Appendix E
Noise Technical Report
PdV WIND ENERGY PROJECT
KERN COUNTY, CALIFORNIA

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INTRODUCTION

This report provides a noise assessment of the PdV Wind Project proposed for the in the southern foothills of the Tehachapi Mountains area of Kern County, California (Figure 1). The report includes basic information on noise measurement and assessment, applicable noise regulations and guidelines, an evaluation of the existing noise environment, an assessment of expected noise levels, and a discussion of noise mitigation options.

ENVIRONMENTAL NOISE FUNDAMENTALS

Noise may be defined as unwanted sound. Noise is usually objectionable because it is disturbing or annoying. The objectionable nature of sound could be caused by its pitch or its loudness. Pitch is the height or depth of a tone or sound, depending on the relative rapidity (frequency) of the vibrations by which it is produced. Higher pitched signals sound louder to humans than sounds with a lower pitch. Loudness is intensity of sound waves combined with the reception characteristics of the ear. Intensity may be compared with the height of an ocean wave in that it is a measure of the amplitude of the sound wave.

In addition to the concepts of pitch and loudness, there are several noise measurement scales which are used to describe noise in a particular location. A decibel (dB) is a unit of measurement which indicates the relative amplitude of a sound. The zero on the decibel scale is based on the lowest sound level that the healthy, unimpaired human ear can detect. Sound levels in decibels are calculated on a logarithmic basis. An increase of 10 decibels represents a ten-fold increase in acoustic energy, while 20 decibels is 100 times more intense, 30 decibels is 1,000 times more intense, etc. There is a relationship between the subjective noisiness or loudness of a sound and its intensity. Each 10 decibel increase in sound level is perceived as approximately a doubling of loudness over a fairly wide range of intensities. Technical terms are defined in Table 1.

There are several methods of characterizing sound. The most common in California is the A-weighted sound level or dBA. This scale gives greater weight to the frequencies of sound to which the human ear is most sensitive for typical environmentally occurring sounds. Representative outdoor and indoor noise levels in units of dBA are shown in Table 2. In special situations, the C-weighted sound level or dBC scale is sometimes used. This scale gives more weight to lower frequency noise. When it is used, the intent is to differentiate between noises that have varying amounts of low frequency noise that would produce only little differences in A-weighted sound level.
Because sound levels can vary markedly over a short period of time, a method for describing either the average character of the sound or the statistical behavior of the

Figure 1: PdV Wind Energy Project Area
<table>
<thead>
<tr>
<th>TERM</th>
<th>DEFINITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decibel, dB</td>
<td>A unit describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure, which is 20 micropascals (20 micronewtons per square meter).</td>
</tr>
<tr>
<td>Frequency, Hz</td>
<td>The number of complete pressure fluctuations per second above and below atmospheric pressure.</td>
</tr>
<tr>
<td>A-Weighted Sound Level, dB</td>
<td>The sound pressure level in decibels as measured on a sound level meter using the A-weighting filter network. The A-weighting filter de-emphasizes the very low and very high frequency components of the sound in a manner similar to the frequency response of the human ear and correlates well with subjective reactions to noise. All sound levels in this report are A-weighted, unless reported otherwise.</td>
</tr>
<tr>
<td>C-Weighted Sound Level, dB</td>
<td>The sound pressure level in decibels as measured using the C-weighting filter network. The C-weighting is very close to an unweighted or “flat” response. C-weighting is only used in special cases when low frequency noise is of particular importance.</td>
</tr>
<tr>
<td>$L_{01}$, $L_{10}$, $L_{50}$, $L_{90}$</td>
<td>The A-weighted noise levels that are exceeded 1%, 10%, 50%, and 90% of the time during the measurement period.</td>
</tr>
<tr>
<td>Equivalent Noise Level, $L_{eq}$</td>
<td>The average A-weighted noise level during the measurement period.</td>
</tr>
<tr>
<td>Community Noise Equivalent Level, CNEL</td>
<td>The average A-weighted noise level during a 24-hour day, obtained after addition of 5 decibels in the evening from 7:00 pm to 10:00 pm and after addition of 10 decibels to sound levels measured in the night between 10:00 pm and 7:00 am.</td>
</tr>
<tr>
<td>Day/Night Noise Level, $L_{dn}$</td>
<td>The average A-weighted noise level during a 24-hour day, obtained after addition of 10 decibels to levels measured in the night between 10:00 pm and 7:00 am.</td>
</tr>
<tr>
<td>$L_{max}$, $L_{min}$</td>
<td>The maximum and minimum A-weighted noise level during the measurement period.</td>
</tr>
<tr>
<td>Ambient Noise Level</td>
<td>The composite of noise from all sources near and far. The normal or existing level of environmental noise at a given location.</td>
</tr>
<tr>
<td>Intrusive</td>
<td>That noise which intrudes over and above the existing ambient noise at a given location. The relative intrusiveness of a sound depends upon its amplitude, duration, frequency, and time of occurrence and tonal or informational content as well as the prevailing ambient noise level.</td>
</tr>
</tbody>
</table>

