## William Cundiff

**From:** Burkard, Robert [BurkardRG@cdm.com]
**Sent:** Wednesday, October 13, 2010 2:03 PM
**To:** William Cundiff
**Cc:** Haskell, Bruce; Guglielmi, Daniel
**Subject:** FW: Douglas Woods Acoustic and Flicker 101210
**Attachments:** NEES APW Acoustic Study 101210.doc; NEES APW Shadow Flicker Study 101210.doc

Bill, Not sure why they did not copy you?

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**From:** Chris Sanderson [mailto:csanderson@atlanticcompanies.com]
**Sent:** Wednesday, October 13, 2010 1:36 PM
**To:** neexpansion@aol.com
**Cc:** Burkard, Robert
**Subject:** Douglas Woods Acoustic and Flicker 101210

Attached are the 10-12-10 revisions on the text portions of the acoustic and flicker studies per last weeks conference call. If you turn the tracked changes on the edits will appear in red.

Let me know if there are any questions.

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## I. SCOPE OF WORK/INTRODUCTION

American Pro Wind, LLC is proposing to construct eleven (11) 100 meter wind turbines on ±300 acres of land west of the Douglas State Forest and south of Webster Street. The proposed site is located at Webster Street (Assessors Map 205, Lots 2 & 3, Map 206, Lot 1, Map 207, Lots 1, 2 & 5 and Map 230, Lots 2 & 4) in Douglas, Massachusetts. The proposed locations of the turbines are shown on Figure 1. The turbines are anticipated to be Nordex N100 machines (or a physically similar model) with a power output of 2,500 KW, a hub height of 100 meters and up to 100 meter rotor diameters (i.e. 50 meter blades).

At the request of the American Pro Wind, LLC a shadow flicker analysis has been completed by Atlantic Design Engineers in order to assess the potential impacts that shadow flickering from the proposed turbines may have on the surrounding community. Shadow flicker from wind turbines is the effect resulting from the shadows cast by the rotating turbine blades on sunny days. Shadow flicker occurs at such low frequencies that it is not considered a health hazard but it can be considered an annoyance. (See Section II for a more complete description of shadow flicker). Shadow flicker modeling was performed using the software WindPRO, version 2.7.473, developed by EMD International. This modeling uses geometry and site specific data to estimate the number of hours per year that shadows could be cast on general areas, as well as specific locations or "receptors", surrounding the site. (See Section IV for a more complete description of the methodology used for the modeling).

The results of the computer modeling were tabulated and compared to known local, state, federal or industry wide thresholds for flicker impacts in order to determine if any problem areas occur as a result of the turbine siting. The results were also shown graphically on a "Shadow Flicker Impact Plan" of the surrounding area (See Appendix B).

## II. INTRODUCTION TO SHADOW FLICKER

An important siting criterion that must be considered for wind turbines is the occurrence of shadow flicker. Shadow flicker can be explained as periodic obstructions of light being projected into an area or onto stationary objects, such as windows, due to short reductions in light intensities caused by the turbines rotating blades passing in front of the sun. This strobe-like effect that is created lasts as long as the sun is directly behind the blades and will not occur in conditions where the sun is obscured by cloud cover or heavy fog. Furthermore, any obstacles including terrain, buildings and vegetation that are located between the turbine and the potential shadow flicker receptor significantly reduces or eliminates these effects. In addition, no flicker effect will take place while the blades of the turbine are not turning or when the turbine rotor is oriented parallel to the receptor.

Shadow flicker is most commonly measured in terms of the "hours per year" and "hours per day" during which a receptor would be exposed to flicker from a wind turbine. Other than within a close proximity to the base of the turbine, shadow flicker usually occurs in the morning or evening, closer to sunrise and sunset, when the sun is low in the horizon producing longer shadows. In addition, shadow flicker is often more of an issue in the winter than in the summer due to the sun's lower position on the horizon during the winter in North America.

Shadow flicker intensity, or how "light" or "dark" a shadow appears at a certain location decreases as the viewer moves further away from the turbine. The closer a receptor is to the turbine, the shadows will tend to be darker and wider due to the blades blocking out a larger portion of the sun's rays. At receptor locations farther away, the blades will not be obstructing as much sunlight and therefore the shadows will be thinner and less distinct. Typically, beyond a distance of 3,280 feet (1,000 meters), atmospheric conditions such as haze or particles in the air will disperse the sunlight and the blades will no longer produce distinct shadows. Therefore, shadow flicker is commonly not considered a concern past this distance. Conservatively, the assessment performed for this report quantifies the total number of "hours per year" that shadow flicker may potentially affect a certain receptor (residential) location, irrespective of intensity level. Therefore, any and all shadow flicker that is generated regardless of how light or dark the shadow is, will be quantified and addressed through mitigation if necessary. Realistically, receptors that are located further away from the turbine are actually likely to experience less shadow flicker impacts than are presented in the model and report. Because all of the receptors (residences) within 3,280 feet (1,000 meters) of the turbines are to the west (specifically west, northwest, and southwest) of the affecting turbine locations, it is likely that all of the Shadow Flicker impacts will be experienced in the early morning hours only.

Shadow flicker frequency is directly related to speed of the turbine rotor and the number of blades on the rotor. The Nordex N-100 wind turbines proposed for the site has three blades with a maximum ~~nominal~~ rotor speed of 14.9 rpm. This translates to a blade pass frequency of .75 hertz (14.9 rpm/60 seconds x 3 blades = 0.75). Shadow flicker frequency this low is considered harmless in terms of health and safety. Flashing lights with frequencies between 5 and 30 HZ are considered to be a potential health and safety issue. The flicker rates that may be realized by the proposed turbines are much lower than this threshold.

## III. ZONING BYLAWS AND LEGISLATION

The following are current known standards, bylaws or legislation that address or regulate shadow flicker from wind turbines.

### Town of Douglas, MA – Zoning Bylaws

At the time of the initial Douglas Woods ZBA variance process, the Zoning Bylaws for Douglas, Massachusetts did not contain any requirements or regulations concerning wind turbine siting and any related criteria such as noise and shadow flicker impact. Therefore, many of the siting conditions including setbacks, shadow flicker limits, and noise regulations were established in the variance agreements (ZBA Decisions 2009-04 and 2010-01) between the Town of Douglas and American Pro Wind. In May 2010, a Wind Energy Conversion System (WECS) Bylaw was adopted by the Town of Douglas. However, an amendment to section 6.7.3.1 of the WECS bylaw exempted any projects for which a variance had previously been granted as of the date of the bylaw adoption. The Douglas Woods Wind Project received its variances in May 2009 and April 2010 respectively. Therefore, the WECS bylaw does not apply to the Douglas Woods Wind Farm Project.

### Commonwealth of Massachusetts Recommendations

The Commonwealth of Massachusetts does not directly address the issue of shadow flicker in any legislation. However, in October 2008, the Massachusetts Department of Energy Resources and the Massachusetts Executive Office of Environmental Affairs prepared a Model Amendment to a Zoning Ordinance or By-law entitled “Allowing Conditional Use of Wind Energy Facilities.” This model bylaw addresses the issue of shadow flicker in Section 3.0 (General Requirements for all Wind Energy Facilities) by stating the following:

*(3.9.3) Shadow/Flicker: Wind energy facilities shall be sited in a manner that minimizes shadowing or flicker impacts. The applicant has the burden of proving that this effect does not have significant adverse*

*impact on neighboring or adjacent uses.*

**Additional Criteria**

The following condition of the ZBA decision for the Douglas Woods project provides the criteria for which shadow flicker mitigation is required.

