SOUND TECHNICAL REPORT FOR THE SAND HILL WIND REPOWERING PROJECT, ALAMEDA COUNTY, CALIFORNIA

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Contents

Acronyms and Abbreviations

ANSI	American National Standard Institute
APWRA	Altamont Pass Wind Resource Area
AWEA	American Wind Energy Association
CNEL	Community Noise Equivalent Level
County	Alameda County
CUP	Conditional Use Permit
dB	decibels
dBA	A-weighted sound level
dBC	C-weighted sound level
Hz	Hertz
kHz	kilohertz
kW	kilowatt
L_{dn}	day-night level
L_{eq}	equivalent sound level
$L_{eq}(h)$	1-hour A-weighted equivalent sound level
L_{max}	maximum A-weighted sound level
L_{min}	minimum A-weighted sound level
L_{xx}	percentile-exceeded sound level
m/s	Meters per second
mPa	micro-Pascals
mph	miles per hour
MW	megawatt
NREL	National Renewable Energy Laboratory
project applicant	Sand Hill Wind, LLC
proposed project	Sand Hill Wind Repowering Project
SLM	sound level meter
WTGS	Wind Turbine Generation Systems

Sound Technical Report for the Sand Hill Wind Repowering Project

Sand Hill Wind, LLC (Sand Hill) has proposed the Sand Hill Wind Repowering Project (project), which would entail the removal and replacement of existing wind turbines on multiple parcels in the Altamont Pass Wind Resource Area (APWRA) (Figure 1). The project would involve installation of up to 40 new wind turbines in the approximately 2,595-acre project area. The conceptual project layout, including alternative turbine locations, is illustrated in Figures 2a–2c.

This technical report provides an assessment of sound associated with operation of the proposed wind turbines under three alternative layouts. The report discusses environmental noise fundamentals, applicable noise regulations and policies, existing noise conditions, and an evaluation of effects on the sound environment associated with project implementation.

Project Description

The project is expected to consist of 5 GE 2.3-116 and 35 GE 3.6-137 or GE 3.8-130 wind turbines, although other turbines of similar capacity and characteristics are being considered. Based on use of these turbines, the project would have an installed capacity of up to 144.5 megawatts (MW) of electrical energy production for distribution to the electrical grid. Sand Hill is reviewing three alternative layouts for the project. Sand Hill is conducting ongoing monitoring of wind characteristics on the site and modeling to optimize wind energy production. When more complete information is available, Sand Hill will choose a single layout. Figures 2a–2c show the proposed turbine locations under all three layouts. Twenty-nine of the turbines would be sited identically under all three layouts (turbines 1–11 and 23–40), while eleven would be arranged differently for each alternative (turbines 12–22). The turbines with an “A” suffix are applicable to layout 2, and turbines with a “B” suffix are applicable to layout 3.

Environmental Noise Fundamentals

Sound can be described as the mechanical energy of a vibrating object transmitted by pressure waves through a liquid or gaseous medium (e.g., air) to a hearing organ, such as a human ear. *Noise* is defined as sound that is objectionable because it is disturbing or annoying.

In the science of acoustics, the fundamental model consists of a sound (or noise) source, a receiver, and the propagation path between the two. The loudness of the noise source and obstructions or atmospheric factors affecting the propagation path to the receiver determine the sound level and characteristics of the noise perceived by the receiver.

Sound Descriptors

Continuous sound can be described by frequency (pitch) and amplitude (loudness). A low-frequency sound is perceived as low in pitch. Frequency is expressed in terms of cycles per second, or Hertz (Hz) (e.g., a frequency of 250 cycles per second is referred to as 250 Hz). High frequencies are sometimes more conveniently expressed in kilohertz (kHz), or thousands of Hz. The audible frequency range for humans is generally between 20 Hz and 20,000 Hz.

The amplitude of pressure waves generated by a sound source determines the loudness of that source. Sound pressure amplitude is measured in micro-Pascals (mPa). One mPa is approximately one hundred-billionth (0.00000000001) of normal atmospheric pressure. Sound pressure amplitudes for different kinds of noise environments can range from less than 100 to 100,000,000 mPa. Because of this huge range of values, sound is rarely expressed in terms of mPa. Instead, a logarithmic scale is used to describe *sound pressure level* (also referred to simply as *sound level*) in terms of decibels (dB). The threshold of hearing for young people is about 0 dB, which corresponds to 20 mPa.

The dB scale alone does not adequately characterize how humans perceive noise. The dominant frequencies of a sound have a substantial effect on the human response to that sound. Although the intensity (energy per unit area) of the sound is a purely physical quantity, the loudness or human response is determined by characteristics of the human ear.

Human hearing is limited in the range of audible frequencies as well as in the way it perceives the sound pressure level in that range. In general, people are most sensitive to the frequency range of 1,000–8,000 Hz and perceive sounds within that range better than sounds of the same amplitude in higher or lower frequencies. To approximate the response of the human ear, sound levels of individual frequency bands are weighted, depending on the human sensitivity to those frequencies. Then, an *A-weighted sound level* (expressed in units of dBA) can be computed based on this information.

The A-weighting network approximates the frequency response of the average young ear when listening to most ordinary sounds. When people make judgments of the relative loudness or annoyance of a sound, their judgments correlate well with the A-scale sound levels of those sounds. Table 1 describes typical A-weighted sound levels for various noise sources.

Other weighting networks have been devised to address high noise levels or other special problems (e.g., B-, C-, and D-scales). C-weighted sound levels are sometimes considered for wind turbine noise analysis. The C-weighted sound level, or dBC, gives more weight to lower frequency noise. C-weighting is very close to an unweighted or *flat* response. When evaluating sounds that have varying amounts of low-frequency energy, A-weighted sound levels will not indicate the low frequency variations, but C-weighted sound levels will.

