rather, the projects are designed to meet the local noise standards at homes, which are presumed to be sufficient. So, these acousticians may be perceived as simply providing information, rather than opinions. However, when it comes time for a community, or a state Public Regulatory Commission, to set noise standards or setbacks, the industry tends to make a case for standards in line with those for other noise sources. They plead for "fair" standards, which generally mean standards that will not preclude construction, and that are no stricter than those used in other places. Hence, the status quo of 45-50dB becomes self-replicating, based on being the most common standard used elsewhere.

This is the habit that the more cautionary acousticians appear to be encouraging regulators to break out of, because of the high incidence of problems in some communities where the status quo standards were applied. It's not clear to me why an acoustician who feels that, say, 35dB is a more reasonable noise limit for rural residential areas, so that turbine noise will be faint or inaudible to neighbors, is biased against wind power, while an acoustician who supports a 50dB day/45dB night standard, effectively saying it's OK for neighbors to live with more noticeable turbine noise, is considered to be unbiased. Most likely, neither is fundamentally biased; each has an opinion as to what is likely to work for communities, based on what they've seen elsewhere. (While some consultants may write what their client wants to hear, in my experience, most scientists and engineers are more interested in facts than spin, so I don't presume that being paid for your opinion or expertise sullies the veracity of the final product.)

As noted above, we are beginning to see that not every community has the same tolerance for noise. At the same time, we're learning that wind farms generate higher rates of annoyance and disruption at lower sound levels than other noise sources. Thus, our generally accepted community noise standards may need to be revisited and revised to be applicable for wind farm noise. This is the essence of what the cautionary acousticians are trying to say.

What do the more cautionary acousticians recommend, and why?

I want to stress once more that the increasing numbers of professional acoustical engineers calling for revised community noise standards for wind farms are not yahoos who just enjoy challenging the status quo: they have decades of experience in acoustics, community noise, and noise control, mostly for corporate and governmental clients (most with very little if any prior work for community or environmental groups). And, to this relatively disinterested observer who supports the growth of the wind industry and has no stake in whether any particular wind farm is or is not built, they don't appear to be operating from a biased perspective. To the contrary, their analyses, field measurements, and recommendations appear to be less connected to a preferred outcome than many of the local and industry voices, which are often quite explicit in saying that a key element of a "workable" regulation is that it will allow large wind farms to be built in most locations, or in a particular location. Part of my purpose in highlighting their work here is the hope that other acousticians reading this will see the integrity of what they are doing, and so turn more professional attention to these important questions. I even have enough faith (or naïveté) to believe that some of their peers who have been content with earlier convictions that wind turbine noise is no different than other noise sources may have their interest piqued as well.

It's important to remember that these recommendations are not meant to bar wind development, and do not spell the death knell of the industry. Any regulations that adopt larger setbacks or lower sound limits can be, and usually are, combined with provisions that allow building closer to landowners who are willing to live with the occasional, or even regular, noise. The point of adopting more cautionary setback guidelines is to protect residents from unwanted noise, not to prevent wind developers from working with willing neighbors.

And while two of the following (Kamperman and James) have gotten the most attention and drawn the most vehement attacks, I can't help but notice that experienced voices are appearing in many regions and countries, all coming to generally similar conclusions. In keeping with my (floundering) intention to stay concise, I will refrain from quoting at length from their various reports and testimonies, but will focus on the particular contributions that each is making toward better understanding of the varied and at times vehement responses we're getting from different communities. I encourage you to read some or all of the footnoted sources, to draw your own conclusions about the relevance of these observations to your community's wind farm setback decisions.

George Kamperman, Illinois

Practicing noise control specialist since 1952, now semi-retired. Independent consultant since 1972, doing environmental assessments of all sorts of noise: industrial facilities in residential areas, mines and quarries, airports, a roller coaster(!), firing range, and many others. Designed noise control systems for industry: production facilities, heavy equipment, drawbridges, outboard motors and lawnmowers. Led development of the Chicago and State of Illinois noise ordinances, and served on committees that created several SAE and ANSI noise standards.

Rick James, Wisconsin

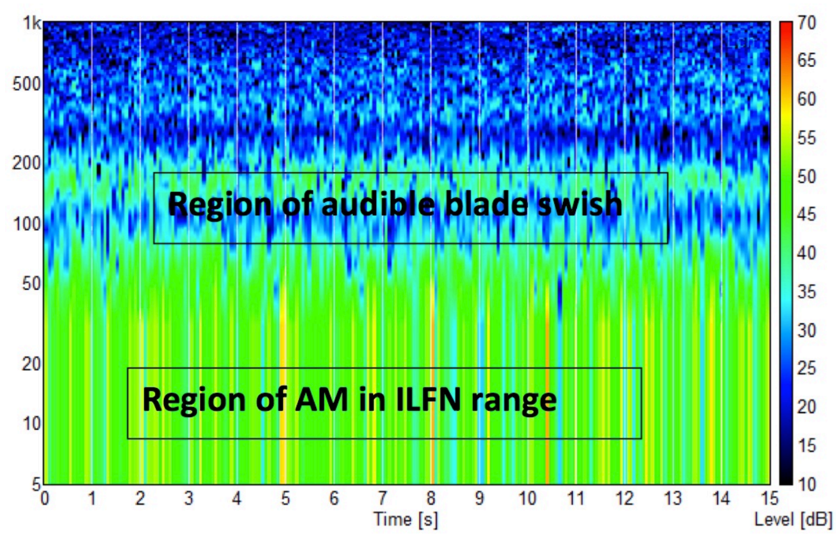
Has worked in noise control and measurement since 1971. Began with GM/Chevrolet, trained specifically to address emerging EPA noise regulations for the auto industry. Since 1976, as an independent consultant, he has provided noise control engineering services to GM, John Deere, and many other large companies; his company peaked with a staff of 45 working across North America. Early practitioner of computer modeling of sound, beginning in the 1970s. Years of testifying for corporate clients, affirming their use of the best available noise control technology.

> George Kamperman and I spent over six months reviewing wind turbine EIS statements and noise studies done in response to complaints before we felt we understood enough about wind turbines to support the position that they are unique and require a different type of criteria than more traditional noise sources found in communities. There is also the unique nature of the communities involved. When I first started reporting the low background sound levels I was measuring at night in many of these communities, people

> like George and even Paul Schomer (who has done considerable work in wilderness settings for the Park Service) were shocked to see that rural residential properties were so quiet.
> *Rick James, email communication*

Kamperman and James threw down a gauntlet in the summer of 2008 with the publication of "The 'How to' Guide to Criteria for Siting Wind Turbines to Prevent Health Risks from Sound." The tone of this guide is indeed aggressive, pushing back hard against perceived industry obfuscation about the noise levels around wind farms; no doubt one source of the reaction against Kamperman and James is the combative tone here. Yet, when faced with industry spokespeople presenting their opinions as unassailable fact, some of this feistiness can be accepted as necessary. Kamperman and James are also among the few more cautionary experts (in acoustics or health professions) who have explicitly incorporated Nina Pierpont's preliminary case series results (published as *Wind Turbine Syndrome*) into their thinking and arguments. Since 2008, James has made clear that he generally defers to medical experts on health issues, but the health basis of this early Guide is another reason that the Kamperman-James work has faced a strong backlash.

Digging into James' more recent field work and writings clarifies that his recommendations are grounded in measurements of audible noise, and in community responses to the sound levels, low-frequency amplitude modulation, and mid-frequency blade swish/thump that is characteristic of the newer, larger turbines. He appears to be most struck by the relatively extreme Amplitude Modulation he's recorded in several locations, both infrasonic and audible. In infrasonic ranges, the "dynamic modulation" is often 30-40dB between low and high sound levels, shifting in well under a second, sometimes peaking as high as 90dB, which even in these extremely low frequencies are likely to be perceptible by the 10% of the population whose hearing is more sensitive than most at these frequencies.



Meanwhile, audible "blade swish," the pulsing louder/softer pattern, which is most often in the 3-5 dB range (just perceptible difference in loudness), has been recorded as high as 13dB:

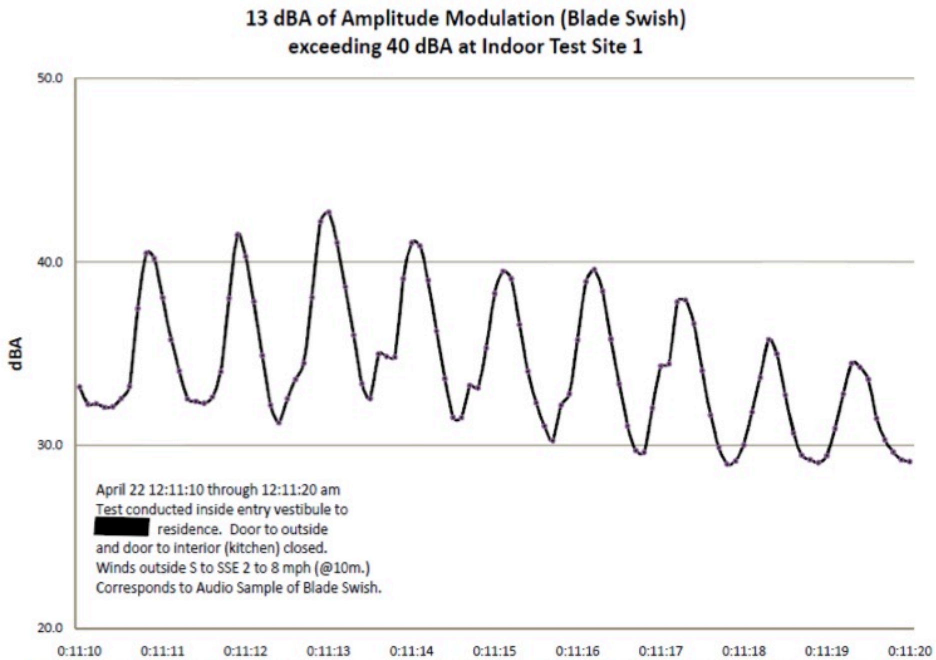


Figure 1 Blade Swish inside a home's entry vestibule (turbines downwind at 1500 feet)

James has often taken exception to fairly widespread assertions that "there is no significant infrasound from current designs of wind turbines." Such statements really mean that infrasound is well below normal perceptual thresholds, while in fact wind turbine sounds are heavily weighted toward low and infrasonic frequencies, with over half their total acoustic energy below 200Hz. When addressing infrasonic issues, though, James is generally careful to stress that his recordings suggest only that they could be audible to those with the most sensitive low-frequency hearing, and does not imply these sound levels are perceptible to most.

The Kamperman-James siting guidelines suggest keeping modern industrial wind turbines at least 1.25 miles (about two km) from homes, with the goal to keep turbine noise to 35dB, or 5dB above the ambient noise levels, whichever is lower. At the time they were published in 2008, James notes that they were aiming to find a precautionary distance that should provide some comfortable room for error; after doing several more years of field recording, he now considers the 1.25mi/2km buffer to be a minimum, if the goal is to avoid widespread impacts on the nearest neighbors.

While Kamperman and James are the lightning rods for both attacks by the industry and cheers from community groups, they are far from the only experienced acousticians who've come to believe that neighbors need larger setback from wind farms because of the noise impacts. Two other "acousticians emeritus," in addition to George Kamperman, have voiced their concerns: Malcomb Swinbanks and Paul Schomer. And several others with thirty years experience have added important perspectives to these questions.

Malcom Swinbanks, UK and Wisconsin

After getting his Ph.D. in applied mathematics in the early 1970's, Swinbanks became an expert in fluid and wave mechanics (which includes sound waves), and became a noise control specialist. Like many other acousticians, he became a consulting engineer, and worked with both the UK and US Navies on noise dampening of Naval vessels, focusing on exhaust and propeller noise. He is especially well-versed in low-frequency and infrasonic sound.

> I have stood beside two people on a site where low-frequency noise was present. One person said 'I can't really hear anything.' The other said 'I feel ill. I should like to leave.' Both were reporting accurately; there can often be more than 12dB difference (a factor of 4) in the sensitivity of individuals to low-frequency noise. Given that for very low frequencies, 12dB represents the difference between just audible, and uncomfortably loud, it is clear that <u>very real problems are experienced by some individuals, while others remain largely unaffected</u>.
>
> It is important to emphasize that there does not yet appear to be a full understanding of how to assess low-frequency wind-turbine noise. So it is difficult to understand how it can be argued emphatically that there is no problem, when it is clearly reported that significant ambiguity still remains in assessing these effects.
>
> <u>The misunderstanding may lie in a failure to take into account correctly the impulsive nature of the turbine noise</u>…Although it is now widely recognized that this can give rise to low-frequency modulation of higher frequency aerodynamic noise, resulting in a "swishing sound" (aerodynamic modulation), it remains the case that the low-frequency effects of the impulse are often incorrectly analyzed. This latter effect has been described as a distinct repetitive "thumping sound" audible at distances of 500 to 1000 meters (~ 1600 to 3300 ft.)
>
> <u>The feature of impulsive noise is that there is a large signal present for a short period of time. Consequently, the mean, or root-mean-square (rms) level of the signal may be very low, apparently well below the threshold of hearing, but the peak level is much higher and can be perceived</u>. [3]

This would help explain why so many neighbors report low-frequency sounds as troublesome, even at distances out to a mile or more at times, because hearing curves are determined using "sinusoidal" waves at various frequencies, which rise and fall gently. By contrast, the impulsive turbine sounds are likely to be more easily heard, because they have a sharper nature, called higher "crest-factors". As Swinbanks notes:

> C.S. Pedersen has reported that band-limited 2Hz-20Hz (infrasonic), and 2Hz-40Hz (infrasonic and low frequency) white noise is audible 7-10dB below the threshold defined for sinusoidal signals. This observation is consistent with the increased crest-factor of such noise. But low-frequency, repetitive impulsive sounds possessing a multiplicity of harmonic components have an even more recognizable characteristic, and are likely to be audible at even lower levels.
>
> Preliminary calculations indicate that periodic 1Hz impulses may be audible even when the individual components of spectral lines lie 25dB below the threshold of hearing. So simply examining low-frequency spectra and observing that individual spectral lines lie well below the threshold of hearing does not begin to summarize this situation accurately.[4]

Swinbanks has also addressed a little-discussed factor: the possible influence of the large wake of turbulent air that flows downwind from each rotating turbine. <u>It may be that some of the physical sensations reported by wind farm neighbors are responses to the air pressure differences in these wakes, rather than sound waves</u>. In addition, Swinbanks suggests that the wakes may contribute to the low-frequency sounds that are reported in some situations:

> For wind-turbines, a likely cause of infrasound is the downstream wake, which can reduce much more slowly than acoustic waves. There are regulations defining the separation time and distance which must be observed between large aircraft taking-off from a runway, because of the slow rate of decay of the wake turbulence and the danger of one aircraft flying into the wake left behind by a preceding aircraft.
>
> There is a downstream helical wake from a wind-turbine, and Denmark (e.g. Vesta) recommend a downwind separation of 7 wind-turbine blade diameters to avoid one wind turbine operating in the wake of another. But recent research at Johns Hopkins University has suggested that this figure should be increased to 15 blade diameters. For 100m diameter turbines, this would then require 1500m separation or just under 1 mile. <u>The intensity of low-frequency wake fluctuations at this distance is probably significantly greater than the acoustic effects associated with the wind turbine.</u>[5]

This seems a good spot to stress that the illustrative quotes I'm sharing here are meant to affirm the depth of careful and creative thinking that these acousticians are applying to the *problem of high complaint rates in some wind farms. These brief observations all appear in more detailed contexts, and should not be cited from this report as evidence or proof of any particular effect in submissions to local or state wind farm siting proceedings. Interested parties are advised to read the full citations, and to initiate in-depth conversations with trained acousticians in order to understand and interpret the significance of any particular statement included here.*

Paul Schomer, IL

Schomer is perhaps the acoustician with the most impressive standing to have challenged the validity of current wind farm siting standards. He is the Chair of the American Acoustical Society's Standards Committee, and widely seen as having an impeccable reputation in his field.

Paul Schomer is one of many to critique the techniques often used in wind farm environmental assessments of existing background ambient noise levels. Such estimates are then the basis of estimating how much louder turbines are apt to be.

