DRAFT
DNV Review of the Falmouth, MA Wind-1 and Wind-2 Mitigation Report

CONFIDENTIAL

Town of Falmouth
Board of Selectmen
c/o Massachusetts Clean Energy Center
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Boston, MA 02110
Attention: Nils Bolgen

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DNV Review of Falmouth Renewable Energy Facilities Mitigation Strategies	DNV Renewables (USA) Inc. 1809 7th Avenue, Suite 900 Seattle, WA 98101 USA Tel: 1-206-387-4200 Fax: 1-206-387-4201 http://www.dnv.com/windenergy
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Summary:

DNV was asked by the Town of Falmouth Board of Selectment to review the Weston & Sampson Town of Falmouth, MA Wind Energy Facility Mitigation Alternatives Analysis and supporting documentation and to comment on additional mitigation options, if available. This report was funded by the Massachusetts Clean Energy Center.

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Indexing Terms	
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1. EXECUTIVE SUMMARY

The Massachusetts Clean Energy Technology Center (MassCEC) retained DNV to provide wind turbine technology and control system expertise to the town of Falmouth, Massachusetts. The support being provided addresses concerns about noise levels around the two town-operated wind turbines at the wastewater treatment plant (WWTP). As part of this effort, this report presents DNV's review of a report by Weston & Sampson Engineers, Inc. (W&S) entitled *"Town of Falmouth, MA Wind Energy Facility Mitigation Alternatives Analysis"* [1] (the "W&S Report") and supporting material, including a report by Harris Miller Miller & Hanson, Inc. (HMMH) entitled *"Falmouth Wind Turbine Noise Study"* [2] (the "HMMH Report"). The report also includes information on additional possible mitigation measures that might be considered with a brief evaluation of the advantages, disadvantages, costs and possible effectiveness of these options.

DNV's most significant general observations on the two reports are:

- The approach and work of W&S and HMMH is professional and with the standard of care ordinarily expected of an acoustical engineer. Nevertheless, DNV has come to alternate conclusions in some instances.
- The dominance of turbine noises over background noises depends on the relative windiness at the ground at residences where the background noises are generated and at the turbine hub height where the turbine noise is generated. As wind conditions on the ground can change relative to wind conditions at the turbine, sometimes on an hourly basis, a characterization of ambient sound levels based on only one condition understates the range of possible ambient noise levels at receptors and when problematic conditions might occur.

Based on these observations, DNV suggests that additional measurements be made to understand better under what conditions neighbors of the Falmouth wind turbines experience which noise levels and when state or local noise guidelines might be exceeded.

DNV reviewed the mitigation options provided by W&S and provided information on additional options including operational or configuration changes of the turbines and economic options to compensate the most affected abutters to the Falmouth wind turbines. In addition, mitigation of shadow flicker and ice throw was considered. DNV evaluated the noise mitigation options using a categorical scale related to the cost per reduction of noise levels ("cost per dB reduction"). Based on this categorization, the most cost effective measures are listed in the table below.

Table 1. Summary of Most Cost-Effective Mitigation Options with Comments

Mitigation Option	Approximate Cost	Cost/dB	Comments
Curtailment – midnight to 3 AM, Wind > 8 meters per second (m/s)	$16,000 annually	Low	Achieves compliance with DEP noise guidelines at low wind speed under typical conditions. It may not address compliance at all wind shear conditions. Does not address complaints that noise issues occur at higher wind speeds.
Curtailment – Nights	$400,000 annually	Low - Moderate	Achieves night time compliance with DEP noise guidelines at all wind speeds (if there are issues at multiple wind speeds). It will not address compliance during the day if that were an issue. Eliminates night time annoyance. Addresses many complaints of abutters. Day time background sounds often exceed turbine noise levels
Smart Curtailment	Unknown	Moderate	Could address most complaints and achieve compliance with DEP noise guidelines. Could address complaints that noise is worse at higher wind speeds. Plan could be tailored to level of mitigation, issues to be addressed and target dB levels.
Curtailment – Nights, April – September Other months: midnight to 3 AM, wind speeds > 8 m/s	$210,000 annually	Low	Achieves night time compliance with DEP noise guidelines at all wind speeds (if there are issues at multiple wind speeds) during months when outside activities are most likely. Achieves compliance with DEP noise guidelines at typical low wind speed conditions at all times of the year. It may not address compliance at all wind shear conditions. Addresses many complaints of abutters when outside activities are most likely. Does not address complaints that noise issues occur at higher wind speeds
Home insulation	$360,000 for 9 homes One-time	Moderate	Addresses indoor audible sound concerns when windows are closed. Provides an indoor environment free of audible noise annoyance as a haven to the most affected residents while other options are considered. Might be considered an attempt to push the problem on to abutters.

Mitigation Option	Approximate Cost	Cost/dB	Comments
Serrated trailing edges on blades	Unknown One-time	Moderate	Reduces turbine noise levels at all locations. Might be used in combination with other options. Should be pursued with Vestas.
Pitch setting changes	Unknown One-time	Moderate	Reduces turbine noise levels at all locations. Might be used in combination with other options. Should be pursued with Vestas.
Noise easements at selected properties	Unknown One-time	Low	The cost and mitigation of this options should be evaluated
Purchase and resale of some residences	Net cost unknown One-time	Moderate?	This would address most or possibly all noise-related concerns. If the resale cost is not significantly different from the purchase price and transaction costs are not too great, this option has a moderate cost/benefit. This option should be considered by the town.
Mitigation of shadow flicker	Low	-	DNV recommends that this be done.
Mitigation of ice throw	Low	-	DNV recommends that this be done.

Based on these results, DNV has the following recommendations for the town:

- The town should obtain additional measurements of ambient noise levels when the turbines are running and not running at a variety of receptor sites and in the range of wind conditions that occur at the site and over different seasons and times of days. These data would refine the town's understanding of the noise conditions around the WWTP site. It would identify the conditions generating high ambient audible noise, excursions greater than the town bylaws' reference sound level or the Massachusetts Department of Environmental Protection noise guidelines and, if infrasound measurements were conducted, would provide information on infrasound levels under different atmospheric and operational conditions. All of these data would provide the town with a clearer picture of what needs to be mitigated and when it might be a problem.
- The town should pursue other options concurrent to any testing. Some of these options have only one-time costs, some have annually recurring costs. A mixture of options might be chosen to address some immediate concerns while additional options are being evaluated.
- The most effective options from the perspective of cost per dB reduction, are:
  - Curtailment at wind speeds below 8 m/s between midnight and 3:00 a.m.
  - Curtailment at wind speeds below 8 m/s between midnight and 3:00 a.m. and for eight hours each night during April through September.
  - The insulation of some nearby homes
  - Purchase at fair market value and resale of homes of most affected abutters

- Reduction of noise emissions with serrated trailing edges or pitch control improvements. These are the most viable operational modifications that might be available. They would provide some reduction of sound but their efficacy and application would need to be discussed with Vestas.

2. INTRODUCTION

The Massachusetts Clean Energy Technology Center (MassCEC) retained DNV to provide wind turbine technology and control system expertise to the town of Falmouth, Massachusetts. This scope of work is governed by Work Order 12-1 dated December 20, 2011, governed by the Master Services Agreement between MassCEC and DNV dated June 27, 2011.

This report presents DNV's review of a report by Weston & Sampson Engineers, Inc. (W&S) entitled "*Town of Falmouth, MA Wind Energy Facility Mitigation Alternatives Analysis*" [1] (the "W&S Report") and supporting material, including a report by Harris Miller Miller & Hanson, Inc. (HMMH) entitled *"Falmouth Wind Turbine Noise Study"* [2] (the "HMMH Report"). The report also includes information on additional possible mitigation measures that might be considered with a brief evaluation of the advantages, disadvantages, costs, and possible effectiveness of these options.