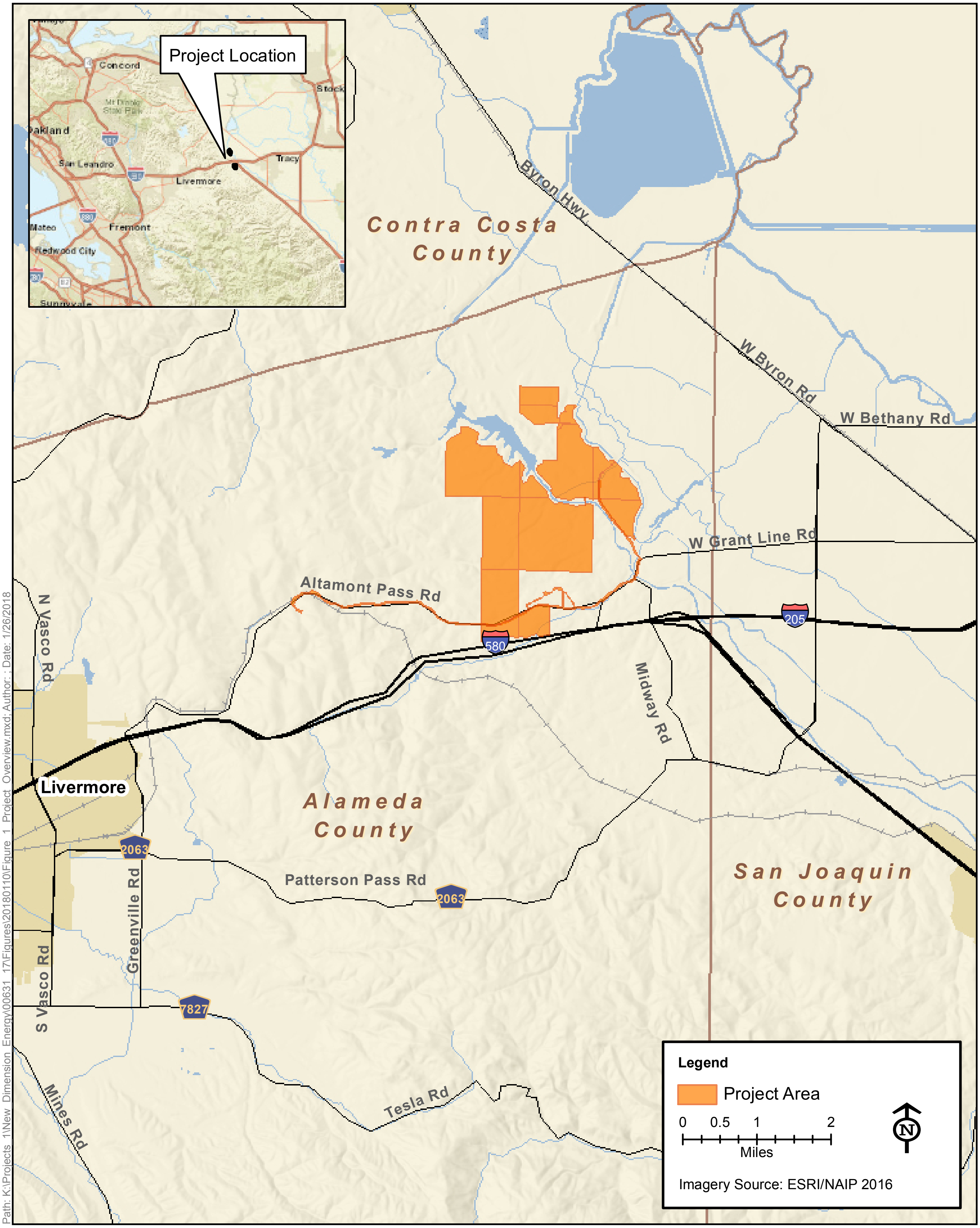

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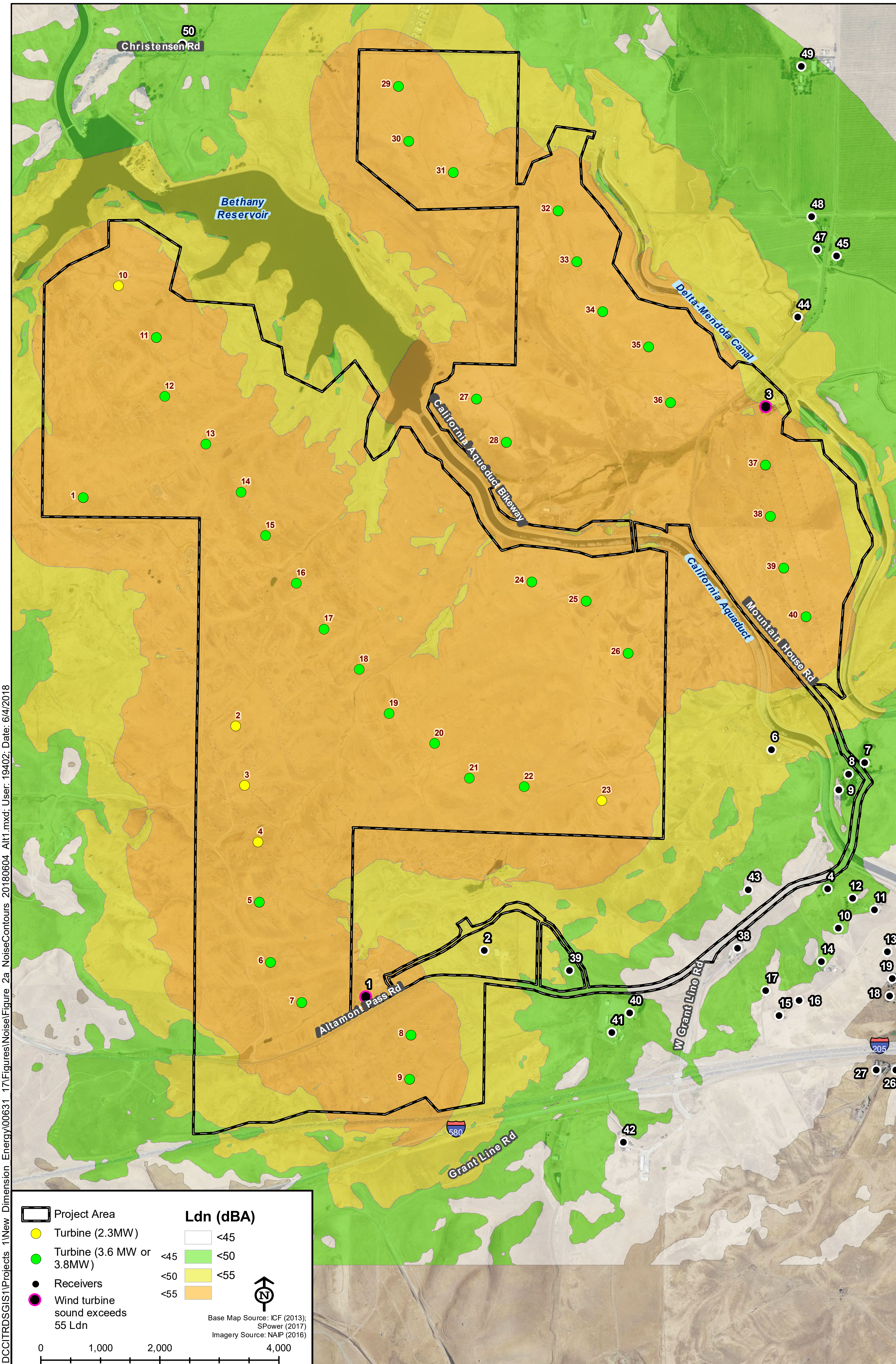
Figure 1
Project Location



