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RESOURCE SYSTEMS GROUP, INC.

Documentation for:

Noise Impact Analysis of Wind Turbines

Searsburg, Vermont

Prepared for:

Green Mountain Power Corp.

26 July 1995

White River Junction, Vermont

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INTRODUCTION

The Green Mountain Power Corporation is proposing to construct a 6 MW wind turbine facility in Searsburg, Vermont. The facility would consist of approximately twelve turbines with a rating of approximately 500 KW. The turbines will be aligned in a row across a ridgeline in the Green Mountains. This project is the first demonstration of a utility-scale wind power station in Vermont.

This study will assess the effects of the wind turbines on noise levels in the surrounding area. Given that the area is fairly remote and borders the Green Mountain National Forest, the study will not only quantify impacts on the nearest human residence, but it will also consider potential impacts on critical wildlife habitat.

A NOISE PRIMER

WHAT IS NOISE?

Noise is defined as "a sound of any kind, especially when loud, confused, indistinct, or disagreeable."[1] Passing vehicles, a noisy refrigerator, or an air conditioning system are sources of noise which may be bothersome or cause annoyance. These sounds are a part of generally accepted everyday life, and can be measured, modeled, and, if necessary, controlled.

HOW IS NOISE DESCRIBED?

Sound is caused by variations in air pressure at a range of frequencies. Noise levels that are detectable by human hearing are defined in the decibel scale, with 0 dB being the threshold of human hearing, and 135 dB causing pain and permanent damage to the ear. Figure 1 shows the dB levels of typical activities which generate noise. For example, average street traffic generates 85 dB, while normal activities in a business office may register 65 dB.

The decibel scale is logarithmic, which tends to weight louder noises. Therefore, it approximates the human perception of relative loudness very well. For example, in a quiet environment, the noise of a single car passing by would be very noticeable and cause a substantial increase in the decibel level; while on a busy street, a single additional car would be barely noticeable.

In addition, the dB scale can be weighted to emphasize human perceptions of annoying frequencies. The most common of these weighting scales is the "A" weighting and this scale is used most frequently in environmental noise analysis. Sound levels that are weighted by the "A" scale have units of dBA.

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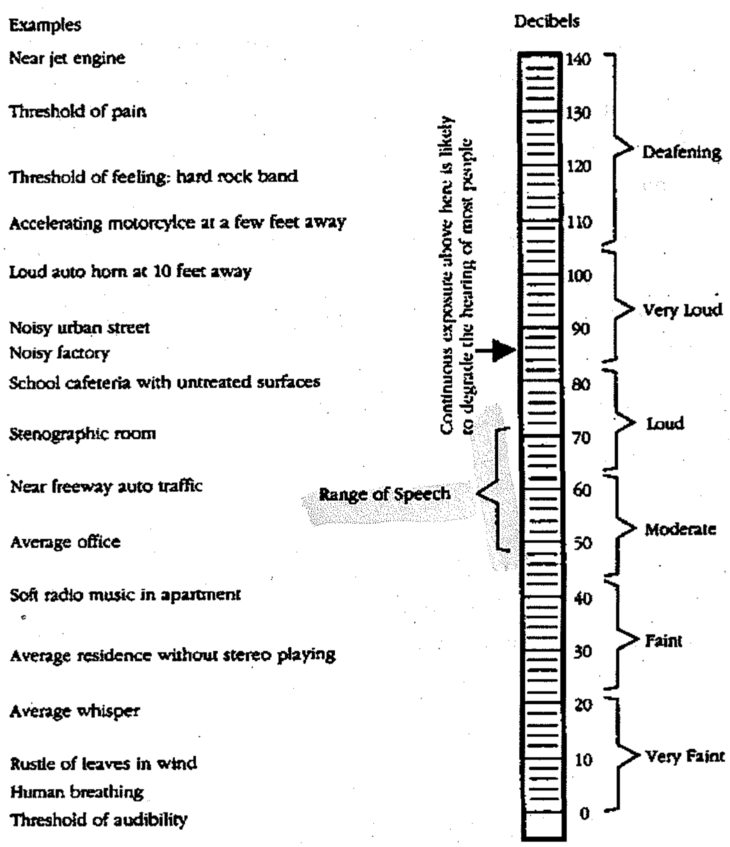
1 "The American Heritage Dictionary of the English Language," Houghton Mifflin Company, 1981.

Figure 1: Basic Theory: Common Sounds in Decibels (dB)



To account for changes in noise over time, a weighted average noise level called "equivalent" noise level (L_{eq}) is often used. L_{eq} averages total noise pressure, and results in weighting loud and infrequent noises more heavily than softer and frequent noises. L_{eq} is also often used in environmental noise analysis.

The day-night noise level (L_{dn}) is also commonly used by the U.S. Environmental Protection Agency (U.S. EPA) in referencing community noise. The L_{dn} is simply a time-weighted average, similar to L_{eq}, except that the nighttime noise levels are weighted by +10 dB.

HOW IS NOISE MODELED?

The decibel noise level is on a logarithmic scale. One manifestation of this is that sound pressure increases by a factor of 10 for every 20 dB increase. For a point source of noise, sound level diminishes or attenuates by 6 dB for every doubling of distance. For example, if an idling truck is measured at 50 feet as 66 dBA, at 100 feet it will be heard as 60 dB(A), and at 200 feet, 54 dB(A).

When the truck begins to move, it generates sound along a line source. Line sources, such as highways, attenuate their sound at 3 dB to 4.5 dB per doubling distance, depending on the sound reflectivity of the ground.

In a similar way, if we add two equal noise sources together, the resulting noise level will be 3 dB higher. For example, if one machine registers 86 dB(A) at 50 feet, two machines would register 3 dB more, or 89 dBA at that distance. In a similar manner, at a distance of 50 feet, four machines, all operating at the same place and time, would register 92 dBA and eight machines would register 95 dB(A).

