

Wind Farm Noise 2012

Science and policy overview

Compiled by Jim Cummings



Contents

1	Introduction
3	Wind farm development and community responses The current “big picture” and AEI’s role as an honest broker
6	On the ground in wind farm communities Visits to noise hot spots and the wide-open plains
12	How loud at how far? Wind turbine noise propagation: idealized and as predicted on project sound maps
16	Community response surveys The few surveys we have all suggest that many close neighbors dislike the noise
24	Recent recommendations and decisions on setbacks and noise limits One size no longer fits all
35	Overviews of previous AEI research summaries this year <i>Full research summaries included as Appendices to this report</i>
35	Turbine sound: peaks & averages, variable source levels, LF
35	Variability of wind turbine sound: source levels / average & peak sound
40	Low frequency noise and infrasound / propagation of low frequencies
44	Industry efforts to quiet turbines
48	Health effects
52	Footnotes and references
Appendix A	Recent research on low frequency noise from turbines (Dec 2011)
Appendix B	Industry efforts to quiet turbines (Dec 2012)
Appendix C	Wind farm noise and health: lay summary of new research (Apr 2012)

A Brief Introduction to a Long Report

Here we go again. This is the Acoustic Ecology Institute's third comprehensive annual overview of wind farm noise issues. Each year's report goes into depth on different topics, and **the three complement each other quite well, though each one clearly engages the issues with more detail and reflects a more nuanced appreciation of the topic than the ones that came before.**

Wind Farm Noise: 2009 in Review offered a broad-based look beneath the surface of the noise issue. While taking noise complaints seriously, it acknowledged that they are far from universal, with many projects spurring few problems. It looked at ways that the nature of turbines sound make it difficult to rely on simple noise limits. And a fair amount of space was devoted to the social dynamics at play in rural communities, and AEI's approach to reconciling the divide between reassuring research overviews and the life-changing impacts reported by some neighbors.

Wind Farm Noise 2011: Science and policy overview includes a 10-page introduction that provides a context for making some sense of both community noise complaints and the industry's faith in its standard siting practices. A long section on community noise standards compares wind turbine noise with other sources of community noise, and includes several pages summarizing the points of view of some of the more cautionary acousticians. Brief sections addressed health effects and property values research. Appendix A summarizes AEI's presentation on Community Responses to Wind Farm Noise at the DOE-funded New England Wind Energy Education Project webinar on noise. Appendix B offers a 5-page introduction to AEI and its approach to wind farm noise issues.

Some readers may be put off by the length of these reports; this one will be the longest yet, thanks to the inclusion, as appendices, of three extensive research overviews that were published separately since the Wind Farm Noise 2011 report was completed. I want to take a moment to explain the reason for the length of these publications, and to invite you to take advantage of the built-in skimming opportunities I've included.

In my work as an editor, I seem to be drawn to **public policy topics where the public dialogue has become polarized to a degree that can undermine the goal of making clear and well-informed decisions.** As each side makes seemingly incompatible statements with equal assurance, the general public and decision-makers (at the local, state, or national level) are left struggling to make sense of the situation. Too often, the primary problem is that both sides oversimplify the picture, discounting inconvenient information that might undermine their self-assurance. This is where AEI comes in: its online news and science coverage, and especially topical special reports such as this one, aim to include more **substantial background information and detailed analysis, in order to provide the wider context necessary to appreciate the valid points** (and distortions or simplifications) made by everyone involved, and to understand the subtleties and ambiguities that are often painted over by advocates on one side or the other in the name of presenting a "clear message."

Yet I know that most of you won't have the time to read all of this in detail; I encourage you to **scan the text using the underlined and colored sections as skimming aids, and to dive in to sections that are most interesting to you.** You should be able to skim the whole thing in fifteen minutes or so. For those of you charged with drafting local wind farm ordinances, or

who work for state or federal agencies or wind farm development companies and often find yourselves discussing these issues with each other or the public, I encourage you to set aside an hour or two to delve more deeply into the sections here that are relevant to you. **The appendices, which summarize recent research on low-frequency noise and infrasound, health effects, and turbine quieting techniques, each offer comprehensive overviews that are not available elsewhere.**

With that, let's open the door and begin exploring the current state of the contentious question of wind farm noise. I hope that these pages shed some light that's helpful to you.

Key topics in this year's report

The body of this report contains several relatively short sections (3-11 pages each) on a range of topics related to wind farm noise. We'll start with a quick "big picture" framing of the state of the current public policy debate over wind farm noise. I'll then go a bit deeper in that direction by sharing some experiences and reflections from a series of visits I've made to communities where noise has become a volatile issue.

The three main sections of this year's report that give examples of the ways that wind companies and local communities are addressing and responding to noise issues. The first will share some maps from actual projects, showing the "noise contours" suggested by the sound modeling used by the wind developer; these give a sense of the distances at which real-world projects are expecting various noise levels to occur. The next section will summarize the few surveys that have been made in communities where wind farm noise has become an issue, and consider as well the ways that some communities have re-considered earlier noise fears and their local siting¹ standards after living with a wind farm for a few years. Finally, we'll take a look at the range of distance setbacks and noise limits being adopted by various communities in the past couple of years.

The report proper will conclude with three sections containing what I consider to be the key takeaways from the in-depth research summaries that are included here as Appendices: a section each on low-frequency noise, health effects, and technologies and new research that could lead to quieter turbines. While these kernels offer some useful perspective, of course I think that the full Appendices are well worth a read—they contain a one to two page summaries of each of a dozen or so important research papers, and provide some threads of inter-connection between them. So please do delve into the Appendices to get a more detailed and comprehensive look at these topics.

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.

Wind farm development and community responses: the current “big picture” and AEI’s role as an honest broker

Four and a half years ago, in the spring of 2008, AEI waded innocently into the wind farm wars with a blog post summarizing several recent news items about towns adopting or considering more stringent setback standards for wind farms, based largely on noise concerns. Little did I realize then just how contentious this issue would become, or how unusual AEI’s middle-ground voice would be in the midst of an increasingly polarized, and at times distorted, public policy discussion.

As a member of the American Society for Acoustic Ecology, the American Wind Energy Association, and the Acoustical Society of America, I bring **an unusual blend of interests to these questions**: a sensitivity to the ways that local soundscapes are central to our experience of place and home, a commitment to a renewable energy future, and an ability to read and make sense of academic and consultant studies of acoustics. As a writer and editor with a 25-year history of making complex environmental and scientific subjects comprehensible to a general audience, and over a decade of covering sound-related environmental topics, I’ve created a body of work here at AEI that has become a valuable resource for a wide range of stakeholders interested in ocean noise, wind energy, and public lands recreation issues¹. The primary goal of AEI’s reports, research summaries, and news coverage is to **create a broad context** within which readers might better understand the diverse – and often apparently contradictory – statements being made by those in the public spotlight on these issues.

On the question of wind farm noise, the public dialogue continues to be quite cacophonous. **Noise concerns have been swept up into a broader resistance to wind energy**; some of this resistance is based on the scale of the technology and questions about its practicality or cost-effectiveness, some targets government incentives as part of a focus on reducing government spending in general, and some is rooted in a more fundamental skepticism about climate change and thus rejects the need for energy alternatives. Much of the public concern about wind farm noise has shifted to questions about the health effects of inaudible infrasound, a topic which is far harder to gain clarity about than simply considering audible noise and assessing public acceptance and annoyance rates. All this has brought a confusing array of voices to the table as communities consider new wind developments.

Meanwhile, the wind industry is beginning to shift its perspective on noise issues, with most developers now acknowledging that turbines will be audible and that some people will be annoyed. A few within the industry still claim that “noise is not a problem with modern wind technology,”² but this is becoming far more rare. However, **noise annoyance is generally seen a “subjective” response, and most companies consider current siting standards to be sufficient for most locations**. The majority of new wind development still occurs in western locales with lots of space, and/or willing hosts on farms and ranches; increasingly, though, projects are being built in more populated areas where turbines are sited in and amongst homes or on nearby ridges, just far enough from non-participating

homes to meet typical 45-55dB noise criteria, assuring that dozens of neighbors will hear turbines on a regular basis. While wind developers continue to have faith in this sort of relatively close siting, and have often shown willingness to respond to noise complaints by quieting existing turbines to the degree that is practical, the negative experiences of neighbors in some communities have **led many towns and counties to adopt more restrictive wind farm siting ordinances, or to ban industrial wind development altogether.** At the same time, industry players are working constructively with other rural communities and building large projects that trigger few if any complaints. Around Breckenridge, MI, this spring, the Gratiot County Wind Project became Michigan's largest (133 turbines), with setbacks of as little as 1000 feet. Utilizing a Community Participation Model that included³ among other things "50 cups of coffee per MW," the project is an example of how to work constructively with communities where wind energy is welcomed with open arms. Clearly, **the industry is facing an increasingly varied landscape for development going forward; companies that adapt will find far more opportunities for future projects.**

At the risk of offering an arguably facile and broad-brush picture, I think it's worthwhile to briefly give a sense of how widespread noise complaints seem to be (see the later section of this report on surveys for more detail). In fact, it's certain that whatever numbers I suggest here will trigger arguments—likely from both industry and community groups. But it's worth taking a crack at it, to give some context to all that follows.

We are sorely lacking in any industry-wide community response surveys, which would be especially useful in indentifying any possible correlations between community characteristics and either tolerance for turbine noise, or sensitivity to community noise sources. We don't even have any clear data on what proportion of wind farms actually trigger noise issues. However, there now exists a well-established and widespread ecosystem of online groups scouring media reports for all articles about wind energy; some compile primarily positive stories about projects moving forward with community support, and some gather every mention of any downsides of wind projects and all regulatory setbacks and denials, everything from noise and health complaints to traffic accidents and town council deliberations. Between my own Google News alerts and email subscriptions to both industry and community group news compilations, I feel fairly confident that I have a bead on the general scale of relative successes and problems.

My sense is that most wind projects are still being built in areas far from homes, or in farm and ranch communities where they are predominantly welcomed with open arms; for these wind projects, it appears that running into widespread noise problems is the exception rather than the rule. Indeed, in the first nine months of 2012, 77 new wind farms (averaging 52MW each) came online in the US, and noise complaints have been minimal or non-existent at the vast majority. But in communities where a **substantial number of residents, especially non-participating residents, live within a half mile or mile, the situation is far less clear-cut.** Complaint clusters are nearly all from this sort of community, though complaints don't *always* arise when non-participants live nearby; it may be that some critical mass of affected neighbors tips the scales toward a community backlash. There are now many communities in which I feel confident saying that a third to half of the

residents living nearby feel negatively impacted by the presence of a wind farm; they don't like the new noise, although many are trying their best to just get used to it and live with it. In such communities, about half of these, or up to 20% or so of nearby neighbors, are strongly impacted, with sleep disruption, stress issues, and their sense of home and place forever changed; some of these push strongly for operational changes in the wind farm and consider moving away. And it appears that extreme impacts, including chronic loss of sleep, stress, or noticeable health changes, may be affecting somewhere around 5% or so of those within a half mile or mile in some communities, with many or most of these people wishing they could move away (though only a few tend to be financially able to do so).

As I say, I know these numbers may infuriate both sides, but this is the best sense I have of it at this point. While if history is repeated, I'll probably be upset to see some bits of what I just said selectively quoted by partisans for one side or the other, I'll close here by stressing that, to me, the idea that "only" 5% of neighbors may be severely impacted does not suggest that impacts are too small to warrant consideration. If turbines were built on the ridge that rises a quarter to third of a mile from the homes that stretch down the heart of my home valley, I wouldn't find any solace in the thought that only one or two of the seventy households would be so affected that they'd need to leave the homes and yards that they've built here with their own hands over the past few decades – and knowing the folks here, my guess is that most of us are deeply connected to this landscape and its peaceful qualities (even though we live within earshot of an interstate) and the impact would easily match or exceed the proportions I noted above. The county, or even the neighborhood, might conceivably decide to build such a project anyway; I would hope that if so, the decision would be made with **full consideration of the possible impacts, rather than after simply pretending or assuming they were not real.**

It's heartening to me to see that, in fact, communities nationwide are undertaking just this sort of deeper consideration of the inevitable audibility of wind farms in the landscape around them. **Some towns are affirming the existing 1000 foot approach,** knowing that most of their residents will be content hearing turbines in their working landscapes; others are choosing to **keep industrial turbines out of more pastoral landscapes altogether,** not wanting to change the lives of even a few close neighbors. Most are experimenting with **moderated responses somewhere between these extremes,** with setbacks of 2000 feet to a mile or more, and noise limits as low as 35dB at night. We'll survey some of these choices, across the entire spectrum, at the end of this report. But for now, I trust that this brief big-picture context has been enough to give you a bit of perspective as we embark on the meat of AEI's 2012 Wind Farm Noise science and policy overview.

On the Ground in Wind Farm Communities

While most of my work on wind farm noise issues takes place online, over the years I've had the opportunity to visit six communities where noise has been a contentious issue (as well as an equal number of wind farms in the wide open spaces of the west). In two – Falmouth, Massachusetts and Vinalhaven, Maine – I spent several days, each time spending the night with affected neighbors, talking to a wide range of locals (including some who don't mind the sound of the turbines) and met with the organizations that had championed the wind projects⁴. At the other four – Freedom and Roxbury, Maine, Keyser, West Virginia, and Fond du Lac County, Wisconsin – I visited a few neighbors, all of whom hear the turbines, and some of whom were upset about the sound. During these visits, I didn't do formal interviews or take detailed notes; the purpose was to simply get a sense of the human aspects of these issues that I've been tracking from afar for four years via the screen in my office. I wanted to get a more visceral feel for the perspectives of a variety of people.

I came away with a **much deeper appreciation for the depth of despair and frustration felt by some wind farm neighbors, as well as the challenges confronting project planners who didn't expect noise to be a significant issue.** The people I've met who are struggling with noise include a mailman, a high school teacher, two retired college professors, an air traffic controller, a farmer, a geologist, and a solar energy professional – grounded, level-headed people, none of whom had a bone to pick with wind energy, and most of whom were excited about their local projects before turbine noise entered their yards and bedrooms. They aren't hysterical or overly wound up; they are, however, distraught at the impact on their lives and intent on rectifying the unintended consequences of their local wind projects. On the other side of the local divides, the people working for groups that planned the projects are not the uncaring, stubborn stonewallers that some neighbors may suspect; they are responsible for multi-million dollar local projects that they couldn't – and don't want to – shut down, and are working in a variety of ways to understand why the reactions to turbine noise are so much more vehement than were expected.

In some communities, communication across this divide has come to a near-total standstill, thanks to lawyers' recommendations, distrust about motivations, or mutual frustration at the very different emotional tones and practical priorities of those each side of the gulf. As always, personalities loom large in shaping the ways that communication develops or flounders; this may be especially true when one side is angry or frustrated, and the other is being careful about how to respond and is fundamentally enthused about the project. One community, Falmouth, is engaged in a “wind turbine options” process involving a full range of stakeholders, including town officials, local pro-wind environmental groups, and affected neighbors⁵; the process has not been easy, and it remains to be seen whether the spring town meeting will be able to adopt a plan that works for everyone, but at least the community is working on it together. Unlike most wind farm projects, this one is town-owned, allowing far more local control over how to deal with noise issues, including shutting them down at night while the options process unfolds (it bears mentioning that this relatively collaborative response took about two years, and a heated town meeting, to

get rolling, despite widespread neighborhood complaints from the first days the turbines became operational).

Most of the towns I visited were coming to grips with fallout from pre-construction sound modeling that suggested turbines would be either inaudible or so close to background sound levels that they'd be easy to live with; instead, the noise is, at times, intrusive enough that a significant proportion of people living within a half or three-quarters of a mile are quite disturbed. (It's hard to nail down proportions, but it seems clear that at least 20%, and up to half, of nearby neighbors are being affected in each place I visited besides Roxbury; most strikingly, over 40 homes within a half mile of the Falmouth turbines reported sleep, stress, or other impacts to their local Department of Health).

Even project planners have, at times, been taken aback by the prominence of turbine sound at neighbor homes. In Falmouth and Vinalhaven, neighbors alarmed by the unexpected noise levels asked key project planners to come to their homes and listen within the first few days of operations; in both cases, their first reaction was surprise. One told a homeowner, "We knew they'd make noise, but I didn't think they'd be this bad," and another said with chagrin that the sound models must be wrong (I suspect this was in reference to how clearly audible it was, rather than the actual dB level). In both places, project planners had accepted without much doubt the then-standard perspective that wind in trees would largely drown out turbine sounds whenever the wind was blowing. In Keyser, a company rep was initially similarly frank with neighbors who were living near turbines that had caused no noise issues for the company in the flat midwest, but were surprisingly loud perched atop a steep Appalachian ridge⁶. In each case, after initially being quite empathetic, project planners pulled back from such frank discussion with neighbors (who were becoming more distraught and asking for immediate action), and began working in various ways to quiet the turbines without substantially impacting the required/desired energy output.



Roxbury (above) was an interesting contrast, because the turbines are over a mile and a quarter from nearly all the neighbors – even those locals who had been most concerned about noise impacts agree that it's not as bad as they feared, and they hear turbines only when it's very still (one reports hearing them every quiet morning, another, on quiet

winter nights; sleep has not been disturbed except for a couple nights when there was a mechanical issue). One person, two miles away, heard them a couple times when clouds were low and socked in. Still, at each distance (whether a mile or two miles), even those with no complaints about the wind farm all said that they wouldn't want turbines any closer than they are. (It should be noted that while noise is not an issue, many locals dislike the lights shining across the pond and the ridgetop road and construction.) Likewise, in Wisconsin, neighbors surrounded by turbines in a large wind farm had varying senses of what would be livable: one (with two turbines about a quarter mile away) said if there were no turbines within a half mile, he'd feel OK about it, and another (with three turbines within a half-mile and two more a bit further away) thought a mile would be more like it. In Freedom, Maine, I met with neighbors and with wind proponents; the most striking effect in this community that has lived with turbines for a few years is that local discussions about a town-wide wind ordinance are focusing on a much different range of options/opinions – the strongly pro-wind element is proposing a 4000-foot setback, rather than the more typical starting point of 1000-1750 feet.



I've also visited several wind farms in the wide-open spaces of the west, in California, Wyoming, Nebraska, Kansas, and Texas. In such places, I've gotten a solid feel for the foundation of the American wind industry; indeed, even now, the vast majority of new wind development takes place far from towns and rarely spur noise complaints. While the striking feature of these landscapes is the **extremely low population density (tens or hundreds of turbines per nearby home, rather than the inverse, as seen in areas where complaints are more common)**, many homes have turbines within a half or even quarter mile (or less), and residents have not been up in arms. This is the fundamental reason that wind developers have considered setbacks of 900-1200 feet to be totally reasonable, and unlikely to cause problems for neighbors.

Yet a growing body of both research and experience suggests that **community response/annoyance rates can vary greatly in different types of communities.** Last year's AEI annual wind farm report went into great detail on this topic, and I refer you there⁷ for the full picture; we'll dip into that topic a bit this year in reviewing the range of setback standards recently adopted around the country. Suffice to say that ranchers and large-

scale farmers, used to working on and around machines, don't generally consider wind turbines to be particularly loud, while retirees or bedroom rural residents are far more apt to react negatively when the sanctity of their backyards or utterly still nights is broken by the presence of wind turbine sounds. In addition, having an income from nearby turbines (as many ranchers do) makes it more likely that moderate noise will be heard as a welcome sign of income, rather than as an intrusion. There is also some indication⁸ than in flat ranch country, the sounds of turbines are more steady than in more complex terrains where turbulent air and generally more rapidly shifting weather conditions lead to more dramatic surges and variation in turbine noise levels.

This is probably a good place to stress that **in every wind farm I've visited where the turbines were turning at close to their full speed (about 20rpm, or one blade passing vertical each second), the turbines have always been audible out to at least a half mile;** generally, they've faded into the background sounds of distant roads or nearby leaves by about three quarters of a mile. So far, this has been in moderate wind conditions (usually just a light breeze at ground level; a couple times, moderate ground breezes in which I had to turn my head to keep wind-in-the-ear noise from being an issue); I've never been near a wind farm at a time of high winds, or in periods with irregular (knocking, banging, impulsive) sounds or palpable pressure waves often cited by neighbors as the most difficult to live with. There have been several occasions in which I could easily hear turbines through nearby rustling leaves, with the turbines being clearly a lower-frequency sound, though the sound levels seemed similar.



The experiences of the neighbors I met varied quite a bit. Again, earlier AEI annual reports and presentations⁹ contain a good range of experiential descriptions, and I don't want to repeat all that here; a few highlights from my recent east coast trip may offer a sense of it. The **most poignant comment I heard was from someone who lives a bit over a half mile from a small wind farm, on the next hill over; he spoke of that first**

snowfall of the year, when everything is totally still, absolutely quiet and so profoundly peaceful....he paused, then said sadly, "I'll never have that again..." (when clouds are low and socked in, sound travels especially well). Another stressed that while the background whoosh of the turbines gently turning is an unwelcome addition to their local soundscape, the real impact comes with much more intrusive knocking and banging, night-time sound peaks, or pressure waves that are felt both outside and inside their home. She said that if they'd been told that they'd have thirty horrible sound days a year, she'd have been more prepared for that, and also stressed how different it would feel even now, if the wider

community also understood that it's very bad quite often, instead of considering neighbors to be whiners or trouble-makers (note that she didn't say that if she'd been more prepared for the intrusive sound, then she'd be OK with it now—just more prepared). On Vinalhaven, the story of a rental property around a half mile away from the turbines may be especially illuminating. As is often the case with vacation rentals, the owners hosted many “regulars” each summer for a week or two at a time. After the first summer of turbine operations, none of the regulars returned this summer. These are people who, not being landowners with investments there, might be relatively objective, dispassionate outsiders for whom the noise might be less of an issue; they stayed a week or two, long enough to get a feel for how often the turbines affect the sense of place, in the least-objectionable season, noise-wise. And all chose not to return. Two other neighbor experiences were especially striking. One person, who often works in his extensive backyard gardens, reports often feeling pressure building up in his head while working, and has found that he can sometimes walk a few hundred feet one way or the other and apparently get out of the zone where this is occurring; this could be an indication that his yard is sometimes in the “wake” of the turbine, where air pressure waves spiral downwind from the turning blades (these are not sound waves, but simply air pressure, which I suspect is a bigger contributor to neighbor complaints than is currently recognized). The last testimonial that was especially impactful was from someone who's **had to move from his retirement home (built with his own hands over many years) because turbine noise kept him awake too much at night and destroyed his enjoyment of the place during the days.** He was the most vehement in expressing the core feeling shared by many of those most affected: that, in his words, “the number one issue” is the collateral damage occurring as lives are disrupted, and this needs to be acknowledged, addressed, and stopped. He sees it as stealing from the middle and lower class residents around wind farms; not just the possible (he thinks certain) financial loss in reduced property values, but even harder, losing the emotional investments in community and place; it's just morally wrong, he stressed.

Faced with these sorts of reactions from neighbors, **wind project managers are left with a high-stakes quandary.** Project investments, whether private or public, were based on getting the projected electricity generation out of the turbines, so there's a lot of pressure to keep them turning. In Vinalhaven, the turbines supply the local electric co-op that services the island; this may be the last community in Maine where well over half the 1200 year-round residents are working lobstermen and their families, all used to life with boat engines both up close and at all hours in the distance, so the couple of dozen families living around the quiet cove near the turbines (most of whom are either summer residents or recent arrivals, i.e. first generation, five to twenty-five years) get little empathy about noise. Falmouth, as noted, is a town-owned project, with the electricity supplying the local wastewater treatment plant and reflecting a strong community commitment to a renewable energy future. Still, in both places (and in Keyser) those behind the project have made efforts to reduce noise. At Vinalhaven the manufacturer added serrated edges to the blades, and operators have experimented with Noise Reduced Operations modes; each of these can reduce turbine noise by a couple decibels or so without reducing electric production very much, which together should help to some degree (the serrated edges seemed to reduce some of the intrusive throbbing, according to neighbors, though may have increased the volume of the swooshing; the pulses remain a problem in high winds)¹⁰.

At Falmouth, night time shut-downs have reduced impacts temporarily, the town Health Department has held hearings and conducted surveys, and the state agency that was behind the project, the Massachusetts Clean Energy Center (MassCEC), along with the state Department of Environmental Protection (DEP), have engaged in short-term noise monitoring. The MassCEC is also working statewide to try to understand what factors lead to more vigorous community reactions, including some preliminary surveys and plans for a detailed statewide turbine noise study during 2013. **These efforts, taking place over periods of months and years, seem methodical and even diligently fast-tracked to those used to working within the context of the planning process of a state agency, electric company, or wind developer, while at the same time appearing incredibly slow (and half-measures) to neighbors.**

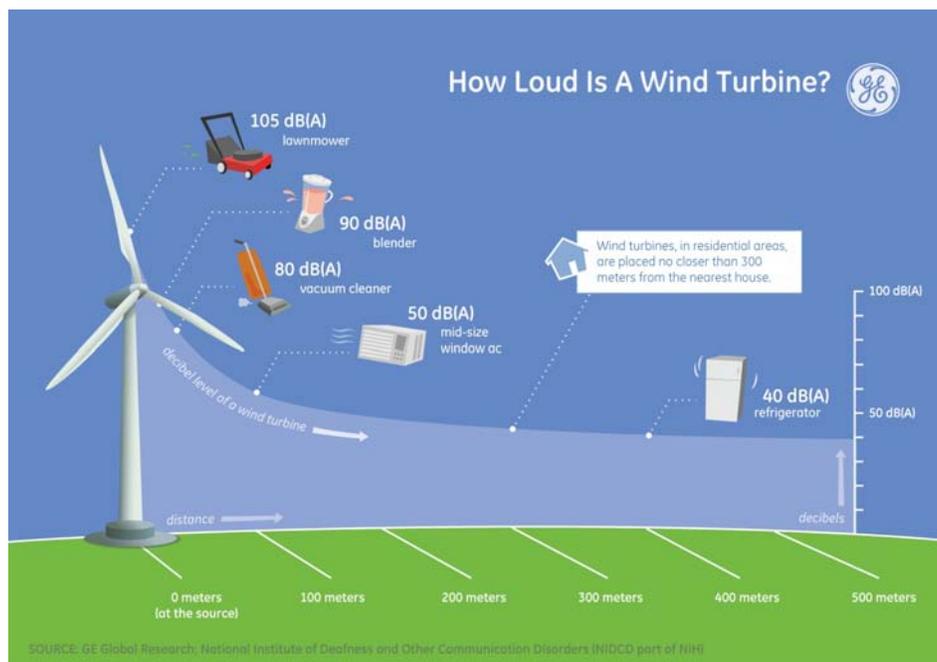
A deeper, difficult question also comes up for project proponents and operators: in moving forward with a project that has community-wide benefits, is it acceptable to create negative impacts on some proportion of the community? If so, and most project planners would agree, then how many? 5%? 10%? (Such questions usually consider the percent of the entire community, rather than of nearby neighbors or of those who hear the turbines). The wide-angle lens sees thousands of residents benefiting from locally-produced wind energy, while some (or many) of those within a half mile or so are dealing with noise impacts. In both Falmouth (within the MassCEC) and Vinalhaven (within the Island Institute¹¹ and Fox Islands Electric Coop), these questions are real, and are being grappled with, albeit in ways that often leave neighbors feeling ignored in the meantime. For neighbors, these are experiences that are real, and the questions are about how and when project managers will accept responsibility for what they see as mistakes made in siting turbines close enough to cause unexpectedly severe problems. Some neighbors want turbines shut down or moved, or operated in low-production modes that won't create intrusive sound levels. Others want to be sure that other communities understand that noise can be a serious issue, and think that project planners should, in the future (at least), see these problems coming and proactively make plans for compensating or buying out more of the nearby neighbors. It does not comfort neighbors to hear that project planners may consider it unfortunate but acceptable that some people feel the need to move away from the area, just as people find airport or new highway noise unacceptable.

I don't to pretend to know the way through these murky and highly-charged conflicts. My intention is to try to paint a picture that makes some sense of all the voices that are being raised. My visits to wind farm communities have made all of this more real to me, while keeping up with ongoing research continues to expand my understanding of the factors that may contribute to the experiences of neighbors, the challenges of those working to build wind projects responsibly, and the potential directions that the wind industry may move in the years and decades to come. In addition, in tracking wind farm ordinances adopted in a wide range of communities around the country, it's **increasingly clear that there's no longer any "one size fits all" approach to wind farm siting. Adapting to varied community standards is becoming an important element of successful wind development.**

How loud at how far? Wind turbine noise propagation

This section will offer a bit of a reality check about wind turbine noise propagation. In some ways, the following examples build on the earlier mention of uncertainty and variability that is inherent when considering noise levels around wind farms.

It's not uncommon to see some pretty reassuring numbers tossed around in basic information about wind farm noise. A widely-reproduced¹² 2010 image created by GE, a major turbine manufacturer, is one example:



Here, we see a very simple, idealized version of the fact that sound is absorbed over distance; it shows 105dB turbine sound dropping below 45dB at 150-200 meters (500-650ft), and below 40dB at 400 meters (1300ft/.25mi).

A bit more realistic is an estimate from the American Wind Energy Association's 2011 Turbine Noise Fact Sheet¹³ says that noise will be 35-45dB at 350m (1150ft/.22mi). **These reassuring numbers have been a big part of the enduring conventional wisdom that says that setbacks long considered standard operating procedure (e.g., 1200-1500 feet) will keep noise levels at tolerable levels (i.e., 40-45dB).**

However, actual sound contour maps generated by consultants hired by wind energy developers paint a much less sanguine picture. Below are four such maps, all of which show sound **dropping to 45dB, and to 40dB, at a surprisingly large range of distances on the ground in each particular project site**. These projects were picked at random from sound studies I collect in my files. I'm highlighting the distance to 45dB because that is a fairly common noise threshold in state and county noise standards (sometimes for daytime,

and often for night). The distance at which sound drops below 40dB is of interest for a couple of reasons, primarily because of the fact that noise levels higher than this are often clearly audible in the quiet of the deep night (i.e., 40dB is often 5dB or even 10-15dB higher than rural ambient night time sound levels, thresholds known to trigger community noise problems); in addition, since some jurisdictions are looking at noise limits below 45dB, this give us a bit of a reality check about what that might look like on the ground.

It's worth remembering, as well, that even the variability shown below is just a reflection of topography and turbine layout (and perhaps prevailing winds), and is based on idealized sound power levels from turbines in steady winds, with no inflow turbulence. Some may be based on "worst case" propagation conditions, such as layers that reflect the sound back to the ground, and ground conditions that encourage propagation. Whatever the factors they include, these maps reflect the average levels that will, at times, be exceeded. (See p.36-41 for more on these sources of variability)

<u>Wind project</u>	<u>45dB contour</u> (sound drops below 45dB)	<u>40dB contour</u> (sound drops below 40dB)
Hardscrabble (operating, NY)	1200-2000 feet .22-.38 miles	3000-4000 feet .57-.75 miles
Canton Mountain (proposed, ME)	1300-2640 feet .25-.5 miles	2100-4500 feet .4-.85 miles
Blue Creek (operating, OH)	1700-2640 feet .3-.5 miles	4000-6600 feet .75-1.25 miles
Horse Creek (proposed, NY)	2000-3000 feet .38-.55 miles	4000-6500 feet .75-1.2 miles
AWEA fact sheet	1150 feet .22 miles	
GE graphic	500-650 feet	1300 feet .25 miles

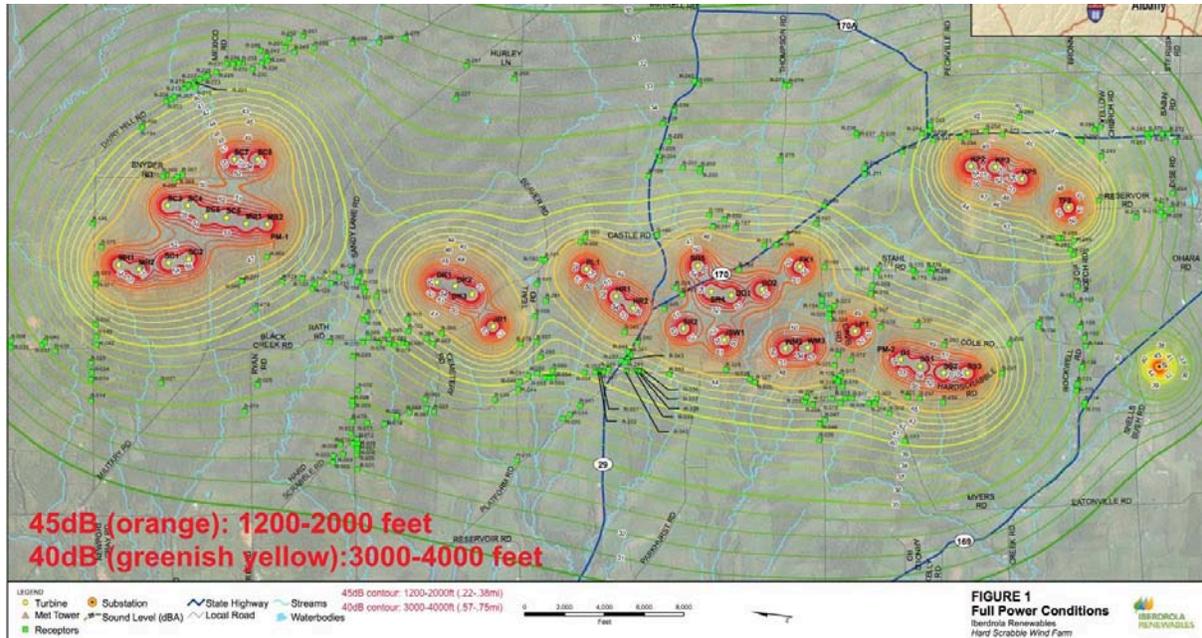
What's most striking to me in looking at these maps is that **the distance it takes to drop to a threshold of interest can vary by 50% or more.** On a practical level, there are locations around three of these four projects where sound is over 45dB all the way out to a half mile or more. And even more striking, there are many locations around each project at which sound levels don't drop to 40dB until three-quarters of a mile, and in two, including Ohio's largest wind farm, sound of 40dB or more extends to well over a mile in some areas.

AWEA's projected distance at which noise will be below 45dB turns out, at best, to reflect only those areas around each wind farm where this happens at the closest (actually, every project map shows 45dB always occurring at greater distances than the AWEA estimate,

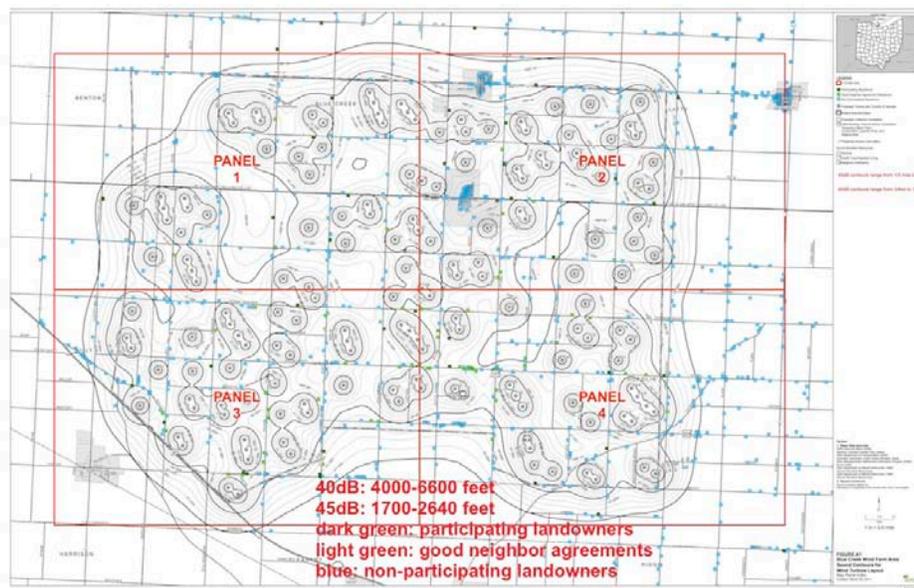
and in many areas, at twice the distance or more). The GE graphic, which continues to appear in articles and information packets, is too far from reality to even consider.

Below are the project sound contour maps. **Full-sized versions, with the distance scale and contours more clearly reproduced, are available on AEI's Wind Farm Noise resource page,** linked in the footer of each page of this report. (The exact layouts of some of these projects may have been changed since these maps were produced, but these versions remain representative examples of the variability being illustrated.)

Hardscrabble Wind Farm¹⁴



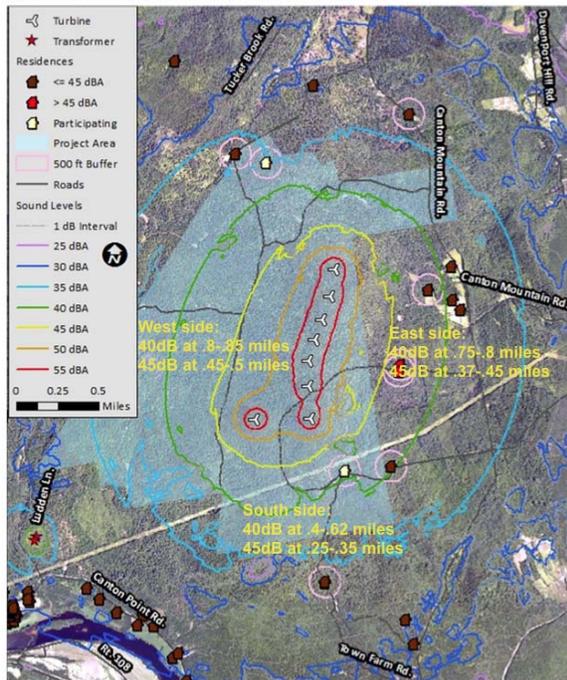
Blue Creek Wind Farm¹⁵



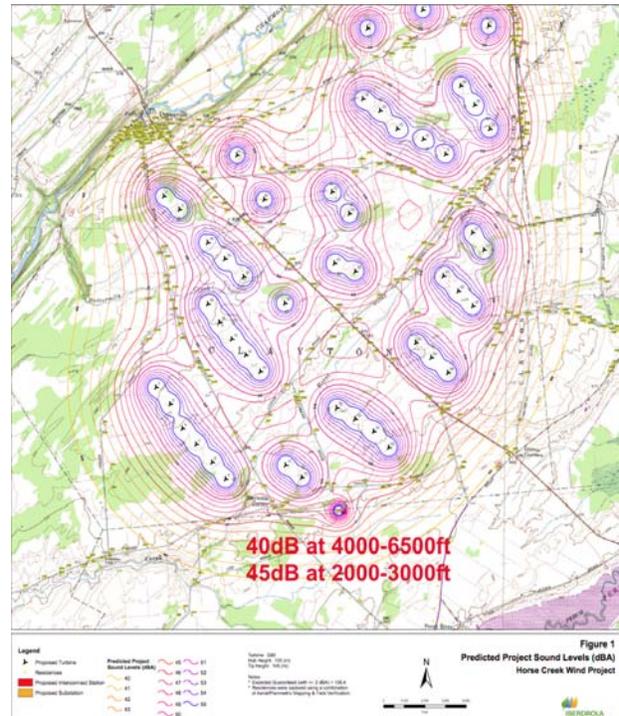
Canton Mountain Wind¹⁶

Canton Mountain Wind

Figure 11: Sound Propagation Modeling Results with Gamesa G90 Turbines



Horse Creek Wind Farm¹⁷



In his sound analysis for the Buckeye Wind project in Ohio¹⁸, David Hessler again stresses that even when modeling using conservative assumptions and worst-case conditions, there are **likely to be times “when the actual sound will exceed the predicted levels in the plots.** Of course, there will also be times, probably the majority of the time, when the perceptibility of Project noise will be less than indicated in the graphics.” He elaborates:

Operational sound emissions from wind turbines are often unsteady and variable with time largely because the wind does not always blow in a completely smooth and ideal manner. **When unsettled air or gusty winds interact with the rotor, or the airflow is not perfectly perpendicular to the rotor plane, an increase in turbulence and noise results.** On top of this, turbines often (although not always) produce a periodic swishing sound. These characteristics make operational noise more perceptible than it would be if it were bland and continuous in nature. Consequently, wind turbines can commonly be discerned at fairly large distances even though the actual sound level may be relatively low and/or comparable to the magnitude of the background level; therefore **the possibility of impacts at residences beyond the impact thresholds shown in the plots certainly cannot be ruled out.** There may also be times, due to wind and atmospheric conditions, when project sound levels temporarily increase to levels that are significantly higher than the predicted mean levels. During these - usually brief - periods of elevated noise complaints also may occur.