The prevalence of faulty pre-construction noise assessment is one reason that community groups have often called on more cautionary acousticians to "assess the assessments." Schomer did his own recordings, designed to avoid insect noise, which had dominated the pre-construction assessment recordings done by consultants for a wind developer. The results were starkly different:

> In Cape Vincent, daytime, evening, and nighttime A-weighted L90s average at 35.5, 30.7 and 24.6 dB, respectively. Thus, the overall day-evening-night simple arithmetic average is about 30 dB compared with (the developer's consultant's) reported average of 45 to 50 dB—a range of levels that exceed the true ambient by 15 to 20 dB—a huge error.[6]

Schomer stresses the relevance of the New York standard of keeping noise to less than 6dB over existing ambient:

> What is the bottom line? During warm-weather months, almost every other night, the ambient…will be about 25 dB(A). At the same time the wind turbine can be producing on the order of 50 dB. Rather than the permitted 6 dB increase, the true increase will be about 25 dB, and this huge increase may occur almost every other night. People will be very unhappy—and rightfully so.[7]

In some later work for the town of Hammond, New York, Schomer drafted a noise ordinance that offers a good sense of his still-evolving[8] recommendations. In this ordinance[9], he recommends varying noise limits for different times of day: 45db in the daytime, 40dB in the evening (7-10pm), and 35dB overnight (10pm-7am). When ambient background levels are lower than these limits, even if 10dB or more lower, he feels these sound limits are sufficient; when ambient levels are close to (within 5dB) or greater than the limits, then turbine sounds of ambient+5dB are allowed[10].

Schomer's work for Hammond also specified some particular approaches to establishing existing background ambient levels, including the use of hourly L90 levels (the use of hourly, rather than longer-period, averaging helps to identify the quietest periods of the night), and an emphasis on avoiding recording during times when insects can increase the ambient measurements (while insects may be loud for some months or hours of the day, these should not be used to establish year-round or full-night ambient conditions). As he explains[11]:

> In relatively quiet areas insect noise, especially during summer months, can easily dominate the A-weighted ambient sound level. This domination occurs partly because the primary frequencies or tones of many, if not most, insect noises are in the range of frequencies where the A-weighting is a maximum, whereas, most mechanical and WECS (wind turbine) noises primarily occur at the lower frequencies where the A-weighting significantly attenuates the sound. Also, insect noise and bird song do not mask WECS noise at all because of the large differences in frequencies or tones between them.

Schomer has developed a weighting/correction method to be used when insects are unavoidable during the ambient assessments, which he terms Ai weighting[12].

Rob Rand and Steve Ambrose, ME

Thirty years experience in general acoustics including ten years in the Noise and Vibration Control Group at the international Stone & Webster Engineering Corporation. INCE member.

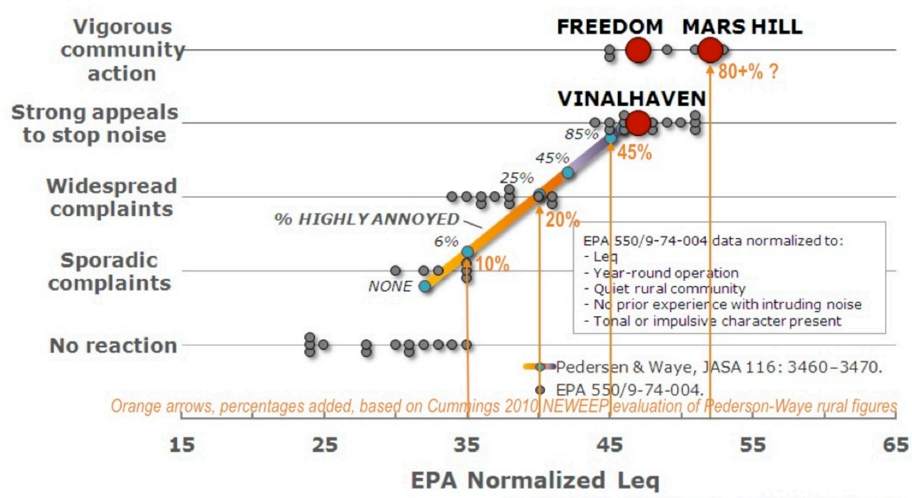
Rand and his equally experienced colleague Steve Ambrose have contributed some very clear reminders about what has long been known: that similar sounds are experienced very differently in different situations. In particular, they have stressed that when the EPA was developing recommendations for community noise standards in the 1970's, it looked very closely at the rates of community disruption caused by increasing noise levels; they correlated noise levels with community responses ranging from "No reaction although noise is generally noticeable" to "sporadic complaints," "widespread complaints," "strong appeals to local officials to stop noise," and "vigorous community action."

While for much of the country, a recommended upper noise limit of 55dB (and 45dB at night) would assure that complaints were sporadic or non-existent, the EPA noted that in quiet rural areas, correction factors should be applied in setting local limits. Rand suggests that for many communities where wind farms are being proposed, three EPA-recommended correction factors make sense: 10dB for quiet or rural areas, 5dB for a noise source the community has no prior experience with, and 5dB for the impulsive character of the blade swish.

If all these correction factors were applied, it would result in noise limits of 35dB; if just the rural correction were applied, it would result in limits of 45dB in the day and 35dB at night. Rand notes that as he and other acousticians have repeatedly found, existing ambient noise conditions in quiet rural areas tend to range from 25-35dB, so these lower noise limits would keep turbines close to existing background noise levels. Again, the early EPA work stresses what has long been accepted: sporadic complaints begin as new noise sources reach 5dB over current background, become widespread when the new noise is 10dB louder than background, and are vigorous and sustained at 20dB above background.[13]

Note: This long-known relationship has been stretched in many places in recent years: it's become quite typical for noise ordinances to allow up to a 10dB increase over the background ambient. I don't know how this gradual shift has been justified, since the record suggests that a 10dB increase will trigger widespread complaints. The New York standard that sets the limit at 6dB over ambient is a much better application of this standard acoustics relationship.

Rand has gone further, demonstrating that these predicted community responses match up very closely with both the peer-reviewed Pederson-Waye survey data from near Scandinavian wind farms, and to the measured levels of sound at recent problem sites in New England. Below is a chart he produced that includes the early EPA measurements of community responses to noise (black dots—original chart was for urban area; here the dB levels are reduced by 20dB as described above to represent rural wind farms as the noise source), along with Rand's overlay of Pederson-Waye annoyance rates from one of their studies (orange bar, extrapolated by Rand to the purple section of the bar), and actual community response levels at three locations in Maine (red dots).[14] *I have added, in orange, my slightly different interpretation of Pederson-Waye, based on response rates in their two rural studies, along with the unusually high complaint rates at Mars Hill, which far exceeds that found at other locations).*



Rand has said:

> As a member of INCE, I am pledged to the INCE Canon of Ethics, including the first fundamental canon, "*Hold paramount the safety, health and welfare of the public.*" If I have a professional disagreement with other INCE members, it's not really about the evolving understanding of infrasound. It's the ethics. It's easy to do an environmental impact prediction (of likely community responses) of wind turbines in rural areas. Yet I have not seen one wind turbine application in which even this most basic assessment was done. We never designed projects to produce "Widespread Complaints" at Stone & Webster, let alone "Vigorous Community Action"![15]

Robert Thorne, New Zealand

Over thirty years experience in measurement and assessment of noise and the effects of noise on people. Degrees in Health Engineering as well as Acoustics, and a Ph.D. focusing on "Assessing Intrusive Noise and Low Amplitude Sound," which addresses both the measurement of low background sound levels and the assessment of moderate noise sources on people. He represents the Australian Acoustical Society on the International Institute of Noise Control Engineering (INCE) Technical Study Group 7, which is working on a global approach to noise control policies.

Thorne has added some interesting new ways of looking at the ways that the experience of new noise sources is different in rural areas than in suburban or urban areas. His recent Ph.D. thesis built on some earlier work (by Zwicker) to propose assessment of how "intrusive" a noise source is, which may provide some subtler ways of assessing likely annoyance. He also stresses the impact of "rural amenity" factors, which provide a way to recognize that a truly quiet ambient environment is important in rural areas. And, he incorporates a recognition that 20-30% of the population is more noise sensitive, and favors taking this into account in predicting local responses to new noise sources.

He has investigated community responses near several New Zealand wind farms where negative reactions occurred at greater distances than reported in other situations. At the Makara wind farm, 906 complaints have been received from residents living 1200-2200meters (three quarters of a mile to a mile and a half) from turbines. The Te Rere Hau wind farm has spurred complaints from "most, if not all, of the non-stakeholder residents within 3 to 4 kilometers (two and a half miles) of the wind farm."[16]

He has observed that 30dB L_{eq} can be clearly audible inside homes on quiet nights, and that "severe annoyance due to noise can be expected" at sound levels as low as 40dB.[17] He suggests that 2km (1.25 miles) is the "minimum buffer" from homes, representing the threshold between moderate and severe annoyance responses, and that a 3.5km buffer "may be required," noting that this distance "does not reduce perceived noise to zero; rather, it provides a working zone between distances of known moderate annoyance to infrequent annoyance."[18]

Richard Horonjeff, MA

Over forty years experience; INCE member with a focus on perception and effects of noise, prediction and modeling techniques, and community noise. Has done research and publication for agencies ranging from the National Park Service (visitor perception of park soundscapes) to NASA (very low frequency noise) and major airports.

Horonjeff has also stressed the need to use the old EPA recommendations to adjust community noise standards downward in rural areas where wind farms are being built; he suggests using two of the three adjustments Rand speaks about, noting that the same total 15dB adjustment is included in the current American National Standard 7, so that "if it is not considered for the rural/new source case (of wind turbines), there should be some justification for why it has not."[19]

Horonjeff also makes the important observation that new noise sources often spur a decade-long evolution of noise standards, as previous standards that are initially assumed to be sufficient are gradually seen to not fully apply to the new situation. He cites the introduction of jet engines as one prior example that may be especially relevant to today's larger wind turbines; as with the change from propeller planes and jets, which generated similar noise levels but spurred more complaints due to the nature of the noise, wind turbines with much larger rotor diameters, generating more low frequencies and encountering more wind shear from bottom to top, are spurring a new kind of community response as compared to older, smaller turbines with similar noise levels.

> This evolutionary process generally begins with anecdotal evidence being presented. This evidence takes the form of some new source's health and welfare effects not being accounted for by existing regulations. Scientific inquiry then begins and research is conducted until a consensus is reached regarding the cause/effect relationship. Next, appropriate national and international standards committees develop new standards to be applied, or existing ones are modified for source specificity. These new standards eventually find their way into guidelines and regulations.
>
> From the time a new source is brought to the attention of the acoustics community it is not unusual for a period of five to ten years to elapse between the onset of literature review and research and the promulgation of an agreed upon noise standard for the source. This has been true for highways, for aircraft, for railroads, industry, and many other sources.[20]
>
> A number of reports have been prepared in recent years purporting that symptoms reported by wind farm neighbors should not be attributed to wind turbine noise since such symptoms are not supported by existing literature. This is particularly the case regarding the controversy regarding the issue of low-frequency wind turbine noise. However, it is safe to say that the existing peer-reviewed literature does not address the specific attributes of wind turbine temporal patterns and long-term exposure to them. Hence, an

important body of information by which standards might be set has simply not yet been developed. It is important to remain mindful that the absence of research and reported findings does not prove the absence of an effect.[21]

Why might wind turbines trigger more annoyance at moderate sound levels than other community noise sources?

In addition to the various points made by the acousticians above, ongoing research is seeking the answer to this key question. The two most significant factors are likely to be the variable nature of the sound and the lack of predictable reduction in noise at night. This has been addressed in many other places, so there's little need to belabor it here.

In brief, a common (though not constant) feature of wind turbine noise is that the noise pulses about once per second. It used to be thought that this was caused by blades moving past the tower; more recently, research has been coalescing around the effect of higher wind speeds at the top of the turbine rotors causing louder air flow (perhaps also aggravated by the fact that blade angles can't be instantaneously optimized for the differential wind speeds). Some additional thumping noise may also be caused by smaller patches of turbulence passing through the rotor plane. In addition, there are indications that the noise can be somewhat directional as it moves off the trailing edges of the turbine blades. As modern turbines continue to increase in size, it's likely that they will encounter even larger wind-speed differentials between the bottom and top of their rotation, as well as more micro-turbulence, perhaps increasing the presence or intensity of these amplitude modulations.

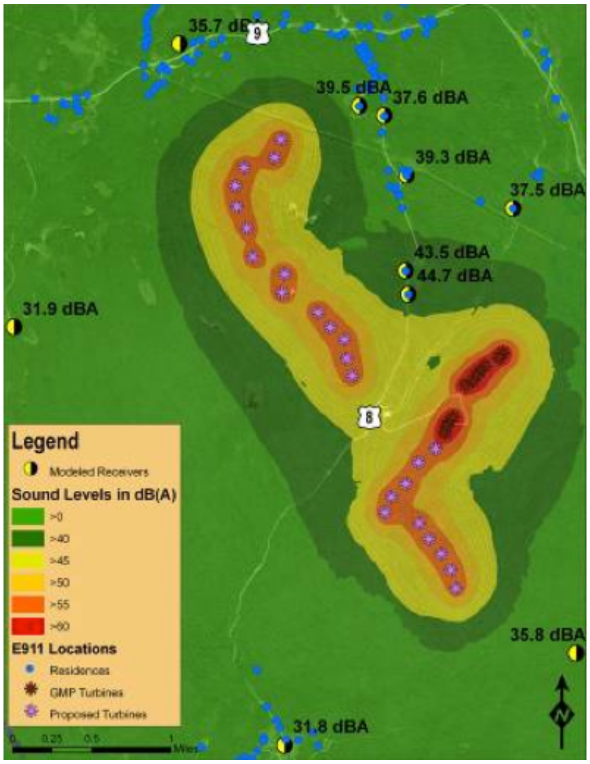
Most community noise sources occur at predictable hours, generally during the workday, and almost always decreasing or ceasing at night. Also, most other noise sources have one characteristic sound. Wind farms noise can come and go at any hour of the day or night, based on changing wind directions and speed and shifting atmospheric conditions. Neighbors report that turbines can create a surprisingly variety of sounds, from whooshing or roaring to thumping, clattering and whining[22]. Many of these changing sounds are caused by wind turbulence at the blades, and some by transient mechanical issues or tiny holes in the blades that can be addressed in routine maintenance. The nighttime sound of nearby turbines is often the primary issue for neighbors who find themselves struggling with turbine noise; sleep loss is often mentioned as the hardest to accommodate issue.

What about acousticians who feel that current community noise guidelines are sufficient?

There are certainly plenty of acousticians who continue to support noise limits of 40-50dB, and the resultant smaller setbacks that have been in use up until now. For a sense of their thinking, readers can seek out nearly any sound modeling or sound monitoring study commissioned by wind farms or government entities. As part of routine permitting, a sound modeling study is completed for virtually all new wind farms; and, if complaints arise, a sound monitoring study will usually be commissioned.

As noted above, most of these formal reports are oriented toward predicting and confirming sound levels around wind farms, rather than assessing what the likely impact of the noise will be on those hearing it; their purpose is to help wind developers to design a site layout that will conform to whatever the local noise or setback ordinances require. When called to testify on their work before county or state regulatory bodies developing wind ordinances, these acousticians present the acoustic data or models in a straightforward way, generally without assessing likely impacts. When pressed to provide some context for the sound levels they are talking about, they often compare the turbine sound levels at homes to familiar sounds, such as a conversation or a refrigerator running. This is accurate, as far as it goes. What is rarely considered is how these moderate noise level may be experienced by people in their daily (and nightly) lives—for example, how will someone react to a sound as loud as a conversation in their backyard while gardening, or one as loud as a refrigerator in their bedroom at 2am? I don't see this as any sort of intentional misleading on the part of these acousticians; rather, it's simply a standard way of viewing and thinking about moderate noise levels. In my experience, the acousticians I've met who are regularly contracted to write these reports are quite open to the perspectives that I'm adding to the conversation, stressing that they work with data, not with subjective interpretation.

Such reports often include a "sound contour" map that shows decreasing sound levels around the turbines, based on local topography and ground cover. Here's a typical example, from Ken Kalisky's NEWEEP presentation[23]:



In this proposed turbine layout, no homes are in the 45dB and above zone (yellow). Based on the distance scale in the lower left corner, received sound drops below 45dB in less than a quarter-mile in some areas, and in about a half-mile in others.

Two homes are located in the 40-45db zone (dark green); one is a half-mile from the closest turbine, and the other a bit more.

Sound levels remain above 40dB (dark green) out to around a half-mile in nearly every direction, and to about three-quarters of a mile in the three highest-sound directions.

