RSG
the science of insight

PSB Workshop,
Rule 5.700 Wind Generation Facility Sound Rulemaking

Introduction

Eddie Duncan, Director

- Board Certified, Institute of Noise Control Engineering
- Member of the Acoustical Society of America
  - Technical Committee on Architectural Acoustics

- Education:
  - M.S. Green Mountain College

    Environmental Studies, Focus: Environmental Law & Policy, Specifically Noise Policy
  - B.S. Rensselaer Polytechnic Institute

    Engineering Science, Focus: Acoustics

Introduction

RSG's Experience

- Involved in noise assessments of wind power since 1993.
  - Maine Land Use Regulatory Commission
- Studied over 80 proposed or installed wind power projects.
  - Maine to Hawaii
  - Including Deerfield Wind, Kingdom Community Wind, Georgia Mountain Community Wind, and others in development
- Conduct research on wind turbine acoustics.
  - Massachusetts Clean Energy Center
  - Lawrence Berkeley National Laboratory (U.S. DOE)
- Staff regularly publish papers and technical presentations on wind turbine acoustics.
- Staff co-chair of INCE Wind Turbine Technical Activity Committee.

Introduction

Presentation Topics

- Post-Construction Compliance Measurements
- Aesthetics, Noise Annoyance, and Acoustical Metrics
- Outdoor-to-Indoor Attenuation
- Noise Reduced Operation of Wind Turbines
- PSB Precedent & the Proposed Rule – Acoustical Context

Post-Construction Compliance Measurements

Post-Construction Compliance Measurements

Proposed Rule's Economic Impact Statement

- The Board's rule results in "…Compliance costs that are relatively lower than other alternatives considered."
- "…by requiring that monitoring occur under worst-case conditions where turbine sound levels will be at their loudest output, and background sound levels at their lowest."
- Does away with accounting for background sound levels.
- Hypothesizes that the proposed methodology, "…allows for monitoring campaigns to be of significantly shorter duration…"

RSG's experience is that the proposed methodology does not cost less than other alternatives and will not necessarily yield accurate results.

Post-Construction Compliance Measurements

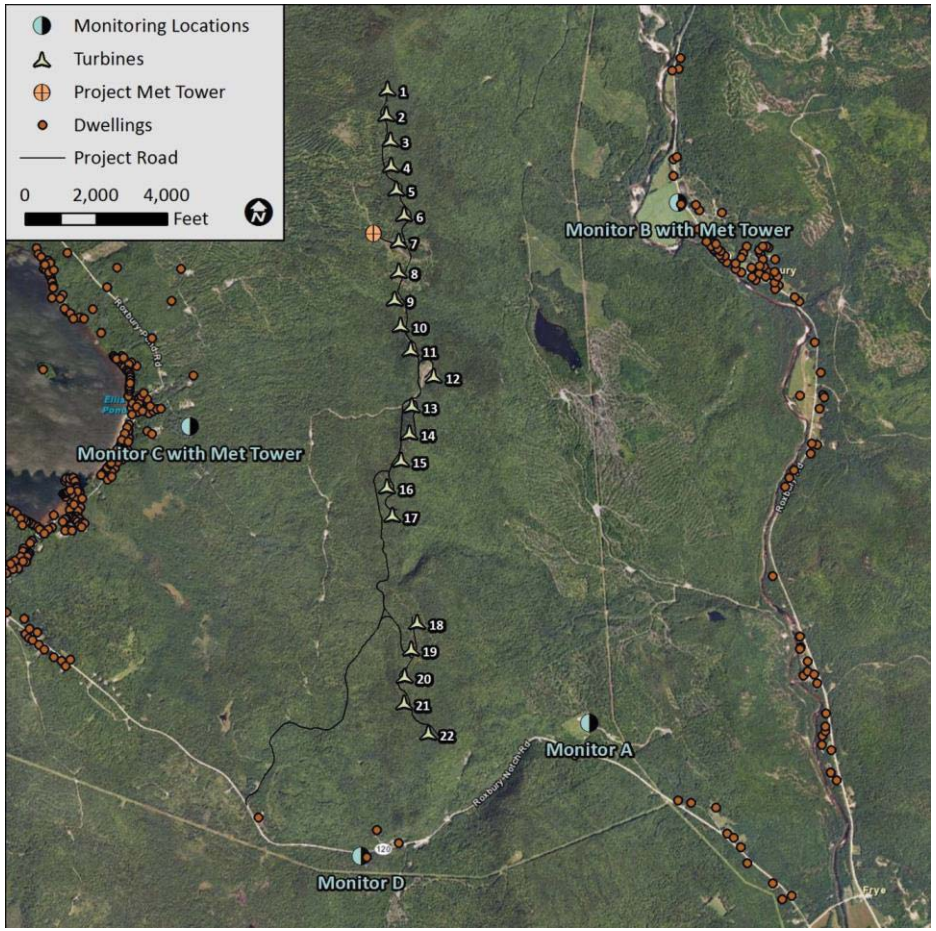
Proposed rule is similar to Maine's compliance procedure.