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### TABLE 2: Typical Sound Levels Measured in the Environment and Industry

<table>
<thead>
<tr>
<th>At a Given Distance From Noise Source</th>
<th>A-Weighted Sound Level in Decibels</th>
<th>Noise Environments</th>
<th>Subjective Impression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil Defense Siren (100')</td>
<td>140</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jet Takeoff (200')</td>
<td>130</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel Pile Driver (100')</td>
<td>120</td>
<td></td>
<td>Pain Threshold</td>
</tr>
<tr>
<td>Freight Cars (50')</td>
<td>110</td>
<td>Rock Music Concert</td>
<td></td>
</tr>
<tr>
<td>Pneumatic Drill (50')</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freeway (100')</td>
<td>100</td>
<td></td>
<td>Very Loud</td>
</tr>
<tr>
<td>Vacuum Cleaner (10')</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In Kitchen With Garbage Disposal Running</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light Traffic (100')</td>
<td>70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large Transformer (200')</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soft Whisper (5')</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private Business Office</td>
<td>40</td>
<td></td>
<td>Moderately Loud</td>
</tr>
<tr>
<td>Quiet Bedroom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recording Studio</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threshold of Hearing</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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variations must be utilized. Most commonly, environmental sounds are described in terms of an average level that has the same acoustical energy as the summation of all the time-varying events. This energy-equivalent sound/noise descriptor is called $L_{eq}$. The
most common averaging period is hourly, but $L_{eq}$ can describe any series of noise events of arbitrary duration.

The scientific instrument used to measure noise is the sound level meter. Sound level meters can accurately measure environmental noise levels to within about plus or minus 1 dBA. Various computer models are used to predict environmental noise levels from sources, such as roadways and airports. The accuracy of the predicted models depends upon the distance the receptor is from the noise source. Close to the noise source, the models are accurate to within about plus or minus 1 to 2 dBA.

Since the sensitivity to noise increases during the evening and at night -- because excessive noise interferes with the ability to sleep -- 24-hour descriptors have been developed that incorporate artificial noise penalties added to quiet-time noise events. The Community Noise Equivalent Level, CNEL, is a measure of the cumulative noise exposure in a community, with a 5 dB penalty added to evening (7:00 pm - 10:00 pm) and a 10 dB addition to nocturnal (10:00 pm - 7:00 am) noise levels. The Day/Night Average Sound Level, $L_{dn}$, is essentially the same as CNEL, with the exception that the evening time period is grouped into the daytime period.

For sound propagation outdoors, some additional concepts are important. For an ideal “point” source, sound level decreases with distance due to the spreading out of sound waves originating from the source. This geometrical or spherical spreading results in a reduction of sound pressure level of 6 dB per doubling of distance from the source. The strength of the source is often characterized by its sound power level. Sound power level is independent of the distance a receiver is from the source and is a property of source alone. Knowing the sound power level of an idealized source and its distance from a receiver, sound pressure level at the receiver point can be calculated based on geometrical spreading. This approach is applied to wind turbine generators in the standard measurement techniques for determining the sound power or source level.

The sound level due to spherical spreading can be modified further by a number of additional factors. The first is the presence of a reflecting plane such as the ground. For hard ground, a reflecting plane typically increases A-weighted sound pressure levels by 3 dB. If some of the reflected sound is absorbed by the surface, this increase will be less than 3 dB. Other factors affecting the predicted sound pressure level are often lumped together into a term called excess attenuation. Excess attenuation is the amount of additional attenuation that occurs beyond simple spherical spreading. For sound propagation outdoors, there is almost always excess attenuation producing lower levels than what would be predicted by spherical spreading. Some examples of these include attenuation by sound absorption in air, attenuation by barriers, attenuation by rain, sleet, snow, or fog, attenuation by grass, shrubbery, and trees, and attenuation from shadow zones created by wind and temperature gradients. For sound propagating over soft ground at near grazing angles of incidence, excess attenuations of 20 to 30 dB can be measured due to interference effect of the direct and reflected sound. Under certain meteorological conditions, some of these excess attenuation mechanisms are reduced or
eliminated leaving spherical spreading as the primary determinate of sound level at a receiver location.

When more than one point source contributes to the sound pressure level at a receiver point, the overall sound level is determined by combining contribution of the sources. This is done by adding the individual sound pressures together. For two sources that are independent and equal, the combined level results in 3 dB increase over the level of each alone. This is due to the logarithmic nature of sound level. In assessing environmental noise, a 3 dB increase in level is typically considered as just perceivable while an increase of 1 dB is difficult to detect.

REGULATORY BACKGROUND

At the federal and state level, there are no regulations that would apply to noise from commercial wind turbine generator operation. However, there are federal and state guidelines that set out acceptable threshold noise levels at residential receptors generally, and these guidelines may help to define a threshold for acceptable noise levels at residences in this case.

As a guideline, the U.S. Environmental Protection Agency identified an $L_{dn}$ value of 55 dBA as the threshold of activity interference outside farm residences\(^1\). As another guideline, the State of California Department of Health Services has identified $L_{dn}$ or CNEL values of 60 dBA or less as normally acceptable outdoor levels for residential use\(^2\). In areas exceeding an $L_{dn}$ of 60 dBA, if a multi-family residential building is proposed, Title 24 of the California Administrative Code requires the preparation of a noise mitigation study.