3. DNV COMMENTS ON HMMH REPORT

The W&S Report includes a variety of mitigation options and evaluates the cost and effectiveness of each. Evaluation of the magnitudes of sound levels to be mitigated is based on acoustic propagation modeling and measurements of background and turbine noise levels by HMMH. Thus, DNV has reviewed both the W&S Report and the HMMH documentation supporting the magnitudes of the turbine noise emissions and the sound levels to be mitigated.

3.1 General Notes on HMMH Report

W&S retained HMMH to conduct a noise measurement and modeling study for the "Wind-1" and" Wind-2" turbines—both Vestas V82 models. Generally we find HMMH's approach and work to be professional and with the standard of care ordinarily expected of an acoustical engineer. We do note several important points related to an alternate approach to the data analysis, which we describe below.

3.2 Measurement of Turbine Noise Emissions in HMMH Report

Wind turbine noise emissions were measured by HMMH in order to confirm if the turbine emissions under operating conditions were consistent with expected turbine noise emission levels provided by the manufacturer. HMMH generally followed the International Electrotechnical Commission (IEC) 61400-11 standard (the IEC Standard) as a guideline for turbine noise characterization. HMMH made it clear that site conditions did not allow the requirements in the IEC Standard to be followed in all aspects.

Differences between the requirements of the IEC Standard and the measurements include:

- **Microphone placement** – The microphone was placed 30.5 meters (m) from the turbine. The IEC Standard requires that the microphone be placed downwind at a distance equivalent to the hub height plus the rotor radius, plus or minus 20% (equivalent to 97 m to 145 m, in this case). HMMH notes that the measurements were adjusted with a distance correction to account for this difference. The inability to measure at the required distance may have some effect on the results as the rotor-generated noise (as opposed to, for example, gearbox noise) would presumably be more prominent in the data than it would be at greater distances from the turbine.
- **Measurement uncertainty** – Measurement uncertainty is not addressed in the HMMH report, but a required by the IEC Standard. Measurement uncertainty comes from many sources, including test equipment, field test setup, atmospheric conditions (turbulence, acoustic absorption of the air, stability), wind speed measurements, direction measurements (and thereby deviation from downwind location), signal-to-noise ratios (turbine on/off level differences), plus scatter of ambient noise levels.
- **Averaging period** – HMMH used 10-minute averages of wind speed and sound levels. One-minute averages, as allowed by the IEC Standard, provide greater insight into how a turbine is behaving. It makes it easier to discard spurious noise in the data.

It should be noted that the scope of the background sound study and measurement program undertaken by HMMH was reviewed and agreed upon by the sound engineers hired by the residents within the surrounding community and the scope of HMMH's work was not to verify the turbine sound power levels in accordance with the IEC Standard.

A complete test according to the IEC Standard would address some of the issues mentioned above and provide:

- A full characterization of the sound pressure and power level throughout the noise curve, up through the wind speed at which stall takes place.
- Reduced scatter within the data set. Wind turbine noise in an IEC Standard compliant test has a typical scatter of less than 5 dB for a given wind speed. Data in the HMMH showed up to 15 dB scatter in the 10-minute averages. Close attention would be paid to each data point so that spurious noises are not attributed to the wind turbine. An example of results from a IEC-compliant wind turbine noise study is provided in Figure 1.

In spite of these identified differences between an IEC compliant test and the HMMH measurements, the sound generation levels provided by Vestas were generally confirmed by the HMMH measurements. Short of subsequent operational problems, there seems to be no reason to suspect that the wind turbine is not operating as claimed by Vestas.

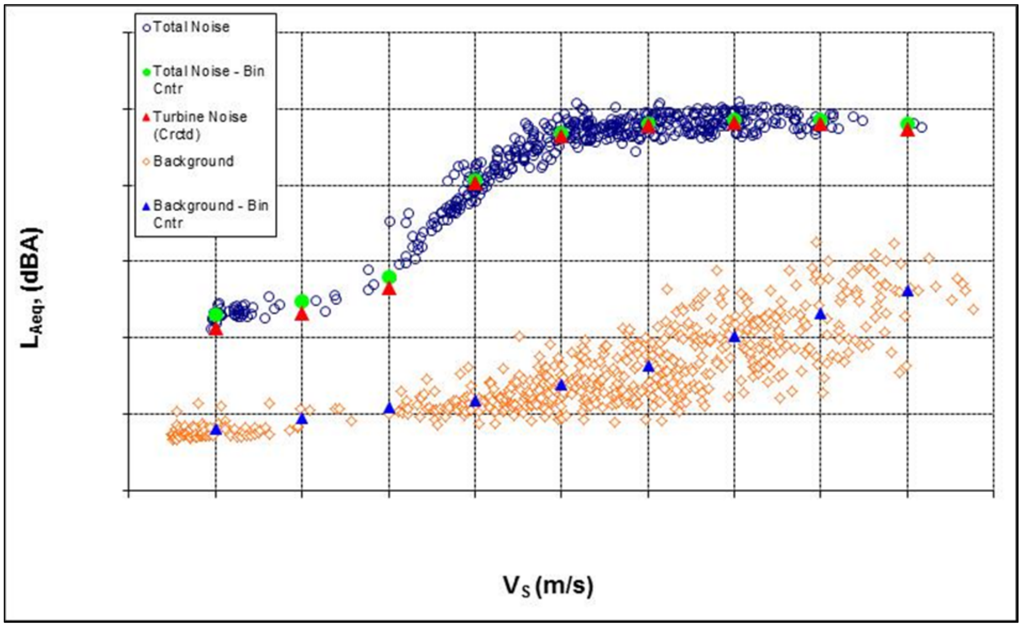

Figure 1. Example of Results from an IEC-compliant Turbine Noise Test; vertical divisions are 5 dB; horizontal divisions are 1 m/s

3.3 Estimation of Noise Levels at Sensitive Receptors in HMMH Report

The HMMH study concluded the following:

- Midnight to 3:00 a.m. could be identified as the quietest hours of the day for the purposes of characterizing quite nighttime conditions.
- The Massachusetts Department of Environmental Protection (DEP) noise guidelines, which require that noise sources should not increase existing background noise levels by more than 10 dBA, would be exceeded only if both Falmouth Wind-1 and Wind-2 turbines were operating at the same time and with hub-height wind speeds of 6 m/s at a time between about midnight and 3:00 a.m.
- These violations would only occur at the two homes closest to the Wind-2 turbine.

These conclusions are based on sound propagation models, turbine sound generation levels provided by Vestas and measurements of background noise at two locations a) near Falmouth Wind-1 and b) at the site of a nearby V82 wind turbine owned by Notus Clean Energy (about a kilometer to the east-northeast of Wind-1). There were no background measurements above nacelle wind speeds of about 9 m/s in the Falmouth Wind-1 data set. As background measurements at higher wind speeds were available from the Notus data set, these were combined for the HMMH analysis.