\\PDCCITRDSGIS1\Projects 1\New Dimension Energy\00631 17\Figures\Noise\Figure 2a NoiseContours 20180604 Alt1.mxd; User: 19402; Date: 6/4/2018

Figure 2a
Sand Hill Wind Repowering Project Noise Contours – Layout 1

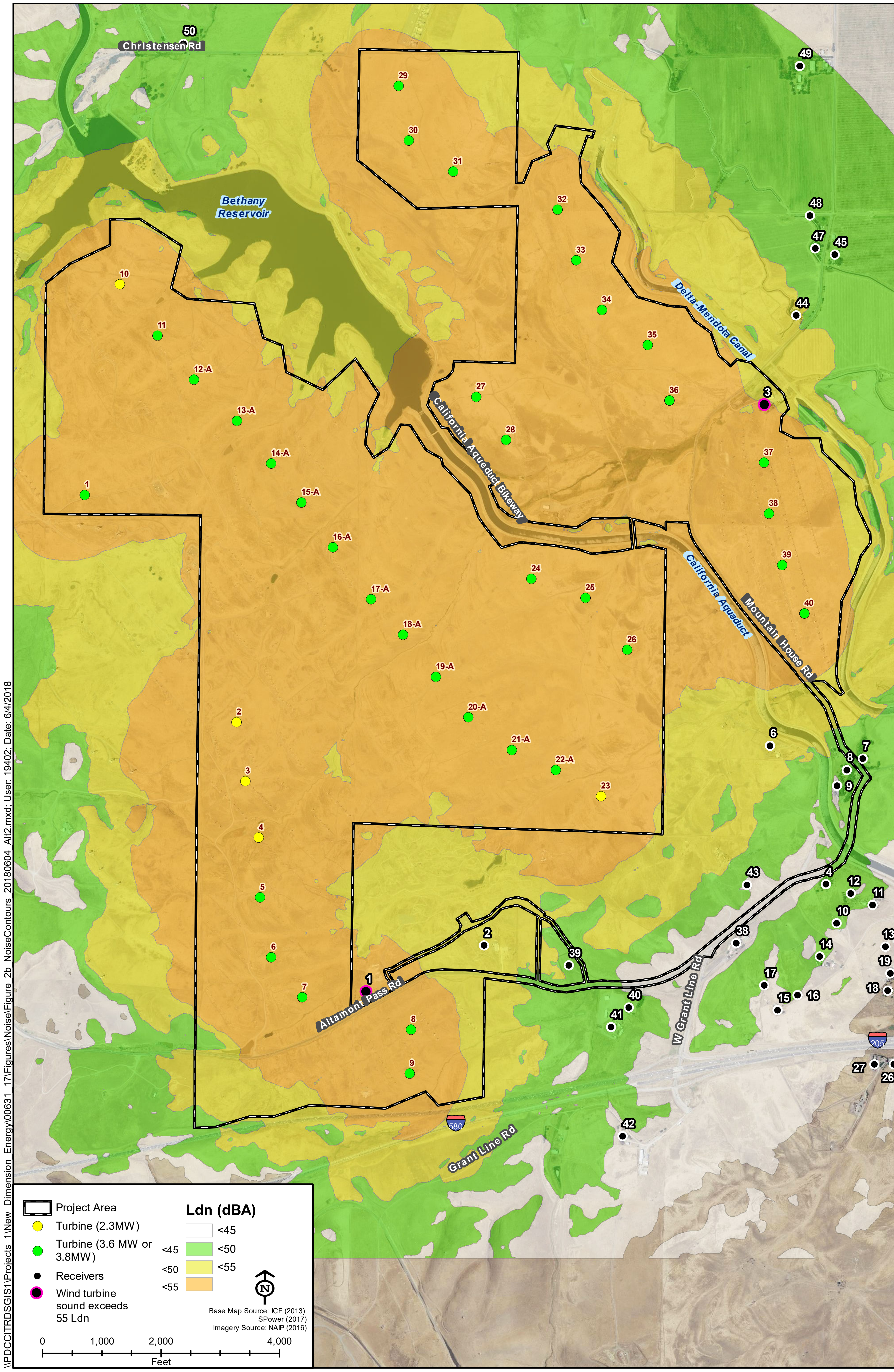


Figure 2b
Sand Hill Wind Repowering Project Noise Contours – Layout 2

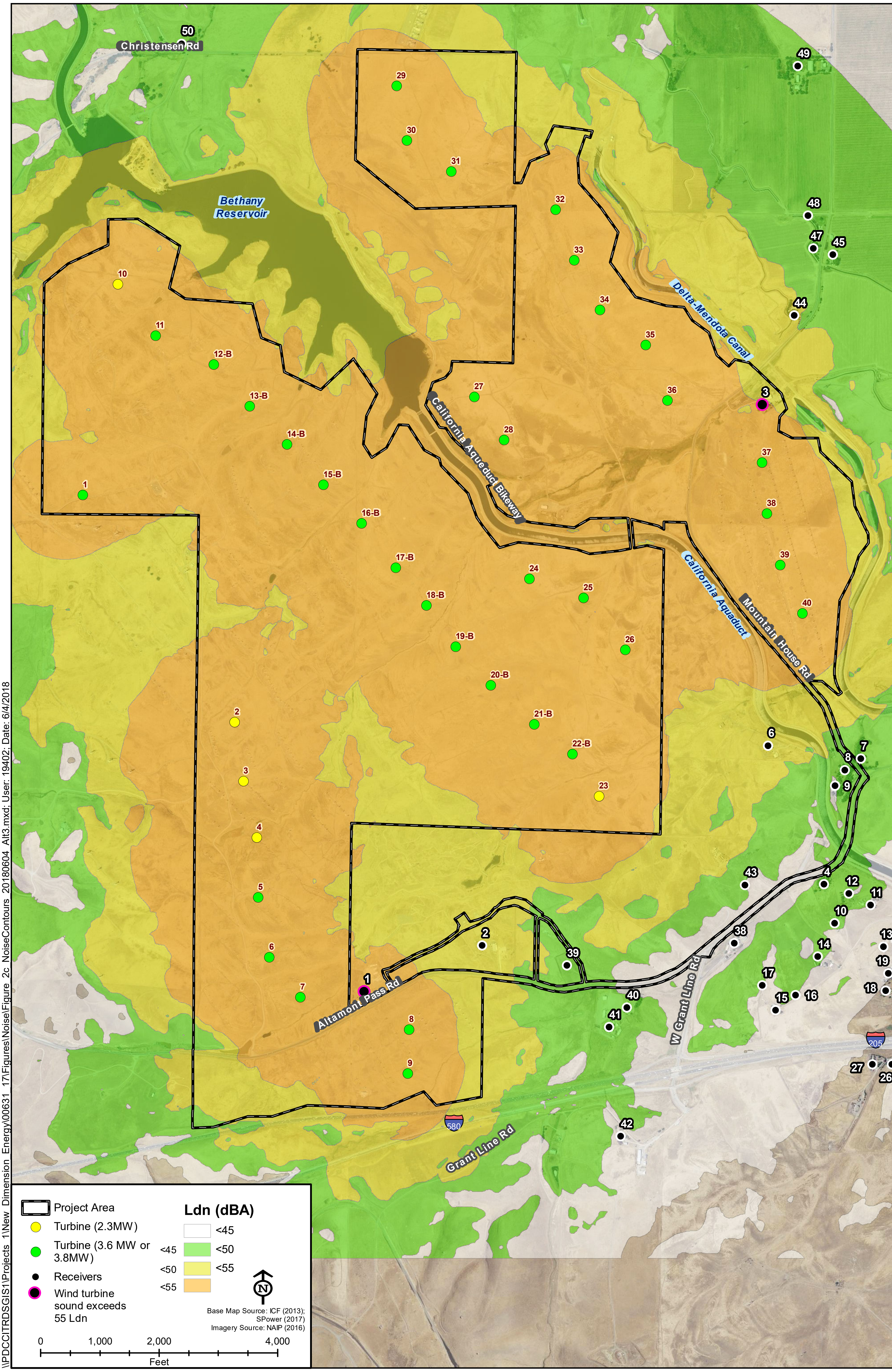


Figure 2c
Sand Hill Wind Repowering Project Noise Contours – Layout 3

Table 1. Typical A-Weighted Sound Levels

Common Outdoor Activities	Sound Level (dBA)	Common Indoor Activities
	— 110 —	Rock band
Jet flying at 1,000 feet		
	— 100 —	
Gas lawn mower at 3 feet		
	— 90 —	
Diesel truck at 50 feet at 50 mph		Food blender at 3 feet
	— 80 —	Garbage disposal at 3 feet
Noisy urban area, daytime		
Gas lawn mower, 100 feet	— 70 —	Vacuum cleaner at 10 feet
Commercial area		Normal speech at 3 feet
Heavy traffic at 300 feet	— 60 —	
		Large business office
Quiet urban daytime	— 50 —	Dishwasher next room
Quiet urban nighttime	— 40 —	Theater, large conference room (background)
Quiet suburban nighttime		
	— 30 —	Library
Quiet rural nighttime		Bedroom at night
	— 20 —	
		Broadcast/recording studio
	— 10 —	
Lowest threshold of human hearing	— 0 —	Lowest threshold of human hearing

Source: California Department of Transportation 2013.
dBA = A-weighted sound level
mph = miles per hour

Noise in most typical environments fluctuates over time. Various noise descriptors have been developed to describe time-varying noise levels. The following are the noise descriptors most commonly used in environmental noise analysis.

- **Equivalent Sound Level (L_{eq}):** L_{eq} represents an average of the sound energy occurring over a specified period. In effect, L_{eq} is the steady-state sound level containing the same acoustical energy as the time-varying sound that actually occurs during the same period. The 1-hour A-weighted equivalent sound level (L_{eq}[h]) is the energy average of A-weighted sound levels occurring during a 1-hour period.