In addition, the State of California has adopted the California Environmental Quality Act (CEQA) to assess the potential for significant noise impacts as a result of a project. In evaluating the impacts of noise for the PdV Wind Energy proposal, CEQA requires that the following questions be asked:

- Would the project result in exposure of persons to or generation of noise levels in excess of standards established in the local General Plan or Noise Ordinance, or applicable standards of other agencies?
- Would the project result in a substantial permanent increase in ambient noise levels in the project vicinity above levels existing without the project?

For purposes of the second question, CEQA does not define what noise level increase would be considered “substantial”. However, in CEQA noise analysis it is common to define a noise impact as significant if the pre-existing noise environment is greater than $L_{dn} = 55$, and if the project would increase noise levels by more than 3 dBA at noise-sensitive receptors. Where the existing noise level is lower than $L_{dn} = 55$, a somewhat higher increase is generally tolerated before a finding of significance is made.
As to local regulations, within the State of California, noise from wind turbine generator operations is typically regulated at the county level. For Kern County, the applicable documents are the Noise Element of the Solano County General Plan, and the zoning regulations of the Kern County Code. In the first of these, the Kern County Noise Element, identifies residential areas as noise sensitive. For these areas, noise level generated by new projects is to be mitigated to 65 dB L_{dn} or less in outdoor activity areas and 45 dB L_{dn} or less within interior living spaces. Subsection J of the Development Standards and Conditions (Section 19.64.140) for wind energy projects of the County General Plan provides more specific requirements for allowable noise from wind turbine generators (WTGs). These fall into four categories: limits on overall A-weighted noise level, limits on noise in specific lower frequency 1/3 octave band levels, more strict requirements for tonal noise emission, and more strict requirements for repetitive impulsive sound. The Code also states “any noise level falling between two (2) whole decibels shall be the lower of the two (2)”. This applies to the new project level. For as existing background noise, levels are to be rounded to highest whole number.

In regard to exterior noise levels, the first requirement in the County Code is that at 50ft from a residence, the project noise level shall not exceed 45 dBA for more than 5 minutes out of any hour. Equivalently, in terms of L_{eq} noise descriptors, the L_{8} can not exceed 45 dBA. The second requirement is the A-weighted not exceed 50 dBA at anytime 50 ft from a residence. For the low frequencies, the limits are given below for 1/3 octave bands centered at 2 to 125 Hz:

<table>
<thead>
<tr>
<th>Frequency, Hz</th>
<th>2 to 16</th>
<th>20</th>
<th>25</th>
<th>31.5</th>
<th>40</th>
<th>50</th>
<th>63</th>
<th>80</th>
<th>100</th>
<th>125</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit, dB</td>
<td>70</td>
<td>68</td>
<td>67</td>
<td>65</td>
<td>62</td>
<td>60</td>
<td>57</td>
<td>55</td>
<td>52</td>
<td>50</td>
</tr>
</tbody>
</table>

If the audible noise from the WTG contains a steady pure tone, the 45 dBA limit is to be reduced by 5 dB to 40 dBA. This reduction applies if the 1/3 octave band noise level in a single band that contains the frequency of the tone is greater than 5 dB above the arithmetic level average of the two adjacent bands for bands of 500 Hz and above. For bands centered between frequencies of 160 to 400 Hz, the limit is 8 dB. For those below 125 Hz, the limit is 15 dB. Additionally, if the audible WTG noise contains “repetitive impulsive sounds”, the limits are lowered by 5 dB, however, if both tones and impulses are present, the total reduction for both is limited to 5 dB, that is, 40 dBA. It should be noted, however, that no quantitative definition of repetitive impulsive sound is provided.

The County Code does allow the criteria to be adjusted to the level of the existing background noise. For the overall A-weighted level, this applies to L_{8} noise level. For lower frequency, 1/3 octave band criteria, the background noise is to be measured on an hourly Leq basis. The background noise levels can be considered for the range of wind speed for which the WTGs operate up to a maximum of 30 mph. The County Code also defines a process for granting waivers in case the calculated project levels exceed the any of the criteria.
EXISTING NOISE ENVIRONMENT

The proposed site for the PdV Wind Energy Project is located in a largely undeveloped, open region of southern Kern County. There are a small number of residential structures scattered throughout the area some of which may be used for ranching purposes. The area is devoid of major man-made noise sources. There are no paved roads in the immediate vicinity of the project and the nearest state highway (LA 138) is more than 7 miles away. In the absence of wind-induced background noise, the sources of the background noise are not identifiable except for the very occasionally flyover of private aircraft and very distant jet airplanes. The network of dirt roads and trails is reported to support the use of off-road vehicle usage, some of which is thought to be recreational. However, at the time of the site visit, none of this activity was observed or measured.