If two sources of noise differ by 2 to 4 dB, an increase of about 2 dB will occur when they are added together. A difference of 5 dB to 9 dB between two noise sources will increase overall noise levels by about 1 dB. If two sources of noise differ by more than 9 dB, then the increase in the combined decibel level will be less then 0.5 dB.

WHAT IS AN ACCEPTABLE LEVEL OF NOISE?

Noise acceptability is subjective. One noise level may be acceptable to one person, while that same noise level would be irritating to another person. Therefore, acceptable noise levels are determined by the historic frequency of complaints that are generated by different levels of background noise.

In Vermont, there are no quantitative standards for community noise. Act 250 and Act 248 have regulated noise under criteria 1A (air) and 8 (aesthetics), although no state-wide standard has been consistently set. In southern Vermont, the District Act 250 Commission in both the Luzenac America and Grafton Ponds decisions set a noise standard of 50 dBA during the daytime and 40 dBA during the nighttime at the property boundary. In both of cases, however, residences were close to the sources of noise.

Other states, counties, and municipalities have set specific standards for noise generated from wind turbines. Examples of these are shown in Table 1.

Table 1: Example noise standards for wind turbines from several communities around the United States

Place	Noise Limit
Benecia CA	55 dBA 300 feet from the tower
Lake County CA	55 dBA CNEL[1] at any property line
Monterey County CA	45 dBA at the property line
Torrance CA	50 dBA at the property line
Solano County CA	50 dBA CNEL at the property line in a residential zone or 60 dBA CNEL at any other property line
Guilford CT	55.4 to 65.4 dBA at the property line depending on background levels
Schaumburg IL	70 dBA to 31 dBA for 20 to 10000 Hz corrected for nighttime operation and periodic character
Andover MA	Background level at the property line
Topsfield MA	10 dBA above background
St Paul, MN	50 dBA at the property line
Sante Fe, NM	Background level
Webster NY	Nighttime background level
Bandon OR	50 dBA
Springettsbury PA	60 dBA at 75 ft from unit
Thornbury PA	50 dBA at the property line
Santa Clara CA	Sufficient to protect adjacent properties from physical damage and noise
Lower NJ	50 dBA at the property line

Neither Searsburg or Readsboro, VT have ordinances restricting noise levels.

As a point of reference, the Town of Colchester, Vermont's zoning regulations require that noise levels shall not exceed 70 dBA in residential areas, and 75 dBA on "developed lands". The Town of Georgia, Vermont has a performance standard which permits noise levels to 70 dBA at the property line.

The Federal Highway Administration (FHWA) has established Noise Abatement Criteria for highway noise.[2] For residential areas, noise abatement is recommended when the L_{eq} exceeds 67 dBA (outside), and for commercial areas, the L_{eq} should not exceed 72 dBA. The FHWA has also set an outdoor noise standard of 57 dBA (Ldn) which applies to "lands on which serenity and quiet are of extraordinary significance and serve an important public

[1] The CNEL is the "Community Noise Equivalent Level", which is calculated as the 24-hour LEq weighted by adding 5 dB to sound levels between 7:00 PM and 10:00 PM and 10 dB to sound levels occurring between 10:00 PM and 7:00 AM.

[2] Code of Federal Regulations 23 Part 772.

need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose."

The Federal Department of Housing and Urban Development (HUD) has also set criteria based on the cumulative impact of background noise. Noise levels over the entire day and night should not exceed 65 dBA two meters from the receptor building.

The U.S. EPA Protective Noise Levels are guideline values for day-night noise levels. For residential areas, they recommend an L_{dn} of less than or equal to 55 dB. Indoors, where wintertime noise levels are typically 27 dB less then outdoors[1], noise levels should not exceed 45 dB L_{dn}.

SITE DESCRIPTION

The site is located along Sleepy Hollow Road in Searsburg, Vermont. The wind turbines will be sited along a ridge which is approximately 1,400 feet from the road and 530 feet higher than the road. The ridge runs roughly from the northeast to southwest. The area within several miles of the site is densely forested.

The closest property line to the south is approximately 100 feet from the closest turbine. That land is maintained by the Green Mountain National Forest. The closest residence is approximately 3,600 feet from the closest turbine. This residence is alongside Route 8 and two running brooks and is generally inhabited only during the summer months.

The project team has been collecting hourly wind data at the site for several years. Based on these data, they have determined the prevailing winds are predominantly from the west and west-north-west. During 16 months of data collection, the wind blew from these directions 65% of the time.

EXISTING NOISE LEVELS

The majority of noise in this area is from overflying aircraft, highway traffic, and birds. Background noise levels were measured during the evening and early morning hours at the four sites of greatest concern (see Figure 2). Two of these sites represented potential bear habitat, one site was at the closest residence, and the fourth site was at the turbine location closest to the forest service boundary.

This period, i.e.. early spring during the evening and night hours, was chosen because it represented a period where background levels were likely to be lowest. During the winter and early spring months, deciduous trees have little or no leaves and thus tend to be quieter during light breezes. Furthermore, at night, noises from birds, airplanes, cars, and other predominantly diurnal sources tend to be less common.

Noise levels were measured using a Brüel and Kjær 2236D Type I noise level meter. Each

[1] 17 dB for open windows, 27 dB for closed windows.