Community Response Surveys

As mentioned earlier, **we are sorely lacking in industry-wide community response surveys, which would be especially useful in indentifying any possible correlations between general community characteristics and their relative degree of noise tolerance or noise sensitivity.** (e.g. differences between working farms and ranches and towns where people have moved to have peace and quiet) What surveys we do have, with the notable exception of the body of work from Scandinavia that's becoming a bit dated, have limitations that make it hard to fully rely on them; most fundamentally, they are often relatively informal, and don't include the sorts of careful structure that can hide the purpose of the survey (so as to not sway opinion) or supplemental study that can confirm how representative the sample is.

Some are **broad community-wide surveys** (most often finding overwhelming support for wind energy, on the order of 70-90% positive), which **tell us nothing about what it's like for those living the closest, so cannot really inform difficult decisions about siting standards.** Others, which tend to crop up in communities where there have been clusters of noise complaints, may suffer from self-selection bias in respondents; these often suggest that 30-50% of residents within earshot have strongly negative reactions to wind farm noise. This summary doesn't include the many broad community surveys, because my main interest is informing decisions about how far turbines need to be from homes in order to avoid causing significant noise impacts among the nearby neighbors.

Despite the shortcomings of the surveys that have been done, it's striking to see the close similarity in their response rates. The fact that **the one universally respected series of academic studies of community responses came to a generally similar assessment offers further validation.** It's also worth noting that the respected Scandinavian studies, unlike all the others, took place in areas where noise complaints were not already rampant; this could suggest that there is more "quiet annoyance" than we presume in areas where there have not been enough vocal complaints to spur surveys (it could also suggest that "annoyance" is not always closely associated with life-changing disruption).

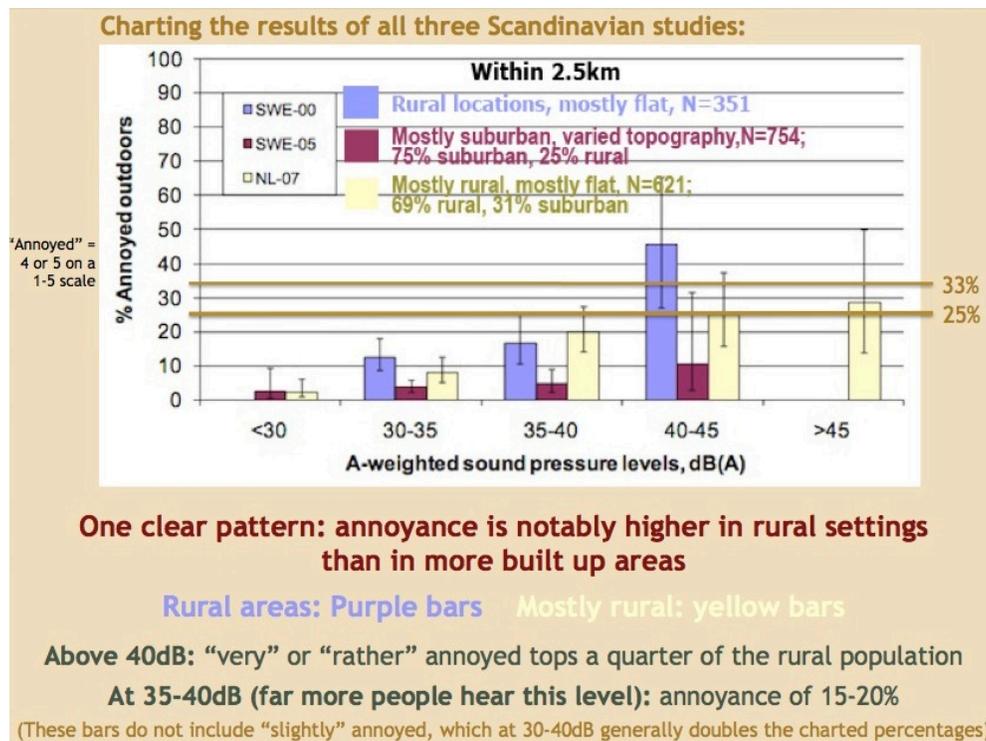
Any community response survey will lead to the key question: what level of noise annoyance is acceptable? All new sources of community noise can be expected to trigger complaints and dissatisfaction. While there is no hard and fast threshold of complaint rates that community noise management aims to stay beneath, it seems that a 10% rate of moderate to severe annoyance is often considered to be within expectations. **Triggering significant annoyance in 25% or more of the affected population is beyond what many community noise managers would like to see.** Some community noise sources (including most industrial facilities) can incorporate noise-muffling design features to keep noise levels at neighbors low enough to avoid such high rates of annoyance. In other cases (airports, new highways), a higher proportion of neighbors may find the noise excessive, but the projects proceed because of the public benefits.

These are difficult questions, and ones that are coming to the fore in many rural areas where wind farms are proposed; the debate moves beyond simply noise impacts, to

questions about whether the benefits of the energy produced by a given wind farm (or the total of wind farms proposed in a region) are worth the change to the local landscape and sense of place. These larger questions are beyond the scope of this report, and of AEI's focus. Here, we are looking not at arguments for or against proposed wind developments, but at **how people living near existing wind turbines respond to the noise that they hear.**

The classic Scandinavian community response surveys, 2000-2007

AEI's Wind Farm Noise 2011¹⁹ report included a comprehensive summary of our analysis of the widely-cited surveys from the Scandinavian research team that includes Eja Pedersen, Kerstin Persson Waye, Frits van den Berg, and their colleagues. Rather than repeat all of that here, I point you to the earlier report, or to AEI's presentation to the DOE-funded New England Wind Energy Education Project²⁰, which contains much of the same information: The key slide is reproduced here:



The essence of AEI's analysis is that **in rural areas, it appears that 22% of those who hear turbines report being moderately or very annoyed; when noise levels are over 40dB, up to 44% of rural residents report moderate or higher annoyance.** While wind proponents often cite the overall annoyance figures of 8-9% in these studies, this number includes a third to half of respondents who report never hearing turbines, as well as large numbers of people in suburban areas. AEI's interpretation of these findings conforms well with annoyance rates reported in several more informal surveys: as turbines begin to be audible (25-35dB), 10-15% of those close enough to hear these levels report moderate or higher annoyance; as turbines become more commonly audible (35-40dB), annoyance can top 20%, and at over 40db, 25-45% of the nearby population may find the noise to be disturbing.

AEI's approach to considering less professional surveys

The primary weakness of surveys such as those considered below is “self-selection bias,” the chance that people having a problem with the wind farm will be more likely to take the time to fill out a survey. None of them had the budget to do the sort of follow-up survey employed by academic researchers, which can confirm that their subjects are representative also of those who did not participate. In our analysis of these surveys, we will consider the reported survey results, and for key results will also present the most extreme bias possibility: that *every* person who did not return a survey is in fact not bothered at all by turbine noise. Of course, it's most likely that the actual community response is somewhere between the two numbers that result.

A secondary concern about some of these surveys is that they took place in areas where substantial public outcry about wind farm noise had already arisen; this critique I consider to be less valid, in that it presumes that people who are not actually all that bothered will be convinced by other's complaints that they, too, are upset. At its most extreme, such critiques posit a “nocebo” effect whereby people are sensitized to their own annoyance or find themselves awakening more often simply because the idea of noise problems is in the public eye.²¹ I consider it more likely that people are becoming more frank about their opinions and experiences in areas where the question is openly discussed in a town; and conversely, in areas where there is little if any public discussion of noise problems, there could well be somewhat more “under the radar” annoyance than we are aware of, because people generally avoid making waves in small communities. And, as I've often stressed, we badly need more community response surveys, in a wide variety of types of communities, including where noise has not been an issue.

Lincoln Township, Wisconsin, 2001

Of the several surveys that have taken place in wind farm communities after construction of wind farms, the most notable is from Lincoln Township, Wisconsin. **A team from the University of Wisconsin conducted the survey in 2001**, and the results were detailed in the Final Report of the Lincoln Township Wind Turbine Moratorium Study Committee in 2002²². This survey stands out for several reasons, and it's surprising to me that it hasn't been more widely appreciated as an early indication of the sorts of problems that have become more widespread in recent years. Perhaps one reason is that it's gotten a bit of a reputation as a source that has been “selectively quoted” by wind farm opponents; it's true that most anti-wind sites tend to highlight the results from closest to turbines, but the survey itself stands up to scrutiny and should not be marginalized. This survey is especially valuable, for it clearly illustrates the ways that community-wide responses can differ markedly from those of the people living close enough to be most affected. Survey forms were sent to all 314 property owners residing in Lincoln Township; 227 returned the forms, for a solid 72% response rate. The survey included a long set of questions about living with the 31 wind turbines that were already operating in the town; in addition to assessing noise problems, it asked about blinking lights, shadow flicker, and TV reception (the latter was, as it turned out, the most widespread problem, with noise second).

Noise annoyance

Community-wide feelings are well captured with two questions. Asked, “Do you believe Lincoln Township is setting a good example in hosting wind turbines?” 71% of respondents

said yes. Town-wide, only 14% said yes when asked, “Are the wind turbines causing problems with noise?”

But if we look closer, a striking pattern emerges: at **under a half mile, exactly half of the residents said noise had been a problem**, while of those living between a half mile and mile, 33% agreed noise was a problem; beyond a mile, those rates dropped to 4% and less. And in case you’re concerned that self-selection bias led those without any problems to simply not respond to the survey, **even if all 87 residents who did not respond are in fact not bothered by noise, we still see noise as an issue for 43% of residents living under a half mile away, and 29% of those between a half mile and mile**. The residents living between a quarter and half mile were also the only group to disagree with the community consensus that they were setting a good example; 55% said no, a few more than the number bothered by noise at that distance. (No sound modeling or real-world sound monitoring is reported here; we can likely assume that within that turbine noise occurs along a gradient, with 45-55dB at the closest homes a quarter third of a mile away, 40-45dB fairly common at a half mile, and 30-35dB being a routine level at a mile or so.)

Sleep and health

The survey also asked questions about sleep and health, though here the results are harder to rely on; the basic sleep question asked only whether turbines had woken the respondent in the past year (though a follow-up gathered some rough information on how often it happened), and the health question asked for no details about what the respondent was referring to. The largest sleep impact was noted between a quarter and half mile, where 35% had been wakened, and most of these more than 16 times (the highest category listed). Beyond a half mile, waking dropped to under 10%, and infrequently. The health numbers closely mimicked the sleep ones out to a half mile, but at a half mile to mile, 21% reported health effects (14% if all non-respondents are considered “no”), far more than the sleep numbers.

It’s worth noting that **among those living the closest – within a quarter mile of turbines – while noise was noted as a problem for just under half, sleep and health effects were reported by only 11%**. And, for good measure, a surprising number of folks (7% overall) reported *positive* health effects from the turbines, though again, no suggestion is offered as to what these may have been; just as many people at a half mile to mile reported positive as negative health effects.

How many people are we really talking about?

As in many such situations, while the percentages of noise problems within a half mile are striking, the numbers represent relatively few people; about three quarters of township residents live a mile or more from turbines, and only 13% within a half mile. Thus, any survey in a small town can be critiqued by noting that (e.g., using the Lincoln numbers) only 14 people reported being woken, or only 32 homeowners had issues with the noise levels. Do we really want to bring America’s renewable energy future to a grinding halt because of a few dozen people?

But such critiques miss the message that's contained in these surveys. No one is suggesting that ten people being woken up within a half mile, even if it happens regularly, is reason enough to halt all wind energy construction. But surveys like this one, and others with similar results, **highlight with stark clarity that living with wind turbines is dramatically different within a mile, and especially within a half mile,** than it is at larger distances. This survey, with its remarkable response rate and done over a decade ago, is a clear harbinger of the road we've continued to travel on, and the push-back that has only grown as more projects are built closer to homes.

Both sides in the debate use surveys like this to make their points. Anti-wind groups highlight the high, if vague, health numbers, while industry groups point to community-wide approval and the small numbers of people for whom the turbines create problems. We need to step back and consider whether, in some types of communities, larger setbacks would make more sense. Larger setbacks – say, a mile, to move into the zone where impacts dropped dramatically here – would certainly mean that in some towns, it would be more difficult to build. But if there are provisions to allow closer siting to residents who don't mind hearing turbines regularly, then it's quite possible that projects could proceed; in Lincoln Township, 56% of those in the half mile to mile range said they'd be willing to host a turbine²³. If enough landowners can't be found to host turbines closer to their homes, then we are probably looking at a community where the long-term prospects are dim, with disgruntled landowners and riled up neighbors making things difficult for this project, and for future projects in the region.

Other surveys are not as solid as this one, but **every survey that I have come across in a town where turbines are operating suggest similar rates of dissatisfaction with the noise of turbines among those living within a half mile to mile, with roughly half of those within a half mile and 20-30% of those a half mile to mile reporting that noise is a problem for them.** *(That said, it's rare to bother to do a survey about turbine noise in a town where there have been few complaints; I'd love to see such surveys done on a much more regular basis, so we get a better idea of the range of dissatisfaction across a wider spectrum of wind projects.)*

Jonesburg, Wisconsin, 2009

A 2009 survey of those within a half mile or a bit more of turbines²⁴ in the Jonesburg, WI area found **exactly 50% saying noise is a problem** (with just a 46% response rate, this represents a minimum of a 23% negative response, still a significant minority). Half of those noting problems with noise said their sleep is disrupted at least once a week. Among the 219 local residents who completed the survey, 23 were hosting turbines, 6 of whom said if they could turn back the clock, they'd choose not to sign the contract. 62% felt that setbacks should be a half mile or more, while 22% supported the current state siting policy of 1000 foot setbacks.

Complaint rates in Vinalhaven, Mars Hill, Falmouth

And while lacking formal surveys of annoyance, **generalized complaint rates in three towns with significant noise issues fit this picture of higher rates of significant noise annoyance than we'd like to see.** In Vinalhaven, ME, residents in 5 of the 15 year-round homes within a half mile or so of the turbines filed formal noise complaints, with several others speaking

of moderate annoyance while learning to live with it. In Falmouth, MA, 45 families have taken issue with the noise; 16 of 59 homes (27%) within a half mile south of the turbines have filed formal reports with the health department, and 11 of 49 homes (18%) the same distance to the west have done the same, while a neighborhood survey²⁵ to the west found that 21% of a larger sample of 75 homeowners reported effects on health and well-being.

In Mars Hill, ME, which likely represents a worst-case “Altamont of noise issues” situation (turbines on ridge above homes, plus a permit allowing turbines to run at 5dB above state noise limits), a survey of health effects²⁶ found that 82% reported new or worsened sleep disturbance (18 of the 22 adults surveyed; these 18 represent 55% of the adult population within 3500 feet of the turbines), with chronic headaches occurring for the first time in 32% of study subjects (representing at least 21% of total residents). Stress was reported by 59% of respondents, and depression for the first time in 45% (representing a minimum of 39% and 24% of all residents, respectively).

Waterloo Wind Farm, South Australia, 2011-12

Perhaps the most striking of recent surveys took place among residents near the Waterloo Wind Farm in South Australia. A 2011 survey was done by a masters degree student, Zhenhua (Frank) Wang, and only a briefing paper summarizing the results²⁷ has appeared publicly; the author was quoted²⁸ as saying he was concerned about the summary being leaked and would not release the full results until it received academic peer-review. The survey was just one aspect of Wang’s thesis, which examines the growth of wind power, public reactions, and the current effectiveness of South Australia’s environmental noise guidelines; it’s unclear whether the thesis is indeed complete, or to what degree Wang or the University are now trying to avoid being pulled into the public debate over wind farm noise; in any case, no further details have been forthcoming. In July 2012, a local individual replicated the survey, in an attempt to fill in the data gap left by the lack of full results from Wang’s study. The surveys should both be considered along with the informal surveys noted above, rather than as solid academic research; the results are similar enough that they bear consideration, whatever the fate of Wang’s original policy-oriented research. Adding to the mix is a survey of the wider community by Waterloo’s owner, which has some balancing, yet also provocative, results.

Delivered to all 75 households within 5km (3 miles) of Waterloo Wind Farm turbines, both surveys had greater than 50% response rates, and as explained above, I’ll assess the results both as presented, and conservatively “downgraded” as a hedge against self-selection bias by presuming that all non-respondents are not affected. American readers will note with surprise that this study finds high noise annoyance at distances far beyond those usually reported in here; I don’t know enough about the situation down under, but **while noise complaints are exceedingly rare in the U.S. beyond a mile or so, it seems far more common to hear of noise issues at well over 2km (1.25miles) in Australia and New Zealand**. Public planning there includes consideration of effects on “rural amenity,” which may open the door to lodging complaints when noise is distant or relatively rare, situations in which Americans may feel that resistance is futile. The turbines at Waterloo are on ridges above rural valleys, which can more often lead to calm conditions at neighboring homes while the

wind is strong at the turbines, as well as, in some places, funneling sound along valleys.

Noise annoyance

Wang found²⁹ that 34 of 48 respondents (71%) reported being moderately (n=17, 35%), very (n=9, 19%), or slightly (n=8) affected by wind farm noise; this high negative response was widely noted among anti-wind activists. Wang's summary noted that this 54% "moderate or very" negative response was significantly higher than that reported in the Pedersen, et al studies. Using the aforementioned extreme conservative assumption, Wang's study suggests that **at least 45% of the 75 households within 5km are affected by wind farm noise, with 12% very affected and a further 23% moderately affected; this conforms fairly closely to AEI's interpretation of the Pedersen work, adjusted to consider rural responses separate from more populated areas**³⁰. In plain terms, the most conservative reading of this data tells us that over a third of those hearing the turbines even occasionally are bothered to a substantial degree by the noise.

Sleep and health effects

Wang further found that of those reporting being affected by noise, 38% said they had health effects, primarily sleep disruption and headaches; this represents 13 households, or 27% of his respondents, or 18% of the 75 households in the area.

Unfortunately, many of the websites spreading the news of this briefing paper not only presumed that the survey was the primary content of a completed masters' thesis (one they're convinced was eventually "buried" by the university), but also sported headlines claiming that the survey found that "Wind Turbine Syndrome" is occurring in 70% of wind farm neighbors; remember that this 70% represents annoyance, rather than health effects, and includes those only slightly annoyed. This is an example of the kind of over-statement that occurs too often, wherein health effects are not clearly separated from annoyance among those discussing wind turbine syndrome. In fact, only **a bit over a third of people who were bothered by noise in this study report any health effects, and the author summarizes these as "mainly related to sleep deprivation and headaches."** Not to downplay the possibility that a quarter (or a fifth, conservatively assessed) of residents within a mile and a half are awakened by turbines, but the sensationalist headlines may well have contributed to the lack of further details from those behind this study.

Follow-up study

The privately-run follow-up study³¹, conducted in the spring of 2012, had a slightly lower response rate within 5km than Wang's, and was also extended to include all 230 residences within 10km (6 miles). Within 5km, it found slightly lower overall noise annoyance, but higher rates of sleep disruption, than did Wang. The Morris survey reports that 56% of those within 5km report some degree of annoyance, with **39% being "seriously" or "moderately" affected by turbine noise** (15% and 24% respectively); this amounts to a minimum of 31% of the 75 homes. And, while Morris did not inquire about generalized health effects, 39% of the total respondents reported sleep disruption (a minimum of 21%, again using the conservative extrapolation).

Lower impacts beyond 5km

Negative responses dropped significantly beyond 5km³². Only 15% of the 52 respondents at 5-10km reported being seriously or moderately affected by noise (n=1, 2%; n=7, 13%); this represents 5% of the 155 homes in this range, again using the conservative extrapolation (which is likely to be more relevant at this range, where noise issues are rare enough that many people would see no point in responding to the survey). Sleep disruption was reported by 21% of those reporting in this range, or 8% of the total population there. Both the sleep and annoyance rates may appear surprisingly high for such distant homes, though the few narrative comments provided suggest that at this distance, most of those reporting issues were dealing with low-frequency noise, which can indeed travel long distances before dropping to inaudibility; vibrating in homes and fences were among the things noted, as well as low clouds and cold nights, both of which enhance sound propagation.

TRUenergy survey³³

A survey by the owner of Waterloo Wind Farm sampled 358 people in the area that is home to three wind farms. As usual in a broad-scale survey, they found that 70% support wind farms, and only 11% are opposed. Yet, **25% of this much larger population said noise is an issue, by far the biggest negative attribute** (only 10% disliked how they look). Even more striking, though only 11% we opposed to wind in the region, 27% would not want a wind farm built on property near them. Bear in mind, this is a population that has experience with wind farm noise.

Cape Vincent, New York, 2009

A survey in Cape Vincent, NY³⁴, also finds relatively low negative reactions to wind turbine noise among residents living about 2 miles (3.2km) from a wind farm on an island in the St. Lawrence River. Here, visual impacts were far more of an issue than sound, though a surprising number did report noise as a problem. 69% do not notice turbine noise, while **16% report being rather or very annoyed by noise**, and another 11% slightly annoyed. Of the 31% who do hear the turbines, about half report being annoyed by the sound at least once a week, most of these daily, while a quarter say they were annoyed at least once a month and another quarter are annoyed less often than that. Applying our routine conservative correction factor, in this location at least 16% of the people living 2 miles from the turbines reported some annoyance, with a minimum of 5% being very annoyed. While these figures represent much lower annoyance rates than among people living within a half-mile or mile, they may seem surprising at two miles. This could be because **this site represents our first survey of response to offshore turbines; the sound is travelling over open water** from the island to these residents along the shoreline of the river.

While again stressing that our understanding of local differences would be well served by seeing more community response surveys in towns where it appears that wind farms are not causing much local controversy, it's hard to look at the consistent findings of the surveys that have taken place without having a better appreciation of the fact that living with turbines is very different within a half mile or so than it is for those living a mile or more away. Where exactly to draw the line that divides "acceptable" from "excessive" noise is the difficult question, and one may vary from town to town, as we'll see in the next section.

Recent recommendations and decisions about wind farm setbacks and noise limits

Wind farm noise first appeared on AEI's radar in May of 2008, when I noticed a flurry of press reports about towns considering larger setback requirements because of questions about noise, and the concerns voiced by developers about how this would limit their ability to build in some areas. That first blog post³⁵ has a sort of innocence; little did I know how deeply I would be pulled into this now-roiling public policy debate. Over the four and a half years since then, those initial questions have led to an increasingly rich body of research, and a diverse range of local ordinances.

In response to both the increasing awareness that significant minorities of people living within earshot of wind farms find the sound objectionable, and the understanding that sound peaks can be notably higher than average sound levels used as regulatory criteria, **noise limit recommendations appear to be shifting lower** in many cases. This can be seen in best practices recommendations from even very mainstream acousticians, as well as in some government recommendations. And, the wide community variability in tolerance for wind turbine noise is clearly reflected in **an increasingly diverse set of local and county ordinances** adopted over the past couple of years.

Professional recommendations

Among mainstream acousticians, David Hessler's 2011 Best Practices Guidelines³⁶, developed for the National Association of Regulatory Utility Commissioners, is a good example of the gradual shift of thinking. In his reading of the annoyance literature, he observes that "the threshold between what it is normally regarded as acceptable noise from a project and what is unacceptable to some is a project sound level falls in a gray area ranging from about 35 to 45 dBA (Ldn)." Citing the classic Pedersen, et al studies, he notes "relatively high annoyance rates of around 20 to 25%" among residents living in areas with project sound of 40-45dB. Bearing the higher peak sound levels in mind, he thus **currently recommends a 24-hour mean (Ldn) sound level of 40dB at residences in most cases**, or 45dB "as long as the number of homes within the 40 to 45 dBA range is relatively small."

He also stresses that for locations with ambient levels over 35dB (which includes most rural locations during the day), it's important to keep turbine noise to no more than 5dB louder than ambient; this is in contrast to many locales where 10dB over ambient is allowed (he also says that "it is important to note that in the particular case of wind turbine noise a 5 dBA increase does not represent the point of inaudibility."³⁷) **Both of these recommendations are based on reported annoyance and complaints at existing wind farms**; while not going all the way to a 30 or 35dBA limit as suggested by some (who may also feel that 5dB over ambient is important in quiet night time conditions as well), this is a notable downward shift from today's regulatory norm of 45-55dB.

Karl Bolin is another mainstream acoustician who is moving toward a somewhat more cautionary stance on wind turbine noise, summarizing annoyance studies as compared to other common community noise sources and concluding that today's 45-50dB turbine noise guidelines may be a bit too high³⁸:

Overall, these comparisons suggest that **guidelines for wind turbine noise in the interval 35–40 dB would correspond to the proportion of annoyed persons comparable to the proportion annoyed by road traffic noise at a typical guideline value.**

Møller and CS Pedersen³⁹ join many of their European colleagues in considering 35dB a "very reasonable limit for wind turbine noise," the same range suggested by TH Pedersen and Nielson, who recommend 33-38dB. As they note, "A limit of 35 dB is used for wind turbines in Sweden for quiet areas... It is also the limit that applies in Denmark in open residential areas (night) and recreational areas (evening, night, and weekend) for industrial noise (but not for wind turbine noise)."

The Danish Society for Occupational and Environmental Medicine (DASAN, Dansk Selskab for Arbejds- og Miljømedicin)⁴⁰ issued a consultation statement⁴¹ in response to 2011 revisions in Denmark's wind turbine regulations that urged a 35dB limit:

A number of original papers and several reviews show that between 10% and 40% of citizens living close to wind turbines feel annoyed or extremely annoyed by the noise, and it is shown that the number of annoyed people rises sharply when the noise exceeds 35 dB...DASAM recommends that the noise limit value is decreased from the current 39 dB (A) so in the future no more than 35 dB is allowed at residences at a wind speed of 8 m/s. It is also recommended to use 35 dB as the noise limit value in noise sensitive land use – today it is covered by the 44 dB noise limit value...Based on present knowledge, this means that less than 10% of citizens living close to wind turbines will be annoyed by the noise.

During 2012, the Massachusetts Departments of Environmental Protection and of Public Health collaborated on a survey of health impacts around wind farms. While concurring with most other previous literature surveys that there was little evidence of direct health effects, and stopping short of making any specific recommendations on noise limits, the section on noise limits identified, as a **"promising practice," Denmark's noise standards of 42-44dBA in sparsely populated areas, and 37-39dBA in residential areas (using ten-minute averages), noting that "these limits are in line with the noise levels that the epidemiological studies connect with insignificant reports of annoyance."**⁴²

The formal recommendation was a bit more murky:

The Panel recommends that noise limits such as those presented in the table above be included as part of a statewide policy regarding new wind turbine installations. In addition, suitable ranges and procedures for cases when the noise levels may be greater than those values should also be considered. The considerations should take into account trade-offs between environmental and health impacts of different energy sources, national and state goals for energy independence, potential extent of impacts, etc.⁴³

In October, 2012, Kenneth Kimmell, commissioner of the Massachusetts Department of Environmental Protection, acknowledged that the uproar around several wind farms in the state has affected how the state considers current siting standards, saying, “All of us have been caught by surprise to some degree to some of the opposition to wind power....I do think that some of our experiences are guiding us to be a little more cautious about where wind turbines are sited.”⁴⁴

Not wanting to fill pages here with redundant information, I point you toward AEI’s Wind Farm Noise 2011 annual report, pages 14-26, for detailed discussion of recommendations from some of the more cautionary acousticians, who generally suggest noise limits of 35dB or less in order to minimize or eliminate substantial negative community response that can be expected as a noise source approaches 10dB louder than background ambient sound levels (rural ambient sound is often 20-25dB at night, and 35-40dB during the day).

In particular, some of these community noise specialists⁴⁵ stress that **noise limits in rural areas require a “normalization” of typical noise standards to adjust for the expectation of more quiet in rural areas** (thanks in part to the lack of the steady-state background noise more common in urban and suburban settings). In practice, and as applied by the EPA in the past, this would lead to a 10-20dB downward adjustment of acceptable noise levels in rural areas (often 10dB for rural setting, 5dB for a new or unfamiliar noise source, and sometimes 5dB for an impulsive source). As compared to fairly common noise limits of 55dB day/45dB night, if all these corrections were applied, it would result in noise limits of 35dB; if just the rural correction were applied, it would result in limits of 45dB day/35dB night. One early observation along these lines⁴⁶ suggests “the EPA normalization factor of +10dB for quiet rural settings is justified and needed not on the basis of the background sound but on the basis of the community expectations for a quiet environment.”

The wind industry does not appear to have generalized recommendations concerning siting with respect to noise levels; instead, a case-by-case approach is usually advocated. The American Wind Energy Siting Handbook⁴⁷ does not contain any specific setback or noise recommendations. It references a DOE Wind Energy Guide for County Commissioners⁴⁸ that cites several “wind myths and facts” documents from 2005 to address noise concerns. These older documents predate many of the more substantial siting and annoyance issues in small towns over the past several years. As noted earlier, the American Wind Energy Association’s 2011 Turbine Noise Fact Sheet⁴⁹ suggests that noise will be 35-45dB at 350m (1150ft/.22mi); **many wind developers consider setbacks in the 1000-1200 foot range to be standard operating procedure, with setbacks of up to 1400-1800 feet sometimes being acceptable.** It appears to be rare for wind companies to readily accept setbacks of much over a third of a mile; in the project sound contour maps included above, individual turbines are carefully sited in order to keep noise levels at all homes within local limits. Without any clear statements of current recommendations, I think it’s fair to say that the industry norm (or certainly preference) is setbacks of a quarter to half mile, or noise limits of 45-55dB.

Wind historian encourages building where noise is unlikely to be an issue

One of the wind industry's longtime champions, historian Robert Righter, has become much more sensitive to noise concerns, as well. This year, the University of Oklahoma Press published his second book-length history of the industry, *Windfall: Wind Energy In America Today*.⁵⁰ (not to be confused with an anti-wind documentary film with the same title)

I've summarized his thoughts both on AEI's blog⁵¹ and for Renewable Energy World⁵², and encourage you to read the full review, and indeed, the book. In brief, Righter is a strong proponent of wind energy, past, present, and future. The book is wide-ranging, covering all aspects of the industry's growth and current increasing role in our energy mix with enthusiasm and optimism. But he spends chunks of three chapters addressing the increasing problems caused by wind farm noise in rural communities, chides developers for not building farther from unwilling neighbors, and says that new development should be focused on the remote high plains, rather than more densely populated rural landscapes in the upper midwest and northeast. While not ruling out wind farms in the latter areas, he calls for far more sensitivity to the quality of life concerns of residents.

Righter stresses the need to set noise standards based on quiet night time conditions, "for a wind turbine should not be allowed to invade a home and rob residents of their peace of mind." He says, "When I first started studying the NIMBY response to turbines I was convinced that viewshed issues were at the heart of people's response. Now I realize that the noise effects are more significant, particularly because residents do not anticipate such strong reactions until the turbines are up and running – by which time, of course, it is almost impossible to perform meaningful mitigation."

As a bottom line, and despite his support for the industry and belief that we may learn to appreciate a landscape with more turbines, Righter calls strongly for new development to proceed in ways that minimize or eliminate intra-community conflict.

"In the final analysis, we can best address the NIMBY response by building wind turbines where they are wanted...and where they do not overlap with other land use options. Conversely, wind developers should give serious consideration to *not* insisting on raising turbines where they are not wanted...Unlike Europe, our nation has land; there are vast areas of the United States that have excellent wind resources and welcome the wind turbines"

Local, county and state ordinances: one size no longer fits all

Over the past couple of years, **towns and counties across the US, and Australian states, have adopted new wind farm siting standards that reflect a growing diversity in local tolerance for wind farm noise.** While in some cases, factors other than noise (including visual impacts and general aesthetics of place) contribute to the decisions, it appears to me that when broader aesthetic considerations are the primary driver, localities are more apt to simply ban industrial wind development altogether. In the UK, the past year has seen an especially dramatic move toward such local bans or denials of permits primarily on local

aesthetic concerns. In March, a UK High Court ruling affirmed that local councils have the right to deny wind farm applications on the basis of protecting “character and appearance” of rural landscapes⁵³. A few towns in Maine and Vermont have followed suit, as did at least one in Michigan.⁵⁴ When we look at the deliberations that take place in county commissions and local planning departments or wind ordinance committees, it’s clear that noise is often the central concern, especially in places where the final decision involves setbacks of a mile or less (turbines are still very prominent visually at a mile). What follows is a **sampling of the range of standards approved over the past couple of years.**

Status quo is fine with us; we don’t mind hearing turbines

Connecticut (2012 draft of state standards)

1.1x turbine height to property line, 61dBA day/51dBA night at homes

Woodford County, IL (Feb 2012)

4x turbine height to non-participating homes (had been 750 ft)

Wells County, IL (Nov 2012)

1200ft to home/440ft to property line; 50dB

Boone County, IL (ongoing late 2012; couldn't reach decision before new board elections)

Planning, Zoning and Building Committee recommended 2000 ft; Regional Planning Commission rejected that proposal.

Current discussion is in the 1200-1500 foot range

October hearing, company said they could live with 1400

November hearing, landowner rep said 1200 would make it hard to proceed.

Farmington, ME (2012)

60dB at property line

Palmyra, MI (2011)

45dB; planning board rescinded a previous reduction to 40dB after developer said it would likely prohibit construction in town

Gratiot County, MI

1000 ft to home / 1.5 hub height to property line; 55dB with louder OK in high winds (Gratiot County Wind Project, Michigan’s largest, went online June 2012)

Carbon County, WY (Oct 2012)

1000 feet

Antrim, NY (Nov 2011)

Voted down an ordinance that would have required setbacks of 6x turbine height (1800-2400 feet) and night noise limit of 40dB or ambient+5, whichever is less. nbAs the signs around town said, “A No vote is is a Yes for Wind!”

Exclusionary/extremely precautionary; we don't want to hear turbines

Outright bans are the most extreme response, of course, as noted above. Meanwhile, some communities approve ordinances that are **designed to keep turbines far enough away to be very rarely heard**; in some situations, such large setbacks effectively preclude development in that town. Many such ordinances include provisions allowing wind developers to obtain **easements from landowners living closer to the turbines**; this approach protects the soundscape of citizens who don't wish to hear turbines, while providing an opening for developers to negotiate mutually agreeable contracts with neighbors in addition to turbine hosts. (While such ordinances provide only a potential opening, we should bear in mind that most surveys suggest that up to half or more of people living within a mile of wind farms don't mind the noise; this provides a realistic possibility that enough good neighbor agreements could be obtained to proceed, at least sometimes.)

Peru, ME (Nov 2012)

1.5 miles from property line; 35dBA day/25dBA night

Selectmen had initially voted this down, and the wind committee chair preferred 1 mile; 40/35dB.

"I am as much against wind power as anyone on this committee," Committee Chairman Jim Pulsifer said, but, "I have a problem with the absurdity of this ordinance." (note: he felt the permanent sound monitoring provision and decommissioning bond would be enough to deter companies without inviting a challenge) Committee member Mike Breau responded that they were all afraid of being sued. "No one wants to be sued, but we have a right to protect our people," he said. "Five years ago our limits wouldn't have been defensible, but now they are defensible because we have more data. If you look at all of the data out there, it is defensible. We are on a learning curve. What existing sites are telling us is their setbacks were too low and their noise limits were too high."⁵⁵

Middletown, RI (Sept 2012)

30dB; no shadow flicker on neighboring properties (revised from "minimize")

Sometimes, a setback that would be exclusionary elsewhere because of limited room to build is instead a strongly precautionary provision because there is plenty of open space. Three such decisions were made in the US in 2011.

Coconino County, AZ (Feb 2011)

2 mile setback (the Perrin Ranch Wind Energy Center plan had included some turbines around a mile from homes; the project proceeded under the tighter restrictions)

Lights are triggered by aircraft radar; County wanted a property value guarantee as the same company had implemented in an Illinois project, but it would be unenforceable in AZ

County Supervisor Carl Taylor: "My hope is that given the control of the lights and the removal of these things to where they are way out of range in terms of sound disturbance, that people will pretty rapidly say 'no big deal.' That's my hope."

Umatilla County, OR (June 2011)

2 miles from non-participating homes; landowners allowed to waive the limit and allow closer siting.

Upon appeal, the state Land Use Board of Appeals did not object to the 2-mile limit, but sent the ordinance back to the county because it allowed landowners themselves to waive the setback limit; individuals should not have the legal right to waive a county rule. So, the county re-wrote the ordinance to use their standard variance process, in which a landowner can request a variance and the county then chooses whether to grant it. It appears that the court filings of these revised provisions are still in process in late 2012

Caratunk, ME (2011)

1.5 miles or more from property line; formula based on number and size of turbines

The rules are restrictive, but there are still places in Caratunk where development could be possible

Likewise, the recent more precautionary standards from Australia belong in this category as well, I think. My impression is that they don't preclude development, because there is plenty of open space, but I have not seen clear indications of new projects moving forward since these rules were imposed. (I'm not really looking that hard at Australia, though....)

Victoria, Australia (2011)

2km from homes

New South Wales (Mar 2012 draft; no final decision yet)

2km from homes, or obtain waiver from any homeowners closer

OR

Developer can engage in a "gateway" process to obtain a government-issued waiver from the 2km setback. It appears that projects obtaining "gateway" waivers would still need to meet a 35dBA limit (or ambient+5, whichever is greater) at homes.

South Australia

35dBA in areas "primarily intended for rural living"

40dBA in other areas

Landowners can agree to allow higher sound levels

I'm not sure whether the **recent decisions in the UK to adopt 2km (1.25 mi) setbacks from homes** belongs are extremely precautionary or exclusionary. Since outright bans and denials of permits are increasingly common there, I suspect that the places that adopt a setback standard may have suitable sites for development using these setbacks. Among the places adopting the 2km standard in recent years are South Cambridgeshire and Lincolnshire.

*Seeking middle ground:
making room for wind, but keeping it at a more comfortable distance*

Many of these ordinances seem to center on the range of a **half to three quarters of a mile, with a few stretching to a mile** (reminder: a half mile is 2640 feet; three quarters of a mile is 3960 feet). Several include waivers to allow closer siting to willing neighbors. All involved extended community deliberation, usually including a committee appointed to come up with a plan for approval by selectmen, county commissioners, or town-wide vote.

Riga, MI (Nov 2011)
45dBA day, 40dBA night

Claybanks, MI (2011)
3000 feet from non-participating property line; 40dBA
(more problematic are participating landowner limits of 1500 feet/47dBA, apparently without waiver option)

Rumford, ME (Nov 2011; passed 1137-465)
4000 feet to property line; 50dB day/40dB night. Mitigation Waiver agreements allow closer siting.