To objectively characterize the noise environment in the area, sound pressure levels were measured in and surrounding the project site. For the current study, 24-hour, unattended noise level measurements were made at three locations in the vicinity of the project area at locations indicated as LT1, LT2, and LT3 in Figure 2. Noise levels were measured with two Larson-Davis 820 precision Type 1 sound level meters (SLMs) and one Larson-Davis 700 Type 2 integrating sound level meter. Each SLM was fitted with a ½-inch pre-polarized condenser microphone and windscreens. The meters were calibrated before and after the surveys with a 114 dB, 1000 hertz Larson Davis acoustical calibrator. The measurements began in the afternoon of June 28, 2006 and proceeded to the morning of June 30, 2006. The start and stop at each location varied somewhat, but data for each are shown in Figure 3 through 5 for LT1 through LT3, respectively. The CNEL values for each site calculated for June 29th are 60, 67, and 65 dB for sites LT1, LT2, and LT3, respectively.

Some attention to the selection of the locations of the long-term measurements sites was given to the proximity of metrological towers (Figure 2). Wind speed from these towers is shown in Figure 6. In general, the visual comparison of these wind speed data to the noise level data is quite striking. Both the wind speed and noise levels were higher at the beginning of the measurement period, fell off, and then increased again toward the end. Comparing the specific met tower data closest to the respective LT location re-enforces this correlation even further. To better quantify these relationships, noise level was plotted against wind speed for each measurement location and met tower pair. The results these comparisons are shown in Figures 7, 8, and 9. For each site, the L₈, Lₑq, L₅₀ and L₉₀ are considered and linear regression lines computed. In all cases, a strong correlation between the ambient noise and wind speed is indicated with individual R² values ranging from 0.85 to 0.97. This implies that the noise level of the existing environment can be confidently estimated from wind speed data alone. It also shows very clearly that the ambient noise is dominated by wind-induced background noise.

As a further investigation of speed effects, the L₉₀, Lₑq, and L₈ noise levels from all three sites were merged and plotted against their respective local wind speed. In Figure 10, the L₉₀ levels are plotted on one chart for all three long-term sites. At low wind speeds, the contribution of the wind-induced is expected to vanish as the wind speed approaches zero.
Figure 2: Project Area with Long Term Noise Measurement Locations and Meteorological Towers Used for Wind Speed Data
Figure 3: Noise Levels Measured at LT1 near Residences #8 and #9 and Met Tower 720 between June 28 and 30, 2006

Figure 4: Noise Levels Measured at LT2 near Residence #6 and Met Towers 720 and 105 between June 28 and 30, 2006
Figure 5: Noise Levels Measured at LT3 near Met Towers 716 between June 28 and 30, 2006

Figure 6: Hourly Average Wind Speed at Met Towers 720, 105, and 716 near LT1, LT2, and LT3
Figure 7: Sound Pressure Level as a Function of Wind Speed for Noise Measurement Site LT1 and Met Tower 720

Figure 8: Sound Pressure Level as a Function of Wind Speed for Noise Measurement Site LT2 and Met Tower 105
To account for this physical behavior, the data for higher speeds (above 6 m/s) can also be considered relative to aeroacoustics theory. For noise induced by airflow around buildings and other obstacles as well as through trees and vegetation, the noise level will increase at a rate proportional to the 6th power of wind speed. This relationship is shown in Figure 10. The difference between the aeroacoustic prediction and measured $L_{90}$ values suggests that at low wind speeds, the $L_{90}$ is dominated by other noise sources (e.g. distance traffic noise, aircraft, etc.) and that this varies somewhat from one site to the next. As the wind speed increases, the noise induced by the wind becomes more dominant and data from the three sites collapse into a similar data trend that follow the theoretical prediction. This implies that at about 7 m/s and above, the wind speed completely defines the $L_{90}$ in the area. A similar behavior is seen for the $L_{eq}$ and $L_8$ levels in Figure 11 and 12, respectively.

NOISE ASSESSMENT

The noise assessment consists of four elements. The first is a review of the noise performance of the wind turbine generators currently being considered for the project. The next element is the estimation of noise levels based on the proposed site plans. The third element is the assessment of the predicted levels relative to the appropriate regulations and guidelines. Finally, different mitigation strategies are discussed.

Wind Turbine Noise Performance

As proposed, the PdV Wind Energy Project will utilize one of two different wind turbine generators. These are either the Vestas V90 3.0 MW, or the Mitsubishi MWT-1000A. Both of these wind turbine generator designs are of an upwind configuration avoiding
Figure 10: Relationship between Wind Speed and Ambient Wind-Induced Noise for $L_{90}$ Sound Levels for Noise Measurement Sites LT1, LT2, and LT3 and Theoretical Estimation of Wind Noise