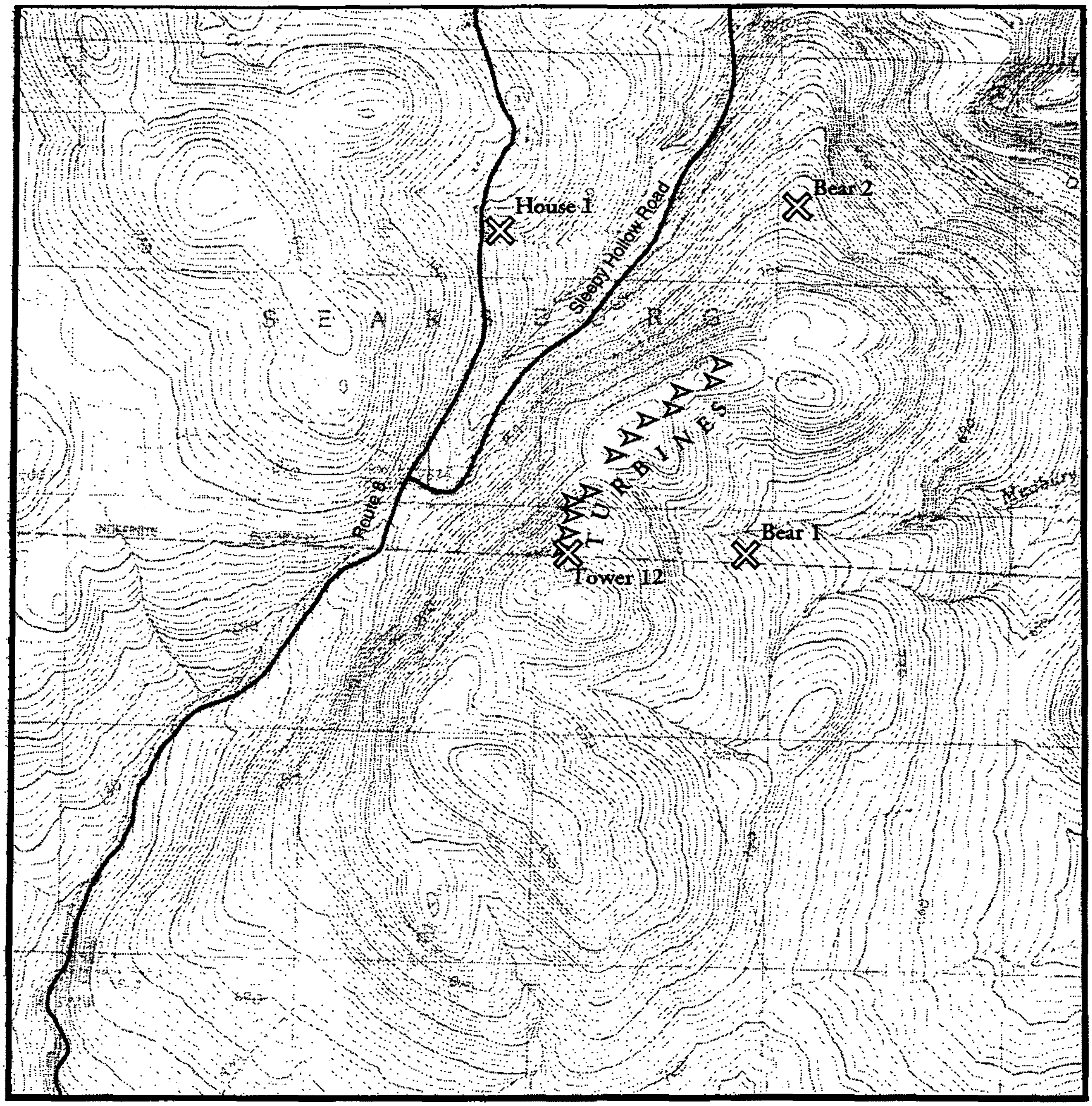


Figure 2

Background Measurement Locations

N

Scale in Feet

1000 0 1000 2000 3000 4000 5000

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noise meter was calibrated on site using a Brüel and Kjær Type 4231 sound level calibrator and fitted with a wind screen to eliminate extraneous noise from wind passing over the microphone. Average background noise levels were continuously measured and recorded every ten seconds over an eight hour period. The noise meters were set on fast response and A-weighted. After the recordings were complete, full-octave noise level readings were sampled over fifteen minutes. These latter readings represented typical background levels without aircraft or nearby vehicular traffic. These are shown in Appendix A.

The results of the noise monitoring are shown in Table 2 and Figures 3 through 6. Average noise levels (Leq) ranged from 32 to 45 dBA. The recordings show that even in the remote sites, quiet background levels were punctuated by fairly frequent louder interruptions. Given that these interruptions occurred simultaneously at each of the sites, we conclude that most are from man-made sources such as airplanes or traffic. Other periods of peak noise levels could be due to wind gusts or wildlife sounds, such as song birds or owls.

Table 2: Results of Noise Monitoring (in dB(A))

Site	Start	End	L90 [1]	L50 [2]	L10 [3]	Leq [4]
Tower 12	5/1 17:24	5/2 01:55	20.0	20.6	30.4	31.7
House 1	5/1/ 19:48	5/2 03:59	33.5	34.0	35.0	40.7
Bear 1	5/8 18:02	5/9 02:14	22.5	25.0	36.0	34.2
Bear 2	5/8 18:51	5/9 03:33	29.5	30.5	36.5	34.8

It should be noted that during the noise monitoring period, wind speeds were fairly light, averaging 5.0 mph during the first monitoring night and 12.5 mph during the second night. These are less than the average wind speeds during the year of 17.2 mph. Since the area is heavily forested, higher wind speeds would result in higher background noise levels. For example, a study in Sweden found that a difference between a 5 mph and 10 mph wind speed would result in an increase in background noise levels of 12 dB(A).[5] Figure 7 shows the projected background noise levels from this study in a typical suburban area due to wind speeds as measured 33 feet above the ground.

[1] The "L90" represents the level at which 90% of the noise readings are above. For example, if 100 noise measurements were taken, the L90 would be the tenth lowest reading.

