Wind Turbine Noise, Annoyance, Health, and Proper Siting Guidelines

By

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To The

Board of Commissioners

And The

Emmet County Office of Planning, Zoning, and Construction Resources

Nov. 4, 2010

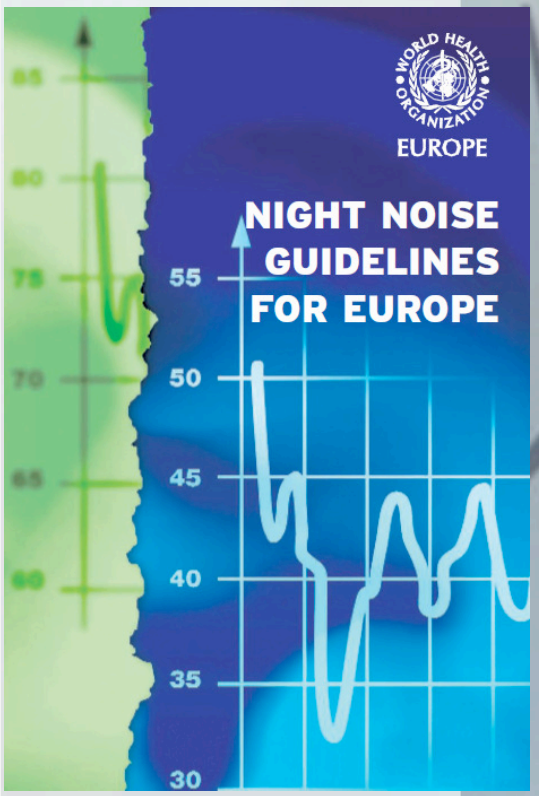
Abbreviated Summary of Experience

- BSc Mech. Eng. with 40 years of experience in applied acoustical engineering.
- Computer Modeling for siting large industrial complexes since 1971.
- Principle Consultant to Major Industry for Noise
  - Auto, Tire, Farm, Brewing, and Entertainment and Machine Tool Builders
- Studied over 30 Wind Projects since 2005

Nighttime Noise and Health

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

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



World Health Organization (WHO, 2007) Nighttime Noise Guidelines

- $L_{night,outside}$ up to 30 dBA: No substantial biological effects observed.
- $L_{night,outside}$ of 30-40 dBA: Body movements, awakening, sleep disturbance, arousal.
  While average effects may be modest, young, chronically ill, and elderly populations are affected to a greater degree.

World Health Organization (WHO, 2007) Nighttime Noise Guidelines (Continued)

- **$L_{night,outside}$ of 40-55 dBA: Sharp increase in adverse health effects, exposed populations have to adapt coping mechanisms, and vulnerable groups are severely affected.**
- **$L_{night,outside}$ above 55 dBA: Adverse health effects occur frequently, high percentage of population is highly annoyed, and limited evidence suggests that human cardiovascular system is stressed.**

World Health Org. on Infra and Low Freq. Noise (1999)

The World Health Organization is one of the bodies which recognizes the special place of low frequency noise as an environmental problem. Its publication on Community Noise (Berglund et al., 2000) makes a number of references to low frequency noise, some of which are as follows:

- *" It should be noted that low frequency noise, for example, from ventilation systems can disturb rest and sleep even at low sound levels"*
- ***"For noise with a large proportion of low frequency sounds a still lower guideline* (than 30dBA) *is recommended"***
- *" When prominent low frequency components are present, noise*
- *measures based on A-weighting are inappropriate"*
- *"Since A-weighting underestimates the sound pressure level of noise with low frequency components, a better assessment of health effects would be to use C-weighting"*
- *"It should be noted that a large proportion of low frequency components in a noise may increase considerably the adverse effects on health"*

"The evidence on low frequency noise is sufficiently strong to warrant immediate concern"

What We Knew About WT Noise

- 1980 to 1991 NASA funded a series of research projects on wind turbine noise. The primary researchers, Hubbard and Shepherd reported:
  - Wind turbines produced primarily infra and low frequency sound
  - Determined that sound propagated from wind turbines at a decay rate half that of common ‘point’ sources. Wind turbine noise travels farther than other sounds.
  - Would be significant indoor noise problem due to room resonance

What we knew about ILFN

- 1970's-early 1990's
  - Work on turboprop jet engines and other sources of infra and low frequency sounds (ILFN) established that inaudible levels of infra sound caused physical responses
  - "Sick Building" syndrome found that poorly or incorrectly designed HVAC systems in large office buildings resulted in inaudible modulated low frequency sounds in work areas. Workers reported symptoms similar to those for Wind Turbine Syndrome

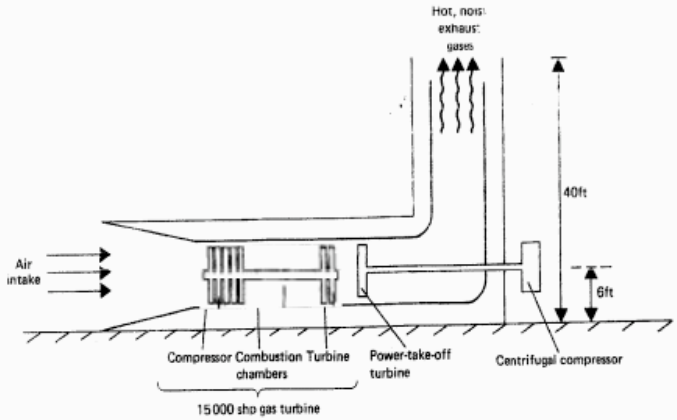
What We Knew about ILFN

- **Malcolm Swinbanks**

Wind Turbines: Low-Frequency Noise & Infrasound Revisited
M.A.Swinbanks

I first became interested in Low-Frequency Sound when tackling theoretical & practical research problems relating to the Active Control of Sound, in the 1970's

Following successful laboratory experiments, in 1979 I was asked to tackle the specific problem of excess low-frequency noise from an industrial gas turbine located in a rural area.



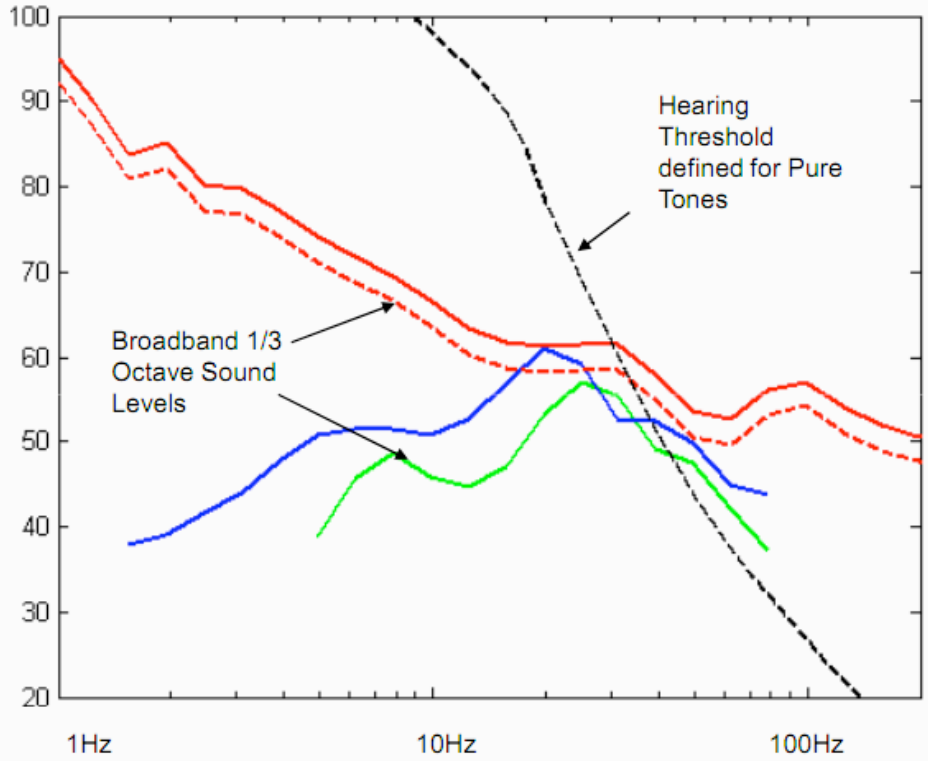
The noise was generated by the gas turbine exhausting into a vertical silencer 40 ft high and 10 ft diameter. The exhaust turbulence induced resonances in the air column of the silencer, giving rise to unacceptable very low-frequency sound levels around 20-30Hz.

As a result of spending long hours working on the site, in the presence of significant levels of very low-frequency noise, I acquired considerable familiarity with its effects and consequences.

What We Knew about ILFN

- **Malcolm Swinbanks**

Comparison of Noise Levels with Threshold of Hearing.

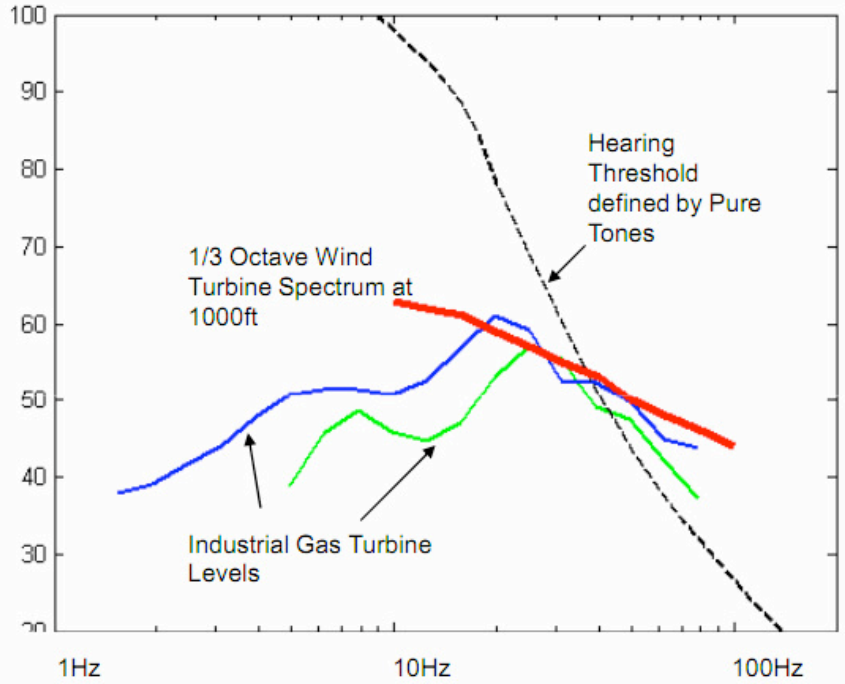


Subsequent Active Reduction of Gas Turbine Noise Levels over 20-40Hz successfully resolved Complaints. So the 20-40Hz Sound Level had been Perceptible, despite being Below the Nominal Threshold of Hearing

What We Knew about ILFN

- **Malcolm Swinbanks**

Example of LF Wind Turbine Spectrum, Considered to be not Audible to the Average Person up to about 31.5Hz – 40Hz. (Dr Geoff Leventhall to Public Service Commission of Wisconsin)



Present Author's Opinion: Wind Turbine LF Spectra compare directly to (projected) Industrial Gas Turbine Levels that gave rise to complaints, 25-30 years ago.