Figure 11: Relationship between Wind Speed and Ambient Wind-Induced Noise for $L_{eq}$ Sound Levels for Noise Measurement Sites LT1, LT2, and LT3 and Theoretical Estimation of Wind Noise
some of the low frequency concern regarding older, downwind turbines. At the time of this report, some data for each of the wind turbines were available. For the Vestas unit, 1/3 octave band sound power levels are provided at wind speeds of 6, 7, 8, 9, and 9.2 m/s. The maximum sound power level (110 dBA) occurs at 9 m/s and corresponding 1/3 octave band spectra is shown in Figure 13. For the Mitsubishi unit, overall A-weighted sound power levels are given for 8 and 13 m/s. The 1/3 octave band spectra are provided as sound pressure levels at the reference position defined in the International Standard IEC 61400-11\textsuperscript{5} procedure, which in this case are 99.8m away from the base of the wind turbine. For the Mitsubishi unit, the maximum sound power level occurs at 13 m/s, and 1/3 octave band sound pressure level was scaled appropriately for an overall sound power level of 107 dBA and is also shown in Figure 13. The overall A-weighted sound power levels as a function of wind speed are plotted in Figure 14. In this figure, the actual data reported by the manufacturers are as solid black symbols while the other data points are estimated from data and trends seen from other, similar wind turbine generator reported values.

Tonality for both the wind turbine generators was reported following the procedures of the IEC 61400-11 standard. For the Vestas unit, narrow band spectra reveal spectral peaks at about 60 Hz and about 900 Hz. Of these two frequencies, only the lower one is identifiable in the 1/3 octave band spectra (Figure 13). Following the evaluation method of the County Code, the difference of the 1/3 octave band containing the peak and average of two adjacent bands is 9 dB. At these frequency, a tonal penalty would be applicable if the difference were 15 dB or greater. As a result, no penalty is applicable in this case. For the Mitsubishi WTG, narrow band analysis does indicate some tonal
Figure 13: 1/3 Octave Band Sound Power Levels of Vestas and Mitsubishi Wind Turbine Generators

Figure 14: Estimated Overall A-Weighted Sound Power Level for Vestas & Mitsubishi Wind Turbine Generators as a Function of Wind Speed – Actual Reported Levels Indicated with Black Symbols
behavior at 1644 to 1700 Hz. However, the 1/3 octave band data gives no indication of tones which that generate the need for a tonal penalty at these or any other frequencies.

**Methods of Noise Level Estimation**

As sound spreads out from a noise source, the underlying physics of sound propagation determines that the sound will reduce by 6 dB for each doubling of distance away from the source. In addition to this expected attenuation, other phenomena can create even more excess attenuation. Given the long propagation distances between some of the wind turbine generators and residences, the effects of excess sound attenuation due to atmospheric absorption were incorporated into the calculated levels based on the measured 1/3 octave band spectra of Figure 13. Some amount of this absorption is present at all times although it will vary somewhat with temperature and humidity. For the project region is primarily a sloping plane from the Tehachapi Mountains down to the Antelope Valley. There some rigid features that could possibly produce some sound barrier effect in between the wind turbine generators and a receptors. As an additional effect, the land is mostly grassland creating the possibly of some excess sound attenuation by propagation over acoustically soft ground. On the other hand, both of these types of excess attenuation can also be reduced by temperature gradients and/or wind speed gradients. These latter two effects are not constant with time and can only be predicted with detailed data. As a result, the excess attenuation at any location and time can vary from none to some large amount. For estimating the noise levels resulting from the wind turbine generators in the PdV project area, it was assumed that the excess attenuation was zero. For downwind noise receptors, this assumption is reasonable in that when the wind is blowing, the wind will diffract the sound downward defeating any positive effect of excess attenuation by shielding of the hills and reflection from the soft ground. For upwind receptors, the wind will diffract sound upwards creating more excess attenuation. Thus, a very conservative approach is to assume no excess attenuation and just consider 6 dB per doubling of distance away from the noise source as the only attenuation beyond atmospheric absorption. To account for some reflection from ground, it was assumed that 70% of the sound striking the ground was reflected. This is also a very conservative assumption for the open ranges. Under these assumptions, the resultant estimations define the highest potential noise levels and are greater than what would be expected most of the time. Implied in the analysis of the wind turbine generator noise is the assumption that turbines radiate sound uniformly in all directions. Data from other, similar size wind turbine generators in use in California suggests this is a reasonable assumption, as does the IEC Standard for sound power determination. Using this assumption along with the 70% ground reflection, the steady sound pressure level 1000 feet from a single wind turbine generator operating at the wind speed producing the highest noise level is calculated to be 50.1 dBA for the Vestas V90 unit (at 9 m/s) and 47.1 dBA for the Mitsubishi unit (at 13 m/s).

**Estimated Overall A-Weighted Levels**

The prediction method described above was used to determine the noise level at each residence based on the highest noise level produced by each of the two WTGs. To do
this, each of the residences indicated in Figure 2 were reviewed using commercially available satellite imagery to more precisely locate the structures. In this process, two additional structures were identified as possible residences. For one location on Figure 2, no structure could be identified and this location was dropped. Further, one structure at the further-most southeast location in the project vicinity has been identified as a trailer that is to be removed. The locations and references of the ten structures included in the noise analysis are provided in Figure 15. For numbered structure locations, the sound pressure level from each individual, adjacent wind turbine generator was determined. The total noise level was then calculated by summing the contribution of the individual turbines until the turbines were too distant to add more to the total. This was repeated for the two wind turbine siting plans, the “Array Development” (Figure 16) and the “Optimized Development” (Figure 17) plans and for the two WTG designs under consideration.