**Town of Douglas, MA – Zoning Board of Appeals – Decision Case No. 2009-04 American Pro Wind, LLC**

***Condition #7).*** *During the site plan review process, the Applicant shall present mitigation of shadowing or flicker impacts as follows: As to any residential location existing as of May 6, 2009, where estimated shadowing/flicker exceeds thirty (30) Experienced Hours per year, the Applicant shall provide to the Board with copies to the affected property owners, a Flicker Mitigation Plan for the Board's review and approval, prior to the submission of the building permit application. Said Mitigation Plan shall either (i) provide for mitigation where shadowing/flicker is reduced to (30) Experienced Hours or below per year, or (ii) set forth such other acceptable resolution that may be approved as part of the Mitigation Plan. "Experienced Hours" are defined as hours a residence is in use and the occupants are awake.*

Common practice is to a) site the wind energy facility in a manner that minimizes significant shadowing or flicker impacts and b) perform an analysis to show that the effect of shadow flicker does not have significant adverse impact on neighboring, on-site, or adjacent uses either through siting or mitigation. Through the use of the data provided in our assessment, the Town of Douglas permitting agency will be able to determine whether or not the proposed turbine layout will have "significant adverse impacts" on the surrounding community and subsequently determine whether the proposed mitigation plan is sufficient to reduce any impact to acceptable levels as defined by the ZBA decision.

## IV. SHADOW FLICKER MODELING & ANALYSIS

A module of the WindPRO software called Shadow was used to model and calculate the annual hours of shadow impact for areas surrounding the proposed turbine installation site.

The WindPro calculations performed by Atlantic estimate both the astronomical "worst case" and the "expected" (or real) shadow flicker hours per year, as well as the maximum shadow flicker hours per day under both scenarios. The astronomical "worst case" calculations assume the turbine is always in operation, it is constantly sunny, and the turbine rotor is always facing the shadow receptor. The "expected" hours or real value calculation takes into account factors such as cloud cover and wind direction, which reduce the actual shadow flicker hours experienced. This provides more realistic results. These calculated "expected" hours values are still on the conservative side because obstacles that will reduce or eliminate shadow flicker, such as structures or vegetation, are not considered in the model. Therefore, the actual "experienced" shadow flicker hours, in many cases, are likely to be less than the calculated "expected" shadow flicker hours in this study.

The following site specific data inputs are required for the Shadow module of WindPRO:

- The location and elevations of the proposed turbines (coordinates)
- Shadow flicker receptor viewing areas (2nd story window), elevations and locations (coordinates)
- USGS topographical information (elevation/height/contours)
- Hub Heights and Rotor Diameters

- Calculation time step (1 minute)
- Calculation day steps (Every Day)
- Wind speed and direction frequency distribution
- Hours of sunshine (monthly probabilities)

The following lists these site specific input parameters along with its source and a brief explanation of the use of the input in the WindPRO model.

| Input Parameter | Source of Information | Explanation |
|---|---|---|
| Turbine Locations and Base Elevations | Proposed site layout and grading plans, which are based on the existing conditions field survey, which is based on MA State Plane NAD83 and NAVD 1988 | Input for model to determine the proximity of the turbines to the receptors, and the proposed base elevations of the turbines in relation to the elevation of the receptors |
| Receptor Locations and Elevations | Existing conditions field survey for receptors in close proximity to the site locus and Mass GIS Aerial Imagery overlay (2005) for all others | Input for model to determine the proximity of the receptors to the turbines and the elevations of the receptors in relation to the turbine elevations (2nd Story Window assumed) |
| Topographical Information | Existing conditions field survey done on site for the project locus and for areas within close proximity of the site locus and Mass GIS for all other areas | Input for model to determine line of sight between turbines and receptors |
| Hub Heights and Rotor Diameters | WindPRO database of manufacturer's data - Nordex N-100 on a 100 meter tower selected | Determines dimensional characteristics of the specific Nordex turbines– being installed at the Douglas Woods Wind Farm. |
| Calculation Time Step | Input setting = 1 minute | The model simulates the position of the sun relative to the turbines and receptors at 1 minute intervals throughout the day |
| Calculation Day Steps | Input setting = 365 days | The model simulates the position of the sun over an entire year at 1 minute intervals (365 days x 24 hours/day x 60 minutes/hour) = 525,600 total data points |
| Wind Speed and Direction | Met tower data collected onsite from 6/9/09 to 6-22-10 @ a 60m height | The model uses the site specific meteorological data to predict ~~Determines~~ the operational time ~~sused in the model to calculate~~ when a turbine is operating and the turbine's orientation to the receptor. |
| Hours of Sunshine | Sunshine probabilities were taken from data presented by www.city-data.com for the Town of Douglas, MA | Input for model to determine monthly sunshine probability, which is used in concert with wind speed and directionality inputs to quantify the predicted hours of shadow flicker |

The parameters listed above were defined in the program and a model was created that simulates the position of the sun at any given time during the year in relation to a specified location. Through the use of vector geometry, the program examined the proposed wind turbines position in relation to the sun and calculated whether a shadow is generated in a general area or at the specific receptor locations. For each day throughout the year the sun's path with respect to each turbine location is calculated by the program at 1 minute intervals for the duration of daylight hours. One of the most important considerations that are accounted for by the model is the terrain of the land and how it affects the direct line of sight between the receptor and the turbine or between the turbine and the sun. The sources of topographical information used in the model include a site survey within the property, MassGIS contours for all areas surrounding the property, and design grading for the base elevations of the proposed turbines. In addition, the amount of time the turbine is running and the direction the turbine is facing was calculated based upon long term wind distribution measurements taken at the site. Also, the effect of cloud cover was calculated using average monthly sunshine probabilities derived from readily available on-line sources.

The output from the computer modeling includes a summary of the input data and results, a tabulation of time of day with shadow flicker at each receptor, a tabulation of time of impact from the turbine at each receptor, as well as a color- coded shadow flicker map of the site and surrounding areas, showing iso-lines representing hours per year of potential shadow flicker. Another output of the program are calendars showing the exact time and date that each receptor will be subjected to shadow flicker. Atlantic has also included a supplemental Shadow Flicker Impact Plan of the area, utilizing the data outputs from WindPRO, as well as AutoCAD 2008, to provide a clearer visualization of the shadow flicker impacts on the surrounding area by delineating color coded areas for different ranges of estimated shadow flicker time that can be expected. (See Appendix B)

This Shadow Impact Plan was utilized to develop a list of receptors at which the affects of shadow flicker were specifically analyzed. Upon review of the Shadow Flicker Impact Plan, all of the residences within the area calculated to experience greater than 30 unmitigated hours/year were chosen as receptors, as well as numerous residences just outside the area calculated to experience 30 unmitigated hours/year.