The IEC Standard specifies that noise emissions of wind turbines shall be based on hub-height wind speeds (although they are expressed as equivalent 10-m wind speeds, assuming specific assumptions about how wind speed changes with height. In order to use turbine emission data measured for specific hub-height wind speeds for modeling, one must relate background noise levels at various ground-level wind speeds to turbine emission levels defined by hub-height wind speeds. HMMH used the following approaches to identifying hub-height wind speeds during the background noise measurements:

- For the background data collected near the Falmouth WWTP, HMMH was able to use wind speed measurements from the nacelle-mounted anemometer of the Wind-1 turbine. These data were not adjusted to correct for the effects of the flow around the nacelle. DNV expects that the measurement error is on the order of ±5%.
- For the background data collected at the Notus turbine site, HMMH estimated hub-height wind speeds from 10-m measurements using site-specific assumptions of how wind speeds change with height (wind shear, defined below). In this case, it appears that HMMH used the approach suggested in the IEC Standard for "Farmland with some vegetation," (the "Log Law" with a roughness length of 0.05 m).[1]

[1] The log law assumes that the wind speed at 80 m (V_{80}) is: $V_{80} = V_{10}(\ln(80/z_0)/\ln(10/z_0))$ where z_0 is the roughness length, V_{10} is the wind speed at 10 m and ln() is the natural logarithm.

Both options (hub-height measurements and using lower measurements with site-specific estimates of wind shear) are included in the IEC Standard for use when defining wind turbine noise emissions.

Wind shear refers to the change of wind speed with height above ground level (AGL). Wind speeds typically increase with increasing height. Wind shear can change depending on wind speed, atmospheric stability (and therefore time of day), upwind surface features (and therefore wind direction and site characteristics) and other factors such as larger atmospheric patterns (which change over the year). Given the great variability in wind shear at a site, assuming shear conditions based on a simple characterization of surface features (as is included in the IEC Standard) can lead to a mischaracterization of the relationship between hub-height emissions and ground-level background noise.

The choices made by W&S and HMMH result in a fixed relationship between the background noise levels and turbine noise emissions. This is an approach typically pursued when modeling wind turbine noise propagation.

Because background noise is a function of the ground-level wind speed and the turbine-generated noise is a function of the hub-height wind speed, a more accurate understanding of the noise levels at a receptor requires knowing the relationship between the rotor hub-height wind speed and the ground-level wind speed at a receptor. This relationship changes as wind shear changes.

To check the consequences of the choice of shear characteristics, DNV looked at data collected at the Falmouth Wind-1 site by the University of Massachusetts from 2004 to 2005. The ratios of average hub height (80 m) to 10 m wind speeds were used to evaluate the shear characteristics. These ratios are shown in Figure 2. The data are plotted by hour of the day. In this case, these measurements indicate that the average ratio of 80-m to 10-m wind speed during the night is slightly greater than 2. The variability of the wind speed ratios over the year is indicated by the dotted lines which are one standard deviation above and below the average. The data show that shear generally decreases in the middle of the day.

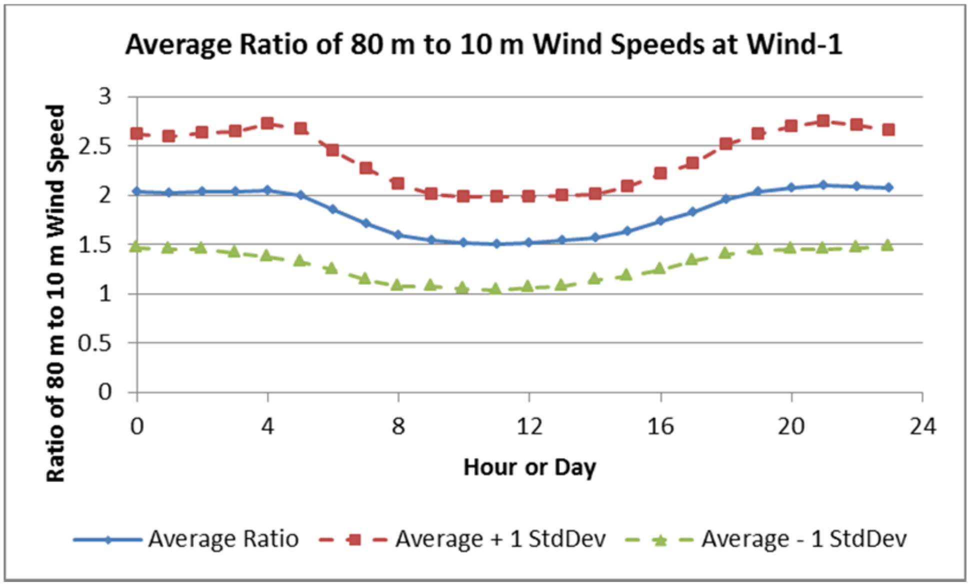

Figure 2. Ratio of 80-m to 10-m Wind Speeds at the Falmouth WWTP; these results are based on measurements at 10 m and 39 m made at the future location of Wind-1

Figure 3 shows DNV's estimate of the average ratio of 80-m to 10-m wind speed during the hours from Midnight to 4:00 a.m. in each month of the year, based on the University of Massachusetts data set. In this case, the data are only for hub-height wind speeds over 10 m/s to reflect the higher wind speed ranges. The ratio is based on the data from 10 m and 39 m on the University of Massachusetts measurement tower. These data and industry standard profiles of how wind speeds change with height (the "power law"[2]) were used to estimate the ratios of 80-m to 10-m wind speeds in Falmouth. The ratios were also adjusted to reflect that the wind shear often decreases a little with height. The average ratio across the year is calculated to be 1.73. This is lower than the annual average of the raw data due to the correction for height and due to the slightly lower shear when wind speeds are greater than 10 m/s. The ratio of 80-m to 10-m wind speeds assumed by HMMH for the Notus data is 1.39, lower than is typically found in Falmouth.

[2] The power law assumes that the wind speed at 80 m (V_{80}) is: $V_{80} = V_{10}(80/10)^{\alpha}$ where α is an exponent determined from the 10 m and 39 m measurements.

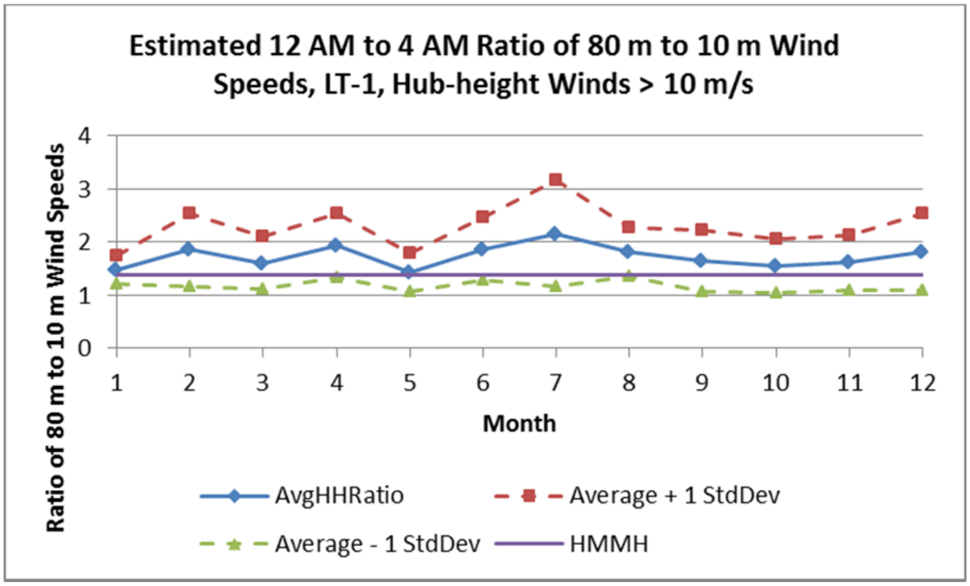

Figure 3. Estimated Nighttime Ratios of 80-m to 10-m Wind Speeds, for 80-m Wind Speeds greater than 10 m/s; the figure also includes the range of typical values that might be found (plus and minus one standard deviation)

A copy of a figure from the HMMH report characterizing noise levels at the long-term measurement site LT-1 (at 211 Blackshmith Shop Road) is shown in Figure 4. The background sound levels at higher wind speeds are based on the relationship HMMH assumed between 80-m and 10-m wind speeds.