This one's especially interesting, as it was a "third time's the charm" decision. An initial 1-mile proposal was voted down for being too stringent, while a second plan that allowed 45dB at night lost for not being protective enough.

Sumner, ME (May 2012)
1 mile from neighboring property, with easements for closer siting
(This proposal was framed locally as requiring the wind developer to reach agreements with all landowners within a mile of a tower; passed by a 2-1 margin among local voters)
Industrial Wind Ordinance Committee Chairwoman Kathy Emory: "The setback of 1 mile may still be too much for some and not nearly enough for others. It is the opinion of the IWOC and is supported by significant research as well as the setback utilized by at least 15 other towns in the State of Maine who have enacted ordinances that a 1 mile setback is adequate and protects all."

Dixfield, ME (Nov 2012; passed 651-622)
4000 feet from property lines; follow state noise limits of 55dBA day/35dBA night
This was the *pro-wind* proposal in town; if the vote had failed, they would have drafted an outright ban. "Basically, it comes down to this vote," Town Manager Eugene Skibitsky said. "If you're in favor of wind power, vote yes. If you're not in favor of wind power, vote no." He favors it as "a great opportunity to stabilize the tax base"⁵⁶

Meanwhile, setbacks that might be considered middle-ground proposals in some more wide-open regions are effectively exclusionary in towns where there is not enough room (especially if they don't include waiver options)

Frankfort, ME (Nov 2011; passed 244-222)

1 mile from property line; 45dBA day/32dBA night (both 10dB lower than state standards)

But: this is the only land-use rule in town, so it has been challenged in court by landowners who want to host turbines⁵⁷; I cannot find any press coverage to confirm how the civil suit against the town is progressing. The developer had asked for 1000 feet and state noise limits; it appears that in this town, at least for the proposed project, the ordinance was designed to be exclusionary.

At a local meeting on the proposal, Josh Dickson, who served on the committee, said: “At the end of the day, this is research. It’s not perfect. Neither are we. We did the best we can. The decision will be up to you guys, not us.”⁵⁸ (After the meeting, the developer and a citizen perfectly encapsulated the state of much of the dialogue on these issues, engaging in a shouting match in which each screamed that the other was a liar....)

Goodhue County, MN (2011)

10 rotor diameters (about a half mile)

National Wind (the developer) challenged this as unjustifiably stricter than state rules. PUC ruled that 6 rotor diameters (about 1600 feet) should be the standard, but told company to engage in a good-faith effort to negotiate agreements with other landowners within the county’s setback area (note: not a requirement that they succeed in obtaining agreements); 200 non-participating landowners were later offered \$10,750 “good neighbor” payments. A June 2012 court ruling denied an appeal of the PUC decision, saying that the county did not meet the “good cause” threshold for superseding state laws, and (strangely, in my view) deemed the 10 rotor setback a “zero-exposure standard.” The project is currently hung up by troubles obtaining state wildlife permits, as well as PTC uncertainties.⁵⁹

Cape Vincent, NY (Aug 2012)

6x total height to residences (about a half mile)

45dBA daytime (7am-7pm), 40dBA evening (7pm-10pm), 35dBA night

Plus penalties (reduce above limits): 5dB for “steady pure tone”, 7dB for “impulsive noises”, and 12dB for “highly impulsive noises”

BP (local developer) proposed “reasonable” guidelines of quarter mile (1320 feet) setbacks, noting that this “exceeds industry standards”; New York State allows localities to supersede state rules only under a “reasonableness” standard. BP is moving to obtain approval for this project via a state “Title X” process that bypasses local regulations.

Several towns that already host some turbines have gone back to the drawing board to adopt more precautionary siting standards, which fall variously in the middle-ground and precautionary/exclusionary categories.

Argyle, Nova Scotia (July 2012)

1000 meters (3280 feet, .62 mile)

Previous standard were as little as 242m, depending on turbine size; an earlier wind farm in this town at Pubnico Point had raised some serious noise issues (one family 330m away moved out; the developer bought the house and resold it). Warden Aldric d'Entremont says they council had little information to go by when they approved the original setback law: "I've been saying for a long time now, (that) 300 metres, like we have in Pubnico, is not far enough. If I had to do it over again I wouldn't do it at 300 metres." When asked by a reporter if 1000 meters would be enough, he said, "Most people think so."⁶⁰

Woodstock, ME (in process late 2012, aiming for March town meeting vote)

1.25 from property lines; 45dB day/32dB night (both 10dB lower than state standards)

A 10-turbine wind farm in town, built under state noise regs – and no closer than three-quarters of a mile to any home – triggered noise complaints from around half of the people living within a mile and a half.⁶¹ Wind Ordinance Committee member Charlie Reiss said the group tried to find the right balance that would make future projects tolerable for neighbors without creating restrictions so severe that the projects would be impossible to build. The committee will continue meeting and making adjustments to the proposal, in anticipation of the town meeting vote in March.

Freedom, ME (Draft May 2012, moving toward vote in early 2013)

13x turbine height from property line (400ft turbine=5200feet)

Those supporting more wind development in town favor a 4000 foot setback (4000 feet was also the pro-wind position in Dixfield, above)

A small wind farm was built in Freedom in 2008, with no local regulations in effect. Several families from 1000-3000 feet, and a few out to a mile, have complained of the noise, though they did not raise the type of ruckus that has occurred in some other communities. But when the town decided to write a wind ordinance, it's striking to me that those strongly in favor of more wind development are calling for 4000-foot setbacks, which would still allow some buildable locations in town.

Planning Board Chair Bill Pickford says, "We had all the sides. I thought we brought in as many people as possible. There are people in town who believe it's perhaps too strict, but it seems to be line with what every other town is doing," he said. "That's the norm for every other town that's adopted something, so I don't think we're out of whack here."⁶²

Of course, **not every town with a wind farm decides that new wind development should be at a greater distance.** **In the midwest and west, many wind projects are developed in stages, or multiple projects are built in the same region, and it's rare that later projects face more stringent siting standards than the earlier one** (which is not to say

there's no local opposition to expansion, just that overall local sentiment doesn't shift to the point that more stringent standards are developed). The Sweetwater, TX, region is a prime example; in Utah, the Milford Wind project has initiated plans for the third phase of development⁶³, after the first two phases went online in 2009 and 2011.

A word of thanks to local public servants



Photo by MacKenzie Burger, The Bay City Times

I've often been impressed by the diligence and hard work of the county commissioners, boards of selectmen, and wind ordinance committees that are charged with regulating wind development in a way that makes sense for the people in their communities. They sit through hours of meetings and read hundreds of pages of often conflicting information, and then do their best to represent their friends and neighbors in a reasonable way. A couple of the summaries above include comments from decision-makers that give a sense of the humility and diligence with which the best of them go at it. One more example, from Michigan, captures a bit more of the dynamic⁶⁴:

"This was the toughest decision they had to make, and hopefully there won't be anymore like this," Township Supervisor Dave Schabel said. "It's heavy pressure, does everyone agree with it, no, but they did the best they could."

Commission members visited wind turbines in Ubly, Pigeon and Gratiot Township. "They studied it thoroughly," said John McQuillan, Merritt Township attorney. "That's why the Planning Commission is appointed to make this decision."

Dee VanDenBoom, Merritt Township resident, was disappointed with the decision but is hoping the community can move forward.

"We're peacemakers," VanDenBoom said. "I hope that people can come together as friends and neighbors again."

Turbine sound: low frequency, propagation, peaks & averages

See Appendix A for full research review, published online December 31, 2011

As regular readers will know, AEI's wind farm coverage has focused primarily on the ways that nearby neighbors respond to the audible noise from wind turbines, with far less emphasis on infrasound. However, given the ongoing public dialogue about the contribution of infrasound and low-frequency sound to the annoyance, sleep disruption, or health effects reported by some wind farm neighbors, I do like to keep abreast of research into the lower end of the sound spectrum. In an Appendix, you can read **detailed summaries of several key papers, including close reading of work from both mainstream and more cautionary acousticians, which may help you to understand the subtleties of our current state of understanding in a new and clearer way.** Many of these papers go beyond strictly addressing low-frequency sound, and offer useful insights into other aspects of wind turbine noise. Here, I'll offer just a quick run-through of what I see as the most important themes from this research.

Variability of wind turbine sound

As I've studied the literature and talked with both neighbors and project planners, **I've become increasingly convinced that a primary driver of complaints about wind turbine noise is its extreme variability.** To some degree, this aspect has been recognized for years, but recent research suggests that there are some factors regarding variability that are not yet widely recognized.

It's long been known that wind turbine sound triggers higher rates of annoyance than other sources of community noise, such as roads or airports, with turbine sound unpredictability and variability considered the primary driver of this difference. Not only does turbine sound often pulse at once-per-second, making it more attention-grabbing and harder to ignore than a steady background sound, but it comes and goes at all hours of the day and night. This much is common knowledge.

But there are a three other aspects of the variability that are less widely appreciated, all of which likely play a key role in community responses to wind farms. First, and hardest to quantify, is the radically differing **sound quality** of turbines in different situations. While we usually think of wind turbine sound as being a gentle swooshing (at times punctuated by pulses in the swoosh), neighbors often report that turbines make knocking, banging, or tumbling sounds; a widespread description is of sneakers in a clothes drier. At times, palpable waves of lower frequency sounds are said to penetrate into homes, and at times are felt in the body. **These more intrusive sounds are often the most bothersome, and hardest to ignore.** All of these sounds are also potentially associated with times of more air turbulence hitting the turbine blades; the turbulence could be caused by the wakes of nearby turbines, or by times of more turbulent airflow at the wind farm's location. *See pages 46-47 for more on current research into turbulence. If these times of atypical turbine*

noise could be identified and operations curtailed in these conditions, it's possible that the negative community response could be greatly reduced.

Variable turbine source levels

While many sound models, especially those used to generate project-specific sound contour maps, base their propagation modeling on relatively worst-case conditions, such as higher winds aloft, sound-reflecting air layers, or frozen, bare ground, these propagation models all start with the **turbine manufacturer's rated sound power level** for the turbines being used. These sound power ratings are based on idealized smooth winds and new equipment, often tested in laboratory conditions.

Once equipment is in the field, of course, things get less ideal in several ways. As noted above, wind flowing into turbines is not always smooth and consistent; inflow turbulence tends to create increased low frequency sound as well as unpredictable bursts of other sounds/noise. In addition, turbine blades gradually become slightly worn, with small pocks and pits that can interfere with the smooth flow of air around the blades and create more turbulence (and noise) on the trailing edges of the blades. This is part of normal wear and aging of turbines; routine maintenance includes monitoring for such surface imperfections, and doing fills and resurfacing as needed. But inevitably, many turbines in the field will be operating at less than the peak aerodynamic efficiency at which they were initially tested, and the source sound levels of individual turbines will indeed vary to some degree. And because of the way that sound drops by 3-6dB for each doubling of distance, **an increase in source sound level of a few decibels can mean that sound levels are doubled at any given distance, or don't reach a threshold of interest (e.g., the regulatory limit) for up to twice as far.**

Surprisingly, very little study appears to have taken place to quantify just how much variation in turbine sound levels there may be in practice. For most wind farm operators, the primary reason for this ongoing maintenance to keep airflow near its designed efficiency is to minimize power losses and loads and stresses on blades, which can then propagate into the internal machinery; small changes in turbine sound levels is not generally something they attend to—perhaps in part because few projects are subject to long-term sound monitoring, with pre-project sound models often being considered the last word on project sound.

A recent study begins to rectify the situation. Møller and CS Pedersen⁶⁵ **measured the actual sound power levels of nine large turbines, and these field measurements found that individual turbines actually had significantly varied sound output.** They then modeled propagation from their individually measured turbines out to the point that turbine sound would drop below 35dB (they chose this threshold because it's the level required in quiet areas of Sweden, and it's the level at which Pedersen-Waye found annoyance begin to spike beyond 5-10%). Because the nine turbines had distinctly different initial (source) sound levels, **the variation in distance was stunning**, with this quiet sound level reached at distances ranging from 629m (2063ft) to 1227m (4024ft). When their models included

cylindrical spreading at greater distances and a sound-channeling layer (as discussed below, see p42-43), sound propagated more than twice as far before dropping to similar levels⁶⁶.

Clearly, replication of the Møller and Pedersen study would be a useful direction for further research. It would be very helpful to know how much the rated sound power levels of new turbines tends to increase over time; in addition, doing field measurements of sound levels around turbines that have been individually would help test the ways any such differences in turbine sound levels actually affect nearby residents' received levels.

Average and peak sound levels:

How a project can be in compliance and sound like it's too loud

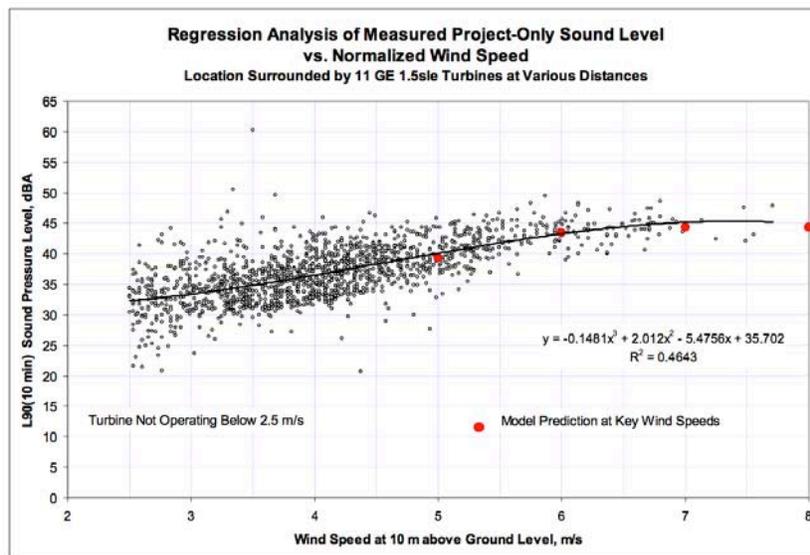
Two other papers in Appendix A discuss a consequence of source level and propagation variability that deserves far more widespread appreciation: that **actual on-the-ground sound levels will vary greatly, and in particular, will peak at up to 20dB above the long-term average that is generally used as a regulatory criterion**. This point is made most clearly by the decidedly mainstream acoustic consultant David Hessler, in a Best Practices Guidelines paper written under the auspices of the National Association of Regulatory Utility Commissioners⁶⁷, and is seconded by Australian Robert Thorne⁶⁸, whose work often focuses on human responses to moderate noise. The likelihood of peak sound levels being higher than regulatory criteria based on averages is a fact that needs to be communicated more clearly, both to help create realistic expectations, and because this may be relevant to the choice of what average sound level to aim for.

This little-appreciated factor plays into noise complaints in a couple ways. For starters, it explains why some wind farm neighbors record sound levels on home sound meters that are well above the regulatory limits, while operators of the local wind farm assert they are operating in compliance. A well-publicized example is the Pinnacle Wind Farm in Keyser, WV⁶⁹, where neighbors often recorded sound levels of 65dB, and sometimes up to 70dB. Knowing that the noise limit was 55dB, they were very upset. Yet **it's entirely plausible that the wind farm was meeting its 55dBA Ldn criteria (average for the entire day and night), while peaks of 65-70dB were balanced by times when the wind wasn't blowing and sound levels were 40dB or less**. In many locations where post-construction complaints triggered sound monitoring, the wind farms were found to be within compliance, or at worst, slightly over the limit on rare occasions.

This points to the second consequence of peaks sounds being well above the average regulatory limits: **noise complaints will tend to be triggered by the peak times**. If the regulatory limit is set relatively high (as at Pinnacle), it's very likely that peak times will occur often enough to cause widespread complaints. And if a lot of homes are right on the edge of even a more modest regulatory limit, the peak times will push sound to levels that are well above local background levels, also triggering complaints. This may be what's happening around the Hardscabble Wind Farm in upstate New York⁷⁰, where over a hundred homes are in the 40-45dB zone of the sound contour map that we saw on page 14.

As Hessler stresses:

It is important to note that the...suggested sound level targets discussed (below) are mean, long-term values and not instantaneous maxima. Wind turbine sound levels naturally vary above and below their mean or average value due to wind and atmospheric conditions and can significantly exceed the mean value at times. Extensive field experience measuring operational projects indicates that sound levels commonly fluctuate by roughly +/- 5 dBA about the mean trend line and that short-lived (10 to 20 minute) **spikes on the order of 15 to 20 dBA above the mean are occasionally observed when atmospheric conditions strongly favor the generation and propagation of noise**.



This graph⁷¹ illustrates Hessler's point about turbine sound variability at one particular location and time. Note that the variability is greatest, and with the highest peak sound levels, at moderate wind speeds. I suspect that the fairly chronic 5-10dB over-average peaks are responsible for much of the community annoyance.

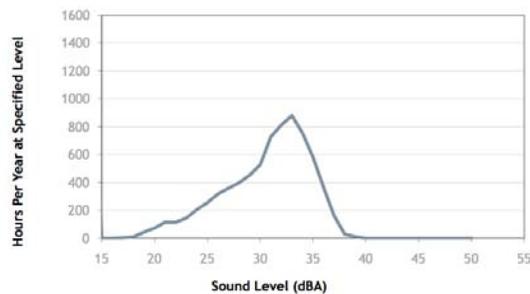
Hessler observes that “the threshold between what it is normally regarded as acceptable noise from a project and what is unacceptable to some is a project sound level falls in a gray area ranging from about 35 to 45 dBA (Ldn).” Citing the classic Pedersen, et al studies, he notes “relatively high annoyance rates of around 20 to 25%” among residents living in areas with project sound of 40-45dB. Bearing the higher peak sound levels in mind, he thus **currently recommends a mean (Ldn) sound level of 40dB at residences in most cases**, or 45dB “as long as the number of homes within the 40 to 45 dBA range is relatively small.”

He also stress that for locations with ambient levels over 35dB (which includes most rural locations during the day), it's important to keep turbine noise to no more than 5dB louder than ambient; this is in contrast to many locales where 10dB over ambient is allowed. Both of these recommendations are based on reported annoyance and complaints at existing wind farms; while not going all the way to a 30 or 35dBA limit as suggested by some, this is a notable downward shift from today's norm of 45dB or more (50-55dB is still quite common).

Australian researcher Robert Thorne agrees that a combination of standard prediction error ranges, magnified over distance, and with the addition of adverse weather effects that either increase turbine source levels or enhance sound propagation, will create peaks of up to 20dB over the predicted levels. He has monitored sound levels at many homes around a mile from wind farms. He notes⁷² that "in 60 seconds the sound character varies regularly by more than 20dB" and that "Sound from wind farms can easily be heard at distances of 2000 meters (1.24 miles); such sound was measured...over the range 29 to 40 dB(A) with conditions of calm to light breeze. The sound was modulating and readily observed and recorded. The sound can be defined as being both unreasonable and a nuisance." (*Ed. note: it's worth noticing these 40dB peaks at over a mile away; most sound modeling will suggest that such levels are common only within a third to half mile or so of turbines; most models are more likely to predict sound to be in the 30-35dB range, the low and middle range of Thorne's, measurements, at a mile.*)

How often will peaks occur?

There are no publicly-available, long-term noise monitoring records from operating wind farms that might give us a sense of how often peak sound levels caused by turbulence or unusually enhanced propagation may occur. But a study by Ken Kalisky gives us a clue about more generalized patterns of wind farm sound variations. Kalisky used meteorological records to model the sound levels likely to be generated by a wind farm over the course of a year, on an hourly basis. He found that **sound levels would be within 5dB of the peak level (in this case, between 35 and 40dB) just 12% of the hours** that turbines were operating⁷³:



Since turbines don't operate all the time, the actual number of hours that turbine sound would approach its normal peaks is even less. A very conservative estimate would be that turbines operate a third of the time; using this adjustment factor, we're down to just 4% of the hours of the year with near-peak sound levels. **That sounds pretty reassuring.**

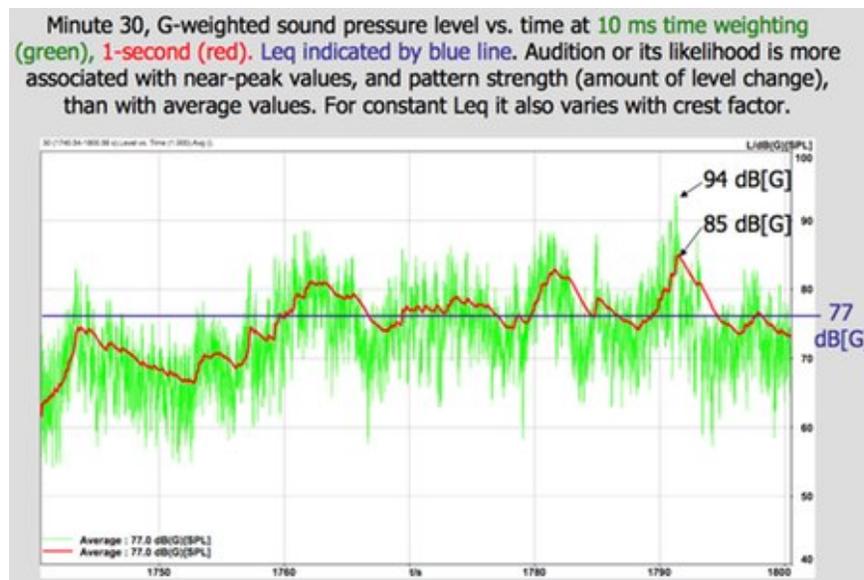
But let's do some math: 4% of the hours in a year could mean 58 days with peak sounds for 6 hours. That's two months of the year. Or, more days with shorter periods of peak sound; say, 116 days (a third of the year) for 3 hours. It's likely that the louder times will cluster seasonally, when high winds or shear conditions or turbulence is more common; this would create longer periods in which the loudest times are a regular occurrence.

It's not hard to see how any of these scenarios could create an experiential sense of fairly chronic peak sound. And this is likely a very conservative estimate; in fact, turbine capacity factors are generally 25-40%; this reflects the percent of power generated as compared to turbines operating at full power 24 hours a day. Much of the time they are turning, turbines operate at below peak power; thus the proportion of hours turbines operate are sure to be higher than the capacity factor. So it's likely that the "peak hours per year" are somewhat higher than what we just figured. Consider as well that Hessler's graph above suggests that in addition to the peak noise times, we'll have fairly common times when wind speeds are moderate, but turbine sounds are prominent, even when not necessarily near their peaks. **All this is not to overstate the severity of these peak noises; indeed, we're talking here about routine turbine operations within regulatory limits.** But it's important to not slip too easily into complacency when we hear that peak sound levels are rare.

Low frequency noise and infrasound

I think it's fair to say that the bottom line continues to be roughly the same as it's been: **wind turbines clearly produce much of their sound energy at lower frequencies, including the low end of the audible spectrum (20-250Hz) and the infrasonic range (below 20Hz,** which is generally below the range humans tend to hear, simply because it has to be very loud to be perceptible). Conventional wisdom continues to be that the infrasound in wind turbine noise is well below human perceptual limits, even of the more sensitive fringe of the population⁷⁴.

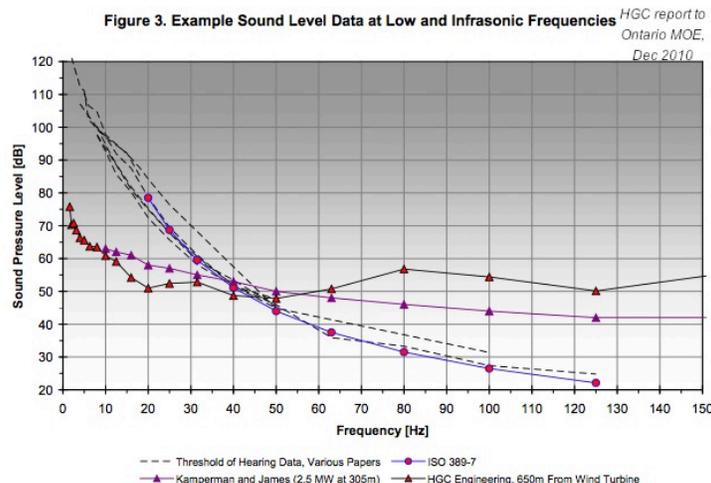
However, some researchers who have looked more closely at sound in areas where complaints were especially severe are becoming more convinced that infrasound may be more of an issue than we've thought.



Bray/James, one minute of sound at a home in Ubly, Michigan, 1500 feet from the nearest turbine in low winds; human perception threshold generally considered to be 95-100dBG

Assessing sound measured in dBG, which includes both audible low-frequency sound and infrasound, and using equipment and filters designed to capture very short time segments – matching the time frame of human auditory responses – Wade Bray and Rick James have recorded **rapid, extreme variation in intensity (high crest factors) and peaks of sound that come very close to standard hearing thresholds**⁷⁵. (Wind farm noise typical distances for homes has been measured at Leq's of 50-80dBG, well below the 95-100dBG hearing threshold. Hearing threshold curves are based on sustained pure tones at specific frequencies; there is some indication that our thresholds for hearing pulses of sound could be lower.) This is fascinating work, although so far data from only two or three sites have been assessed using these techniques; we'll need more field measurements to get a better sense of how common these high peaks are, and the range of intensity of the peaks⁷⁶. Meanwhile, Alec Salt continues to investigate ways that our ears' **outer hair cells (OHC) may respond to much lower intensities of infrasonic sound than our inner hair cells**, which drive actual perception; while intriguing, this line of research is so far coming out of just one lab, and are animal studies (albeit on animals widely used as proxies for human hearing), and the mechanisms by which OHC stimulation might relate to physiological responses still uncertain. These new lines of research are intriguing, and certainly worth pursuing; I look forward to further replication of these findings, and for the metrics and methods to be assessed more widely by the acoustics and auditory physiology communities. Only after this important line of inquiry is more thoroughly investigated will it be widely considered viable as a basis for setting policy.

Meanwhile, whether or not this new line of research succeeds in reframing the infrasound question, **it's widely recognized that low-frequency audible sound is a key factor in annoyance about wind farm noise**, and several recent papers contain some good ways of looking at this. It's important to not conflate infrasound and low-frequency sound; while the former is (always or mostly) imperceptible, the latter is clearly very audible in many situations, and indeed, is the **dominant sound component of wind farm noise at moderate and larger distances**.



Dotted lines show standard average hearing threshold curves, with an ISO standard overlaid on them; the two other curves, marked with triangles, are actual measurements of wind farm noise.

A few things are worth noticing in this graph, from a report on low frequency noise commissioned by the Ontario Ministry of Environment⁷⁷. Most importantly, it shows **lots of easily audible low frequency sound from 50Hz on up**; it's likely that some individuals would be sensitive to the wind farm sound levels shown here at 30-50Hz. Note that even these lower frequencies are not infrasound (which is below 20Hz), but borderline- audible low frequencies. The data here is affirmed by field observations by the report's author of "strong, audible low frequency (but not infrasonic) tones from some turbines." Notice also that this graph affirms that there is indeed a lot of sound in frequencies below 20Hz, the typical human hearing threshold. **Clearly, turbine noise does include infrasound**, though here it is far below the hearing threshold curves for those frequencies.

Also, the two studies of wind farm noise plotted here show **surprisingly little difference** in overall sound levels between 305m/**1000ft** (purple line with triangles) and 650m/**2100ft** (black line with triangles) – this may reflect differences in the local topography or turbine size, or could be a reminder that our sound models (which would suggest that the black line should be routinely 3-6dB below the purple line) are not as reliable as we might wish (due to a confluence of factors, including the source sound levels of turbines varying from the ideal conditions used as a the starting point for models, and the variability of sound propagation due to transient meteorological conditions).

It's quite likely that much of the annoyance reported by neighbors could be triggered by very low frequency, moderately audible noise, which can be more ear-catching when it contains one or more dominant tones, fluctuates rapidly, or contains more intrusive knocking or banging sounds (which are likely caused by air turbulence increasing the sound level of the turbine in irregular patterns). Further, increasing evidence confirms neighbors' reports that **moderate but hard-to-ignore low frequency noise can be more perceptible inside their homes than outside**.

These elements are part of the reason that several of the papers summarized in the Appendix from relatively mainstream perspectives (and which consider infrasound a non- or minimal issue) recommend lower noise limits than the 45-50dB standard commonly used in the US; **you'll see in these papers that 40dBA is becoming a common recommendation** (usually averaged over a full 24-hour period). Most of the more cautionary acousticians tend to recommend 30-35dB (often using a shorter averaging time of ten minutes or less); it's striking to me that the gap between these two perspectives has narrowed considerably in the last year or so.

More distant propagation of low frequencies

Also of particular note are **observations from multiple researchers which are relevant to two key aspects of sound modeling**: **surprisingly high variations in the source sound level** being generated by turbines, and more distant propagation of low-frequencies than is often assumed.

Two of the papers featured in the Appendix, one from mainstream consultants HGC for a report to the Ontario Ministry of Environment⁷⁸, one by Danish researchers Møller and CS Pedersen⁷⁹, stress that lower frequencies appear to drop by more like 3dB per doubling distance (cylindrical spreading), rather than the 6dB (spherical spreading) as with most audible sound, and most dBA sound models. This, combined with atmospheric refraction creating a sound channel with the ground below, can create **much higher sound levels than expected at distances beyond a few hundred meters.** At greater distances, the sound that makes it that far will be mostly low-frequency, and will be at higher levels than typically predicted using spherical spreading models. As Møller and Pedersen note, "Cylindrical propagation may thus explain case stories, where rumbling of wind turbines is claimed to be audible kilometers away."

Several of the papers summarized in the Appendix address the challenges inherent in recording low frequencies. One researcher, David Hessler, maintains that most measurements of low frequency noise around wind farms are little more than records of the noise of wind on the mics. Others point to solutions to this problem, including wind screens designed specifically to protect mics from low frequency contamination, and measuring turbine sounds at times when the recording location is sheltered from wind. And the afore-mentioned Bray/James work suggests that it's important to be attentive to the time period over which you are assessing low-frequency sound. It's worth being aware of these questions as you consider low frequency monitoring data.

One other aspect of low-frequency noise that is noted in several recent papers is that it's quite common that **low frequencies are more noticeable inside a house than outside**, after walls filter out the remaining, faint mid-frequencies. Thus, inside a bedroom, a faintly audible pulse of low-frequency noise can become a subtle yet inescapable presence. Both Thorne⁸⁰ and Ambrose and Rand⁸¹ have measured such noise inside homes. Residents studied by Thorne often report that the low-frequency sound is noticeably worse in their homes than it is outside (Thorne's studies have taken place at 1.5-2km, 5000-6500ft, from turbines). Even more surprising, and frustrating for some residents, "rooms in a residence can and will show significantly different characteristics. What may be inaudible or not perceptible in one room can be easily heard or perceived in another room on the same side of the house."

These are the "hot topics" in noise assessment for wind farms, the current lines of research that are attempting to both make sense of unexpected noise annoyance and to generate practical guidelines for use by regulators. Again, for those of you working more deeply on regulatory issues or community noise responses, I encourage you to read Appendix A on this topic to get a better picture of the current thinking of both mainstream and more cautionary acousticians.

Industry efforts to quiet wind turbines

See Appendix B for full paper, submitted for the proceedings of Renewable Energy World North America, December 2012

As part of my ongoing coverage of wind farm noise issues, I regularly read several trade magazines that cover renewable energy and wind technology topics. In the past year or so, I've seen a marked increase in articles in the trade press about efforts to reduce the noise output of wind turbines. A good example is a July 2011 article in *North American Windpower*:

As the so-called “low-hanging fruit” of land with good wind and transmission access gets used up and wind turbines move closer to residential areas, noise concerns are expected to become more prevalent, according to wind turbine manufacturers.

“It’s on the top of the minds for all manufacturers,” said Paul Thompson, commercial director of Mitsubishi’s wind turbine group, “we’re all doing things to reduce the amount of noise that’s generated.”

GE’s Henrik Stiesdel stressed that wind turbines do “have a noise impact. The main remedy is to ensure that they are not sited too close to dwellings. If that’s not possible because you are in a densely populated area, then we have remedies where we control the power output when conditions are such that noise might be exceeding limits.”

Appendix B of this report contains a wide-ranging paper I wrote for Renewable Energy World North America’s December conference proceedings, detailing a range of quieting techniques and new research initiatives. Here, I’ll touch on the practical effects of these efforts while attempting to be quite brief.

For current projects, there are two primary approaches to reducing noise output of turbines, both of which have been used in projects where neighbors complained, and as part of initial project planning, in order to meet noise standards while building relatively close to homes.

Most widespread is Noise Reduced Operations (NRO) or Noise Reduction Systems (NRS), which lower turbine sound power levels by slowing them down and “feathering” the blades a bit (i.e., tipping them back so that wind flows past them more easily). Nearly all turbine manufacturers have proprietary NRO software and operational settings that can be triggered as needed; settings are usually available to reduce noise to the degree that is desired, from 1dB to 4dB. **Generally, 1-2dB NRO settings don’t reduce electricity production very much (i.e., under 5%), while higher NRO settings can result in 10-25% reductions in power output.**

Recently, turbine manufacturers have been experimenting with serrated trailing edges on turbine blades, either as retrofits where noise has become a problem, or as part of the

initial blade design. Of several different blade modifications being researched, serrations have the most extensive research track record, with **overall dBA noise reductions of 2-8dB** being reported⁸². However, many studies have found that these reductions are frequency-dependent, with reductions in low-frequency noise and increases at higher frequencies (over 2kHz). Serrations may also be less effective at low or moderate wind speeds; in some situations, this can be when neighbors find turbine noise most audible.



Photos by Charlotte Goodhue, Courier-Gazette, Rockland, ME

During its first summer in operation, the three Fox Islands Wind turbines on the island of Vinalhaven, ME, were retrofitted with serrated edges (above) as part of an effort to reduce noise impacts on neighbors, with the hope of achieving a 2-3dB decrease in sound levels. No formal study of the effects has yet been released⁸³, though neighbors report that the serrations seemed to moderate the lower-frequency thumping element of the sound, while slightly increasing the overall whooshing aspects, as the studies summarized in Barrone might suggest. Interestingly, neighbors suggest the lower frequency improvements were most noticeable in low and moderate wind speeds, counter to the research findings.

The use of either serrated blades or NRO may be expected to reduce sound levels by 2-3dB, which is just barely perceptible. However, **a combination of noise-reduction techniques that reduce the sound output by 6dB could double the distance at which turbines are heard at any given level, offering significant relief for nearby neighbors.** For example, instead of homes at 1700 feet hearing 45dB, they would hear 39dB, with sound reaching 45dB only at 3400 feet. So while current techniques are just starting to be perceptible, this line of research could make a difference if we are able to continue building on it. In the meantime, even a 3dB reduction would sound slightly quieter at any distance, and would slightly increase the distance where any given sound level occurs.

Longer-term research on quieter (but longer?) blades

Several lines of research at Sandia National Laboratory and the National Renewable Energy Laboratory, and within the wind industry, offer promises of future noise reductions thanks to improved blade design and wind farm layouts. All of this research is focused on reducing the stresses on turbine blades caused by air turbulence. Sudden changes in wind speed and direction create stresses on blades, and by extension on all the inner components of turbines, and reduce power output significantly. **This “in-flow turbulence” also triggers both increased broadband and pulses of low-frequency noise, and is quite likely responsible for some of the most intrusive knocking, banging, or “sneakers in a**

dryer” sounds that are often reported by wind farm neighbors. While the researchers doing this work are not primarily investigating how turbulence and blade stresses influence noise levels, it’s likely that the acoustics of these dynamics will become an important secondary interest of many in the industry.

One line of research is developing blades that can flexibly respond to differences in wind speed and blade stress along their length. A Sandia NL paper summarized the situation thusly⁸⁴:

“...greatest structural fatigue damage tends to occur during nighttime hours from coherent turbulence that develops in the stable, nocturnal atmospheric boundary layer. Under such conditions, intense vertical wind shear and temperature gradients create resonant flow fields capable of imparting short-period loading and vibrational energy as wind turbine rotor blades pass through regions of organized or coherent turbulence. This energy is subsequently propagated throughout the remainder of the structure...”

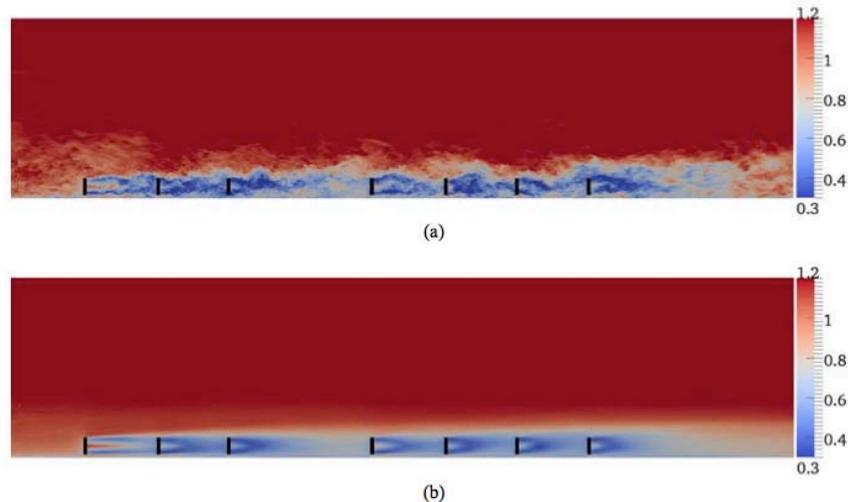
The leading-edge research now underway aims to reduce these load stresses in two ways⁸⁵. First is “passive load mitigation,” including innovative materials (such as carbon fiber as a component in various places within the blade core) and blade geometries (one design reduces loads through a geometric sweep that allows “bend twist coupling” in which blade tips can flex in response to stresses). This is a step forward from simply trying to reduce stress by adjusting the pitch angle (which can only respond to average loads along the blade), but such passive mitigations cannot respond to local load variations as the blade sweeps through turbulent air. That’s where Active Aerodynamic Load Control (AALC) comes in: **sensors along the blade that can instantaneously trigger small flaps along the trailing edge of the blade to relieve transient pressures**.

So far, the primary thrust of this research is to reduce loads on blades (and thus on generators), in large part to facilitate the use of longer blades on larger turbines that can generate more electricity per cost of construction. Often, the benefit is seen as being able to build a bigger turbine that doesn’t make more noise than current ones, rather than in quieting current designs. It’s likely that **these breakthroughs could be applied to smaller (i.e. current-size) turbines as well, in order to allow projects to proceed under local noise limits that are lower than what today’s designs can achieve**. In moving to larger turbines, whether quieter or the same sound output as today’s, we need to bear in mind that larger designs may exacerbate amplitude modulation triggered by wind speed differentials between the top and bottom of the rotor diameter, and may be associated with moderately increased sound levels at low frequencies, which can be the primary noise annoyance at greater distances, especially indoors⁸⁶.

Better understanding of wake turbulence and wind shear

Two related lines of research at Sandia and NREL are also of interest. Again, the primary interest is reducing load stresses, but here, the goal is to learn more about wind flow patterns so to avoid the situations that cause the stresses – and the increased noise – caused by turbulence.