Care must be taken when comparing broad-band measurements, having noise simultaneously present at all frequencies, against a threshold defined by individual, stand-alone pure tones.

What NASA Knew

- **Malcolm Swinbanks**

NASA Also Identified and Investigated Important Low Frequency Effects that are not Cured by Modern Upstream Rotors

(1) Atmospheric Wind Gradients lead to Low Frequency Impulsive Noise, even from Modern Upwind Designs [1] (1989)

(2) The Threshold of Hearing can be up to 10 Times more Sensitive to the Dominant Components of Low-Frequency Impulsive Noise [2] (1982)

(3) The Threshold of Detection was found to be lower in level (7-10dB) for Coherent Phase (Repetitive) rather than for Random Phase Low Frequency Components [3] (1982).

Some Parties Dismiss this NASA Research as Out-of-Date, 1980's, and No Longer Relevant

The Author believes it is Incorrect to do so – It is Directly Relevant

The properties of the winds, and the characteristics of human hearing, have not changed.

[1] Low Frequency Acoustic Emissions from Large Horizontal Wind Turbines, H.H.Hubbard & K.P.Shepherd* Inter-Noise 89, 4-6 December 1989
[2] Acoustical Criteria Applicable to Large Wind Turbine Generators K.P.Shepherd* & D.G.Stevens Inter-Noise 82, 17-19 May 1982
[3] Guide to the Evaluation of Human Exposure to Noise from Large Wind Turbines D.G.Stephens, K.P.Shepherd, H.H.Hubbard,,F.W.Grosveld NASA Technical Memorandum 83288 March 1982/

What We Knew about ILFN

- **Sick Buildings**

Journal of Sound and Vibration (1997) **205**(4), 467–474

EFFECTS ON PERFORMANCE AND WORK QUALITY DUE TO LOW FREQUENCY VENTILATION NOISE

K. Persson Waye, R. Rylander

Department of Environmental Medicine, Göteborg University, Sweden

S. Benton

Division of Psychology, University of Westminster, London, England

AND

H. G. Leventhall

What We Knew About Modulated ILFN

- **Sick Buildings**

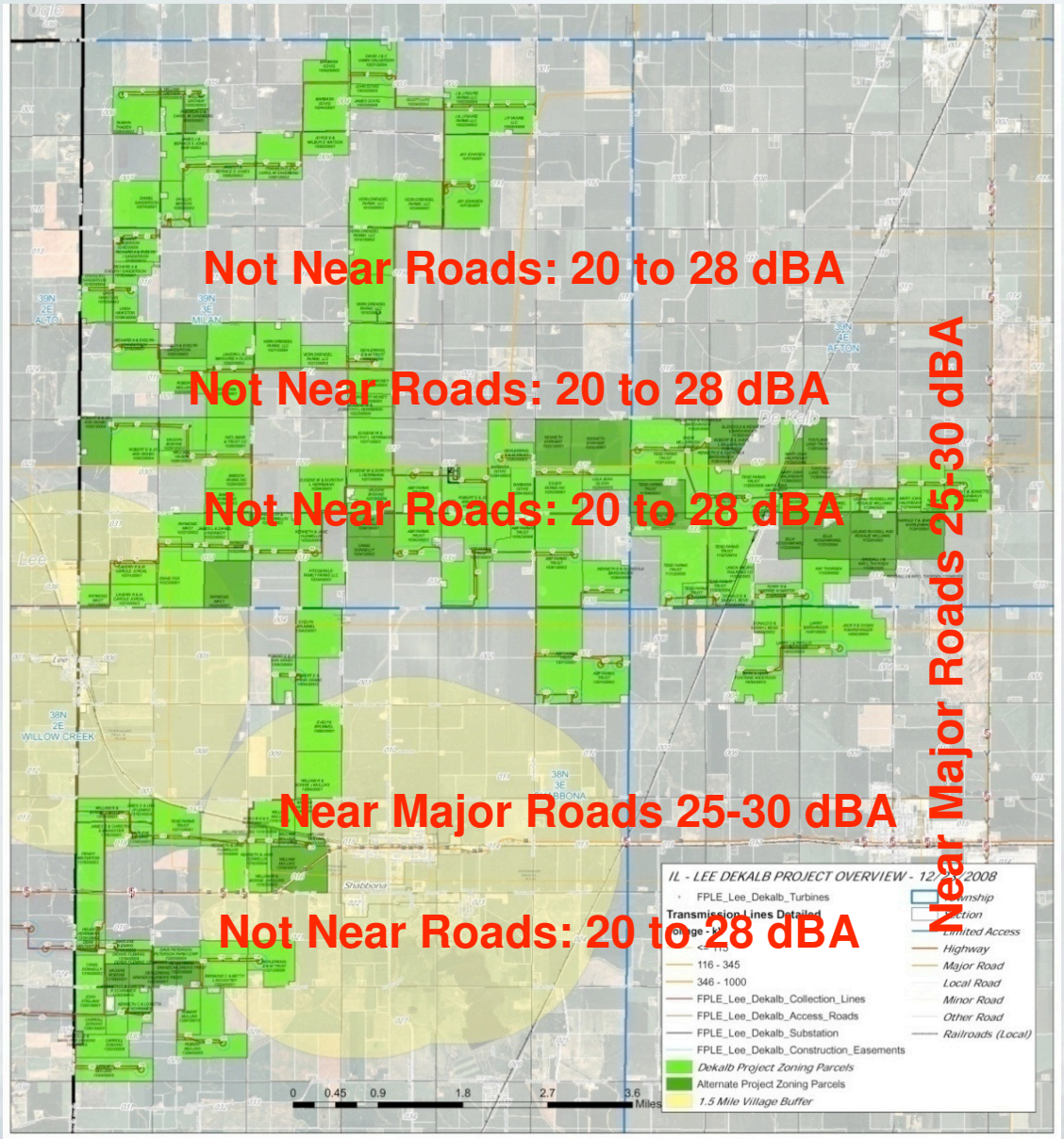
1. BACKGROUND

In occupational environments such as control rooms and office-like areas, there is growing concern as to the effects of low frequency noise (20–200 Hz). Low frequency noise may be emitted from ventilation, heating and air-conditioning (HVAC) systems or may occur as a result of the selective attenuation of walls, floor etc. A few previous studies indicate that low frequency noise may reduce performance at levels that can occur in such occupational environments [1, 2]. Some of the symptoms that are related to exposure to low frequency noise such as mental tiredness, lack of concentration and headache related symptoms, could be associated with a reduced performance and work satisfaction.

5. CONCLUSION

The results showed that the low frequency noise was estimated to interfere more strongly with performance. The results also gave some indications that cognitive demands were less well coped with under the low frequency noise condition. This effect was especially pronounced in the last parts of the tests, which indicates that the effects appear over time. If this effect can be verified in further studies, it could be hypothesized that the low frequency exposure was more difficult to habituate to. The relation between the reduced activity and response time, which was especially pronounced in the low frequency noise condition, may also indicate that increased fatigue was of importance for the results. The underlying mechanisms responsible for reduced performance caused by low frequency

Background Sound In Rural Areas Below 30 dBA (L_{90})



What is Noise Pollution?

Thresholds for Significant Sound Pressure Level (SPL) Increase

The goal for any permitted operation should be to minimize increases in sound pressure level above ambient levels at the chosen point of sound reception.

•Increases ranging from 0-3 dB should have no appreciable effect on receptors.

•Increases from 3-6 dB may have potential for adverse noise impact only in cases where the most sensitive of receptors are present.

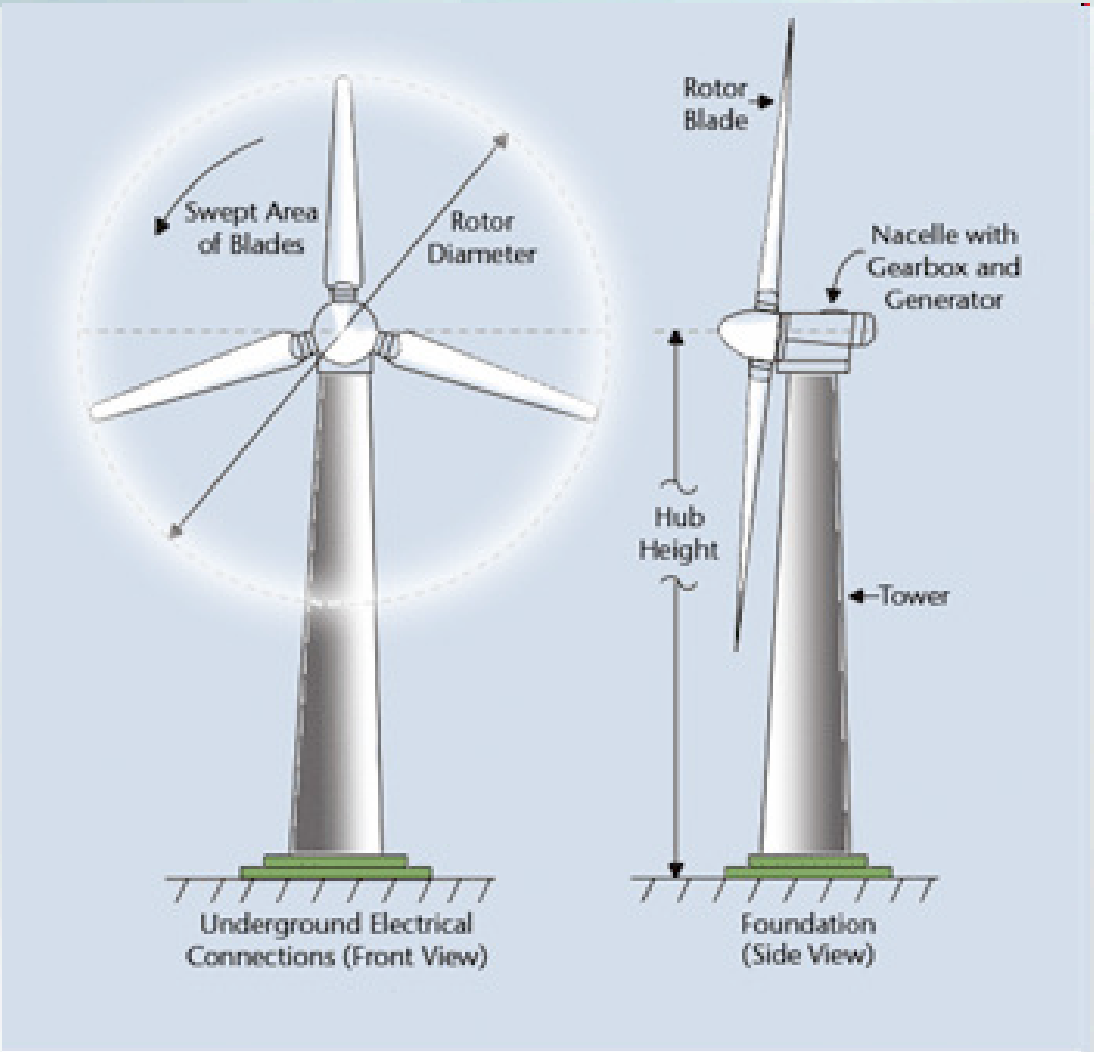
•Sound pressure increases of more than 6 dB may require a closer analysis of impact potential depending on existing SPLs and the character of surrounding land use and receptors.