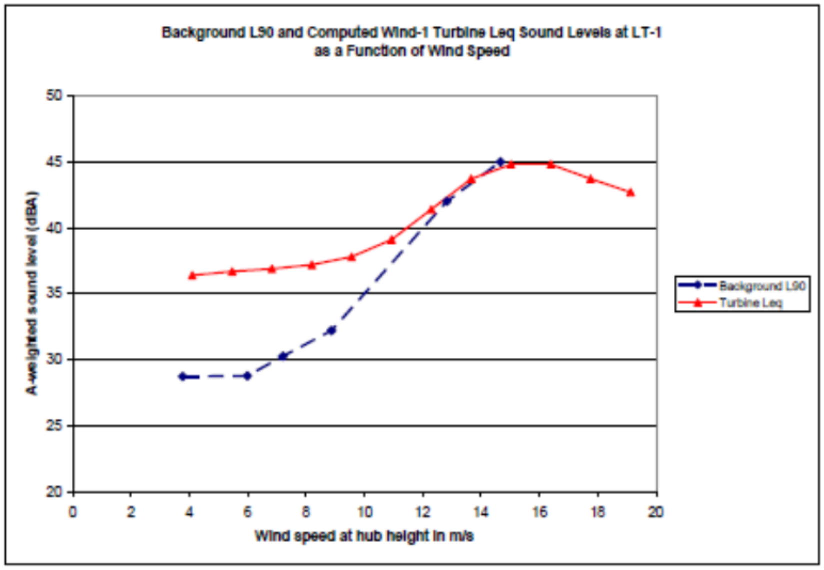

Figure 16 Background L90 and Wind-1 Turbine Noise Levels at LT-1 with Varying Wind Speed

Figure 4. Figure from HMMH Report Characterizing Background and Turbine Noise Levels at Measurement Site LT-1

DNV estimated the relationship between the background and the turbine sound levels at LT-1, as shown in Figure 5. The figure shows the average conditions that are expected and the range over which background sound levels will typically vary, given the range of wind shear at night at the site (± one standard deviation of the values over the year). These estimates are based on:

- The background measurements provided by HMMH and the corresponding 10-m wind speed measurements
- The turbine sound emissions as reported by Vestas and provided in the HMMH report that are referenced to hub-height wind speeds
- The average nighttime wind shear at the Wind-1 turbine location

The figure also shows the estimated peak hub-height early-morning wind speeds at the site over a typical year. These results assume that the receptor is downwind of the wind turbine, although that would not always be the case.

The following observations follow from these results:

- As shown in Figure 5 DNV expects that the turbine sound levels will be greater than those of the background at LT-1 for a variety of conditions, including at wind speeds over hub height.
- The results also indicate that there will be times when the turbine sounds will be lower than the background sounds even at moderate to low hub-height wind speeds.

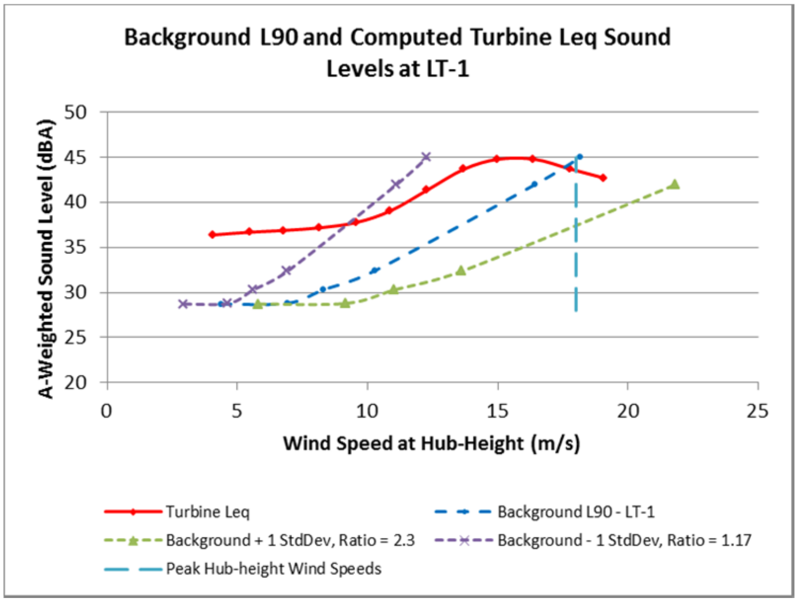

Figure 5. Turbine Leq as well as DNV's Estimate of Nighttime Background Sound Levels at LT-1, including the Range of Typical Nighttime Background Sound Levels Expected at LT-1

- These results also indicate that the Massachusetts DEP noise limit of an increase of 10 dBA over background levels will only occur under during high wind shear conditions, if at all. (See the comments below on uncertainties of the DNV analysis.)
- DNV estimates that the conditions at which the turbine sound levels will exceed the background levels and will be loudest will occur at hub-height wind speeds of 15 to 16 m/s when nighttime wind shear is greater than or close to average conditions. These conditions will result in levels in excess of the town bylaws' 40 dBA reference level.

There are a number of uncertainties in DNV's estimates of background sound levels at LT-1 with respect to the turbine noise levels. The most important sources of uncertainty are related to:

- Whether background sound levels are the same at all receptor sites
- Whether the background sound levels are the same as at the two different background sound level measurement sites
- Whether the measured shear values apply to the location of receptors

Given these uncertainties, DNV strongly recommends a better characterization of background sound levels in a variety of wind conditions at receptor sites and of the relationship between those background sound levels and hub-height wind speeds, and the variability of that relationship. There is a possibility that current DEP sound measurements will provide this information.

There is the possibility that the Massachusetts DEP 10 dBA limit could be exceeded under some high shear conditions more often than predicted by HMMH. Should this be the case, then sound mitigation measures such as sound barriers and sound insulation, as described in the W&S report, would need to be designed for greater ambient noise levels.

DNV's analysis and Figure 5 indicate that:

- The range of wind speeds at which the turbine sound level is greater than the background level for at least some of the time at LT-1 is greater than estimated by HMMH.
- At times the turbine sounds will exceed the background sounds at LT-1 when hub-height wind speeds are greater than 10 m/s.
- Given that the difference between 10- and 80-m wind speeds can vary significantly, even if the modeling results assumed in the HMMH report were found to be typical conditions, there would be times when the turbine sounds would dominate the background sounds at higher wind speeds and times when the turbine sounds were drowned out by the background sounds even at low wind speeds.
- The conditions with the greatest turbine noise levels exceeding the background sounds at LT-1 will be at wind speeds of about 15 m/s and high wind shear when the turbine noise is about 6 dBA greater than that used for the scenario modeled by HMMH (with hub-height wind speeds of 10.9 m/s).
- Because of the slope of the curve of the turbine noise levels at LT-1, any uncertainty or variability in the background noise levels at high wind speeds will have a significant effect on the range of wind speeds over which the turbine sounds will dominate the background sounds.
- DNV believes additional measurements at higher wind speeds to confirm background noise levels are needed. The lack of a clear understanding of noise conditions at moderate to high wind speeds has an impact on appropriate curtailment options, on appropriate mitigation options, and on the acrimony of the public discussion of resident's annoyance.