- Arithmetic average of twelve, 10-minute intervals from the same measurement period. (5.704)
- Measurements when wind turbine sound is dominant.
  - Nighttime
  - Downwind – within 45° of the acoustic center of the five nearest turbines
  - Maximum surface wind speeds (at 10 meters) of 6 mph or less
  - Hub height wind speeds able to generate maximum turbine sound power ±1 dB

This requires:

- Long-term monitoring similar to other methods because finding these conditions can be very difficult.
- Installation of a temporary 10-meter mast in a cleared location.

Post-Construction Compliance Measurements

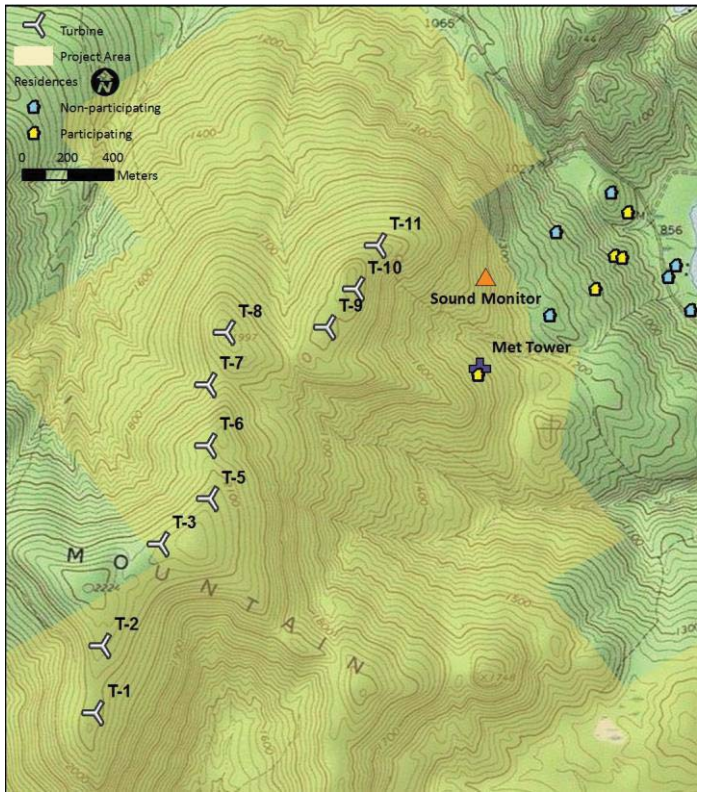


Example1: Maine Project

- 4 compliance monitor locations = 4 wind directions
- Weather forecasts monitored on a weekly basis for nine months.
- Monitored over 7 periods for 53 total days.
- Valid Periods
  - Monitor A: 7, not 12
  - Monitor B: 0, not 12
  - Monitor C: 8, not 12
  - Monitor D: 0, not 12

Post-Construction Compliance Measurements

Example 2: Maine Project



- 1 continuous sound monitor
- Valid Periods
  - Year 1: 5 days of data analyzed to find 12 periods
  - Year 2: 5 days of data analyzed to find 12 periods
  - Year 3: 11 days of data analyzed to find 12 periods
  - Year 4: 5 days of data analyzed to find 12 periods
  - Year 5: 8 days of data analyzed to find 12 periods
- Still had to filter out extraneous events such as bird calls.