This resulted in a total of 34 receptors chosen for specific analysis. The receptors are shown in Figures 2, 3, and 4 and are listed as follows:

**LIST OF SHADOW RECEPTORS**

| Receptor | Receptor Name | Description/Address |
|---|---|---|
| A | Neighbor A | Single family home at 135 Douglas Road, Webster, MA |
| B | Neighbor B | Single family home at 78 Old Douglas Road, Webster, MA |
| C | Neighbor C | Single family home at 4 Dream Street, Webster, MA |
| D | Neighbor D | Single family home at 63 Blueberry Hill, Webster, MA |
| E | Neighbor E | Single family home at 133 Douglas Road, Webster, MA |
| F | Neighbor F | Single family home at 129 Douglas Road, Webster, MA |
| G | Neighbor G | Single family home at 127 Douglas Road, Webster, MA |
| H | Neighbor H | Single family home at 76 Old Douglas Road, Webster, MA |
| I | Neighbor I | Single family home at 74 Old Douglas Road, Webster, MA |
| J | Neighbor J | Single family home at 72 Old Douglas Road, Webster, MA |
| K | Neighbor K | Single family home at 70 Old Douglas Road, Webster, MA |
| L | Neighbor L | Single family home at 68 Old Douglas, Webster, MA |
| M | Neighbor M | Single family home at 66 Old Douglas Road, Webster, MA |
| N | Neighbor N | Single family home at 64 Old Douglas Road, Webster, MA |
| P | Neighbor P | Single family home at 61 Blueberry Hill, Webster, MA |
| Q | Neighbor Q | Single family home at 59 Blueberry Hill, Webster, MA |
| R | Neighbor R | Single family home at 57 Blueberry Hill, Webster, MA |
| S | Neighbor S | Single family home at 55 Blueberry Hill, Webster, MA |
| T | Neighbor T | Single family home at 53 Blueberry Hill, Webster, MA |
| U | Neighbor U | Single family home at 51 Blueberry Hill, Webster, MA |
| V | Neighbor V | Single family home at 49 Blueberry Hill, Webster, MA |
| W | Neighbor W | Single family home at 47 Blueberry Hill, Webster, MA |
| X | Neighbor X | Single family home at 45 Blueberry Hill, Webster, MA |
| Y | Neighbor Y | Single family home at 3 Dream Street, Webster, MA |
| Z | Neighbor Z | Single family home at 41 Blueberry Hill, Webster, MA |
| AA | Neighbor AA | Single family home at 56 Blueberry Hill, Webster, MA |
| BB | Neighbor BB | Single family home at 54 Blueberry Hill, Webster, MA |
| CC | Neighbor CC | Single family home at 52 Blueberry Hill, Webster, MA |
| DD | Neighbor DD | Single family home at 50 Blueberry Hill, Webster, MA |
| EE | Neighbor EE | Single family home at 48 Blueberry Hill, Webster, MA |
| FF | Neighbor FF | Single family home at 40 Blueberry Hill, Webster, MA |
| GG | Neighbor GG | Single family home at 39 Blueberry Hill, Webster, MA |
| HH | Neighbor HH | Single family home at 37 Blueberry Hill, Webster, MA |
| II | Neighbor II | Single family home at 35 Blueberry Hill, Webster, MA |

Including such a comprehensive list of receptors from the affected neighborhoods allows us to identify each individual household that may be subject to greater than 30 hours/year of unmitigated flicker affect. Those households will be included in the mitigation plan required by Condition #7 of the aforementioned ZBA decision.

## V. RESULTS AND CONCLUSIONS

The results of the analysis are provided in Appendix A and are shown graphically on the Shadow Flicker Impact Plan enclosed in Appendix B. The shadow flicker affect from the proposed turbines on each location is shown on the following table.

## ESTIMATED SHADOW FLICKER

| Receptor Name | Astronomical Maximum Hours/Year | Expected Hours/Year | Astronomical Maximum Minutes/Day | Expected Minutes/Day | Include In Mitigation Plan |
|---|---|---|---|---|---|
| A.- 135 Douglas Road | 122:59 hours/year | 34:03 hours/year | 71 min/day | 19 min/day | Y |
| B.- 78 Old Douglas Road | 101:08 hours/year | 32:25 hours/year | 45 min/day | 14 min/day | Y |
| C. - 4 Dream Street | 153:28 hours/year | 54:02 hours/year | 61 min/day | 24 min/day | Y |
| D. – 63 Blueberry ~~Way~~Hill | 97:49 hours/year | 37:19 hours/year | 57 min/day | 23 min/day | Y |
| E - 133 Douglas Road | 112:44 hours/year | 30:44 hours/year | 66 min/day | 18 min/day | Y |
| F – 129 Douglas Road | 74:20 hours/year | 20:32 hours/year | 55 min/day | 15 min/day | N |
| G – 127 Douglas Road | 84:29 hours/year | 23:08 hours/year | 55 min/day | 14 min/day | N |
| H –76 Old Douglas Road | 99:22 hours/year | 32:25 hours/year | 43 min/day | 17 min/day | Y |
| I – 74 Old Douglas Road | 132:39 hours/year | 45:18 hours/year | 50 min/day | 20 min/day | Y |
| J – 72 Old Douglas Road | 116:51 hours/year | 40:29 hours/year | 47 min/day | 19 min/day | Y |
| K – 70 Old Douglas Road | 112:04 hours/year | 38:55 hours/year | 45 min/day | 18 min/day | Y |
| L – 68 Old Douglas Road | 89:03 hours/year | 30:15 hours/year | 43 min/day | 17 min/day | Y |
| M – 66 Old Douglas Road | 89:38 hours/year | 31:53 hours/year | 40 min/day | 16 min/day | Y |
| N – 64 Old Douglas Road | 65:55 hours/year | 22:06 hours/year | 39 min/day | 15 min/day | N |
| P – 61 Blueberry Hill | 99:15 hours/year | 37:38 hours/year | 56 min/day | 22 min/day | Y |
| Q – 59 Blueberry Hill | 66:58 hours/year | 24:52 hours/year | 55 min/day | 22 min/day | N |
| R – 57 Blueberry Hill | 56:15 hours/year | 20:26 hours year | 53 min/day | 21 min/day | N |
| S – 55 Blueberry Hill | 65:50 hours year | 23:58 hours/year | 61 min/day | 23 min/day | N |
| T – 53 Blueberry Hill | 89:20 hours/year | 32:34 hours/year | 69 min/day | 25 min/day | Y |
| U – 51 Blueberry Hill | 102:35 hours/year | 37:02 hours/year | 70 min/day | 22 min/day | Y |
| V - 49 Blueberry Hill | 120:21 hours/year | 43:51 hours/year | 60 min/day | 24 min/day | Y |
| W – 47 Blueberry Hill | 97:36 hours/year | 34:55 hours/year | 48 min/day | 17 min/day | Y |
| X – 45 Blueberry Hill | 65:16 hours/year | 22:32 hours/year | 44 min/day | 14 min/day | N |
| Y – 3 Dream Street | 115:31 hours/year | 41:53 hours/year | 49 min/day | 20 min/day | Y |
| Z -41 Blueberry Hill | 49:48 hours/year | 17:15 hours/year | 37 min/day | 12 min/day | N |
| AA – 56 Blueberry Hill | 45:21 hours/year | 16:57 hours/year | 48 min/day | 19 min/day | N |
| BB – 54 Blueberry Hill | 56:16 hours/year | 21:03 hours/year | 44 min/day | 17 min/day | N |
| CC – 52 Blueberry Hill | 69:36 hours/year | 26:03 hours/year | 43 min/day | 16 min/day | N |
| DD – 50 Blueberry Hill | 74:17 hours/year | 27:32 hours/year | 41 min/day | 15 min/day | N |
| EE – 48 Blueberry Hill | 60:00 hours/year | 21:31 hours/year | 40 min/day | 14 min/day | N |
| FF – 40 Blueberry Hill | 52:04 hours/year | 18:12 hours/year | 39 min/day | 13 min/day | N |
| GG – 39 Blueberry Hill | 56:11 hours/year | 20:01 hours/year | 36 min/day | 12 min/day | N |
| HH – 37 Blueberry Hill | 59:48 hours/year | 21:38 hours/year | 34 min/day | 13 min/day | N |
| II – 35 Blueberry Hill | 58:52 hours/year | 21:26 hours/year | 35 min/day | 12 min/day | N |

Note: The values presented above are based upon the receptor defined as a typical 2nd story window.