3.4 Comments on Criteria for Evaluation of Acceptable Noise Levels

Finally, the HMMH and W&S reports use noise level thresholds or reference values in state and community noise regulations as the benchmark for addressing public concern and mitigation measures. This is appropriate as there are no other standards to apply and as these have been determined by a public political process. We also note that the state and local thresholds are not out of line with limits in other states and countries, per a recent review and recommendations document in the Noise Control Engineering Journal [7]. Nevertheless, regarding acceptable wind turbine noise levels, DNV has the following comments:

- Compliance with the DEP regulations and/or the local bylaws does not guarantee that a wind turbine will never be heard or that noise levels will be found acceptable by everyone. There will be atmospheric conditions, wind shear conditions, or background noise conditions at which the turbine will be audible for some period of time.

- DNV's observations only address time-averaged audible noise and not the effects of any amplitude modulation, impulsivity, or infrasound.
- The town's sound bylaw does not address the fact that background sound levels are often in excess of 40 dBA, particularly at higher wind speeds.

3.5 Additional Comments of Predicted Wind Turbine Noise Levels and Impact

HMMH used SoundPLAN and industry-standard software for evaluation of the wind turbine noise. The propagation standard utilized in this model is International Organization for Standardization (ISO) 9613, which has been the standard model utilized in the industry for many years. HMMH was able to determine a best fit for the ground attenuation factor in their model. The results indicated that a few residential locations would be slightly higher than the DEP's 10 dBA limit. DNV has the following comments:

- The ISO 9613 Standard provides a long-term average A-weighted sound pressure level for noise from the source (turbines). It is up to the acoustician to decide what background levels to add to this wind turbine-only calculation to determine the long-term overall level at each location. There are no standards for how best to determine these background levels for wind turbine modeling.
- The ISO 9613 Standard provides an estimated accuracy for propagation distances between 10 and 1000 m of ± 3dB, due to meteorological condition variations.
- "Pure tones" may be evaluated based on different kinds of spectral data—e.g., third-octave, octave, or narrowband (Fast Fourier Transform [FFT]) data. The IEC Standard requires that tonality analysis (determination of tones) be performed not on the third-octave results (which are also required in a report), but rather the narrowband FFT results.
- The V82 specifications reported appear to have only included octave band data and overall sound power level data. In DNV's experience, test data may reveal tones (or "tonal audibilities") not previously predicted or included in a specification. Although not included in the DEP or town noise ordinances, in some locations turbines containing tones are penalized by adding, for example, 5 dB to the total sound power level to the turbine during the planning phase of a wind farm project, resulting in a greater setback. DNV acknowledges that this essentially is "making up" for the additional annoyance that tones can cause. The effect that other wind turbine noise characteristics (infrasound, low frequency noise, amplitude modulation, and impulsivity) may have on the listener is less clear.

4. DNV COMMENTS ON OPTIONS IN WESTON AND SAMPSON REPORT

The W&S Report includes a number of possible mitigation options. DNV's comments on each of these are included below.

4.1 Curtailment

4.1.1 Curtailment of One Wind Turbine below 8 m/s from Midnight until 3:00 a.m.

The curtailment that is examined in the W&S Report is a plan to limit operation of one of the two wind turbines at the Falmouth WWTP to those periods when hub-height wind speeds are greater than 8 m/s between Midnight and 3:00 a.m. This recommendation is based on the conclusions of the HMMH report which identified those conditions under which the DEP noise limits would be exceeded. W&S has identified the cost of this option as about $16,000 per year.

DNV has the following comments on this option:

- HMMH results show that curtailment of one wind turbine when hub-height wind speeds are less than 8 m/s between Midnight and 3:00 a.m. will ensure that the town-mandated noise limit will not be exceeded.
- If turbine noise during periods when the wind speeds are above 8 m/s is shown to be a problem then this proposed curtailment will not address those issues.
- Given the variability of ground-level background noise levels with respect to turbine noise levels at a receptor, there will be periods when the turbine will be much louder than the background noise in spite of the curtailment. Thus, this curtailment may not address all occurrences of non-compliance with the DEP noise limits.

4.1.2 Other Curtailment Approaches

If noise at other wind speeds or times of day turn out to be problematic and/or if weather or turbine operational conditions causing complaints are more complex than currently understood, then other curtailment options could be considered.

4.1.2.1 Curtailment at Night

According to the HMMH study, background noise levels increase significantly during the day compared to nighttime levels (by at least 6 dBA and up to over 15 dBA at some locations or at some times). These levels should be enough to mask a significant amount of wind turbine noise, even at 15 m/s. Thus, if wind turbine noise above 8 m/s were shown to be a problem, one option would be shut down one or both wind turbines at night (from, for example, 10:00 p.m. until 6:00 a.m.) under all wind conditions. The impact of selected additional curtailment options is described below.

Curtailment at night would address nighttime noise complaints and might be necessary to meet noise regulations if noise above 8 m/s were confirmed to be an issue. The extent of curtailment of either Wind-1 or Wind-2, the wind speed ranges used for curtailment and the most appropriate hours for curtailment would need to be determined from a detailed analysis.

In order to provide a sense of the magnitude of the impact of such curtailment, DNV estimates that if operation of Wind-1 and Wind-2 were curtailed for 8 hours during the night, then overall production from both wind turbines would be reduced on the order of 40%. This is a rough estimate based the fact that the wind speeds in Falmouth are slightly greater, on average, during the night time hours than during the daytime hours. Using W&S revenue forecast figures, this would result in a loss of about $400,000 in annual revenues.

4.1.2.2 Other Curtailment Approaches and Comments

Additional curtailment approaches could be considered. For example, these might be considered in an effort to reassure the community that all avenues were being pursued to address concerns. One example curtailment approach could be curtailment in the summer, which would stop sound emissions from the turbines when residents and visitors are most active outdoors and when windows are most often left open at night. Such curtailment strategies may have significant costs to the town. Curtailment for three months during the summer without any other curtailment would cost the town about $213,000 in revenue.

DNV has looked into the effects of curtailment on turbine wear based on the typical contribution to the fatigue life of a wind turbine from operation at different wind speeds and from start-up and shutdown events in different wind conditions. For all of the curtailment scenarios considered here, DNV estimates that the decreased wear from fewer hours of operation will outweigh any minor increase in wear from a possible increase of start-up or shutdown events. It will be important to pitch the blades such that the rotor can idle, without the use of the parking brake, during long periods without operation. This will help to ensure that that gears are lubricated at all times.

Finally, noise complaints may be a result of clearly audible turbine sounds at wind speeds greater than 8 m/s. Complaints may be a result of specific operating conditions under certain atmospheric conditions. A “smart” curtailment plan may have benefits. The curtailment options discussed so far are relatively blunt instruments designed to eliminate the occurrence of problematic conditions. It is recommended that the town obtain a better understanding of the background and turbine noise levels at wind speeds over 8 m/s and define what the objective of any curtailment is in order to optimize a curtailment strategy to limit the impact on revenue. Addition of a turbine control signal which monitored a ground-level anemometer in addition to the nacelle wind speed and, perhaps, even a measure of traffic on Rt. 28, might be used to define curtailment periods based on actual conditions rather than general periods when noise is more likely to be a problem (i.e., the identified Midnight to 3:00 a.m. window). This approach would require a better understanding of moderate and high wind speed background noise levels, but such an approach could yield a solution that would minimize noise impacts while limiting revenue loss. More detailed assessment of wind data from Falmouth should be conducted to determine the effectiveness and revenue impacts of such a curtailment plan.