Post-Construction Compliance Measurements

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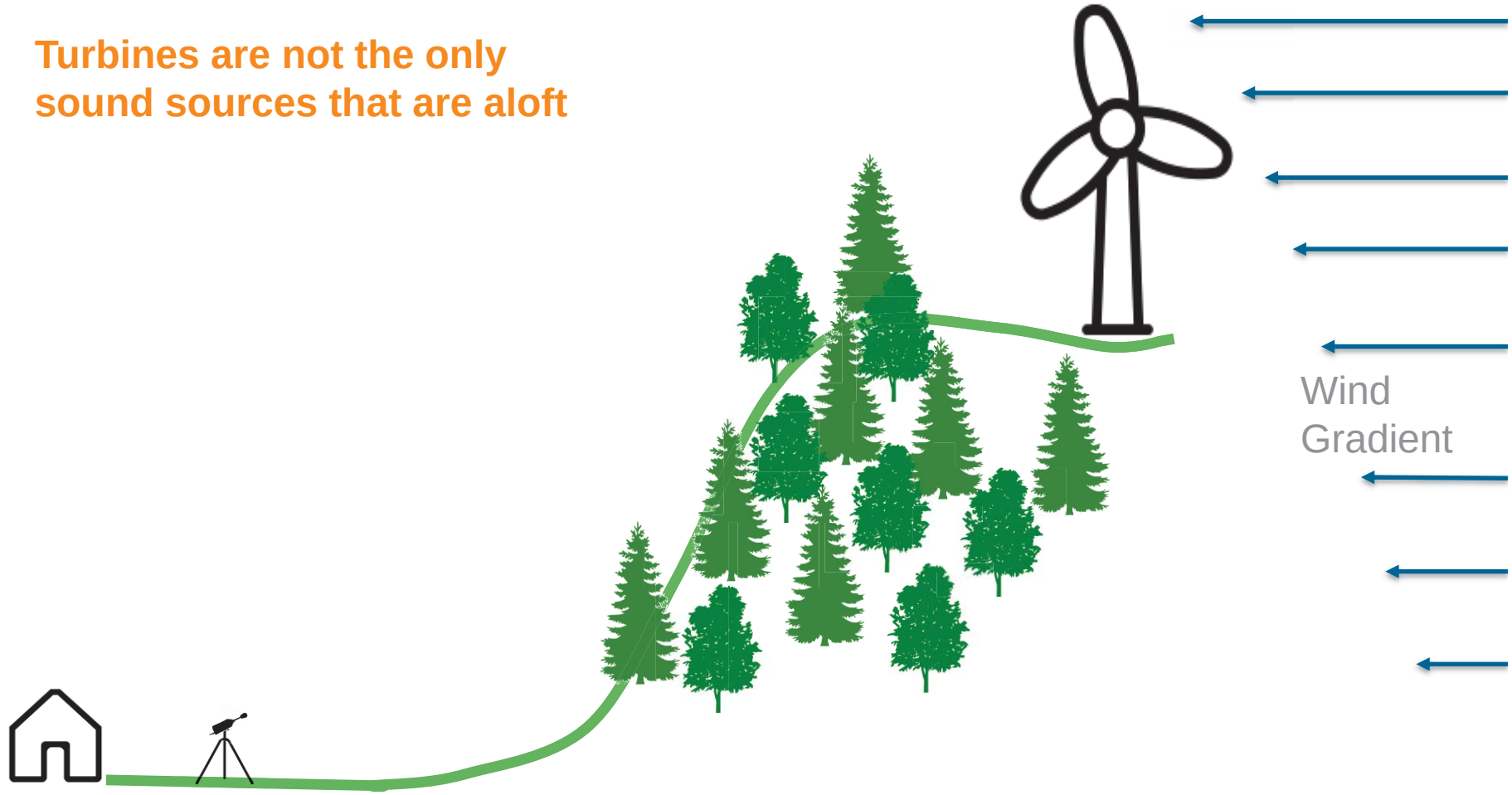
Quite problematic to capture.

Significant data analysis required.

Amounts to a Continuous Monitoring Exercise.