This table provides the calculated astronomical maximum shadow flicker hours/year and the more realistic calculated expected shadow flicker hours/year for each receptor. As stated previously, the astronomical maximum value that WindPro calculates assumes that the sun is always shining, that the wind is always blowing at sufficient velocity to spin the turbine blades and that the wind is always blowing in a direction which results in the blades being perpendicular to the receptor. Realistically, this scenario will never occur but the results are provided in the report to demonstrate the significant reduction of shadow flicker when considering realistic estimates of sunshine, wind speed and wind direction probabilities, which the "expected" scenario does.

It should be noted that both calculation scenarios do not take into account trees, vegetation, buildings, fences or other obstructions that may exist in the line of site between the receptor and the turbines that would subsequently reduce the amount of actual experienced shadow flicker. In our professional judgment, this reduction is significant, particularly in the area of Old Douglas and Douglas Roads. In many cases, these obstructions will result in actual experienced shadow flicker hours/year being well below the conservative "expected" hours/year calculations. A discount factor to reduce the "expected" hours/year calculation to reflect these obstructions may be appropriate. However, to calculate the exact discount factor to be used for each receptor location could be an arduous task and the results debatable because of intermittent factors like seasonality, foliage, etc. Therefore, to be conservative in our approach, and to provide the Town and affected residences with greater confidence that flicker impacts will be entirely captured by the analysis, our shadow flicker analysis and proposed mitigation plan do not to apply any reduction factors to the WindPro results that would account for existing trees/vegetation/screening. As a result, the "expected" flicker hours/year calculation in our analysis is conservative and, in some cases, the actual experienced hours may be significantly less that the "expected" hours calculations due to the presence of trees.

Graphical calendars showing the times of the day and year when shadow flicker is expected at each receptor is provided in Appendix A. For example, Receptor C, which has the highest estimated "expected" hours of shadow flicker per year, is expected to experience shadow flicker in the morning throughout the year. Since all of the receptors are located to the west (specifically west, northwest, and southwest) of the affecting turbines, it is expected that all of the shadow flicker affects will be experienced in the early morning hours. The above table also includes the calculated maximum shadow hours per day for the astronomical worst case and expected scenarios to show that none of the receptors analyzed will receive greater than 30 "expected" minutes/day of shadow flicker.

Of the 34 receptors analyzed, a total of 17 are calculated to receive greater than 30 "expected" hours /year of shadow flicker. Realistically, due to existing obstructions such as trees and vegetation, the actual amount of experienced shadow flicker will, in some cases, be less than 30 hours/year. To be conservative, the proponent is committing to include all of these 17 receptors (residences) in the proposed Flicker Mitigation Plan and to use the calculated "expected" hours/year as the basis for mitigation.

## VI. FLICKER MITIGATION PLAN

In accordance with Condition #7 of the ZBA Decision for American Pro Wind, LLC a Flicker Mitigation Plan has been prepared by American Pro Wind, LLC, in consultation with Atlantic Design Engineers, and New England Expansion Strategies. The plan will reduce the "expected" shadow flicker to 30 hours/year or less for all receptors (residences) that are calculated to have more than 30 "expected" hours/year without mitigation.

Based upon the results of WindPro calculations and analysis, the following 17 receptors (residences) are calculated to receive greater than 30 expected hours of flicker per year prior to mitigation:

**ESTIMATED SHADOW FLICKER AND MITIGATION PLAN**

| SHADOW RECEPTOR | ESTIMATED SHADOW FLICKER | | | |
|---|---|---|---|---|
| Receptor Name | Astronomical Maximum Value Hours/Year | Expected Hours/Year | Mitigated Hours/Year | Net Expected Hours/Year After Mitigation |
| A. – 135 Douglas Road | 122:59 hours/year | 34:03 hours/year | ≈ 5:03 hours/year | ≈ 29 hours/year |
| B. – 78 Old Douglas Road | 101:08 hours/year | 32:25 hours/year | ≈ 3:25 hours/year | ≈ 29 hours/year |
| C. – 4 Dream Street | 153:28 hours/year | 54:02 hours/year | ≈ 25:02 hours/year | ≈ 29 hours/year |
| D. – 63 Blueberry ~~Way~~Hill | 97:49 hours/year | 37:19 hours/year | ≈ 8:19 hours/year | ≈ 29 hours/year |
| E. – 133 Douglas Road | 112:44 hours/year | 30:44 hours/year | ≈ 1:44 hours/year | ≈ 29 hours/year |
| H. – 76 Old Douglas Road | 99:22 hours/year | 32:25 hours/year | ≈ 3:25 hours/year | ≈ 29 hours/year |
| I. – 74 Old Douglas Road | 132:39 hours/year | 45:18 hours/year | ≈ 16:18 hours/year | ≈ 29 hours/year |
| J. – 72 Old Douglas Road | 116:51 hours/year | 40:29 hours/year | ≈ 11:29 hours/year | ≈ 29 hours/year |
| K. – 70 Old Douglas Road | 112:04 hours/year | 38:55 hours/year | ≈ 9:55 hours/year | ≈ 29 hours/year |
| L. – 68 Old Douglas Road | 89:03 hours/year | 30:15 hours/year | ≈ 1:15 hours/year | ≈ 29 hours/year |
| M. – 66 Old Douglas Road | 89:38 hours/year | 31:53 hours/year | ≈ 2:53 hours/year | ≈ 29 hours/year |
| P .– 61 Blueberry Hill | 99:15 hours/year | 37:38 hours/year | ≈ 8:38 hours/year | ≈ 29 hours/year |
| T. – 53 Blueberry Hill | 89:20 hours/year | 32:34 hours/year | ≈ 3:34 hours/year | ≈ 29 hours/year |
| U. – 51 Blueberry Hill | 102:35 hours/year | 37:02 hours/year | ≈ 8:02 hours/year | ≈ 29 hours/year |
| V. – 49 Blueberry Hill | 120:21 hours/year | 43:51 hours/year | ≈ 14:51 hours/year | ≈ 29 hours/year |
| W. – 47 Blueberry Hill | 97:36 hours/year | 34:55 hours/year | ≈ 5:55 hours/year | ≈ 29 hours/year |
| Y. – 3 Dream Street | 115:43 hours/year | 41:53 hours/year | ≈ 12:53 hours/year | ≈ 29 hours/year |

As stated previously, the estimated shadow flicker values are conservative in that they assume full exposure of the viewing areas and do not include any obstacles such as trees, vegetation, or buildings that may be in line between the turbine and the receptor. Therefore, for many of the receptors, the actual duration of shadow flicker will likely be even less than the calculated "expected" hours/year values. However, to be conservative, the proposed flicker mitigation is based upon these calculated "expected" hours/year values, assuming no obstructions or trees.