First is the study of **turbine wake interactions**. Turbines work best when the wind entering the blades is consistent, or “laminar.” Behind each turbine, the air is swirled into a tumbling mess, leaving downwind turbines struggling to extract energy from far more turbulent inflow. One recent study⁸⁷ at an existing offshore wind farm found that downwind turbines can produce 60-70% less power than the front row; it’s likely they’re also noisier (and, crucially, noisier than assumed by models based on the sound power level of turbines in an ideal laminar flow). The image below shows (a) instantaneous and (b) time-averaged wind velocity, clearly illustrating that only the front row operates at peak efficiency:



The final area of ongoing research that is likely to pay dividends in noise reduction as well as in power increases is the **study of wind shear in far more detail** than typically found in current wind farm noise modeling and project design. As noted in a recent overview of current research⁸⁸, we must look beyond “the narrow definition of shear (i.e., the change in wind speed with height). Wind direction can also change with height. During the day, when there is strong mixing throughout the lower ABL (atmospheric boundary layer), this change is a few degrees throughout the typical 40m to 120m rotor plane. However, **at night, as turbulent mixing decreases, directional shear can be 20-40 degrees or more**, depending on how much temperature increases with height. Directional shear also has an impact on the power derived from the wind and can impart considerable stress on turbine infrastructure...” Indeed, while vertical shear (which is more apt to be relatively consistent) can increase power output, directional shear (which can change rapidly) generally leads to power losses and increased stresses⁸⁹ (and again, perhaps noise).

For more on operational innovations and this leading edge research that could lead to quieter turbines and wind farm layouts that better minimize wake effects, see Appendix B.

Health Effects

See Appendix C for full research review, published online April 3, 2012

In February of this year, I wrote a column for *Renewable Energy World*⁹⁰ that addressed the recent increase in claims that wind farms are causing negative health effects among nearby neighbors. The column suggested that while many of the symptoms being reported are clearly related to the presence of the turbines and their noise, the relationship between wind farms and health effects may most often (though not always) be an indirect one, as many of the symptoms cropping up are ones that are widely triggered by chronic stress. In recent months, the dialogue around these issues has hardened, with both sides seemingly intent on painting the question in simple black and white—community groups assert that turbines "are making" people sick, while government and industry reports insist that there's "no evidence" that turbines can or do make people sick. **The gulf between the conclusions of formal health impact studies and the experiences of some neighbors has widened to the point that both sides consider the other to be inherently fraudulent.** I suggested that the rigidity of both sides' approach to this subtle and complex issue is likely increasing the stress and anxiety within wind farms communities that may in fact be the actual primary trigger for health reactions.

In an extensive summary of new research that is included as an Appendix here, I took a closer look at the few surveys and studies that have attempted to directly assess the prevalence of health effects around wind farms.

Even as the public becomes increasingly concerned about health effects, with a lot of focus on the role of inaudible infrasound, it's been striking to me to that the researchers investigating health effects – even clearly sympathetic researchers – are not talking about infrasound much at all, and are instead focusing on stress-related symptoms. (Readers of the full Appendix C will see that this applies to researchers including Michael Nissenbaum, Daniel Shepherd, and Carl Phillips.) Drawing from studies done in areas where health concerns have been most widely reported, AEI's review found that **most of the studies find little difference in overall health based on proximity to turbines, though they did find reductions in some specific measures of health, especially sleep quality, and overall local amenity or quality of life.** *(It should be stressed that these studies, using widely-recognized health rating systems, looked at average ratings in the vicinity of wind farms; the data as presented does not clarify whether an increased proportion of individuals – even just, say, 10-15% – closer to turbine reported lower health ratings, while the overall average remained relatively unchanged.)*

And, **where health effects are reported (primarily sleep disruption and stress-related symptoms), those who have been most diligent and open in assessing community responses estimate that health problems – whether direct or indirect – appear to crop up in no more than 5-15% of those living within earshot;** this is a surprisingly small number, considering the central role health effects has taken in the public perception and debate about new wind farms. While we shouldn't discount the impact on these people, it appears that fears of widespread health impacts may be misplaced. Though impacts on even a few,

whether direct or indirect, are certainly a valid consideration in making wind farm siting decisions, it's helpful to have a clearer picture of how widespread the issue may be.

Not too surprisingly, what these researchers are finding contradicts both the "all is well" literature survey findings, as well as the fear that worst-case scenarios – being driven from homes by lack of sleep, headaches, kids struggling in school – are likely to widespread.

The bottom line appears to be that this first wave of research, undertaken by relatively cautionary and empathetic researchers, is finding that just **a small proportion of nearby residents are reporting actual health impacts, though far more report degradation of the overall quality of life and sense of place.** These studies use a diverse range of approaches and criteria, so can't all be directly compared, or compiled to suggest global patterns, but each of them offers a clear window into particular communities' responses to wind farms in their vicinity. As noted earlier, while all of the papers reviewed here come from researchers with much interest in and empathy for reports from affected neighbors, none of them propose inaudible infrasound as the central factor in health effects; the first four papers⁹¹ all focus on stress and sleep factors, and the last two, while including infrasound in their discussions, focus mostly on other factors (one on pre-existing risk factors⁹², and the other⁹³ on pulses in the dBG level, which includes substantial audible low-frequency sound as well as infrasound). In particular, there are indications that people prone to motion sickness may be more sensitive to wind turbine sound (perhaps to the variability of low-frequency content), and that certain pre-existing conditions may be triggered or accentuated by turbine sounds, including susceptibility to migraines and inner-ear-related balance issues.

Hearing the real stories through the noise

I think **it's important to acknowledge a key factor that has hampered the ability of some within both the public and the industry to clearly address the possibility that neighbors have experienced legitimate changes in their health,** whether by direct or indirect means. Many (though not all) of those most vehemently stressing the *potential* for health impacts in areas where wind farms are proposed are fundamentally anti-wind, anti-renewables, and anti-government incentives; health impacts are but one of a litany of arguments they make against new wind farms, and many simply dismiss all their claims as distorted rhetoric. This can too often **blind us to the fact that nearly all of the individuals who are telling us about their *actual* health impacts have no dog in the energy-policy fight;** their personal stories are often compelling and sober accounts of struggling with unexpected and disabling sleep issues, disorientation, and mood disorders. No matter how rare, or common, health effects may be, I'm more interested in understanding what's going on around existing wind farms, than on the fears and opposition being raised in places where wind farms have yet to be built.

In my visits to wind farm communities, while many people spoke about annoyance, occasional sleep disruption, and dramatically changed sense of place, I also met individuals who have clearly faced new health challenges since turbines were built near their homes. I

cannot know whether these health effects have been triggered by the noise itself, by the stress and sleep disruption the noise has caused, or by their own ways of responding to the change in their home place. But I can say that **actually spending time with people who've been dramatically affected makes the magnitude of possible impacts far more real.** Perhaps the saddest was a woman who's changed from an outgoing community member to a shell of her former self, dulled by newly prescribed drugs to control bouts of depression and anxiety. (Two acousticians doing a sound study at her home found themselves, for the first time in 30-year careers, having mental difficulties as they set up their equipment: unable to concentrate, confusion, and disorientation.) Several sleep in their basements to escape subtle (or not so subtle) pulses in their bedrooms, while two have abandoned homes they built themselves, chronically unable to get unbroken sleep; one of these had a heart attack, while speaking at a public meeting on the turbines. In one family, three children have been prescribed sleeping pills. A particularly stark account comes from Mark Cool in Falmouth, MA, as detailed in this October 2012 letter to the local Health Board:

"Wind 1 has been a neighborhood health issue since April of 2010. My last lodged noise complaint was August 29, 2012. I've been potentially exposed to Wind 1 daytime operations roughly 580 days. This means that during 8.4% of Wind 1's potential daytime operations, I've suffered pressure headaches (one bout of vertigo), at my property. I have never experienced these type headaches, nor any vertigo, before April of 2010. A noteworthy fact is that on numerous occasions, I've left my property (exiting the wake effect of Wind 1) and gained relief. I've also noted, that upon returning to my property, all wind direction and velocities being constant, the same symptomatic pressure headache returned. The only change – my spatial relationship to the wind turbine."

It's these sorts of personal stories that lead me to look around my home valley and wonder who among my neighbors I'd feel OK about affecting, should turbines sprout on our ridges.

Much Ado About Nothing?

As mentioned earlier, local regulatory bodies and wind project planners often grapple with the idea that it's impossible to avoid any and all negative impacts. Some people will always be annoyed by new public infrastructure, and some of these will experience increased stress that can trigger health consequences. The question really comes down to how extensive or how severe an impact a community feels is reasonable to expect and accept. Of course, **it's also possible, even probable, that simply keeping turbines a bit farther from non-participating neighbors would solve most or all of the problems.**

Some observers suggest that **if actual, acute symptoms appear in as few as 5-10% of the people living near wind farms, then we may simply be hearing from people who represent the normal baseline rates for conditions like headaches, dizziness, tinnitus, and insomnia.** This is an important question to keep in mind as we move forward and have larger studies⁹⁴ to draw conclusions from.

However, most health effects research and testimonies assess *changes* in health: typically, subjects report symptoms appearing, or increasing, after wind farms began operation, and decreasing when turbines are not operating or the subjects are away from the area. The fact that most of these studies use self-reporting of current health conditions, and retrospective reporting of earlier health status, is considered by some to be a weakness; memories can be distorted by recent upsets about the wind farm. Some of the studies now beginning will be attempting to redress this by doing health surveys before wind farms begin operation, and following up later with the same subjects⁹⁵.

But again, for now, we start where we are, and these initial studies, while not ideal, can be assessed on their merits. The authors generally are quite forthright about their methods, making it relatively easy to see both the strengths and shortcomings of the data we currently have to work with.

Likewise, we should beware of settling too easily into the comfortable thought that health effects are all “simply” indirect consequences of stress. **Even if the vast majority of reported health problems appear to be indirect, stress-mediated effects, it also appears that some people are being directly affected.** Whether these people have a relatively common pre-existing condition (such as motion sensitivity), or are part of the very few on the perceptive fringe of the normal auditory perception curve, so that they actually do hear or sense some of the low-frequency sounds more readily than most, **we need to be careful not to lump all reports into any easy-to-accept framework.** This applies equally to those who seem to imply that all health issues are “merely” psychological, as well as to those who might fear that everyone near turbines will get headaches or vertigo.⁹⁶

We might also bear in mind that **in addition to the sound waves that are the focus of virtually all discussion of community responses and health effects, turbines also create air pressure vortices** that travel in downwind (these are the wakes discussed above). Some of the reported turbine-related symptoms, including pressure in ears or chest, and a general sense of discomfort, could be related to these pressure waves. The only community response researcher to consider them that I am aware of is Bob Thorne⁹⁷, who feels these vortices may contribute to his observed “heightened noise zones,” areas in which noise levels are noticeably higher, often at distances of 1-2km from turbines.

For those with an interest in the health effects research, I highly recommend you take the time to read through the full 26-page summary, included here as Appendix C. There, you’ll find key excerpts from the studies, and detailed analysis of the data presented in each.

AEI has previously summarized most of the larger wind turbine and health literature reviews put together by industry groups and government agencies (including reports from AWEA/CanWEA, Ontario, Oregon, Massachusetts, Minnesota, and the World Health Organization). These can be accessed at AEI’s Wind Farm Noise Resource page: <http://www.acousticecology.org/wind/>

Footnotes and References

¹ Federal agency staff (NOAA, NMFS, DOE, NSF, MMS, NPS; Canadian DFO), state agencies overseeing wind energy (MA, RI, MI), US Navy, Alberta Energy Resources Conservation Board (provincial oil, gas, wind agency), Joint Industry Program (US offshore oil and gas companies), ocean noise, acoustics, and wildlife researchers at institutions worldwide, environmental organizations (including NRDC, Greenpeace, Winter Wildlands Alliance, Ocean Conservation Research), local and county boards of selectmen and commissioners.

² See this October 2012 article, including that sentiment from Duke Energy Renewables: <http://www.michigandaily.com/opinion/22-daily-support-wind-farms-michigan-15>

³ See Michigan Land Use Institute article by Jim Dulzo: <http://www.mlui.org/energy/news-views/news-views-articles/trust-teamwork-keys-to-gratiots-windpower-success.html#.UJBc4mmMVdQ>

⁴ Regarding Falmouth, I met with nearly the entire wind energy team at the Massachusetts Clean Energy Center (MassCEC), which supplied both the turbines and technical expertise to the town. Regarding Vinalhaven, I met with three staff at the Island Institute, a regional non-profit that championed the wind project as a path toward energy independence for the island community; I've also spoken by phone many times with George Baker, head Fox Islands Wind, the small company formed to own the turbines (in order to qualify for key tax credits not available to a non-profit), and I met with the town manager, who is also on the board of Fox Islands Electric Coop.

⁵ For records of this process, see <http://cbuilding.org/falmouthwind>

⁶ See <http://aeinews.org/archives/1848>

⁷ Acoustic Ecology Institute. Wind Farm Noise 2011: Science and policy overview. 2011.

http://www.acousticecology.org/wind/winddocs/AEI_WindFarmNoise2011.pdf

See especially the Appendix which summarizes AEI's presentation to the DOE-funded New England Wind Energy Education Project webinar on noise issues, or see the NEWEEP presentation at <http://aeinews.org/archives/972>

⁸ See O'Neal, Hellweg, Lempeter. Low frequency noise and infrasound from wind turbines. *Noise Control Eng. J.* 59 (2), March-April 2011.

This paper includes Texas field measurements of 1.5 and 2.3MW turbines, from which several things stand out. First is that the sound emissions from the Texas turbines was incredibly consistent: moderate sound output periods were only 2-3dB lower than maximum periods, and in the low-frequency one-third octave bands, the standard deviation in sound levels was under 1dB across six measurement periods.

⁹ See <http://www.acousticecology.org/wind/> for AEI's archive of wind energy reports

¹⁰ This would be consistent with research on such serrated edges; often, lower frequencies are reduced, but mid and higher frequencies increase; the overall dBA rating generally is reduced by up to 2dB. See Appendix section below on "Addressing Wind Farm Noise Concerns" for more detail.

¹¹ See *Island Journal*, 2012.

¹² See <http://bit.ly/SNKLGY> for a Google image search I did on this image in November 2012.

Among other places, I came across this image in a November 10, 2010 Renewable Energy World article Measuring Wind Turbine Noise.

<http://www.renewableenergyworld.com/rea/news/article/2010/11/measuring-wind-turbine-noise>

¹³ http://awea.org/learnabout/publications/upload/Utility-Scale-Wind-Sound-Fact-Sheet_May-2011.pdf

¹⁴ CH2MHill Technical Memorandum. IBR Hardscrabble: Supplemental Acoustical Analysis – Turbine Array Adjustments and a New Residential Structure. December 1, 2009. Page 4.

¹⁵ Iberdrola Renewables. Blue Creek Final Amendment 4/12/2011. Appendix T1c, Figure A1, Noise Contours Participating Residences.

¹⁶ Patriot Renewables. Canton Mountain Wind Project, Maine DEP Site Location of Development Act Permit Application. Section 5: Noise. Page 18.

¹⁷ CH2MHill Memorandum. Acoustical Analysis of the Horse Creek Wind Project. January 27, 2011. Figure 1.

¹⁸ Hessler Associates. Environmental Sound Survey and Noise Impact Assessment, Buckeye Wind Project. Report No. 1819-05=41708-C. March 12, 2009. Issued as Appendix J of Buckeye project Draft Environmental Impact Statement, Volume II, June 22, 2012.

¹⁹ See AEI's Wind Farm Noise 2011 report, along with the 2009 overview, and AEI's other coverage of wind farm noise issues at <http://www.acousticecology.org/wind/>

²⁰ AEI's NEWEEP presentation: <http://aeinews.org/archives/972>

²¹ A milder interpretation of the nocebo holds that people blame turbine noise for things that happen anyway, whether it be sleep issues or headaches; this is somewhat more plausible, though most neighbor reports are quite clear about seeing changes after turbines began operating, and finding relief when they away from the turbines.

²² The full report can be downloaded at http://betterplan.squarespace.com/-health-and-safety/7.%20lincoln_township-full_moratorium_report.pdf

²³ At closer ranges, willingness to host dropped dramatically: In Lincoln Township, after living with turbines for a year, of ten respondents within a quarter mile of a turbine, only 1 said they'd host another one, five said they would not, and four more chose to not provide an answer; only one landowner living that close did not participate in the survey at all. At a quarter to half mile, prospects improved slightly: 9 of 27 landowners (33%) would host a turbine; if the five landowners in this range who didn't fill out a survey all were fine with hosting, then this would increase to 44%.

²⁴ See <http://aeinews.org/archives/465> for more on the Jonesburg survey

²⁵ Craggy Ridge Homeowners Association, Wind Turbine Survey September 2012. 71 of 81 homeowners responded. The survey asked about a range of effects; in addition to those reporting health and well-being effects, larger proportions cited not liking how they look (30%), concerns about property values (64%), and "they don't really impact me personally" (38%)

²⁶ Michael Nissenbaum, Mars Hill Wind Turbine Project Health Effects—Pilot Study. Presentation in Rutland and Montpelier, VT, 2010.

²⁷ Zhenhua Wang, Evaluation of Wind Farm Noise Policies in South Australia: A case study of Waterloo Wind Farm.

²⁸ Article in The Australian, 4/21/12: <http://www.theaustralian.com.au/news/nation/where-eagles-dare-not-fly-waterloo-looms-as-wind-farms-power-town-revolt/story-e6frg6nf-1226334835470>

Accessed 10/22/12

²⁹ I have used basic math to flesh out the numbers of affected residents from the summary presented by Wang, which only presented percentage results among those who returned surveys; I have further done the calculations as mentioned to assess rates among the entire population using the extreme conservative assumption that all non-respondents are not affected.

³⁰ See AEI's presentation to the New England Wind Energy Education Project: <http://aeinews.org/archives/972>

³¹ Mary Morris. Waterloo Wind Farm Survey April 2012.

³² While Morris presented two sets of complete data, 0-5km and 0-10km, she did not separate out the 5-10km data for analysis. I did so using simple math.

³³ TRUenergy Mid North Community Survey Summary. February 2012.

³⁴ Clifford P. Schneider, Visual and sound impacts from the Wolfe Island Wind Project on residents of Tibbetts Point Road, Cape Vincent, NY. April 2010 presentation.

³⁵ <http://aeinews.org/archives/55>

³⁶ David Hessler, Best Practices Guidelines for Assessing Sound Emissions From Proposed Wind Farms and Measuring the Performance of Completed Projects. Prepared for the Minnesota Public Utilities Commission, under the auspices of the National Association of Regulatory Utility Commissioners (NARUC). October 13, 2011.

³⁷ Hessler Associates. Environmental Sound Survey and Noise Impact Assessment, Buckeye Wind Project. Report No. 1819-05=41708-C. March 12, 2009. Issued as Appendix J of Buckeye project Draft Environmental Impact Statement, Volume II, June 22, 2012.

³⁸ Bolin et al. Infrasound and low frequency noise from wind turbines: exposure and health effects. Environ. Res. Lett. 6 (2011) 035103

³⁹ Møller and CS Pedersen. Low-frequency noise from large wind turbines. J. Acoust. Soc. Am. 129 (6), June 2011, 3727-3744.

⁴⁰ See <http://dasam.dk/?q=node/62>

⁴¹ Danish version is at http://dasam.dk/Dasam_upload/Dasam_bestyrelses_ref/hoerings svarvindmoeller-nov-2011.pdf

English translation available at <http://www.wind-watch.org/documents/statement-on-the-revision-of-the-executive-order-on-noise-from-wind-turbines/>

⁴² Wind Turbine Health Impact Study: Report of Independent Expert Panel, January 2012. Prepared for Massachusetts Department of Environmental Protection, Massachusetts Department of Public Health. Page 60.

⁴³ Ibid.

⁴⁴ See <http://www.governing.com/blogs/view/gov-growing-wind-turbine-opposition-creates-hurdles.html>

Accessed 10/17/12

⁴⁵ See, for example, Rand, Community reactions to noise. Report/letter submitted to Riga, Michigan Township Planning Commission, 2/5/11; and Rand, Wind Turbine Sound, An Independent Investigation: Siting to Prevent Adverse Noise Impacts. Powerpoint presentation to Informed Citizens Coalition, 2/5/11. See AEI Wind page (linked in page footers) for links to these; also please see full discussion of these issues in the AEI Wind Farm Noise 2011 annual report.

⁴⁶ Paul Schomer. On Normalizing DNL to Provide Better Correlation with Response. Sound and Vibration, December 2002, p 14-18

⁴⁷ http://www.awea.org/sitinghandbook/download_center.html

⁴⁸ Available at <http://www.nrel.gov/docs/fy07osti/40403.pdf>

⁴⁹ http://awea.org/learnabout/publications/upload/Utility-Scale-Wind-Sound-Fact-Sheet_May-2011.pdf

⁵⁰ Robert Righter. Windfall: Wind Energy in America Today. University of Oklahoma Press, Norman, OK. 2011.g

⁵¹ Wind historian and booster urges remote locations for wind farms, <http://aeinews.org/archives/1726>

⁵² Jim Cummings. Wind historian says build new wind farms farther from neighbors. Renewable Energy World, 2/9/2012

<http://www.renewableenergyworld.com/rea/news/article/2012/02/wind-historian-says-build-new-wind-farms-farther-from-neighbors>

⁵³ See coverage of the landscape decision at

<http://www.telegraph.co.uk/earth/earthnews/9298265/Ruling-on-wind-farm-says-the-countryside-is-as-important-as-climate-change-targets.html> and

<http://www.dailymail.co.uk/news/article-2152460/The-wind-farm-rebellion-blows-Britain-campaigners-heart-villages-victory.html>

⁵⁴ I'm not tracking wind bans with any real diligence, since I'm more interested in places where there's an effort to establish setbacks that reflect local noise tolerance. Among the places where bans have been implemented or proposed projects were turned down on generalized aesthetic grounds are Merritt Township, MI, Brookville, ME, Lake County, IL, Christchurch Borough, UK, and Mitchell Shire, UK.

⁵⁵ Lewiston Sun-Journal, October 3, 2012. <http://www.sunjournal.com/news/river-valley/2012/10/03/peru-wind-ordinance-tweaked/1259850>

⁵⁶ Lewiston Sun-Journal, Oct. 30, 2012. <http://www.sunjournal.com/news/river-valley/2012/10/30/dixfield-residents-vote-wind-ordinance/1273688>

⁵⁷ Bangor Daily News, 1/24/12.

<http://bangordailynews.com/2012/01/24/news/midcoast/landowners-sue-frankfort-over-new-wind-ordinance/>

⁵⁸ Bangor Daily News, 10/27/11.

<http://bangordailynews.com/2011/10/27/news/midcoast/tempers-flare-at-frankfort-hearing-on-mount-waldo-wind-project/>

⁵⁹ For more on the various Goodhue setback rulings, see <http://aeinews.org/?s=goodhue>

⁶⁰ <http://thechronicleherald.ca/novascotia/119413-argyle-votes-to-increase-wind-farm-buffer>

⁶¹ <http://aeinews.org/archives/2025>

⁶² Detailed story from May: http://www.onlinesentinel.com/news/wind-farm-resentments-seep-back-to-surface_2012-05-11.html

Shorter story from October:

<http://freepressonline.com/main.asp?SectionID=52&SubSectionID=78&ArticleID=22252>

⁶³ <http://www.deseretnews.com/article/705365976/3rd-phase-of-Milford-wind-project-proposed.html?pg=all>

⁶⁴ This was from Merritt Township, MI, which voted to deny a permit for 9 turbines in their town; this was part of a much larger wind project, and Merritt Twp did allow for siting of a substation, cables, and other elements of the project in town. Not surprisingly, the decision shocked the project developer: "Mary Wells, spokesperson for NexEra, said that officials were surprised and very disappointed by the decision.

"It's astonishing," Wells said. "We showed them how we had adhered to all of the regulations of their ordinance, and they completely disregarded the rules that they had set in place."

http://www.mlive.com/news/bay-city/index.ssf/2012/02/merritt_township_supervisor_lo.html

⁶⁵ Møller and CS Pedersen (2011). Low-frequency noise from large wind turbines. *J. Acoust. Soc. Am.* 129 (6), June 2011, 3727-3744.

⁶⁶ Please see the Appendix summary for full details; the researchers report on studies with individual turbines as well as a small wind farm, and used models based on pure spherical spreading, as well as ones shifting to cylindrical at 200m. They focused on 44dB thresholds at times (the Danish limit), and 35dB at times (Swedish quiet limit, and the level this research team recommends as "a very reasonable limit for wind farm noise," in part because of the variable propagation distances they found).

⁶⁷ David Hessler, Best Practices Guidelines for Assessing Sound Emissions From Proposed Wind Farms and Measuring the Performance of Completed Projects. Prepared for the Minnesota Public Utilities Commission, under the auspices of the National Association of Regulatory Utility Commissioners (NARUC). October 13, 2011.

⁶⁸ Bob Thorne. The Problems with "Noise Numbers" for Wind Farm Noise Assessment. *Bulletin of Science Technology and Society* 2011 31: 262.

⁶⁹ For more on the Pinnacle Wind Farm noise issues, including company efforts to quiet turbines, see AEInews coverage at <http://aeinews.org/?s=pinnacle>

⁷⁰ At Hardscrabble, noise complaints cropped up shortly after operations began, and in late 2012, sixty residents sued the company for nuisance and negligence. Sound monitoring suggests that the project operates generally in compliance with the local 50dB limit, but occasional periods slightly over the limit were recorded. For more on Hardscrabble, see AEInews coverage at <http://aeinews.org/?s=hardscrabble>

⁷¹ Hessler 2011, p.15

⁷² Bob Thorne. The Problems with "Noise Numbers" for Wind Farm Noise Assessment. *Bulletin of Science Technology and Society* 2011 31: 262.

⁷³ Kenneth Kalisky. Wind Turbine Noise Regulation: Perspectives in New England. *NEWEEP Webinar #2*, July 2010.

⁷⁴ See several papers in the Appendix on Low-Frequency Noise Research for the basis of this widespread understanding, especially:

O'Neal, Hellweg, Lempeter. Low frequency noise and infrasound from wind turbines. *Noise Control Eng. J.* 59 (2), March-April 2011.

Bolin et al. Infrasound and low frequency noise from wind turbines: exposure and health effects. *Environ. Res. Lett.* 6 (2011) 035103

David Hessler, Best Practices Guidelines for Assessing Sound Emissions From Proposed Wind Farms and Measuring the Performance of Completed Projects. Prepared for the Minnesota Public Utilities Commission, under the auspices of the National Association of Regulatory Utility Commissioners (NARUC). October 13, 2011.

HGC Engineering, Low frequency noise and infrasound associated with wind turbine generator systems: A literature review. Ontario Ministry of the Environment RFP No. OSS-078696. 2010.

⁷⁵ Bray and James. Dynamic measurements of wind turbine acoustic signals, employing sound quality engineering methods considering the time and frequency sensitivities of human perception. *Noise-Con* 2011.

⁷⁶ One other research team has replicated this approach that I'm aware of: Ambrose and Rand found similar dynamic patterns of dBG-weighted sound, though the peaks they identified (around 65dBG, one peak to 75dBG) were significantly lower than those reported in the Wade and James work that introduced the technique (regularly 80dBG, and up to 94dBG).

⁷⁷ HGC Engineering, Low frequency noise and infrasound associated with wind turbine generator systems: A literature review. Ontario Ministry of the Environment RFP No. OSS-078696. 2010.

⁷⁸ HGC Engineering, Low frequency noise and infrasound associated with wind turbine generator systems: A literature review. Ontario Ministry of the Environment RFP No. OSS-078696.

⁷⁹ Møller and CS Pedersen. Low-frequency noise from large wind turbines. *J. Acoust. Soc. Am.* 129 (6), June 2011, 3727-3744.

⁸⁰ Bob Thorne. The Problems with "Noise Numbers" for Wind Farm Noise Assessment. *Bulletin of Science Technology and Society* 2011 31: 262.

⁸¹ Ambrose, Rand, Krogh. Falmouth, Massachusetts turbine infrasound and low frequency noise measurements. *Internoise* 2012, August 19-22, 2012.

⁸² Matthew Barone (2011). Survey of Techniques for Reduction of Wind Turbine Blade Trailing Edge Noise. Sandia National Laboratory. SAND2011-5252, August 2011.

⁸³ A report on Vinalhaven noise reduction efforts, including both the serrated edges and use of NRO, is nearing completion, and will presumably soon be delivered to Island Institute, Fox Islands Wind, and Fox Islands Electric. I believe it's being done under the auspices of the Lawrence Berkeley National Laboratory (which did a preliminary study), though it may be coming out of the National Renewable Energy Lab.

⁸⁴ D. Wilson, D. Berg, M. Barone, J. Berg, B. Reser, D. Lobitz (2009). Active aerodynamic blade control design for load reduction on large wind turbines. *European Wind Energy Conference and Exhibition* 2009. Corresponding author: dwilso@sandia.gov

-
- ⁸⁵ Jose Zayas. Technology Innovation for Wind Energy: SNL's SMART Rotor Program. Sandia National Laboratories. (No date on presentation; 2010 or later) sandia.gov/wind
jrzayas@sandia.gov
- ⁸⁶ Møller and CS Pedersen (2011). Low-frequency noise from large wind turbines. *J. Acoust. Soc. Am.* 129 (6), June 2011, 3727-3744.
- ⁸⁷ M. Churchfield, S. Lee, P. Moriarty, L. Martinez, S. Leonardi, G. Vijayakumar, J. Brasseur (2012). A Large-Eddy Simulation of Wind-Plant Aerodynamics. Presented at the 50th AIAA Aerospace Sciences Meeting, Nashville, Tennessee, January 2012. Available electronically at <http://www.osti.gov/bridge>
- ⁸⁸ Jeffrey Freedman & Kathleen Moore (2012). Wind Shear and Why it Matters. *North American Windpower*, Volume 9, Number 5, June 2012, p.48-51.
- ⁸⁹ Sonia Wharton and Julie K. Lundquist (2012). Atmospheric stability affects wind turbine power collection. *Environ. Res. Lett.* 7(2012) 014005
- ⁹⁰ See www.renewableenergyworld.com/rea/u/AcousticEcologyInstitute/articles
- ⁹¹ Carl V. Phillips. Properly Interpreting the Epidemiologic Evidence About the Health Effects of Industrial Wind Turbines on Nearby Residents. *Bulletin of Science Technology & Society* 2011 31: 303 DOI: 10.1177/0270467611412554
- Daniel Shepherd et al. Evaluating the impact of wind turbine noise on health-related quality of life. *Noise & Health*, September-October 2011, 13:54,333-9.
- Daniel Shepherd, Witness Statement, Ontario MOE Environmental Review Tribunal, January 19, 2011.
- Michael Nissenbaum, Jeff Aramini, Chris Hanning. Adverse health effects of industrial wind turbines: a preliminary report. 10th International Congress on Noise as a Public Health Problem (ICBEN) 2011, London, UK.
- Bob Thorne (Noise Measurement Services). *Wind Farm Noise Guidelines*, 2011.
- ⁹² Nina Pierpont. *Wind Turbine Syndrome: A Report on a Natural Experiment*. 2009. Nina Pierpont. Presentation to the Hammond (NY) Wind Committee, July 2010
- ⁹³ Stephen E. Ambrose, Robert W. Rand. The Bruce McPherson Infrasound and Low Frequency Noise Study: Adverse health effects produced by large industrial wind turbines confirmed. December 14, 2011.
- ⁹⁴ Large-scale government-initiated studies are underway in Japan (see <http://aeinews.org/archives/644>) and Ontario (see <http://aeinews.org/archives/1862>)
- ⁹⁵ One such study is ongoing at Wolfe Island, Ontario. See <http://aeinews.org/archives/227> and <http://www.theglobeandmail.com/life/health/study-to-determine-health-effects-of-turbines/article1210357/>
- ⁹⁶ To repeat a well-worn AEI theme: Both direct and indirect health effects would be minimized by adopting local siting standards that prevent sleep disruption, high annoyance rates, and profound changes in the local sense of home and place, thus avoiding most stress-mediated effects. While some of those with pre-existing sensitivities may be affected at greater distances, I suspect that protecting sleep and avoiding stress for the many would also largely protect the few who are susceptible to the rare direct effects.
- ⁹⁷ Bob Thorne. The Problems with "Noise Numbers" for Wind Farm Noise Assessment. *Bulletin of Science Technology and Society* 2011 31: 262.

Appendix A: Turbine Sound Research

As published on AEInews.org on 12/31/11: <http://aeinews.org/archives/1711>

PDF version of this is available at <http://www.acousticecology.org/wind/>

Recent research on low frequency noise from wind turbines

If AEI were a mass media outlet, publishing this on New Year's Eve would be considered an attempt to "bury" the story on a weekend when few people are following the news. But since our readership works on a longer time scale and are likely to find their way here over the next couple of weeks, I hope you'll instead consider this a New Year present! It's taken many (many...) hours of work, and I hope it helps all those working on wind farm noise issues - including local and state regulators, environmental consultants, wind developers, and community groups - to make sense of the insanely confusing world of low-frequency noise and infrasound. Here's to a constructive 2012 as we continue to work toward siting policies that protect residents from unwanted changes to their sense of place while encouraging responsible and widespread growth of wind energy!

[Download this extended post as a 22-page pdf file](#)

As regular readers will know, AEI's wind farm coverage has focused primarily on the ways that nearby neighbors respond to the audible noise from wind turbines, with far less emphasis on infrasound. However, given the ongoing public dialogue about the contribution of infrasound and low-frequency sound to the annoyance, sleep disruption, or health effects reported by some wind farm neighbors, I do like to keep abreast of research into the lower end of the sound spectrum. In this post, I'll be summarizing several papers that have appeared in journals and conference proceedings over the past several months. This will be a much longer post than normal, but I encourage you to take the time to read through it, and to download the source papers for further study. What you'll find here is a close reading of work from both mainstream and more cautionary acousticians, which I believe will help you to understand the subtleties of our current state of understanding in a new and clearer way.

I think it's fair to say that the bottom line continues to be roughly the same as it's been: wind turbines clearly produce much of their sound energy at lower frequencies, including the low end of the audible spectrum (20-250Hz) and the infrasonic range (below 20Hz, which is generally below the range humans tend to hear, simply because it has to be very loud to be perceptible). Conventional wisdom continues to be that the infrasound in wind turbine noise is well below human perceptual limits, even of the more sensitive fringe of the population. This summary doesn't directly challenge that idea, though as you'll see, there are some indications that we may have been a bit too quick to entirely rule out any perception of infrasound produced by wind turbines. Still, I hasten to stress that any possible connection between physically perceptible infrasound and health effects remains beyond the scope of most of these papers (with a couple of exceptions).

More importantly, though, it's increasingly being recognized that low-frequency audible sound could very well be a key factor in widespread annoyance about wind farm noise. It's important to not conflate infrasound and low-frequency sound; while the former is (always or mostly) imperceptible, the latter is clearly very audible in many situations, and indeed, is the dominant sound component of wind farm noise at moderate and larger distances. It's quite likely that much of the annoyance people report could be triggered by very low frequency, moderately audible noise, which can be more ear-catching (or perhaps even cause physiological reactions) when it contains one or more dominant tones or fluctuates

rapidly. Further, increasing evidence confirms neighbors' reports that moderate but extremely bothersome low frequency noise can be more perceptible inside their homes than outside. These elements are part of the reason that several of the papers here from relatively mainstream perspectives (and which consider infrasound a non- or minimal issue) recommend lower noise limits than the 45–50dB standard commonly used in the US; you'll see in these papers that 40dBA is becoming a common recommendation. Most of the more cautionary acousticians tend to recommend 30–35dB; it's striking to me that the gap between these two perspectives has narrowed considerably in the last year or so.

Among the highlights of the recent research is Møller and Pedersen's finding that larger turbines produce more low-frequency sound (especially audible low-frequency), and that in many atmospheric conditions, sound levels will remain annoyingly high for much farther than often assumed by more idealized sound modeling. Also of note, Bray and James' field measurements of wind turbine sound, using equipment designed to capture very short time segments, reveals a remarkable variability and surprisingly high peak sound levels in the low-frequency and infrasonic sound, to a degree that raises questions about our tendency to rely on longer-time-period averages that indicate infrasound is always well below perceptual limits. As we look more closely into low-frequency and infrasound data, both the mainstream papers and the more cautionary acousticians' work suggest that these questions are far from settled.

(I should clarify that my use of the word "mainstream" is meant to simply mean studies by folks working with techniques and perspectives on bothersome noise levels that have been standard in noise control assessment for many community noise sources. And conversely, the use of the term "cautionary acousticians" does not imply they are less qualified or biased in any way. Indeed, most of them have decades of noise control experience and have been drawn to the study of wind farm noise only because of the unexpectedly robust complaints that have arisen, and are professionally interested in trying to ascertain the reasons, either by using innovative measurement techniques or closely assessing annoyance patterns. They may be more "cautionary" in their recommended noise limits simply because they've looked more closely at specific problems, rather than keeping their distance and approaching the issue through standard noise modeling and analysis techniques.)

Some of the papers I'm summarizing here address aspects of annoyance and sound characteristics of wind farm noise that are not limited to low frequency and infrasound issues (especially including acknowledgement of the extreme variability of the overall sound levels); these papers provide important perspectives that may help us to understand why wind farms are producing more annoyance reactions than we might expect, considering their moderate sound levels.

For more (much more...but worth it!), click on through to read lay summaries of the following recent papers:

- Møller and CS Pedersen. Low-frequency noise from large wind turbines. J. Acoust. Soc. Am. 129 (6), June 2011, 3727–3744.
- O'Neal, Hellweg, Lempeter. Low frequency noise and infrasound from wind turbines. Noise Control Eng. J. 59 (2), March–April 2011.
- Bolin et al. Infrasound and low frequency noise from wind turbines: exposure and health effects. Environ. Res. Lett. 6 (2011) 035103
- Bray and James. Dynamic measurements of wind turbine acoustic signals, employing sound quality engineering methods considering the time and frequency sensitivities of human perception. Noise-Con 2011.
- Stephen E. Ambrose and Robert W. Rand. The Bruce McPherson Infrasound and Low Frequency

Noise Study: Adverse health effects produced by large industrial wind turbines confirmed. December 14, 2011.

- David Hessler, Best Practices Guidelines for Assessing Sound Emissions From Proposed Wind Farms and Measuring the Performance of Completed Projects. Prepared for the Minnesota Public Utilities Commission, under the auspices of the National Association of Regulatory Utility Commissioners (NARUC). October 13, 2011.
- Knopper and Ollsen. Health effects and wind turbines: A review of the literature. *Environmental Health* 2011, 10:78
- Kroesen and Schreckenber. A measurement model for general noise reaction in response to aircraft noise. *J. Acoust. Soc. Am.* 129 (1), January 2011, 200–210.
- HGC Engineering, Low frequency noise and infrasound associated with wind turbine generator systems: A literature review. Ontario Ministry of the Environment RFP No. OSS-078696.
- Bob Thorne. The Problems with "Noise Numbers" for Wind Farm Noise Assessment. *Bulletin of Science Technology and Society* 2011 31: 262.

Let's start with a paper from Møller and CS Pedersen that got a fair amount of attention when it was published. The leading take-away from the paper in the popular and trade press was their finding that larger turbines (2.3–3.6MW) produce more low-frequency sound than smaller ones (below 2MW); specifically, the sound spectrum shifted downward by about a third of an octave. This has important implications moving forward, because of the push to increase turbine size in order to generate more electricity from each turbine; 3MW is becoming a common size in new wind farms. The increase in low frequency sound was moderate, just 1.5–3.2dB, but the authors remind us that at low frequencies, small dB differences are perceived as larger differences in loudness than at higher frequencies. And, the farther you go from the turbine, the more higher frequencies are dissipated while lower frequencies become the dominant component of the sound that remains.