[2] The "L50" represents the mode of the measurements.

[3] The "L10" represents the level at which 10% of the noise readings are above. For example, if 100 noise measurements were taken, the L10 would be the tenth highest reading.

[4] The "Leq" is the average noise reading weighted by sound power.

[5] "A Preliminary Study of the Masking of Wind Turbine Noise by Ambient Sound," L. Ekstrom and S. Ljunggren, Aeronautical Research Institute of Sweden, 1990.

Figure 3: Background Noise Measurements at "Tower 12", May 1, 1995

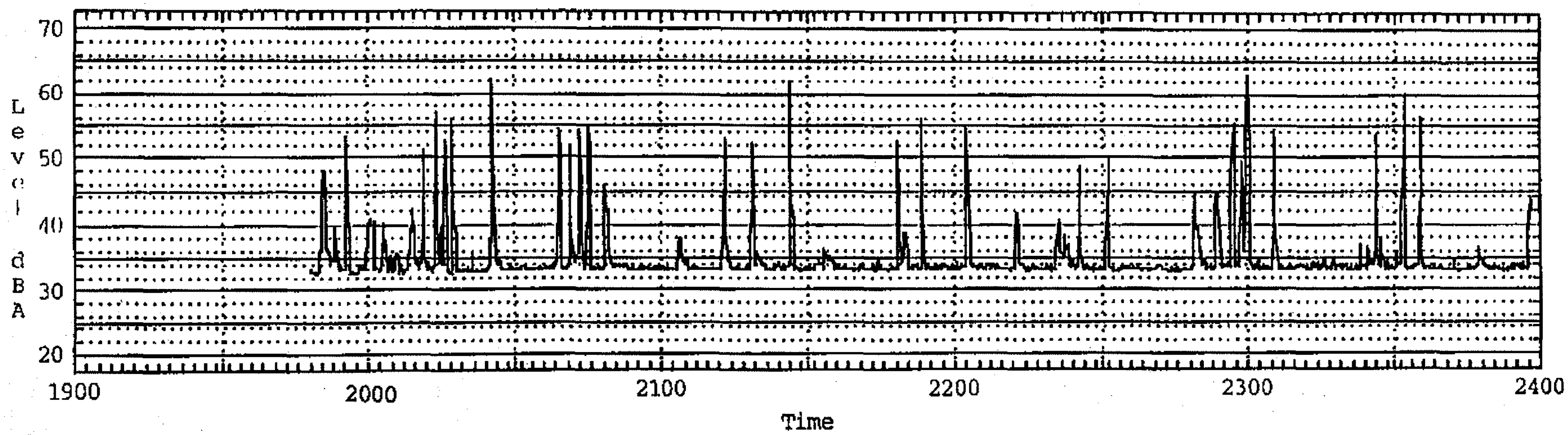


Figure 4: Background Noise Measurements at "House 1", May 1, 1995

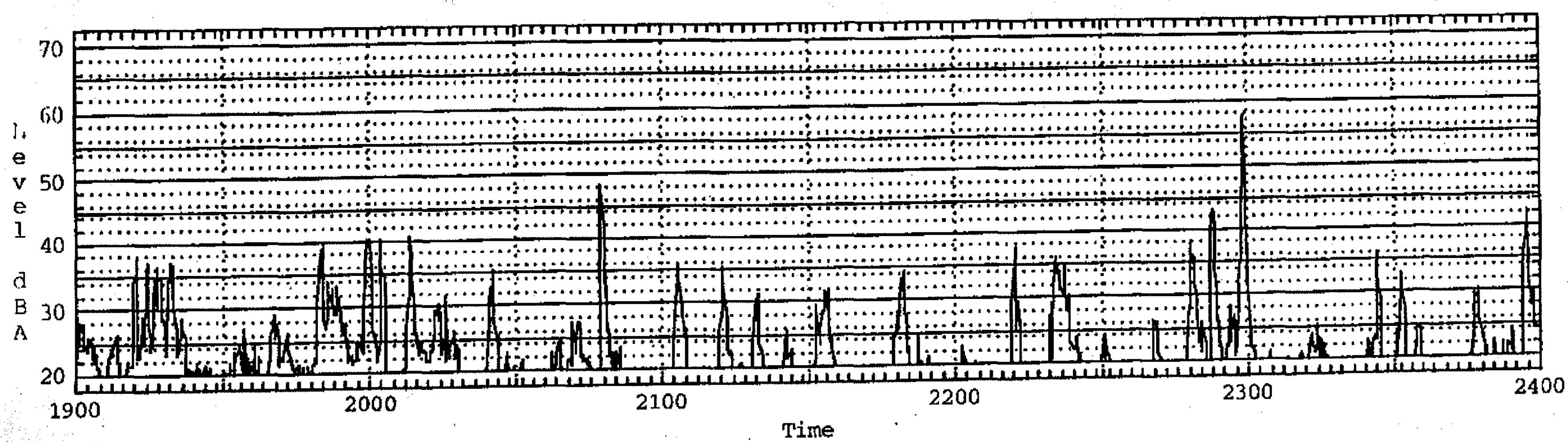


Figure 5: Background Noise Measurements at "Bear 1", May 8, 1995