Post-Construction Compliance Measurements

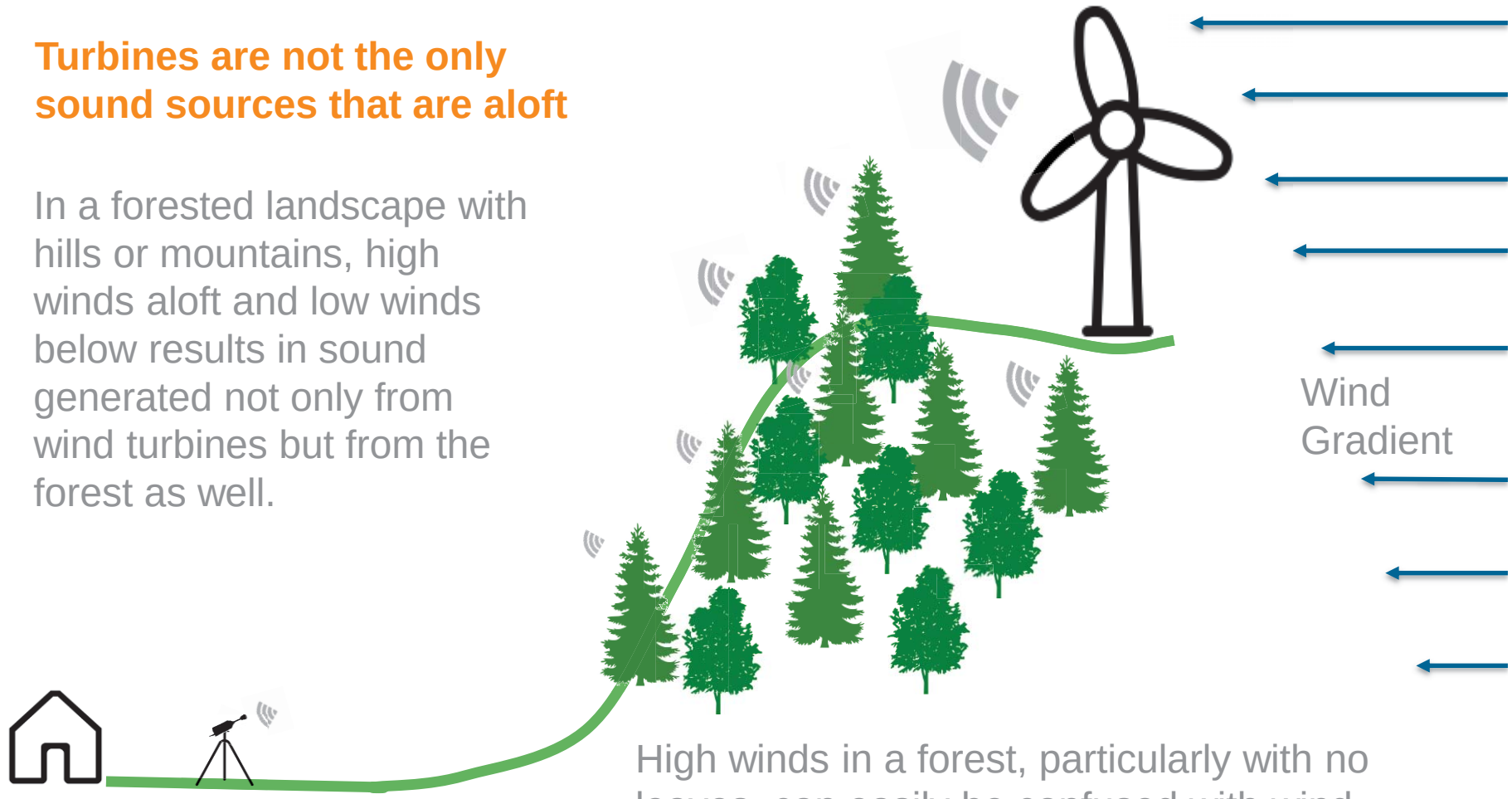
Turbines are not the only sound sources that are aloft



Post-Construction Compliance Measurements

Turbines are not the only sound sources that are aloft

In a forested landscape with hills or mountains, high winds aloft and low winds below results in sound generated not only from wind turbines but from the forest as well.



High winds in a forest, particularly with no leaves, can easily be confused with wind turbine sound.

Post-Construction Compliance Measurements

Recommendations

1. Account for background sound levels.
   a) Turbine shut-down method works well.
   b) Shielding method also works if locations are selected properly.
   c) Proxy monitor locations are problematic for hilly terrain and heterogeneous landscapes. Don’t seem to work well in the Northeast.
2. Keep the current instrumentation, personnel, and calibration requirements in Section 5.707.
3. Use the post-construction measurements to verify and modify, if necessary, the pre-construction sound modeling.