Some examples of sound studies:
(see AEI Wind Farm Noise Resources page to download copies)

- Allegheny Ridge Wind Farm Sound Monitoring Study, Prepared for Juniata Township by Resource Systems Group, Inc., 2009
- Noise Analysis PPM Clayton Wind Farm, CH2M HILL, 2007

Some more general reports by acoustic consultants and/or wind developers, industry trade groups, or other wind advocates have provided a summary of what is known about the effects of noise, especially low-frequency noise and infrasound; by and large, these summaries tend to cover similar ground, generally supporting the status quo noise limits. They point out that infrasound is well below perceptible levels (using standard perception curves, without considering Swinbanks' observations as noted above, p. 20-21), and that the noise of turbines is no louder than many other noises that people seem to easily live with. It often seems that the purpose of these reports is to reassure people that they should not expect problems with noise, while they rarely if ever address or investigate the experiences of those who are struggling with noise. These overview reports do usually note that turbines will be audible, and may annoy some nearby residents, and then go on to affirm that annoyance is not a health impact, usually leaving it at that. By contrast, the acousticians noted above treat widespread annoyance as a problem worth investigating, and more actively seek to understand what acoustic properties of the turbine noise may be triggering the unexpectedly high levels of annoyance.

Some examples of noise overviews (also available at the AEI Wind Farm Noise Resources page)

- AWEA Siting Handbook, 2008

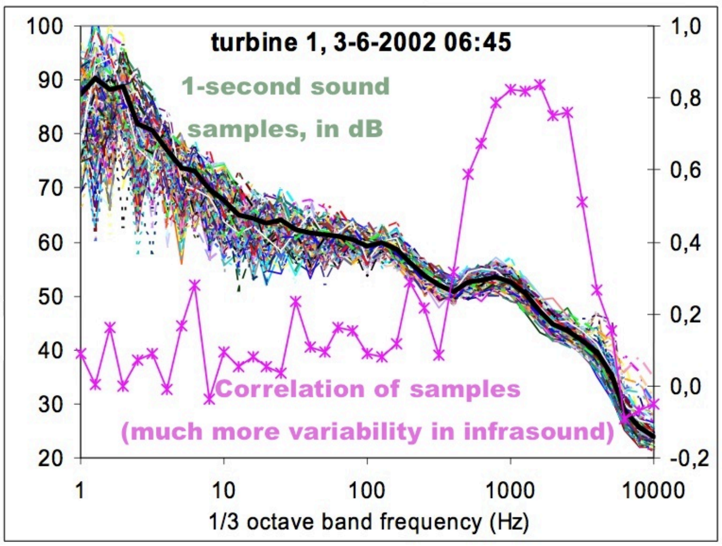
- State of Maine: Tracking Progress Toward Meeting Maine's Wind Energy Goals, Including an Examination of Current Wind Energy Noise Guidelines and the Opportunity for Public Hearing, 2011
- Mark Bastasch et al. Wind Turbine Noise – An Overview. Canadian Acoustics Vol. 34(2). pp. 7-15. 2006.

Note: The methods used by acousticians to assess existing ambient background noise levels, as well as to model likely sound levels once operational, are subject to differing techniques, assumptions, and interpretations. Many of the assessments done on behalf of developers have been criticized by other acousticians, and likewise, the work of acousticians suggesting that ambient levels are very low or that turbines may generate troublesome low-frequency noise increases at homes have been criticized by others. I am including links to both types of reports in order to allow readers to see both approaches.

Low-frequency sound, infrasound, and health

As stated at the outset, this report will not attempt to fully assess the controversies or state of research into low-frequency and infrasound levels around wind farms, or the widely discussed question of possible health effects triggered by such sound. Perhaps next year.

I do want to make a few observations, though. First and foremost, any shorthand claim that wind turbines do not produce much low-frequency or infrasound should be taken with a grain of salt. The vast majority of the acoustic energy of large wind turbines is indeed in the lower end of the frequency spectrum, and the lower the frequency, the higher the sound level. Nonetheless, it is also true that below around 40Hz, near the bottom of normal human hearing range, wind turbines tend to be quieter than what humans can hear (on the fringes of our hearing range, sounds must be very loud for us to hear them), and this is why some observers suggest that this (large) part of the wind turbine noise spectrum is insignificant.



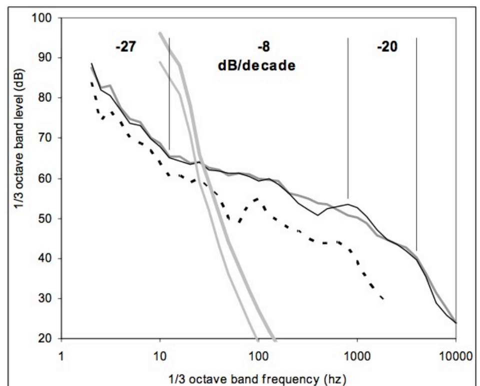


Figure 3: regions in 1/3 octave band spectra near turbines (grey and thin black line) and dwelling (dotted line) with average spectrum slope in dB/decade, and 10 and 50 percentile hearing threshold level for young adults

These two graphs from Fritz van den Berg[24] show the frequency spectrum of wind turbine sound. On the left graph, note the increasing (unweighted) dB levels in lower frequencies, and the extreme variability of infrasound (below 20Hz) as compared to relatively much more consistent sound levels at higher audible frequencies. On the right graph, the steep light grey lines show typical hearing thresholds, while the darker lines and doted lines show mean sound levels of turbines; when the turbine sound level is below the hearing curve (as it is below around 40Hz), the sound should be inaudible to most people.

Two key things need to be kept in mind, however. First, ongoing research continues to assess the actual noise around wind farms (rather than modeled levels), and as noted earlier and illustrated above, there are some indications that at very low frequencies the sound can be very dynamic, much different than the pure-tone lab sounds used to determine human perceptual thresholds. We are still learning much about the complex frequency and temporal patterns of wind turbine noise, and it's clearly premature to close the book on possible perceptual effects.

Second, whether or not LFN (low-frequency noise) and infrasound from turbines triggers direct health effects, it's entirely plausible that this relatively extreme aspect of the wind turbine noise could contribute to the higher levels of annoyance triggered by wind farms, or to the sense of wind farm noise being especially hard to ignore, even at moderate sound levels. This could be simply due to the lower audible frequencies, which make turbines noticeable even when rustling leaves are making similar levels of noise, or it could be due to barely-perceptible inaudible low frequencies or infrasound, as suggested by Malcomb Swinbanks above. In addition, there will always be some people who perceive even the lowest frequencies at lower sound levels than most; these will be few, but the impact on them will be real. Speculation that people with compromised or hyper-sensitive vestibular systems may be more apt to be affected by these extreme low frequencies also deserves continued investigation; it's not uncommon to hear from war veterans or others with injuries that cause balance or inner ear problems who find themselves more sensitive to wind farm noise than their neighbors or spouses.

There are several different ways to "weight" noise measurements, each of which highlights different parts of the sound spectrum. A-weighting, which reflects the way the human ear hears sounds, discounts low-frequency sounds and disregards infrasound altogether. C-weighting focuses more on the lower frequencies, and G-weighting highlights the lowest frequencies. Wind farm noise assessments nearly always use just A-weighted sound levels, which makes sense in terms of what we will hear, but doesn't reflect the increased sound energy that accompanies operating turbines heavy in lower frequencies, and which may contribute to an increased annoyance response.

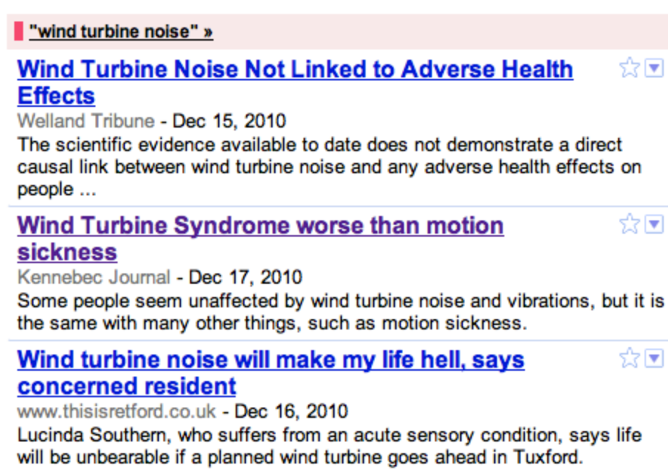
In a paper presented at the spring 2011 Acoustical Society of America meeting[25], Bill Palmer reported that LFN and infrasound increased notably as soon as turbines begin operation. His well-designed study measured the full sound spectrum from about a third of a mile away during turbine operation, and in a location close enough to have similar weather and topographical conditions, but far enough away (3 miles) that turbine noise was not predominant. He reports an increase of 20dB at all frequencies below 1000Hz at the close locations as compared to distant ones, even at very low-power operational speeds. Even as sound levels increased at the distant location with an increase in ground level wind speed, the sound levels at the locations near the turbines continued to rise, staying some 20 dB higher at all frequencies below 1000Hz. His study also noted a cyclical shift in frequency around 125Hz, which could be audible as a subtle siren-like sliding of the tone up and down, and may contribute to attracting perceptual attention to even a barely audible noise.

It is important to note, of course, that such on-site recordings often vary from site to site and even more so, over time. It is common that acousticians are called in to investigate locations that have especially bothersome low-frequency sound issues, and we should be careful not to assume that what is found in one time and place represents what is happening everywhere. This goes for both the worst-case examples and the reassuring no-problem examples offered by various acousticians. At the same time, though, such examples can help us to understand that the noise conditions around wind farms do vary, and that sound models or predictions of impacts can't represent the whole story. We do need to have such models and predictions as starting points as we assess impacts, but we also need to acknowledge the real-world variability that is central to the actual experience of those living near wind farms.

I should also mention new research published this year by Alec Salt[26], which suggests that our outer ear hair cells (tiny hairs that stimulate auditory nerve responses) may respond physiologically to very low frequency sounds at levels up to 40dB lower than what is necessary to actually hear the sounds; this is important because wind turbine infrasound is often 20-40dB below hearing thresholds. His work doesn't address whether this response in the outer ear hair cells is or can be related to any reported symptoms or full-body sensations, or even suggest any mechanism (process) by which they might do anything more than their known role in amplifying or dampening the responses of the inner ear hair cells. But the research has intrigued many observers, including the National Institutes of Health, which noted[27] that this may be related to the physical sensations and odd perceptual experiences some people report when exposed to inaudible levels of low-frequency sound. See the footnote above for much more detail on this work.

Health Effects

Regarding health effects, it's again beyond the scope of this report to provide a full assessment. With several studies underway in particular locations (notably Wolfe Island, Ontario, which includes an all-too-rare "before the wind farm" phase of study[28]), as well as some governmental agencies putting together overview reports (including among others Japan, Oregon, Massachusetts), the next couple of years will provide us with more data to use in assessing how prevalent reported health problems really are around wind farms. Meanwhile, a typical daily set of headlines in my Google News customized "wind turbine noise" section sums up the current situation pretty well:


"wind turbine noise" »

Wind Turbine Noise Not Linked to Adverse Health Effects
Welland Tribune - Dec 15, 2010
The scientific evidence available to date does not demonstrate a direct causal link between wind turbine noise and any adverse health effects on people ...

Wind Turbine Syndrome worse than motion sickness
Kennebec Journal - Dec 17, 2010
Some people seem unaffected by wind turbine noise and vibrations, but it is the same with many other things, such as motion sickness.

Wind turbine noise will make my life hell, says concerned resident
www.thisisretford.co.uk - Dec 16, 2010
Lucinda Southern, who suffers from an acute sensory condition, says life will be unbearable if a planned wind turbine goes ahead in Tuxford.

For now, I'll just mention a couple things to keep in mind as you try to make sense of the starkly opposing views about health impacts of wind farm noise. First is the fact that there are clearly some people who are experiencing physical reactions to turbine operation; many have left their homes to find relief, and find that they get worse again when they come back. While some of these cases may be "just" caused by their negative feelings toward the wind farm, or fear of problems, when you hear the people's stories, it's hard to chalk it all up to such hysteria. Something is going on for some people. At the same time, it also seems clear that only a small proportion of those bothered by wind turbine noise report definite physical health symptoms; the few surveys we have suggest that most of those annoyed by turbines don't even report sleep disruption. It appears that health problems, while all too real for some individuals, are not nearly as widespread as the quality-of-life impacts that are at the heart of most negative reactions to audible turbine noise. One location where health impacts have been reported by a much higher proportion of residents is Mars Hill, Maine[29]; this exception may be helping to highlight the possible impacts, in that the residents are being exposed to higher sound levels than most other locations due to an exemption this wind farm received, allowing it to create noise of up to 50dB at neighboring properties. As is the case elsewhere, though, it's very difficult to make the case that health effects are being caused directly, by the noise itself, or to prove an indirect connection, via quality-of-life impacts including annoyance and sleep disruption.

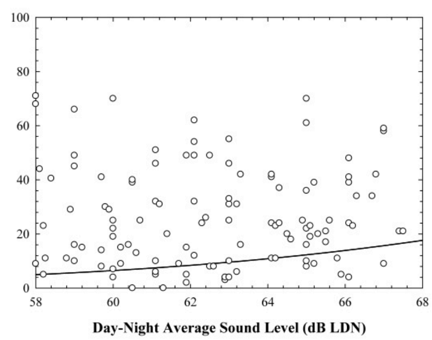
AEI has covered the various health reports as they have come out; for more detail on the strengths as well as the missing pieces in these reports, see the following links:
CanWEA/AWEA report: http://aeinews.org/archives/584
Ontario report: http://aeinews.org/archives/915 and http://aeinews.org/archives/937
Two earlier studies provide more comprehensive assessments of possible health effects near wind farms:
State of Minnesota Department of Health: http://aeinews.org/archives/456
World Health Organization night time noise: http://aeinews.org/archives/429
In October, 2010, the Society for Wind Vigilance put together a symposium on health effects that featured many of the leading voices of concern about this issue; it could be considered the polar opposite of the CanWEA/AWEA report in that the range of views is similarly constrained, but from the opposite perspective: rather than focusing solely on previous peer-reviewed studies (many of non-wind farm noise, and none investigating actual reports of health reactions to wind turbines), the proceedings of the SWV symposium present a range of research and on-the-ground reports that take the effects being reported near turbines at face value, and make attempts to develop possible explanations.
http://www.windvigilance.com/international-symposium/proceedings-first-international-symposium

One recent overview of health effects[30], put together by Jevon McFadden of the Wisconsin Department of Health Services, offers a relatively fair overview of the research that has been done to date, and concludes with this perspective on the key impact of turbine noise, annoyance:

> Annoyance is not a disease, and does not require a public health intervention. It is a quality of life issue, and can be a legitimate factor to consider in wind turbine siting.

Another recent overview that I found especially useful came from Daniel Shepherd, a New Zealand psycho-acoustician. His submission[31] for consideration by authorities considering a wind farm in the Ohariu Valley provides a comprehensive look at the fascinating interactions between sound levels, annoyance, and health effects (direct and indirect) in different types of communities. Shepherd's Masters and Ph.D. theses focused on human perception of low level sounds, and among his key points are:

- The study of health effects of wind farm noise is in the early stages of a well-recognized progression in public health *(note: similar to Horonjeff's perspective on community noise standards)*; one feature of the earliest stage of response is that symptoms are seen as either caused by some other factor, or as psychosomatic.
- Noise sensitivity plays a key role in annoyance levels, and there is solid evidence that rural populations attract higher proportions of noise-sensitive people. (I don't think there have been studies of noise sensitivity rates in people who work with farm machinery routinely, but it would seem likely this attracts less noise-sensitive people, and/or leads to moderate hearing impairment over time, helping explain why some rural communities do better with nearby wind farms than others do.)
- He shares a dramatic pair of graphs to illustrate the fact that annoyance responses are very poorly correlated with noise levels, and are clearly affected by many other factors; but also notes that noise regulations are often based on large-scale average responses rather than the likely more-relevant local factors.



Shepherd's interpretation of this graph[32]: Note the incompatibility of the theoretical dose-response curve (solid curve) and the empirically derived data (data taken from Fidell, 2003). Scrutiny reveals that annoyance reactions to noise vary substantially and do not appear to be correlated with noise level.

(I would add that it's extremely revealing to see the incredibly wide annoyance levels found at any one dB level; for example, at 58dB (which we might equate with 43dB wind farm noise, using corrections/normalizations recommended earlier), annoyance in some studies is 10% or less, while others find annoyance of 70%. These are differences between studies, not individuals! Clearly there is wide variation based on location, expectation, and other factors. Also: this graph addresses annoyance from

aircraft; the dB levels in the dose-responses to wind farm noise would be 15-20dB lower.)