- **Percentile-Exceeded Sound Level (L_{xx}):** L_{xx} represents the sound level exceeded for a given percentage of a specified period (e.g., L_{10} is the sound level exceeded 10% of the time, and L_{90} is the sound level exceeded 90% of the time).
- **Minimum and Maximum Sound Level (L_{min} and L_{max}):** L_{min} is the lowest A-weighted sound level during a specified period, while L_{max} is the highest.

- **Day-Night Level (L_{dn}):** L_{dn} is the energy average of A-weighted sound levels occurring over a 24-hour period, with a 10-dB penalty added to A-weighted sound levels occurring between 10:00 p.m. and 7:00 a.m.
- **Community Noise Equivalent Level (CNEL):** Much like L_{dn}, CNEL is the energy average of the A-weighted sound levels occurring over a 24-hour period, with a 10-dB penalty added to A-weighted sound levels occurring between 10:00 p.m. and 7:00 a.m. and a 5-dB penalty added to A-weighted sound levels occurring between 7:00 p.m. and 10:00 p.m.

Decibel Addition

Because decibels are logarithmic units, sound pressure levels cannot be added or subtracted through ordinary arithmetic. On the dB scale, a doubling of sound energy corresponds to a 3-dB increase. In other words, when two identical sources are each producing sound of the same loudness, their combined sound level at a given distance would be 3 dB higher than one source under the same conditions. For example, if one wind turbine produces a sound pressure level of 70 dBA, two wind turbines would not produce 140 dBA—rather, they would combine to produce 73 dBA. The cumulative sound level of any number of sources such as wind turbines can be determined using decibel addition.