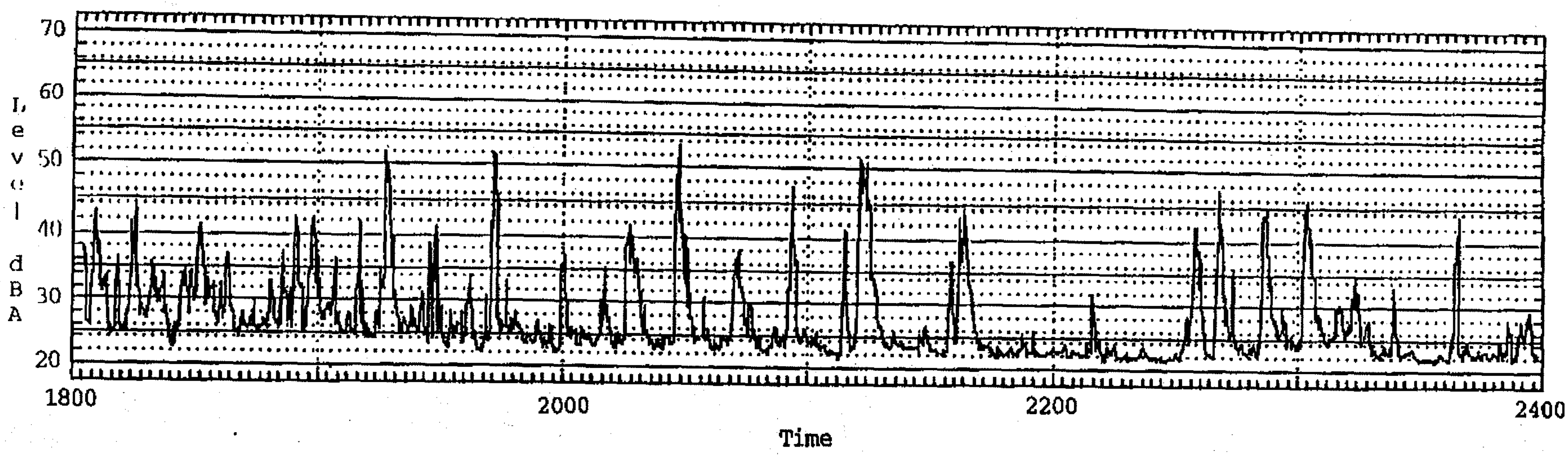


Figure 6: Background Noise Measurements at "Bear 2", 8 May 1995

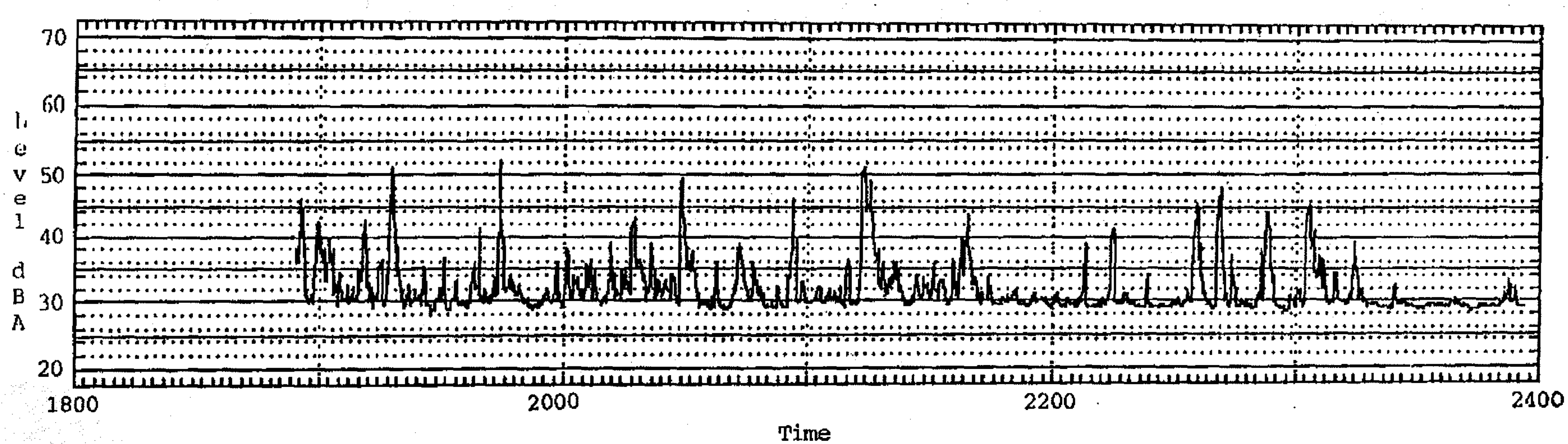
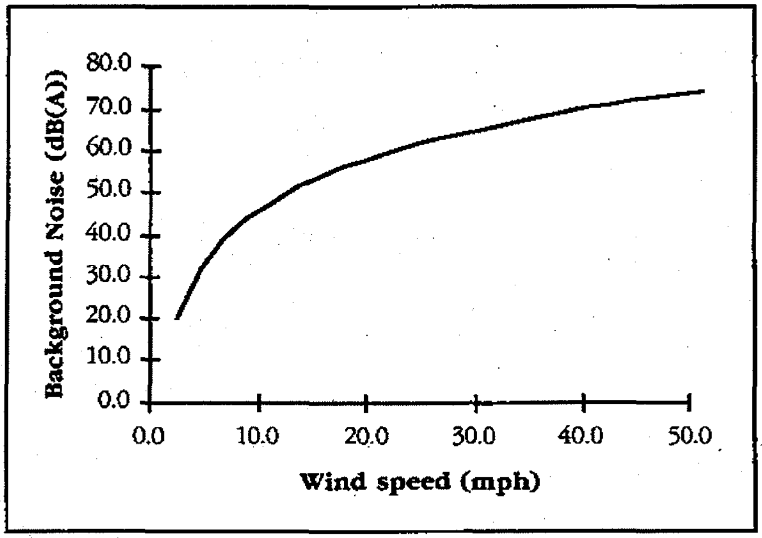


Figure 7: Background levels due to the effects of increasing wind speed



The wind speed at which the turbines start to rotate is approximately 10 mph and do not start to significantly generate noise until winds reach 13 mph. Background noise levels were measured at wind speeds below 13 mph during each of the monitoring periods. Background levels were therefore adjusted to that generated at 13 mph. This was done assuming that the fiftieth percentile noise level coincides with the average wind speed measured.[1] The average noise levels adjusted to 13 mph are shown in Table 3.