Aesthetics, Noise Annoyance, & Acoustical Metrics

Aesthetics, Noise Annoyance, & Metrics

Generally, aesthetics is not something the professional acoustics community studies or talks about.

- Sound quality – typically applied to product design
- Natural & cultural sounds as a natural resource – National Park Service
- Acoustical aesthetics in rural working landscapes – not addressed

Except in Act 250

- Criterion 1 – Air Pollution – Noise covered as a health impact.
- Criterion 8 – Aesthetics
  - Noise not explicitly mentioned in the statute
  - Case law covers it as an aesthetics issue

Aesthetics, Noise Annoyance, & Metrics

Quechee Test

- Developed by landscape architects for the Environmental Board in Quechee Lakes Corporation, 1985
- Two Part Test
    1. Is the project adverse? Does it fit the context of the area?
    2. If found to be adverse, Is the project unduly adverse?
        a. Does the project violate a clear, written community standard intended to preserve the aesthetics or scenic natural beauty of the area?
        b. Does the project offend the sensibilities of the average person?
        c. Has the Applicant failed to take generally available mitigating steps which a reasonable person would take to improve the harmony of the proposed project with its surroundings?

Aesthetics, Noise Annoyance, & Metrics

Quechee Test

b. Does the project offend the sensibilities of the average person?

Threshold: Would the sound be considered shocking and offensive to the average person?

Aesthetics, Noise Annoyance, & Metrics

Quechee Test

b. Does the project offend the sensibilities of the average person?

Threshold: Would the sound be considered shocking and offensive to the average person?

If the Board is considering aesthetics in it's decision-making process, is a daytime limit of 42 dBA and a nighttime limit of 35 dBA necessary to keep the average person from being shocked and offended?

Aesthetics, Noise Annoyance, & Metrics

Noise Annoyance

- More commonly studied in acoustics than aesthetics
- Fairly standardized methodologies (ISO/TS 15666:2003)[1]
  - Social surveying methods
  - 0 to 100 scale, 28/50/72 - lightly/moderately/highly annoyed[2]
  - Dose-response relationships – at sound level of X dBA, causes % of a population to be lightly, moderately, or highly annoyed.

- WHO's Guidelines for Community Noise[3]
  - Serious Annoyance, daytime and evening, 55 dBA Leq_{16hr}
  - Moderate Annoyance, daytime and evening, 50 dBA Leq_{16hr}

1. ISO/TS 15666:2003. Acoustics – Assessment of noise annoyance by means of social and socio-acoustic surveys.
2. Miedema, H.M.E., & Vos, H. (2004). Noise annoyance from stationary sources: Relationships with exposure metric day-evening-night level (DENL) and their confidence intervals. *The Journal of the Acoustical Society of America*, 116(1), 334-343.
3. Berglund, B., Lindvall, T., & Schwela, D.A. (1999). *Guidelines for community noise*. World Health Organization.