•SPL increases approaching 10 dB result in a perceived doubling of SPL. **An increase of 10 dB(A) deserves consideration of avoidance and mitigation measures in most cases.**

From: New York State DEC Policy on "**Assessing and Mitigating Noise Impacts" Revised Feb. 2, 2001**

Wind Turbines

Major Components of a Modern Wind Turbine



Drawing of the rotor and blades of a wind turbine, courtesy of ESN

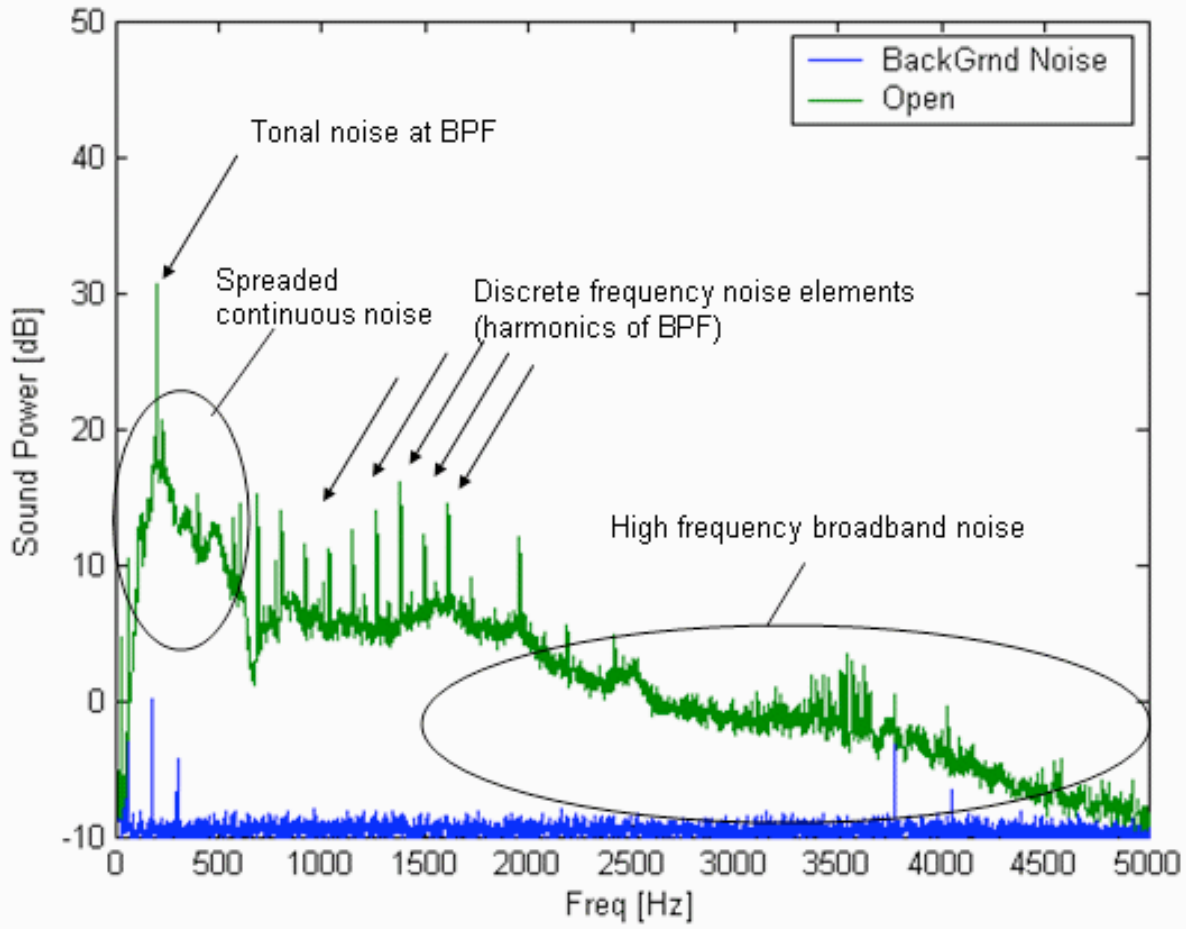
Source: http://ec.europa.eu/research/energy/nn/nn_rt/nn_rt_wind/images/wind_en_1370.gif

Wind Turbine Complaints Attributed to Sound

- **Audible Sounds**
  - Reasonably steady sound of blades moving through air
  - Swishes, Thumps, etc
  - Periodic mechanical sounds
  - Rumble inside homes and other buildings
  - Higher annoyance at lower levels than other common Community Sound Sources
- **Non-auditory**
  - Body sensations
  - Building response

Rotating Machines Have Common Characteristics

- **Fans and Wind Turbines share common acoustical attributes**



NASA Research during 1980's

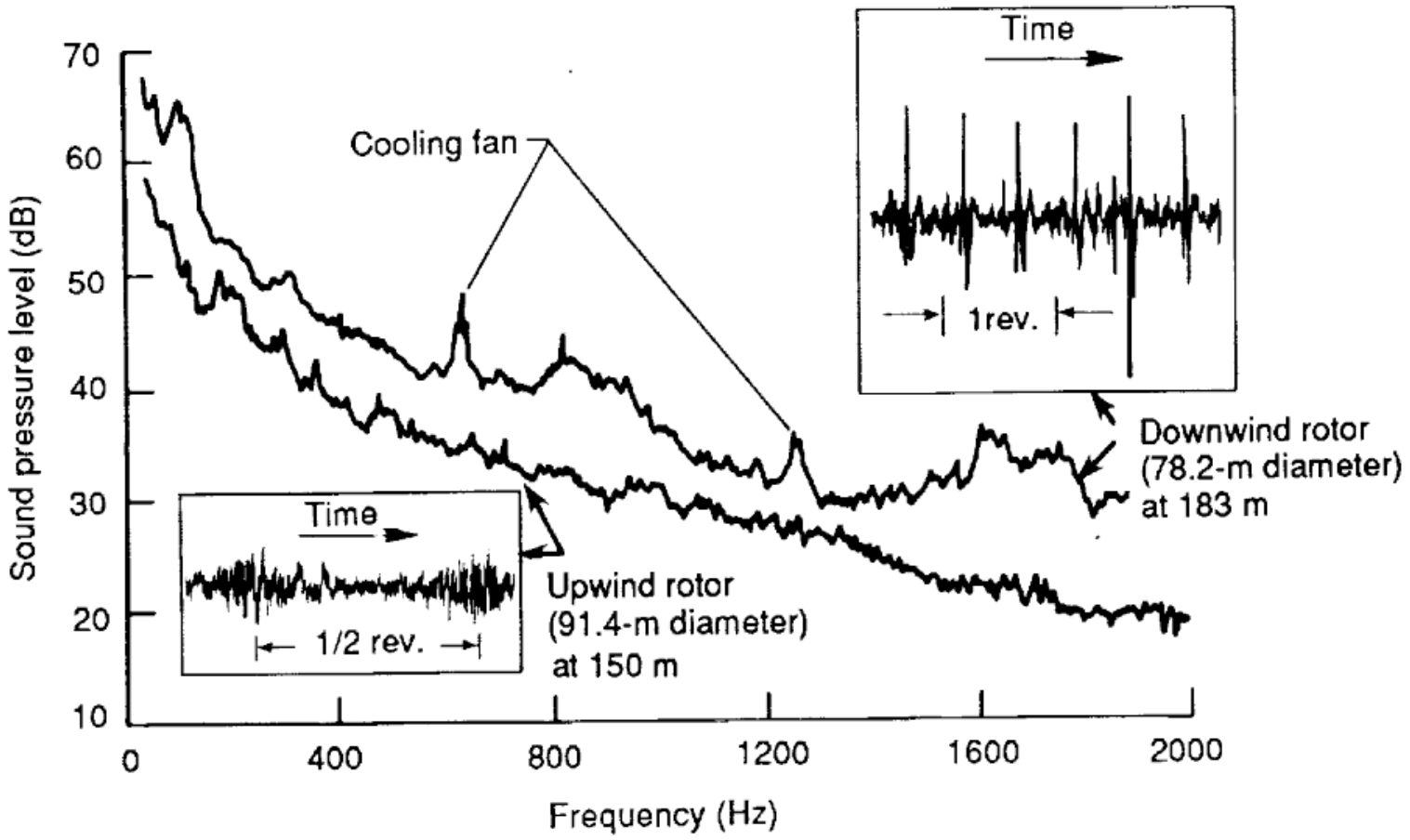
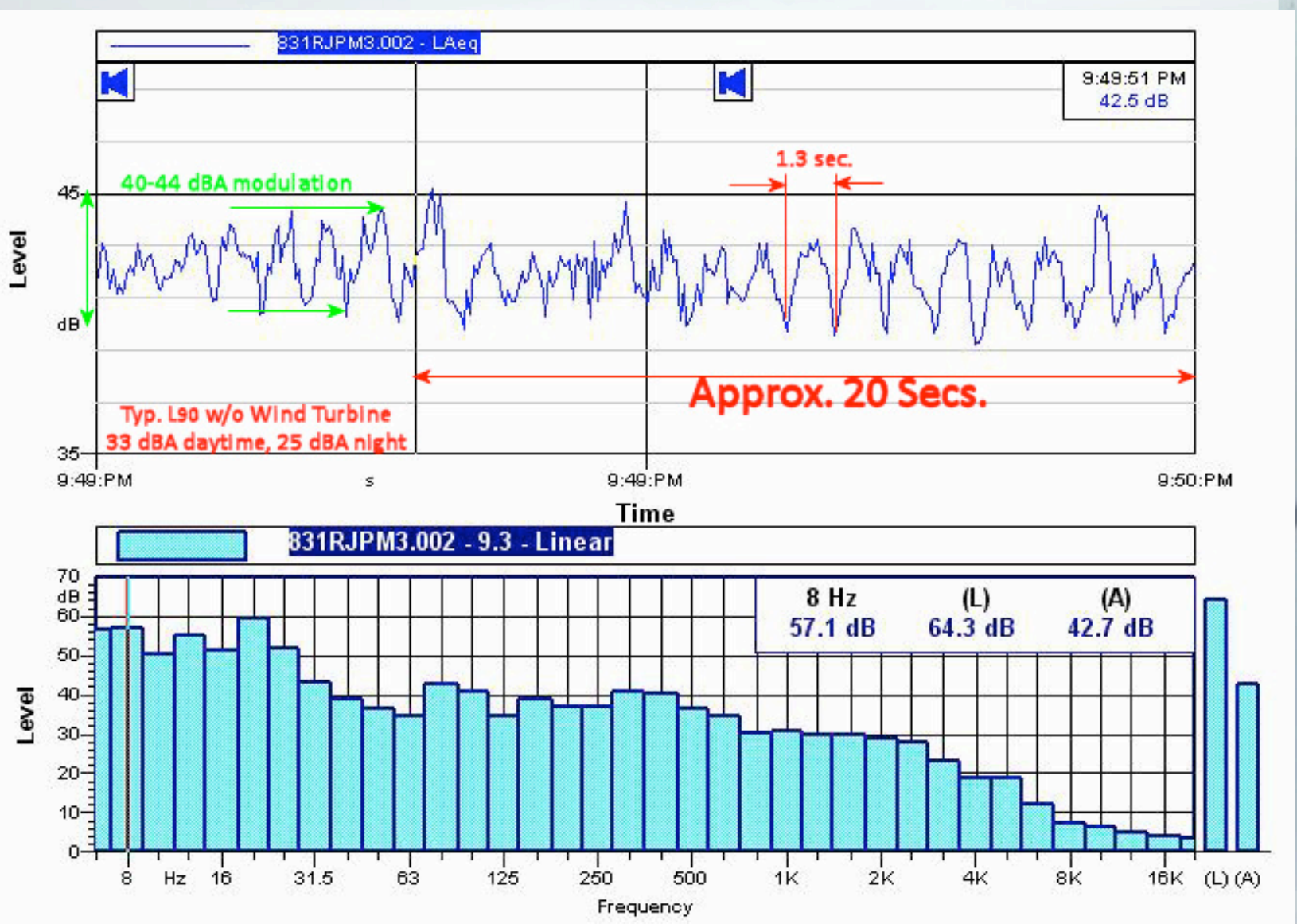