Perception of Sound Level Changes

Under controlled conditions in an acoustical laboratory, the trained, healthy human ear is able to discern 1-dB changes in sound levels when exposed to steady, single-frequency (pure tone) signals in the mid-frequency (1,000–8,000 Hz) range. In typical noisy environments, changes in sound of 1–2 dB are generally not perceptible. However, it is widely accepted that people are able to begin to detect sound level increases of 3 dB in typical noisy environments. Further, a 5-dB increase is generally perceived as a distinctly noticeable increase, and a 10-dB increase is generally perceived as a doubling of loudness. Accordingly, a doubling of sound energy (e.g., doubling the volume of traffic on a highway) that would result in a 3-dB increase in sound would generally be barely detectable.

Sound Propagation

When sound propagates over distance, it changes in level and frequency. The manner in which sound reduces with distance depends on the factors described in this section.

Geometric Spreading

Sound from a stationary localized source (i.e., a point source) propagates uniformly outward in a spherical pattern. The sound level attenuates (i.e., decreases) at a rate of 6 dB for each doubling of distance from a point 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 the source alone. If the sound power level of an idealized source and its distance from a receiver are known, sound pressure level at the receiver point can be calculated based on geometric spreading. This approach is applied to wind turbine generators in the standard measurement techniques for determining the sound power or source level (Illingworth & Rodkin 2009).

A number of factors can modify the sound level associated with spherical spreading. The first factor is the ground, which acts as a reflecting plane. If the ground is hard, sound energy is reflected off the ground and typically increases A-weighted sound levels by 3 dB. If the ground plane is acoustically soft or absorptive (such as grassland or a plowed field), some sound energy is absorbed by the ground and the increase from reflection will be less than 3 dB.

Other Factors that Affect Propagation

Additional factors that affect sound propagation are often grouped under the term *excess attenuation*. Excess attenuation is any additional attenuation that is not attributed to simple spherical spreading. Excess attenuation includes shielding effects from barriers (e.g., hills or structures); attenuation effects associated with vegetation, trees, rain, sleet, snow, or fog; and attenuation associated with wind and temperature gradients. Excess attenuation is almost always present under outdoor propagation conditions. For sound propagating over soft ground at near grazing angles of incidence, excess attenuations of 20–30 dB can be measured as a result of the interference effect of the direct and reflected sound. However, under certain meteorological conditions, some of these excess attenuation mechanisms are reduced or eliminated, leaving spherical spreading as the primary determinant of sound level at a receiver location (Illingworth & Rodkin 2009).

Other Factors Related to Wind Turbines

Operating wind turbines can generate two types of sound: mechanical sound from components such as gearboxes, generators, yaw drives, and cooling fans; and aerodynamic sound from the flow of air over and past the rotor blades. Modern wind turbine design has greatly reduced mechanical sound, which can generally be ignored in comparison to the aerodynamic sound—often described as a swishing or whooshing sound.

Wind turbines produce a broadband sound (i.e., the sound covers a wide range of frequencies, including low frequencies). Low-frequency sounds are in the range of 20–100 Hz, and infrasonic sound (or infrasound) is low-frequency sound of less than 20 Hz. Low-frequency sound propagates over longer distances than higher frequency sound, is transmitted through buildings more readily, and can excite structural vibrations (e.g., rattling windows or doors). The threshold of perception, in decibels, also increases as the frequency decreases. For example, in the frequency range where humans hear best (in the low kH), the threshold of hearing is at about 0 dB, but at a frequency of only 10 Hz, the threshold of hearing is about 100 dB (Rogers et al. 2006).

Older wind turbines—particularly those in which the blades were on the downwind side of the tower—produced more low-frequency sound because their towers blocked wind flow, causing the blades to pass through more turbulent air. Modern, upwind turbines produce a broadband sound that includes low-frequency sounds, but not at significant levels. A primary cause for low-frequency sounds in modern turbines is the blade passing through the change in air flow at the front of the tower, and this can be aggravated by unusually turbulent wind conditions. This effect is generally referred to as blade amplitude modulation because the aerodynamic sound generated by the blades (i.e., the swishing sound) is modulated as the turbine blades pass through uneven air velocities. The uneven air that causes this effect may be due to interaction of other turbines, excessive wind shear, or topography (Bowdler 2008).

Wind generates sound. The amount of sound generated can vary widely depending primarily on the amount of vegetation in the area and the speed of the wind. For a given wind speed, the sound level in a desert with no trees or vegetation will be different than in a highly vegetated area. When trees are in full leaf, wind rustling through the leaves produces high-frequency sound. The amount of sound generated depends on wind speed, the distance to the trees or foliage, and the approximate frontal area of the trees or foliage as seen from the observed position. Sound levels generated by wind can range from approximately 20 to 60 dBA for wind speeds in the range of 2–20 miles per hour (mph) (Hoover & Keith 2000).

Regulatory Setting

Federal, state, and local agencies regulate different aspects of environmental noise. Generally, the federal government establishes noise standards for transportation-related noise sources closely linked to interstate commerce. These sources include aircraft, locomotives, and heavy-duty trucks. The state government sets noise standards for transportation noise sources such as automobiles, light trucks, and motorcycles. Noise sources associated with industrial, commercial, and construction activities are generally subject to local control through noise ordinances and general plan policies. Local general plans identify general principles intended to guide and influence development plans. No federal or state regulations are directly applicable to the proposed project. The local regulatory setting is discussed below.

Local

County General Plan Noise Element

The County's General Plan Noise Element (Alameda County 1975) contains goals, objectives, and implementation programs to provide county residents with an environment that is free from excessive noise, and promotes compatibility of land uses with respect to noise. The Noise Element does not explicitly define the acceptable outdoor noise level for the backyards of single-family homes or common outdoor spaces of multifamily housing projects, but it recognizes the U.S. Environmental Protection Agency noise level standards for residential land uses. These standards are an exterior L_{dn} of 55 dBA and an interior L_{dn} of 45 dBA. (The L_{dn} measurement, which also includes a 10 dB weighting for nighttime sound, is approximately equal to the CNEL for most environmental settings.) The Noise Element also references noise and land use compatibility standards developed by an Association of Bay Area Governments–sponsored study.