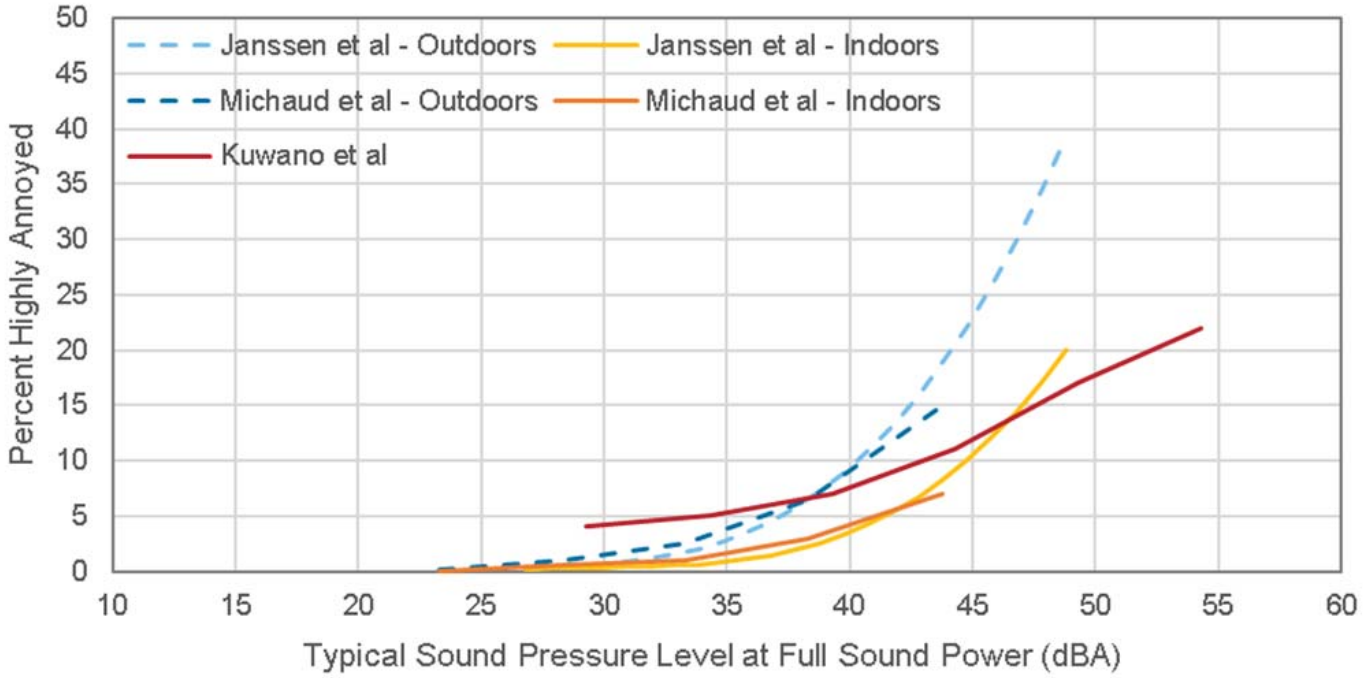
Aesthetics, Noise Annoyance, & Metrics

Noise Annoyance – Wind Turbine Specific Studies

- Several studies, but most use different acoustical metrics.[1,2,3]
- Results from Swedish & Dutch, Japanese, and Canadian studies have been normalized to a common metric.[4]
  - A-weighted hourly equivalent average sound level: L_{Aeq1hr}
  - Modeled using ISO 9613-2, G=0.5, 4 meter high receivers
    - These modeling parameters would yield results 2 dB lower than what is currently used in Vermont.
    - Doesn't include turbine sound power uncertainty.

1. Janssen, S., Vos, H., Eisses, A., & Pedersen, E. (2011). A comparison between exposure-response relationships for wind turbine annoyance and annoyance due to other noise sources. *The Journal of the Acoustical Society of America*, 130(6), 3746-3753.
2. Kuwano, S., Yano, T., Kageyama, T., Sueoka, S., and Tachibana, H., (2014). Social survey on wind turbine noise in Japan. *Noise Control Engineering Journal,* 62(6), 503-520.
3. Michaud, D., et.al. (2016). Exposure to wind turbine noise: Perceptual responses and reported health effects. *The Journal of the Acoustical Society of America*, 139(3), 1443-1454.
4. Old, I., and Kaliski, K., (2017). Wind turbine noise dose response – comparison of recent studies. Proceedings of the 7th International Conference on Wind Turbine Noise, Rotterdam.

Aesthetics, Noise Annoyance, & Metrics



- At 43 dBA (equivalent to Vermont's 45 dBA one-hour maximum):
  - 15% highly annoyed - Swedish, Dutch, & Health Canada Studies
  - 10% highly annoyed – Japanese Study

Aesthetics, Noise Annoyance, & Metrics

Noise Annoyance – Additional Observations

- Attitudinal variables strongly affect noise annoyance[1,2,3,4]
  - Fear
  - Belief that the noise could be prevented
  - Perceived fairness in the decision making process
  - Awareness of non-noise problems related to the noise source
  - Perceived importance of the source of noise
  - Personal benefit
- Annoyance occurs primarily when spending time outdoors with activities such as relaxing, picnicking, or barbecuing.[6]