Figure 7-4. Narrow-band noise spectra from large-scale HAWTS with upwind and downwind rotors (bandwidth = 2.5 Hz)

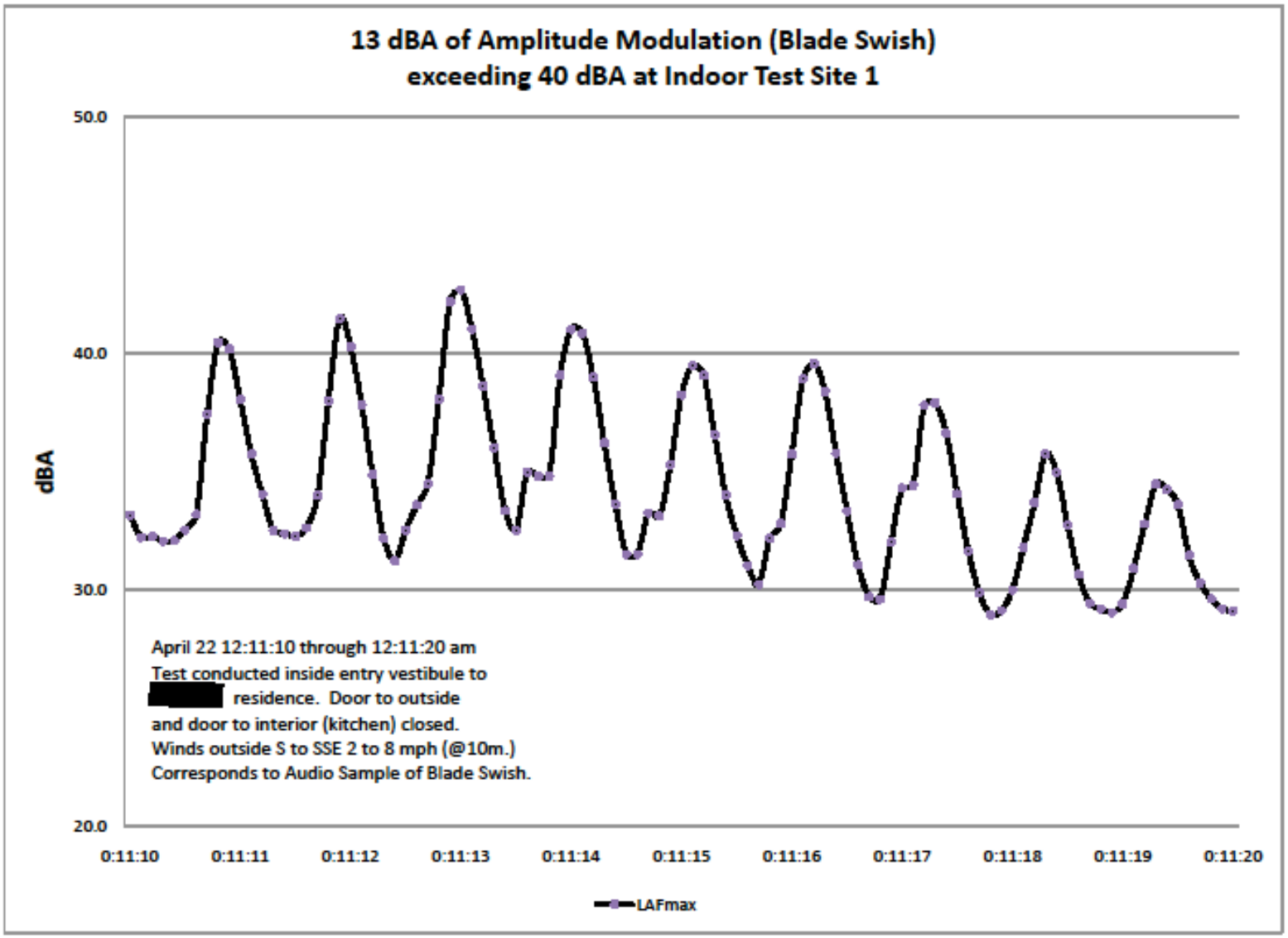
Audio Demonstrations

- Sound Quality
  - Steady Tone
  - Modulated Tone
  - Which is has the higher sound level (Leq)?
  - Which is the most annoying?
- Example of Amplitude Modulation Outside a Farm in Wisconsin
- Example of Amplitude Modulation Outside a home in Michigan
- Example of Amplitude Modulation Inside a home in New York