There's much more in Shepherd's two reports[33], and I highly recommend them to anyone seeking to understand the subtleties that are necessary to address either the quality of life or health impacts in rural communities.

Quality of life protections will likely address future understanding of health effects

I am surely moved and disturbed by the stories of people who have had physical reactions to wind farm noise, especially those who have taken the undeniably non-imaginary step of abandoning their homes. There's no doubt that some people are physiologically affected by the nearby presence of wind turbines. Yet I can also clearly see that the experiences of these few have triggered outsized fears in the many; while a town with a dozen nearby neighbors upset about noise may have a handful who've felt health impacts, those in other towns fear that they all will find themselves with degraded health. While it's natural to want to protect oneself from the worst possible outcome, there is as yet not enough clear evidence to provide a legal underpinning for authorities to impose restrictions based on public health concerns. By all means, we need to continue researching this issue, before and after construction, in a variety of locations. Concrete measures, including blood pressure and stress hormone levels, would provide much-needed clarification as we continue to assess the possible indirect health effects of living near wind farms.

But I suspect that as we learn more about these health questions in the coming years, it will become clear that both (relatively rare) acute physiological reactions and (much more widespread) subtler indirect effects fade to insignificance at about the same distances that the more easily understood quality-of-life impacts also become tolerable. With the notable exception of several New Zealand communities living in valleys below wind farms (which may capture or otherwise enhance the sound fields), it's extremely rare to hear of health problems from residents more than 1.5-2km from wind turbines (three quarters of a mile to a mile and a quarter). This coincides closely with the recommended community noise levels of 30-35dB that has become the most common recommendation of acousticians looking at the nature of the audible turbine noise in rural areas. And yes, rural areas that are predominantly home to working farmers and ranchers appear to be more tolerant of turbine noise, so it's important to take the nature of the community into account as we make siting decisions. Again, using larger standard setbacks, with easily adopted provisions for closer siting to willing neighbors, is likely to address both quality of life and health concerns in a way that is effective for communities while providing the wind industry with plenty of opportunities for future expansion in areas where few neighbors will find their lives irrevocably changed.

Property Values

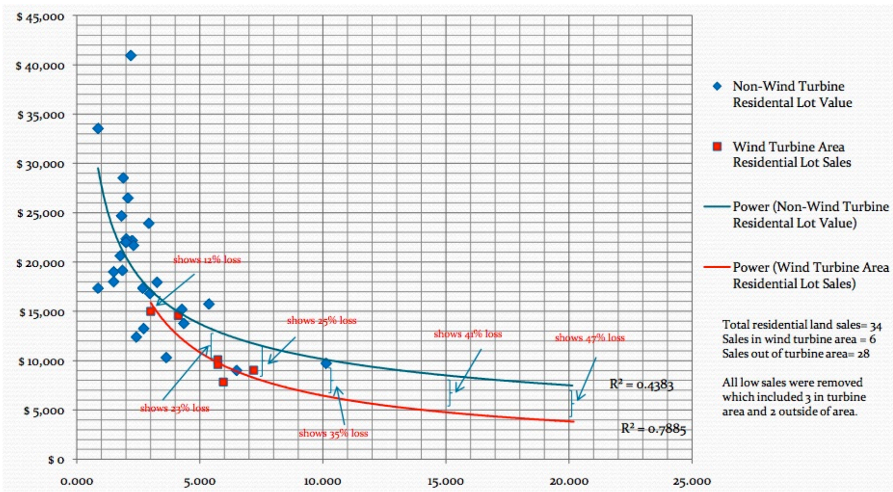
I suspect that you are as exhausted by now in the reading of this report as I am in the compiling! So, this final section will be mercifully brief, while also serving as a conclusion.

This is possible because the short version of what we know about property values echoes what we know about the overall effects of wind farm noise: while there is no appreciable effect at distances of several miles, once we move into the range of a mile or so, there is far less certainty and some moderate impacts likely, and within a half-mile, there's apt to be a notable impact on some but not all properties and people.

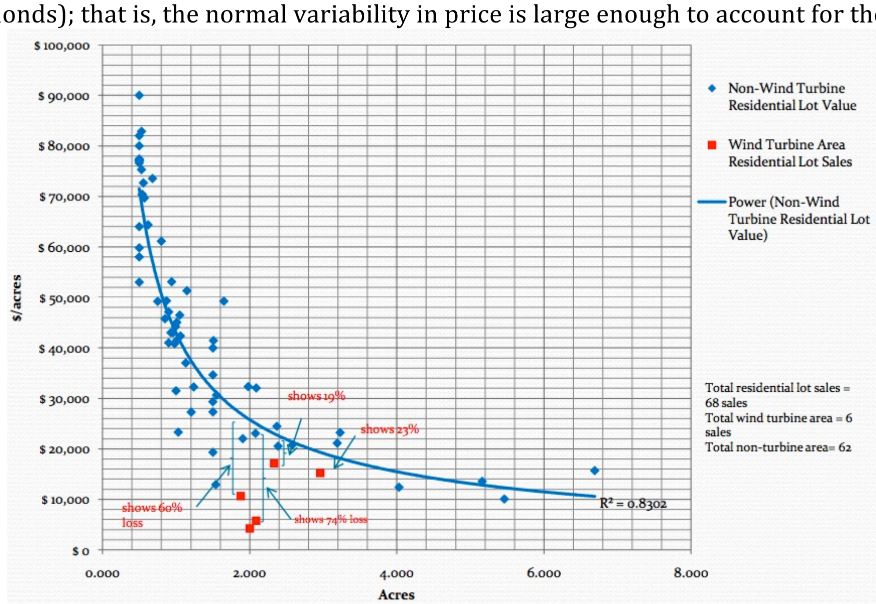
There have been two key academic studies that sought correlations between property values and proximity to wind farms. Both were more focused on possible impacts of seeing turbines than hearing them (neither assessed noise levels, just distance), so both looked at properties out to several miles from the edge of the wind farm. In neither study did enough properties sell within a mile to provide "statistical significance," which means that the variability in sales trends that close was too great to be sure of whatever hints of an effect of proximity might appear among the few sales. The authors of both reports, though, stressed that their results (which overall saw no clear relationship between sales price and distance to turbines) were more confidently applicable to the many homes at greater distances, and that there's a pressing need for more data and study to determine whether sales prices closer to turbines are impacted.

In both cases, there were slight decreases in average sales price for homes close enough to wind farms for the sound to be regularly audible, in the range of 5% decreases on average, though the data suggests that it's likely this average was driven by a few homes with more dramatic decreases. Also in both cases, the biggest impact on sales prices occurred after the wind farm was announced, and before it was operational, with prices bouncing back after the wind farm was operating. For more on these studies, see AEI's summaries and commentary at the time of their release (both posts include download links for the full reports):
Jennifer Hinman, property values around two Illinois wind farms:
http://aeinews.org/archives/1114
Ben Hoen and Ryan Wiser, DOE/Lawrence Berkeley Lab nationwide report:
http://aeinews.org/archives/529

Anyone who's been involved in the wind farm issue over the past couple of years will also know that there have been several other reports released which say property values are significantly reduced near wind farms, with declines of 20-40% being suggested. Michael McCann has put together the most comprehensive argument for decreases[34], some of which is based on his interpretation of the Hoen/Wiser study (which seems to ignore some of the study's key findings[35]), and some on analysis of sales around an Illinois wind farm, which is more convincing. Kurt Klielisch, a Wisconsin appraiser, has done similar work, surveying realtors who had worked in wind farm areas, and charting the actual sales prices of homes near two wind farms[36]. The sales data largely confirmed the realtors' reported likely price differentials, but also offers a good illustration of the ambiguity that exists in most of the real-estate data to date:



The top graph shows sales of 1-20 acre residential lots in and around the Forward Wind Farm, with low sales removed. As you can see, the red curve tracing and extrapolating the average price-per-acre paid for homes within the wind farm area (distance not specified) is clearly lower than the blue curve of homes outside the wind farm. At the same time, though, it seems that the sales within the wind farm area (red squares) fall largely within the lower-range scatter of non-wind farm home sales (blue diamonds); that is, the normal variability in price is large enough to account for the red sales.



This similar graph is from the Blue Sky Green Field Wind Farm. Here, all sales are included (probably in order to have more than 2 or 3 in the wind farm area), and once again, we see that all the red sales fall below local average price-per-acre. However, two sales are generally within the normal range of variability, one marginally lower than the lowest similar distant lot, and two sales well below all others (this type of outlier was presumably removed from the study shown in the upper graph, presuming impacts of some other, non-wind farm factor, such as poor condition of the house).

There have been other surveys of assessors or real estate agents[37], asking their opinion about likely impacts, which did not include actual price data. These generally find that, on average, decreases are expected; but there is always divergence of opinion, with a substantial minority saying there will be no decrease, while a somewhat higher proportion expect some decrease, and many remain unsure. Such surveys do seem useful, as a bellwether of expert opinion, but hard to base policy decisions on.

I want to mention one other report. Chris Luxemburger, a Canadian real estate broker and director of his local Real Estate Board, looked at property sales in and around a big wind farm in Ontario[38]; while he found that prices were lower for those within 3 miles of the wind farm, more interesting was a dramatic increase in the "days on market" for the closer properties (twice as long to sell) and an 11% rate of homes not selling at all, compared 3% for those further away. His report is not very detailed, and likely also suffers from the typical problem of relatively few sales close to the wind farm, but offers some useful new perspective on the real estate questions.

Not surprisingly, real estate professionals and researchers disagree on the best ways to assess potential property value impacts; those finding little impact are not impressed by the studies finding decreases, and vice versa. For now, AEI's stance on the property value question is decidedly uncertain. As with health effects, it seems clear that there are some homes that are dramatically impacted (some have been unable to find a real estate broker to even list them), but that overall it's hard to say what the degree of impact is, or how widespread it is. And, as with the other aspects of the wind farm noise issue, those within a half-mile are more likely to see impacts than those over a mile or so.

Buy-out provisions, Property value guarantees

Some community groups and other observers[39] say that if wind developers are so sure that they won't be decreasing property values, then they should be willing to stand behind their words (and shoulder the risk that they are wrong) by providing Property Value Guarantees or buying out unwilling neighbors at current market value, then reselling the homes themselves.

Property value guarantees have been used in support of other types of municipal projects, including landfills, transmission lines, and public parks[40]. Three Illinois counties have extended the concept to wind farm permitting; one of them has abandoned the practice after no claims were made during the 5-year time period enforced on the first wind farm permit that required a property value guarantee.

While claims under Property Value Guarantees are rare (partly due to lower-than-feared decreases in property values, and partly due to the complexities of proving a change), they serve to shift the risk from local homeowners to the developers of the project in question. One of Michael McCann's analyses of property value decreases (which you may remember predicts more dramatic property value decreases than most other studies) finds that a theoretical 3-square mile wind farm with 100 turbines could decrease local property values by about 3% of the cost of the project[41]. His point is that even in this worst-case scenario, the company should be able to shoulder this indirect cost of their operations.

In a few cases[42], developers have bought homes in or near wind farms from people who found that they could not live with the turbines. This practice makes developers nervous, as do property value guarantees; they cite the unacceptable budgetary uncertainties that such programs would impose. However, such buyout programs (which can lead to the company reselling properties to willing buyers) would go a long way to calming local fears, which may often run higher than their eventual experience will warrant. Certainly, the fact that some developers do buy multiple homes suggests that such a policy does not threaten the viability of most wind farm projects.

Banging the drum one more time for AEI's preferred path forward

Of course, the need for property value guarantees or buyouts would evaporate if wind developers agreed to maintain even moderately larger setbacks from existing homes. Once more, it appears to AEI that the combination of larger setbacks and the availability of waivers for closer siting to willing neighbors offers the best way forward. Failing that, then these financial guarantees would provide a fair way out for those close neighbors who find that their quality of life or health is being severely impacted enough to uproot them.

You will have probably have noticed that this report has resisted the temptation to name a single setback or noise limit that should be applied across the board. As must be readily apparent, this is because it's clear that different types of communities will need different standards. Ideally, each region, county, or town could set standards appropriate to their location; if this is deemed too complicated or unpredictable a path forward for successful wind development, then the combination of strongly precautionary limits and easy-to-negotiate easements may be the best universal solution. If pressed to suggest such a "precautionary limit" I would lean toward setbacks of at least three-quarters of a mile, or sound limits of 35dB or less, while once again stressing that there are clearly places where closer siting is locally acceptable and waivers will be easy to obtain. It's encouraging that setbacks of 2000 feet to a half mile have become an acceptable "middle ground" option in recent months; these setbacks should significantly reduce the extent of noise issues and I look forward to hearing how these distances work out, but there are a fairly consistent reports of disruptive noise out to 3000 feet or so, which leads me to favor a slightly larger minimum setback.

Many areas will indeed be "off the table" for wind development if this sort of approach were to take hold; but these are exactly the locations where wind farms would be squeezed into minimally-sufficient spaces among people who especially value their rural peace and quiet, and we are not yet that desperate for suitable locations to have to go there.

And I bid you goodnight…

As stated up front, I certainly hope that this report has provided some useful perspective and information to those seeking to untangle the knot of conflicting information about wind farm noise. The Appendices include more useful information, especially on the factors that seem to influence disparate community responses to moderate wind farm noise, if you have the endurance to keep going!

Please feel free to be in touch with any questions or comments. I can be reached at cummings@acousticecology.org or at 505-466-1879.

Many of the sources cited in the footnotes, along with a collection of publications by AEI on the issue, are available for download on the AEI Wind Farm Noise Resources page:
http://AcousticEcology.org/wind

For ongoing coverage of sound-related environmental issues, follow the AEI News blog/feed at http://AEInews.org
Or, zero in on the wind farm noise posts by using this url:
http://aeinews.org/archives/category/wind-turbines

Appendix A

NEWEEP presentation on Community Responses to Wind Farm Noise

What about in the real world?
How do people actually respond to increasing wind farm noise levels?

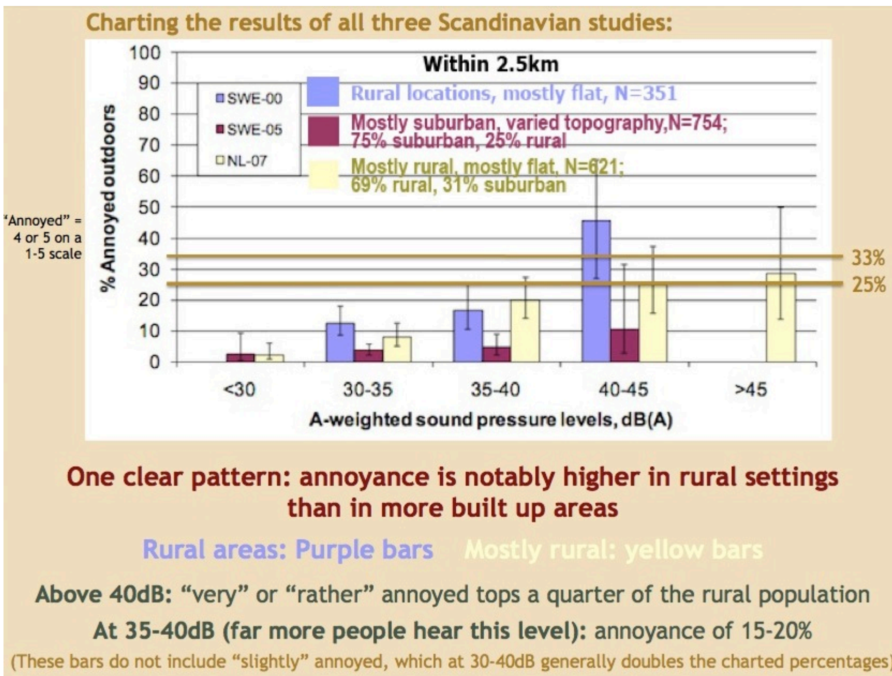
As is probably clear from what you've already read, "people" do not all respond in any one way to wind farm noise—this is why we so often seem to talking at cross-purposes to each other, with each side acting as if their preferred examples of noise disruption, or lack of any problems, represent the entire story. Some communities are more tolerant as a whole to new noise, and some individuals in any community are likewise more tolerant, or more sensitive, than others.