Table 3: Results of Noise Monitoring (in dB(A))

Site	Unadjusted Leq	Leq[2] adjusted to winds of 12.5 mph
Tower 12	31.7	37.9
House 1	40.7	50.6
Bear 1	34.2	34.2
Bear 2	34.8	35.0

PROPOSED NOISE LEVELS

NOISE LEVELS FROM THE PROPOSED OPERATION

At this time, the type of turbine that will be used on the site is still under consideration. It will likely be rated at about 500 KW, have a hub height of approximately 130 feet, and a

[1] For the House 1 receptor, since more of the man-made sources contribute to background, the assumptions was that the L10 represented average wind levels.
[2] The "Leq" is the average noise reading weighted by sound power.

rotor diameter of approximately 130 feet. The designs that are currently being investigated are state-of-the-art in terms of their efficiency and low noise emissions.

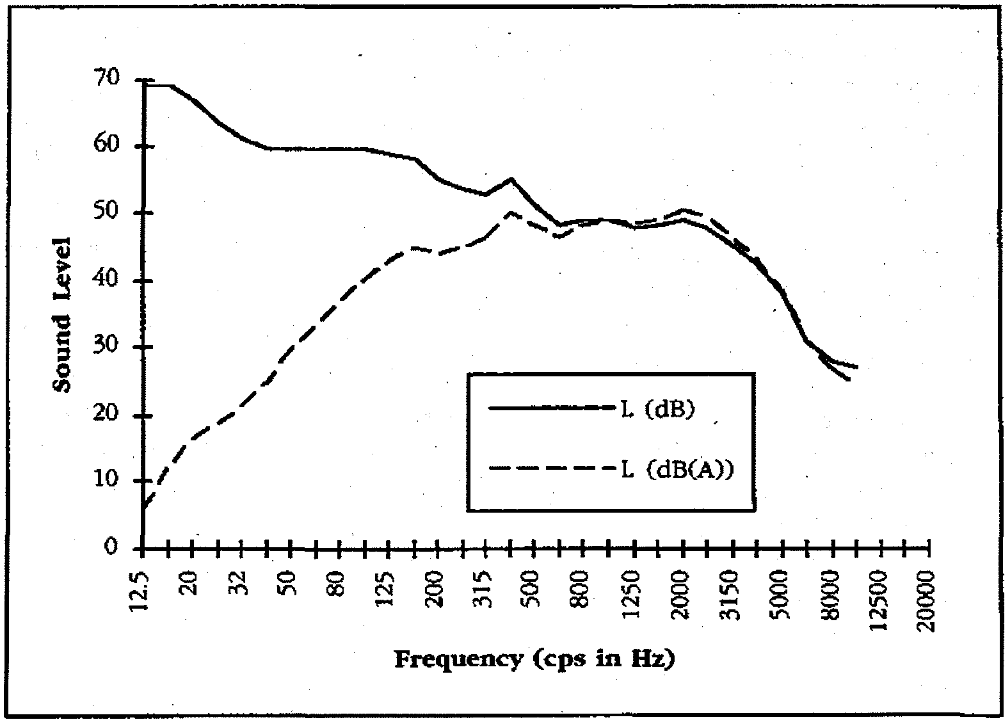
The turbine noise emissions used for this modeling are for a prototype turbine that is currently under development. Since the data is from a prototype, the manufacturer has required us to keep their name confidential until such time as the final design is marketed. At that time, updated noise emission data will be provided that will accurately reflect refinements made to the prototype design.

Noise levels from turbines are generally considered from two distinct sources: lower frequency aerodynamic noises, and broadband mechanical noises. The aerodynamic noises are caused by interactions between the blades and the tower. Mechanical noises are associated with the gearbox and turbine operation.

Audible noise emissions from the prototype turbine are shown in Figure 8. The values shown represent the measured noise levels and those levels which are adjusted to represent A-weighted annoyance response. The overall noise level at 198 feet downwind from a single turbine is expected to be approximately 60 dB(A). The 198 foot distance is a standard measurement distance for wind turbines, and is calculated as the sum of the hub height and the rotor radius.[1]

[1] "Procedure for Measurement of Acoustic Emissions from Wind Turbine Generator Systems, Volume I," American Wind Energy Association, 1989.

Figure 8: Expected Noise Levels at 198 feet Downwind of Turbine with Winds at 18 mph[1]



MODELING NOISE LEVELS AT NEARBY RECEPTORS

Since the noise levels at a given distance are known, we can estimate the levels at other distances, as well. The simple formula for attenuation due to distance is:

$$L_{\text{Location 2}} = L_{\text{Location 1}} + 20 Log\left(\frac{r_1}{r_2}\right)$$

Where "L" is the noise level at distance "r".

There may be additional attenuation due to vegetative cover and topography that acts as a noise barrier. Vegetative attenuation generally ranges from between -3 dB per 100 m for bare trees to -20 dB per 100 m for dense pine forest[2] with a maximum attenuation of 10 dB. This modeling uses the lower end as represented by the attenuation equation[3]:

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1 Levels of noise at frequencies above 4KHz are below 30 dB.
2 "Noise and Noise Control," M.J. Crocker and A.J. Price, CRC Press, 1975,
3 "Noise and Vibration Control Engineering," L.L. Beranek & I.L. Ver, 1992, page 134.

$$A_{Woods} = 6\left(\frac{f}{1kHz}\right)^{1/3}\left(\frac{r_{woods}}{100m}\right) \leq 10$$

Where "r_{woods}" is the distance the ray passes through the woods and "f" is the frequency of the sound.