4.2 Removal and Sale or Salvage of Wind I and Wind II

The removal and the sale or salvage of Wind-1 and Wind-2 were considered by W&S. DNV has conducted a high level review of these options but has not done independent research to confirm or refute the cost numbers. Based on our experience the costs as outlined by W&S seem reasonable and possibly conservative. Significant costs would be incurred due to the repayment of debt obligations for Wind-1.

4.3 Relocation of Wind-1 and Wind-2

Relocation of Wind-1 and Wind-2 is a viable option which preserves many of the advantages of the wind turbine for the town, although with significant costs. This option requires a suitable site at which there are appropriate set-backs for safety and compliance with state and local noise regulations. Analyses to determine those set-backs for noise will need to consider the appropriate hub-height and ground-level wind speeds for background noise levels and turbine noise emissions. The expected turbine revenues should be re-evaluated based on an assessment of applicability of current agreements and commercial operating conditions (e.g., net-metering) to the turbines at an alternate location as well as the energy production potential.

4.4 Sound Mitigation

Sound mitigation will have to consider the appropriate nighttime acoustic conditions at sensitive receptors. Should conditions with sound levels greater than assumed in the HMMH report be identified as needing mitigation, the design of these mitigation measures may need to be re-evaluated.

DNV is not qualified to comment on the specifics of the sound insulation and noise barrier design.

4.5 Shadow Flicker and Ice Throw Mitigation

The W&S report also includes a discussion of mitigation of shadow flicker and ice throw.

4.5.1 Shadow Flicker Mitigation

Generally, we find W&S' assumptions and approach to shadow flicker modeling be consistent with industry practice. DNV offers the following observations:

- W&S has modeled both a worst case scenario, assuming that each day is clear, the turbine rotors are always perpendicular to the residence and the rotor is always spinning, and a "real case" scenario, which incorporates sunshine probability, operational time, and turbine yaw position. DNV has not independently verified the "real case" model inputs; however, the directional distribution (primarily southwest) and assumed operational time

(94%) appear consistent with site wind distribution. DNV also believes the assumed daily sunshine hours per day per month (ranging from 4.7 hours in December to 10.0 hours in July) to be reasonable given distribution of daylight hours throughout the year and the higher potential for cloud cover during the winter.

- W&S has assumed a single 1 m x 1 m window located 1 m above ground level in an omnidirectional or "greenhouse" mode, which is consistent with industry practice for assessing indoor shadow flicker impacts. If the actual window location, dimensions and height are known, a more realistic calendar of potential indoor shadow flicker can be determined. Nevertheless, the W&S results with respect to hours of curtailment should be correct.
- W&S notes that they have also defined the object for the yard area to measure 10 m x 4 m and 1 m above ground level. However, it is unclear if this object was intended to be a shadow flicker receptor or potential shadow flicker blocking obstacle. The object does not appear on the WindPRO SHADOW – Main Result Report (in the Appendix to the W&S Report) as a "shadow receptor-input", nor do the "Assumptions for shadow calculations" list the object as used in calculation.
- The mitigation options proposed in the W&S report are curtailment of the wind turbines during periods of shadow flicker or the use of window blinds, shades, or landscaping. If mitigating the indoor shadow flicker impact by curtailment, actual window dimensions should be used for determining the calendar of potential shadow flicker. The duration of potential shadow flicker would be greater for mitigating the outdoor shadow flicker impact.
- Shadow flicker can be annoying to those affected and mitigation of shadow flicker by curtailment of turbine operations during critical periods typically has a small impact on revenue generation.
- Options include the integration of a pyronometer (a device used to measure sunlight intensity) into the turbine control software to only curtail operation when the sun is shining. This option would be relatively low cost and would reduce curtailment to a minimum.
- Since the potential for shadow flicker to occur is during a time of day residents would likely be home, DNV recommends that shadow flicker be mitigated.

4.5.2 Ice Throw Mitigation

DNV offers the following observations regarding ice throw assessment and mitigation:

- W&S notes that sensor malfunction due to ice build-up will cause automatic turbine shutdown. Automatic turbine shutdown may also occur when there is a detection of performance degradation or inertial imbalance.

- Figure 5-2 Ice Throw Risk Potential vs. Distance and the last paragraph on page 5-7 of the W&S Report appear to reference lightning strikes. We do not believe this was intended to be included in the report. We would request to review the actual Figure 5-2.
- W&S recommend that an estimate of the number of days per year during which icing conditions occur be made. We agree. However, it is unclear where the ranking of "light" to "heavy" icing is sourced from.
- The source data for W&S Report Figure 5-3 Ice Throw Distance vs. Rotor Diameter is not discussed. W&S notes the data are based on ice accretion rate, but no assumptions of potential mass are provided. Also, the data represented are for turbine rotor sizes of up to 60 m, and no extrapolation to the Vestas V82's rotor size of 82 m is made.
- A turbine cold weather package is listed as a mitigation measure to reduce the risk of ice accumulation, noting that these included special coating on the blades to eliminate the adherence of ice. DNV is unaware of the availability of such coatings or their effectiveness.

Initial DNV comments regarding ice throw mitigation:

- Given the distance that ice from blades tends to travel, icing will affect primarily the WWTP site
- Icing tends to considerably alter the power production of turbines and may increase turbine vibrations.
- Verification of icing conditions on site and deviation from normal power production could be used to design and implement a curtailment/shut-down strategy. DNV could identify exact conditions if that is helpful to the town.
- In one study in the Swiss Alps, ice throw was typically downwind, within a distance equal to the turbine radius. The maximum distance ice was thrown was 93 m, which is approximately equal to the tip height of the turbine (90 m), and less than the empirical formula used to calculate ice throw.
- It is unclear from the report how the cold weather package turbine reduces the risk of ice accumulation on the turbine blades. It is unclear if there is some sort of blade treatment that does this.

5. ADDITIONAL MITIGATION OPTIONS: CHANGING THE TURBINE CONFIGURATION OR OPERATION

This section considers possible options for reduction of the noise emissions at their source, using alterations to the turbine blades or components or alterations to the operations of the wind turbine. These options were not considered in the W&S Report. This sections starts with background information on the operation of the V82 wind turbine and on sources of turbine noise. These are followed by a review of possible options and a discussion of their feasibility.

5.1 Operation of the V82

All wind turbines use some method to limit power production in high winds. The most advanced wind turbines employ a variable speed rotor and reductions of the blade pitch angle to control power production when the power in the wind is greater than the design rating of the system. Blade pitch angle is angle at which the blade axis is set. It is adjusted by the pitch angle mechanism in the rotor hub. Reducing the blade pitch angle reduces the wind power transferred to the drive train.

The V82 wind turbine design has a fixed rotation speed and relies on pitching the blades to greater pitch angles to control power in high winds. This approach reduces the wind power transferred to the drive train by inducing stall along the blade. Stall results in increased turbulence over the blade surface and poor aerodynamic performance. It is an effective means of reducing the power transferred to the drive train but may induce conditions that generate more noise from the blade. Cyclic stall (cyclic changes in stall conditions) can be induced by the changing aerodynamic conditions that blades encounter as they rotate. It is possible that these cyclic changes in stall conditions might generate low frequency sounds.

5.2 Wind Turbine Noise Sources

Noise from wind turbines has two main sources, mechanical and aeroacoustic. Mechanical noises stem from such systems as gearboxes, hydraulic pumps and heat exchangers. Mechanical noises are generally easy to isolate, damp or absorb using conventional noise reduction technologies. As a result they are usually a small contributor to overall noise emissions in utility-scale wind turbines unless there is a maintenance problem that needs to be addressed. Aeroacoustic noises are much more difficult to control and make up the largest proportion of noises from modern utility scale wind turbines.