But the Møller/Pederson paper is important for several other key reasons as well. Firstly, they stress that much of the information being promulgated by both sides of the wind turbine siting debate fails to distinguish between infrasound and low-frequency sound. As they say (parenthetical phrases are in the original, not editorial additions):

Infrasound and low-frequency sound are often not properly distinguished, and, as a peculiar consequence, low-frequency noise is frequently rejected as the cause of nuisances, just because infrasound can be discarded (usually rightfully). Infrasound is (still) often claimed inaudible, and sometimes even low-frequency noise, or it is reported that both can only be heard by especially sensitive people—which is all wrong. Weighting curves are misunderstood or (mis)used to give the impression of dramatically high or negligibly low levels. Sometimes, political utterances (from both sides) are disguised as scientific contributions.

Infrasound is addressed only briefly in this paper, but their treatment provides a good foundation for understanding other papers. They use **G-weighted sound levels** in their consideration of infrasound, which, unlike C or A weighting, includes sounds below 10Hz, while accentuating the frequencies from 2–70Hz (though still adjusted in a way that lets one final dB number reflect a combined contribution of different frequencies' sound levels). The human hearing threshold is 95–100 dBG, with anything below 85–90 dBG generally considered imperceptible. Their measurements of wind turbine sound at 90–525m were below 65 dBG; the highest measurements they found in the literature were 80 dBG at 360m, still below perceptible thresholds. The paper includes an unusually thorough survey of research into individual differences in hearing sensitivity at low frequencies (including

studies suggesting that we respond to peak sound levels when there are large fluctuations, a precursor to the Bray/James study below which found peaks of over 90dBG), though the authors conclude that except for the possibility of a very few people with anatomical abnormalities in the hearing organs, the variation found to date is modest and so infrasound is unlikely to be a contributing factor to wind farm annoyance.

But don't rest easy just yet: they also stress that downwind propagation of low-frequency noise, and overall turbine noise, is often vastly underestimated using standard models.

Atmospheric refraction – sound bouncing back down from air density boundaries overhead, and sometimes (especially with low frequencies) bouncing off the ground as well, so it's channeled greater distances – can create much higher sound levels than we might expect at distances of beyond a few hundred meters. Sound just below the border of low frequency and infrasound (especially 8–16Hz) appears to dissipate much more slowly ("cylindrical" instead of "spherical" spreading), dropping by only 3dB with each doubling of distance, rather than 6dB as do most audible sounds. (Other papers included here, including the HGC/Ontario MOE report, also stress this factor, which the Ambrose/Rand field measurements confirm.) This means that at greater distances, the turbines noise that makes it that far will sound lower in frequency, and be louder than predicted by spherical spreading models.

Their measurements of actual wind turbines also led to some quite remarkable results. They measured the sound power levels of 9 large turbines, then did two rounds of sound modeling. The first assumed simply spherical spreading, sound dropping 6dB for each doubling of distance. They measured how far they had to be from individual turbines in order for the sound to drop to 35dB, the level above which E Pedersen and Persson-Waye found annoyance begin to spike beyond 5–10% of the population, and also the level required in quiet areas in Sweden. Because the nine turbines had distinctly different initial (source) sound levels, the variation in distance was stunning, with this quiet sound level reached at distances ranging from 629m (2063ft) to 1227m (4024ft). Interestingly, when modeling small wind farms of 12 turbines, they found that sound levels of 44dB (Danish wind farm noise limit at homes) were reached at a very similar wide range of distances, 530m–1241m.

But more striking still was the dramatic increase in setback distances necessary when they considered atmospheric conditions with a sound-reflecting layer. Here, they joined an emerging consensus in acoustics that propagation can be cylindrical beyond 200m, and found that homes would need to be anywhere from 1414m (4600ft) to 3482m (11,421ft / 2.16miles) in order for the sound to drop to 35dB. Again, they note that at these greater distances, as higher frequencies are absorbed and lower frequencies are less impeded, the sound becomes more dominated by lower frequencies, and that "Cylindrical propagation may thus explain case stories, where rumbling of wind turbines is claimed to be audible kilometers away." This also helps explain the fact, noted in both the Hessler and Thorne papers below, that noise levels well above those predicted by noise modeling can be expected to occur with some regularity.

Møller and CS Pedersen repeatedly stress that the audible low-frequency components of wind turbine noise, especially as distance increases, are likely a key factor in reported annoyance by neighbors. After modeling likely indoor noise levels, they note:

If the noise from the investigated large turbines has an outdoor A-weighted sound pressure level of 44dB (the maximum of the Danish regulation for wind turbines), there is a risk that a substantial part of the residents will be annoyed by low-frequency noise even indoors. The Danish evening/night limit of 20dB

for the A-weighted noise in the 10–160 Hz range, which applies to industrial noise (but not to wind turbine noise), will be exceeded somewhere in many living rooms at the neighbors that are near the 44dB outdoor limit. Problems are much reduced with an outdoor limit of 35dB.

Given all they found, Møller and CS Pedersen consider 35dB a "very reasonable limit for wind turbine noise," joining their Scandinavian colleagues TH Pedersen and Nielson, who recommend 33–38dB. As they also note, "A limit of 35 dB is used for wind turbines in Sweden for quiet areas... It is also the limit that applies in Denmark in open residential areas (night) and recreational areas (evening, night, and weekend) for industrial noise (but not for wind turbine noise)."

Note: If you, like I, have been wondering whether all these Scandinavian Pedersens citing each others' work are engaged in scientific nepotism, rest easy. I recently confirmed that none of them are related; they just share a common name (lots of family lines had Peder at the top of the lineage, I guess!)

A literature survey paper by Karl Bolin, et al, Infrasound and low frequency noise from wind turbines: exposure and health effects, generally affirms the conventional wisdom that infrasound is of minimal concern, but also includes several somewhat cautionary notes. The paper begins by focusing on the mechanism that creates the low frequency and infrasound components of wind turbine noise, zeroing in on inflow turbulence as the primary contributor in the 10Hz to several hundred Hz range, covering audible low-frequency noise and some infrasound. A quick look at measured low-frequency and infrasound levels finds them, per usual, well below typical perceptual thresholds. The authors twice note that studies cited by Salt et al to suggest that infrasound is commonly at high enough levels – 60dBG – to trigger outer ear hair cell responses took place at very close range (20–100m) from turbines, much closer than residential sites. (*Ed. note: however, see two studies below at residences where peaks of 60–90dBG were observed.*) The section of the paper on annoyance levels notes that the widely-cited E Pedersen–Waye et al annoyance surveys all focused primarily on outdoor annoyance, while the same studies found indoor annoyance levels to be about half of those found outside at each noise level.

Here, though, Bolin et al move toward a cautionary stance, summarizing annoyance studies as compared to other common community noise sources and concluding that today's 45–50dB turbine noise guidelines may be a bit too high:

Overall, these comparisons suggest that guidelines for wind turbine noise in the interval 35–40 dB would correspond to the proportion of annoyed persons comparable to the proportion annoyed by road traffic noise at a typical guideline value.

The final section of the Bolin paper surveys sleep disturbance and other health effects, reporting on the health findings in the big Pedersen surveys, which found that while annoyance and some sleep disturbance were reported, there was no consistent association between noise levels and specific health factors, including chronic disease, headaches, tinnitus, or tiredness. At the end of this section, the authors report that cardiovascular risk has been found to be elevated near road noise of 55dB or more, which is "significantly higher than typical exposure from wind turbine noise." However, noting that these cardiovascular

risks are considered to be largely related to stress, annoyance, and sleep disruption (i.e., not from direct physiological effects of the noise itself), and that wind turbines tend to trigger stress and annoyance at lower levels than road noise (*note: this is the basis for their suggestion of a 35–40dB guideline above*), then "one cannot completely rule out effects on the cardiovascular system after prolonged exposure to wind turbine noise, despite moderate levels of exposure."

The most comprehensive look at low frequency sound and infrasound from turbines to come out in recent months appeared in the journal *Noise Control Engineering*, and was written by Robert O'Neal and two colleagues at Epsilon Associates, a consulting firm.

This paper includes an extensive literature survey, an indoor and outdoor field measurement program at a wind farm in Texas, and a comparison of the field measurements to several key noise control criteria. In short, they find that the low-frequency and infrasound components of the wind turbine sounds they measured meet all relevant standard criteria, including those from the International Standards Organization (ISO), American National Standard (ANSI), and UK and Japanese environmental agency guidance. Most of the findings are pretty straightforward, as well as rather detailed, so I'll refrain from recounting them here, and encourage you to check out the paper yourself.

I'll note a few things that caught my eye as I read it through, though. Right off the bat, the authors stress that the widespread idea that sound below 20Hz or so is inaudible to humans "is incorrect since sound remains audible at frequencies well below 16 Hz provided that the sound level is sufficiently high....The division into 'low-frequency sound' and 'infrasound' should only be considered 'practical and conventional.'" (*Ed. note: still, we need to be attentive to perceptual thresholds, which range as high as well over 100dB at the lowest frequencies.*)

The discussion here of physical sensations in response to infrasound also shed some interesting light. The authors note that sensations in the chest, lower back, and thighs sometimes occur, but only at sound levels 20–25dB above the hearing thresholds (*Ed. note: this is very high indeed at low frequencies, unlikely to occur near wind farms even considering the more cautionary field studies below*); the ears are the most sensitive receptors even of sounds between 4 and 25Hz. Yet also, this observation may illuminate some neighbor reports: "Below 10 Hz it is possible to perceive the single cycles of a tone, and the perception changes into a sensation of pressure at the ears."

This paper relies on standard measurement procedures that average the sounds over relatively long periods of time (10 minute averages; sampling rate is not noted, though the "fast" rate typically employed is 125ms, with 1-second sampling also being common). As we'll see in the Bray/James paper below, this methodology may miss some of the dynamic, rapidly varying aspects of wind turbine noise. But for now, let's take this work at face value, and see that the authors note of ANSI outdoor criteria:

annoyance is minimal when the 16, 31.5 and 63 Hz octave band sound pressure levels are each less than 65 dB and there are no rapid fluctuations of the low frequency sounds.

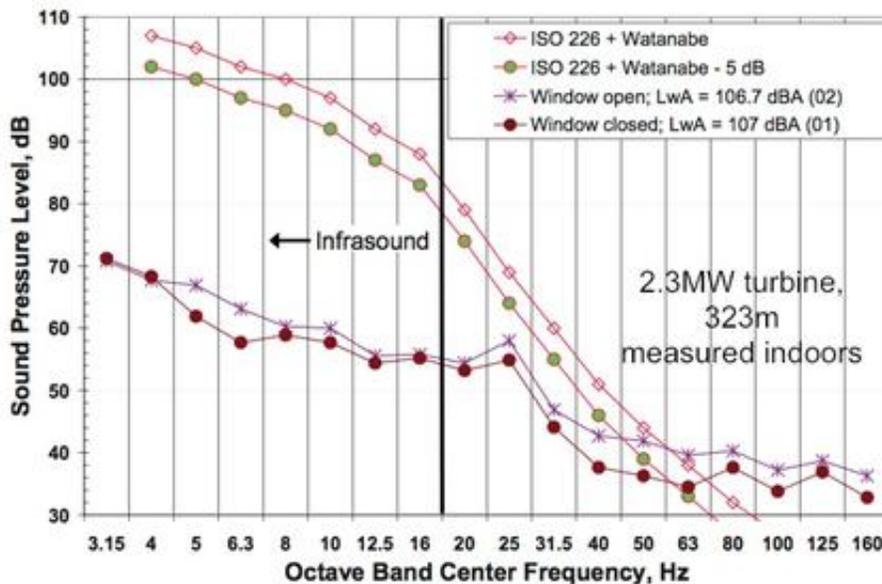
And, that according to UK standards, "A low frequency noise is considered steady if either

L10 minus L90 (i.e., the difference between the loudest and quietest times) is greater than 5 dB or the rate of change of sound pressure level (Fast time weighting) is less than 10 dB per second" in the most extreme third-octave band.

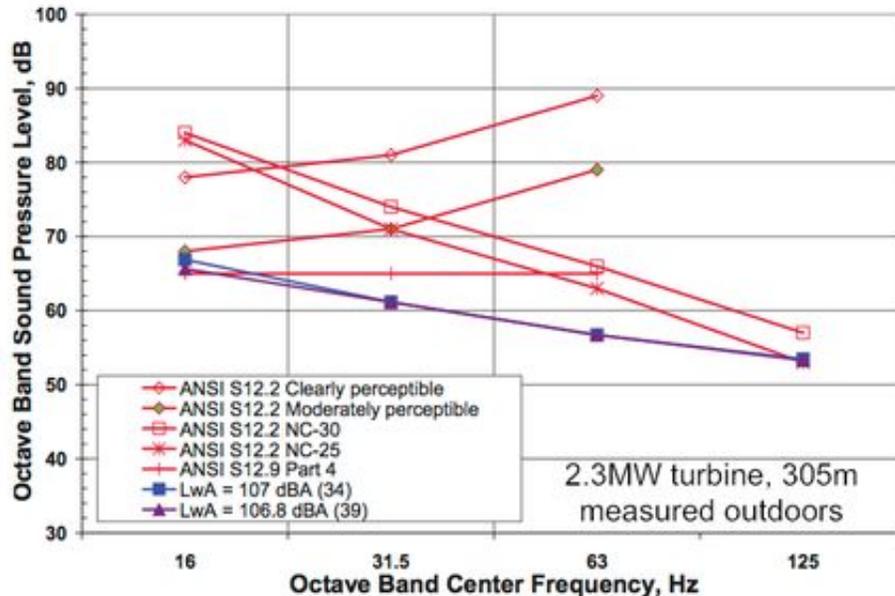
Ed. note: Bear these caveats in mind as we move to consideration of the faster time-averaged measurements reported below by Bray/James and Ambrose/Rand, both of which found significant variation of sound levels and rapid fluctuations in low frequencies.

Turning to the Texas field measurements of 1.5 and 2.3MW turbines, several things stand out. First is that the sound emissions from the Texas turbines was incredibly consistent: moderate sound output periods were only 2–3dB lower than maximum periods, and in the low-frequency one-third octave bands, the standard deviation in sound levels was under 1dB across six measurement periods. (*Ed. note: This suggests that, following on the Bolin paper above, inflow turbulence was likely quite low at this site (flat open land); I wonder whether the results would be applicable to sites with more rolling landscape or other factors that could increase localized turbulence.*)

Most of the Epsilon measurements came in well under the various criteria; this figure is representative of most of their results:



One measurement, however, was fairly edgy, bumping up against the "moderately perceptible" vibration level, as well as the ANSI standard that is modified for low-frequency noise (ANSI 512.9 Part 4); this one tracks sound only down to 16Hz, and one wonders what's going on in the deeper infrasound range below:



Overall, though, O'Neal and his Epsilon colleagues conclude that their measurements indicate:

Infrasound is inaudible to even the most sensitive people 305 meters (1,000 feet) from these wind turbines (more than 20 dB below the median thresholds of hearing). Low frequency sound above 40 Hz may be audible depending on background sound levels.

At present, this paper is the clearest summation of this widespread conventional wisdom.

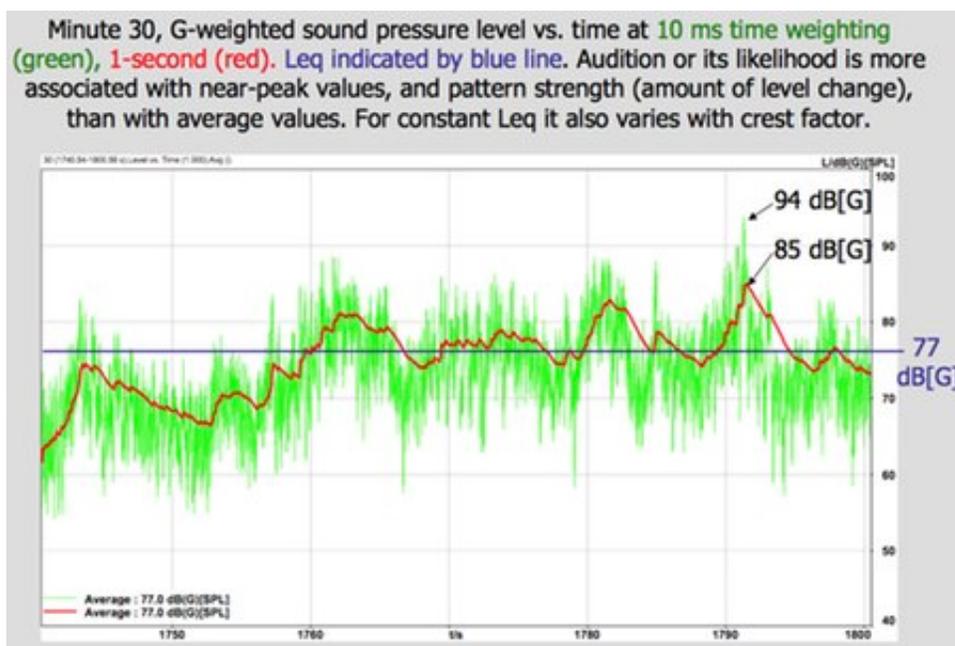
Well, dear reader, you're doing well to be hanging in this long! Your diligence will be rewarded, as the next few papers move the discussion forward in several interesting directions. We'll see some intriguing – and possibly troubling – sound measurements in very short time scales, an innovative approach to predicting annoyance reaction to noise, and a critique of typical noise measurement metrics. Alright, then, on we go!

Probably the most provocative and ground-breaking paper among this batch of new research is the paper presented by Wade Bray and Rick James at [Noise-Con 2011](#), the annual conference of the Institute of Noise Control Engineering (INCE).

For years, Bray has stressed the need to assess sounds at time scales that reflect human auditory perception, and James has in recent years been on the forefront of investigating the sound of wind farms in locations where people have been especially bothered by the noise. In their recent paper and presentation, they worked together to assess the sound at a home in Ubly, Michigan 1500 feet from the nearest turbine (wind speeds were low, under 10mph, with temperatures of 17–22 degrees F, overcast skies, and no precipitation).

Given the innovative approach this paper takes toward assessing noise levels, it's especially difficult to summarize briefly; here I'll mention the key concepts and findings, but I encourage you to read the full paper for a more complete context as to why the authors think this approach is an important adjunct to traditional assessment techniques.

Typical noise assessment focuses primarily on measuring the sound levels at the full range of frequencies, with an emphasis on very fine resolution between frequencies (one-third of an octave is the typical resolution; so that spectrograms present the dB level for each third-octave). This works fine at higher frequencies, but as you move down the frequency scale, a trade-off has been made for historic and technical reasons: several third-octave bands are combined into "critical bandwidths" forcing the time scale of the measurements to be extended far beyond the time scale of human perception. While we perceive and respond to low frequency (20–100Hz) sounds on a timescale of about 10ms (milliseconds; one one-hundredth of a second), most noise assessment standards use "fast" time weightings of 125ms, or even levels averaged over as much as 1–10 seconds. These longer averaging times hide the peaks and troughs of the sound that occur at very short time scales:



For the one minute of the Ubyly data graphed above, the sound level averaged across the entire 60 seconds was 77dBG. When averaged every second, the red line shows levels ranging from about 62dB to 85dB, and when averaged every 10ms, it ranged from about 55dB to 94dB. (The G-weighted sound level primarily emphasizes sounds from 10–30Hz, and only moderately reduces the emphasis on sounds from 2–10Hz and 30–70Hz. While still not reflecting the pure, un-adjusted sound spectrum, dBG provides a better focus on low frequency and infrasonic ranges than A or C weightings.)

Ed. note: Because dBG weighting includes sound below 10Hz (unlike dBA or dBC weightings), some people tend to think this is a measure of primarily infrasound. Yet note that it actually includes a large chunk of audible low frequencies (up to 70Hz), while centering on that fuzzy transition between infrasound and low frequencies (10–30Hz).

A central point of this Bray/James paper is that human perception responds to the peak sound levels, rather than averages (as also affirmed in Møller/CS Pedersen's paper, above). In addition, sounds that are highly variable in short time spans (called a "high crest factor") are also more perceptible than sounds at a steady level or closely varying around the average, because human ears are very attuned to patterns in sound. These two observations, combined with the fact that the measured peak levels approach much closer to the standard human perception curves than do the averages (which are typically used to assess likely perceptibility of low frequency wind farm noise), suggest to the authors that the low frequency and infrasonic components of wind turbine sound could be more readily perceptible than is normally assumed. (The standard human perception curves are derived by playing pure-tone sounds at carefully controlled dB levels; this method suggests a perceptual threshold for infrasound in the range of 95–100dBG).

In addition to the very rapid pulses of sound over 90dBG (and much more often over 80dBG), which occur over a span of about 60ms, Bray and James reported several other variations in sound levels that they suggest may aggravate or increase the annoyance responses in nearby neighbors. They found tone-like higher sound levels at 30, 75, and 150Hz, pulsing a bit louder once per second (which corresponds to the "blade-pass rate," the rhythm at which one of the three blades either passes the tower, or sweeps across the top of its rotation, through higher wind speeds). And, they noted several other "periodicities," or fluctuations in sound level, including periods of 6–9 seconds of higher sound levels that came and went unpredictably (*Ed. note: perhaps corresponding to periods of high inflow turbulence*) and blade-pass rate sound peaks that varied in several frequency regions over time periods of less than a second, several seconds, and several minutes. This variability in the audible sound levels is likely a key reason that turbines trigger more annoyance than other noise sources.

I'll be very interested to see what other acousticians make of this new data, particularly the discovery of very rapid fluctuations and high peaks in the low frequency dB levels. It appears to my untrained reading that this is important new information, though I am far from conversant in the arcane details of short-time-period considerations of either human perception or sound levels. And while they didn't find peak dBG levels above the classic perception curves (though they were close), these field measurements clearly confirm that infrasound is present at relatively high and very dynamic levels in wind farm noise. Time and further research will tell whether this is part of the reason why wind farm noise seems to trigger more annoyance than other sound sources at similarly moderate average dB levels. I should also note that this paper makes no claims about health effects being triggered by the infrasound levels; its focus is on the fine-time-scale structure and sound levels of the measured wind turbine noise and the relation of their findings to human perceptibility.

Ed. note: While Hessler, below, suggests all infrasound recordings are contaminated by wind on the mic, Bray notes that his binaural mics provide a means to identify wind noise, which would be subtly different on each mic; and, the pulses of sound in synch with the blade-pass rate are clearly not wind noise.

Another study just released by two longtime noise control engineers, Stephen Ambrose and Rob Rand, offers a close look at noise levels and health effects, while also providing some detailed sound data that complements the Bray/James work.

This report is being circulated from Rand's consultancy website, so unlike the others here, is not peer reviewed, but the authors are operating exactly in the area of their decades of expertise, and the reporting is detailed enough to be worthy of full consideration. It presents a very short-term assessment of a particular location in Falmouth, Massachusetts where the resident was experiencing sleep disruption, headaches, and the like, located 1700 feet from a single operating turbine (a 2nd turbine nearby was shut down in high winds as a noise mitigation for neighbors). The authors were on-site for a bit under two days, and were surprised to experience the disorientation, difficulty in focusing, and sleep disruption reported by many Falmouth residents; they note that they are both prone to motion sickness, which may indicate some vestibular sensitivity. Since the authors had not experienced such reactions before in decades of noise control and monitoring work, they feel that their physical reactions give credence to the connection between health and focus/attention issues and exposure to the wind turbine's sounds.

Again, this paper contains much detail worth reading and evaluating for yourself, and I'll just mention several key points. They note a clear correlation between their physical symptoms and both the wind speed and the power output of the turbines; a correlation with the dBG sound levels is suggestive as well, with ill effects more prominent with higher dBG levels, and at times with dBG pulsations (they felt fewer ill effects when dBG variation was random). As interesting as their fatigue, headaches, and lack of appetite may be – especially since they occurred without the stress, anxiety, or other personal responses to turbines that are commonly posited as the sources of reported health effects – this is clearly a very short period of study with just two (unplanned) subjects. While providing a solid indication of the value of further similarly targeted research, this study alone is far from definitive proof of a direct health and turbine noise link at this point.

Near the end of their paper, however, the authors make an interesting observation. They note that the ramping-up onset of symptoms that they experienced, along with the more gradual dissipation of the symptoms after they left the site, both mimic a classic dose-response relationship; they suggest that the peak sound pressure events, which occurred on average once every 1.4 seconds, often over 60dBG (as reflected in their detailed measurements discussed below), can be considered the recurring "dose" that triggered their "response." They mention a standard dose-response equation for considering cumulative effects that could be used to explore this idea further.

Some of the actual sound measurements that were made are also particularly valuable. Their measurements found two tones with higher sound levels, at 22.9Hz and 129Hz; these are both low-frequency, not infrasound. The authors note that both tones exceeded the Outer Hair Cell stimulation threshold proposed by Alec Salt, both indoors and outdoors. They also point out that 22.9Hz lies at the high end of the range of the brain's "beta waves," which are associated with alertness, concentration, and active thinking.

Interestingly, a closer analysis of the 22.9Hz tone shows a high variability in peak levels as also found by Bray and James; in this case, the average sound level was 50dB (unweighted dB I believe, but unspecified in the paper), with faster time sampling showing sound ranging from 15 to 60dB over the course of just a second, with a rapid peaks occurring every 40ms or so. And, at this location, 1700 feet from the turbine, dBG levels were often over 60dBG indoors, and consistently over 60dBG outdoors. (some critiques of Salt's proposed 60dBG threshold for hair cell response to infrasound, including O'Neal, above, point out that Salt's examples of turbines producing these levels were taken much closer to turbines, with the implication that 60dBG is unlikely at typical residential distances over 1200 feet or more).

Finally, the authors made measurements at increasing distances from the turbine (268ft, 830ft, 1340ft, and 1700ft), and report that while the dBA decreased at a standard 6dBA for every doubling of distance (the assumption used in most sound modeling), the unweighted sound levels (dBL) dropped at only 3dB per doubling distance, due to the slower dissipation of lower frequency components of the sound. And most interestingly, while at 1700 feet, the measured dBA was much lower indoors than out (43dBA outside, 21dBA inside), the unweighted sound level was actually higher inside than out (75dBL outside, 79dBL inside).

This affirms many residents' reports that the low frequency sound can be more noticeable, and more bothersome, inside than outside their homes. As the authors note: "Despite the apparent increase in energy indoors, the wind turbine was almost inaudible indoors. The house envelope blocked most of the frequency content above 10 Hz, and amplified the remaining low frequency pulsations....The acoustic pressure swung from positive (compressed) to negative (rarefied) 0.2 Pa peak-to-peak." As they note, residents often say they experience these low frequency pulsations as if they are living inside a drum.

A recent addition to the pile of papers was David Hessler's comprehensive guidelines for assessing sound emissions from proposed and completed wind farms, prepared for the Minnesota PUC and funded by the US DOE.

A few things stand out here. First and foremost is the claim that all low-frequency and infrasound recorded near wind farms is simply flow noise of wind on microphones. Again, I'm not an acoustician or engineer, so can only make a few comments on that; you may want to read his logic yourself. He notes that tests of wind screens in quiet wind tunnels show high levels of LF and infrasonic noise (up to 70dB, unweighted at the lowest frequencies); he likewise presents some data showing near-identical dBC readings (averaging time not noted) at a residence surrounded by wind turbines and a location several miles from the wind farm, both of which vary with wind speed, and are seen by Hessler as further evidence that the dBC readings are nothing but wind noise.

Ed. Note: I can't help but note that the dBC levels reported by Hessler, as well as the dBC and dB L levels reported by Bray/James and Rand/Ambrose are well above the air-flow noise Hessler reports from the wind tunnel; this implies that there is additional low-frequency noise occurring above and beyond any microphone contamination noise. Also, much of the low-frequency and infrasonic sound measured at faster time scales (by Bray/James) show clear patterns in synch with the blade-pass rate, which would not be seen in air-flow noise on the mics. Finally, the problem of air flow on the mics can be bypassed by recording at times when wind is very low at the ground/recording level, and high at hub height. And, binaural systems (such as those used by Bray/James) allow a comparison of the two channels; wind noise will tend to be somewhat different at each mic, showing up as some incoherent measurements between the two, while turbine noise will be synched or similar in each mic (if the data shows perfect coherence between the two mics, you can be quite sure there is no wind noise contamination).

Beyond the low-frequency data and suggestions presented by Hessler, this set of guidelines includes several general recommendations for non-low-frequency noise that are worth noting. Most strikingly, the guidelines suggest keeping average dBA sound levels to 40dB at homes, and urges site plans that include many homes in the 40-45dB range to be adjusted to minimize the number of homes receiving more than 40dBA. They also stress that for locations with ambient levels over 35dB (which includes most rural locations during the day),

it is important to keep turbine noise to no more than 5dB louder than ambient; this is in contrast to many locales where 10dB over ambient is allowed. Both of these recommendations are based on reported annoyance and complaints at existing wind farms; while not going "all the way" to a 30 or 35dBA limit as suggested by some, this downward shift from today's norm of 45dB or more is notable.

Relatedly, Hessler stresses that the use of a mean sound level (full day and full night, or perhaps even full day-night 24-hour averages) is necessitated by the fact that sound levels vary quite notably, making peak levels difficult to predict and peak limits difficult to enforce:

Extensive field experience measuring operational projects indicates that sound levels commonly fluctuate by roughly +/- 5 dBA about the mean trend line and that short-lived (10 to 20 minute) spikes on the order of 15 to 20 dBA above the mean are occasionally observed when atmospheric conditions strongly favor the generation and propagation of noise. Because no project can be designed so that all such spikes would remain below the 40 or 45 dBA targets at all times, these values are expressed as long-term mean levels, or the central trend through data collected over a period of several weeks.

Indeed, they also present some compelling graphs showing actual noise levels as the wind speed increases, which show that there is typically a 20dBA range of noise level at any given wind speed; this represents both variation in how strong the wind and ambient rustling of grass and leaves is when hub-height wind is creating turbine noise, and the impacts of various atmospheric conditions that change the noise level at the turbine and sound propagation in the surrounding environment.

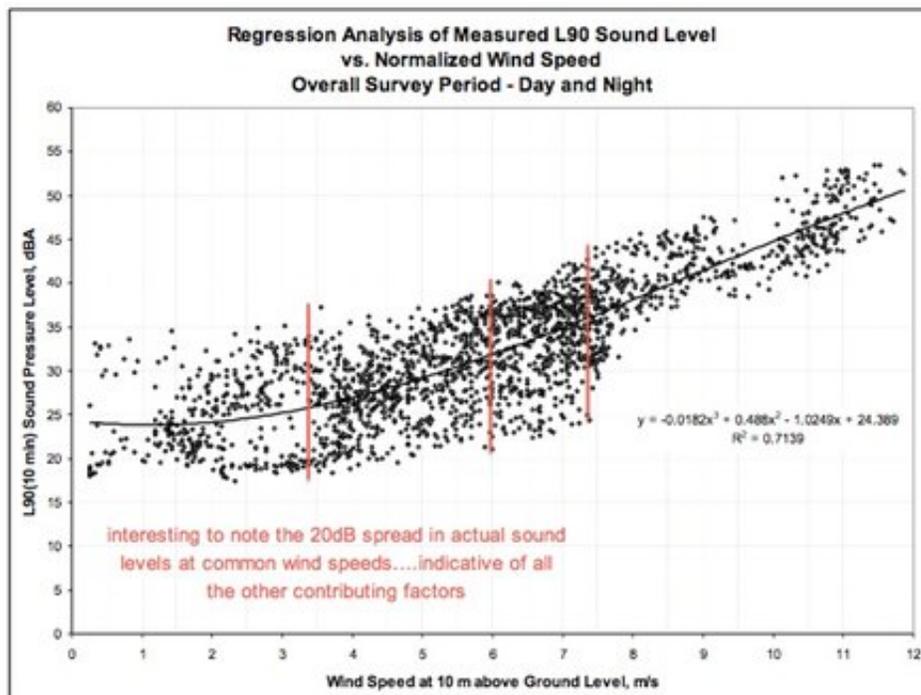


Figure 4.4.1.3

Hessler notes that "the possibility, even likelihood, that project noise will occasionally spike

for short periods should be factored into regulatory limits....As a suggestion, it seems reasonable to conclude that a project is in compliance with an absolute regulatory limit if the measurements indicate that the project-only sound level is lower than the stated limit at least 95% of the time..."

Ed. note: While this seems logical, we should note that 5% of the time over the limit can translate into a chronic experience for neighbors, and may create significant impacts when added to an already potentially marginal regulatory limit of 45dB or even 40dB, where "over the limit" can mean 10dB or more over background ambient. Five percent of the time translates to 72 days with 6 hours of excessive noise (20% of days), or 219 days with 2 hours of excessive noise (60% of days). For this reason, I'd lean to seeing this acknowledgement of the impracticality of 100% absolute limit be seen as a reason to set a somewhat lower average limit. If the limit were 30–35dB, it may be that we could tolerate more "over-limit" time, up to 10% or more.

The final take-away of note from Hessler's assessment guidelines is the fact that Leq, or average sound levels, even at short 10-minute averaging times, is not appropriate for assessing existing background ambient noise levels or project sound levels; instead, Hessler stresses the use of the L90 level, representing the dB level that is exceeded 90% of the time, as more able to discern actual ambient levels and project noise levels (though again, he proposes long averaging times for the L90 noise criteria).

As I was completing this summary of recent low-frequency noise reports, a new one was released; while actually written in late 2010, in December 2011 the **Ontario Ministry of Environment released a literature review on low frequency noise and infrasound written by HGC Engineering**, a noise consultancy.

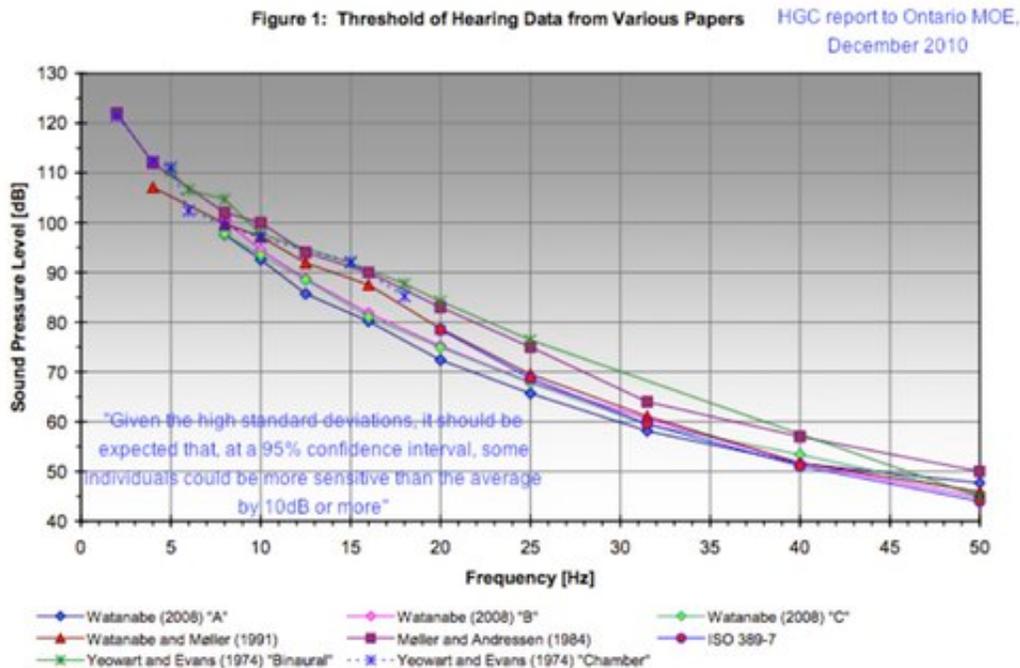
As usual, I urge you to check out the full report for more detail; the general tone and findings follows from most other similar overviews, concluding that while wind farms produce plenty of audible low-frequency noise, the infrasonic frequencies are below the levels necessary for human perception. **At the same time, though, the report contains a number of details that, to my eye, reinforce many of the other reports here in justifying the raising of a cautionary yellow flag, rather than relaxing into assurance that there are no low-frequency and infrasound issues to be further explored.** In particular, the literature references and recommendations dealing with low frequency sound inside homes, and the detailed references regarding wide individual variability in low frequency and infrasonic perceptual thresholds both bear close attention.

The Ontario report stresses the need to assess indoor low frequency noise, since many complaints come from folks who are more bothered inside their homes than outside. The Ambrose/Rand study (above) provides some initial data that confirms this experience. The HGC authors cite studies showing that transmission loss through walls is zero or near zero in low frequencies and infrasonic ranges (in contrast to the commonly assumed 15dB reduction in dBA full-spectrum sound). When combined with studies, also cited here, affirming just a 3dB reduction in lower frequencies with doubling of distance (rather than the 6dBA reduction presumed in most sound modeling, which focuses more on higher-frequency audible sound), the likelihood that neighbors at distances beyond 500m–1km may be experiencing elevated low-frequency sound in their homes becomes quite clearly understandable.

Because of "the significant variation in sound impact from house to house as a function of

room layout and sound transmission characteristics," the HGC team recommends that MOE develop a protocol for assessing noise indoors. The report notes that best practices for indoor recording are still in development; it is challenging, since sound levels can vary by 20–30dB in different parts of a room (due to complex interactions of sound reflected from the walls, floor, and ceiling). One current best-practices approach is to average the sound of 4 points in the floor or ceiling corners of the room.

This report presents a good, clear graph of the various studies of perceptual thresholds for low frequency and infrasound:



A few things bear noticing here. These curves show hearing thresholds only at very low frequencies (below 50Hz), and are measured in unweighted dB (which is sometimes called dBL and sometimes dBZ, and sometimes, just dB). The authors note that some (few) individuals are expected to be more sensitive than these curves "by 10dB or more." You can see the 95–100dBL thresholds at 10Hz, which dominate the dBG levels that result in the same threshold; remember here the Bray/James data showing dBG peaks of over 90dB, and more often, over 80dB.

Remember that these curves are the average thresholds found in each of these 8 different studies, and that the studies use simple pure tones at each frequency, gradually increasing the volume/amplitude of the sound until the subject reports being able to hear it. Bearing this in mind, the HGC report has a good set of literature summaries that address the individual variability within each of these average curves.