This is the theme of the research I did for last summer's New England Wind Energy Education Project webinar on wind farm noise. Rather than repeat all that is there, I'll point you toward a pdf version of the Powerpoint, and summarize a few of the key points of the presentation. As with the above research excerpts, I do encourage you to read the full presentation for a more nuanced and complete understanding of these central themes.

The full presentation is available at http://aeinews.org/archives/972
Links are included there to the other two other presentations made that day.

How about asking people around wind farms about how it affects their lives?

There have been surprisingly few surveys of community responses to existing wind farms. There's just one widely recognized, peer-reviewed series of studies that are the primary source for secondary interpretation, and they're used by nearly everyone, including industry reports, some of the acousticians mentioned above, and AEI. These three main studies sampled from thousands of people living near wind farms in Scandinavia; the annoyance rates they report varied widely from study to study, though when considering the proportion of rural to suburban respondents in each study, the variation begins to make more sense, and suggests that rural respondents report far higher annoyance rates than suburban people:



Over the course of about a decade, the research team published many papers, most of which focused on one or two of the three large surveys. Most advocacy groups that cite these studies tend to draw on one or two of the papers, and imply this is the entire body of research; in particular, there are some papers in which the authors combined the results of their two studies in Sweden (in purple and red above). As you can see, these Swedish results combine the surveys with the highest and the lowest annoyance rates; the difference in annoyance can likely be explained by the fact that one location is entirely rural (purple) and the other mostly suburban (red), where existing noise levels are higher. However, when the studies are combined, the much larger suburban-focused study dominates the average response rate. What results is a sample that is about half rural and half suburban, which is informative, but should not be considered a reliable prediction of annoyance rates in rural areas; the purple study and yellow studies are more predictive of rural response rates.

An especially useful perspective on the range of annoyance responses is provided when we chart all five levels of response to the wind farm noise, from "very annoyed" down to "notice, but not annoyed." This comes from one of the papers that combines the most rural and most suburban studies (purple and red above), to create a sample that is just about evenly split between rural and suburban locations:

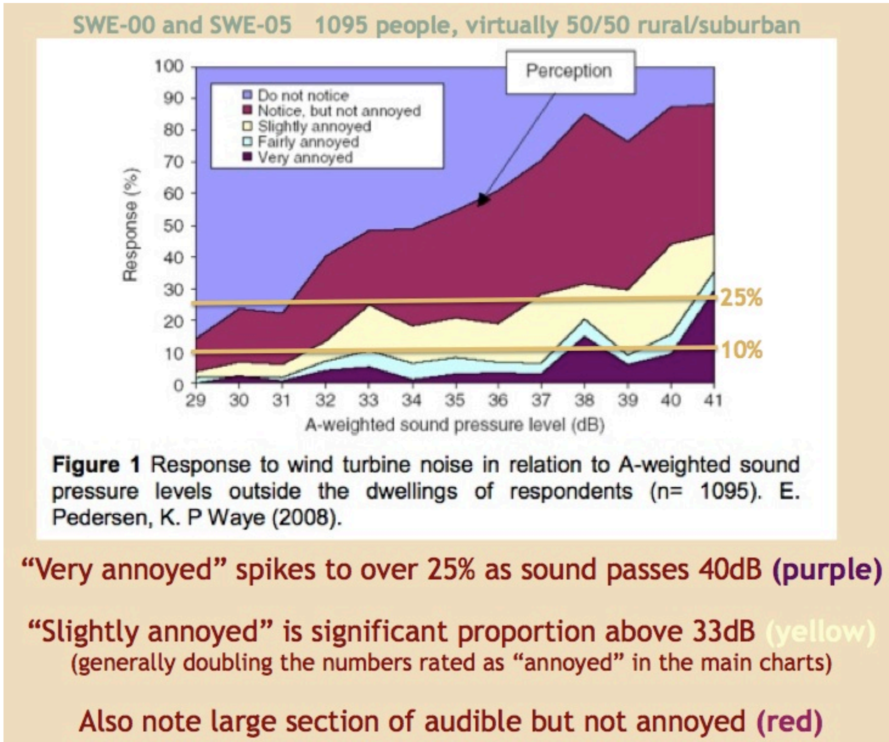


Figure 1 Response to wind turbine noise in relation to A-weighted sound pressure levels outside the dwellings of respondents (n= 1095). E. Pedersen, K. P Waye (2008).

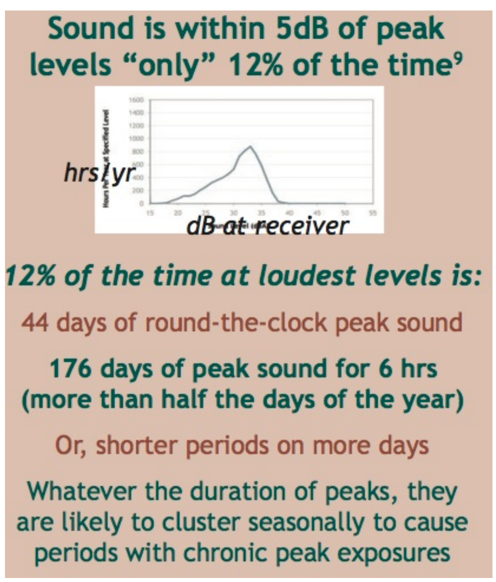
The NEWEEP presentation considers several things we should keep in mind as assessing these results; a few bear mentioning here. These studies included residents out to 1.5km (almost a mile) and 2.5km (1.5 miles) from relatively small turbines (600kw); the <u>vast majority of these residents were far enough away to only hear turbines very faintly, if at all (35-40% were totally out of earshot, and 87-97% did not experience noise levels above 40dB)</u>. Yet even so, among rural respondents who could hear turbines at any level, 22% reported moderate to extreme annoyance, and when sound was over 40dB, annoyance was 28% in all studies combined, 30% in the rural-dominated studies, and 44% in the most rural study. It's not surprising that standard US regulatory limits (which usually allow sound levels of 45dB) will lead to widespread noise issues. <u>Wind farms that are built in and amongst existing homes are often designed to keep noise at the homes just under the regulatory limits; in these situations, as compared to the Scandinavian studies, a much higher proportion of the nearby population is likely to be within a half mile or so of turbines, and to experience noise levels of 40dB or above</u>.

It's often noted that this Scandinavian research found that annoyance levels are more strongly correlated to seeing turbines than to noise levels, and that there is a strong association between annoyance and a generally negative attitude toward turbines.

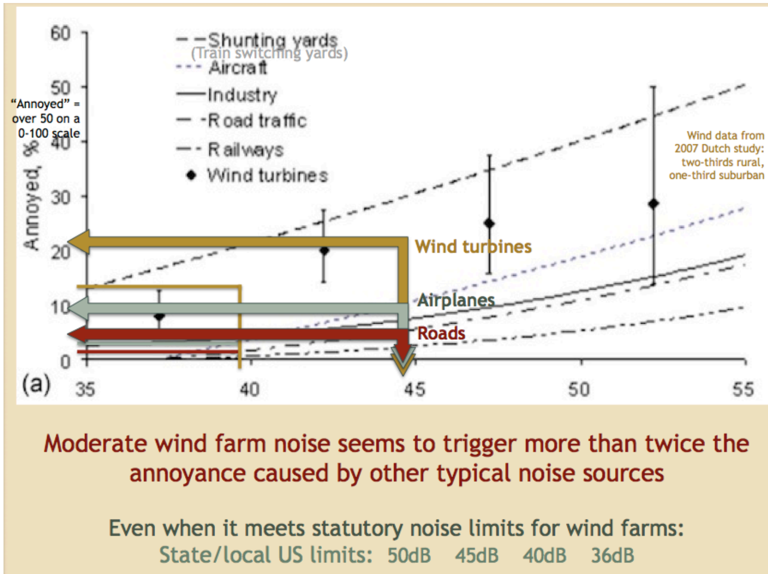
However, we have to be careful not to overstate these correlations, or to jump to conclusions that the sound is an insignificant factor in the problem. It's a natural consequence that turbines within line of sight will be more audible than those hidden by a hill; in addition, there is a perceptual synergistic effect in that the sight of spinning turbines can draw our attention to their sounds. This does not mean that what is really annoying everyone is the sight of the turbines; the sound often becomes the more omnipresent factor as neighbors go about their day-to-day life in and around their homes, when they are rarely seeing the turbines, but often hearing them. Likewise, the studies assessed current attitudes toward the wind farm in general, along with current annoyance; there was no pre-construction assessment of whether people started out with a negative attitude toward the wind farms. So, the causality is murky; it's equally plausible that once the turbines arrived, that those who were being bothered by the sound would develop a negative attitude toward the project. And most importantly, this is just a partial correlation: it cannot be used to explain away the fact that many people are primarily bothered by the noise.

An interesting point was raised by one of the other NEWEEP presenters, Ken Kalisky, who did a fascinating study[43] that analyzed weather conditions over the course of a year, and showed that turbine noise levels are within 5dB of their predicted maximum sound output only 12% of the hours in a year. On the face of it, this seems quite reassuring: even for the close neighbors who may hear 40-45dB, the experience will be rare and fleeting. Is it really too much to ask folks to hear turbines a tenth of the time?

However, a little number-crunching paints a picture that may be helpful in explaining why people living in such places feel that their lives are being disrupted on a chronic basis, and don't experience it to be a once-in-a-while problem[44]:



The Scandinavian research also affirms that annoyance is triggered by wind farms at lower sound levels than any other common community noise source other than train switching yards. It is likely that the variability and around-the-clock nature of the noise is a big part of the problem. This chart uses data from just one study, the yellow one in the first graph, that took place in an area that was mostly rural with some suburban areas as well, which averaged to create slightly less annoyance than the purely rural study.



Why are some people so annoyed by 40dB noise, while others aren't particularly bothered?

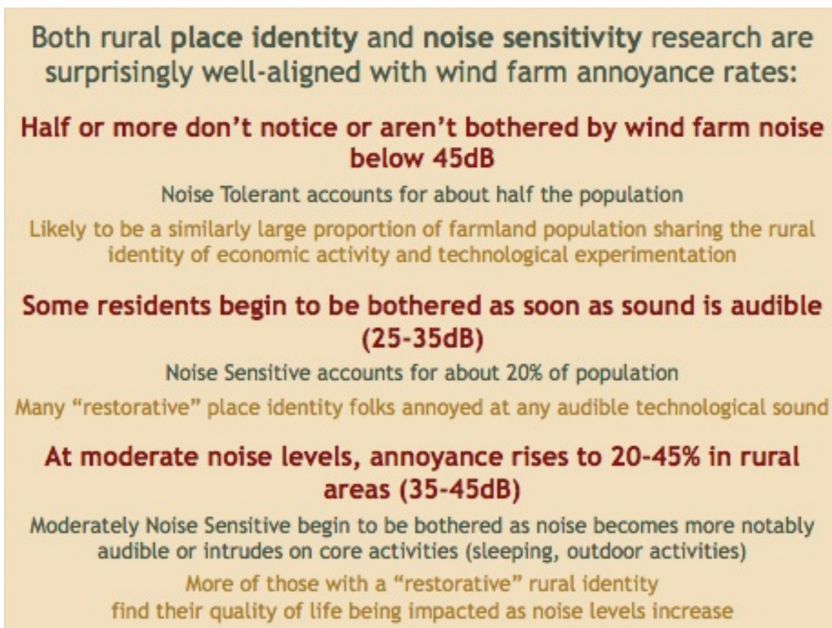
The last important points from the NEWEEP presentation involve Noise Sensitivity and Place Identity. One more, the presentation offers a more complete picture, but the nut of it focuses in on two research findings that offer a good sense of why individual and community reactions to moderate noise varies so much:

Noise Sensitivity: A 40-year body of research has studied the natural range of individual sensitivity to noise. About half the population is broadly noise-tolerant, and will rarely react to a noise unless it is very loud and/or intrusive. On the other end of the spectrum, about a quarter of the population is quite noise-sensitive, noticing and often bothered by noise as soon as it becomes audible; meanwhile, about 30% of the population is moderately noise-sensitive, with negative reactions increasing as the noise increases in volume or intrudes on daily activities. These percentages seem to line up remarkably well with the Scandinavian research as well as with the proportions of neighbors reacting with varying degrees of vehemence to wind farms in their areas.

Interestingly, the differences in responses of Noise Sensitive and Noise Tolerant people are most striking at soft and moderate noise levels, exactly the situation around wind farms.

Place Identity: The Scandinavian team did detailed interviews with a subset of their research subject who had reacted very differently to noise levels of 37-40dB (some had heard but not been bothered, others had been very annoyed). They found that those who are most bothered saw the countryside as a place for peace and restoration, while those not bothered were far more apt to see the countryside as a place for economic activity and technical developments/experimentation. Those who are not bothered by turbine noise tend to like new machines and technologies, and see turbine noise from neighboring land as outside their territory, while those bothered by neighboring turbines are more apt to feel that the noise intrudes into their space and privacy.

This place identity perspective goes a long way toward helping us understand why wind farms in and among agricultural spreads in Iowa are easily accepted, while similar layouts in New York or Wisconsin trigger widespread community push-back. It also bears a close resemblance to the Australian and New Zealand approach that includes local "amenity values" or "rural amenity" as a factor that should be considered as authorities assess the likely impacts of wind farms.



While it may seem extreme to set our standards so as to protect the most noise-sensitive from any disturbance (by setting noise limits of 25dB), it is equally extreme to suggest that noise is too loud only when the most noise tolerant part of the population begins to be bothered (45dB or above). It seems eminently reasonable to set our noise limits to assure that those who are moderately noise sensitive are not impacted; this would lead us to a limit of around 35dB, still likely to bother that 20% of the most sensitive. In rural areas with many folks looking for peace and quiet, any limit above 35dB will lead to negative impacts on a rapidly increasing proportion of the population; while in rural areas where most people are working the land, it's likely that more of the moderately noise sensitive will find the noise tolerable, so noise limits of 40-45dB may work well.

Once again, you see the full NEWEEP presentation at http://aeinews.org/archives/972

Appendix B

About AEI

And some background on how and why this report was written

This section takes a few minutes to read and isn't directly related to the topic. It's included in order to provide some important context for understanding who I am and how I decided what to include in this report, so you as a reader may be more likely to trust me as an interpreter, and understand how what you read here fits into the larger world of wind farm effects research.

First off, AEI is not an advocacy organization; it's a non-profit information and resource center, funded by donations from people who value clear information about current science findings and policy options. I am not an engineer or acoustician or scientist. I am an editor and writer who has become comfortable over the past 25 years with reading science journals, in-depth environmental impact statements, and "white" and "grey" literature reports from government agencies, trade organizations, and researchers. My expertise as an editor is in translating and synthesizing complex science and policy for a lay audience.

Since 2004, my work as the sole full-time employee of the Acoustic Ecology Institute has been focused on sound-related environmental issues, especially ocean noise and wind farm noise. Top agency staff, professional organizations, and academic researchers in the US and Canada consider me an honest broker of what is known about these often contentious issues: the Canadian Department of Fisheries and Oceans, US Navy, and US Department of Energy have all asked for my participation in expert committees and specialized symposia. I was guest-editor of a special double issue of the *Journal of International Wildlife Law and Policy* on ocean noise, and was twice invited to be a plenary speaker at the biannual Alberta oil and gas industry noise control conference.

AEI's first annual wind farm noise report, Wind Farm Noise 2009 (published in February 2010) has been widely read and disseminated. I receive several calls a month from county commissioners, wind ordinance task force members, and engaged citizens working to help their own communities grapple with questions about wind farm noise. My relatively unbiased stance has been the primary reason that people seek me out as they try to make sense of the strident or overly assured tones of much of what is available online and in industry presentations. Since the publication of that first report, I've been asked to contribute my perspectives on wind farm noise to two well-established and very mainstream sources of wind energy information, both of which fundamentally support the expansion of the industry: the trade magazine and website *Renewable Energy World*, and the New England Wind Energy Education Project, a regional effort of the DOE-funded Wind Powering America project. Likewise, my work has become an important contributor to many community groups working to help neighbors, local governments, and wind developers better understand the real effects of wind farm noise on those living nearby, even though my conclusions are not generally as absolute as some of them may wish. The fact that both wind advocates and opponents find value in what I have put together suggests that I'm on the right track toward the ultimate goal of finding a workable middle ground on these issues.

Since the turn of the new year, I've been stymied in my efforts to get this next annual report written. Three challenging factors have slowed me down.

First is the steady stream of new research, local and regional siting guideline decisions, and reports from communities that deserve to be incorporated into my understanding of the issues. Now, as we move from spring to summer, I've decided to just go ahead and write what I can, knowing that my self-education continues on a weekly basis. I hope that by framing the report around these three key themes, along with the call for respect and openness, I can contribute something to the situation, knowing that I don't yet know all I need to.