What We Know about WT Amplitude Modulation

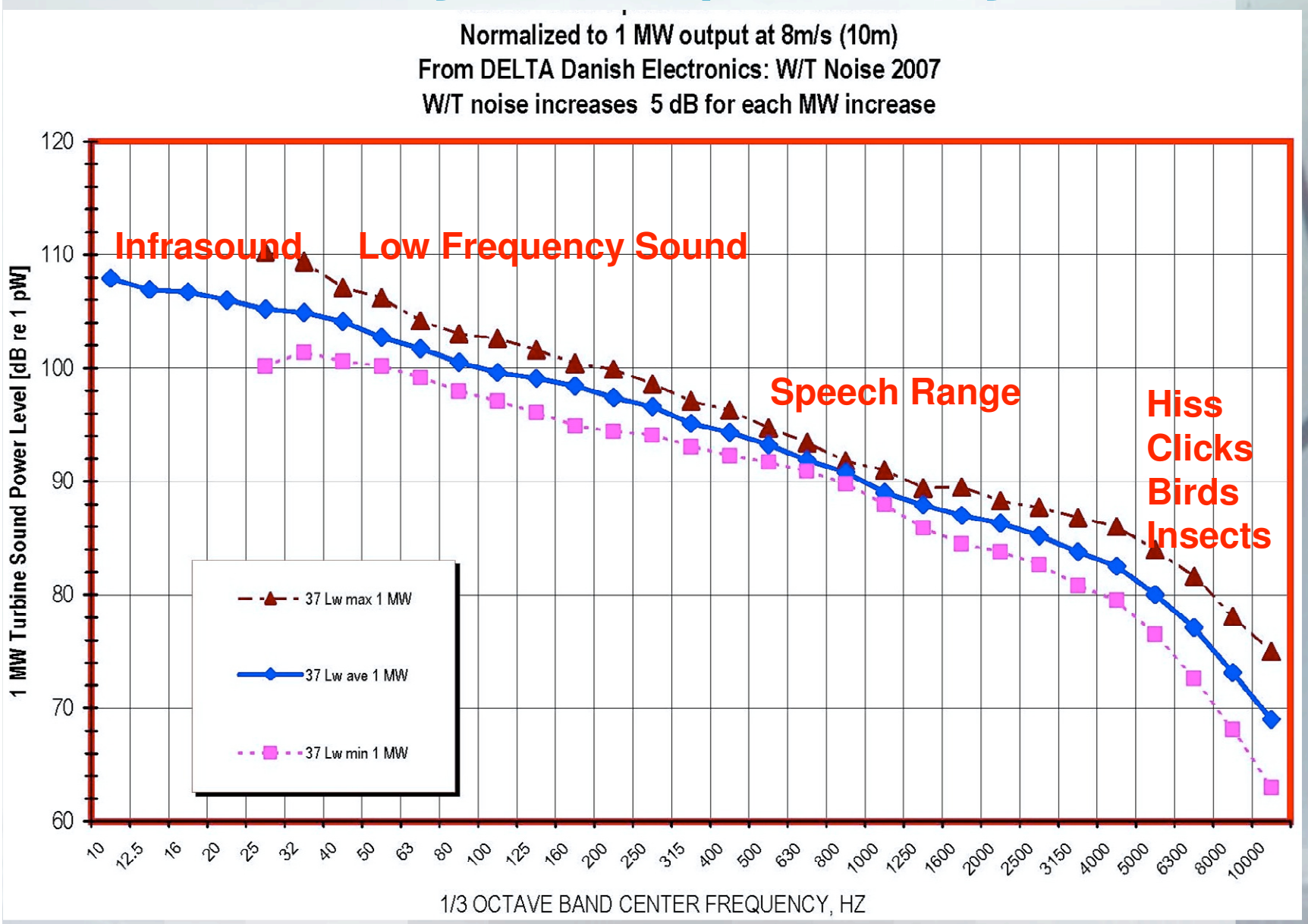


Amplitude Modulation of Wind-Turbine Noise Indoors

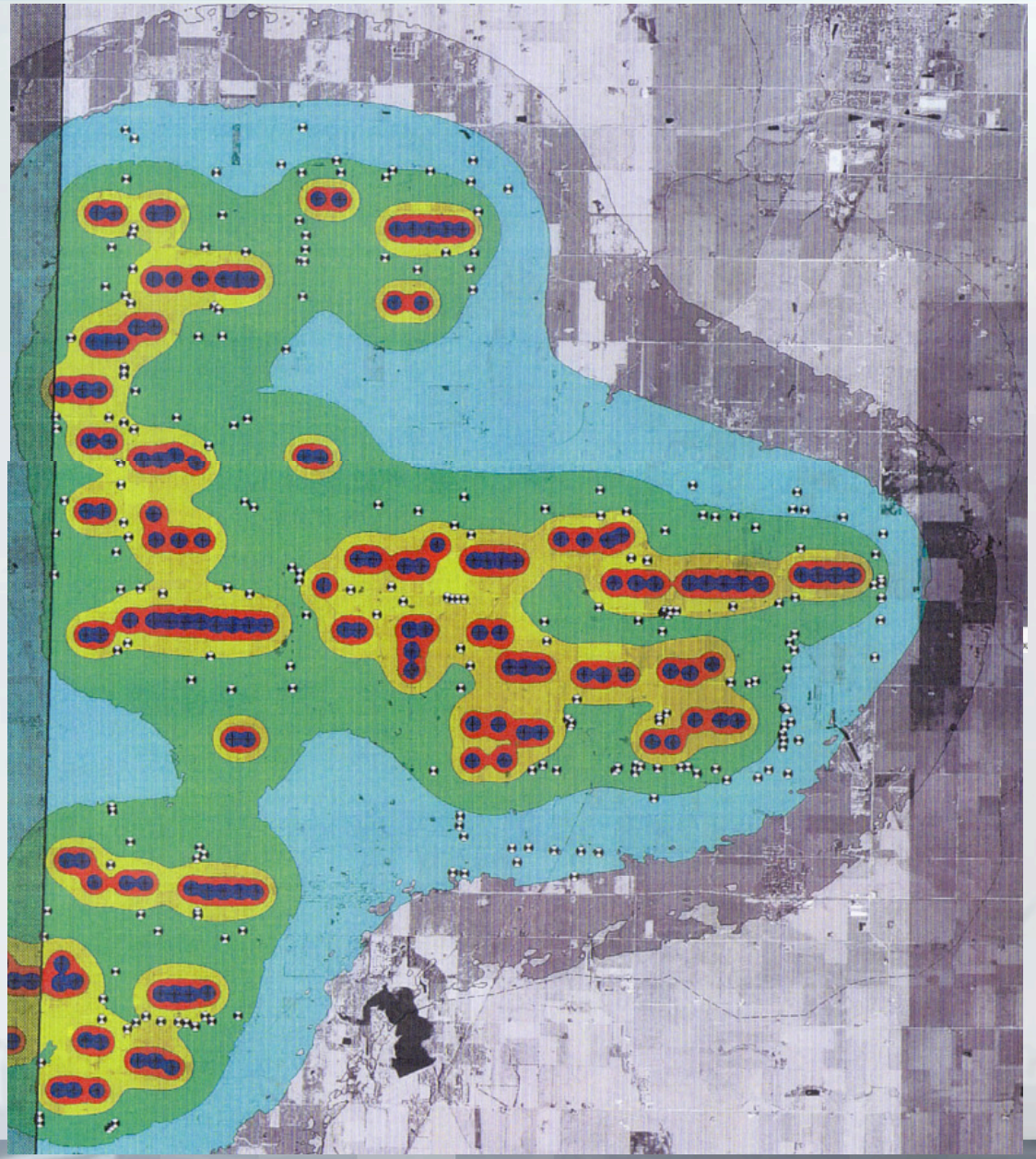


High Levels of Infra and Low Frequency Sound

(Study of 37 Modern Upwind Turbines by DELTA)



Models Are Used to Demonstrate Noise Impact of Project



Sound Contour Isopleths

- 28.6 to 33.6 dBA
- 33.6 to 38.6 dBA
- 38.6 to 43.6 dBA
- 43.6 to 48.6 dBA
- 48.6 to 53.6 dBA
- > 53.6 dBA

FIGURE 4B
RECEIVED SOUND LEVELS
WTGs AT FULL ROTATIONAL
ANAMOLOUS METEROLOGICAL
CONDITIONS

dBA

March 2009

Sound Levels will be much higher than predicted

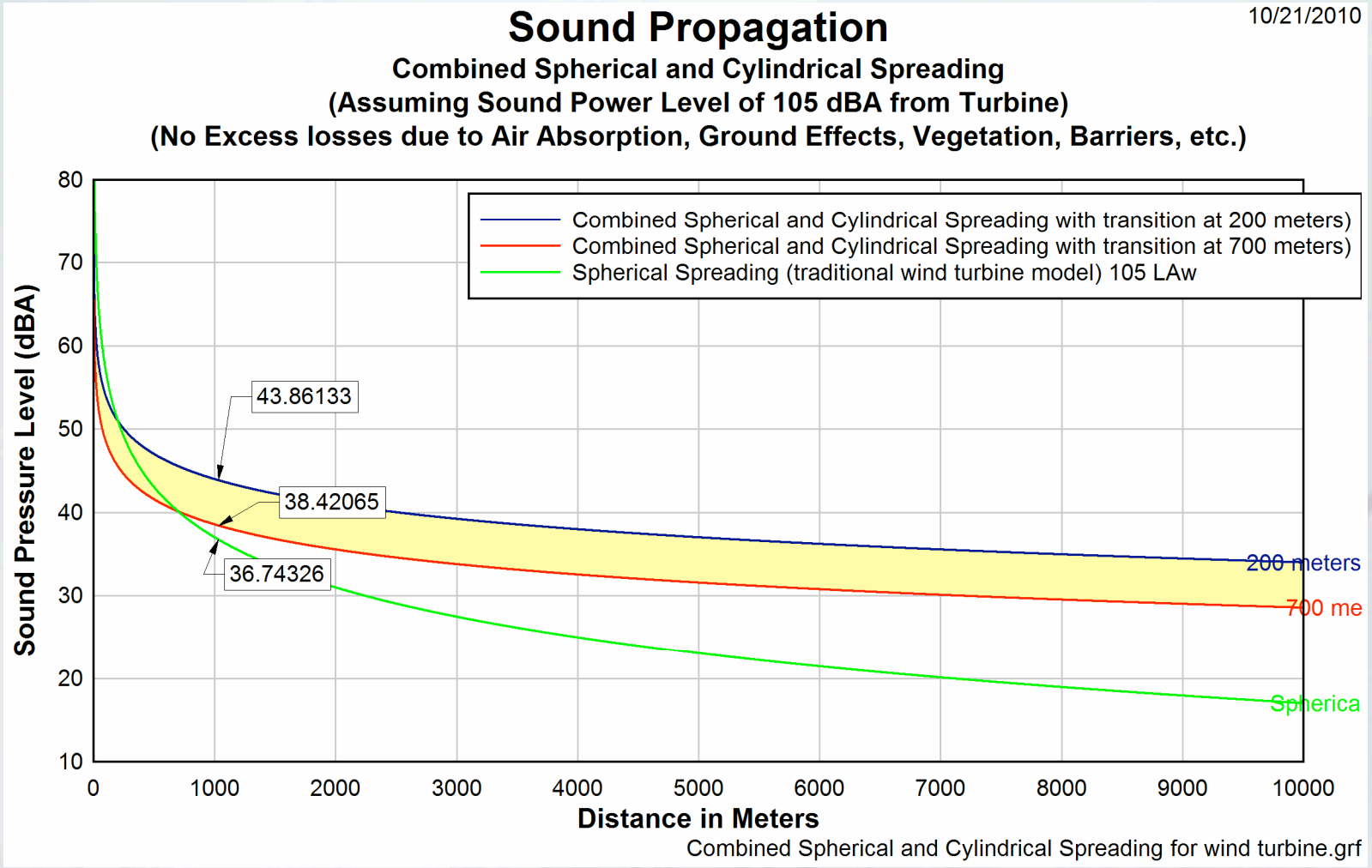
"Multiple wind turbines complicate matters further. From relatively long distances, an assembly of machines appears as a point source….

Closer to the turbines, they begin to act as a line source. The decay rate for line sources is **3-dB**, **not 6 dB** for true spherical propagation."

Paul Gipe, Wind Turbines Coming of Age, ©1995 (page 379)
Mr. Gipe was awarded the **World Wind Energy Award** in 2008 by the World Wind Energy Association

The standard wind turbine computer model used to estimate sound levels for Wind Project assumes 'Spherical Propagation" not "Line Propagation" even though turbines are arranged in rows. **This error means that the tables of sound levels and the contour maps grossly underestimate the true impact of the sounds on adjacent properties located along the rows.**