Under Non-Varying Wind Conditions

The results of the above calculations are presented in Figure 18 for steady A-weighted noise levels corresponding to the maximum noise level produced for each WTG type. It will be noted that the predicted maximum noise levels are all equal to or above the uncorrected 45 dBA L₈ criterion stated in the Kern County Code for constant wind speeds of 9 m/s for the Vestas unit and 13 m/s for the Mitsubishi unit. For the WTGs operating at a constant wind speed, it is assumed that the sound produced is constant over time. As a result, all of the L₈ values are equal and the L₈ criterion is appropriate. Contours of constant noise level were also generated using SoundPLAN 6.3 (Figures 19 and 20). Inputs for the wind turbine generator locations were obtained from DXF files while the locations of structures were taken from Figure 15. Following the methodology described previously, the ground was assumed to be flat and a reflection coefficient of 70% was used. The receiver height was 5 ft and the actual heights of the wind turbines were used. The results were virtually identical to those obtained with simplified modeling reported in Figure 18.

Using the sound levels of Figure 18, the worst-case CNEL values can also be calculated. For this scenario, the wind turbines would be operating at their highest noise level operating point for the complete 24-hour period. As an upper bound, the level at Residence #9 for the Vestas unit was used. This produced a CNEL of 65 dBA, equal to the Kern County limit for new projects. For other residences and for the Mitsubishi WTG, the CNEL values will be below this level under this worst-case assumption.

Under Varying Wind Conditions

Under the Kern County Code, the 45 dBA L₈ criterion should be adjusted to equal the existing background noise level. At noted in regard to Figures 7 through 11, the background noise is very much a function of the wind speed. To determine wind speed varying noise level criteria, the results of Figure 11 were used along with the 45 dBA criterion applicable to no or low wind speed when the background noise is set by other noises and the L₈ levels are below 45 dBA. This is done by adding the 45 dBA static
Figure 15: Location of (Residential) Structures Included in Noise Analysis
Figure 16: Array Development Siting Plan with Structures Indicated
Figure 17: Optimized Development Siting Plan with Structures Indicated
limit to the theoretical fit of the wind-dominated background noise of Figure 11 on a mean-square pressure basis. The resultant criteria are presented in Figure 21 as a function of wind speed along with the measured background noise levels.

To apply these criteria, the noise level at each residence was determined as a function of wind speed using the sound power level curves from Figure 3 for the two WTGs. This was done in 1 m/s increments for each residence and each of 4 siting plan/WTG combinations. These levels are plotted in Figures 22 through 25. For the Mitsubishi unit, the predicted levels remain below the criteria for all wind speeds, all residences, and both siting plans. For the Vestas V90, the levels at all residences except #9 are below the criteria. For both siting plans, the predicted levels for the V90 at Residence #9 exceed the criteria in the range from 5 to 7 m/s by about 3 dB.

**Estimated Low Frequency Noise Levels**

In the Kern County Code, limits for the noise at residences are stated for 1/3 octave bands centered from 2 to 125 Hz. As indicated by Figure 13, complete data for this assessment was not available from the WTG manufacturers. As a result, the analysis was only performed for those frequencies where the data were reported. To do this, the A-weighted sound power levels of Figure 13 from 125 Hz and below were un-weighted. These levels were used in the same prediction processing described previously for the A-weighted levels.
Figure 19: Noise Contours for the Array Development Siting Plan for both Wind Turbines Operating at Maximum Noise Generation Wind Speed
Figure 20: Noise Contours for the Optimized Development Siting Plan for both Wind Turbines Operating at Maximum Noise Generation Wind Speed
Figure 21: Limit for Project Noise $L_8$ Levels as a Function of Wind Speed Compared to Background Noise Measured at LT1, LT2, and LT3 and the No Wind Limit of 45 dBA

Figure 22: Estimated Overall A-Weighted Sound Pressure Levels at Each Residence for the Array Development Site Plan and the Vestas V90 Wind Turbine Compared to the Noise Limit
Figure 23: Estimated Overall A-Weighted Sound Pressure Levels at Each Residence for the Array Development Site Plan and the Mitsubishi MWT-1000A Wind Turbine Compared to the Noise Limit

Figure 24: Estimated Overall A-Weighted Sound Pressure Levels at Each Residence for the Optimized Development Site Plan and the Vestas V90 Wind Turbine Compared to the Noise Limit
As an initial evaluation, the low frequency levels were calculated for the maximum noise generation wind speed for each wind turbine, 9 m/s for the Vestas V90 and 13 m/s for the Mitsubishi MWT-1000A. This was done for each frequency band, residence, and site plan/WTG configuration. As an example, the predicted levels for Residence #9 are shown in Figure 26 for both WTGs under the Array Development siting plan along with the low frequency limits defined by the county. As may be expected from the spectrum of the Vestas unit (Figure 13), the 1/3 octave band centered at 63 Hz is most problematic, however 4 other frequencies also exceed the limits. For the Mitsubishi unit, the 2 band limits are also exceeded, though by smaller amounts. For the Mitsubishi unit, the most problematic frequency is 125 Hz.