Individuals' hearing thresholds tend to not be nearly as smooth as these group averages would suggest; in fact, these studies show "an extremely diverse range of individual responses to low frequency noise." In some individuals, the curves flatten out at some of the lower frequencies rather than rising so sharply. Several other studies (not hearing/threshold tests) found sounds being perceived at levels below these traditional thresholds, especially

when there is a combination of tones and frequencies more complex than the simple pure tones used in the threshold studies. *(Ed. note: Of course, wind farm sounds are also far more complex, with some tones and rhythms/pulses, and an overall sound that encompasses a broad spectrum of frequencies.)* HGC cites another lit review, by Schust (2004), which "highlights a few papers which identified possible effects ('somnia, irritability, tiredness, tense and restlessness') which were associated with infrasonic noise at levels below (although close to) a level equivalent to the mean threshold of hearing less one standard deviation." *(Ed. Note: i.e., not just below the classic mean threshold, but just below a standard deviation quieter than that...which may really bring the Bray/James data into play)*

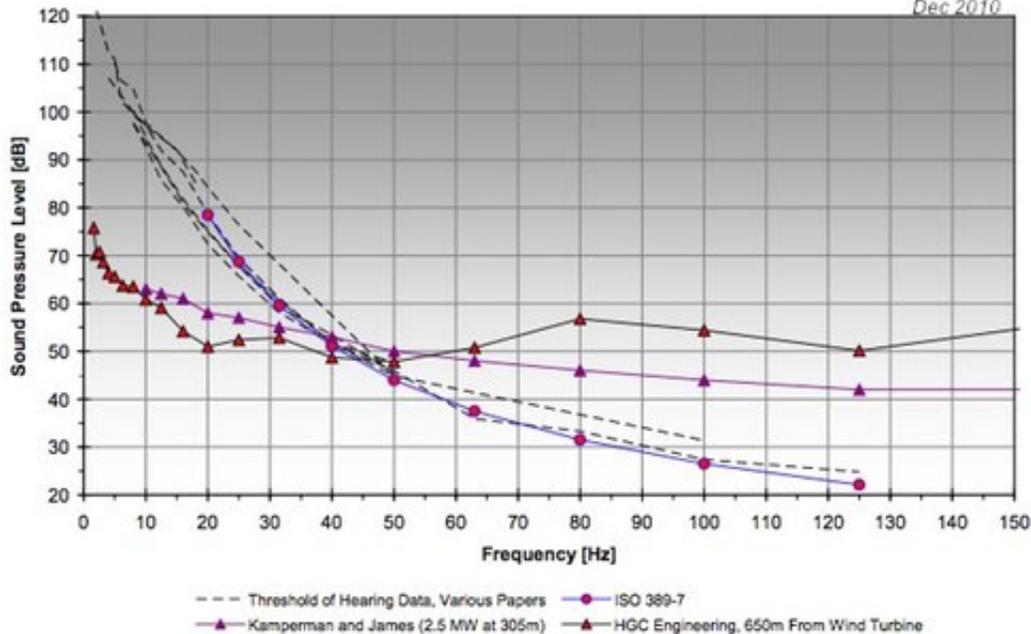
In sum, the HGC/Ontario report stresses that "it is clear that some caution is needed when judging the audibility of sound which approach the mean thresholds of hearing." Yet they also concludes that, below 20Hz, "sound pressure levels produced by modern upwind turbines will be well below (on the order of 20dB below) the average threshold of hearing, at the setback distances typical in Ontario." (setbacks are 550m/1800ft; bear in mind that beyond here, infrasound will drop by only 3dB per doubling distance, so that at 1.1km/3600ft, sound will be perhaps 23dB below the average thresholds). *Ed. note: To my eye, given the individual variability noted in this report and the emerging study of peak, rather than average, infrasound and low-frequency noise levels, this relatively close gap between (average) infrasonic and (average) hearing thresholds does suggest that peak sounds could easily approach the average thresholds and be above some individuals' thresholds.*

This report also notes the infrasonic sound levels of other things people are commonly exposed to, including riding in trains (with extreme infrasound, up to 150dB, as they enter and leave tunnels), and riding in a car, which commonly exposes us to over 100dB of infrasound. This may be reassuring, since even peak levels at homes near wind turbines are significantly lower. *(Ed. note: However, these reassurances don't take into account the difference between a few seconds of train/tunnel exposure, a few hours of being in a car (which most of us can affirm leads to mental and physical discomfort/fatigue), and chronic exposure at one's home. And more importantly, if the Bray/James and Ambrose/Rand data is representative of other locations, the rapidly pulsing nature of the infrasonic sound from turbines may well be of an entirely different nature, contributing to the fatigue and focus issues reported by Ambrose and Rand, even at lower intensities than we experience in trains or cars.)*

The HGC report also addresses the challenges of getting accurate low-frequency readings in windy conditions, as Hessler stresses. But rather than joining Hessler in considering low-frequency and infrasonic readings to be entirely unreliable or impossible around wind farms, HGC notes several approaches, including a NASA-designed wind screen and an in-ground system, both of which allow for accurate infrasonic readings, though they distort or miss higher frequencies. Indeed, while the HGC report concludes that infrasound is unlikely to be an issue, so need not be routinely measured as part of project permitting, they also note the ongoing investigations taking place by acousticians (as well as the public apprehension), and recommend that MOE adopt measurement procedures for infrasound, to be used in specific situations – presumably, when complaints arise, and perhaps also to provide for better comparison between studies that are performed in the coming years.

Finally, this graph presents a pretty good overview of the relationship between wind farm noise and hearing thresholds:

Figure 3. Example Sound Level Data at Low and Infrasonic Frequencies HGC report to
Ontario MOE,
Dec 2010



A few things are worth noticing here. The dotted lines show the same hearing threshold curves we saw in the previous graph, with an International Standards Organization standard overlaid on them; the two other curves, marked with triangles, are actual measurements of wind farm noise. The first thing I noticed was that the two studies of wind farm noise plotted here show surprisingly little difference in overall sound levels between 305m/1000ft (Kamperman and James) and 650m/2100ft (HGC) – this may reflect differences in the local topography or turbine size, or could be a reminder that simple sound propagation models (which would suggest that the darker triangles from HGC should be routinely 3–6dB below the purple Kamperman/James data) are not as reliable as we might wish. We can expect, once again, these low-frequency sound levels to continue to drop only 3dB at 4200ft, and 6dB at 8400ft.

The graph shows lots of easily audible low frequency sound from 50Hz on up, while it is likely that some individuals would be sensitive to the wind farm sound levels shown here at 25–50Hz. (Note that even these lower frequencies are not infrasound, but borderline-audible low frequencies.)

If we add to this graph the reminder noted by HGC of "strong, audible low frequency (but not infrasonic) tones from some turbines," it once again comes into clear focus that the lower frequency parts of the wind turbine sound spectrum are likely to be key factors in triggering annoyance among neighbors.

Ed. note: While some reports, including this one, tend to suggest that leaf rustling and wind in trees and ears will mask these lower frequencies (which are not that much above our hearing thresholds), the experiential reality in most situations is that the turbine noise remains clearly audible at a lower frequency than the wind and rustling sounds in vegetation; while the absolute dB levels may match or suggest that the turbines would be masked, the higher frequencies of the leaves do not in fact mask the generally lower overall frequency

content of the turbines.

Finally, I want to mention a brief summary included in the HGC report of a very interesting detailed study by Møller, CS Pedersen, and Persson-Waye, which investigated a randomly selected sample of 21 cases of low-frequency noise complaints from a pool of 203 cases (these were not wind farm noise locations; just homes where people reported a bothersome low frequency noise). The study involved making recordings of sound in the homes of the complainants, after which the subjects were exposed to the sounds in blind listening tests at a low-frequency test facility. The study concluded that some of the complainants were annoyed by physical sounds, and others were suffering from low frequency tinnitus. That is, this latter group did not hear or respond to the actual sounds recorded in their homes. The authors stressed that physical sounds in the infrasonic range were not found to be responsible for the annoyance in any of the cases, which means that the ones who did hear and respond to the sounds recorded in their home were in fact being bothered by low-frequency noise, rather than infrasound.

Ed. note: of course, this is not evidence that no infrasound-related complaints are valid, especially if considering the new measurement methods being used by Bray/James. But we also must be cautious not to simply assume that the Bray/James work, or the Ambrose/Rand work (where the infrasound peaks were significantly lower than Bray/James) can be instantly and broadly applied to presume that any situation reporting no infrasound issue is inherently invalid, just because these new methods were not employed. Science moves slowly, to be sure, but it does move as evidence accumulates and is affirmed elsewhere. It's important to note the newest studies, but there needs to be far more investigation, using similar methods in different situations, before these provocative new results could support widespread changes in policy or standards.

While supporting the current Ontario MOE approach to wind farm noise assessment, which relies exclusively on dBA measurements, with penalties for tones, "which often occur in the low frequency range," the HGC report stresses that "there is a degree of disagreement and uncertainty in the literature of some of the subjects discussed in this review, and research efforts are ongoing." They recommend that any low-frequency or infrasound policies adopted by the province of Ontario should have some built-in flexibility, so as to incorporate new research findings in the future.

Okay, almost there! Just three more, each much shorter summaries than those we've covered so far.

Knopper and Olsen's paper in Environmental Health, which is a literature review of health effects of wind turbines, affirms the conventional wisdom that the noise from wind farms is not loud enough to directly trigger physiological reactions.

They do note that annoyance and sleep disturbance "have been statistically associated with wind turbine noise especially when found at sound pressure levels greater than 40 dB(A)," which lines up well with the emerging consensus we see in the mainstream papers here, encouraging project planners to limit exposures above that level at nearby residences. This annoyance and sleep disruption is also correlated with visual impact and attitudes to the

local wind farm, as well as to general noise sensitivity. This literature review largely suggests that most of the annoyance reactions and health effects are caused indirectly, via anxiety or annoyance about the wind farm, citing a long history of studies of other community noise sources that show similar links between health effects and attitudes.

One key point in this paper caught my attention: this idea that most health effects are due to various cognitive stresses means to the authors that "it appears that it is the change in the environment that is associated with reported health effects, not a turbine-specific variable like audible noise or infrasound." What leapt out at me from this is that the change in the environment IS a "turbine-specific variable," the wind farm itself! Even if the sound is not directly triggering health issues (noting that these reviews of previous literature do not include any recent work on short time-averaging and higher peak levels), what we are seeing is that for many people, their sense of place and home is of such importance that the arrival of a wind farm in their rural landscape triggers a strong negative response that encompasses aesthetic, stress, sleep, and quality of life issues. Acknowledging that the change in the environment is a substantial impact in and of itself is an important insight to bear in mind.

A fascinating paper by Kroesen and Shreckenberg appeared in the Journal of the Acoustical Society of America in early 2011, which proposed a multi-faceted approach to understanding why noise can be annoying to people at their homes.

The paper focused on aircraft noise, but would seem to be applicable to our emerging inquiries into wind farm annoyance issues as well. Again, reading the paper itself is recommended, as it draws from rich research streams in psychological acoustics which cannot be adequately summarized here. The nut of it is the authors' suggestion that what they term a "general noise reaction" (GNR) can be calculated from assessing several different aspects of the individual's response to the noise source. "Residential satisfaction" and "perceived health" (both mental and physical health) are seen as being outcomes of the GNR, which has three main types of contributors: traditional noise annoyance, activity disturbance, and anxiety and fear related to the noise source. Activity disturbance can include specific activities such as relaxation, reading/concentrating, "domestic coziness or visitation," and sleeping. Anxiety and fear includes such factors as concern about stress-related health effects or impacts on property values. Overall, the authors found that mental health was more than twice as strongly affected as physical health, based on the GNR ratings obtained from their study, with direct noise annoyance and activity disturbance being the dominant factors, "while the anxiety and fear dimension operates at a more distant level."

This seems to be an important finding, for it is one of the more detailed investigations of the underlying factors in noise reactions; all too often, subjective factors such as anxiety, fear, and prior attitudes are assumed to be the primary drivers of negative reactions to wind farms, based either on assumptions or on simpler survey results. This study seems to point to more concrete experiences such as the noise itself being bothersome or intruding into valued activities as the core factors.

With the exception of the Pedersen non-clan in Scandinavia, most of the best-known research and reports on wind farm noise have come from the US and Canada. But a lot of important work is ongoing in Australia and New Zealand as well, where several large wind farms have spurred widespread complaints at greater distances than we commonly hear about elsewhere (2-4km). Bob Thorns is one one of the acousticians there who has

investigated wind farm noise in as much detail as anyone here; his Ph.D. thesis on perception and annoyance in response to moderate noise plowed some very fresh ground.

This year, Thorne published a paper that addressed *The Problems with "Noise Numbers" for Wind Farm Noise Assessment* that introduced a new hypothesis worthy of serious followup study: the concept of heightened noise zones (HNZ) as a key driver of unexpectedly high levels of annoyance.

Thorne predicates this paper on a key, fundamental observation:

Wind farms and wind turbines are a unique source of sound and noise. The noise generation from a wind farm is like no other noise source or set of noise sources. The sounds are often of low amplitude (volume or loudness) and are constantly shifting in character ("waves on beach," "rumble-thump," "plane never landing," etc.). People who are not exposed to the sounds of a wind farm find it very difficult to understand the problems of people who do live near wind farms...

This paper includes much of interest (including some consideration of health effects), but again, I'll focus in on just a few of its themes. There is a significant amount of focus here on the elevated low-frequency "thumps" experienced inside homes, generally 1.5–2km (5000–6500ft) from turbines. As Thorne notes, "Low-frequency sound and infrasound are normal characteristics of a wind farm as they are the normal characteristics of wind, as such. The difference is that "normal" wind is laminar or smooth in effect whereas wind farm sound is non-laminar and presents a pulsing nature." Residents studied by Thorne often report that the low-frequency sound is noticeably worse in their homes it is outside. Even more surprising, and frustrating for some residents, "rooms in a residence can and will show significantly different characteristics. What may be inaudible or not perceptible in one room can be easily heard or perceived in another room on the same side of the house."

Like many others, including the Hessler guidelines report above, Thorne stresses the wide variability in noise levels at different times, leading to his conclusion that "wind farm noise level predictions can therefore only be considered as approximations and cannot be given any weight other than this." More specifically, he notes that in sound modeling,

the predicted values are given as a range, ± 3 dB(A) at 1,000 meters for the most common prediction method with the predicted value being the "middle" of the range. The uncertainty increases with distance and the effect of two or more turbines operating in phase with a light/strong breeze blowing toward a residence. A variation of 6 to 7 dB(A) can be expected under such adverse conditions. Thus, on any given day the wind farm background LA95 or "source" time-average (LAeq) sound levels—assuming the wind farm is operating—could vary significantly in comparison with the predicted sound level. This is without the additional effect of any adverse wind effects or weather effects such as inversions.

As noted by Hessler, when considering all such effects, peaks of up to 20dB over the predicted (modeled) levels can be expected.

Thorne has monitored sound levels at many homes around a mile from wind farms. He notes that "in 60 seconds the sound character varies regularly by more than 20dB" and that "Sound from wind farms can easily be heard at distances of 2000 meters (1.24 miles); such

sound was measured...over the range 29 to 40 dB(A) with conditions of calm to light breeze. The sound was modulating and readily observed and recorded. The sound can be defined as being both unreasonable and a nuisance." (*Ed. note: it's worth noticing these 40dB peaks at over a mile away; most sound modeling will suggest that such levels are common only within a third to half mile or so of turbines*)

Thorne also notes that he has often observed what he calls heightened noise zones, which "can be small in extent—even for low frequencies and infrasound—leading to turbine sounds 'disappearing' and 'appearing' in areas spaced only a few meters apart. The concept of HNZ goes a long way in explaining the problem of wind farm noise and its variability on residents." (*Ed. note: I've heard similar anecdotal reports from many residents and visitors to wind farms, though this is the first paper I've seen that's addressed this important and confounding factor*)

As an initial hypothesis, Thorne suggests that these HNZs are generated in part by the air vortex traveling downwind from turning turbine blades, which "travels downwind in the form of a helix, rotating about its axis with each vortex replacing the previous one in space at approximately 1-second intervals." If they encounter another turbine within 10 rotor diameters (1160m/3800ft for a 2.5MW turbine), these vortices can cause turbulence that increases the noise output of the second turbine; in addition, they continue downwind with lesser power for much greater distances. Thorne hypothesizes that these vortices and the increased sound they trigger in nearby turbines interact with the less directional audible sound waves emanating from each turbine, lensing in the air or ground, and interference between turbines' noise (audible) and vibration causing very localized patches of heightened noise and/or vibration. He reports that "the effect has been consistently measured at a residence 1,400 to 2,000 meters (roughly three quarters of a mile to a mile and a quarter) downwind from a row of turbines."

All of this leads Thorne to conclude that any compliance criteria based on a single value (including a low 35dBA Leq, a higher 40dBA L95, or an ambient-plus 5dB) are ineffective and "unacceptable" as protection from noise nuisance, because "current noise prediction models are simplistic, have a high degree of uncertainty, and do not make allowance for" the sorts of variables and effects reported above.

If all noise measurements are invalid, I'm not sure where that leaves us, in terms of generating siting policies. Thorne suggests setting siting standards based on observed reactions by residents, including sleep disturbance, anxiety, and stress, and suggests that these reactions are likely to begin to crop up as sound levels rise above 32dBA (Leq) outside homes, or above the individual's threshold of hearing inside. He concludes that setbacks of up to 3.5km may be necessary to achieve these low sound levels at homes, though also proposes that "no large-scale wind turbine should be installed within 2,000 meters of any dwelling or noise-sensitive place unless with the approval of the landowner."

This latter proposal dovetails nicely with an emerging "cautionary" consensus of trying to keep noise at non-participating neighbors homes to no more than 35dB. As AEI often emphasizes, such limits need not preclude development if they also include provisions to allow closer siting to neighbors who don't mind hearing turbines more often or more noticeably.

Phew! We made it. I appreciate your diligence in reading all this through, and

hope you'll agree that the details found in this wide-ranging set of papers add some important and helpful perspectives as we try to understand why wind farms are triggering more annoyance than most other community noise sources.

While the possible role of infrasound in community responses remains highly contentious, I'm struck by the increasing acknowledgement of the importance of low frequency components of wind farm noise (especially inside homes), and the move toward lower (40dB) noise limits even among mainstream acousticians. It appears that the common U.S. regulatory standards of 45–50dB are no longer considered appropriate in many situations, especially because of the low frequency considerations. While many acousticians continue to recommend limits of 30–35dB to effectively eliminate noise complaints, I'm struck by how the gap between the mainstream and cautionary views is rapidly shrinking. This bodes well for a more positive dialogue on these subtle but important questions surrounding noise annoyance, quality of life, and wind farm siting guidelines.

Even 40dB standards will require a new level of collaboration between wind developers and host communities – and in this lies the possibility of a gradual move toward what AEI sees as the obvious win-win path forward: adoption of lower noise limits (which will likely vary by community, based on the local sense of place and tolerance for moderate noise), in combination with negotiated easements allowing closer siting to homes where the residents don't mind somewhat higher noise levels.

Time will tell how siting policy will evolve, but it's clear that the conventional wisdom is shifting. Ongoing research and more informed public debate are likely to keep the process of learning, listening, and experimenting very interesting in the next few years. Here's to a constructive dialogue in 2012 and beyond!

Appendix B: Addressing Wind Farm Noise Concerns

By Jim Cummings, for inclusion in the proceedings of
Renewable Energy World North America, December 2012

In the past several years, as wind energy development expanded from the plains and west, into rural areas with fewer working farms and ranches and higher population densities, complaints about wind turbine noise have become more common. Initially, based on experience in ranching communities where sound levels of 50dB and more were easily tolerated, noise complaints were often seen as a surrogate for broader NIMBY attitudes or as the habitual response of local complainers. But over the past year or two, as it's become clear that some residents are experiencing genuine annoyance and stress responses to "normal" wind turbine noise levels, developers have been seeking new ways of working with noise concerns. Paul Thompson, commercial director of Mitsubishi's wind turbine group, has said, "It's on the top of the minds for all manufacturers. We're all doing things to reduce the amount of noise that's generated." (Beniwal, 2011)

At the 2012 AWEA Project Siting seminar, John Anderson (AWEA Director of Siting Policy) noted that siting controversies can damage "wind's brand" and create attitudinal obstacles among citizens or political leaders. While bird and bat mortality have long been at the forefront of such challenges, concerns about wind turbine noise have rapidly ramped up in many areas where new development is proposed, to the point that in some types of communities, addressing noise concerns has become a primary consideration during planning, permitting, and operation of new wind farms. Wind farm operators are experiencing an uptick in the number of projects that trigger post-construction noise complaints in communities; often, the degree of annoyance being reported is unexpected at the distances where complainants live. Even more impactful, complaints at some wind farms have spurred a widespread rise in community resistance to many new projects. (It's important to stress that post-construction noise issues arise in only a small minority of wind farms overall; such problems seem to occur more often around projects in areas with a significant population within earshot.)

Within this context, most project developers have moved past earlier assumptions (and public assurances) that turbines will be inaudible at nearby homes, or will always be masked by nearby wind-driven ambient noise in leaves, bushes, or ears. Efforts are increasing to better understand, predict, and communicate the variability in turbine noise output, as well as to reduce the noise generated by turbines. In addition, ongoing research is investigating the ways that turbine audibility may be experienced by nearby residents (how far, how often, the quality of the sound, annoyance rates). This paper summarizes current research aimed at reducing the community noise impacts of wind farms, including:

- Passive noise reduction blade design
- Active aerodynamic load control
- Noise-reduced operation protocols
- Conditional curtailments
- New research on inflow turbulence and turbine wakes
- Low-noise brake linings
- Cooling fan noise mufflers

- Adapting to variable levels of noise sensitivity in different types of communities

An extensive list of references will provide access to more detail on each of these ways that wind farm noise concerns are currently being addressed.

Turbine noise reduction as primary goal

Reducing the source level of the sounds made by wind turbines is the area in which the greatest strides have been made to date. The two primary lines of research and implementation have been in the evolution of equipment design to reduce mechanical noise and trailing-edge aerodynamic noise during normal turbine operation, and in the development of Noise Reduced Operation (NRO) protocols for use in situations where local noise standards cannot be met during full power operations.

Mechanical noise

Mechanical noise, primarily from gears and fans in the nacelle, has been largely addressed in the past two decades, to the point that it is rarely the source of noise complaints or siting limitations. However, continued improvement is always the name of the game, especially when siting relatively close to homes. A recent example is this past summer's addition of noise-muffling louvers on the 23 turbines at the Pinnacle Wind Farm in Keyser, WV, after several neighbors along the road below the ridgeline complained of excessive noise. Likewise, several brake manufacturers are developing new linings that are being designed specifically for noise reduction in comparison with standard linings.

Aerodynamic blade noise

Aerodynamic noise from the trailing edge of turbine blades is the primary noise source of most modern turbines. This is generally a broadband noise, though most notable at frequencies of 700Hz to 2kHz. A range of design modifications are being developed by most turbine manufacturers, including shape of the airfoil, tip modifications, vortex generators along the fin's crest, and porous or serrated trailing edges. Serrated edges appear to be the most widely studied, with overall noise reductions of 3-8dB being reported (Barrone, 2011). However, many studies have found that these reductions are frequency-dependent, with reductions in low-frequency noise and increases at higher frequencies (over 2kHz). Serrations may be less effective at low or moderate wind speeds; in some situations, this can be when neighbors find turbine noise most audible.



During its first summer in operation, the three Fox Islands Wind turbines on the island of Vinalhaven, ME, were retrofitted with serrated edges as part of an effort to reduce noise impacts

on neighbors (photos above by Charlotte Goodhue). No formal study of the effects has yet been released, though neighbors report that the serrations seemed to moderate the lower-frequency thumping element of the sound, while slightly increasing the overall whooshing aspects, as the studies summarized in Barrone might suggest (personal communications, 2012).

Operational adjustments

In some situations, turbines operating at full power either cannot quite meet local noise criteria, or continue to trigger complaints even while in compliance. To address these cases, wind farm manufacturers have developed Noise Reduced Operations (NRO) or Noise Reduction Systems (NRS), which are software-driven operational protocols that aim to reduce noise with minimal reductions in power output. These systems typically combine changes in the pitch angle of the blades and reduction in RPMs, and can be set to achieve the desired noise reduction, often from 1dB to 4dB. Power losses are modest at moderate wind speeds when aiming for 2dB noise reduction, and increase with additional noise reduction and at higher wind speeds (Leloudas, 2007; see images below from NRO applied on a 2.3MW turbine). Such settings are often used to meet reduced nighttime noise criteria, or to adjust a few turbines within a larger wind farm that are closer to neighbors (for example, one of the three Fox Islands Wind turbines routinely operates in NRO 1dB mode).

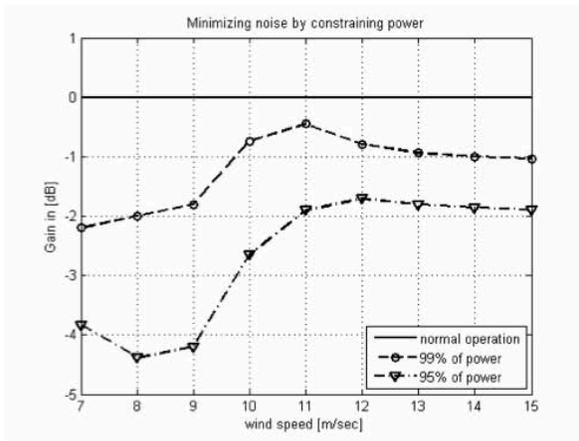


Figure 8: Noise reduction in dB(A) as a result of optimization at different wind speeds.

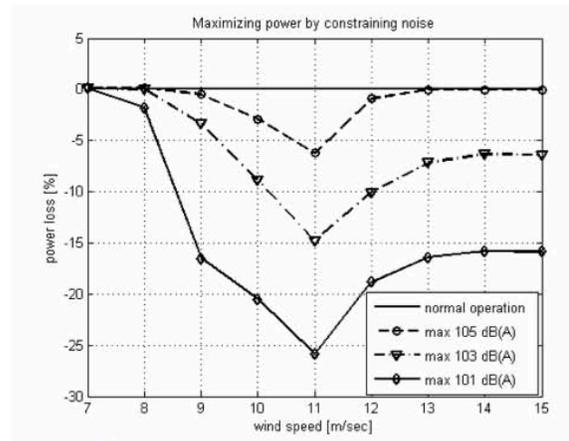


Figure 9: optimized (minimum) power losses for different noise constraints at different wind speeds. The stricter the constraint, the lower the power production. The maximum losses are at 11 m/s.

During 2011, Fox Islands Wind experimented with NRO in addition to the serrated blades. A Lawrence Berkeley National Laboratory study of the relationship between NRO, noise levels, and neighbor annoyance is still being finalized; a preliminary analysis suggests a small but not statistically significant reduction in annoyance during NRO. During the summer and fall of 2012, Iberdrola’s Hardscrabble Wind Farm in upstate New York began experimenting with a new software package from Gamesa, the turbine manufacturer, in order to reduce instances of noise peaking over the local noise limit.

NRO can be applied in several ways: all the time, only at night, or only in certain meteorological conditions (e.g. particular wind speeds or directions that either increase noise output or direct sound to nearby homes). In practice, most use of NRO operates in one of the first two situations; research is ongoing to better understand specific conditions in which NRO could be effective in reducing the noise footprint of projects (see Bockstael 2012 for some of this research).

Conditional curtailments

Some projects have faced the more challenging prospect of full curtailment in particular situations. The town-owned turbines in Falmouth, MA, have been shut down at night for several months after several dozen neighbors raised issues about sleep disruption; prior to this, the Falmouth turbines were shut down in winds over 22mph (10m/s). However, to my knowledge no such noise-related full curtailments have been imposed on North American commercial wind farms.

Turbine noise reduction as secondary benefit

Increased cut-in speeds as bat mortality mitigation

One high-profile type of conditional curtailment may provide some degree of noise relief for neighbors: seasonal night-time operational adjustments designed to reduce bat mortality. As with conditional NRO, research is ongoing to better understand the conditions in which bat mortality may be most effectively reduced. So far, an increase in turbine cut-in speed appears to be the most likely path forward in areas with high concentrations of bats. Bats tend not to fly in high winds, so keeping turbines shut down (or fully feathered and freewheeling slowly) in light winds can reduce mortality to half or even a fifth of the rates measured under normal operations (Arnett et al, 2011). Since relatively little power is generated at the low end of operational wind speeds, an increase of the cut-in speed from 3-4m/s to 5m/s results in a reduction in total power output of only 1-3%. An earlier study (Baerwald, 2009) of similar moderate increases in cut-in speeds reduced total turbine operating time by 42% (in a season with a generally lower wind speeds, so this reduction would likely be less at other times). This was obviously great for bats, though it could be a worthy area of further research in community noise/annoyance mitigation (while turbines create less noise at these low wind speeds, it could be worth investigating whether such a noticeable reduction in turbine operations reduces the stress/annoyance that underlie many noise complaints).

Inflow turbulence, directional shear, and turbine wake research

More far-reaching and promising is a large body of ongoing research at the National Renewable Energy Laboratory (NREL), Sandia National Laboratories (SNL), and within the wind industry aimed at reducing turbine blade loads caused by turbulence. The primary goal of this line of research is to lower the overall cost of energy (COE) by both avoiding power output losses in turbulent conditions, and reducing structural stress enough to allow the use of longer blades that can capture more energy from the wind. Cost reductions are also achieved by reducing wear and tear caused by sudden, shifting blade loads; these stresses take their toll not just on blades, but on all turbine components.

However, blade load research may well turn out to be as effective in reducing community noise impacts as the explicit noise-reduction approaches that are already being pursued. Worn or damaged blades are not just less effective at capturing the wind's energy – the loss of coherent laminar flow and increase in trailing-edge turbulence also creates more noise. Likewise, worn bearings and gears are often louder, or emit tonal noise. *Note: Such noise benefits will of course be minimal if design innovations remain focused increasing size while maintaining current noise levels and/or stress tolerance; and, even if quieter, larger turbines are developed, increasing size may exacerbate amplitude modulation triggered by wind speed differentials between the top and bottom of the rotor diameter, and may be associated with increased sound levels at low frequencies, which can be the primary noise annoyance at greater distances, especially indoors (Moller and Pedersen, 2011)*

Other aspects of this new research, especially the development of adaptive blade designs and incorporation of new insights about wake and other flow dynamics into wind farm layouts, offer even more promising possibilities for creating unexpected benefits in terms of community noise, because of the likelihood that turbulence in the blade-swept area is a key factor in the most problematic aspect of wind turbine noise: its extreme variability, in both amplitude (with peaks of up to 20dB above daylong averages) and in sound quality and intrusiveness.

While many of us think of wind turbine noise as a gentle whooshing, wind farm neighbors often speak about knocking, banging, and tumbling sounds that are especially disruptive, and of deep rumbling low-frequency sounds that, even when barely audible, intrude into their bedrooms. These are just the sorts of noises that are often associated with blades operating in the presence of inflow turbulence.

Research efforts are aimed at innovative new blade designs that can reduce the physical stress on blades and mechanical components that is caused by rapid variations in wind speed or direction along the length of the blade. A Sandia NL paper summarized the situation thusly (Wilson et al, quoting Kelly, 2005):

“...greatest structural fatigue damage tends to occur during nighttime hours from coherent turbulence that develops in the stable, nocturnal atmospheric boundary layer. Under such conditions, intense vertical wind shear and temperature gradients create resonant flow fields capable of imparting short-period loading and vibrational energy as wind turbine rotor blades pass through regions of organized or coherent turbulence. This energy is subsequently propagated throughout the remainder of the structure...”

The leading-edge research now underway aims to reduce these load stresses in two ways (Zayas presentation). First is “passive load mitigation,” including innovative materials (such as carbon fiber as a component in various places within the blade core) and blade geometries (one design reduces loads through a geometric sweep that allows “bend twist coupling”). This is a step forward from simply trying to reduce stress by adjusting the pitch angle (which can only respond to average loads along the blade), but such passive mitigations cannot respond to local load variations as the blade sweeps through turbulent air.

That’s where Active Aerodynamic Load Control (AALC) comes in: sensors along the blade that can instantaneously trigger small flaps along the trailing edge of the blade to relieve transient pressures.

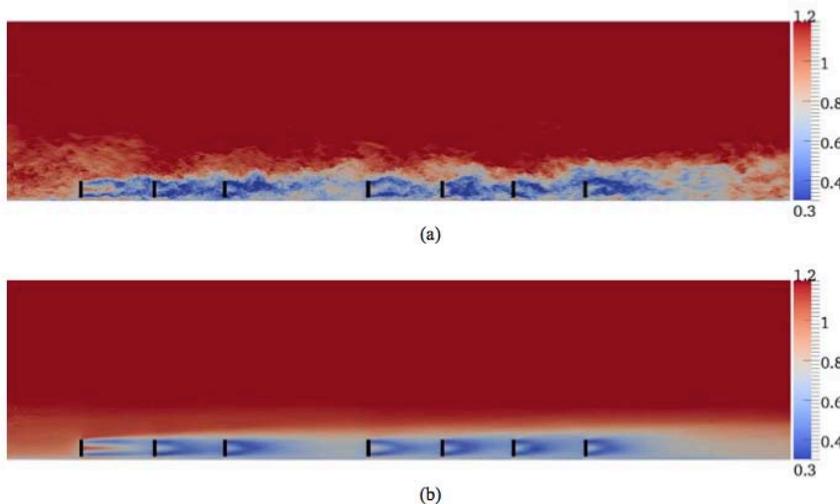


Sandia’s Structural and Mechanical Adaptive Rotor Technology (SMART) blades are in an intermediate R&D stage, with 30-foot blades currently being tested (image left). Other active blade control approaches being studied include wings whose trailing edge can deflect either way, and flexing microtabs with the height of the boundary layer (Wilson et al 2009; Zipp 2012).

Sandia National Lab is also on the leading edge of wake research. Their Scaled Wind Farm Technology Facility (SWiFT) facility, under construction near Lubbock, will feature an array of four turbines with 27m rotors to study wake interactions (Windpower Engineering, July 2012). Project lead Jon White affirms that they are expanding the original project design to perform a variety of acoustic measurements (personal communication, 8/19/12).

Researchers at NREL are also investigating wake interactions, with the goal of better assessing the power production and load effects of turbine wakes on downwind turbines. Early indications are that we have much to learn, and once again, the same power losses and physical stresses being studied here are very likely associated with some of the more troublesome turbine noise events.

One recent study found that in “perfect” worst-case, but typical average, wind conditions (wind head-on the rows in a 48 turbine wind farm of 2.3MW turbines with a spacing of 4.3 rotor diameter), there was a 60-70% decrease in power output behind the front row; their modeling matched the average power plant output well, but actually over-estimated the feeble power output of the turbines in the farthest back rows (Churchfield et al, 2012; image below shows (a) instantaneous and (b) time-averaged velocity, clearly illustrating that only the front row operates at peak efficiency). The authors note that “it will be an interesting future study to examine the structural response of the turbines in the plant.”



Another NREL research team stresses that “the enhanced turbulence in turbine wakes increases the loads on downwind turbines. Furthermore, turbines located in the center of large arrays experience more faults and damaging loads than turbines located at the edge of wind farms.” (Lundquist and Clifton, 2012)

The final area of ongoing research that is likely to pay dividends in noise reduction as well as in power increases is the study of wind shear in far more detail than typically found in current wind farm modeling. As noted in a recent overview of current research, we must look beyond “the narrow definition of shear (i.e., the change in wind speed with height). Wind direction can also change with height. During the day, when there is strong mixing throughout the lower ABL (atmospheric boundary layer), this change is a few degrees throughout the typical 40m to 120m rotor plane. However, at night, as turbulent mixing decreases, directional shear can be 20-40 degrees or more, depending on how much temperature increases with height. Directional shear also has an impact on the power derived from the wind and can impart considerable stress on turbine infrastructure...” (Freedman and Moore, 2012) Indeed, while vertical shear (which is more apt to be relatively consistent) can increase power output, directional shear (which can change rapidly) generally leads to power losses and increased stresses (Wharton & Lundquist, 2012)

For the latest thinking from industry, agency, and academic researchers on many of these issues, the report of this year’s DOE Complex Flow Workshop is a great starting point (DOE Wind Program, 2012). Working groups summarized current knowledge, complicating factors, and desired next steps in great detail at three scales: regional atmospheric, wind-farm scale, and single-turbine scale (down to millimeter-scale wind interactions with blades!). Of special interest is this observation from their conclusion (emphasis added):

One of the largest obstacles to obtaining useful validation data for public use has been the inability of the research community to convince industry players to share their data. While this is entirely understandable given the competitive nature of the wind industry, future public R&D efforts must rely on such data. As such, it will be highly important to **find ways to incentivize data owners and users to share their data and/or provide access to their assets for testing purposes.** The idea is not to simply expect that these data should and would be provided, but rather that public research institutions need to find ways to bring value to the industry participants in exchange for their openness.

While several (workshop members from industry) commented that complex flow R&D is a high priority area for their respective companies, they also noted that the resources and access to data required are difficult to come by for a single company in the competitive wind industry. **There seems to be a strong desire on the part of turbine manufacturer R&D groups to work together and share data; however, the management of these companies will still require convincing.**

Mitigation of reported noise impacts (existing projects)

Reducing fear of noise impacts (proposed projects)

In addition to the physical and operational adjustments covered in the first section of this paper, several approaches have been taken to addressing homeowners directly about both existing noise complaints, and fears of noise impacts.

Home retrofits, including double-glazed windows and air conditioning systems, have sometimes been offered to mitigate intrusion from many community noise sources. Recently, residents near the Hardscrabble Wind Farm were offered white-noise machines to help mask turbine sounds (initial press reports suggest they did not fully mask the troublesome noise, perhaps because the turbine sounds, especially inside the house, were weighted heavily toward the audible low-frequency range and sometimes have a pulsing quality).

Very occasionally, homes of nearby residents are purchased by wind developers. Most often, this occurs prior to construction, and involves homes that are simply too close to the project site for noise standards to be met; for example, one such house was purchased in Vinalhaven, ME prior to Fox Islands Wind becoming operational. Rarely, homes are bought after complaints arise, and are generally then resold or used by the wind farm operator. Records are spotty on this, though it clearly happens in some situations (two Ontario projects are the best documented; see aeinews.org/archives/350 and aeinews.org/archives/1344).

The most constructive approach, and one pursued by many developers with varying degrees of commitment, transparency, and success, is engaging in open dialogue with community members. A leading player in such efforts has been the Cambridge, MA, based Consensus Building Institute (Raab and Suskind, 2009; Suskind, 1990), which stresses, among other things, developing trust and keeping multiple project siting options open. AWEA's Siting Handbook also includes suggestions to help shape community outreach efforts, including fostering a sense of local ownership and empowerment along with proactively engaging allies in the local dialogue.

Once problems arise, things get more difficult, and all too often wind up in the courts (again, Ontario provides an instructive example: aeinews.org/archives/1432). The most intensive and constructive community engagement process to take place after noise issues cropped up seems to be the ongoing Falmouth, MA, Wind Turbine Options Analysis Process (WTOP), which includes a variety of local stakeholders including town officials, wind advocates, and affected neighbor who have been meeting since June and plan to offer the town a set of options for reducing the noise impacts of the two town-owned turbines in time for the spring Town Meeting. For records of this process, see cbuilding.org/falmouthwind

Bigger-picture considerations

My work over the past four years has largely been about developing an understanding of the points of view and experiences that underlie both the current project design and siting of wind energy in America, and the ways that the resultant changes in local soundscapes have spurred a

push-back in some areas. I am a member of both AWEA and the American Society for Acoustic Ecology. While this has involved a great deal of research, reading, listening, meeting, and talking about a wide variety of specific and detailed information, it has also helped me to come to some larger framings that are clearly relevant to moving forward constructively in a way that fosters the continued expansion of wind energy while being empathetic and respectful of the varied character of host communities.

So I'd like to close with a couple of bigger-picture considerations that might help everyone involved to understand each other's point of view a bit better, one technical and one sociological: first, a look at how the use of average sound levels can be confusing, and second, a consideration of place identity as a clue about why wind farms are more easily accepted in some areas than in others.