What We Know About Sound Propagation



Model Underestimates dB Perpendicular to Rows of Turbines

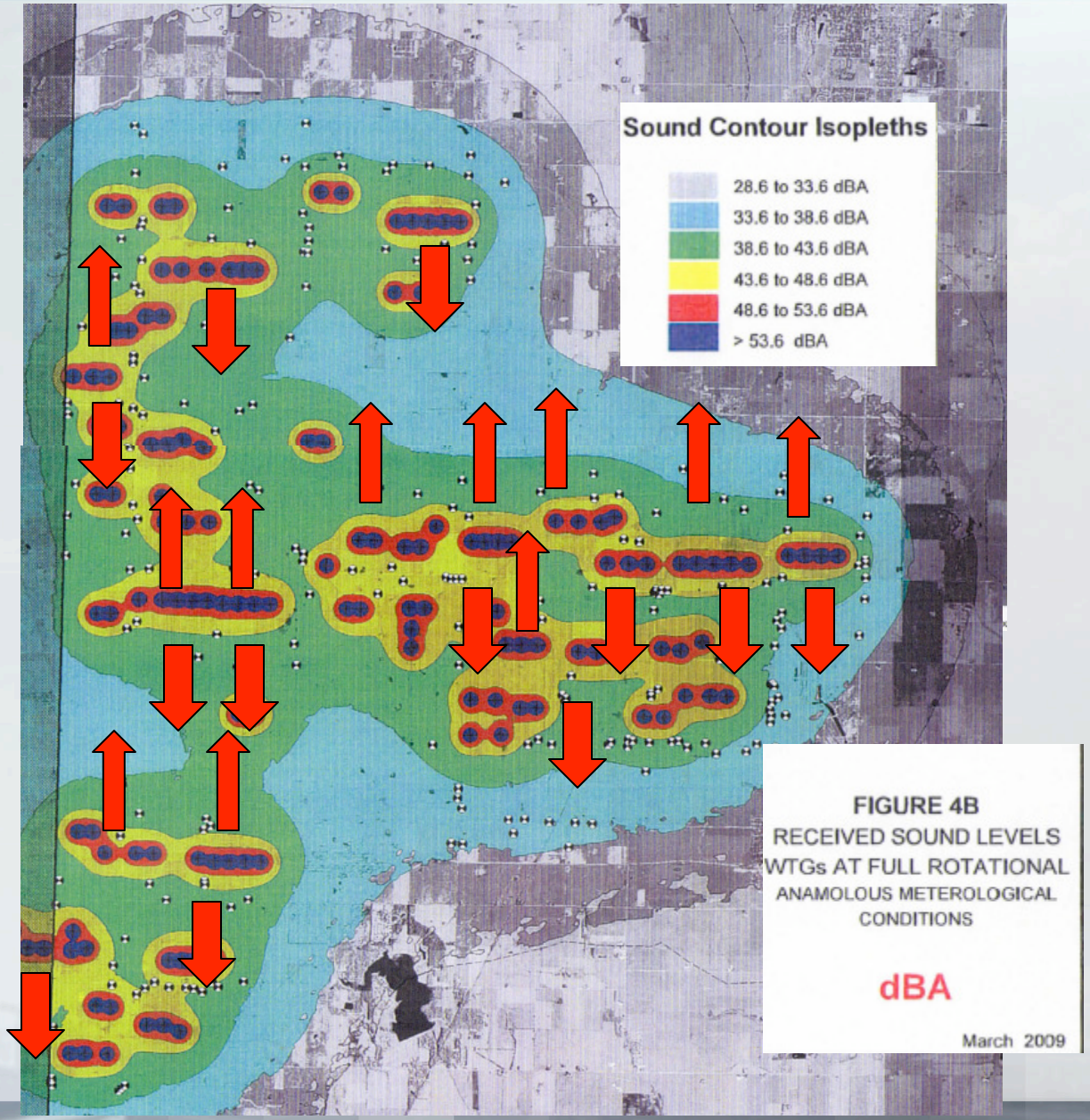
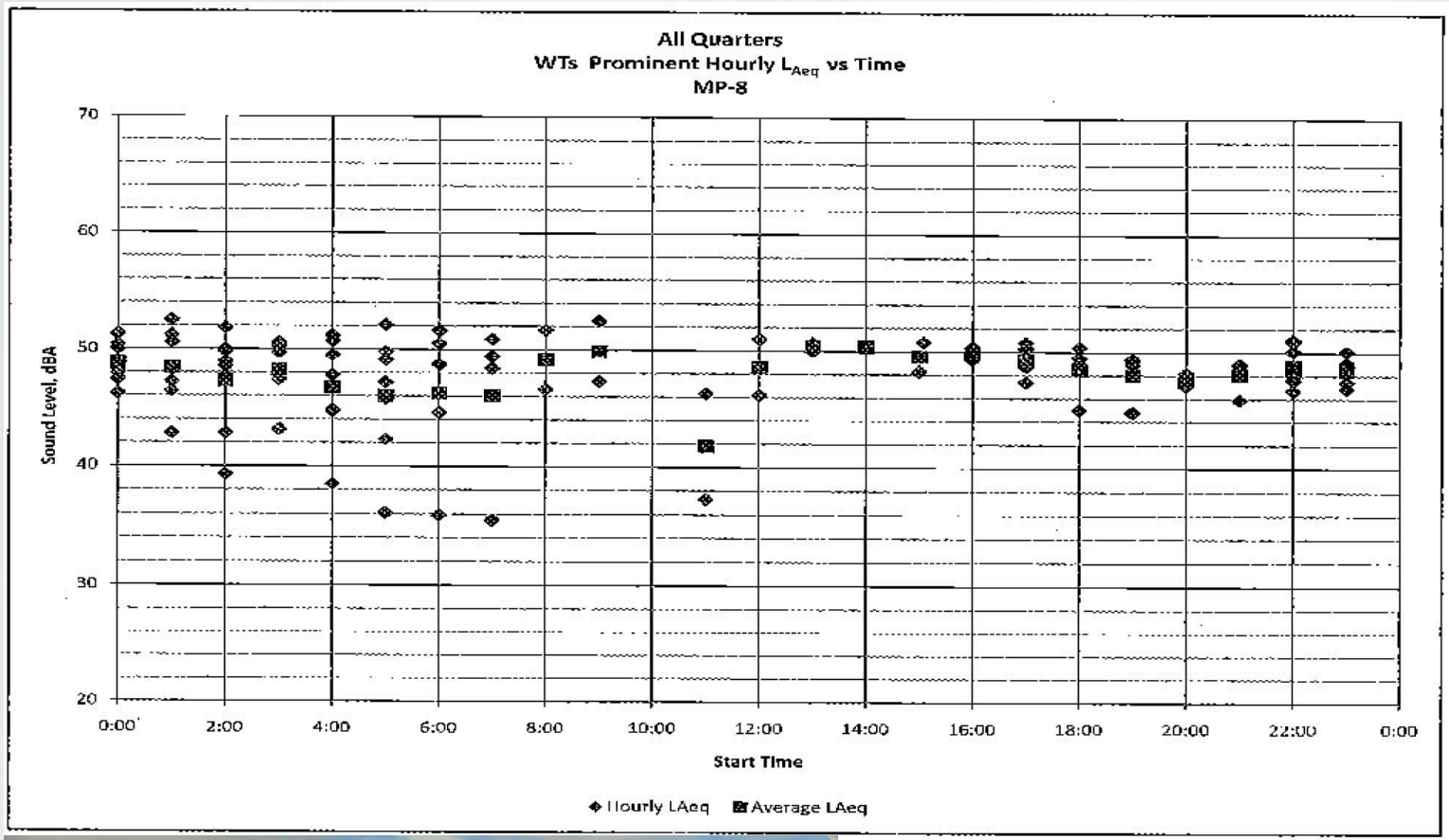


FIGURE 4B
RECEIVED SOUND LEVELS
WTGs AT FULL ROTATIONAL
ANAMOLOUS METEROLOGICAL
CONDITIONS

dBA

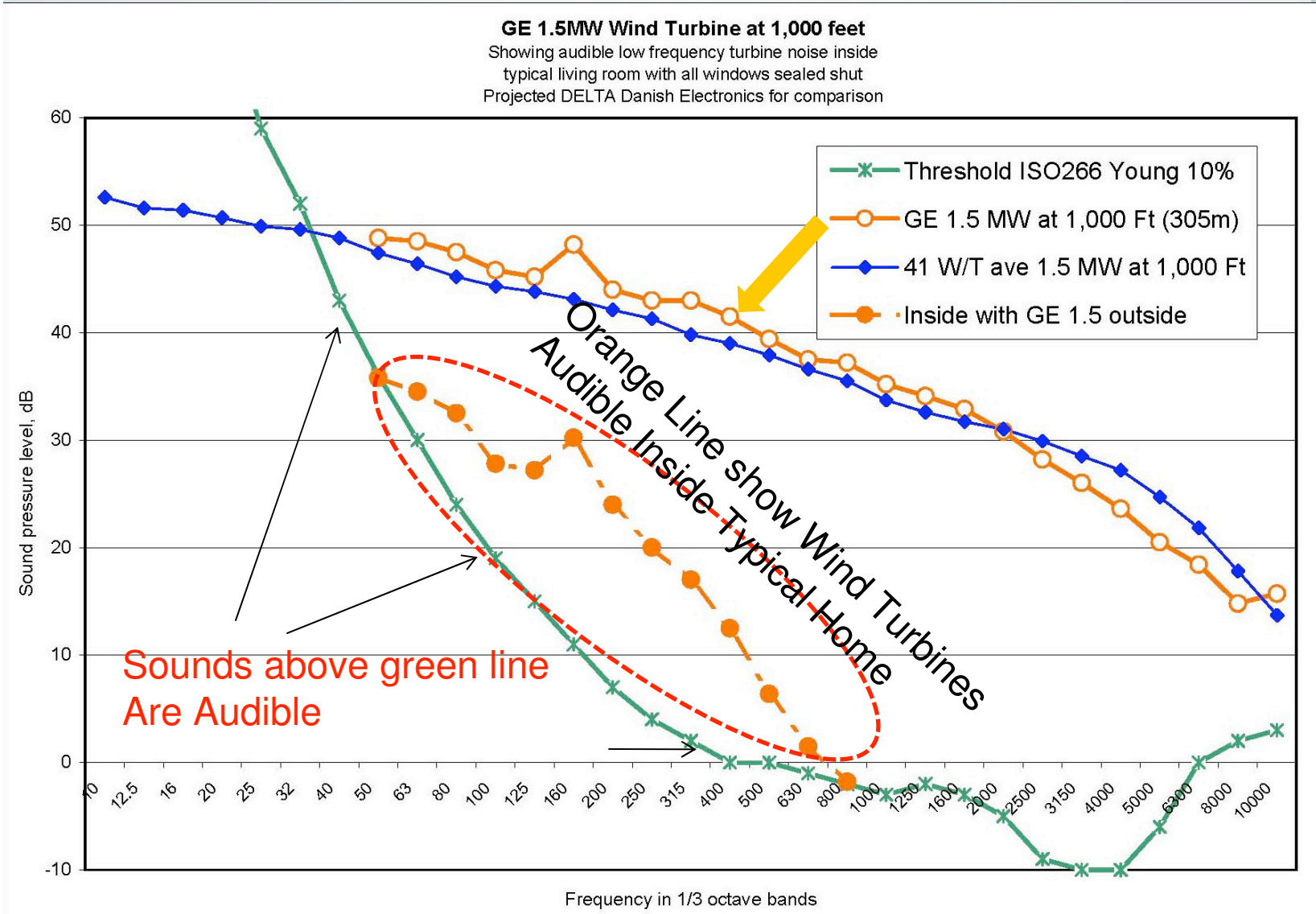
March 2009

Mars Hill, ME -One Year Study Summary-MP8 (2000-3000Feet)