Any structure which impedes the line of sight between the noise source and its receptor will reduce the noise level reaching that receptor. In this case, there are cases where the variation in elevation affects the line-of-sight between the noise sources and certain receptors . These act as barriers to the noise from the turbines. Attenuation due to topographic obstructions was calculated using formulas for insertion loss of semifinite barriers in a free field[1]. Semi-finite barriers are those which have left, right, and top sides, but are sitting on a finite surface. A free field is one in which there are no walls, i.e.. outdoors. These are standard physical models which predict attenuation where the line-of-sight between source and receptor is blocked.

Wind can reduce noise levels upwind of a source. Our modeling used upwind attenuation formulas derived for wind turbines[2]. Attenuation was only calculated in the "shadow zone" which is defined as any area more then 5 times the turbine height upwind from the turbine. For each receptor, the turbine height was calculated as the hub elevation minus the receptor elevation.

Modeling was performed in order to determine the noise levels around the project using the NTerrain noise computer model, which takes into account these distance, vegetation, barrier, and shadow zone attenuation effects. Table 4 shows the assumptions and inputs to the model. Results are shown in Table 5 for specific critical areas. Figure 9 shows the results as contours of noise in the area around the project. Appendix B details the model's results for specific receptors.

1 "Industrial Noise and Vibration Control," J.D. Irwin and E.R. Graf, Prentice Hall, Inc, 1979.
2 "Wind Turbine Acoustics," NASA, December , 1990.

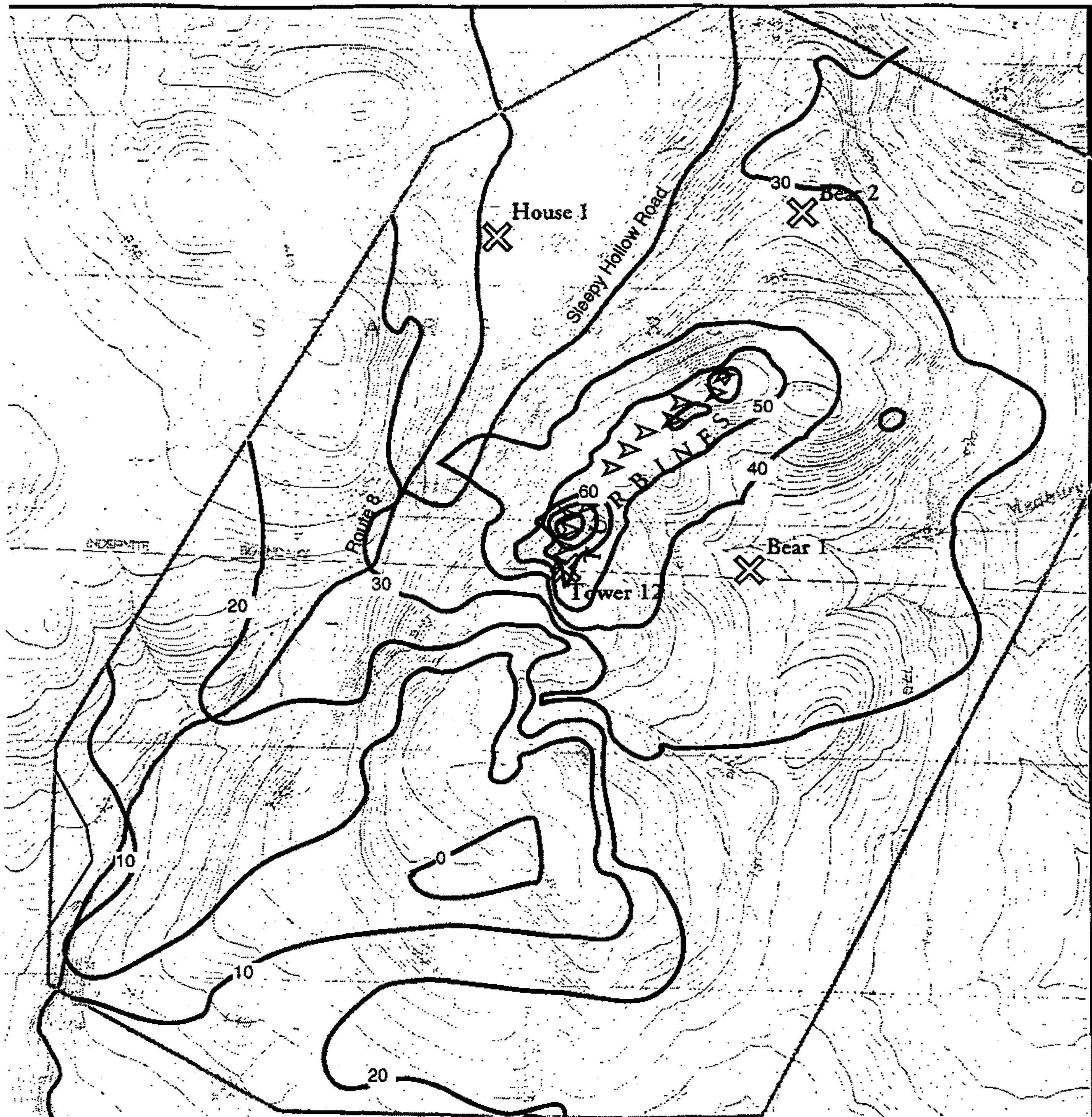

Figure 9

Critical Receptor Locations at Wildlife Habitat and Nearby Residences and 10 dB(A) Noise Contours from Tubines