For the above listed 17 receptors (residences), the developer is committed to a flicker mitigation plan summarized as follows:

- American Pro Wind will install a photovoltaic light sensor and a shadow impact switch off module on Turbines #1, 7, 8 and 9 (the turbines causing the most flicker at the 17 listed receptors). This module will automatically shut down the turbine during critical shadow flicker times when the sun is shining and wind conditions exist that will result in potential flicker affects.
- The affecting turbine(s) will be shut off for a sufficient number of hours to reduce expected shadow flicker to 30 hours/year or less at each of the 17 receptor (residence) locations. As the above Estimated Shadow Flicker and Mitigation Plan chart shows, the net "expected" flicker hours/year after mitigation (or in other words the projected "Experienced" hours) will be reduced to 29

hours/year or less at each of the 17 receptor (residence) locations.

- Although not required by the conditions of the Variance Agreement or any other bylaw, the Flicker Mitigation Plan proposed by American Pro Wind, LLC will also seek to keep the maximum flicker experienced per day to 30 minutes or less at each of the 17 receptor (residence) locations. Even though the calculations for expected shadow flicker hours in the chart above show that none of the 17 residences are expected to receive more than 30 minutes/day of shadow flicker, the affecting turbine(s) will be programmed to automatically shut off in a manner that will keep the experienced shadow flicker hours/day to 30 minutes or less at each of the 17 locations.
- Note that even though the turbine shut-down periods will be targeting specifically the shadow flicker experienced by the 17 receptors (residences) listed above, many additional homes near these receptors (those houses with 30 hours/year or less of unmitigated shadow flicker) will also benefit with reduced shadow flicker times due to the turbines shutting down. With the exception of the most impacted of the 17 receptors (residences), the actual experienced hours of shadow flicker after mitigation for many of the other affected receptors (residences) will likely be significantly lower than the 29 hours/year presented in the Estimated Shadow Flicker and Mitigation Plan table.

The complete Flicker Mitigation Plan to be submitted as a separate document by American Pro Wind, LLC provides a more detailed description of the shadow impact module, along with it's operation, maintenance, testing and reporting capabilities.

With this mitigation plan in place, the project is not expected to generate shadow flicker in excess of 30 "experienced" hours/year maximum at any of the receptor (residence) locations per the maximum limit established by the variance agreements.

## VII. MOON SHADOW FLICKER

The purported issue of moon shadow flicker was a concern raised at a recent Planning Board Site Plan Review meeting. In our professional judgment, the moving shadows cast by turbine blades passing in front of the moon is not an issue of valid concern for several reasons.

The moon is rarely bright enough to cause distinct shadows. Shadows from moonlight typically occur only on those occasional full or nearly full moons when the sky is extremely clear. In these instances, the moon is typically at its brightest when it is higher in the sky and therefore won't be in line with any turbines. When the moon is lower in the horizon and possibly in line with a turbine, it is typically not bright enough to cause discernable shadows. Additionally, based on our research, moon flicker is not an acknowledged phenomenon in the wind energy industry, nor are the purported effects of moon flicker analyzed or even mentioned in any Shadow Flicker Studies that we have reviewed. Our research has also not uncovered any pattern, or even a few mentions, of moon flicker as the basis for complaints among residents who live near wind farms.

## 1. SCOPE OF WORK / INTRODUCTION

American Pro Wind, LLC is proposing to construct eleven (11) 100 meter wind turbines on ± 300 acres of land west of the Douglas State Forest and south of Webster Street. The proposed site is located on Webster Street (Assessors Map 205, Lots 2 & 3, Map 206, Lot 1, Map 207, Lots 1, 2 & 5 and Map 230 Lots 2 & 4) in Douglas, Massachusetts. The proposed locations of the turbines are shown on Figure 1. The turbines are anticipated to be similar to Nordex N100 machines with power outputs of 2,500 KW, a hub height of 100 meters and up to 100 meter rotor diameters (i.e. 50 meter blades).

At the request of American Pro Wind, LLC, an acoustic analysis has been completed by Atlantic Design Engineers in order to assess the affect of noise from the proposed turbines at nearby residential properties at Blueberry Hill and on Old Douglas Road.

Between the dates of February 9 to February 13, 2009 and June 8, 2010 to June 21, 2010, Atlantic conducted on-site ambient noise measurements to establish the current sound pressure levels (decibels) at two locations. These sound monitoring locations are designated Location 1 and Location 2 and can be seen on Figure 2.

The information gathered from these measurements was used in concert with data from the Nordex N100 Wind Turbine Specifications, wind speed data obtained from an onsite Met tower, SODAR unit, and nearby weather station, and the software program WindPRO, version 2.7.473, to determine projected sound levels that will be produced at designated locations once the turbines are in operation. Using the WindPRO software, acoustic modeling was performed for the cut in wind speed (3 m/s) up to the design wind speed (12 m/s) operating conditions of the wind turbines. Note that the cut in wind speed of 3 m/s refers to the wind speed threshold needed for turbine operation. In other words, the turbine will not be in operation when hub height wind speeds are less than 3 m/s. The ~~accurately~~ projected sound values were reviewed for compliance with both state and town noise related by-laws and regulations.

## 2. SOUND FUNDAMENTALS

All sounds are generated from a source and proceed to travel to a person's ear as sound waves or minute variations in air pressure. Sounds have many varying characteristics including loudness, character, temporal pattern, and are audible to different extents by different people in a range of environments. "Noise" can be defined simply as unwanted sound. Factors such as the amplitude and duration of the sound determine whether or not it is perceived as "noise". In terms of the scope of this analysis and report, it is helpful to understand some basic sound and noise characteristics and terminology.

### 2.1 Sound Pressure Level

The sound pressure level (SPL) determines the loudness of a sound and can be defined as the ratio of the measured sound pressure from the source to a reference pressure (the quietest sound we can hear). The sound pressure level is measured in units of decibels (dB) or A-weighted decibels (dBA) and is plotted on a logarithmic scale. On this scale, 0 dB is the quietest sound we can hear, with 120 dB being the loudest. A-weighted decibels more closely correlate with the subjective loudness of a sound, as discerned by the human ear.

As an example, some typical sound levels associated with common activities and environments are provided in the following:

Sound Levels and Relative Loudness of Steady Noises[1]

| dBA | Subjective Impression | Relative Loudness |
|---|---|---|
| **130** | | |
| **120** | *Uncomfortably Loud* | Loud Rock Concert |
| **110** | | |
| **100** | *Very Loud* | |
| **90** | | Heavy Traffic |
| **80** | | |
| **70** | *Moderately Loud* | Normal Conversation |
| **60** | | |
| **50** | *Quiet* | |
| **40** | | |
| **30** | | Quiet Library |
| **20** | | |
| **10** | *Just audible* | |
| **0** | *Threshold of Hearing* | Weakest Sound Heard |

Some properties of sounds measured on the decibel scale include:

- A 1 dB change in the SPL is below the level of human perception.
- For a sound to double in loudness, an increase of 10 dB is required.
- A 3 dB change in the SPL level is minimum level of human perception. (it is just barely noticeable).
- A 6 dB increase in the SPL is the equivalent of moving half the distance to the source.
- A SPL of 140 dB is the threshold of pain.