East County Area Plan

The County's *East County Area Plan* (Alameda County 2000) contains a goal, policies, and implementation programs related to community noise and windfarms.

Goal: To minimize East County residents and workers exposure to excessive noise.

Policy 170: The County shall protect nearby existing uses from potential traffic, noise, dust, visual, and other impacts generated by the construction and operation of windfarm facilities.

Policy 288: The County shall endeavor to maintain acceptable noise levels throughout East County.

Policy 289: The County shall limit or appropriately mitigate new noise sensitive development in areas exposed to projected noise levels exceeding 60 dB based on the California Office of Noise Control Land Use Compatibility Guidelines.

Policy 290: The County shall require noise studies as part of development review for projects located in areas exposed to high noise levels and in areas adjacent to existing residential or other sensitive land uses. Where noise studies show that noise levels in areas of existing housing will exceed "normally acceptable" standards (as defined by the California Office of Noise Control Land Use Compatibility Guidelines), major development projects shall contribute their pro-rated share to the cost of noise mitigation measures such as those described in Program 104.

Program 74: The County shall amend the Zoning Ordinance to incorporate siting and design standards for wind turbines to mitigate biological, visual, noise, and other impacts generated by windfarm operations.

Program 104: The County shall require the use of noise reduction techniques (such as buffers, building design modifications, lot orientation, sound walls, earth berms, landscaping, building setbacks, and real estate disclosure notices) to mitigate noise impacts generated by transportation-related and stationary sources as specified in the California Office of Noise Control Land Use Compatibility Guidelines.

County General Code

Several components of the County's General Code are applicable to the project. The County's Noise Ordinance (County General Code, Chapter 6.60) allows higher noise exposure levels for commercial properties than for residential uses, schools, hospitals, churches, or libraries. These standards augment the state-mandated requirements of the County Building Code, which establishes standards for interior noise levels consistent with the noise insulation standards in the California State Building Code. Table 2 shows the number of cumulative minutes that a particular external noise level is permitted, as well as the maximum noise allowed under the County General Code.

Table 2. Alameda County Exterior Noise Standards

Cumulative Number of Minutes in any 1-hour Period	Daytime (7:00 a.m. to 10:00 p.m.) (dBA)	Nighttime (10:00 p.m. to 7:00 a.m.) (dBA)
Residential uses, schools, hospitals, churches, and libraries		
30	50	45
15	55	50
5	60	55
1	65	60
Maximum (0)	70	65
Commercial uses		
30	65	60
15	70	65
5	75	70
1	80	75
Maximum (0)	85	80

dBA = A-weighted sound level

The County Zoning Ordinance (County General Code, Chapter 17) restricts noise from commercial activities by prohibiting any use that would generate a noise or vibration that is discernible without instruments beyond the property line. This performance standard does not apply to transportation activities or temporary construction work. The provisions of the zoning ordinance do not apply to noise sources associated with construction, provided the activities do not take place before 7:00 a.m. or after 7:00 p.m. on any day except Saturday or Sunday, or before 8:00 a.m. or after 5:00 p.m. on Saturday or Sunday.

APWRA Repowering Final Program EIR

The Altamont Pass Wind Resource Area Repowering Final Program Environmental Impact Report (PEIR) (Alameda County 2014) refers to the County's conditional use permits (CUPs) for the operation of windfarms regulated by Resolution Number R-2005-463.. The following specific condition regarding noise levels is stated:

> Noise Standards: Wind turbines shall be operated so as to not exceed the County's noise standard of 55 dBA (L_{dn}) or 70 dBC (L_{dn}) as measured in both cases at the exterior of any dwelling unit. If the dwelling unit is on land under lease from the Permittee, the applicable standard shall be 65 dBA (L_{dn}) and 70 dBC (L_{dn}).

The County has determined that use of a single 55 dBA standard will be sufficient to ensure that no 70 dBC threshold is exceeded. Research and analysis indicate that a low-frequency noise level of 70 dBC could not be reached unless the noise level were also well over the 55 dBA threshold.

The resolution approving the CUPs for windfarm operations included a finding that as a land use, the wind energy use "is properly related to other land uses and transportation and service facilities in the vicinity, in that… d) Although some residents may object to the visual, noise, or other effects of the turbines, the County has determined that the wind energy projects are in compliance with the conditions of approval and are an acceptable use in the area."

The PEIR identifies thresholds for assessing the significance of noise impacts from wind turbine operations. The PEIR states that a project would be considered to have a significant effect if it would result in any of the conditions listed below.

- Exposure of residences to noise from new wind turbines in excess of 55 dBA (L_{dn}) where wind turbine noise is currently less than 55 dBA (L_{dn}). In the situation where the dwelling unit is on the same parcel being leased for windfarm, 65 dBA (L_{dn}) is used as the threshold.
- Exposure of residences to a daily noise increase in L_{dn} value of more than 5 dB from the addition of new wind turbines where the existing noise level is in excess of 55 dBA (L_{dn}). In the situation where the dwelling unit is on the same parcel being leased for windfarm, 65 dBA (L_{dn}) is used as the threshold.
- Exposure of residences to equipment noise associated with construction activities that exceed Alameda County noise ordinance standards (Table 3.11-3) during nonexempt hours (7 p.m. to 7 a.m. on weekdays and 5 p.m. to 8 a.m. on Saturday and Sunday).

The PEIR concluded that significant noise impacts could occur during decommissioning of existing turbine, construction of new turbines, and operation of new wind turbines in the project area. The following mitigation measures were identified to reduce these impacts to a less-than-significant level.

Mitigation Measure NOI-1: Perform project-specific noise studies and implement measures to comply with County noise standards

The applicant for any proposed repowering project will retain a qualified acoustic consultant to prepare a report that evaluates noise impacts associated with operation of the proposed wind turbines. This evaluation will include a noise monitoring survey to quantify existing noise conditions at noise sensitive receptors located within 2,000 feet of any proposed turbine location. This survey will include measurement of the daily A-weighted L_{dn} values over a 1-week period and concurrent logging of wind speeds at the nearest meteorological station. The study will include a site-specific evaluation of predicted operational noise levels at nearby noise sensitive uses. If operation of the project is predicted to result in noise in excess of 55 dBA (L_{dn}) where noise is currently less than 55 dBA (L_{dn}) or result in a 5 dB increase where noise is currently greater than 55 dBA(L_{dn}), the applicant will modify the project, including selecting new specific installation sites within the program area, to ensure that these performance standards will not be exceeded.