The fact is, we are all in this same situation, even – and perhaps most crucially – the "experts" who those on all sides of the issue rely upon to help us understand how to balance large societal questions about energy priorities with the local and very personal quality of life considerations that are raised as wind farm development expands. We *don't* know all we need to, and we *all* are learning more every month.

Second is the question of how much detail to include here. This question is always at the heart of AEI's reports: finding balance between being comprehensive and concise. Given the complexity and subtlety of the topics covered, there is a temptation to include many excerpts from relevant research reports, testimony, and environmental assessments of various kinds, so that readers can draw their own conclusions. Yet this amount of detail would overwhelm readers, I'm sure. Most will want to be able to get the key information they need in a few minutes. I've decided my job here is *not* to try to give readers all the information they need to make a decision, but rather to help them get a better perspective on where we are in our current understanding.

So, for the purposes of this overview it seems I can best serve by including just some of the key ideas and themes of the research that I've pored over. In making this choice, I'm asking you to trust that I am indeed being a fair broker of all this information, that I am presenting the information fairly and in a proper context. The fact that I'm asking for this trust is the main reason I've included this Appendix, in an attempt to help you feel comfortable with who I am and where I'm coming from. I plan to follow up this overview report with more detailed collections of source links and excerpts on the three key issues, which will be available online for those who want to read more and dig deeper for themselves.

The third and final challenge has been the question of how to best frame the information in this report. It was not my intention to stress anti-wind opinions or cautionary voices more prominently than those of acousticians, physicians, and property value researchers who are more comfortable with the current wind farm siting standards.

However, my sense is that these "business as usual" voices are well represented in most existing wind farm planning documents (put together by wind energy developers, trade organizations, and consultants hired to write environmental assessments of wind farm proposals). Certainly, this point of view is strongly voiced by wind energy companies in their presentations to local and county planning boards and state public utility commissions, as such authorities consider new wind farm siting regulations. I will be mentioning and linking to some of the reports and research that is used to buttress the argument that current consensus siting standards are sufficient, and that community noise standards designed for other noise sources are easily applicable to wind farms as well.

Nonetheless, the bulk of the material presented here is more cautionary or contrarian, largely because it's my perspective that these voices have been unduly marginalized by the voices of the status quo. After reading and listening to the full spectrum of research, interpretation, and opinion, I believe that the key questions about wind farm noise impacts are not as settled as those on either end of the spectrum suggest. The goal of this report is to help create a balanced perspective on the current state of our understanding and research; I hope that this is helpful to citizens, elected leaders and decision-makers – and to the wind industry itself – as the robust debate about siting guidelines continues over the coming year or two.

In writing this report, I've worked hard to not harp on negative reports or exaggerate the problems that come with wind farm development. At the same time, it's important to not disregard negative reports or accept broad-brush reassurances about minimal noise intrusions without looking closely at the actual experiences of wind farm neighbors. I hope that readers will note the tempered tone that I try to maintain, as well as the underlying desire to help chart a way forward that enhances the industry's ability to plan and develop new projects with a minimum of delays and unexpected legal or community relationship costs. The past two years have seen some important shifts within the industry, in the ways it deals with communities: specifically, it's become very rare to hear project planners claim that turbines will always be masked by wind noise, and there is an increasing commitment to community engagement. So far, though, these positive shifts have been focused largely on making the case for development-as-usual, with relatively little understanding that not all communities will have the same tolerance for wind farm noise as those that the industry has been working with over the past decade or so.

I hope that this summary will help everyone involved to understand both the current sources of disagreement among experts, and the likelihood that some communities will require a different approach to wind farm siting than has been the norm.

Personal experiences with noise: highway at home, wind farm in Texas

On a personal note, this year I've had a startling realization: the interstate highway that sits a bit over a mile from my house is clearly audible most of the time that wind is not blowing very much! My home is in a quiet rural valley of five- to twenty-acre lots, shielded from the highway by nearby hills; yet the sound easily travels the mile and a quarter or so to where I am, and many times the highway noise actually bounces off hills on the other side of the valley, surrounding me with its gentle rumble. I've lived here for 16 years, and while I sometimes noticed the highway, I'd filed it away as an occasional thing. Indeed, in spring when the winds are high, the multi-layered symphony of breezes in the tree-covered slopes around me is a highlight of living in this place; in these times, the highway noise is swept off to the east rather than spreading in all directions, including south to me. And the nighttime insects and morning birdsong are still a delight, whether the still air also holds some traffic noise or a slight breeze keeps it at bay.

I've learned two things from this emerging awareness of the road noise. First, that thinking about noise intrusions can make subtle noise more noticeable. And, now that I notice it the noise *is* annoying to me. With each passing week, I'm more surprised by how present the noise is. Obviously, it's always been here, and I have and will continue to live with it.

Interestingly, the highway noise became obvious to me after a visit to an active large-scale wind farm area this past November, in the Roscoe TX area. There, I noticed the similarities, as well as the differences, between the sounds of turbines and distant roadways. I had some very interesting listening experiences there, but I knew I was only getting a snapshot, a few hours on two days. While the turbines were not objectively *loud*, they were clearly the loudest thing in the landscape except when a car passed closer to me than the turbines. I can imagine how some people might "tune them out" over time, and others would have a hard time ignoring their intrusion on the natural sounds of their homes.

I visited several wind farms over the course of an afternoon and the following morning, one on a small mesa and the rest on broad open plains, much planted in cotton, and the rest grassy scrubland. Throughout, the wind was moderate, but usually enough to get the turbines rotating at their maximum speed of about 20rpm (one blade per second passed the high point of the turbine). I did lots of listening, while measuring distances using my car's odometer. I could nearly always hear any turbine within a half mile, and generally they faded into distant background traffic (a mile or so away) when I was about seven tenths of a mile or so from the closest turbine. There were times when I was near rustling bushes, and could still easily hear turbines about a third of a mile away; the turbine hum was clearly at a lower frequency than the leaf rustling. At one point the wind was strong enough that the roaring in my ears drowned out turbines a third to half mile away; but when I oriented my car to block the wind noise I could again easily hear the turbines through the open window (i.e., moderate wind noise in the grasses did not mask the turbines; it seems likely that the open car window mimics what it would be like in a house with an open window on a windy night). The only time I really felt that a turbine seemed objectively loud was when I drove very close and stood perhaps 600 feet away; my thought was, "I don't understand how anyone could stand under a spinning turbine and hear nothing!" (Such reports are relatively common; perhaps they are turning very slowly, not at full operating speed.)

In one location, I could hear three or four turbines in various directions; each one had the characteristic amplitude modulation, with louder pulses of sound about once per second as the top blade passed through higher wind speed. The pulses were not in synch, of course, and the random, chaotic nature of the beats was very noticeable. I was only there for a few minutes, but I got a sense of how this experience could be disorienting or distressing to someone if it was going on for hours at a time.

This leads back to the second thing I've learned from the presence of highway noise in my own personal soundscape: very moderate noise can indeed become a dominant sound in my experience of my home place. I estimate that the highway noise varies from around 30dB to 40dB, from just audible in my quiet environs, to very noticeable. It may even hit 45dB sometimes, perhaps when the light breeze is headed my direction. I'm tempted to go buy a sound meter, to find out for sure. What I can say is that it is generally quieter than my refrigerator, to use a common descriptor of 40-45dB sound in wind farm circles.

By hearing this sound outside my home every day, I've come to have a more concrete sense of what wind farm neighbors are talking about when they describe the noise of turbines as being obvious, or dominant, or disruptive, even when the noise is not all that loud by objective measures. For many of us in rural areas, where gentle wind in the trees, distant birdsong, and a fundamental absence of chronic human noise is central to our sense of place, even quiet technological sounds can be jarring.

At the same time, this is a good example of the way that paying attention to a noise can change how someone experiences it. In particular, I found that paying attention to the sound made it seem – or, more to the point, actually made it *be* – worse than it was before I noticed it so closely. The road noise shifted *in my mind* from being an occasional presence, to being something that was always here except in certain situations; with that shift, I began listening for it when I went outside, and found, yes, there it is! Again. Previously, it was here, but I didn't listen for it; so, most of the time I was unconscious of it. I can easily imagine how this happens for many people living within earshot of wind farms.

Once in a while the highway noise is notably louder than normal; it's some sort of atmospheric condition(s) in which the sound carries far better. Perhaps these are the times I used to notice. Even when the sound was present but not bothersome, there were times when it intruded enough to be noticed. Then, I might have said, oh, there's the highway. I probably wouldn't say, "that damned highway!" Yet for some people, the nearly constant presence of the noise could indeed be distracting, disturbing, and distressing.

So, I find that this personal experience helps me to understand the responses both of neighbors who are bothered by nearby wind farms, and of others who feel the noise is generally inconsequential even when it is noticeable. I've lived with both of these responses over the years with this highway.

Footnotes

(links in the notes are live in the pdf version, though not formatted to show it)

---

1 See, for example: http://aeinews.org/archives/1344 and http://aeinews.org/archives/350

2 Source: AWEA website data as of 9/30/10. National Total Power Capacities: 36,698 MW. Texas: 9,727 MW; Iowa 3,670 MW
web page accessed 2/10/11: http://www.awea.org/la_usprojects.cfm

3 From Swinbanks letter submitted to the Michigan PSC, December 9, 2009

4 Ibid.

5 Email correspondence, 2/19/01

6 Ibid. Hessler later did a winter noise monitoring study, which Schomer found further fault with; see next footnote to read more on this.

7 Paul Schomer letter to Cape Vincent NY Supervisor, 4/23/10

8 In an email on June 23, 2011, Schomer noted about his Hammond ordinance proposal: "in the few months since I wrote it, I have learned enough that I would make some minor changes--this is a rapidly evolving field…The changes I would make involve the parameters for the use of ISO-9613-2 for predicting turbine levels in the community, and I would treat the limits I suggest as energy averages and not as 'not to exceed' limits."

9 Noise Standards and Enforcement for Wind Energy Conversion Systems, Hammond, NY, revised wind law, November 19, 2010.

10 For example, if daytime ambient is 44dB, then turbine noise limit would be raised from 45dB to 49dB.

11 Noise Standards and Enforcement for Wind Energy Conversion Systems, Hammond, NY, revised wind law, November 19, 2010, page 2 footnote.

12 Schomer, Paul D. *et al.,* "Proposed 'Ai'-Weighting; a weighting to remove insect noise from A-weighted field measurements," InterNoise 2010, Lisbon Portugal, 13-16 June 2010.

13 Rand, Community reactions to noise. Report/letter submitted to Riga, Michigan Township Planning Commission, 2/5/11

14 Rand, Wind Turbine Sound, An Independent Investigation: Siting to Prevent Adverse Noise Impacts. Powerpoint presentation to Informed Citizens Coalition, 2/5/11

15 Email correspondence, 1/21/11

16 Thorne, Statement of Evidence, Planning Panel Hearing on Moorabool Wind Farm, May 19, 2010, p28.

17 Thorne, Statement of Evidence, Planning Panel Hearing on Moorabool Wind Farm, May 19, 2010, p25

18 Ibid, p31

19 Horonjeff, Siting of wind turbines with respect to noise emissions and their health and welfare effects on humans. July 6, 2010.

20 Ibid, p4

21 Ibid, p6

22 One example of this is documented in a report by an acoustic consultant hired by a town to do sound monitoring in an area where complaints had arisen. The consultant found that sound levels were within statutory limits, but the field representative noted two "atypical noises" and described them: "1. A fluttery, high frequency sound was heard from the

direction of turbine A32 on the nights of February 13 and 14; and 2. A highly annoying and perceived high level low frequency swoosh was heard from the direction of turbine A31 on the night of February 16." From the Allegheny Ridge Wind Farm Sound Monitoring Study, Prepared for Juniata Township by Resource Systems Group, Inc., 2009.

[23] Kenneth Kalisky. Wind Turbine Noise Regulation: Perspectives in New England. NEWEEP Webinar #2, July 2010.

[24] G.P. van den Berg. Do wind turbines produce significant low frequency sound levels? 11th International Meeting on Low Frequency Noise and Vibration and its Control, 2004.

[25] William K.G. Palmer. Collecting Data on Wind Turbine Sound to Identify Causes of Identified Concerns. Paper 3aNSa2, Acoustical Society of America 161st Meeting, May 2011.

[26] Alec N. Salt and Timothy E. Hullar. Responses of the ear to low frequency sounds, infrasound and wind turbines. Hearing Research, Vol. 268, Issues 1-2, September 2010, pp12-21.
Also: Alec N. Salt. Responses of the Inner Ear to Infrasound. Presentation at Wind Turbine Noise 2011, Rome, Italy.
And: Alec N. Salt. Infrasound, the Ear and Wind Turbines. Presentation to the Arkansas Academy of Audiology, 2011. (more slides and detail than the WTN presentation)
See also Salt's lab page: http://oto2.wustl.edu/cochlea/

[27] Press release: http://www.nidcd.nih.gov/news/releases/10/07_28_10.htm

[28] Neil Michelutti of Queens University is conducting this study. For an early news report about it, see http://www.theglobeandmail.com/life/health/study-to-determine-health-effects-of-turbines/article1210357/

[29] Physician Michael Nissenbaum, who initially interviewed residents near the wind farm, has expanded his study to include a sampling of local residents over 3 miles from the turbines, as a control "cohort" to examine differences in reported health. For links to his work, see http://aeinews.org/archives/380

[30] Jevon D. McFadden. Wind Turbines: A Brief Health Overview. Centers for Disease Control and Prevention, Epidemic Intelligence Service, Wisconsin Department of Health Services.

[31] Daniel Shepherd, Mill Creek Wind Farm submission, 2010. See also his independent white paper, Wind Farm Noise and Health in the New Zealand Context, 2010.

[32] Shepherd, Mill Creek Wind Farm submission, 2010, p. 6 and 7

[33] See footnotes 25 and 26 above.

[34] Michael McCann, Property Value Impact and Zoning evaluation, Cape & Vineyard Electrical Cooperative, Brewster, MA. January 2011.

[35] In particular, McCann notes the study's observed price benefit of a good view as compared to a poor view, and presumes that seeing turbines will produce the poor view condition, whereas the study found that seeing turbines did not reduce prices; that is, seeing turbines did not equate with the study's findings about places with poor views. McCann likely basis this different assessment of the data on his fundamental critique of the statistical technique used in the Hoen/Wiser and Hinman; I can't assess this critique due to my lack of training in statistics, but the point seems to be that the hedonistic regression analysis of diverse location sales data that's used in these two studies can obscure real effects, which are more apparent when studying particular locations over time.

[36] Kielisch, Wind Turbines and Property Value presentation/pdf submitted to the Wisconsin PSC, June 2010.
[37] Royal Institute of Chartered Surveyors, Impact of wind turbines on the value of residential property and agricultural land: An RISC survey, 2004. This survey found that 60% of surveyors who had sold land near wind farms saw a negative effect, while 40% reported no negative effect. The negative impact on homes was expected to be more noticeable, with effect on agricultural land seen to be negligible.
[38] Chris Luxemburger, Living with the impact of windmills, November 2008.
[39] Even including one co-author of the DOE/Lawrence Berkeley property values study, Ben Hoen, who has been quoted by Clif Schneider as saying: ""You know we are very cautious about what happens close to the turbines. We really don't know what's going on there (e.g., 1,250 ft from turbines). I just spoke in Illinois about this. You might know about a Property Value Guarantee. It's a dicey situation and complicated, but I think homes that are very close, there is just too much unknown right now; that seems reasonable. I think one of the things that often happens is that (wind) developers put our report forward and say look property values aren't affected, and that's not what we would say specifically. On the other hand, they have little ground to stand on if they say we won't guarantee that. I think for homes that are close we have a lot more ambiguity and real issues. If we are talking about views that's one thing, but if we are hearing it or shadow flicker that might be really regular, the kind of things that happen at night. ... I'm not a lawyer and I'm not the developer, these (PVGs) are just options in the tool kit."
[40] See Pete Poletti, Property Value Guarantees and Decommissioning Costs, presentation to the Siting, Zoning, and Taxing of Wind Farms in Illinois Conference, February 2011.
[41] See McCann, response to Hoen study, December 2009, page 9.
[42] Notably two in Canada: near the Ripley Wind Power project–see http://aeinews.org/archives/1344 and the Melancthon EcoPower Centre–see http://aeinews.org/archives/350
[43] Kenneth Kalisky and Eddie Duncan. Calculating annualized sound levels within a wind farm. Acoustical Society of America 159th Meeting. Proceedings of Meetings on Acoustics, Vol. 9, 2010.
[44] Graphic from Cummings, The management implications of individual variability in sensitivity to noise within wildlife populations. Poster presented at the National Wind Coordinating Committee's 8th Annual Wind and Wildlife workshop, Denver, CO, 2010. Embedded in this graphic is the annualized sound level data from the Kalisky and Duncan paper cited in the previous footnote; the horizontal axis shows the dB level, and the vertical axis shows the number of hours per year at that sound level; the vast majority of hours per year are at moderate noise levels of 30-35dB, with most of the rest lower than this, and just 12% of the hours within 5dB of the loudest measured sound levels at this location, which were about 40dB, where the curve goes horizontal against the bottom axis.