1. Fields, J.M. (1993). Effect of personal and situational variables on noise annoyance in residential areas. *The Journal of the Acoustical Society of America*, 93(5), 2753-2763.
2. Miedema, H.M.E., & Vos, H. (1999). Demographic and attitudinal factors that modify annoyance from transportation noise. *The Journal of the Acoustical Society of America*, 105(6), 3336-3344.
3. Miedema, H.M.E., & Vos, H. (2004). Noise annoyance from stationary sources: Relationships with exposure metric day-evening-night level (DENL) and their confidence intervals. *The Journal of the Acoustical Society of America*, 116(1), 334-343.
4. Michaud, D.S., et.al. (2016). Personal and situational variables associated with wind turbine noise annoyance. *The Journal of the Acoustical Society of America*, 139(3), 1455-1466.
5. van Kamp, I., Job, R.F.S., Hatfield, J., Haines, M., Stellato, R.K., & Stansfeld, S.A. (2004). The role of noise sensitivity in the noise-response relation: A comparison of three international airport studies. *The Journal of the Acoustical Society of America*, 116(6), 3471-3479.
6. Pedersen, E., & Waye, K.P. (2004). Perception and annoyance due to wind turbine noise—a does-response relationship. *The Journal of the Acoustical Society of America*, 116(6), 3460-3470.

Aesthetics, Noise Annoyance, & Metrics

Given: Annoyance occurs primarily when spending time outdoors with activities such as relaxing, picnicking, or barbecuing.

- Does it even make sense to have nighttime limits to address aesthetics?
- Perhaps, if a different limit was needed for aesthetics, an evening limit (5 p.m. to 9 p.m.) that differs from the rest of the 24 hour period would make the most sense.

1. Pedersen, E., & Waye, K.P. (2004). Perception and annoyance due to wind turbine noise—a does-response relationship. *The Journal of the Acoustical Society of America*, 116(6), 3460-3470.

Aesthetics, Noise Annoyance, & Metrics

Given:

- Per annoyance research, the current 45 dBA one-hour maximum level limit used in Vermont results in 10 to 15% of population exposed to those levels being highly annoyed.
- For the proposed rule:
  - 35 dBA night: 2.5% highly annoyed (outdoors)
  - 42 dBA day: 6 to 9% highly annoyed (outdoors)

Propose:

- The current PSB precedent protects against the average person being shocked and offended.
- The current PSB precedent protects against undue adverse impact to aesthetics.

1. Pedersen, E., & Waye, K.P. (2004). Perception and annoyance due to wind turbine noise—a does-response relationship. *The Journal of the Acoustical Society of America*, 116(6), 3460-3470.

Outdoor-to-Indoor Attenuation

Outdoor-to-Indoor Attenuation

- Current PSB precedent has been based on the World Health Organization (WHO) guideline of 45 dBA L_{8hr} outside bedroom windows which is derived from a threshold of 30 dBA L_{8hr} inside bedrooms to protect against sleep disturbance.
  - 15 dB of attenuation for a partially open window

- Vermont tests (2 data points)
  - Sheffield (Brouha): less than 5 dB of attenuation (windows open)
    - Large windows located in a small bedroom
    - Window panes that can rotate perpendicular with the façade
  - Georgia (Fitzgerald): 15 dB of attenuation (windows open)
    - Standard sized window

Outdoor-to-Indoor Attenuation

Literature Review (Additional Data Points)

- Waters-Fuller 7 Lurcock (2007)[1]
  - 7 to 26 dB reduction with windows open 0.2 m^2 (2.2 ft^2)
  - Most values between 10 to 17 dB reduction
  - When attenuation values applied to a wind turbine sound spectrum:
    - 14 dB worst-case
    - 18 dB best-case
- Hayes McKenzie Partnership (2006) [2]
  - Focused on wind turbine acoustics
  - One window-open measurement: 10 dB reduction

1. Waters-Fuller and Lurcock, Department for Environment, Food and Rural Affairs, UK, 2007.
2. Hayes McKenzie Partnership, Department of Trade and Industry, UK, 2006.

Outdoor-to-Indoor Attenuation

Literature Review (Additional Data Points)

- Environmental Protection Agency (1974)
  - 12 dB reduction for warm climates, windows open 0.19 m^2 (2 ft^2)
  - 17 dB reduction for cold climates, windows open 0.19 m^2 (2 ft^2)
- Federal Highway Administration (2011)
  - Uses a 10 dB reduction for windows open, all climates

Outdoor-to-Indoor Attenuation

Takeaway

- While 5 dB or less of attenuation is possible, it is only one data point.
- Reductions between 10 and 15 dB are more common.
- In some cases, 20 dB reductions may be present.