Methods that can be used to ensure compliance with these performance standards include but not limited to increasing the distance between proposed turbines and noise sensitive uses and the use of alternative turbine operational modes to reduce noise. Upon completion of the evaluation, the project applicant will submit a report to the County demonstrating how the project will comply with these performance standards. After review and approval of the report by County staff, the applicant will incorporate measures as necessary into the project to ensure compliance with these performance standards.

Mitigation Measure NOI-2: Employ noise-reducing practices during decommissioning and new turbine construction

Project applicants will employ noise-reducing construction practices so that construction noise does not exceed Alameda County noise ordinance standards. Measures to limit noise may include the following:

- Prohibit noise-generating activities before 7 a.m. and after 7 p.m. on any day except Saturday or Sunday, and before 8 a.m. and after 5 p.m. on Saturday or Sunday.
- Locate equipment as far as practical from noise sensitive uses.
- Require that all construction equipment powered by gasoline or diesel engines have sound-control devices that are at least as effective as those originally provided by the manufacturer and that all equipment be operated and maintained to minimize noise generation.
- Use noise-reducing enclosures around noise-generating equipment where practicable.
- Implement other measures with demonstrated practicability in reducing equipment noise upon prior approval by the County.

In no case will the applicant be allowed to use gasoline or diesel engines without muffled exhausts.

Existing Sound Environment

Land around the project area is primarily agricultural with some scattered rural residences. Sound sources in the project area are primarily traffic on local and distant roadways and natural sources such as birds and wind blowing through tall grass. The older existing turbines on the project site have been either removed or are non-operational so they are no longer a source of sound in the area. New turbines that have been installed on adjacent properties are a source of sound as well but are not dominant in the sound environment on the project site. Short- and long-term noise monitoring for a previous project was conducted on the site in January 2016 near residential uses (ICF International 2016).

Short-Term Monitoring

Short-term (1–2 minute average) measurements were collected at three monitoring locations designated as S1, S2, and S3 (Figures 2a–2c). ICF was not granted landowner access to the properties near S1 and S3, so those locations were sited in the public right-of-way directly adjacent to Altamont Pass Road and Midway Road, respectively. The landowner granted ICF access to the property at S2.

Monitoring was conducted at S1, S2, and S3 on Monday, January 25, 2016, at 11:21 a.m., 11:53 a.m., and 12:31 p.m., respectively, using a Larson Davis Model 831 sound level meter (SLM). This SLM is classified as a Type 1 (precision-grade) instrument, as defined in American National Standard Institute (ANSI) specification S1.4-1984 and International Electrotechnical Commission publications 804 and 651. The meters were set to the "slow" time-response mode and the A-weighting filter network.

Wind speed, temperature, and relative humidity measurements were taken during the sound measurement periods with a handheld Kestrel 3000 portable weather meter. Weather conditions were generally calm with occasional gusts to 5 or 6 mph. Skies were overcast, with temperature at 53°F and relative humidity at 75%. The sound level measurements were taken during calm, quiet periods when there were no vehicles or other obvious sources of sound. None of the existing turbines in the immediate area were operating. Table 3 summarizes the short-term sound level measurement results at each monitoring position.

Table 3. Summary of Short-Term Measurements

Position	Start Time	Duration	L_{eq}	L_{max}	L_{min}	L_{10}	L_{33}	L_{50}	L_{90}
S1	11:21 a.m.	1 min	40.8	57.2	35.7	43.1	39.1	38.1	36.9
S2	11:53 a.m.	2 min	34.9	44.1	27.1	38.5	34.0	32.6	28.7
S3	12:31 a.m.	2 min	48.2	62.4	42.6	51.9	48.5	47.4	44.3

Latitude, Longitude Coordinates: 37.743639°, -121.603321°.
L_{eq} = equivalent sound level.
L_{max} = maximum A-weighted sound level.
L_{min} = minimum A-weighted sound level.
L_{xx} = percentile-exceeded sound level (i.e., 10%, 33%, 50%, and 90%) .

Long-Term Monitoring

Long-term sound level data were collected at monitoring positions S1, S2, and S3 in 1-hour increments on Tuesday, January 26, and Wednesday, January 27, 2016, beginning at midnight and ending at midnight. Monitoring was conducted using three Piccolo SLM-P3 SLMs, a Type 2 instrument as defined in ANSI specification S1.4-1984 and International Electrotechnical Commission publications 804 and 651. As previously noted, positions S1 and S3 were located in the public right-of-way directly adjacent to the roadway. Accordingly, the measurements at these positions were strongly influenced by traffic and reflect sound levels that are higher than at the nearby residences; the results at these positions are provided for general reference. Table 4 summarizes the measurement results.

Table 4. Summary of Long-Term Measurements

Location	Tuesday January 26 (L_{dn})	Wednesday January 27 (L_{dn})
S1*	77.5	77.2
S2	50.8	49.5
S3*	67.0	65.5

*Measurement location abuts roadway and is strongly influenced by traffic. This measurement value reflects a sound level higher than on the nearby residential property.

L_{dn} = day-night level

Impact Discussion

Analysis Methods

Wind Turbine Sound

Sand Hill provided one-third octave band A-weighted sound power data from GE for the proposed wind turbines. Sound power levels in terms of octave band levels and the overall A-weighted level for each of the two turbines are shown in Table 5. For both turbine types, the highest total sound power level was determined to occur at a hub height wind speed of 10 meters per second or more. The sound power data for the GE 2.3-116 indicated wind speeds for hub heights ranging from 80 to 94 meters. For the GE 3.8-137, wind speeds were calculated for hub heights ranging from 110 to 131 meters.