Aeroacoustic noise is often grouped in to two categories:

- **Airfoil self-noise** – This is noise generated by the normal flow of air over the blades. There are many sources of airfoil self-noise but the most important are trailing edge noise and blade tip vortex noise.

- **Turbulent inflow noise** – This is noise generated by interactions between the turbulence in the air and the blades. This can be aggravated by changes in flow conditions as the blades rotate.

One additional source of pure tones may be blade surface imperfections. These are generally caused by manufacturing errors or blade damage and can usually be easily addressed.

Recent research has shown that, as a result of improvements of aeroacoustic performance over time, the dominant source of aeroacoustic noise above 250 Hz in modern wind turbines tends to be trailing edge noise. The amplitude of this is often modulated by the blade passage frequency with the loudest noises occurring as the blade is traveling downward (about 15 dB greater than from the upward-traveling blade). Turbulent inflow noise may contribute more at frequencies below 250 Hz. Finally, blade-generated noise tends to increase in amplitude by the fifth power of the rotor rotational speed.

It is unclear to DNV at this point what the source of the major complaints of some Falmouth residents is—infrasound (1-20 Hz, inaudible), low-frequency noise (LFN, 20-100 Hz, marginally audible), broadband noise or amplitude modulation (AM) and Impulsivity (IP). These four wind turbine noise characteristics are often present in wind turbine noise emissions. Tests to identify these are recommended, although not required, for an IEC Standard compliant test. Collectively these optional tests are the "Annex A" tests in the IEC Standard. The IEC Standard provides some "possible quantitative measures" that can be used to attempt to quantify these characteristics, and then states: "These measures are not universally accepted and are given for guidance only." Infrasound is an area where research is currently beginning to be undertaken, but is not yet well-understood. It is known that typical sound level meters used for IEC tests and environmental noise studies do not suffice for quantifying infrasound (IS) properly, due to the frequency response of the equipment used; this is one likely reason why this analysis is not required for an IEC test. The costs of these optional measurements are sufficiently high, such that they are not typically being done and hence very limited data are available. Without these Annex A test results, governmental bodies do not have a basis on which to determine realistic and appropriate noise ordinances. If it is suspected that any of these Annex A noise characteristics are the source of complaints in Falmouth, DNV can pursue measurements to further understand noise emissions from the Falmouth turbines. Alternatively, data mining of the resident complaint logs might identify specific problematic operating conditions.

5.3 Options for Mitigating Wind Turbine Noise Emissions through Changes of Configuration or Operation

A number of possibilities for reducing wind turbine noise emissions at the source have been proposed by Falmouth residents and/or by the wind industry. Some have been tested. The following subsections list some of these and provide comments on the potential for these options to provide relief to residents of Falmouth.

Most of these options would require research and all would require the involvement of Vestas in any implementation. Unless Vestas has considered some of these options and found them promising, most of them are not practical in the short or medium term. DNV has been in discussions with Vestas regarding mitigation strategies that might be available for the V82 turbines in Falmouth. A summary of the discussions is provided below. Two of these options hold some promise of being available in the short-term and of providing some noise emissions reductions. These are the application of serrated trailing edges to the blades and possible pitch control system modifications. Each of these would possible provide noise emission reductions of a few dBA. Further discussions should be held with Vestas to encourage their willingness to consider these options.

Before considering some of these options, there would need to be a clearer understanding of the exact sources of noise generation in the V82.

5.3.1 Serrated Trailing Edges

Serrated trailing edges have shown promise for reducing trailing edge noise in tests but their effect may depend on a variety of factors. In one study they reduced overall noise emissions by an average of 3.2 dB over 6 m/s to 10 m/s. Lower noise reductions occurred at lower wind speeds although it was conjectured that this might be due to blade tip vortex noise becoming a dominant mechanism at lower wind speeds. In any case, its effectiveness may depend on details of the blade design and operation.

Serrated edges may be part of the original blade design or may be added as an after-market mitigation measure. Serrated edges have been applied to already-installed blades on General Electric (GE) wind turbines in Vinalhaven, Maine, and are now being tested. This appears to be one realistic option to consider although its effectiveness on a V82 and on stall-regulated turbines is unproven.

The application of serrated trailing edges to the Falmouth wind turbines could result in a slight reduction in generation. The extent of any effect on generation cannot be estimated at this time.

This option should be pursued with Vestas. Its cost should be significantly less than blade replacement. The magnitudes of noise emissions benefits are not clear.

If effective, serrated trailing edges could be used in conjunction with other measures, to augment other measures with additional noise reduction or to allow a modification of other measures (such as reducing or eliminating the need for periods of curtailment).

5.3.2 Low Noise Airfoils

Low noise airfoils have shown some promise in wind tunnel tests but limited field tests have not been as promising. Lower than expected performance in the field may be due to manufacturing deviations from the intended blade shape or turbulent conditions in operating environments.

Taking advantage of low noise airfoils would require the installation of new blades. Whether low noise airfoils can offer advantages on the V82 and whether they would be available from Vestas is still being explored.

5.3.3 Porous Trailing Edges

Porous trailing edges, including trailing edge brushes, attempt to alleviate the abruptness of the trailing edge that is encountered by flow over the blade. These should, theoretically, reduce trailing edge noise but little research has been done on this concept and its effectiveness on a V82 is unknown.

5.3.4 Various Nontraditional Tip Shapes

Nontraditional tip shapes have been shown in one GE study to provide a decrease of up to 5-6 dBA in overall sound power level as compared to the traditional blunt tip shape [5].

These are unproven on a V82 and require blade modifications. These may also excite dynamic issues in the wind turbine. Consideration of non-traditional tip shapes would be a longer-term research project, would need the involvement of Vestas and would only be justified if tip vortex noise were identified as the source of the greatest noise emissions in this turbine design.

5.3.5 Gurney Flaps

Gurney flaps are small flaps that can be attached to the underside of a blade at the trailing edge and perpendicular to the blade surface. They improve blade performance by helping the flow to stay attached to the blade. It is possible that applying gurney flaps to some portion of the blade might change the coherence of cyclic stall along the blade (if that is indeed causing unwanted noise), and perhaps reduce low frequency sound generation.

5.3.6 Trailing Edge Streamers

Trailing edge streamers are long flexible strips attached to the trailing edge of the blade in multiple locations along each blade, to help break up large coherent structures (turbulence “bubbles”) that are formed behind the blade. There is a possibility that streamers would reduce blade-tower interaction and trailing edge noise, including perhaps infrasound and low frequency noise, if these were significant to begin with.

5.3.7 Reducing Rotor Rotational Speed

Blade-generated noise amplitudes vary approximately with the fifth power of the speed of the air across the blade. Thus, significant reductions in blade noise generation might be possible by operating at reduced rotor speed. Reduced rotor speed could be accomplished by installing a different gearbox or generator or by installing a converter in the electrical system between the grid and the wind turbine. The converter would transform the 60 Hz power to power at a lower frequency. Each of these options would be costly. The first two depend on whether Vestas had gearbox or generator options that are compatible with the Falmouth wind turbines. The converter could be installed on the ground, separate from the wind turbine. Each option would also require control system changes by Vestas. Fundamentally, whether any such option could be considered is a question of what dynamic consequences would incur from such a change. Wind turbine design choices involve a complex trade-off between forces and the durability and capabilities of the system components. Vestas would need to determine whether the wind turbine would successfully reach its design life when operated at another rotation speed, and would need to implement any changes.