Under Varying Wind Conditions

To evaluate the low frequency WTG noise against the wind varying background $L_{eq}$ levels (see Figure 11), the same process to generate the noise criteria curve for the overall A-weighted levels was applied for each of the 1/3 octave bands between 25 and 125 Hz. To accomplish this, a wind-induced background noise spectral shape was required. Such data had been previously acquired in the Birds Landing area of Solano County, California. This site was quite similar to that in the PdV project area as there was an absence of trees and nearby structures. There were also no operating wind turbines in the measurement vicinity. The un-weighted data from this measurement are presented in Figure 27 for a wind speed of 8 m/s along with the Kern County limits for the low frequency band levels. Using the Birds Landing data, the relationship between overall A-

Figure 25: Estimated Overall A-Weighted Sound Pressure Levels at Each Residence for the Optimized Development Site Plan and the Mitsubishi MWT-1000A Wind Turbine Compared to the Noise Limit

Under Non-Varying Wind Conditions
Figure 26: Estimated 1/3 Octave Band Lower Frequency Noise Levels at Residence #9 for the Array Development Site Plan and the Vestas V90 Wind Turbines Operating at Constant Speed and Producing the Maximum Noise Level Compared to Kern County Limits

Figure 27: Wind-Induced Background Noise Measured near Birds Landing, CA at a Wind Speed of 8 m/s along with Kern County Low Frequency Criteria
weighted sound pressure level and the un-weighted level in each lower frequency band of interest was determined. These offsets could then be applied to the overall A-weighted background noise levels measured at LT1, LT2, and LT3 to produce an estimated wind-induced background noise level for each band. These data were fitted by a velocity to the 6th power curve and combined with the appropriate static noise limit for each band. An example of this is shown in Figure 28 for the 63 Hz band. Following this process, a family of criteria curves were generated for each of the 1/3 octave bands from 25 to 125 Hz (Figure 29).

To estimate the 1/3 octave band levels at each residence, the offsets defined above were applied to the estimated overall A-weighted levels of Figures 22 through 25. These levels are shown for each siting plan/WTG combination in Figures 30 through 33 for the most problematic frequency for each WTG, 63 Hz for the Vestas V90 and 125 Hz for the Mitsubishi MWT-1000A. The appropriate criteria curve from Figure 29 is also shown in each figure. The results of Figures 30 through 33 are summarized in Figure 34 in terms of cases that exceed the Kern County criteria as adjusted for background wind-induced noise.

**Assessment of Estimated Noise Levels**

From the Regulatory Background discussion, the most stringent requirements for project noise are the 45 dBA limit on $L_{eq}$ levels and low frequency limits between 2 and 125 Hz.
Figure 29: Limits for Project Noise $L_{eq}$ Levels in the Lower Frequency 1/3 Octave Bands as a Function of Wind Speed

Figure 30: Estimated 63 Hz 1/3 Octave Band Sound Pressure Levels at Each Residence for the Array Development Site Plan and the Vestas V90 Wind Turbine Compared to the Low Frequency Noise Limit
Figure 31: Estimated 125 Hz 1/3 Octave Band Sound Pressure Levels at Each Residence for the Array Development Site Plan and the Mitsubishi MWT-1000A Wind Turbine Compared to the Low Frequency Noise Limit

Figure 32: Estimated 63 Hz 1/3 Octave Band Sound Pressure Levels at Each Residence for the Optimized Development Site Plan and the Vestas V90 Wind Turbine Compared to the Low Frequency Noise Limit
Figure 33: Estimated 125 Hz 1/3 Octave Band Sound Pressure Levels at Each Residence for the Optimized Development Site Plan and the Mitsubishi MWT-1000A Wind Turbine Compared to the Low Frequency Noise Limit

Figure 34: Amount of Noise Reduction Required to Meet the Kern County Low Frequency Criteria as Defined at 63 Hz for the Vestas V90 and 125 Hz for the Mitsubishi MWT-1000A
Overall A-Weighted Level Criteria

Based on the information supplied by the WTG manufacturers, there is no reason to apply the 5 dB penalty for either tonality or impulsive sound to the 45 dBA $L_{8}$ criterion. However, this criterion can be adjusted upward to reflect the background noise conditions. As it was found that the background noise increased with increasing wind speed, a limit based on wind speed was established (Figure 21). Applying these criteria levels the predicted levels at each residence for each site plan/WTG combination (Figures 2 through 25), it was found that only the noise level at Residence #9 and only for the Vestas V90 unit exceeded the county regulations by about 3 dB over a limited wind speed range, 5 to 7 m/s. Assuming the wind turbine could be operating in this speed range for more than 5 minutes out of any given hour, there would be a significant noise impact in this circumstance and mitigation measurements should be considered.