- Depends on a number of factors:
  - Window size and type
  - Amount open
  - Window area relative to that of the façade
  - Sound insulation of the wall and window
  - Bedroom size, furnishings, and orientation to the sound source

Noise Reduced Operation (NRO) of Wind Turbines

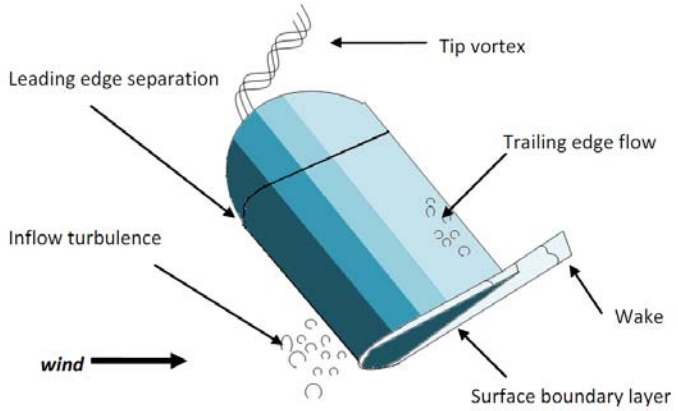
Noise Reduced Operation of Wind Turbines

Section 5.703 of the proposed rule

- Daytime 42 dBA
- Nighttime 35 dBA

Sound Generation by Wind Turbines

- Aerodynamics – primary source
- Mechanical (nacelle) – secondary
- Noise Reduced Operation (NRO) reduces aerodynamic noise.



Noise Reduced Operation of Wind Turbines

Designing a Wind Power Project

- Developers design the entire project to the most stringent sound level limit.
  - Array layout
  - Turbine model
  - NRO
  - Shutdowns
- When daytime and nighttime standards vary, NRO is the tool that is used to regulate sound emissions.
- Shutdowns effect the economics of a project too strongly making them infeasible.

Noise Reduced Operation of Wind Turbines

How does NRO work?

- Blades are pitched
- Often a slight RPM reduction
- Often modest power losses
- Operational protocols, typically driven by software
  - Time of day
  - Wind direction
  - Wind speed
  - Different protocols for individual turbines

Noise Reduced Operation of Wind Turbines

Limits to it's usefulness

- 1 to 3 dB reduction is typical
- Greater than 4 dB, only offered by one manufacturer
- 1 to 2 dB reduction - modest power losses
- 3 to 4 dB reduction – greater than modest power losses

Proposed Rule 5.700 Context

- 7 dB difference between daytime and nighttime limits (42 dBA to 35 dBA).
- Projects will need to be designed to 35 dBA, likely using NROs.
- If shutdowns are needed, project economics are affected too strongly.
- With 4 dB NRO, the effective daytime limit is 39 dBA.

Noise Reduced Operation of Wind Turbines

Developers have tools to reduce sound emissions from wind turbines,

But

There are limits to the range of reductions that are achievable.

Recommendation

1. If Rule 5.700 is to have different specified limits by time-of-day, decrease the difference to not more than 4 dB.

PSB Precedent & the Proposed Rule – Acoustical Context

PSB Precedent & the Proposed Rule

From previous testimony, presentations, and submissions:

- Current precedent 45 dBA one-hour maximum, exterior, guards against public health impacts.
- Same limit used in Kingdom Community Wind, Georgia Mountain Community Wind, and Deerfield Wind.

Proposed Rule of 35 dBA nighttime and 42 dBA daytime goes beyond protecting public health.

PSB Precedent & the Proposed Rule

Effective Limit is Lower than Proposed

- With limitations to NRO technology and how projects are designed, the effective limit is 35 dBA nighttime and 40 dBA daytime.
- Since Section 5.705 requires potential model error to also be added on to each source emission, the effective limits are even lower than 35 dBA nighttime and 40 dBA daytime.

PSB Precedent & the Proposed Rule

Closing Thoughts

- Under the proposed rule, Kingdom Community Wind, which has provided over 700,000 MWhs of clean power to the Vermont grid and likely other projects built under the 45 dBA precedent, would not have been built.

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- Compliance monitoring must account for background sound levels.

- The current PSB precedent of 45 dBA one-hour maximum protects against public health impacts and undue adverse impact on aesthetics per Act 250 framework.

PSB Precedent & the Proposed Rule

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Contacts

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