Average and peak sound levels

We all know that it can be hard for people to really know what a particular decibel level will sound like. Yet even once a noise limit has been agreed upon, the necessary use of averaging sound levels over time only adds to the confusion. Of course, wind farm sound emissions vary greatly, as do background sounds, with transient noises moving through as well; this is why we need to use time-averaged sound metrics. Yet it is often far less clear to community members that this is how it works. In my work monitoring contentious local situations, it's increasingly common to hear wind farm operators struggling to communicate the fact that they are operating within compliance conditions even though sound levels occasionally exceed the stated limit. For example, the Pinnacle Wind Farm in Keyser, WV, operates under a state noise limit of 55dBA Ldn – the noise is averaged over a full 24-hour period. Thus, it's not surprising that neighbors may occasionally record sounds of 65dB or even more; such peaks alarm residents, while being a natural consequence of a project operating in compliance.

As David Hessler stresses in a recent “Best Practices” report prepared under the auspices of the National Association of Regulatory Utility Commissioners:

It is important to note that the...suggested sound level targets discussed above are mean, long-term values and not instantaneous maxima. Wind turbine sound levels naturally vary above and below their mean or average value due to wind and atmospheric conditions and can significantly exceed the mean value at times. Extensive field experience measuring operational projects indicates that sound levels commonly fluctuate by roughly +/- 5 dBA about the mean trend line and that **short-lived (10 to 20 minute) spikes on the order of 15 to 20 dBA above the mean are occasionally observed** (emphasis added) when atmospheric conditions strongly favor the generation and propagation of noise. Because no project can be designed so that all such spikes would remain below the 40 or 45 dBA targets at all times, these values are expressed as long-term mean levels, or the central trend through data collected over a period of several weeks.

Hessler observes that “the threshold between what it is normally regarded as acceptable noise from a project and what is unacceptable to some is a project sound level that falls in a gray area ranging from about 35 to 45 dBA (Ldn). Below that range the project is so quiet in absolute terms that almost no adverse reaction is usually observed and when the mean project sound level exceeds 45 dBA a certain number of complaints are almost inevitable.” Citing the classic

Pedersen, et al studies, he notes “relatively high annoyance rates of around 20 to 25%” among residents living in areas with project sound of 40-45dB. He thus currently recommends a mean (Ldn) sound level of 40dB at residences in most cases, or 45dB “as long as the number of homes within the 40 to 45 dBA range is relatively small.” He stresses, “It is important to note that a project sound level of 40 dBA does not mean that the project would be inaudible or completely insignificant, only that its noise would generally be low enough that it would probably not be considered objectionable by the vast majority of neighbors. “ (Hessler, 2011)

While Hessler’s recent work seems to point to a lower noise standard than has been typically used in projects up until now, we must bear in mind that he is working with the full day-night average, rather than an hourly or ten-minute average threshold. The lower long-term average takes into consideration the likelihood of frequent periods of 5dB higher (and lower) sound, fairly regular peaks of 10dB higher, and rare peaks of 15-20dB higher.

It appears that project managers are increasingly aware of the divergence between expectations based on averages and experiences based on peak sound levels; several projects have implemented noise-reduction efforts over the past couple of years, even when operating in compliance with the time-averaged standards. As Charley Parnell, vice president of Public Affairs for Edison Mission Group, owners of the Pinnacle Wind Farm, said in regards to the addition of noise-muffling louvres, “We believe Pinnacle is operating in a manner that meets the requirements of our permits, but taking additional steps to mitigate noise is an important part of our commitment to be a responsible corporate citizen of the communities in which we operate. We look forward to many years of providing clean energy generated by Pinnacle, and we intend to work in good faith to address local concerns.” Likewise, at the Hardscrabble Wind Farm, where new NRO software is being tested, Paul Copleman, Iberdrola Communications Manager concurred: “While our studies do not show turbine sound levels by themselves exceeding the permit limit, we do acknowledge we have received complaints from some of the residents and we are working diligently to address the situation.”

Hessler’s 40dB Ldn recommendation, coming from a stalwart of mainstream acoustics assessment, is moving closer to the recommendations of the more cautionary acousticians, who have been recommending targets of 30-35dB in some types of communities, in order to reduce nearby annoyance rates to near zero (though they often are speaking of shorter-term averages). Both approaches acknowledge that whatever averaging period is used, there will be peak events above the perceived “limit.” This crucial point needs to be more clearly communicated, in order to better manage expectations.

Place Identity and Expectations Regarding Local Soundscapes

Over the past five years, the wind industry has been faced with more widespread questions about noise impacts than it had been used to. For many years, wind farms built in either remote locations in the west, or in farming and ranching communities in the great plains, had been operating with virtually no noise problems. Suddenly, in Wisconsin, Maine, Ontario, New York, and Massachusetts, among other places, small local communities were in an uproar about perceived noise intrusions. Initially, industry representatives were taken aback, assuming the noise complaints were rooted in simple NIMBY sentiments, since we “knew” from experience

that 50-60dB wind turbine noise was easily accommodated in other places. Over time, though, it's become more clear that different types of communities have different noise tolerances.

Many rural communities have begun seeking a balance that represents their self-perceived willingness to live with wind farm noise, adopting a wide range of noise and setback standards, ranging from the effectively exclusionary (1 mile is often impossible, 2 miles nearly always is), to attempts to find a happy medium, such as nighttime noise limits of 35 or 40dB and setbacks of 2500-4000ft. Other communities have adopted more familiar and accommodating standards, such as 45-50dB daytime average sound levels, or setbacks of 1200-1800ft. The era of "one size fits all" siting (which was commonly in the 900-1200 feet/50-60dB ballpark) is clearly coming to a close.

The best assessment of what is going on here comes from the Scandinavian team responsible for the only in-depth, peer-reviewed community annoyance research to date. In one of the most fascinating side studies from that body of research, Eja Pedersen and her collaborators dug more deeply into the paradoxical polarization of responses to very similar noise levels. They conducted in-depth interviews with survey subjects who rated their annoyance at the opposite extremes of the scale, and the results shed some much-needed light on what we've been seeing in communities over the past few years (Pedersen et al, 2007). It applies both to varied responses in any given community, and to the larger differences between types of communities.

They found that annoyance levels tracked closely with two very different ways of viewing the rural lifestyle and landscape, a differentiation that they termed "place identity." For some, the countryside is a place for economic activity and technological development/experimentation. These people like new machines and technology, are glad to see a new use for the land (and wind!), and easily accept local disturbances (flies, odors, sounds). They let others use their land as they see fit, and consider turbine sounds as both relatively insignificant compared to the machinery they use every day, and also as outside their territory. Conversely, many other rural residents see the countryside as a place for peace and restoration, a tranquil refuge (or retirement) from their busy life of work in town. For them, turbine sound, especially at the times when it's the loudest element in their soundscape, intrudes on what they see as their space and privacy, disrupting their enjoyment of their backyards, porches, and living rooms (see Cummings, 2010, for an overview of community response studies, including the full body of Pedersen et al research).

It's not hard to see that in farm and ranch communities, the "economic activity" place identity will dominate, and that in the northeast and upper midwest, there is a higher proportion of residents who live in pastoral landscapes with a "peace and restoration" approach to place and home. A broad-brush look at projects around the country certainly can fit this framework: In Texas and Iowa ranch country, very few problems arise even in sprawling wind farm complexes such as those around Sweetwater, TX. In Wisconsin and New York state, though, some wind projects in farmland where there is a mix of these place identities, such as Blue Sky Green Field (WI) and Tug Hill (NY), revealed a vocal minority that is very clear about the disruption of their sense of place that wind farms created. At the other end of the spectrum, a few wind farms placed in areas with virtually no working farms, and where landowners are predominantly seeking peace and quiet, ran into substantial local uproar (e.g., Mars Hill, ME), as have some

municipally-owned turbines placed in towns with higher population densities, such as Falmouth and Fairhaven, Massachusetts. In Falmouth, 45 residents, about a quarter of homeowners within a half-mile downwind of the three turbines, have filed formal complaints with local authorities, a remarkably high number.

Still, it's not as simple as this brief sketch may imply. Many wind farms in relatively rural, non-farming country don't seem to trigger an outcry. The Massachusetts Clean Energy Center has conducted some preliminary studies, attempting to discern what the differences may be between places where projects go online with little fuss, and places where significant community reaction occurs (personal communication, June 2012). Much more needs to be done along these lines, in order to help clarify the factors that contribute to project success or a rocky road.

It could be, as Hessler suggests, as simple as population density; it's quite likely that some version of place identity and expectations about natural quiet play into it; generic psychological noise sensitivity could be a factor (with the likelihood that fewer noise sensitive people are ranchers, and more noise sensitive people choose to live outside of towns in search of relative tranquility). There's much to learn, and a few well-designed, comprehensive surveys in a well-selected variety of types of communities would go a long way toward helping the industry to plan future projects in ways that will be in synch with differences in local sense of place.

Paths Forward

Looking a decade or so down the line, we can expect that current research efforts will lead to the development of new blade designs and wind farm layouts that greatly reduce the significant impacts of chaotic air flow on the intrusive sorts of noises that underlie many of the noise issues among the more noise-sensitive neighbors of wind farms. We can also hope and imagine that more new development efforts will be located offshore, including deep-water floating offshore installations in relative proximity to coastal urban centers, taking some development pressure off the "nearby" rural landscapes in the more densely-populated states of the east and upper midwest.

In the meantime, though, current and near-future project planning will occur in three rather distinct paths, each of which is likely to be pursued vigorously. Perhaps some companies will choose to focus on one or another of these paths, though most will likely make do as they can with projects in all three as needed and as possible.

- Continue current siting practices (e.g. 1200-1800 feet; 45-55dB). Be prepared to spend the time/money to engage in proactive pre-proposal work in communities, and in some cases, to respond to heated resistance. Even when there is little pre-construction resistance, be prepared to apply post-construction mitigations in response to noise complaints at the margins of the regulatory criteria.
Examples: BP has been planning the Cape Vincent Wind Farm (NY) for several years, in the face of strong local resistance; this fall, they began the process of seeking state-regulated "Article X" approval. Previous examples at Pinnacle and Hardscrabble wind

farms illustrate willing application post-construction mitigation after noise concerns arose post-construction.

- Continue current siting practices, and focus efforts only or mainly in communities where there is little or no objection, as well as low population densities (to minimize risk of post-construction surprises).

Examples: The majority of current new wind farm construction, taking place as it always has in the great plains and intermountain west. As Clipper Windpower Vice President told wind historian Robert Righter, “If people don’t want it, we’ll go someplace else.” (Righter, 2011)

- Avoid community conflict and reduce noise impacts by prioritizing sites with few non-participating homes within a mile, and/or by working with communities or states that adopt larger standard setbacks to minimize or nearly eliminate audible noise at homes (e.g., 35-40dB, half-mile or mile setbacks,), along with easy-to-obtain waivers or easements for closer siting to willing neighbors.

Examples: Most wind project in the State of Oregon are developed under a 36dB standard with easements available for construction closer to willing neighbors, which has minimized neighbor noise problems (and when they occur, issues tend to be moderate, with noise levels of under 40dB, far less likely to cause the severely distressing reactions that are sometimes reported with 45dB or louder noise). The site of the Record Hill Wind Farm in Roxbury, ME, was selected because there were only a handful of homes within a mile; these became project participants, while concentrations of homes at a mile and a quarter to mile and a half report they can hear turbines regularly when it’s very still, but that their lives are not disrupted by the sound (though some do still resent the lights reflecting in the lake and/or the ridgetop construction). The project developer was careful to not promise the turbines would be inaudible even at those distances, which helped manage expectations.

In conclusion, I’d like to recommend Robert W. Righter’s recent history of wind energy in America (Righter, 2011). Within a context of full support of the increasing role of wind in our energy future (and his longtime work on NIMBY reactions), he makes a strong case for pursuing the second two options above. He’s unusually sensitive to noise concerns, while affirming that not everyone will be pleased with any public infrastructure development. He notes, “When I first started studying the NIMBY response to turbines I was convinced that viewshed issues were at the heart of people’s response. Now I realize that the noise effects are more significant, particularly because residents do not anticipate such strong reactions until the turbines are up and running – by which time, of course, it is almost impossible to perform meaningful mitigation....Good corporate citizens must identify potential problems and take action.”

Righter’s conclusion offers a ready path forward: “Most developers understand that it is in their best interest to operate openly and in good faith with the local community. More problematical is the question of landscape....Wind developers should take to heart geographer Martin Pasqualetti’s advice: ‘If developers are to cultivate the promise of wind power, they should not intrude on favored (or even conspicuous) landscapes, regardless of the technical temptations these spots may offer.’ The nation is large. Wind turbines do not have to go up where they are not wanted. We can expand the grid and put them where they are welcome.”

References

Note: the Powerpoint version of this paper, presented at Renewable Energy World North America, 12/12/2012, included a slide referencing content (re: surveys of noise annoyance near wind farms) not included in this text. This content is covered, with references, in part in Cummings (2010) below, and also in AEI's Wind Farm Noise 2012 annual report.

In addition, the Powerpoint version includes a Kalisky 2010 graph of noise levels over a year that is discussed in more detail, and referenced, in AEI's Wind Farm Noise 2011 annual report (the interpretation here is more accurate; previous interpretation did not account for hours in the year turbines are not operating)

See <http://www.acousticecology.org/wind/> for these and other AEI documents

Papers and Presentations

Carlos A. Arce-León (2010). Modelling of Serrated Trailing Edges to Reduce Aerodynamic Noise in Wind Turbines. October 2010. Department of Information Technology, Uppsala University.

Arnett, Huso, Schirmacher, Hayes (2011). Altering turbine speed reduces bat mortality at wind-energy facilities. *Front Ecol Environ* 2011; 9(4): 209-214, doi:10.1890/100103

E. Baerwald, J. Edworthy, M. Holder, R. Barclay (2009). A Large-Scale Mitigation Experiment to Reduce Bat Fatalities at Wind Energy Facilities. *The Journal of Wildlife Management*, 73(7): 1077-1081; 2009. Corresponding author: erin.baerwald@ucalgary.ca

Matthew Barone (2011). Survey of Techniques for Reduction of Wind Turbine Blade Trailing Edge Noise. Sandia National Laboratory. SAND2011-5252, August 2011.

A. Bockstael, L. Dekoninck, A. Can, D. Oldoni, B. Coensel, D. Botteldooren (2012). Reduction of Wind Turbine Noise Annoyance: An Operational Approach. *Acta Acustica*, Vol. 98 (2012) 392-401. DOI 10.3813/AAA.918524 Corresponding author: annelies.bockstael@ugent.be

M. Churchfield, S. Lee, P. Moriarty, L. Martinez, S. Leonardi, G. Vijayakumar, J. Brasseur (2012). A Large-Eddy Simulation of Wind-Plant Aerodynamics. Presented at the 50th AIAA Aerospace Sciences Meeting, Nashville, Tennessee, January 2012. Available electronically at <http://www.osti.gov/bridge>

Jim Cummings (2010). Wind Farm Noise: Public Perception and Annoyance. New England Wind Energy Education Project webinar: Understanding the Impacts of Wind Turbine Sound. Wind Powering America, July 2010.

http://acousticecology.org/docs/AEI_PublicPerceptionAnnoyance_4up.pdf

C. Doolan, D. Moreau, L. Brooks (2012). Wind turbine noise mechanisms and some concepts for its control. *Acoustics Australia*. Vol. 40, No. 1, April 2012, p. 7-13.

David Hessler (2011). Best Practices Guidelines for Assessing Sound Emissions From Proposed Wind Farms and Measuring the Performance of Completed Projects. Prepared for the Minnesota Public Utilities Commission, under the auspices of the National Association of Regulatory Utility Commissioners (NARUC). October 13, 2011.

Ben Hoen, Ryan Wisser, Haftan Eckholdt (2010). Assessing the Impacts of Reduced Noise Operations of Wind Turbines on Neighbor Annoyance: A Preliminary Analysis in Vinalhaven, Maine. Office of Energy Efficiency and Renewable Energy Program, Wind and Hydropower Technologies Program, US Department of Energy. 2010.

G. Leloudas, W.J. Zhu, J.N. Sorensen, W.Z. Shen, S. Hjort (2007). Prediction and Reduction of Noise from a 2.3MW Wind Turbine. *Journal of Physics: Conference Series* 75 (2007) 012083. doi:10.1088/1742-6596/75/1/012083 <http://iopscience.iop.org/1742-6596/75/1/012083>
Corresponding author: giorgos@dark-cosmology.dk

Møller and CS Pedersen (2011). Low-frequency noise from large wind turbines. *J. Acoust. Soc. Am.* 129 (6), June 2011, 3727-3744.

E. Pederson, LR-M. Hallberg, K.P. Waye (2007). Living in the Vicinity of Wind Turbines – A Grounded Theory Study. *Qualitative Research in Psychology*, 4:49-63, 2007. DOI: 10.1080/14780880701473409

Raab and Suskind (2009). New Approaches to Consensus Building and Speeding up Large-Scale Energy Infrastructure Projects. Conference paper at Expansion of the German Transmission Grid, 2009.

Susskind, Lawrence (1990). A Negotiation Credo for Controversial Siting Disputes. *Negotiation Journal*, October 1990. p.309-314 or Kunreuther, Howard and Susskind, Lawrence (1991). The Facility Siting Credo: Guidelines for an Effective Facility Siting Process, in *Environmental Impact Assessment Review*, 1991. Publication Services, University of Pennsylvania

Sonia Wharton and Julie K. Lundquist (2012). Atmospheric stability affects wind turbine power collection. *Environ. Res. Lett.* 7(2012) 014005

D. Wilson, D. Berg, M. Barone, J. Berg, B. Reser, D. Lobitz (2009). Active aerodynamic blade control design for load reduction on large wind turbines. European Wind Energy Conference and Exhibition 2009. Corresponding author: dwilso@sandia.gov

Jose Zayas. Technology Innovation for Wind Energy: SNL's SMART Rotor Program. Sandia National Laboratories. (No date on presentation; 2010 or later) sandia.gov/wind
jrzayas@sandia.gov

Complex Flow Workshop Report (2012). Boulder, Colorado, May 2012. US Department of Energy Wind Program (2012).

Media Coverage, Books, and Articles

Angela Beniwal (2011) Turbine Manufacturers Focus on Reducing Noise Emissions. North American Windpower, Volume 8, Number 6, July 2011, p.38-41.

Jeffrey Freedman & Kathleen Moore (2012). Wind Shear and Why it Matters. North American Windpower, Volume 9, Number 5, June 2012, p.48-51.

Julie Lundquist & Andrew Clifton (2012). How Turbulence Can Impact Power Performance. North American Windpower, Volume 9, Number 8, September 2012, p.1, 13-18.

Robert W. Righter (2011). Windfall: Wind Energy in America Today. University of Oklahoma Press, Norman, OK. 2011. *(Not to be confused with the anti-wind film by the same name; this is a current history of wind energy in America from an academic historian and longtime proponent of the industry.)* See <http://aeinews.org/archives/1726> for an overview of the book, centered on his views on community noise and wind farm siting.

Jennifer Runyan (2011). Fort Felkner: Driving Innovation in Wind Power. Renewable Energy World, July 2011, p.???. Online archive:
<http://www.renewableenergyworld.com/rea/news/article/2011/07/fort-felker-driving-innovation-in-wind-power>

Kathleen Zipp (2012) “Shape-shifting blades promise more efficient turbines.” Wind Power Engineering and Development, March 9, 2012. Accessed September 19, 2012.
<http://www.windpowerengineering.com/design/mechanical/blades/shape-shifting-blades-promise-more-efficient-turbines/>

Windpower Engineering and Development. National lab plans turbine array, reports on 100m blade, and more, July 2012, p 10-11.

Windpower Engineering and Development. Trends in operations and maintenance, May 2012, p.116.

Windpower Engineering and Development. Trends in simulation software, May 2012, p.70-72

Windpower Engineering and Development. Trends in turbine brakes, May 2012, p.98-99.

WKTV.com (2012). Fairfield residents given noise generators to drown out sound of windmills, July 16, 2012. Accessed August 5, 2012. <http://www.wktv.com/news/local/Fairfield-residents-given-noise-generators-to-drown-out-sound-of-windmills-162627096.html>

Appendix C



Wind Farm Noise and Health: Lay summary of new research released in 2011

Jim Cummings, Acoustic Ecology Institute, April 2012
<http://www.acousticecology.org/wind/> jim@acousticecology.org

In February of this year, I wrote a column for Renewable Energy World¹ that addressed the recent increase in claims that wind farms are causing negative health effects among nearby neighbors. The column suggested that while many of the symptoms being reported are clearly related to the presence of the turbines and their noise, the relationship between wind farms and health effects may most often (though not always) be an indirect one, as many of the symptoms cropping up are ones that are widely triggered by chronic stress. In recent months, the dialogue around these issues has hardened, with both sides seemingly intent on painting the question in simple black and white—community groups assert that turbines "are making" people sick, while government and industry reports insist that there's "no evidence" that turbines can or do make people sick. The gulf between the conclusions of formal health impact studies and the experiences of some neighbors has widened to the point that both sides consider the other to be inherently fraudulent. I suggested that the rigidity of both sides' approach to this subtle and complex issue is likely increasing the stress and anxiety within wind farms communities that may in fact be the actual primary trigger for health reactions.

Here, I'll expand on that shorter column by taking a closer look at the few surveys and studies that have attempted to directly assess the prevalence of health effects around wind farms.

Even as the public becomes increasingly concerned about health effects, with a lot of focus on the role of inaudible infrasound, it's been striking to me to that the researchers investigating health effects – even clearly sympathetic researchers – are not talking about infrasound much at all, and are instead focusing on stress-related symptoms. Drawing from studies done in areas where health concerns have been most widely reported, we'll see that while some types of health problems may be more common near

¹ See www.renewableenergyworld.com/rea/u/AcousticEcologyInstitute/articles

wind farms, most of the studies find little difference in overall health based on proximity to turbines.

And, where health effects are reported (primarily sleep disruption and stress-related symptoms), those who have been most diligent and open in assessing community responses estimate that health problems (whether direct or indirect) appear to crop up in no more than 5-15% of those living nearest; this is a surprisingly small number, considering the central role health effects has taken in the public perception and debate about new wind farms. While we shouldn't discount the impact on these people, it appears that fears of widespread health impacts may be misplaced. Though impacts on even a few, whether direct or indirect, are certainly a valid consideration in making wind farm siting decisions, it's helpful to have a clearer picture of how widespread the issue may be.

Just last week, a news report² about a public presentation by Carmen Krogh of Ontario's Society for Wind Vigilance, one of the major voices in the health-effects debate, starkly illustrated the disconnect between public fear and the message actually coming from the voices of caution. I was struck to see that even as "the main concern" of the audience was the invisible dangers of infrasound and stray voltage, Krogh "focused on the stress affects of exposure and clinical annoyance. 'We find that the number one complaint that people come forward with is sleep disturbance,' she explained to the crowd." While including the audience's concerns in her assessment of five contributing factors, "Out of the five causes, Krogh focused on amplitude modulation (or the "swooshing" sounds) and audible low frequency..." As you'll read here, this is no anomaly; nearly all the sympathetic experts have a similarly grounded focus on audible noise, sleep disruption, and stress. While some researchers continue to investigate questions around infrasound levels and perception³, the public focus on infrasound as a primary or central contributor to reported health issues is not reflected in the actual findings of those studying the issues most diligently.

With this in mind, I hope that this detailed look at recent papers on health effects near wind farms will help to clarify the scope of the issue, and to provide useful context for decision-makers who are struggling to make sense of the complex and contradictory information that advocates on both sides of the issue present to them.

Investigating the health questions

Increasing public concern about health impacts has spurred a **slew of reports over the**

² See <http://www.shorelinebeacon.com/ArticleDisplay.aspx?e=3515675>

³ For more on this, see AEI's recent overview of research on low frequency noise and infrasound at <http://aeinews.org/archives/1711> The most interesting work is looking at rapid pulsing of low frequency and infrasonic sound, and the question of whether they be more perceptible than human perception curves generated using pure tones may suggest.

last three years from government entities and industry trade associations. Most of the official health impact studies have actually been literature reviews of previous research on noise from many sources, and have focused on questions such as whether inaudible infrasound around wind farms is strong enough to cause a direct physical reaction in neighbors (and just in case you've been out of the loop: they universally find that it's not). I will not be summarizing these reports here; they've all been summarized previously by AEI⁴, and as just mentioned, they generally steer clear of attempting to assess actual reported health effects, preferring to stay in the presumably more objective realm of published studies relating to noise and health in general. To the degree that they include studies of on-the-ground responses to wind turbines, they tend to note that the early studies are limited by relatively small sample sizes, which is true. Still, **we need to start somewhere, and as in most inquiries, the first investigations will tend to be smaller and more tentative**. In any case, the omission of detailed analyses of these literature reviews should not be viewed as an attempt to skew the evidence presented here, since AEI has covered them in depth, affirming their value while also noting their limitations.

Meanwhile, a few acousticians and epidemiologists have **begun taking a look at what is occurring in communities where health impacts are being reported, and this paper will summarize the recent findings of these attempts to dig into actual community responses**. It should be noted that a few governmental entities, including the nation of Japan⁵ and the Province of Ontario⁶, have initiated larger scale studies that will likely provide more comprehensive and statistically robust results over the next few years. But for now, we do have several worthwhile papers that examine actual reported health effects that can begin to help us move beyond the current quagmire.

Not too surprisingly, we'll discover that what these researchers are finding contradicts both the "all is well" literature survey findings, as well as the fear that worst-case scenarios – being driven from homes by lack of sleep, headaches, kids struggling in school – are likely to occur. Rather, these studies take us beyond the cartoons of sunshine and disaster, and drop us right down into an uncomfortably murky zone in which the answers are no longer presented in easily-understood black and white, but rather in harder-to-decipher shades of grey.

The bottom line appears to be that this first wave of research, undertaken by relatively cautionary and empathetic researchers, is finding that just **a small proportion of nearby residents are reporting actual health impacts, though far more report degradation of the overall quality of life and sense of place**. These studies use a diverse range of approaches and criteria, so can't all be directly compared, or compiled to suggest global

⁴ See <http://aeinews.org/archives/584> (AWEA/CanWEA), <http://aeinews.org/archives/915> and <http://aeinews.org/archives/937> (Ontario MOE), <http://aeinews.org/archives/1750> (Oregon Health Authority), <http://aeinews.org/archives/1782> (Massachusetts)

⁵ See <http://aeinews.org/archives/644>

⁶ See <http://aeinews.org/archives/1862>

patterns, but each of them offers a clear window into particular communities' responses to wind farms in their vicinity. As noted earlier, while all of the papers reviewed here come from researchers with much interest in and empathy for reports from affected neighbors, none of them propose inaudible infrasound as a central factor in health effects; the first four papers all focus on stress and sleep factors, and the last two, while including infrasound in their discussions, focus mostly on other factors (one on pre-existing risk factors, and the other on pulses in the dBG level, which includes substantial audible low-frequency sound as well as infrasound).

Seeking a clear path through murky ground

In the face of the growing clamor about health impacts, taking a direct, clear look at these studies may help to local and state regulators to step out of the confusing cross-fire of opinions, and to focus on the task at hand: designing siting standards that reflect the local best sense of how to balance the potential local economic and national climate change benefits with the likelihood of a diminished rural quality of life for some local citizens, and possible or likely health effects for a few. **There is no one "right answer" to these questions**, though wind promoters will suggest we must accept that we can't expect everyone to be happy, and wind opponents will say that any new illness is one too many. Both have a point, and some towns will set standards that allow relatively close siting in the name of money for local schools or other priorities, while others will establish large setbacks that effectively keep wind development away. Meanwhile, **many towns or counties will aim to find a middle ground that tries to minimize impacts while leaving some avenues for development to occur, either at a moderately greater distance or by encouraging or requiring developers to make agreements with neighbors before building**.

I think it's important to preface our consideration of these studies by acknowledging a key factor that has hampered the ability of some within both the public and the industry to clearly address the possibility that neighbors have experienced legitimate changes in their health, whether by direct or indirect means. Many of those most vehemently stressing the *potential* for health impacts in areas where wind farms are proposed are fundamentally anti-wind, anti-renewables, and anti-government incentives; health impacts are but one of a litany of arguments they make against new wind farms, and many simply dismiss all their claims as distorted rhetoric. This can too often **blind us to the fact that nearly all of the individuals who are telling us about their *actual* health impacts have no dog in the energy-policy fight**; their personal stories are often compelling and sober accounts of struggling with unexpected and disabling sleep issues, disorientation, and mood disorders. In my work with the Acoustic Ecology Institute, and in the papers that follow, the focus is on better understanding what's going on with those reporting health effects around existing wind farms, rather than on the fears and opposition being raised in places where wind farms have yet to be built.

Alright then, let's dive in. The approach here will be similar to the one I took in AEI's late 2011 summary of ten papers on low frequency noise⁷; I'll address one paper at a time, while pointing out connections and contradictions between them. We'll be looking closely at the following seven publications, in addition to referring to several others in the final sections of this post⁸:

Carl V. Phillips. Properly Interpreting the Epidemiologic Evidence About the Health Effects of Industrial Wind Turbines on Nearby Residents. *Bulletin of Science Technology & Society* 2011 31: 303 DOI: 10.1177/0270467611412554

Daniel Shepherd et al. Evaluating the impact of wind turbine noise on health-related quality of life. *Noise & Health*, September-October 2011, 13:54,333-9.

Daniel Shepherd, Witness Statement, Ontario MOE Environmental Review Tribunal, January 19, 2011.

Michael Nissenbaum, Jeff Aramini, Chris Hanning. Adverse health effects of industrial wind turbines: a preliminary report. 10th International Congress on Noise as a Public Health Problem (ICBEN) 2011, London, UK.

Bob Thorne (Noise Measurement Services). *Wind Farm Noise Guidelines*, 2011.

Nina Pierpont. *Wind Turbine Syndrome: A Report on a Natural Experiment*. 2009.
Nina Pierpont. Presentation to the Hammond (NY) Wind Committee, July 2010

Stephen E. Ambrose, Robert W. Rand. The Bruce McPherson Infrasound and Low Frequency Noise Study: Adverse health effects produced by large industrial wind turbines confirmed. December 14, 2011.

The famous “Overwhelming evidence (of) serious health problems” paper

Carl V. Phillips. Properly Interpreting the Epidemiologic Evidence About the Health Effects of Industrial Wind Turbines on Nearby Residents. *Bulletin of Science Technology & Society* 2011 31: 303 DOI: 10.1177/0270467611412554
The online version of this article can be purchased at:
<http://bst.sagepub.com/content/31/4/303>

This paper is one of the "crown jewels" for community activists who have raised health impacts into prominence in the public policy debate over wind farm siting. Phillips' paper was one of several on wind farm siting policy published last summer in the *Bulletin of Science, Technology, and Society*, thus breaking through the invisible, and

⁷ <http://aeinews.org/archives/1711>

⁸ Many of these papers can be downloaded from AEI's wind noise resource page at <http://aeinews.org/archives/category/wind-turbines>

(as Phillips himself points out) somewhat illusory, threshold of appearing in a "peer-reviewed journal."⁹ Most of the paper is devoted to detailed epidemiological critiques of the arguments that deny the validity of any evidence of health effects among wind farm neighbors; much of this material is effective and well worth taking into consideration, though some of it is less sharp or relevant, and at times, rather vitriolic. But this paper's claim to fame is its oft-quoted opening phrase: "There is overwhelming evidence that large electricity-generating wind turbines cause serious health problems in a nontrivial fraction of residents living near them." That phrase, touted as published in a peer-reviewed journal, shows up as Exhibit A in more than a few letters to the editor in towns considering wind farm proposals.

Yet, while the paper does make a strong case for disregarding easy dismissals of the problem, it does not provide any concrete data to suggest just how widespread health impacts actually are. The closest it comes to quantifying is to note, "Since several research groups and nongovernmental organizations have collections (of reported health effects, or "adverse event reports"¹⁰ that number in the three-figure range, it seems **safe to conclude that the total number published or collected in some form is in the four-figure range, and it is quite conceivable that the total numbers of adverse event reports are in five figures.**" I would probably grant him that there may well be over a thousand clear reports of health impacts worldwide at this point; the very existence of so many people making such reports can justifiably be considered reason enough to dig deeper and find out what's going on. Yet this doesn't get us any closer to assessing whether these impacts are rare, or common; even his conceived-of 10,000 such reports would represent a small proportion of residents living within a mile or so of today's several thousand large wind farms worldwide.

But those who hold up Phillips' paper as clear published evidence of the vast scope of an insidious hidden health risk (most commonly tied in public imagination to

⁹ Setting aside for the sake of celebration the fact that within the scientific community, the 20,000+ refereed or peer-reviewed journals represent a spectrum of reputation and quality that might be compared the spectrum within culinary arts, from chefs whose work is respected in kitchens around the world, to a local Denny's, both of which can boast of passing their local health inspections; still, wind proponents had harped on the lack of peer-reviewed input from the cautionary perspective, despite the fact that most of their "conclusive" reports were also white papers published outside the peer-reviewed journal process, so this became a big deal.

¹⁰ To those who may consider unsolicited reports of problems to be meaningless "self-selection," Phillips says: "In cases of emerging and unpredictable disease risk, adverse event reports are the cornerstone of public health research. Since it is obviously not possible to study every possible exposure-disease combination using more formalized study methods, just in case an association is stumbled on, collecting reports of disease cases apparently attributable to a particular exposure is the critical first step. The most familiar examples of hazards revealed by adverse event reporting are infectious disease outbreaks or side effects from pharmaceuticals, but the case of turbines and health also fits the pattern. Pharmaceutical regulators rely heavily on clearinghouses they create for adverse event reporting about drug side effects (and often become actively concerned and even implement policy interventions based on tens of reports). The WindVOiCe report collection is an example of this same well-accepted kind of active-recruiting data collection system."

physiological reactions to inaudible infrasound) conveniently **overlook the second sentence in his paper, the one following his incendiary opening salvo: "...many people living near them have reported a collection of health effects that appear to be manifestations of a chronic stress reaction or something similar."**

Indeed, Phillips goes even further in this direction, in a critique of the claim that health effects should be dismissed because they are "subjective" responses. He notes that such arguments "seem to be confusing 'subjective' with 'psychologically mediated,' which most of the observed effects might well be (though there are hypotheses about nonpsychological pathways)."

Phillips then offers **his most valuable contributions to this discussion: "Being subjective or psychologically mediated does not mean that these effects are minor or less real.** Indeed, there is a case to be made that such diseases (i.e. psychologically-mediated ones), which include everything from transient headaches to chronic pain and depression, account for the majority of the total burden of disease in our society."

On a similar note, Phillips stresses that the lack of an officially recognized labeled disease (ala "wind turbine syndrome") should not be reason to discount the health effects being reported: "...the individual diseases people are suffering from, such as chronic stress and sleep disorders, are often well defined (they are just not defined in terms of a specific cause)....There is no epistemic significance to the health outcomes in question having or not having a label."

And, he also points out, convincingly, that while not everyone who hears turbines gets sick, those who do get sick uniformly report some sensory experience of the turbines that's clearly not imaginary (*ed. note: and, being sensed, are thus apparently not related to inaudible infrasound*), and further, that:

"It is, of course, possible that some personal characteristic sensitizes them to be more bothered by the sensory effects, increasing the psychologically-mediated effects. But **it is inevitable that some personal characteristics will be causal cofactors (factors that, along with the turbine, are part of the necessary constellation of causes for there to be a disease effect). This is true for every exposure-disease combination:** Some exposed people get the disease and some do not, and sometimes we can identify other differences between the two groups."

While this paper makes no attempt to quantify just what the asserted "nontrivial fraction of residents" who experience health effects may be, Phillips did offer an estimate during a presentation to the Lee County (IL) Zoning Board of Appeals in late 2011¹¹. When asked what percentage of residents report health problems, he told the Board that there have not been solid studies of that, but that **his best guess, based on what research has**

¹¹ See <http://aeinews.org/archives/1591>

been done, is about 5 percent of those within a mile or so, with some reports of health effects out to two miles.

While this low estimate may surprise some, we'll see that other cautionary researchers also come to generally similar conclusions (estimates range from 5-15% of those close enough to hear turbines regularly). This more dramatically affected (and indeed non-trivial) minority may be those who are more sensitive in some way – to sound, air pressure fluctuations, or annoyance-induced stress. These relatively low percentages may also remind us of the need to separate the equally important, and more widespread, impacts on quality of life and sense of place from the more dramatic but apparently less widespread question of acute or chronic health impacts.

Health Related Quality of Life (HRQOL) Survey in New Zealand

Daniel Shepherd et al. Evaluating the impact of wind turbine noise on health-related quality of life. *Noise & Health*, September-October 2011, 13:54,333-9.

Daniel Shepherd, Witness Statement, Ontario MOE Environmental Review Tribunal, January 19, 2011.

Our second paper offers an interesting contrast and complement to the first – a contrast in that it's a rigorous field research project, and a complement in that it highlights the quality of life element that plays such a big factor in community responses to wind farms. A team researchers from New Zealand led by Daniel Shepherd conducted a comprehensive survey of residents living within 2km of a wind farm in the Makara Valley, just west of Wellington, with a comparison group of residents at least 8km from any wind farm. The survey was given a generic title, and included no questions specifically asking about wind turbines, in order to mask its intent to compare health-related quality of life (HRQOL) in two areas where the only substantial difference was the presence or absence of turbines.

The study utilized a well-known protocol, the health-related quality of life survey, which uses a series of questions to rate HRQOL in Physical, Psychological, and Social domains, while also assessing many specific sub-factors that contribute to these three main overall HRQOL scores; additional sections addressed general health, Environmental quality of life, neighborhood amenity, and annoyance. The authors note that "A variety of outcome measures have been proposed to assess the impacts of community noise, including annoyance, sleep disturbance, cardiovascular disease, and cortisol levels," and that the World Health Organization "recommends the use of HRQOL measures as an outcome variable, arguing that the effects of noise are strongest for those outcomes classified under HRQOL rather than illness."

The local wind farm consisted of 66 turbines running along a ridgeline, with homes

mostly in the bottomland of the river valley below; as in many locations, field measurements indicate that the turbines are generally compliant with their consent conditions, but complaints have been widespread nonetheless.

One of the most striking findings in this study was that **23 of the 39 respondents in the group living within 2km of turbines (59%) wrote in a comment that turbines were a noise source that bothered them, and rated it as extremely annoying**, with a mean of 4.5 on a 5-point scale (the noise annoyance questions included only two noise sources, traffic and neighbors, with a space to specify an "other" source if they chose; **no "other" source besides turbines spurred notation by more than 3 people**). Also of note is that "scrutiny of the comments provided by the turbine group revealed no mention of the impact of turbines on the landscape, reinforcing suggestions made by other (researchers), that wind farm noise is more dominant than their visual aspects."

The HRQOL ratings that showed the strongest impacts among the turbine group were reductions in Physical quality of life (with sub-factors of **sleep quality and energy level being the primary contributors**), as well as Environmental quality of life. There was **no statistical difference between the groups in Social or Psychological quality of life, or – notably – in the self-rated general health scores**; this lack of a difference in average self-reported health is replicated in some of the other surveys we'll address here.

It's worth noting that these are overall averages; the data as presented does not clarify whether an increased proportion of individuals (even just, say, 10-15%) closer to turbine reported lower health ratings, while the overall average remained relatively unchanged. In both this study and the one that follows, researchers chose to use standard, widely-recognized health-related rating systems, rather than to detail specific complaints. This may allow the moderate sample sizes to be assessed in ways that are less prone to distortions by a few individuals, while also having the benefit of matching well-established protocols.