Table 5. A-Weighted Sound Power Levels

Turbine Type	Octave Bands, A-Weighted										Total Sound Power Level (dBA)
	16	32	63	125	250	500	1000	2000	4000	8000	
GE 2.3-116	65.1	79.0	89.0	95.2	99.7	102.8	102.5	97.3	87.1	66.4	107.5
GE 3.8-137	66.5	78.5	86.8	92.6	96.4	99.4	102.1	102.0	93.7	79.2	107.0

Modeling of Proposed Repowering Project

Noise levels from wind turbines were modeled using the SoundPlan 7.4 acoustical modeling software, which implements ISO Standard 9613-2: Acoustics—Attenuation of Sound during Propagation Outdoors—Part 2 General Method of Calculation for Propagation Modelling. The standard is designed to calculate sound pressure levels under "average" meteorological conditions that are favorable to propagation. The standard applies downwind and temperature inversion conditions to predict reasonable worst-case sound levels.

Each of the three alternative layouts would involve the operation of 40 turbines. A hub height of 80 meters was assumed for all turbines. The layout for each option consists of 5 of the model GE 2.3-116 turbines and 35 of the model GE-3.8-137 turbines. The cumulative sound level from simultaneous operation of all turbines under reasonable worst-case sound propagation conditions at nearby residences was used as the model case for each layout. 24-hour operation of the turbines was assumed. The ground type was modeled as a hard surface (zero value) to apply a worst-case ground attenuation factor. No other attenuation factors or safety factors were applied. Receiver locations are shown in Figures 2a–2c.

Modeled sound levels at each receiver location under each layout are shown in Table 6 in terms of L_{eq} and L_{dn} using A-weighting. Figures 2a–2c depict the sound contours for each layout.

Table 6. Modeling Results (dBA)

	Layout 1		Layout 2		Layout 3	
Receiver	L_{dn}	L_{eq}	L_{dn}	L_{eq}	L_{dn}	L_{eq}
R01	**58.3**	51.9	**58.2**	51.8	**58.2**	51.8
R02	53.6	47.2	53.3	46.9	53.0	46.6
R03	**55.0**	48.6	**55.0**	48.6	**55.1**	48.6
R04	45.3	38.9	45.1	38.7	45.1	38.7
R05	39.0	32.6	39.1	32.7	39.2	32.7
R06	52.0	45.6	52.3	45.9	52.4	46.0
R07	47.7	41.3	47.8	41.4	47.8	41.4
R08	48.8	42.4	48.9	42.5	49.0	42.6
R09	46.5	40.1	46.6	40.2	46.7	40.3
R10	45.5	39.1	45.7	39.3	45.8	39.4
R11	42.4	36.0	42.5	36.1	42.5	36.0
R12	46.5	40.1	46.7	40.3	46.7	40.3
R13	44.7	38.3	44.9	38.5	45.0	38.6
R14	45.7	39.3	46.0	39.6	46.0	39.6
R15	44.3	37.9	44.4	38.0	44.3	37.9
R16	44.7	38.3	44.8	38.4	44.8	38.4
R17	46.5	40.0	46.7	40.3	46.7	40.3
R18	40.0	33.6	40.1	33.7	40.1	33.7
R19	40.2	33.8	40.3	33.9	40.3	33.9
R20	40.9	34.5	41.0	34.6	41.0	34.6
R21	39.6	33.1	39.7	33.2	39.7	33.3

Receiver	Layout 1		Layout 2		Layout 3	
	L_{dn}	L_{eq}	L_{dn}	L_{eq}	L_{dn}	L_{eq}
R22	41.7	35.2	41.7	35.3	41.6	35.2
R23	41.7	35.3	42.0	35.6	42.0	35.6
R24	43.7	37.3	43.8	37.4	43.8	37.4
R25	38.6	32.2	38.7	32.3	38.7	32.3
R26	38.7	32.3	38.8	32.4	38.8	32.4
R27	39.1	32.6	39.2	32.7	39.2	32.7
R28	38.6	32.2	38.5	32.0	38.4	31.9
R29	40.1	33.7	40.2	33.8	40.0	33.6
R30	38.0	31.5	38.1	31.6	38.0	31.6
R31	37.9	31.5	38.0	31.6	38.0	31.5
R32	37.6	31.2	37.7	31.3	37.7	31.3
R33	40.9	34.5	41.0	34.6	41.2	34.8
R34	40.0	33.6	40.2	33.7	40.1	33.7
R35	38.7	32.3	39.1	32.7	39.1	32.7
R36	37.7	31.3	37.8	31.4	37.8	31.4
R37	39.2	32.8	39.3	32.9	39.4	33.0
R38	44.1	37.6	44.2	37.8	44.2	37.8
R39	50.3	43.9	50.3	43.9	49.8	43.3
R40	47.8	41.4	47.5	41.0	46.8	40.4
R41	47.5	41.1	47.5	41.1	47.1	40.7
R42	46.6	40.2	46.5	40.1	46.4	40.0
R43	47.5	41.1	47.9	41.4	47.8	41.4
R44	51.5	45.1	51.5	45.1	51.5	45.1
R45	48.7	42.3	48.8	42.3	48.8	42.4
R47	49.0	42.6	49.0	42.6	49.0	42.6
R48	48.3	41.9	48.3	41.9	48.4	42.0
R49	45.8	39.4	45.9	39.5	45.9	39.5
R50	47.0	40.6	47.1	40.7	47.1	40.7
R70	44.5	38.1	44.6	38.2	44.7	38.3
R71	45.2	38.8	45.3	38.9	45.3	38.9
R72	44.9	38.5	45.0	38.6	45.0	38.6
R73	44.2	37.8	44.3	37.9	44.4	38.0
R74	44.5	38.1	44.6	38.2	44.7	38.3
R75	42.1	35.7	42.3	35.8	42.3	35.9
R76	43.2	36.8	43.3	36.9	43.4	37.0

dBA = A-weighted decibels.

The results in Table 6 show an exceedance of the County 55 L_{dn} (A) noise standard at Receivers R1 and R3.

Discussion and Conclusions

As discussed above, worst-case modeled sound levels exceed County noise standards at two residential receivers (R1 and R3) under all three project layouts. Table 7 summarizes the exceedances.

Table 7. Modeling Conclusions

	Layout 1		Layout 2		Layout 3	
Receiver	L_{dn} (dBA)	Exceedance of 55 L_{dn}	L_{dn} (dBA)	Exceedance of 55 L_{dn}	L_{dn} (dBA)	Exceedance of 55 L_{dn}
R1	58.3	3.3	58.2	3.2	58.2	3.2
R3	55.0	0.0	55.0	0.0	55.1	0.1

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