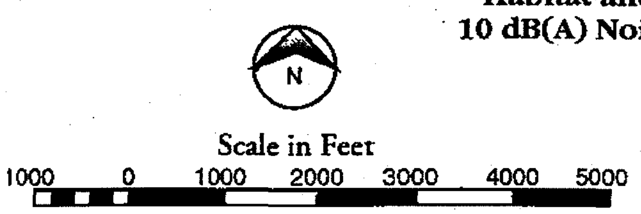

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Table 4: Assumptions and Inputs to the NTerrain Model

Parameter	Value
Elevation contours	Digitized from the Readsboro 7.5 minute USGS topographic map
Receptors	Over 200 receptors placed at 100 meter to 250 meter intervals in a one-mile radius around the project. Six special receptors were also placed at locations representing critical wildlife habitat and nearby residential areas
Sources	12 wind turbines placed as shown in Figure 2. Full-octave levels input as shown in Figure 8. Hub height of 131 feet assumed.
Meteorology	Noise from turbines based on wind speed of 18 mph from the west (270°), humidity 70%. Background noise based on wind speed of 13 mph.

Table 5: Calculated Noise Levels at Critical Wildlife Habitat Locations and Nearby Residences

Receptor	Background Noise (Leq)	Noise from Turbine (dB(A))	Total Noise (Leq)
House 1	50.6	37.3	50.8
House 2	50.6 est	35.4	50.7
House 3	35.0 est	31.3	36.5
Bear Habitat 1	34.2	35.2	37.7
Bear Habitat 2	35.0	11.3	35.0
Bear Habitat 3	37.9	30.9	38.7

DISCUSSION

MODELED CONDITIONS COMPARED WITH OTHERS POSSIBLE

The modeling assumed a certain fixed set of conditions, specifically those described in Table 4. Other meteorological conditions are possible, but not as common, that could either make the modeled noise levels higher or lower. For example, extreme temperature inversions, such as those that occur during sunrise can increase noise levels downwind more than that assumed in the model. However, sunrise is typically a period of lighter winds, and is thus less likely to generate noise from the turbines.

The wind speeds assumed for the turbines and background noise levels was chosen to represent a worst-case scenario. Noise levels from the turbine increase by approximately 0.12 dB(A) for every increase of 1 mph wind speed. So, between 13 mph and 36 mph, the turbine would increase its noise levels by approximately 2.8 dB(A). By comparison, background noise would increase by approximately 17 dB(A) over the same range of wind speeds. Therefore, the worst-case impacts would occur during periods of lighter winds, where the turbine noise is not masked by background wind produced noise.

Other meteorological conditions that also affect noise propagation are temperature and humidity. However at the distances being modeled, these effects are very small and would not have an significant bearing on the final results of the modeling.

MODELED LEVELS COMPARED WITH BACKGROUND LEVELS

As is shown on Figure 9, at each of the houses, noise levels from the turbines are expected to be well below the average ambient level and should not be noticeable during most periods of the day and night. The only exception is at "House 3", where some noise from the turbines may be noticeable outside during very quiet times. For example, when winds are light and there is no traffic in the area. However, these noise levels are extremely low: equivalent to a faint whisper. Within the houses, noise levels should not be noticeable at all, even with the windows open.

At the locations of bear habitat, the worst-case noise levels are expected to increase by approximately 3.5 dB(A). During quiet times with low wind speeds, the sound from the turbines may be noticeable at "Bear 1" and potentially at "Bear 2". This level of noise is extremely low and has similar spectral characteristics to wind noise and normal background noise. Furthermore, these levels are below the strictest standards for nighttime noise levels based on human reactions of disturbance.

COMPARISON WITH LOCAL AND NATIONAL STANDARDS AND GUIDELINES

At the present time, there are no standards that apply to this project. However, noise levels at critical receptors are below EPA indoor and outdoor noise guidelines. These levels are 45 dBA L_{dn} and 55 dBA respectively. In addition, both the HUD and FHWA standards are also met.

CONSTRUCTION IMPACTS

Most of the construction activity will occur between April 15 and October 1, with the heaviest and noisiest work being road construction and excavation for foundations. This is planned to take place in June, July, and August. All construction activities are expected to take place between 7:00 AM and 7:00 PM.

The road construction activity will involve similar equipment to other forestry projects in the area. The noise from tree cutting and road grading is common in this region and, if noticeable at nearby residences, should not be out of place during the daytime hours.

The loudest construction activities will be the drilling and blasting of ledge to set the foundations of the towers. To estimate the maximum impacts of these activities, three rock drills were modeled to be operating simultaneously at the locations of proposed Towers 1, 6, and 12. Each rock drill is estimated to generate noise at a level of 78 dB(A) at 82 feet.[1] The results of this modeling are shown in Table 6

Table 6: Noise Levels at Critical Areas around the Project

Receptor	Background Noise (Leq)	Noise from Construction (dB(A))	Total Noise (Leq)
House 1	50.6	46.7	52.1
House 2	50.6 est	44.8	51.6
House 3	35.0 est	42.2	43.0
Bear Habitat 1	34.2	45.2	45.5
Bear Habitat 2	35.0	28.2	35.8
Bear Habitat 3	37.9	43.2	44.3

As shown in the above table, noise levels may exceed background levels due to construction in some locations, however, these levels are temporary, will likely only occur during the daytime, and are below EPA's strict guidelines for human exposure.

CONCLUSIONS

The construction of a 6 MW wind power station in Searsburg Vermont will generate both mechanical noise and noise from interactions between the wind and the turbine blades and tower. These noise levels were modeled and found to be near or below current ambient levels at critical wildlife habitats and nearby residences. As such, we believe that the GMP wind energy project will not create any undue adverse impact on critical wildlife habitats or neighboring residences.

1 "1990 Noise Study for John and Joyce Belter, South Burlington, Vermont." Gregory Wight, May 1990.