In this study, **the most dramatic difference was in the separately-assessed Amenity score, where the turbine group scored dramatically lower** (this is where the very high annoyance at turbine noise factored in, in stark contrast to finding no differences between the two groups in annoyance at other noise sources). Amenity is a term used in environmental planning in Australia and New Zealand, which correlates closely with what we would tend to call "sense of place," relationship with home and landscape, or perhaps overall quality of life. Those living near turbines reported much lower overall Amenity scores, indicating a substantial decrease in rural quality of life.

The authors also note a strong correlation between self-reported noise sensitivity and annoyance in response to the turbines in that group. In the paper we'll briefly discuss next, Shepherd stresses this factor, suggesting that rural areas attract a higher proportion of noise-sensitive individuals, and that this should be factored into permit conditions.

In conclusion, the authors of this paper suggest (based largely on the high levels of annoyance, decreased sleep quality/energy level, and reduced amenity) that "night-time wind turbine noise limits should be set conservatively to minimize harm," and that "setback distances need to be greater than 2km in hilly terrain."

We'll turn briefly now to another contribution from Daniel Shepherd, a statement submitted to a 2011 Environmental Review Tribunal considering an appeal to the permits issued to a wind farm in Ontario.

Here, Shepherd repeats from the above paper a constructive contribution to the discussion: a flow chart illustrating the complex pathways by which wind turbine noise can lead to "primary health effects" of annoyance and sleep disturbance, and on to "secondary health effects" of quality of life and stress-related disease:

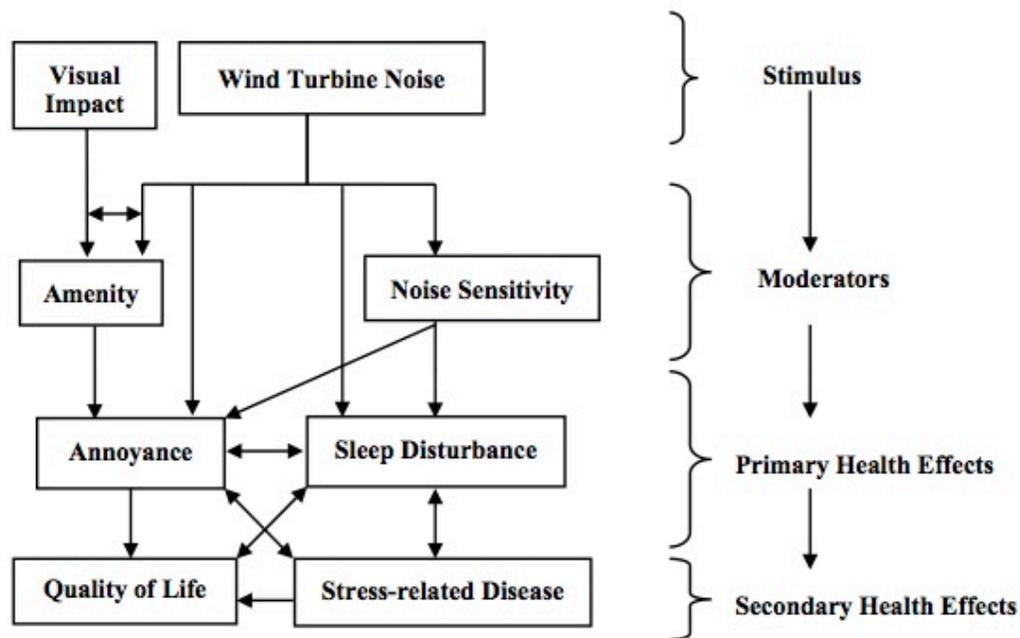


Figure 1: A schematic representation of the relationship between wind-turbines and health in a rural setting such as that proposed with the Kent Breeze Wind Farms. Arrows represent cause-and-effect relationships, which maybe bidirectional. The multiplicity of relationships emerges due to variability in the response of individuals to noise.

He also stresses the finding from many other studies, that noise annoyance is not readily correlated with noise exposure; **only about 20-25% of the annoyance effect can be explained by the noise level itself.** While some claim that visual impact or general attitude toward the wind farm drives annoyance, Shepherd stresses the inherent complexity of individual reactions to any noise source. As noted above, visual/landscape impacts did not seem to be a factor in the annoyance reported in the

Makara Valley; and further, Shepherd stresses individual psychological factors, as did Phillips. In particular, Shepherd puts forth the **high proportion of noise-sensitive individuals in rural areas (roughly 20%, about twice the proportion found in cities) as an indicator that annoyance rates will be at least that high, leading to associated stress-related effects in 10-15% of residents who can hear the proposed wind farm.**

Sleep quality survey in Maine

Nissenbaum, Aramani, Hanning. Adverse health effects of industrial wind turbines: a preliminary report [A version of this paper was published in Noise & Health in 2012. See AEI's summary, with link to the paper, at http://aeinews.org/archives/2144](http://aeinews.org/archives/2144)

This paper, presented at the 2011 ICBEN Noise as a Public Health Problem conference, like the Shepherd study above, uses widely recognized standard assessment questionnaires to assess mental and physical health, sleep disturbance, and sleepiness in two sets of residents in rural Maine, one living within 1.5km (just under a mile) from wind turbines, and the other 3.5-6km from any turbines. About two-thirds of adults living within 1.5 km of the Mars Hill wind farm participated, along with about half of the adults within that distance of the Vinalhaven turbines; the near-turbine group was about evenly split between those within a half-mile and those between a half-mile and mile. The total number of participants (38 near turbines and 41 at a greater distance) is slightly smaller than the Shepherd survey; both would benefit from larger sample sizes, especially in the measures that show no statistical difference. However, both also boast a very good response rate among the local residents, adding to confidence in the validity of the findings.

Also as in the Shepherd survey, the results are presented as overall averages, contrasting near and far groups, so, again, there is no direct reporting of the proportion of either group reporting any particular health effects. In addition, in the categories where a significant difference was found between the groups, the results were presented on graphs scaled over the full range of distances.

Following on a preliminary survey at Mars Hill that found "sleep disturbance was the main health effect," this larger study also found that the **sleep measures showed "a clear and significant relationship, with the effect diminishing with increasing distance" from the turbines.** The Pittsburgh Sleep Quality Index and Epworth Sleepiness Scale both showed significantly worse sleep for the turbine group; likely following from this, the most statistically significant result was a dramatically lower SF36 Mental Component Score (MCS) for the turbine group, indicating worse mental health (the MCS includes vitality, social functioning, and emotional health) – MCS scores dropped rapidly within the turbine group with increasing proximity to the turbines, especially moving in closer than a half mile. The authors note that this "first controlled study of the effects of IWT noise on sleep and health shows that those living within 1.4km of IWT have suffered **sleep disruption which is sufficiently severe as to affect their daytime functioning and**

mental health." They note that "while not proven, it is highly likely that IWT noise will cause arousals (brief lightening of sleep which are not recalled) which may prove to be the major mechanism for sleep disruption."

Notably, given concerns about physical health effects, the SF36 Physical Component Score (PCS) showed **no difference in average overall physical health between those close to turbines and farther away**; the PCS assesses physical functioning, bodily pain, and general health perceptions.

The results here closely parallel those reported above by Shepherd in New Zealand, where the Physical sub-factors of sleep quality and energy level were one of the strongest differences between those close and far from turbines, while neither study found a measurable difference in general health ratings. By contrast, Shepherd did not find the dramatic impact on psychological measures resulting from the sleep issues that were found in Maine; instead, his study saw a similarly dramatic increase in annoyance and decreased Amenity.

The study design used here does not provide any data on individual reports of specific health or annoyance reactions, so we can't speculate on what proportion of the turbine group may have experienced any given health or sleep impacts; likewise, this study does not assess annoyance rates. (The introduction to the paper suggests that such questions were included in the questionnaire, but this paper presents only results from the more standardized assessment instruments.)

The **earlier preliminary study** (shared in public forums by Nissenbaum during 2009 and after; currently submitted for publication), which included just under half of the Mars Hill residents living within 3400 feet, indicated that the majority of those surveyed were experiencing sleep disturbance on most nights (which is likely directly related to 40% reporting new onset of headaches); **20% or less reported specific symptoms such as dizziness, tinnitus, or unusual sensations in their chest or ears.** These figures are a notch above the 5-15% estimated by other investigators, but we may do well to remember that Mars Hill could be a worst-case scenario: ridgetop turbines close to sheltered valley homes, operating with a state-issued exception that allows them to run at 5dB louder than state regulations otherwise require (ie 50dB at night, rather than 45dB).

Comprehensive guidelines proposal aims to reduce 5-10% health effects rate near wind farms

Bob Thorne (Noise Measurement Services). Wind Farm Noise Guidelines, 2011.

In this comprehensive 116p document, Thorne, an acoustician who has specialized in human responses to moderate noise, reviews basic acoustics as well as field

measurements made at operating wind farms, and assessment of previous research into health effects. For these review qualities, it deserves a place in any basic wind farm noise document library. Of particular note – though unrelated to our purpose here – Thorne stresses that noise models cannot account for all the transient atmospheric factors that routinely increase temporary noise levels well above the average levels that the models predict reasonably well; he includes his field observations of "heightened noise zones" which match observations often made by people living around wind farms. For more on this, see the paper, or **AEI's recent summary of low-frequency noise research**.

Thorne's conclusions are straightforward:

It is concluded that, based on professional opinion, serious harm to health occurs when a susceptible individual is so beset by the noise in question that he or she suffers recurring sleep disturbance, anxiety and stress. The markers for this are (a) a sound level of LAeq 32 dB outside the residence and (b) above the individual's threshold of hearing inside the home.

It is concluded that there are **sufficient credible observations, measurements and peer reviewed research papers and affidavits indicating that for 5% to 10% of the individuals living in the vicinity of a large rural wind farm its operation will cause serious harm to their health.**

It is recommended that no large-scale wind farm or large turbine should be installed within 2000 metres of any dwelling or noise sensitive place unless with the approval of the landowner.

(Ed. Note: it appears that Thorne's 32dBA threshold is chosen because as sound levels rise past this point, audibility increases in quiet rural areas, so that negative responses begin to be reported; or, to look at it from a slightly different perspective, 5-10% of those hearing noise levels above 32dB are likely to experience negative health affects (the current state-of-the-art large community response surveys, from Pedersen et al, show annoyance rates in rural areas of around 5-12% at 30-35dB, rising substantially as noise increases to 40dB and beyond). It also appears that Thorne is especially concerned about the fact that peak noise levels are often quite a bit louder than average (Leq) noise levels; he makes it clear that 40dBA (Leq) is not likely to prevent a significant number of amenity complaints and health changes, so it's probably safe to presume that he feels that 32dBA (Leq) is a low enough average to assure that transient peaks and heightened noise zones do not cause widespread problems.)

Thorne's conclusion, which is based on both the possible health effects on this 5-10% of neighbors, and on his studies of reduced rural amenity in a much larger proportion of residents around two existing wind farms, is **shared by regulators in at least two Australian states (New South Wales and Victoria), where a 2km buffer has been proposed, with provisions to allow closer siting to willing neighbors.** These much more stringent standards are designed to minimize the audibility of wind turbines in otherwise quiet rural areas, thereby largely preventing annoyance and health reactions. As Thorne

notes in this paper:

Wind farms are now causing concerns regarding noise, especially from those residents immediately near to the turbines. In this regard, the Board of Inquiry into the proposed Turitea (New Zealand) wind farm is important, as it is the outcome of nearly two years' deliberations. The Board, in its draft decision of February 2011, says:

"Creating an environment where wind farm noise will be clearly noticeable at times of quiet background sound levels is not an option the Board condones, especially where large numbers of residents are affected. It is the Board's view that energy operations in New Zealand will have to learn not to place wind farms so close to residential communities if they are not prepared to accept constraints on noise limits under such conditions."

The decision highlights the duty of care that decision-makers, developers, acoustical consultants and regulatory authorities have to themselves and potentially affected communities.

What Nina Pierpont really found: pre-existing conditions underlie most health impacts

Nina Pierpont, *Wind Turbine Syndrome: A Report on a Natural Experiment*. K-Select Books, 2009.

Nina Pierpont, Presentation to the Hammond (NY) Wind Committee, July 2010

Even Nina Pierpont, the godmother of wind farm health concerns, **does not suggest that the problems she documents in her *Wind Turbine Syndrome* book are common**; she affirms that her research gives no indication of how widespread the issues are (while recognizing ways others researchers might begin to find out), and has suggested that the same 5-15% estimation we've seen from others here is a likely range.

Regular readers of AEI's wind farm noise materials may have noticed how rarely I reference Nina's work, other than defenses of the value of case series studies as a first step, in the face of unwarranted attacks on the work for not being something it isn't designed to be.¹² This has partly been because of what a hot button her research has become (especially as others make more of her results than even she does), and partly because I've been put off by some of the over-reach in the narratives that Nina and Calvin (her husband and website editor) have themselves used, both in the book and their website.¹³ But that has not affected my ability to listen to what she and her

¹² See <http://aeinews.org/archives/298>

¹³ Such narrative over-reach includes sections of the book itself, which while calling the "low-frequency/infrasound" and vestibular effects connection a "hypothesis," read as if they are presenting proof, rather than conjecture. More egregious has been the tendency of the website to underplay the point of the book, which is about "risk factors" and instead to foster the impression that health effects are very common among the population at large. For example, the website routinely trumpets outside

interviewees have to say about their actual experiences. The case histories in the book, and the interviews she has done with Falmouth residents,¹⁴ are most often **compelling and sober testimonies, from grounded citizens who are not out to "get" wind power, but simply were shocked at the ways their bodies reacted to the nearby turbines.** In the book, and in later case studies conducted by Pierpont, not all family members had health impacts; a key part of the initial study was aimed to begin to understand why some people reacted more dramatically than others.

In the book itself and several other documents, the actual findings of the "Wind Turbine Syndrome" research are quite simple, and perhaps even reassuring to many: As Pierpont has written:

Not everyone near turbines has these symptoms. This does not mean people are making them up; it means there are differences among people in susceptibility. These differences are known as risk factors.¹⁵

Centrally, she found that common WTS symptoms are most apt to occur in people with particular pre-existing conditions; specifically, she found "strong and statistically significant relationships" between three pre-existing conditions and the likelihood that residents would report new or aggravated health responses when turbines are operational nearby¹⁶:

- Pre-existing **motion sensitivity** appears to be make it more likely to experience symptoms of waking in alarm and/or a sense of internal pulsations in the chest or abdomen
- People with **migraine disorders** report even more severe headaches than they're used to when turbines are operational
- Residents with **previous inner-ear damage** from noise or chemotherapy are more apt to report new onset of tinnitus.

Similar to the findings of all of these studies, chronic sleep disturbance is the most common symptom Pierpont has identified. Exhaustion, mood problems, and problems with concentration and learning are natural outcomes of poor sleep. She also often stresses that her work suggests that older people and young children are more at risk than adolescents and young to middle-aged adults. (*Ed. Note: The very young and the*

mention of any health effects as further proof of Wind Turbine Syndrome, or as attempts to ignore WTS; and, one abstract of a Pierpont talk presents figures that, while including qualifiers, can easily be oversimplified by casual readers, eg, "70% of school-age children and teens in the affected WTS families had worsening of schoolwork, concentration, or test-taking" and "Tinnitus affected 58% of the adults and older teens in the affected families, compared to 4% in the general population" (it would be easy to read "affected families" as "families living near wind farms," when in fact that's not what she has investigated). In some ways, their promotion of the concept of WTS has undermined the value of the much more focused study that actually took place, as well as the human decency message in the case studies and interviews.

¹⁴ See <http://www.windturbinesyndrome.com/articles.html>

¹⁵ Nina Pierpont, Review of the Noble Environmental DEIS for Ellenburg, NY. May 31, 2006.

¹⁶ Nina Pierpont, Presentation to the Hammond (NY) Wind Committee, July 2010

old are well known to be more sensitive to sound/noise in general, as highlighted by WHO noise guidelines)

As for how common any of this may be, her most specific statements on that question basically build from the risk factors identified above:

I estimate **the proportion of the population likely to be susceptible to the symptoms of Wind Turbine Syndrome to be in the range of 20-30%**, including the 12% of the American population with migraine disorder, older people with age-related problems with inner ear function, children with disabilities (especially autism spectrum disorders, of which a common attribute is auditory oversensitivity and scrambling of incoming auditory signals), and some proportion of people with noise-induced hearing loss.¹⁷

Note that this "susceptibility" estimate does not imply that all of them will fall ill; this is the population with what Pierpont suggests are the possible risk factors.

Ambrose/Rand: Acousticians experience health effects

Stephen E. Ambrose, Robert W. Rand. The Bruce McPherson Infrasound and Low Frequency Noise Study: Adverse health effects produced by large industrial wind turbines confirmed. December 14, 2011.

A recent report from acousticians Stephen Ambrose and Robert Rand provides both the **first case study of health effects involving trained acoustics professionals**, and some affirmation of Pierpont's risk factor associated with motion sensitivity. Within a half hour of arriving at their study site (a home in Falmouth, MA), both Ambrose and Rand experienced disorientation and a difficulty in concentrating on the routine task of setting up their equipment. Both of them have a history of being prone to motion sickness. The authors note:

This research revealed that persons without a pre-existing sleep deprivation condition, not tied to the location nor invested in the property, can experience within a few minutes the same debilitating health effects described and testified to by neighbors living near the wind turbines. The debilitating health effects were judged to be visceral (proceeding from instinct, not intellect) and related to as yet unidentified discordant physical inputs or stimulation to the vestibular system.

They elaborate:

As is our custom on field surveys, we were enthusiastic and ready to begin our work. It was a beautiful spring afternoon, warm with a strong westerly wind aloft

¹⁷ See Nina Pierpont, Review of the Noble Environmental DEIS for Ellenburg, NY. May 31, 2006.

at the wind turbine blade height. We observed that there was a soft southeasterly wind extending from ground level to tree top (about 60 feet). Within twenty minutes of being inside their house, while setting up our instruments, each of us started to lose our initial enthusiasm and actually started to feel less well. As time went on, we got progressively worse. We each experienced unpleasant symptoms of motion sickness, including ear pressure, headache, nausea, dizziness, vertigo, especially when moving about. We had a sense that the room was moving or slightly displaced from where it appeared. We experienced a loss of appetite, cloudy thinking, fatigue, some anxiety and an inexplicable desire to get outside; similar to motion sickness we have experienced on a boat or plane. We felt slightly better when we did go outside.

On the morning of the second day we left the house to go out for breakfast. About 30 minutes later and a few miles away we shared a light conversation about the night before... We talked about the difficulties we had staying motivated and the challenges we encountered performing our usual work. As time went we started to feel better, and then by the contrast in our state of mind, it hit us. We realized and understood the true extent of the debilitating symptoms expressed by neighbors; we had experienced many of them the previous evening.

As this was a short (just over two days) study, it is impossible to draw definitive conclusions from the results, though there appear to be correlations between higher winds and the appearance and disappearance of the symptoms in these two unplanned subjects. In addition, their noise measurements and analysis, following on some innovative techniques recently developed by Wade Bray, revealed the presence of **rapidly pulsing low frequency sound. Using the dBG weighting, which is centered on 10-30Hz (the frequencies at the very low end of the normal "audible" range and the higher end of infrasound)** along with considerable contribution from frequencies up to 70Hz and down to 2Hz, the authors report dramatic fluctuations of dBG levels, with peaks over 60dBG. Their symptoms appeared to worsen when the dBG levels varied in a regular pulse, and to be ameliorated when dBG levels varied in a more random fashion.

I will refrain here from detailed discussion of low frequency perceptual thresholds, which has been subject to some debate within the acoustics community over the past year or so. The key new factor is the contention by some acousticians that rapidly pulsing sound, with peaks much higher than the levels measured using longer time-averaging techniques, can be perceived at lower dB levels than is indicated by standard hearing threshold curves, which are generated using simple, pure-tone sounds. For much more discussion of these questions, including Wade Bray's rapid timescale measurement techniques, see AEI's lay summary of recent low-frequency noise research.¹⁸

¹⁸ <http://aeinews.org/archives/1711>

Ambrose and Rand conclude their paper with the observation that the ramping-up onset of symptoms that they experienced, along with the more gradual dissipation of the symptoms after they left the site, both mimic a classic dose-response relationship; they suggest that the peak sound pressure events, which occurred on average once every 1.4 seconds, can be considered the recurring "dose" that triggered their "response." They mention a standard dose-response equation for considering cumulative effects that could be used to explore this idea further.

You may have noticed that this paper stands apart from the others reviewed here, in that it involves reported health effects that are presumably NOT stress-mediated or related to sleep disruption. That is, Ambrose and Rand may indeed have experienced an effect triggered directly by the noise exposure itself. They cannot, and do not, claim to have proven that in this short study, but their experience is an important reality check that **even if the vast majority of reported health problems may be indirect, stress-mediated effects, it is also likely that some people are being directly affected**. Whether these people have a pre-existing condition (such as motion sensitivity), or are part of the most perceptive fringe of the normal auditory perception curve, so that they actually do hear or sense some of the low-frequency sounds more readily than most, **we need to be careful not to lump all reports into any easy-to-accept framework**. This applies equally to those who seem to imply that all health issues are "merely" psychological, as well as to those who might fear that everyone near turbines will get vertigo. While it appears to me that many, likely most, of the health effects being reported are stress-related, I do not for a minute presume that they all are.

We might also bear in mind that **in addition to the sound waves that are the focus of virtually all discussion of community responses and health effects, turbines also create air pressure vortices** that travel in the downwind direction (turbine spacing is carefully designed to avoid having downwind turbines impacted by these significant pressure differentials). Some of the reported turbine-related symptoms, including pressure in ears or chest, and a general sense of discomfort, could be related to these pressure waves. The only community response researcher to consider them that I am aware of is Bob Thorne, who feels these vortices may contribute to his observed "heightened noise zones."

A few more things to keep in mind

Much Ado About Nothing?

Some observers suggest that if actual, acute symptoms appear in as few as 5-10% of the people living near wind farms, then **we may simply be hearing from people who represent the normal baseline rates for conditions like headaches, dizziness, tinnitus, and insomnia**. This is an important question to keep in mind as we move forward and

have larger studies to draw conclusions from.

However, the papers considered here are assessing **changes in health**: typically, subjects report symptoms appearing, or increasing, after wind farms began operation, and decreasing when turbines are not operating or the subjects are away from the area. The fact that most of these studies use self-reporting of current health conditions, and retrospective reporting of earlier health status, is considered by some to be a weakness; people's memories can be distorted by recent upsets at the wind farm. Some of the studies now beginning will be attempting to redress this by doing health surveys before wind farms begin operation, and following up later with the same subjects.

But again, for now, we start where we are, and these initial studies, while perhaps not ideal, can be assessed on their merits. The authors generally are quite forthright about their methods, making it relatively easy to see both the strengths and shortcomings of the data we currently have to work with.

Other surveys old and new

Scandinavia

As further evidence of the trend suggesting that health effects may occur in just 5-15% of the nearby population, we can also look to the three seminal Scandinavian surveys by Pedersen et al. These are much larger than the recent papers considered here, ranging from 350 to 750 people each. They were primarily assessing annoyance levels, but also asked some questions about health and sleep.¹⁹

The studies found that **in rural areas, annoyance ranged from 5-12% at 30-35dB, 15-20% at 35-40dB, and 25-45% at 40-45dB.** These annoyance rates dropped by half when inside homes, decreasing the stress-related risk group dramatically. And, relevant to our inquiry here, less than a third of those reporting outdoor annoyance reported any physical/health effects at all...bringing us right into the 5-10% range for people hearing 35-45dB, which generally coincides with living between a third of a mile and a mile of modern wind farms. For more on these studies, see AEI's presentation to the webinar presented by the New England Wind Energy Education Project in the summer of 2010²⁰.

¹⁹ In considering the results of these surveys, it is important to keep in mind that the first two focused on sites that generally had only one turbine nearby, most of which were relatively small by today's standards (hundreds of kW); only the third centered predominantly on wind farms, and included some turbines up to 3MW. In addition, about half the respondents lived in "suburban" areas in which existing noise levels and noise tolerance were notably higher than in most rural areas. Still, the detail collected in these studies provides a valuable grounding for discussions that are more often based on vague impressions of annoyance rates.

²⁰ Cummings. Wind Farm Noise: Public Perception and Annoyance. NEWEEP, 2010. Available online at <http://www.acousticecology.org/wind/> and <http://aeinews.org/archives/972>

The Scandinavian data has also provided raw data that has been analyzed in two recent papers. Both of these focused on a statistical analysis of many factors, rather than on rates of any specific factor; both suggest that annoyance is a better predictor of negative effects than are noise levels. Eja Pedersen²¹ found that **several measures of stress were associated with annoyance due to wind farm noise in all three studies, specifically, feeling “tense” and “irritable.”** Headache was associated with annoyance in two of the studies, and undue tiredness in one. Pedersen points out, however, that we should not assume that this is clear evidence of even an indirect causal relationship between turbine noise and stress, mediated by annoyance; she points out that people already under stress may be more apt to attend to turbine noise as an additional contributor to their pre-existing discomforts.

Roel Bakker is lead author of a forthcoming paper that was summarized in the 2011 book *Wind Turbine Noise*²², and is just about to be published in the journal *Science of the Total Environment*²³. This analysis looked at sleep disturbance and psychological distress (as measured by a 12-item questionnaire). Here, too, the effects were related to annoyance levels, rather than noise levels. Perhaps most importantly, **sleep disruption and psychological distress was far more significantly related to annoyance among those living in quiet rural areas** than in more built up areas, where the relationships were weak or non-existent.

Australia

The **most recent survey to address annoyance and health effects comes from South Australia.** It's part of a Masters dissertation by a Zhenhua Wang, student at the University of Adelaide; a few-page summary of the results²⁴ was publicly released in early 2012, with the full dissertation to follow. There are several wind farms in Australia and New Zealand where complaints are numerous at distances much greater than those we generally hear about in the US, Canada, and Europe – many complaints beyond 2km (1.25mi), and quite a few at 3-4km, with a few scattered complaints out as far as 10km (over 6 miles). I'm not sure whether this reflects wind farms being built in areas that are otherwise particularly pristine and quiet, or a different cultural attitude toward outside noise Down Under. It appears that most of these wind farms are on ridges, with homes below; some have suggested that the landscape in some of these areas may funnel the sound further than normal, as well; such topographic factors could be responsible for the higher annoyance rates.

This new survey was returned by 64% of the residents living within 5km (3.1mi) of the

²¹ Eja Pedersen. Health aspects associated with wind turbine noise—Results from three field studies. *Noise Control Eng. J.* 59 (1), Jan-Feb 2011.

²² Dick Bowdler and Geoff Leventhall, *Wind Turbine Noise*. Multi-Science Publishing Co. Ltd., 2011.

²³ R.H. Bakker, E. Pedersen, W. Lok, G.P. van den Berg, R.E. Stewart, J. Bouma. Effects of wind turbine sound on health and psychological distress. *Science of the Total Environment* (in press, 2012).

²⁴ Wang, Zhenhua. Evaluation of Wind Farm Noise Policies in South Australia: A Case Study of Waterloo Wind Farm. 2011.

Waterloo Wind Farm, and in keeping with the apparently greater annoyance levels Down Under, its results are striking: **70% of respondents said they'd been negatively affected by noise, including 54% who rated themselves moderately or very affected.** Of those affected, 38% reported health effects (i.e., 26.6% of the total number of respondents); i.e. about half of those moderately or very affected by noise. Even if the entire 36% of local residents who did not respond to the survey were totally unaffected, those reporting effects in the survey represent **32% of all residents within 5km being moderately or very affected by the noise, with 18% reporting health effects.** Huh.

For reference on the other end of the spectrum, the Netherlands surveys suggest that just 8% of those within 2.5 km (1.5mi) of turbines are "rather" or "very" annoyed with wind farm noise. This has become a commonly referenced "general" annoyance rate; though the Pedersen studies (which this one builds on) also tend to show substantially higher annoyance in rural areas than in suburban ones (these overall averages include about half suburban respondents; see also footnote 20).

van den Berg "Effects of sound on people" chapter

Likewise, Frits van den Berg's chapter in *Wind Turbine Noise*²⁵, which was also presented as a paper²⁶ at the Wind Turbine Noise 2011 meeting in Rome, provides a **detailed overview of earlier and more recent studies of looking at annoyance, sleep disruption, and health effects around wind farms** (it includes the Shepherd and Hanning papers summarized above). Rather than repeat much of this here, I encourage you to read the chapter or paper; the latter will be available on AEI's wind farm noise resource page²⁷. I will note that van den Berg manages to summarize the essence of each paper's findings far more concisely than I have!

But for now, our focus is health effects, rather than annoyance; look to the AEI Wind Farm Noise 2012 annual report (forthcoming, summer 2012) for more comprehensive summaries of annoyance rate surveys, including summations in the van den Berg chapter and paper.

Meet the New Stress, Same as the Old Stress

Geoff Leventhall, a British acoustician who's become one of the most widely-cited critics of the idea that infrasound and low-frequency sound from wind farms is strong enough to cause health problems, has also been **quick to acknowledge that noise-related stress is likely to be a significant factor in community responses to wind farms.**

²⁵ Dick Bowdler and Geoff Leventhall, *Wind Turbine Noise*. Multi-Science Publishing Co. Ltd., 2011.

²⁶ Frits van den Berg. An overview of residential health effects in relation to wind turbine noise. Fourth International Meeting on Wind Turbine Noise, Rome, Italy, 12-14 April 2011.

²⁷ See <http://www.acousticecology.org/wind/>

In a detailed article in Engineering and Technology Magazine²⁸, published in 2009 just prior to the publication of Nina Pierpont's Wind Turbine Syndrome book, Leventhal opined, "The wind developers are going to rubbish her book, and quite rightly so, but **what must be accepted – and developers don't want to accept this – is that yes, people are disturbed. If people are consistently disturbed, and their sleep is consistently disturbed, then they will develop some very 'unclever' stress symptoms. That will lead to stress-related illness.**"

Elaborating in a white paper he wrote entitled, "Wind Turbine Syndrome – An appraisal," Dr Leventhal critiques Pierpont's approach and conclusions, but says of the identified stress symptoms:

"I am happy to accept these symptoms, as they have been known to me for many years as the symptoms of extreme psychological stress from environmental noise, particularly low frequency noise. The symptoms have been published before... The so called "wind turbine syndrome" cannot be distinguished from the stress effects from (any) persistent and unwanted sound. These are experienced by a small proportion of the population and have been well known for some time."

In other words, Leventhal believes that the stress-mediated health effects we're hearing about around wind farms are not due to any special qualities of turbine noise, but rather simply to people dealing with unwanted turbine noise in their environment and homes.

Doctors Down Under urging people to move from homes?

While most of my energy and attention has been focused on community responses in the U.S., along with following the publications in journals and conferences and press reports worldwide, I should mention at least in passing that I've come across several news reports from Australia that mention doctors urging patients move from their homes after they experienced negative health effects. This is not something I've found any solid studies on, but it has stood out in my ongoing monitoring of wind farm siting; I'm not aware of other regions in which doctors have made such recommendations (update: I just came across reference to an initiative in Quebec that was signed on to by 40 physicians²⁹). Two General Practitioners are seen in a short video by the Waubra Foundation³⁰ on health issues near wind farms, as are two apparently hearty men who

²⁸ See <http://eandt.theiet.org/magazine/2009/17/quiet-revolution.cfm>

²⁹ See <http://terrecitoyenne.qc.ca/?p=325>

³⁰ The Waubra Foundation is closely associated with Landscape Guardians, which is widely seen as a climate-change denialism organization, with significant ties to the oil and gas industry. Dr. Sarah Laurie, who spearheads their health-related efforts, affirms in personal communication that some board members have a broader agenda, but says she was strongly pro-wind until 2010 when she began hearing from GPs about patients with health issues, that her sole concern is health of neighbors, and that board members "respect each others' differences." As suggested above, and as studied by Robert Thorne, reports of both quality of life impacts and health effects are more commonly reported at relatively large distances in Australia and New Zealand, with many complaints at 2km, and quite a few out to 3-4km. Waubra

had to move from their homes after wind farms became operational nearby; the video can be viewed at <http://www.youtube.com/watch?v=IEh3sooKU8A>

The Waubra video is actually **a perfect example of the difficulty we confront in considering the health effects issue**. The testimonials are heartfelt and compelling; as I mentioned, I wouldn't wish this on any of the folks living in my valley. Yet also, the end of the video highlights that after years of working on this issue, the Waubra Foundation has identified 90 people in four southeastern Australia states who are struggling with health effects (and that "over 20 families" have abandoned their homes across the country). I think it's **safe to say that those 90 people once again represent 10% or less of the total population living within earshot of the thirteen wind farms they list as locations of issues, and certainly of the thirty wind farms operating in the four states**³¹ (though it would be interesting to know if the bulk of those 90 families live around just a few of the thirteen).

So again, I find myself turning to the Thorne and Shepherd studies from Australia and New Zealand that focus on the much higher rates of severe annoyance and impacts on rural quality of life and amenity. And again, I find myself wondering how we can begin to discern the differences between the few wind farms triggering widespread noise issues – the 13 in this region – and the 17 others where even Waubra hasn't heard of any problems. In the US, it's likely that the proportion of "problem wind farms" is even lower, since most of our installed capacity is still in the wide-open spaces of the west. What are the indicators that might clue us in to where we need to be more sensitive to more significant community reactions to wind farm noise? **Looking at typical setbacks, population density, or community make-up of places with lots of complaints, as compared to places with few or no noise issues**, might help us to move forward in a way that both protects rural quality of life and maintains our momentum toward increased wind energy generation.

Conclusions

So, what have we found? Remembering that to get a full picture of health impacts research, you should also be familiar with some of the larger literature reviews published by government entities and industry trade associations, this overview of direct research in communities where health impacts are being reported suggests a few things:

- First, health effects may be more common in a relatively small subset of the population that have pre-existing conditions that could make them more

Foundation appears to take an especially hard line, urging setbacks of 10km, since that's the greatest distance they've heard of problems. This extreme position raises questions about whether Waubra's goal is simply health, or effectively stopping wind development.

³¹ See <http://ramblingsdc.net/Australia/WindPower.html>

- susceptible to being affected by noise, perhaps especially low-frequency noise.
- Second, those who are noise sensitive (roughly 20% of the population, especially in rural areas) are more likely to be annoyed by sound in general, and wind turbines in particular. This annoyance, and/or a related increase in sleep disruption caused by turbine noise, can lead to stress-related disease symptoms.
 - Third, among the rest of the population, especially among the 30-50% who are neither especially noise sensitive nor extremely noise tolerant, those who are annoyed by wind turbine noise (due to being woken, or simply because they resent the new noise intrusion in their rural landscape) may also develop some stress-related responses. This group is also more likely to simply resent the new noise intrusion in their community, even if they are not experiencing any health effects.

The evidence currently available from community surveys suggests that while in some types of communities, **a quarter to half of those close enough to turbines to hear them at 40dB or more may find them particularly annoying and unwelcome, a much smaller proportion of the nearby population is actually reporting negative health effects.** (For more on rural annoyance rates, see AEI's Wind Turbine Noise 2011 report³², and the upcoming 2012 version, which will summarize all known community response surveys.)

If this inquiry is being undertaken in order to inform decisions about siting standards, then it will always be important to look at both annoyance rates and health impact rates among those closest to the turbines. It tells us nothing to hear that, say, 95% of community members feel fine about a wind farm, when most in the community live miles away from turbines. Analysis of annoyance (as a possible precursor to stress-related health effects) and of reported health changes needs to consider rates within a half mile or kilometer, as well as rates between a half mile and mile or 1-2km, in order to provide useful information for deciding what setback between wind turbines and neighbors is appropriate.

But **however we analyze these questions, we will be left with a social choice.** Some people will be negatively affected by almost any new noise source or change in the local landscape. A tiny proportion of the population could well experience authentic health effects from turbine sounds that are over a mile away and just barely audible; at the other end of the spectrum, in some types of communities, a large proportion of those hearing nearby turbines regularly may hate the new noise and become quite worked up over it.

Communities will need to decide what level of impact is acceptable. Some may decide that they don't want to subject any neighbors to even occasionally audible wind turbine noise (some such communities have adopted large setbacks, up to 2km or even 2 miles). Others might feel that contributing to a national push toward renewable energy

³² See aeinews.org/archives/1393

is worth the trade-off of knowing that 5-10% of those within a mile may have more headaches, or sleep disruption that leads to poor concentration and work performance (such communities, aiming for a "happy medium," have chosen setbacks of a mile, or sometimes 3000 feet). I suspect that few would welcome the thought of half of the nearby neighbors feeling that their homes were far less welcoming and relaxing than they used to be (which has been the experience in some of the communities that adopted setbacks of a third of a mile or less). But the question will always be there: where do we want to draw the line?

I would be remiss if I didn't also stress here that the annoyance rates and health effects rates reported in communities with strong negative reactions to wind farms are not representative of all wind farms. By contrast, it's notable that **in ranching country, where most residents are leaseholders and many live within a quarter to half mile of turbines, health and annoyance complaints are close to non-existent**; some have suggested that this is evidence of an antidote to wind turbine syndrome: earning some money from the turbines. More to the point, though, the equanimity with which turbine sound is accommodated in ranching communities again suggests that those who see turbines as a welcome addition to their community are far less likely to be annoyed, and thus to trigger indirect stress-related effects. Equally important to consider, ranchers who work around heavy equipment on a daily basis are also likely to be less noise sensitive than average, whereas people who live in the country for peace and quiet and solitude are likely more noise-sensitive than average. And, there are some indications that in flat ranching country, turbine noise levels may be more steady, less prone to atmospheric conditions that make turbines unpredictably louder or more intrusive. When considering the dozens of wind farms in the midwest and west where noise complaints are minimal or non-existent, it remains true that **the vast majority of U.S. wind turbines are built either far from homes or in areas where there is widespread tolerance** for the noise they add to the local soundscape.

Here we find ourselves once again at the crux point that needs to be factored in to wind farm siting standards: **not every community will respond similarly to the new noise that wind farms undeniably add to the local soundscape. Siting standards need to be flexible enough to recognize these differences; one setback, or one dB limit, clearly does not fit all.** Let's not forget, either, that a large proportion of US wind farms are still being built in the vast expanses of the Great Plains and intermountain west. Many of these, likely still representing the majority of US wind generating capacity, are miles from any home. This is clearly the best place for them to be, as recently stressed by wind historian Robert Righter³³.

One of the purposes of this summary is to ease the fear that health impacts will be widespread around any new wind farm. But I certainly am not implying that the 10%, or 5%, who are suffering, should be disregarded. To make it personal, if faced with the

³³ Robert Righter. Windfall: Wind Energy in America Today. University of Oklahoma Press, 2011. See summary of his point on noise and siting at <http://aeinews.org/archives/1726>

possibility that two of the forty families in my valley would likely experience substantial health effects (whether because they were prone to motion sickness or just hated the sound enough to rile them up) from a wind farm on the ridge that sits – as indeed one does – a third to half mile from our homes, I would likely not want to trade their well-being for a few megawatts of green energy, despite my commitment to a renewable future.

Of course, the **simple solution for communities would be to keep turbines farther away**; opinions differ, but somewhere in the half mile to mile or so range is likely to greatly reduce audibility, annoyance, stress, and stimulation of pre-existing conditions. Some suggest 1.25 miles, or 2km, in order to be more sure that peak sound levels, triggered in worst-case atmospheric conditions, remain barely audible.

It's not my intention or my place to pick a solution to this quandary, especially given the clear differences between communities as to what is likely to be the best choice. My goal is simply to help clarify what has been found by those looking most closely at these questions in communities where it has become an issue.