## 2.2 Sound Power Level

The sound power level (PWL) is a basic quantity directly describing the amount of acoustic power radiated by a source. It is the fundamental quantity that produces a sound pressure level (SPL) at a distance. In addition to defining the source of the sound for assessment purposes, the (PWL) is also used to calculate the (SPL) at a receptor location. Similar to the sound pressure level, the sound power level is also usually described in decibels (dB) or A-weighted decibels (dBA).

[1] Derived from Table 1.1 in *Community Noise Rating* by Theodore J. Shultz

### 2.3 Frequency

Frequency is the property of sound that we perceive as pitch, which gives a sound its unique character. The human ear can detect a wide range of frequencies, but it is more sensitive to some than others. Sounds that we experience in daily life are typically formed from a mixture of numerous frequencies, from numerous sources. A spectral analysis breaks a measured sound into a number of frequency bands of defined width, comparable to notes on a musical scale. Frequency is most commonly measured in cycles per second, or Hertz (Hz).

### 2.4 Sound Measurement

Sound Level Meters are devices that are used to measure sound pressure levels. These meters are equipped with a single microphone that converts pressure variations into a voltage signal. This signal is then recorded onto the meter in units of decibels. The measurements taken combine all frequencies to obtain a broadband sound level, or a single weighted reading. For the purpose of this study, the A-weighted sound pressure was recorded, which is the most common scale for assessing environmental and occupational noise. This weighting approximates the response of the human ear to sounds of medium intensity.

Once the A-weighted sound pressure level is recorded over a period of time, a number of statistical sound reference levels can be determined. $L_{10}$ statistics measure the noise levels, which are exceeded during only 10 percent of the time period. $L_{10}$ levels indicate noise which is generated by intermittent sources such as traffic, passing jets, etc. $L_{90}$ statistics measure the sound level which is exceeded during 90 percent of the time period. These $L_{90}$ levels reveal the ambient background sound and can strongly affect the audibility of a particular sound in a particular environment. For example, on a very windy day, the sounds that are created by wind flowing over vegetation may be loud enough to mask other nearby sounds such as those produced by wind turbines. However, we must also consider that the sound level emitted from the turbine is a function of wind speed, and in general, the higher the wind speed, the higher the PWL or sound generated by the turbine. Finally, the $L_{eq}$ is determined, which is the continuous equivalent noise level over the period of measurement.

## 3. SOURCES OF WIND TURBINE SOUND

The sources of sounds emitted from operating wind turbines can be divided into two categories: 1.) Mechanical sounds, from the interaction of turbine components, and 2.) Aerodynamic sounds, produced by the flow of air over the blades. As wind turbine technology has advanced, the sounds that they produce have significantly diminished, however it is still an important siting criterion.

### 3.1 Mechanical Sounds

Mechanical sounds originate from the relative motion of mechanical components and the dynamic response among them. Sources of such sounds include:

a. Gearbox
b. Generator
c. Yaw Drives

d. Cooling Fans
e. Auxiliary Equipment (e.g. hydraulics)

Since the emitted sound is associated with the rotation of mechanical and electrical equipment, it tends to be tonal (of a common frequency), although it may have a broadband component. For example, pure tones can be emitted at the rotational frequencies of shafts and generators, and the meshing frequencies of the gears. In addition, the hub, rotor, and tower may act as loudspeakers, transmitting the mechanical sound and radiating it. The transmission path of the sound can be air-borne or structure-borne. Air-borne means that the sound is directly propagated into the air from the component surface or interior. Structure-borne sound is transmitted along other structural components before it is radiated into the air.

### 3.2 Aerodynamic Sounds

Aerodynamic broadband sound is typically the largest component of wind turbine acoustic emissions. It originates from the flow of air around the blades. Aerodynamic sound generally increases with rotor speed. The various aerodynamic sound generation mechanisms that have to be considered are divided into three groups:

1. *Low Frequency Sound*: Sound in the low frequency part of the sound spectrum is generated when the rotating blade encounters localized flow deficiencies due to the flow around a tower, wind speed changes, or wakes shed from other blades.
2. *Inflow Turbulence Sound*: This sound depends on the amount of atmospheric turbulence which results in local force or local pressure fluctuations around the blade.
3. *Airfoil Self Noise*: This group includes the sound generated by the air flow right along the surface of the airfoil. This type of sound is typically of a broadband nature, but tonal components may occur due to blunt trailing edges, or flow over slits and holes.[2]

## 4. BYLAWS AND LEGISLATION

Current known standards, bylaws or legislation that addresses or regulates noise from wind turbines are provided in Appendix B and are summarized as follows:

### 4.1 Town of Douglas, Massachusetts Zoning Bylaw

The Zoning Bylaws for Douglas, Massachusetts, dated October 25, 2004, do not contain any requirements or regulations concerning wind turbine siting and any related criteria such as noise and shadow flicker impacts.

### 4.2 Massachusetts DEP Noise Policy (Regulations and Criteria)

Noise is defined by the Massachusetts Department of Environmental Protection as a type of air pollution that results from sounds that cause a nuisance, are or could injure public health, or unreasonably interfere with the comfortable enjoyment of life, property, or the conduct of business.

[2] “Wind Turbine Acoustic Noise” UMASS Renewable Energy Research Laboratory

A noise source will be considered to be violation the Department's noise regulation (310 CMR 7.10) if the source results in

A. An increase in the broadband sound pressure level of more than 10 decibels (dBA) above ambient, or

B. Produce a "pure tone" condition – when any octave band center frequency sound pressure level exceeds the two adjacent center frequency sound pressure levels by 3 dB or more.

For this report, these criteria have been measured at nearby residential properties on Old Douglas Road and Blueberry Hill. "Ambient" is defined as the background A-weighted sound level that is exceeded 90% of the time, measured during equipment operating hours. This is also referred to as the L90 baseline.

## 5. EXISTING AMBIENT SOUND LEVELS

In order to establish ambient background sound levels, Atlantic Design Engineers utilized an environmental sound level meter over 24-hour to 10-day periods to quantify the background sound levels for relevant parameters at locations on the site located near the adjacent residential properties (See Figure 2). The parameters selected for determination of ambient sound levels were average hourly ($L_{eq}$) and both the $L_{10}$ and $L_{90}$ baseline levels. The combination of this data will provide an understanding of existing daytime and diurnal noise patterns, as well as statistical reference levels, which are used to screen out traffic impacts and other sound amplifiers. Average ten (10) minute L90 sound levels were extracted from the entire measurement period's data set in order to compare them to the equivalent ten minute wind speed measurements. These 10-minute wind speed measurements were obtained from an onsite 60 meter meteorological "Met" tower as well as a SecondWind SODAR unit. Note that for the data set collected in February 2009, the Met tower was not yet installed on the site, so wind speed data for that time period was obtained from the Cross Street Weather Station, located approximately 4 miles away. Note that at sound level monitoring location 2, wind speeds did not exceed 7 m/s during the measurement period so Atlantic conservatively used the same ambient L90 value measured at 7 m/s for all wind speeds up to 12 m/s, assuming no increase in ambient background noise.