Low Frequency 1/3 Octave Band Level Criteria

In comparing the low frequency noise predictions to the Kern County criteria as adjusted for background wind-induced noise, it was found that limits were exceeded at six of ten residences for at least some of the siting plans for the Vestas V90 wind turbines. The typical range of reduction required meet the criterion is from 1 to 6 dB. For the Mitsubishi unit, the limits are not exceeded for any of the residences under either of the siting plans. For the cases where the low frequency criteria are exceeded, a significant noise impact would occur based on the Kern County Code and mitigation should be considered in each case as appropriate.

Mitigation Alternatives

From the analysis above, no mitigation is required if the Mitsubishi MWT-1000A units are used. As a result, use of the Mitsubishi unit exclusively is the first mitigation alternative.

For the either plan using Vestas V90 wind turbines, some mitigation of noise levels exterior to some of residential structures would be required under the Kern County Code. Potential acoustical mitigation falls into two the categories: 1.) Reducing the noise of the source, that is the wind turbine generators, or 2.) Modifying the path between the source and receiver. Reducing the noise source levels would mean either using WTG’s, which produce less noise, or limiting the lower wind speed operation of some WTG’s. Path mitigation is typically achieved by inserting barriers or by increasing distance. Lowering levels by placing barriers between the source and the receiver, however, would not be effective in this case because of the height of the WTG’s. As a result, mitigation by modifying the path amounts to relocating the position of some of the wind turbines. The extent to which any of these mitigation measure need to be applied depends very much on which of the two criteria are considered, the $L_{8}$ criteria on the overall A-weighted level or the limits on the lower frequency 1/3 octave band levels. For this reason, is convenient to discuss the mitigation alternatives for these two types of criteria separately. However, it will be noted that applying the low frequency mitigation will
address will be more than sufficient to meet the overall A-weighted noise level requirements

**Overall A-Weighted Level Mitigation**

For the Vestas V90’s, mitigation is only required for Residence #9. As this residence has many WTG’s that contribute to the noise at this location, mitigation could be achieved by addressing any of a number of different units. One alternative would be to substitute the Mitsubishi MWT-1000A for the Vestas units for all WTG locations within 2500 ft of the residence. This would reduce the noise level sufficiently under either of the two siting plans. If only the Vestas units can be used, then attention can be focused on those few units, which contribute the most to the noise level at this point. These are identified in Figure 35 and 36 for the Array and Optimized Development for siting plans, respectively.

Figure 35: Vestas V90 Wind Turbines to Be Addressed for Overall A-Weighted Noise Level Mitigation – Array Development Site Plan

Figure 36: Vestas V90 Wind Turbines to Be Addressed for Overall A-Weighted Noise Level Mitigation – Optimized Development Site Plan
Considering these WTG’s, two options can be considered. The first is relocating or eliminating the units for the plan. Relocation would have to be to a distance greater than about 5000 ft from Residence #9 and away from any other residences. The second option is limit the cut-on speed of these units to 9 m/s. This will reduce the noise level in the speed range from 5 to 8 m/s by the amount required to match the background noise limit as illustrated in Figures 22 and 24.

Low Frequency 1/3 Octave Band Level Mitigation

For the Vestas V90’s, mitigation is only required for a number of residences depending on which siting plan is used. For the Array Development plan, the impacted residences include #1, #7, #9, and #10. For the Optimized Development plan, these include #2, #6, #7, #9, and #10. For any of this cases a number of mitigation scenarios could be developed. For Residences except #9 under either siting plan, the low frequency noise could be mitigation by the substitution the Mitsubishi MWT-1000A for the Vestas units for all WTG locations within 2500 ft of the residence. Residence #9 would require some additional mitigation if this substitution was done for the WTGs within 2500 ft. If such substitution is not feasible, specific attention could be focused those units which contribute the most to the noise level at any specific residence under each of the siting plans. The wind turbine generators that would require attention are identified in Figure 37 and 38 for the Array and Optimized Development plans, respectively. As in the case of the overall A-weighted level criterion, two options can be considered for the identified WTG’s. The first is relocating or eliminating the units for the plan. Relocation would have to be to a distance greater than about 5000 ft from impacted residence and away from any other residences. The second option is limit the cut-on speed of these units. Because the amount that noise level exceeds the criteria depends on the residence involved and the siting plan, the required speeds are listed below by residence and siting plan:

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<thead>
<tr>
<th>Residence #</th>
<th>Cut-on Speed (m/s)</th>
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<tr>
<td></td>
<td>Array Development Plan</td>
</tr>
<tr>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>No Limit</td>
</tr>
<tr>
<td>6</td>
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</tr>
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<td>9</td>
<td>11</td>
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<td>10</td>
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</tbody>
</table>

Residence # Array Development Plan Optimized Development Plan
1 8 No Limit
2 No Limit 10
6 No Limit 9
7 9 10
9 11 11
10 10 No Limit
REFERENCES

2 Guidelines for Preparation and Content of Noise Elements in General Plans, California Department of Health Services, Office of Noise Control, 1976.
3 Chapter 3, Noise Element, Kern County General Plan, County of Kern, California, June, 2004.
4 Development Standards and Conditions, Section 19.64.140, Chapter 19.64 Wind Energy (WE) Combining District, Title 19 Zoning, the Ordinance Code of Kern County, California, June 15, 2006.
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