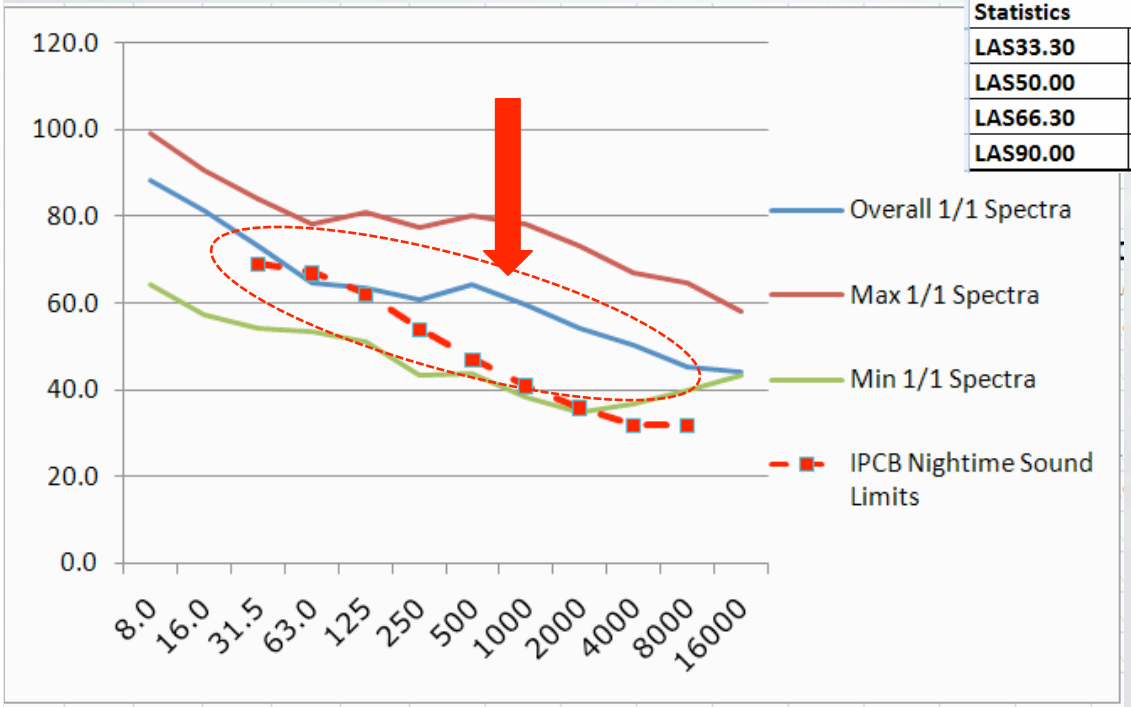


SUBMITTED BY RSE TO DEP
BASED ON ALL 4 QUARTERS MONITORING @ MP-8
12/08

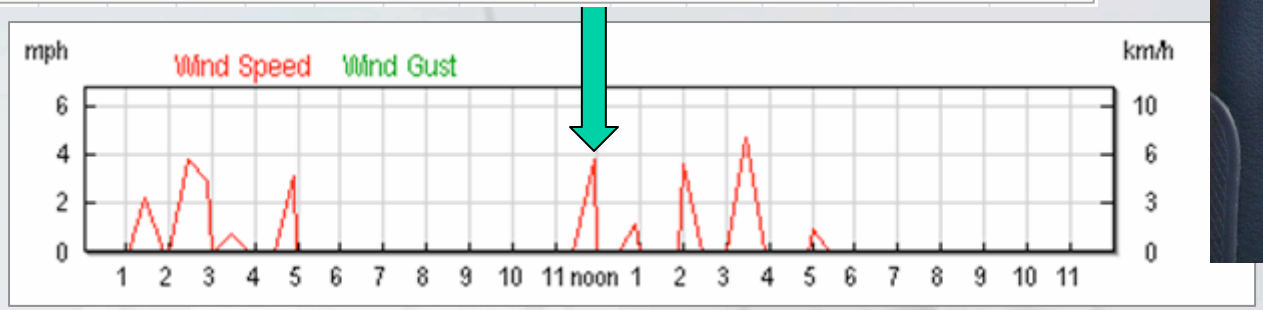
GE 1.5 MW Wind Turbine Clearly Audible Indoors



Story County Wind, FPL Nevada, ILL, Exceeds IPCB Limits



Statistics		
LAS33.30	51.2	dBA
LAS50.00	50	dBA
LAS66.30	49.1	dBA
LAS90.00	47.8	dBA



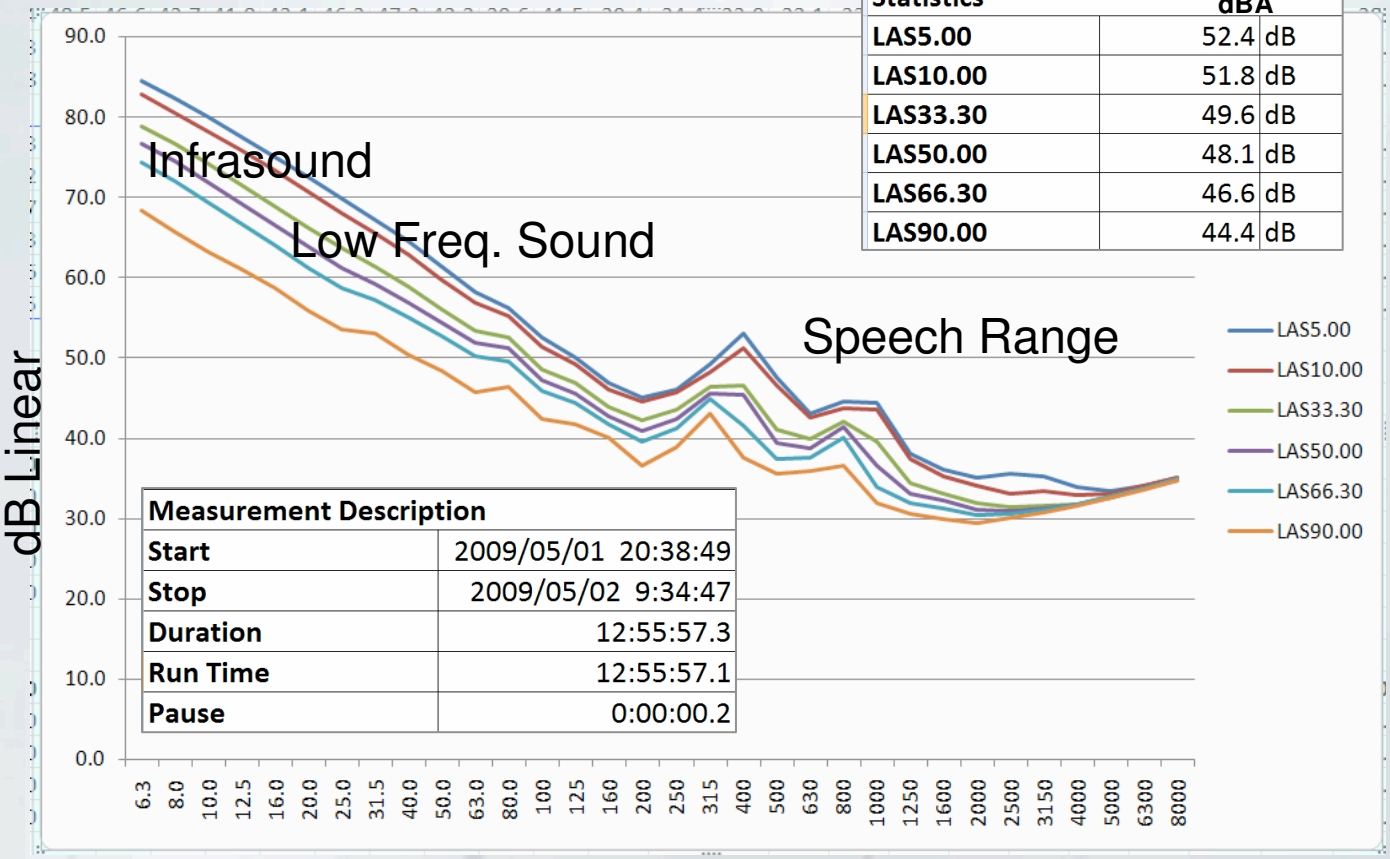
Measurement Description	
Start	2009/05/01 12:31:36
Stop	2009/05/01 12:36:52
Duration	0:05:16.0
Run Time	0:05:16.0
Pause	0:00:00.0

Turbines rotating at approx. 12 rpm during test

Wind speeds at microphone < 5mph

FPL's Story County Wind, Nevada, Iowa

Harris, Iowa, FPL Endeavor Wind, Showing LFN & Noise Pollution



Statistics	dBA
LAS5.00	52.4 dB
LAS10.00	51.8 dB
LAS33.30	49.6 dB
LAS50.00	48.1 dB
LAS66.30	46.6 dB
LAS90.00	44.4 dB

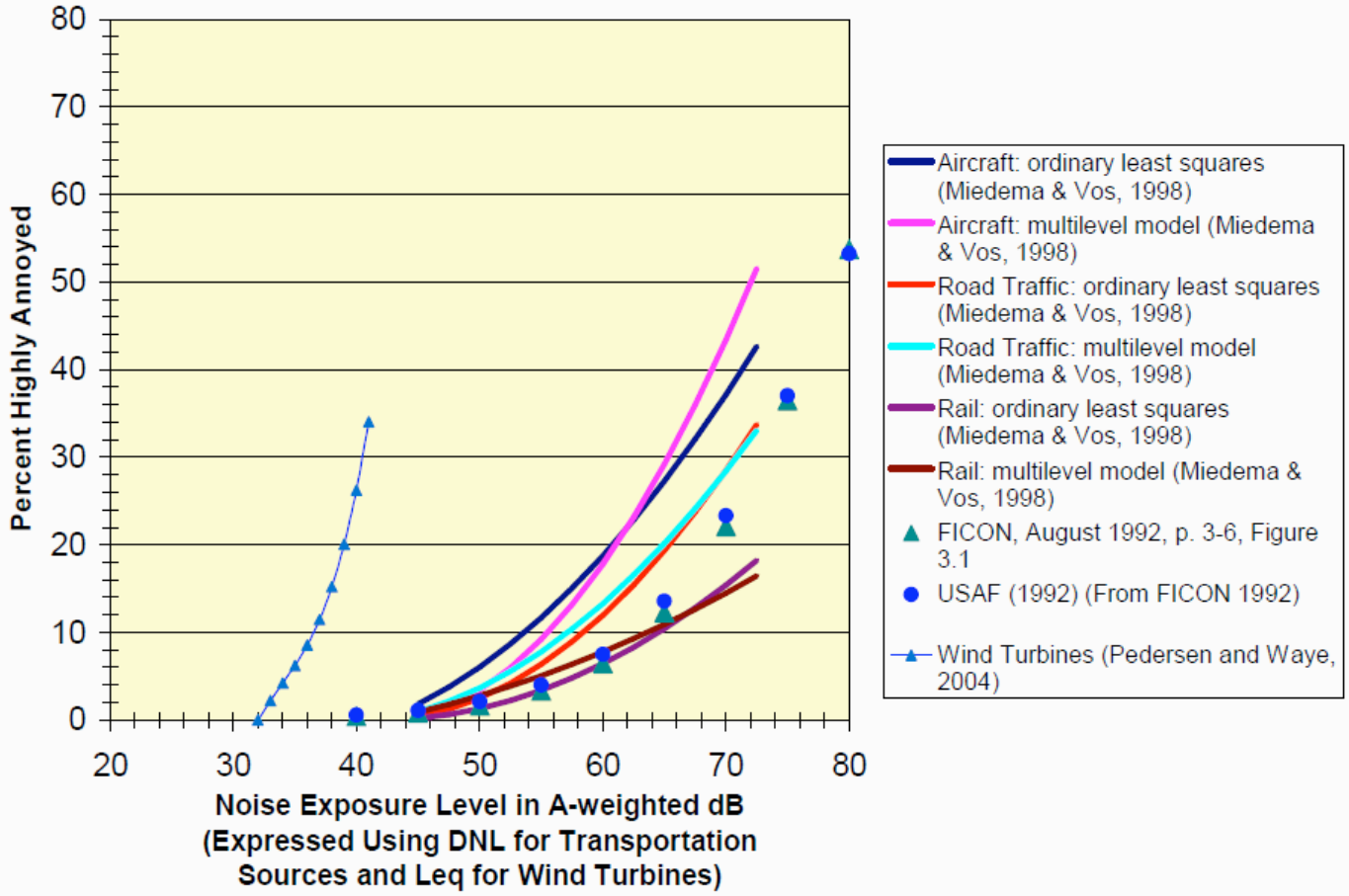
Measurement Description	
Start	2009/05/01 20:38:49
Stop	2009/05/02 9:34:47
Duration	12:55:57.3
Run Time	12:55:57.1
Pause	0:00:00.2

1/3 Octave Band Frequency Centers (Hz)

Surface winds at microphone <10Mph
From 8:40 pm May 1, 09 through 9 am May 2, 09

Annoyance of Common Noises vs Wind Turbines

more familiar dose-response relationships for transportation sources, which were developed by various researchers as noted in the legend of the graph.