5.3.8 Pitch to Feather

One additional option that has been suggested is pitching the blades to "feather." This refers to reducing the blade pitch angle in high winds to control the power in the turbine. The advantage is that operation at blade pitch angles that do not induce stall is quieter. The disadvantage is that the blade aerodynamics no longer passively limit forces in the system, so gusts can cause sudden spikes in power. This disadvantage is addressed in variable speed wind turbines by allowing the rotor to speed up when a gust occurs. The rotor absorbs the power as opposed to the drive train. In principle, this might be able to be implemented with changes to the turbine control system but, as with the question of reduced rotor speed, the advisability and consequences of such a change would need to be determined and implemented by Vestas.

5.4 Discussion with Vestas and Industry Contacts

As mentioned above, DNV has been in discussions with Vestas regarding mitigation strategies that might be available for the V82 model. Contact has been through offices in Portland, Oregon, office and Texas. A quick summary of the contacts to date includes:

- Bryan Kappa, a Test and Verification Engineer from the Portland office tried to identify any noise mitigation strategies that Vestas has considered or has available for the V82. His response was:

  > After an exhaustive effort by our local and Danish engineering teams, no commercially available means for further noise mitigation of the V82 is available. If an after-market technology is developed to further reduce V82 noise emissions, we will work to make this available to current V82 owners and operators.

- DNV also contacted Sidney Xue, Principal Engineer of Aerodynamics at Vestas R&D in Texas. He is looking into possible noise mitigation options but mentioned that he thought a sister office in Denmark had been working on turbine controller improvements (which include pitch setting changes) to address noise issues. He thinks it may be implemented only for one customer and is not sure if it is an item that is currently available for others to consider. He is looking further into this.

DNV has also been in discussion with others in the wind industry to identify any mitigation options known to be employed in V82 wind turbines. As of issuance of this report no such mitigation options have been identified or are commercially available.

6. OTHER ADDITIONAL MITIGATION OPTIONS

There are additional actions that might be considered by the town of Falmouth to mitigate concerns about noise from the wind turbines or to better understand the source of the wind turbine noise levels and, thus, provide a basis for more focused discussions with Vestas about possible noise reduction options.

6.1 Addressing Resident's Concerns

Other options not presented in the W&S or HMMH Reports include:

- Offer to purchase noise easements for selected nearby properties.
- Offer to purchase at a fair market price and then resell selected nearby properties.

These options should be considered by the town as additional measures that can be taken to address the concerns of those most affected. The offer to purchase at a fair market price and then resell will cost the town any transaction costs plus any difference in the town's purchase and sales price.

7. SUMMARY AND RECOMMENDATIONS

7.1 Summary

Table 2 summarizes the mitigation options discussed in this review. This summary includes costs, when known, a categorical estimate of (Low, Moderate, High and Very High) of costs per dB reduction of sound levels at abutters affected by the turbine noise and comments about these options. The estimated dB reduction is necessarily subjective as some mitigation options reduce sound levels at all locations, some only at some times or at some locations. Removal of the turbines is assumed to result in a reduction of 10 dB. The cost per dB reduction roughly corresponds to those shown in Table 3.

Table 2. Summary of curtailment options

Mitigation Option	Approximate Cost	Cost/dB	Comments
Curtailment – midnight to 3 AM, Wind > 8 m/s	$16,000 annually	Low	Achieves compliance with DEP noise guidelines at low wind speed under typical conditions. It may not address compliance at all wind shear conditions. Does not address complaints that noise issues occur at higher wind speeds.
Curtailment – Nights	$400,000 annually	Low - Moderate	Achieves night time compliance with DEP noise guidelines at all wind speeds (if there are issues at multiple wind speeds). It will not address compliance during the day if that were an issue. Eliminates night time annoyance. Addresses many complaints of abutters. Day time background sounds often exceed turbine noise levels
Curtailment – June-August	$213,000 annually	Moderate - High	Addresses concerns when many residents and visitors may be outside. Does not address concerns at other times of the year.
Smart Curtailment	Unknown	Moderate	Could address most complaints and achieve compliance with DEP noise guidelines. Could address complaints that noise is worse at higher wind speeds. Plan could be tailored to: level of mitigation, issues to be addressed and target dB levels.
Curtailment – Nights, April – September Other months: midnight to 3 AM, wind speeds > 8 m/s	$210,000 annually	Low	Achieves night time compliance with DEP noise guidelines at all wind speeds (if there are issues at multiple wind speeds) during months when outside activities are most likely. Achieves compliance with DEP noise guidelines at typical low wind speed conditions at all times of the year. It may not address compliance at all wind shear conditions. Addresses many complaints of abutters when outside activities are most likely but does not address complaints that noise issues occur at higher wind speeds
Removal or Salvage	Very High One-time	Very High	Solves all noise issues. Incurs very high costs.
Relocation	$4,500,000 One-time	Very High	Solves all noise issues. Incurs high costs. The town still gets significant revenues from the turbines.

Mitigation Option	Approximate Cost	Cost/dB	Comments
Home insulation	$360,000 for 9 homes One-time	Moderate	Addresses indoor audible sound concerns when windows are closed. Provides an indoor environment free of audible noise annoyance as a haven to the most affected residents while other options are considered. Might be considered an attempt to push the problem on to abutters.
Serrated trailing edges on blades	Unknown One-time	Moderate	Reduces turbine noise levels at all locations. Might be used in combination with other options. Should be pursued with Vestas.
Pitch setting changes	Unknown One-time	Moderate	Reduces turbine noise levels at all locations. Might be used in combination with other options. Should be pursued with Vestas.
Other operational or configuration changes	Unknown One-time	Moderate to Very High	Sound reduction and costs are uncertain, not available at this time. Not viable options at this time.
Noise easements at selected properties	Unknown One-time	Low	The cost and mitigation of this options should be evaluated
Purchase and resale of some residences	Net cost unknown One-time	Moderate?	This would address most or possibly all noise-related concerns. If the resale cost is not significantly different from the purchase price and transaction costs are not too great, this option has a moderate cost/benefit. This option should be considered by the town.
Mitigation of shadow flicker	Low	-	DNV recommends that this be done.
Mitigation of ice throw	Low	-	DNV recommends that this be done.

Table 3. Cost per dB Reduction Categories

Category	Cost per dB reduction
Low	Less than $10,000 per dB reduction
Moderate	$10,000 to $100,000 per dB reduction
High	$100,000 to $500,000 per dB reduction
Very High	Greater than $500,000 per dB reduction

7.2 Recommendations

DNV has the following recommendations for the town:

- The town should obtain additional measurements of ambient noise levels when the turbines are running and not running at a variety of receptor sites and in the range of wind conditions that occur at the site and over different seasons and times of days. These data would refine the town's understanding of the noise conditions around the WWTP site. It would identify the conditions generating high ambient audible noise, excursions greater than the town bylaws' reference sound level or the DEP noise guidelines and, if infrasound measurements were conducted, would provide information on infrasound levels under different atmospheric and operational conditions. All of these data would provide the town with a clearer picture of what needs to be mitigated and when it might be a problem.

- The town should pursue other options concurrent to any testing. Some of these options have only one-time costs, some have annually recurring costs. A mixture of options might be chosen to address some immediate concerns while additional options are being evaluated.
- The most effective options from the perspective of cost per dB reduction, are:
  - Curtailment at wind speeds below 8 m/s between midnight and 3:00 a.m.
  - Curtailment at wind speeds below 8 m/s between midnight and 3:00 a.m. and for eight hours each night during April through September
  - The insulation of some nearby homes
  - Purchase at fair market value and resale of homes of most affected abutters
  - Reduction of noise emissions with serrated trailing edges or pitch control improvements. These are the most viable operational modifications that might be available. They would provide some reduction of sound but their efficacy and application would need to be discussed with Vestas.

8. REFERENCES

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