**Second International Meeting
on
Wind Turbine Noise
Lyon France September 20 – 21 2007**

Wind Farm Noise and Regulations in the Eastern United States

**Hilkat Soysal and Oguz Soysal
Department of Physics and Engineering
Frostburg State University
Frostburg, MD 21532
e-mail: renewable@frostburg.edu**

Abstract

Recent advancements in the wind turbine technology, combined with available federal and state incentives, have greatly enhanced the development of wind powered electric generation facilities in the Eastern United States. Particularly ridges of the Allegany Mountains in New York, Pennsylvania, Maryland, West Virginia, and Virginia have become attractive sites for commercial wind farm developers. The fast development of commercial wind farms is currently an important issue in these regions due to environmental impacts.

The paper describes the demographic structure of the Allegany Mountains and presents an assessment of the audible noise at residences near actual wind turbines. The noise level recommendations of the USA Environmental Protection Agency (US-EPA) and local noise ordinances that apply to wind turbines are compared with the acceptable noise levels in various countries. The current status and trend of the wind power development in the Eastern USA, the expected benefits, and public concerns are discussed.

Introduction

Since the beginning of the 21^{st} century, wind power development in the eastern part of the United States has grown significantly due to recent improvements in the wind turbine technology and financial incentives provided by the federal government and states. Data collected by American Wind Energy Association (AWEA) indicates that the total capacity of wind farms installed in 14 states east of the Mississippi river, which was 29 MW in 1999, has reached 843 MW in the end of 2006 (Flowers, L., 2007). Total 605 MW wind power plants were developed in New York, Pennsylvania, and West Virginia between 2000 and 2006. While the proportion of electricity generated by wind farms is still relatively small compared to the other sources, wind seems to be a potential clean energy alternative to the fossil fuels used in the region.

Environmental concerns about the wind power development include interactions with wild life, visual impacts, and annoyance due to the audible sound level. This paper focuses on the acoustic issues related to wind turbines and the associated public concerns in eastern United States.

Wind Power Development in the USA and Demographics

Wind farms are perhaps one of the most visible power generation facilities and have triggered significant public attention and discussions over the past several years. Because of substantial social interactions, demographic characteristics of the regions where the wind farms are located must be considered when evaluating the consequences of the wind power development.

Wind power development in the United States is summarized in Figure 1 (Wiser, R. et al., 2007). The map presents the wind projects above 1 MW that became online prior to 2006 and added in 2006.

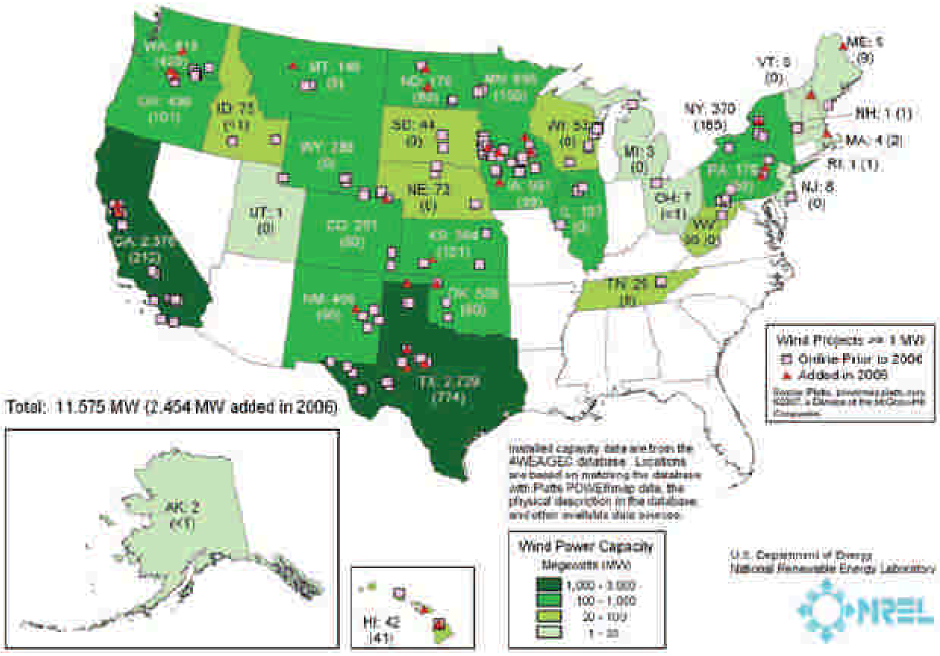


Figure 1 Installed wind power generation facilities as of December 31, 2006

Table 1 shows the major wind developments and the population density of the states grouped based on their location in respect to the Mississippi river. The wind development in the western part of the USA is significantly higher than the eastern part. On the other hand, the population density in eastern states is in general above the national density and significantly higher than the western states except California.

Wind development on the ridges of the Appalachian Mountains in New York, Pennsylvania, and West Virginia started after the year 2000. The wind farms are mostly located near agricultural and recreational areas where residences are sparsely distributed. The wind turbines are therefore close to many farms and residences and visible from small towns.

The effects on the wildlife, visual impact, and audible noise of the wind turbines have been the major issues discussed during the planning and approval process of the commercial wind generation facilities in eastern states, particularly in New York, Pennsylvania, Maryland, West Virginia, and Virginia.

Table 1 Major wind development and population density by states

	State	Installed Capacity, MW		Incremental Capacity 2000 to 2006	Population Density Persons/square mile
		End of 1999	End of 2006		
East of Mississippi	New York	0	370	370	402
	Pennsylvania	0	179	179	274
	Illinois	0	107	107	223
	West Virginia	0	66	66	75
	Wisconsin	23	53	30	99
West of Nississippi	Texas	180	2,739	2559	80
	California	1646	2,376	730	217
	Iowa	243	931	688	52
	Minnesota	273	895	622	62
	Washington	0	818	818	89
	Oklahoma	0	535	535	50
	New Mexico	1	496	495	15
	Oregon	25	438	413	36
	Kansas	2	364	362	33
	Colorado	22	291	269	42
	Wyoming	73	288	215	5
	North Dakota	0	178	178	9
	Montana	0	146	146	6
	Idaho	0	75	75	16
	Nebraska	3	73	70	22
	USA	2500	11,575	9075	80

Characteristics of Wind Turbine Sound

The characteristics of the wind turbine sound are studied in many publications in detail. The "White Paper" prepared by the Renewable Energy Research Laboratory (Rogers, A. L. and Manwell, J. F., 2002) classifies the wind turbine noise in four types as

1. Tonal noise, which is a combination of components at discrete frequencies

2. Broadband noise is characterized by a continuous distribution of sound pressure with frequencies greater than 100 Hz. It is usually modulated by low frequency fluctuations and described as a characteristic "whooshing" sound.
3. Low frequency noise is within the frequency range below 100 Hz.
4. Impulsive noise is described by short acoustic impulses or thumping sounds that vary in amplitude with time.

The operation of mechanical parts such as gearbox, generator, hydraulics, pneumatics and various control mechanisms generates mechanical noise. Rotating parts usually produce sound components at discrete frequencies related to the rotation speed, which result in tonal noise. Some mechanical parts can also generate broadband noise. This type of noise can be reduced by improving the design of the mechanical parts and using more effective acoustic insulation. However, the mechanical noise can be transmitted to the environment through the vibrations of the hub, rotor, and tower.

The interaction of the wind flow with the blades produces the aerodynamic noise. Aerodynamic noise is associated with various complex air flow phenomena and has both broadband and low frequency components. The interaction of the blades with the disturbed air flow around the tower results in low frequency and impulsive sound components. Changing wind speed around the blades can also produce low frequency and impulsive noise. This type of noise is usually bigger in downwind turbines, where the rotor is located on the downwind side of the tower.

Van Den Berg (2005) discusses the significance of the low frequency modulation of the broadband noise under stable atmospheric conditions. The study shows that the fluctuations become stronger especially during night time because of the stable atmosphere resulting in a bigger difference between the rotor averaged and near-tower wind speeds. Although the human ear is less sensitive to low frequency sound components, the modulation effect makes them more perceptible, creating a “whooshing” or “swishing” sound as described by residents who live near wind turbines.

The level of the sound generated by wind turbines depends on a number of factors such as

- Design characteristics of the wind turbine such as tower height, number of the blades, rotation speed, blade control mechanism – that is whether the blades are attached at a fixed or variable angle along their long axis (fixed or pitched)
- Distance to the source, sound blocks, obstructions, and uneven geometry of the terrain
- Sound absorption of the propagation medium between the source and location of the observer
- Acoustic characteristics of the ground surface affecting the sound propagation such as reflection, absorption of sound waves. Sound propagation depends on the physical properties of the ground surface, rock and soil composition, and vegetation covering the terrain.
- Frequency composition of the sound waves
- Weather conditions such as wind speed, direction, temperature, humidity, precipitation, etc.

Ambient Noise Recorded at a Residence near Wind Turbines

A number of tests were conducted between 2004 and 2005 near wind turbines located in Meyersdale, PA, to analyze the characteristics of the generated sound and determine the noise levels under various conditions.
The wind powered electric generation plant located in Somerset County near Meyersdale is a typical wind power facility (wind farm) with main characteristics similar to others constructed in the South Western Pennsylvania and Northern West Virginia over the last five years. New wind farms planned to be constructed in the region will have similar blade design, but possibly bigger turbines and higher towers.
The plant consists of twenty wind turbines installed on 262 feet tall towers on the mountain ridge. The NM72 type turbines are manufactured by Neg-Micon in 2003. The NM72 is a three blade upwind turbine generating electricity by an induction machine. It has a rated power of 1500 kW and an apparent power of 1667 kVA.
A number of tests were performed around a residence located at a distance of 900m (0.55 miles or 3000ft) to the windmills. Four windmills were visible from the residence. The tests are presented below in two parts: ambient noise recordings and sound level measurements.

The noise generated by wind turbines was recorded at a distance of approximately 3000 ft from the nearest turbine. Four turbines were visible at

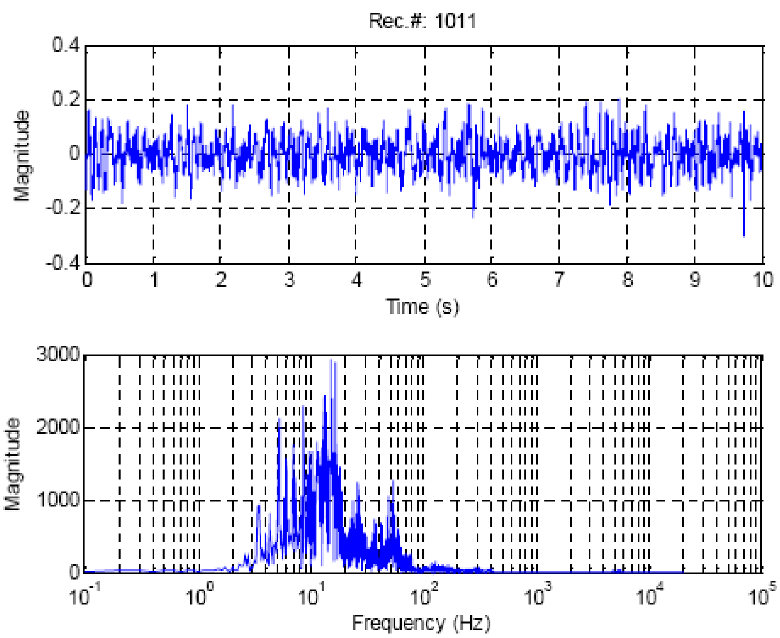
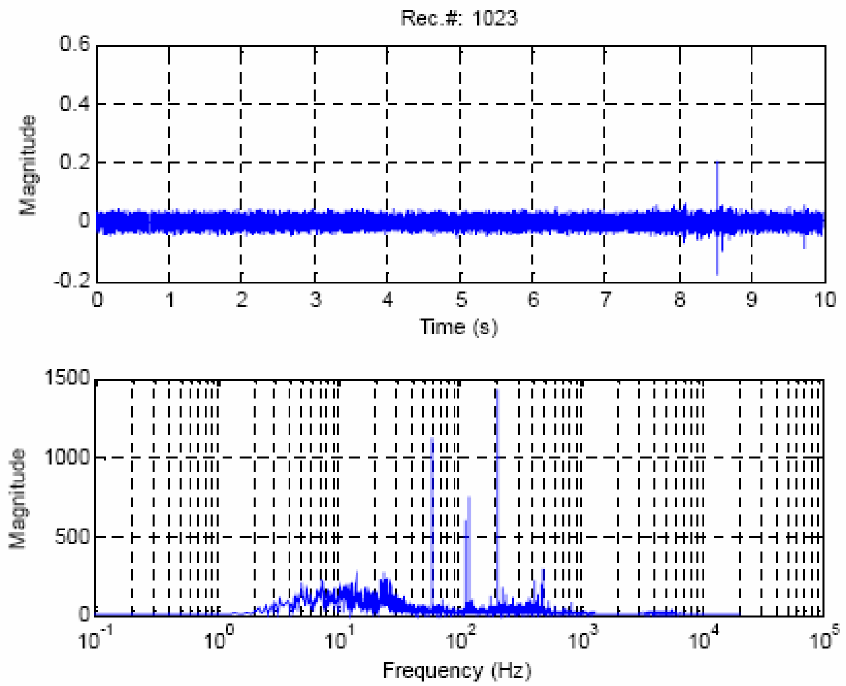


Figure 2 Sound recorded at a distance of 3000 ft from the wind turbines

the recording point, three of them were operating. Several recordings were made between 11:00 AM and 4:00 PM at different days. Wind speed was moderate (3 – 5 miles/hr) at the recording point (ground level) during the tests. A solid state digital recorder was used to obtain the waveform data. An example 10-s fragment is shown in Figure 2. The frequency distribution obtained by discreet Fourier transform indicates a dominance of low frequency components below 100Hz. Examination of the time variation of the sound waveform shows a periodic change of the magnitude, which is translated as "low frequency modulation."

Figure 3 shows the ambient noise recorded in another location without wind turbines. Light traffic noise from distance was contributing to the natural sound of wind and trees. The time variation of the noise shown in Figure 3 is random and uniform over the 10-s recording time. The Fourier transform indicates significant tonal and broadband components above 100 Hz. This represents a typical suburban



residential ambient noise without industrial noise sources.

Figure 3 Ambient noise containing natural sounds and light traffic noise

The decibel level of the ambient noise was measured at the same location (3000 ft from the closest wind turbine). Figure 4 shows a set of plots obtained during short intervals at different times of a day.

The instrument used to record sound levels is an Extech Datalogging Sound Level Meter, model # 407764. The instrument can record up to 16,000 records to the internal memory with a sampling rate from 1 to 86,400 seconds per record. The sampling rate is selected depending on the type of test. The instrument is equipped with dBA and dBC weighting filters.