The environmental sound meters used by Atlantic Design Engineers for the on-site measurements were a Quest Technologies SoundPro DLX, and a Rion, NL-22 environmental sound level meter with inherent data loggers and supporting software. The measurement range for the meters is between 0 and 140 dBA. These models meet or exceed all requirements set forth in the American National Standards Institute (ANSI) Standards for General Purpose Type 2 accuracy. Prior to the studies, the meters were laboratory calibrated as per ANSI recommendations. The meters were equipped with environmental windscreens during each of the studies in order to negate the effects of air movement. All the data that was logged on-site was downloaded to a computer following the studies for further analysis and storage.

The test results for the relevant sound parameters are presented in Figures 3-8. From February 10 to February 13, the first study was performed at Locations 1 and 2. The skies were partly cloudy with the temperatures in the 30's and the ground winds were fairly calm to moderate (0-13 mph or 0-5.8 m/s). Between the dates of June 8, 2010 and June 21, 2010 Atlantic further conducted ambient noise measurements at the two previously mentioned locations. A wide range of weather conditions were seen over this period with calm to moderate ground winds (0-11 mph or 0-4.9 m/s).

## 6. PROJECTED SOUND LEVELS

### 6.1 Methodology

Future sound levels for the Douglas Woods Wind Farm were projected using a module of the WindPRO software called "Decibel". This module creates a sophisticated 3-D model for outdoor sound propagation and attenuation based on the international norm “DIN ISO 9613-2 Acoustics.” The sound emission for the Nordex N-100 was user input based on the most recent specifications provided by the manufacturer. See below:

**Nordex N-100 - Manufacturer Noise Emission Data**

| Hub Height (m) | Wind Speed (m/s) | LwA, ref (dBA) | Pure Tones |
|---|---|---|---|
| 100.0 | 3.0 (6.7 mph) | 97.0 | No |
| 100.0 | 4.0 (8.9 mph) | 99.0 | No |
| 100.0 | 5.0 (11.2 mph) | 101.5 | No |
| 100.0 | 6.0 (13.4 mph) | 105.0 | No |
| 100.0 | 7.0 (15.7 mph) | 106.0 | No |
| 100.0 | 8.0 (17.9 mph) | 106.0 | No |
| 100.0 | 9.0 (20.1 mph) | 106.0 | No |
| 100.0 | 10.0 (22.4 mph) | 106.0 | No |
| 100.0 | 11.0 (24.6 mph) | 106.0 | No |
| 100.0 | 12.0 (26.8 mph) | 106.0 | No |

As shown, the sound power level emitted from the N-100 turbine peaks at 106 dBA at a wind speed of 7.0 m/s and remains constant at 106 dBA at all wind speeds above 7.0 m/s. Also note that the turbine is not operating at wind speeds below 3.0 m/s and therefore will not generate noise at these levels.

The reference topographical information used in the WindPRO model included an aerial mapping survey of the site, as well as Massachusetts and Rhode Island GIS data for areas surrounding the site. The turbine locations and elevations used in modeling were based on proposed site plans being produced by another company.

Four nearby residential properties were chosen as "receptors" to calculate the increase in noise levels over ambient conditions due to the turbines. These four (4) receptors were chosen as representative of the nearby neighborhoods or residential areas and are the homes in those areas that are closest to the turbines. These receptor locations are:

A. - 78 Old Douglas Road – Representative of residences on Old Douglas Road
A1. - 135 Douglas Road – Representative of residences on Douglas Road
B. - 63 Blueberry Hill – Representative of residences on southern end of Blueberry Hill and eastern end of Blueberry Way
B1. - 4 Dream Street – Representative of residences on Dream Street and northeastern end of Blueberry Hill

For Receptors A and A1 the ambient noise levels from Sound Level Monitoring Location 1 were used and for Receptors B and B1, the ambient noise levels from Sound Level Monitoring Location 2 were used.

### 6.2 WindPRO Parameters

The following table lists the site specific input parameters necessary for calculating projected sound along with its source and a brief explanation of the input's use in the WindPRO model.

| Input Parameter | Source of Information | Explanation |
|---|---|---|
| Turbine Locations and Base Elevations | Proposed site layout and grading plans, which are based on the existing conditions field survey, which is based on MA State Plane NAD83 and NAVD 1988 | Input for model to determine the proximity of the turbines to the receptors, and the proposed base elevations of the turbines in relation to the elevation of the receptors |
| Receptor Locations and Elevations | Existing conditions field survey for receptors in close proximity to the site locus and Mass GIS Aerial Imagery overlay (2005) for all others | Input for model to determine the proximity of the receptors to the turbines and the elevations of the receptors in relation to the turbine elevations |
| Topographical Information | Existing conditions field survey on the site and within close proximity of the site locus and Mass GIS for all other areas | Input for model to determine line of sight between turbines and receptors |
| Turbine Noise Emission Data | See table in Section 6.1- Noise Data provided by the turbine manufacturer, measured in accordance with IEC Standard 61400-11 - Acoustic Noise Measurement Techniques, which translates to the listed sound power levels emitted at the source of the turbine at hub height. | Input for model to calculate what the turbine generated sound levels will be at the receptor locations |
| Ambient Background Noise Data | Measured onsite with sound level meters between the dates of February 9 to February 13, 2009 and June 8, 2010 to June 21, 2010, | Input for model to determine existing ambient sound levels at the receptor locations |
| Calculation Model | Wind Speed range of 3 to 12 m/s | The wind speed that the proposed turbines start to operate at is 3 meters per second and 12 meters per second is the wind speed at which they produce their maximum energy output and maximum noise level. From 12 meters per second to 20 meters per second (the wind speed at which the turbine shuts down) the turbine blades do not rotate any faster or produce any more power. Therefore no additional noise emissions are created and no additional analysis at these wind speeds is needed |
| Ground Attenuation | Ranges from 0 to 1.0 depending upon terrain in the area. 1.0 being a completely porous surface such as snow, and 0 being a completely hard surface such as | Atlantic, American Pro Wind and the UMass Wind Energy Center agreed upon a value of 0.8~~, which is representative of a porous ground surface~~, which is representative of a highly wooded, |

| | | |
|---|---|---|
| | pavement | vegetated area such that exists between the turbines and the receptors. |
| Type of Demand | WindPRO Options: "WTG plus ambient noise is compared to ambient noise plus margin" | Under this option, the noise level calculated at the receptor is the background noise plus the noise contribution from the turbine. This total is compared to a noise "demand" that consists of the background noise plus a margin of 10 dBA, in accordance with State DEP regulations |
| Height Above Ground Level | 1.5 meters | Input height for the receptors representing average height of a person's ear. Also the height at which ambient noise levels were measured. |

**6.3 Results**

Based on the noise data collected from our study, wind speed data obtained from the onsite Met tower, SODAR unit, and nearby Cross Street Weather Station, and the mono noise specifications provided for the Nordex N100 wind turbines, the projected sound levels at Locations A, B, A1 and B1 with the turbines operating between 3 and 12 m/s conditions.