Pedersen's Chart of % Highly Annoyed

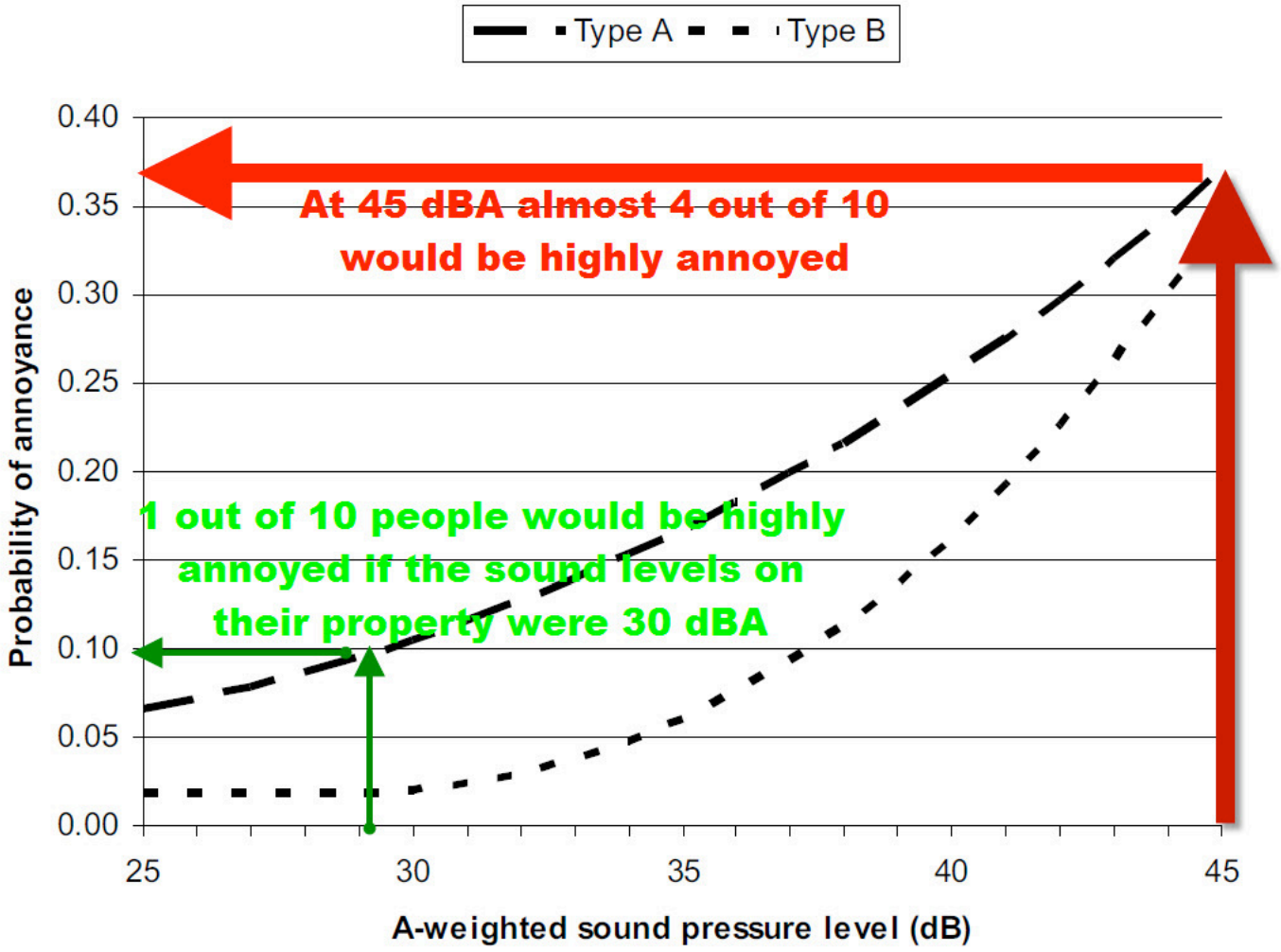


Figure 11. Estimated probability of annoyance with wind turbine noise outdoors, related to A-weighted SPLs in landscapes of type A (rural, with low background sound levels) and type B (suburban).

Wind Industry Position

AWEA AMERICAN WIND ENERGY ASSOCIATION

Utility Scale Wind Energy and Sound

Wind Energy, Sound, and Science

In 2009, the American Wind Energy Association (AWEA) and the Canadian Wind Energy Association (CanWEA) established a multidisciplinary scientific advisory panel comprising medical doctors, audiologists, and acoustical professionals to review current literature available on the perceived health effects of wind turbines. The panel, whose findings were published at the end of 2009, concluded that wind turbine sounds are not unique. Based on the levels and frequencies of the sounds, the panel found no reason to believe that turbines could plausibly have direct adverse physiological effects. An executive summary of the report is at http://www.awea.org/newsroom/releases/AWEA_CanWEA_SoundWhitePaper_ExecSumm.pdf.

Wind Industry Position

AWEA AMERICAN WIND ENERGY ASSOCIATION

Utility Scale Wind Energy and Sound

Advisory Panel Findings

The scientific advisory panel that addressed wind turbine human health concerns, came to the following conclusions:

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

Wind Industry Position

Leventhal talks to BWEA

- "I can state quite categorically that there is no significant infrasound from current designs of wind turbines. To say that there is an infrasound problem is one of the hares which objectors to wind farms like to run. There will not be any effects from infrasound from the turbines.
- The turbines produce a modulated higher frequency - the swish, swish - which people may not like, but this is not infrasound. There is no low frequency in it.
- There is negligible infrasound and very little low frequency noise from wind turbines - a few low level tones from the gearbox. Whatever might be making people ill it is not low frequency noise - there just isn't enough of it from modern wind turbines. [22]"

[22] Personal communication, September 2004.

People Living Near Wind Farms Report Problems

Residents of the Blue Sky Green Field Wind Farm in northern Fond du Lac County who reside within a half mile of at least one of the 88 turbines currently installed in this project were surveyed about quality of life issues.

1.Sixty percent of Johnsburg area residents who answered a survey question said if they had it to do over again, they would not want wind turbines on their property or near their home.
2.Since the development of the wind farm, 57.3 percent of respondents believe their property value went down significantly, while 3.8 percent indicated it increased.
3.Over 56 percent of respondents said they have problems with TV and radio reception,
4.52 percent experience shadow flicker, 49 percent have problems with noise from the turbines,
5.30 percent have problems with cellphone reception and 22 percent of respondents indicated they had no problems.
6.When asked about health problems attributed to the turbines, 33 percent indicated sustaining health issues such as sleep deprivation, headaches, nausea, stress, seizures, and heart rate ailments.

Doctors Linking Pathologies of Vestibular, Cardio, and Cellular organs to Wind Turbine Sound Emissions

- **Dr. Amanda Harry, M.D.** (U.K.) First to document and report pathologies related to wind turbine sound
- **Dr. Nina Pierpont, M.D.** (U.S. New York) Ph.D. from Princeton University, M.D. From Johns Hopkins University School of Medicine
- **Dr. Owen Black, M.D.** (U.S. Peer Reviewer for Dr. Pierpont, Fellow of American College of Surgeons and Senior Scientist and Director of Neuro-Otology Research at Legacy Health System, Portland Or.)
- **Dr. Michael Nissenbaum,** M.D. Bd. Cert. (U.S., Northern Maine Medical Center, Studying Mars Hill, Maine)
- **Dr. Robert McMurtry M.D.** (Ontario, Retired, Former Dean of McMaster University Medical School)
- **Dr. Alec Salt, Ph.D.** (NIDCD-supported researcher at Washington University in St. Louis, Mo)
- **Eileen, Mulvihill, Ph.D.** Retired molecular Biologist
- **Dr. Carlos Bruno M.D. and Mariana Alves-Pereira** (Portugal Vibro-Acoustic Disease (VAD))

Apply the Precautionary Principle

- If an action or policy **might** cause harm to the public or to the environment, in the absence of a scientific consensus that harm would **not** ensue, the action or policy should be prohibited. <u>The burden of proof to demonstrate safety falls on those who would advocate taking the action.</u>
- The wind utility developers have failed to present any independent peer-reviewed evidence that long term exposure to wind turbine noise is safe for all.
- Placing turbines within 2 km (1.25 miles) of homes on flat land and up to 3 km (2 miles) when turbines are ridge mounted and people are in the valley's below has been shown to have adverse health effects on people.
- WHO (2009) Night Noise Guidelines state 30 dBA outside a home is needed for healthful sleep.

Current vs. Proposed Guidelines

Guidelines Promoted by Wind Industry	**Kamperman/James Proposed Guidelines**
Sound level cannot exceed 50 dBA or L_{90}+5 dBA, whichever is **greater**.	Operating **L_{Aeq} is not-to-exceed the background L_{A90}+5 dBA**, where L_{A90} is measured during a noise study at the quietest time of night. Similar dBC limits should also be applied. Note: L_{A90}+5 dBA is commonly used throughout the world for siting new noise sources in communities and is supported by ANSI and ISO acoustical test procedure standards.
Limits apply to sound levels measured at homes.	Limits apply to sound levels measured at property lines.
No provisions are made for limiting low-frequency sounds from wind-turbine operations.	**L_{Ceq}-L_{A90} cannot exceed 20 dB** at receiving property, e.g., **L_{Ceq} (from turbines) minus (L_{A90} (background) +5) $\leq$ 20 dB**, and is **not to exceed 55 L_{Ceq} from wind turbines** (60 L_{Ceq} for properties within one mile of major heavily trafficked roads).