The international standard IEC 61400 (Wind Turbine Generator Systems – Part 11: Acoustic Noise Measurement Techniques) [5] indicates that the annoyance caused by noise dominated by low frequencies is often not adequately described by the A-weighted sound pressure level (p. 35, Annex A). According to the standard, this is likely the case if the difference between A and C-weighted sound level pressure levels exceeds approximately 20 dB. The plots in Figure 4 reflect the dominance of low frequency components since the difference between dBA and dBC levels is generally around 20 dB. This is also consistent with the spectrum analysis presented in Figure 2

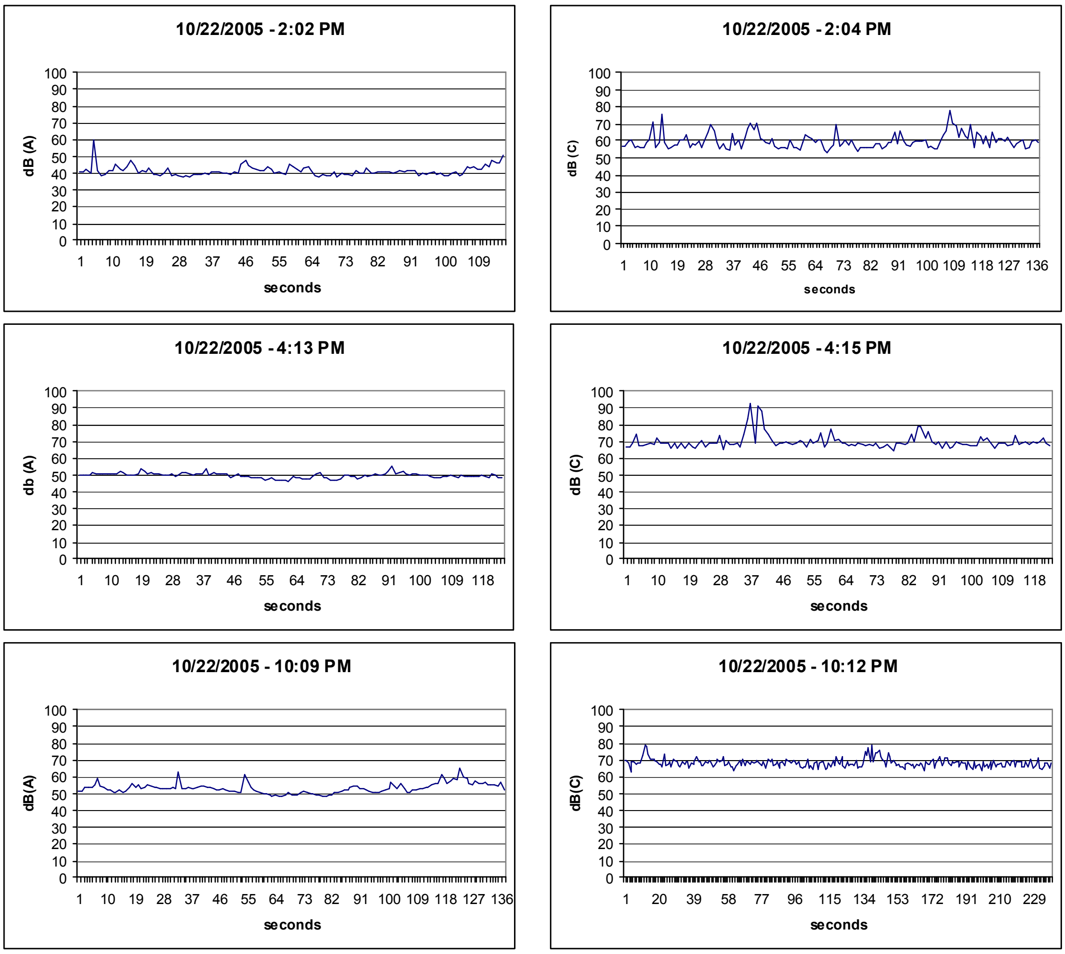
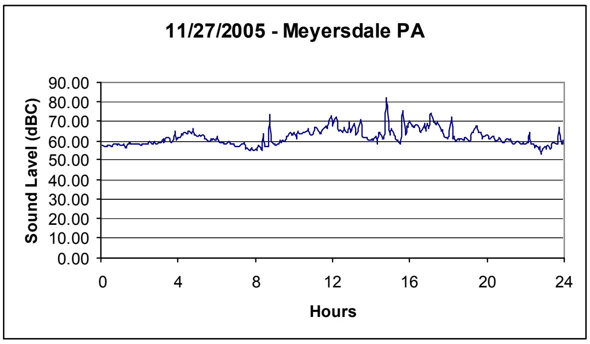


Figure 4 Noise level measurements at a distance of 3000ft from the nearest wind turbine



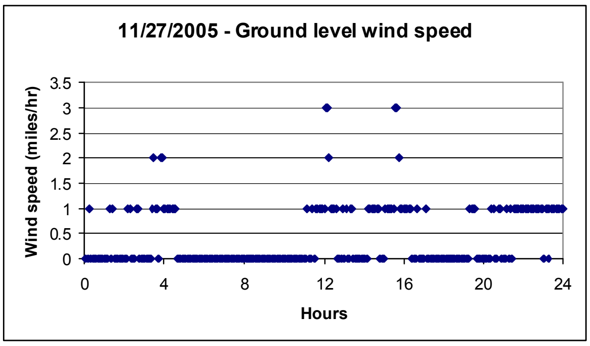


Figure 5 One-day record of noise level and wind speed

Figure 5 shows a one-day C-weighted noise pressure level recorded at the same location. The wind speed measured near the sound level meter is also plotted.

The plots shown above represent the sound of windmills combined with the natural ambient noise from wind, trees, bushes, and animals. Other noise sources such as traffic, machines, and commercial sources were occasional and minimal at the test location. In order estimate the contribution of the wind, noise levels are plotted in Figure 6 versus wind speed near the wind farm and at another rural location without windmill noise.

It should be noted that the wind speed at the test location may be very different than the wind speed at the turbine height. This explains why at lower wind speeds the noise level near wind turbines is much higher compared to the location where there is no windmill noise.

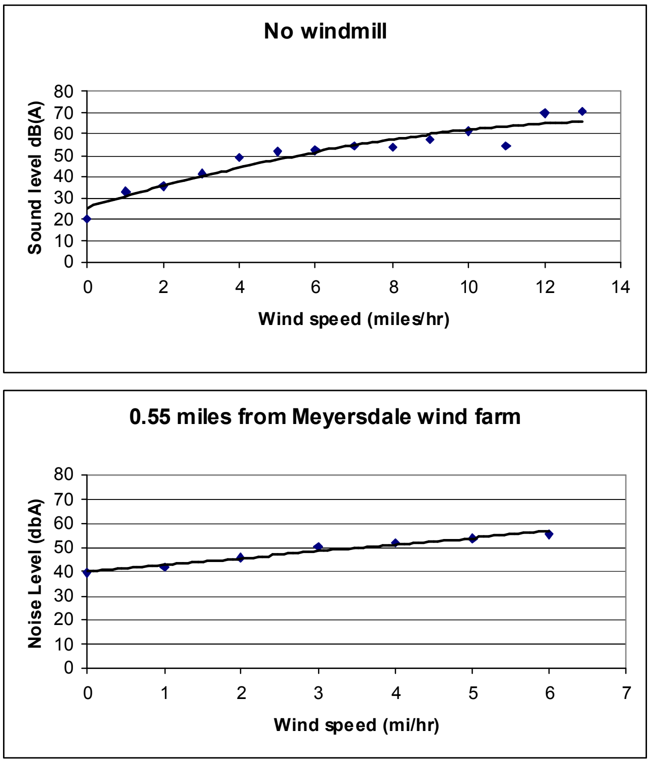


Figure 6 Noise levels with and without windmills

Assessment of the Nuisance Caused by Wind Turbine Noise

The tests performed near wind farms confirm the observations of several residents describing the windmill sound. The following psycho-physical characteristics of the windmill sound distinguish it from the typical urban and occupational noise.

- Windmill sound has dominant low frequency components
- The windmill sound is often periodic and rhythmic
- The very low frequency and infrasound components, for which human ear is normally not sensitive, are highlighted and become perceptible due to the low frequency modulation (fluctuations) of the broadband noise (Van Den Berg, 2005). This effect is usually described as swishing or whooshing sound.
- Low frequency modulation effect is stronger in stable atmosphere due to the interaction of the blades with the steady wind around the tower. This mostly occurs during night and early morning (Van Den Berg, 2005).

- The windmill sound is present day and night and can be disturbing at night because other sources of noise are reduced.

For the reasons listed above, the noise levels defined for urban and occupational noise may not represent the effects of the windmill sound. The A weighting network may be inadequate because of the dominant low frequency components and the modulation of the weak broadband noise.

Codes and Regulations Concerning Wind Turbine Noise

A nationwide applicable limit for windmill noise is not available in the USA. Instead of imposing standard noise limits, the US Environmental Agency (US-EPA) recommends that local governments develop their own noise regulations or zoning ordinances. The publication EPA-550/9-74-004 (EPA 1974) is one of the most detailed studies to date on disturbances and activity interference caused by various sources of noise. The publication presents data collected for 55 community noise problems between 1949 and 1974. The noise sources considered in the document are transportation vehicles, single-event operations (such as circuit breaker testing, shooting, rocket testing and body shop), steady state neighborhood sources, and industrial operations.

The day-night averaged A-weighted noise level is one of the parameters commonly used to assess the wind turbine noise. EPA added correction factors to the measured day-night sound level (Ldn) to obtain a normalized chart. The correction factor for a quiet suburban or rural community (remote from large cities and from industrial activity and trucking) is +10 dB. Whereas the night time noise is considered differently than day time, this parameter does not reflect the disturbing effects caused by the low frequency modulation of the background noise. In addition, the low frequency components are significantly suppressed in A weighting. In fact, IEC 61400-11 recommends the comparison of the A and C weighting to assess the presence of low frequency noise. The IEC standard recommends using C weighting if the difference is usually equal or above 20 dB.

Local governments in the USA are currently developing county noise ordinances based on the guidelines suggested by Environmental Protection Agency (EPA) and American Wind Energy Association. The ordinances are typically concerned with neighborhood, construction, and industrial noise. The strength of such regulations and ordinances is the consideration of the characteristics and tolerance limits of local communities. The residents living in counties where noise ordinances have not been established are currently unprotected from development of wind generation facilities near their homes and farms. The lack of noise limits increases the public reaction to wind farms, mostly motivated by subjective opinions.

The permissible noise levels applicable to wind turbines in various countries are listed in Table 2. While many countries do not specify the noise sources, Denmark clearly distinguished the noise limits for different sources. The noise limits for wind turbines are specified by the Ministry of the Environment (statutory order no. 304 of 14 May 1991) in open outdoor areas as 45 dB in open country and 40 db in residential and noise sensitive zones.

Table 2

Permissible L_{eq} Noise Levels in dBA applicable to wind turbines

(compiled from various sources)

Country	Commercial		Mixed		Residential		Rural	
	Day	Night	Day	Night	Day	Night	Day	Night
Germany	65	50	60	45	55	50	50	35
Netherlands (EPA)			50	40	45	35	40	30
Denmark (EPA)					45		40	
Australia	65	60			52	45	47	40
Ghana	75	65	65	60	65	48		
USA	No federal noise regulations, US-EPA established guidelines. Most states (including VA) do not have noise regulations. Local governments have noise ordinances (Rogers and Manwell, 2002).							

Conclusions

Sound generated by wind turbines has particular characteristics and it creates a different type of nuisance compared to usual urban, industrial, or commercial noise. The interaction of the blades with air turbulences around the towers creates low frequency and infrasound components, which modulate the broadband noise and create fluctuations of sound level. The low frequency fluctuations of the noise is described as “swishing” or “whooshing” sound, creating an additional disturbance due to the periodic and rhythmic characteristic.

A set of permissible limits for windmill noise that can be uniformly applicable over the nation is not available in the USA. Instead of imposing standard noise limits, the US Environmental Agency (US-EPA) suggests local governments developing their own noise regulations or zoning ordinances. Many countries developed national noise limits applicable to wind turbines.

Specific noise limits need to be developed by considering the characteristics of wind turbine noise. Especially the low frequency sound components and the modulation of the background noise resulting must be considered to represent the activity interference of the wind turbine sound. Adequate criteria to assess the wind turbine sound will greatly help the development of the wind industry by reducing the community reaction based on subjective opinions.

References

Flowers, L. (2007), "National Energy Update," National Renewable Energy Lab, http://www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/wpa/wpa_update.pdf, April 3, 2007

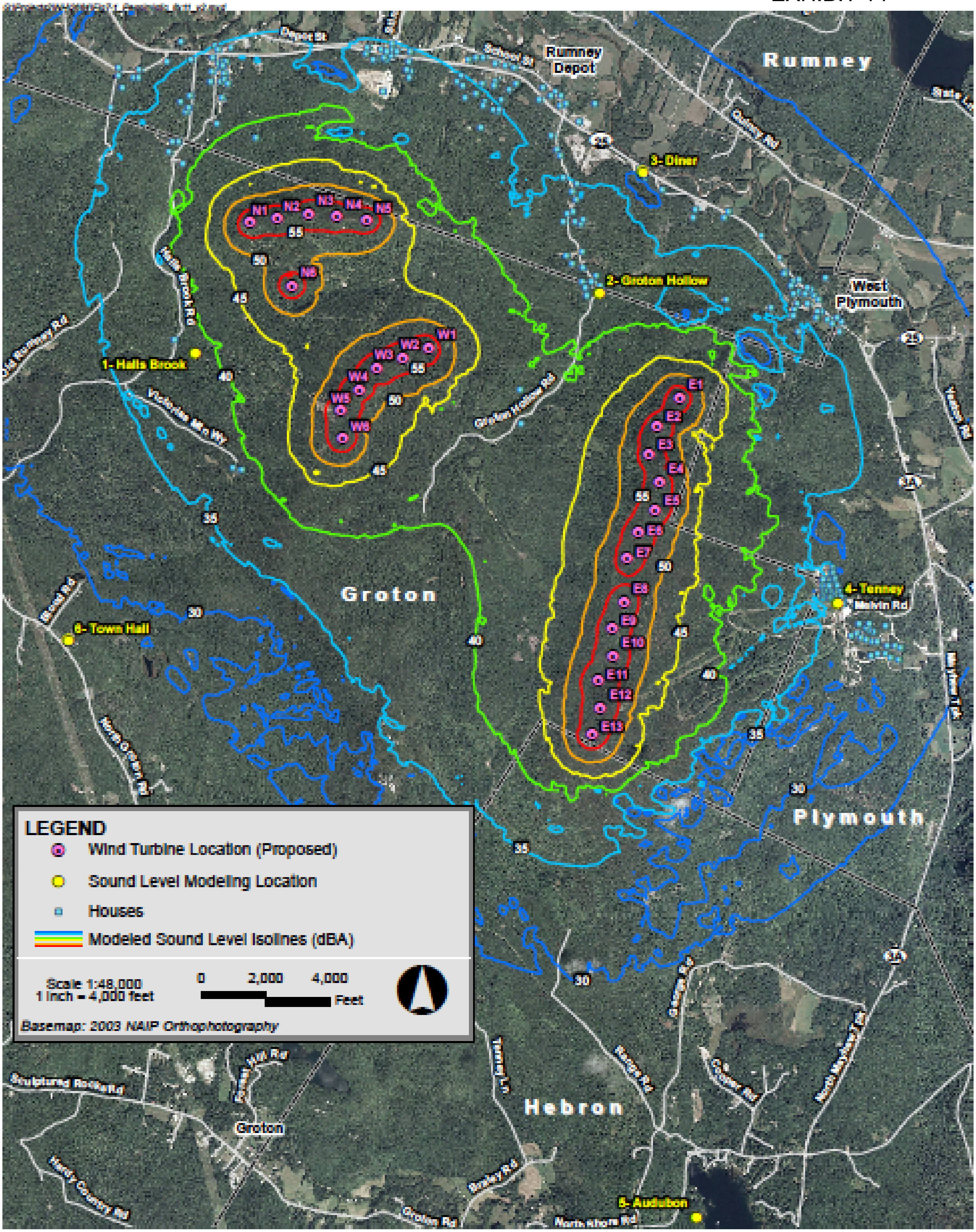
Wiser, R. et al., (2007), "Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2006," US Department of Energy, Energy Efficiency and Renewable Energy, May 2007.

Rogers, A. L. and Manwell, J. F., (2002) "Wind Turbine Noise Issues," A White Paper prepared by the Renewable Energy Research Laboratory, Center for Energy Efficiency and Renewable Energy, Department of Mechanical and Industrial Engineering, University of Massachusetts at Amherst, June 2002 (Amended March 2004).

Van Den Berg, G. P., (2005) "The Beat is Getting Stronger: "The Effect of Atmospheric Stability on Low Frequency Modulated Sound of Wind Turbines," Journal of Low Frequency Noise, Vibration, and Active Control, Vol. 24, No. 1, 2005.

EPA (1974), *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety*, EPA-550/9-74-004, U.S. Environmental Protection Agency, Washington, DC.

EXHIBIT 14



Groton Wind Project Groton, New Hampshire

Epsilon

Figure 7-1

Modeled Project Only Sound Levels - Gamesa G87 "Pessimistic" Data 106.5 dBA