## ***Location A***

| Wind Speed (m/s) | Ambient L90 Level (dBA) | Wind Turbine Sound (dBA) | Combined Sound Level (dBA) | Net Increase (dBA) |
|---|---|---|---|---|
| 3.0 (6.7 mph) | 32.8 | 31.7 | 35.3 | 2.5 |
| 4.0 (8.9 mph) | 33.1 | 33.7 | 36.4 | 3.3 |
| 5.0 (11.2 mph) | 33.3 | 36.2 | 38.0 | 4.7 |
| 6.0 (13.4 mph) | 33.5 | 39.7 | 40.6 | 7.1 |
| 7.0 (15.7 mph) | 33.8 | 40.7 | 41.5 | 7.7 |
| 8.0 (17.9 mph) | 34.0 | 40.7 | 41.6 | 7.6 |
| 9.0 (20.1 mph) | 34.2 | 40.7 | 41.6 | 7.4 |
| 10.0 (22.4 mph) | 34.5 | 40.7 | 41.6 | 7.1 |
| 11.0 (24.6 mph) | 34.7 | 40.7 | 41.7 | 7.0 |
| 12.0 (26.8 mph) | 35.0 | 40.7 | 41.7 | 6.7 |

## ***Location B***

| Wind Speed (m/s) | Ambient L90 Level (dBA) | Wind Turbine Sound (dBA) | Combined Sound Level (dBA) | Net Increase (dBA) |
|---|---|---|---|---|
| 3.0 (6.7 mph) | 31.2 | 32.0 | 34.6 | 3.4 |
| 4.0 (8.9 mph) | 32.6 | 34.0 | 36.3 | 3.7 |
| 5.0 (11.2 mph) | 33.7 | 36.5 | 38.3 | 4.6 |
| 6.0 (13.4 mph) | 37.9 | 39.9 | 42.1 | 4.2 |
| 7.0 (15.7 mph) | 39.3~~*~~ | 40.9 | 43.2 | 3.9 |
| 8.0 (17.9 mph) | 39.3* | 40.9 | >43.2** | <3.9* |
| 9.0 (20.1 mph) | 39.3* | 40.9 | >43.2** | <3.9* |
| 10.0 (22.4 mph) | 39.3* | 40.9 | >43.2** | <3.9* |
| 11.0 (24.6 mph) | 39.3* | 40.9 | >43.2** | <3.9* |
| 12.0 (26.8 mph) | 39.3* | 40.9 | >43.2** | <3.9* |

* Note that at sound level monitoring location 2, wind speeds did not exceed 7 m/s during the measurement period so Atlantic conservatively used the same ambient L90 value measured at 7 m/s for all wind speeds up to 12 m/s, assuming no increase in ambient background noise. Therefore, net increases for wind speeds greater than 7 m/s will likely be less than shown.

**Wind speeds did not exceed 7 m/s during the on-site noise measurement period. Therefore ambient noise levels at wind speeds above 7 m/s have not been determined and as a result, combined sound levels cannot be calculated.

***Location A1***

| Wind Speed (m/s) | Ambient L90 Level (dBA) | Wind Turbine Sound (dBA) | Combined Sound Level (dBA) | Net Increase (dBA) |
|---|---|---|---|---|
| 3.0 (6.7 mph) | 32.8 | 32.3 | 35.6 | 2.8 |
| 4.0 (8.9 mph) | 33.1 | 34.3 | 36.8 | 3.7 |
| 5.0 (11.2 mph) | 33.3 | 36.8 | 38.4 | 5.1 |
| 6.0 (13.4 mph) | 33.5 | 40.3 | 41.1 | 7.6 |
| 7.0 (15.7 mph) | 33.8 | 41.3 | 42.0 | 8.2 |
| 8.0 (17.9 mph) | 34.0 | 41.3 | 42.0 | 8.0 |
| 9.0 (20.1 mph) | 34.2 | 41.3 | 42.1 | 7.9 |
| 10.0 (22.4 mph) | 34.5 | 41.3 | 42.1 | 7.6 |
| 11.0 (24.6 mph) | 34.7 | 41.3 | 42.1 | 7.4 |
| 12.0 (26.8 mph) | 35.0 | 41.3 | 42.2 | 7.2 |

**_Location B1_**

| Wind Speed (m/s) | Ambient L90 Level (dBA) | Wind Turbine Sound (dBA) | Combined Sound Level (dBA) | Net Increase (dBA) |
|---|---|---|---|---|
| 3.0 (6.7 mph) | 31.2 | 35.2 | 36.7 | 5.5 |
| 4.0 (8.9 mph) | 32.6 | 37.2 | 38.5 | 5.9 |
| 5.0 (11.2 mph) | 33.7 | 39.7 | 40.7 | 7.0 |
| 6.0 (13.4 mph) | 37.9 | 43.2 | 44.3 | 6.4 |
| 7.0 (15.7 mph) | 39.3~~*~~ | 44.2 | 45.4 | 6.1 |
| 8.0 (17.9 mph) | 39.3* | 44.2 | >45.4** | <6.1* |
| 9.0 (20.1 mph) | 39.3* | 44.2 | >45.4** | <6.1* |
| 10.0 (22.4 mph) | 39.3* | 44.2 | >45.4** | <6.1* |
| 11.0 (24.6 mph) | 39.3* | 44.2 | >45.4** | <6.1* |
| 12.0 (26.8 mph) | 39.3* | 44.2 | >45.4** | <6.1* |

* Note that at sound level monitoring location 2, wind speeds did not exceed 7 m/s during the measurement period so Atlantic conservatively used the same ambient L90 value measured at 7 m/s for all wind speeds up to 12 m/s, assuming no increase in ambient background noise. Therefore, net increases for wind speeds greater than 7 m/s will likely be less than shown.

**Wind speeds did not exceed 7 m/s during the on-site noise measurement period. Therefore ambient noise levels at wind speeds above 7 m/s have not been determined and as a result, combined sound levels cannot be calculated.

The results for the wind turbines cut in wind speed of 3 m/s, and the turbines design wind speed of 12 m/s are shown in Figures 3 through 8. The WindPRO calculations along with a graphic depiction of the turbine generated sound and charts showing how the proposed sound levels fall within the allowable 10 dBA increase are provided in Appendix A.

Note: That for each of the residential receptors, the peak increase in noise levels did not occur at either the cut in speed or design speed, but occurred at a midrange wind speed (See Figure 9). This can be attributed to the noise emissions from the turbines peaking at a wind speed of 7 m/s, where the ambient noise is less than what it would be at higher wind speeds.

## 7. CONCLUSIONS

The study's conclusions are as follows:

- The Douglas Woods Wind Farm Project complies with the Massachusetts Department of Environmental Protection Noise Policy by not increasing noise levels at the nearby residential properties more than 10 decibels. The turbine is expected to increase the ambient $L_{90}$ sound level by a range of 2.5 dBA to 8.2 dBA at nearby residential properties, well below the DEP allowable. In addition, the Nordex N100 Wind Turbines are not anticipated to produce any audible "pure tones". Sound emissions from modern wind turbines are mostly comprised of broadband tones.