Arche Solar Project

Case No. 20-0979-EL-BGN

7X.energy™

Exhibit H

Noise Assessment

7X ENERGY

ARCHE SOLAR

Noise Assessment | July 20, 2020

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1.0 INTRODUCTION

The Arche Solar Project ("Project") is a photovoltaic power facility proposed for Fulton County in northwest Ohio. The project is proposed to have a nameplate capacity of up to 107 MW and include solar panels, inverters, and transformers. To inform the Ohio Power Siting Board ("OPSB") permitting process, RSG was hired by the developer of the Project, 7X Energy, to perform a Noise Assessment of existing acoustical conditions in the area and sound emissions of the primary sound-producing Project components. This report of the assessment includes:

- A Project description;
- Sound level limits applicable to the Project;
- Sound level monitoring procedures and results;
- Operational sound propagation modeling procedures and results;
- Construction noise modeling; and
- Results.

A primer of acoustical terminology used in this report can be found in Appendix A.

2.0 PROJECT DESCRIPTION

The Project is proposed to be located in the northern part of Fulton County, Ohio. Fulton County is located in northwest Ohio, abutting the Michigan border to the north. The project will be bordered on the east by County Road 21, County Road 23 to the west, and Country Road N to the south. U.S. Highway 20 ("US-20") runs through the northern half of the Project Area. The western side of the Project extends approximately 800 meters (2,625 feet) north of US-20. The Town of Fayette is approximately 1,300 meters (4,265 feet) west of the nearest project parcel.

The area is primarily agricultural with scattered residences and farmsteads throughout. A total of 33 residences are included in this assessment and are shown along with Project elements in Figure 1.

Based on the preliminary layout for the Project, the primary operational sound sources include 33 inverter skids (Power Electronics HEM) spread throughout the Project Area and a main high-voltage transformer (139 MVA) at the Project substation. The Project substation is located on the western edge of the Project Area. An existing substation on County Road 23 is located just west of the proposed substation. Each inverter skid includes an inverter and medium voltage transformer. Noise emissions from all of these sources are analyzed in this assessment. Typical operations of the Project include transformers and inverters operating during the day and only transformers operating at night. However, the inverters may operate sometimes at night for VAR[1] support. As such, it has been assumed for this assessment that all sources could operate at night.

[1] volt-ampere reactive

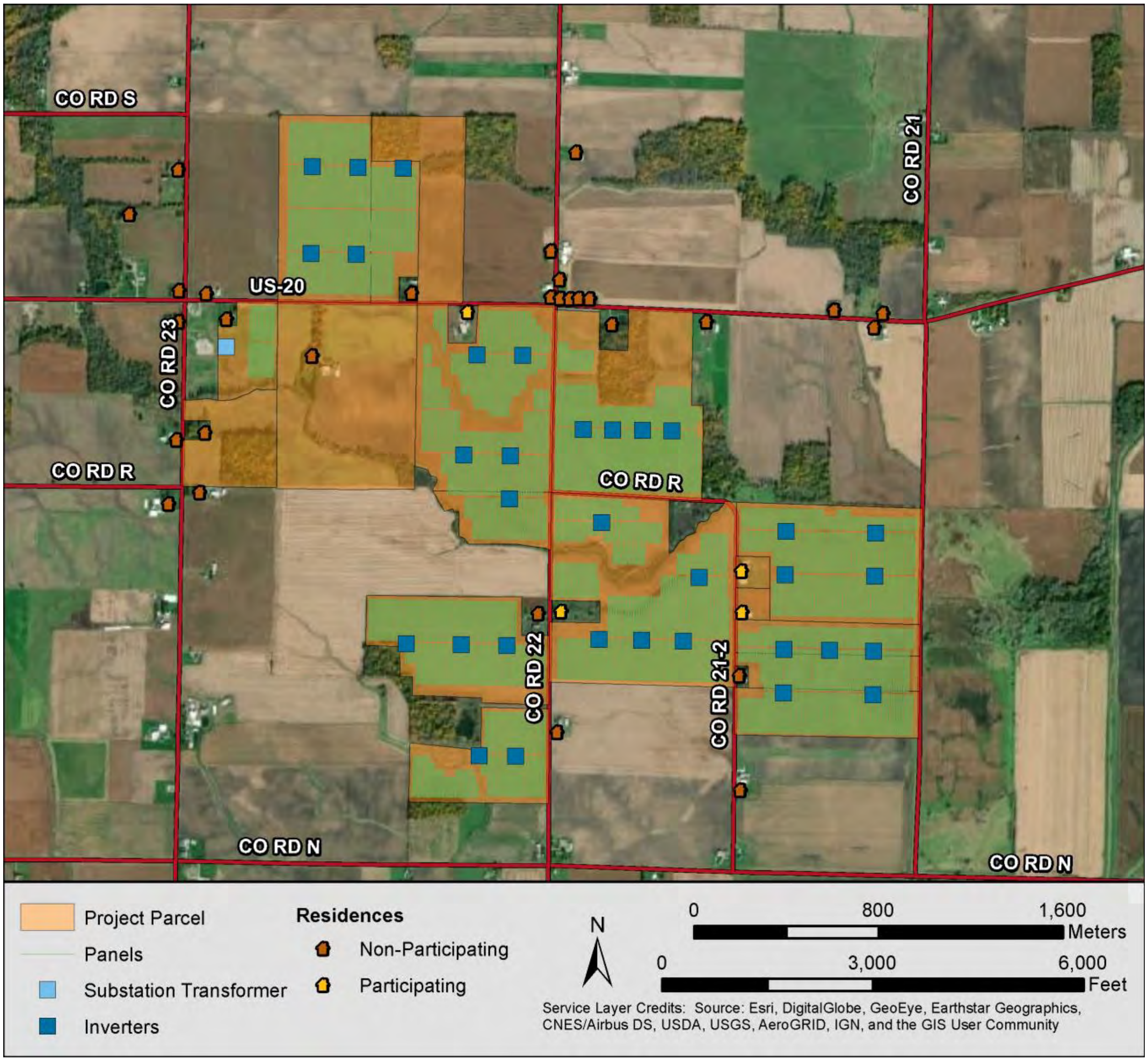

FIGURE 1: PROJECT AREA MAP

3.0 APPLICABLE SOUND LEVEL LIMITS

State noise policy applicable to this Project can be found in Ohio Administrative Code ("OAC") Chapter 4906-4 Section 8(A), which is reproduced below. This Section requires that information on noise be provided including:

- Projected sound levels at the nearest property boundary due to construction;
- Projected sound levels at the nearest property boundary due to operation;
- Descriptions of mitigation measures; and
- A preconstruction background sound level study.

Although there is a specific sound level limit for wind power projects within the OAC, there is not one for solar power projects. The design threshold for non-participating sensitive receptors used in this assessment of the Project is the measured ambient sound level plus 5 dB for daytime and nighttime periods. That is, the design threshold during the daytime is the measured daytime ambient sound level plus 5 dB, and the nighttime design threshold will be the measured nighttime ambient sound level plus 5 dB.

Based on the background sound monitoring conducted at three locations throughout the Project Area (see Section 4.2), the average existing daytime and nighttime equivalent continuous sound levels (L_{eq}) in the area are 45 dBA and 42 dBA, respectively. This sets the daytime design threshold at 50 dBA and the nighttime design threshold at 47 dBA.

4.0 SOUND LEVEL MONITORING

4.1 PROCEDURES

Background sound levels were measured at three locations around the Project Area. A map showing all three monitor locations is provided in Figure 2. Continuous monitoring was conducted over a period of seven days from June 12 to June 19, 2020.

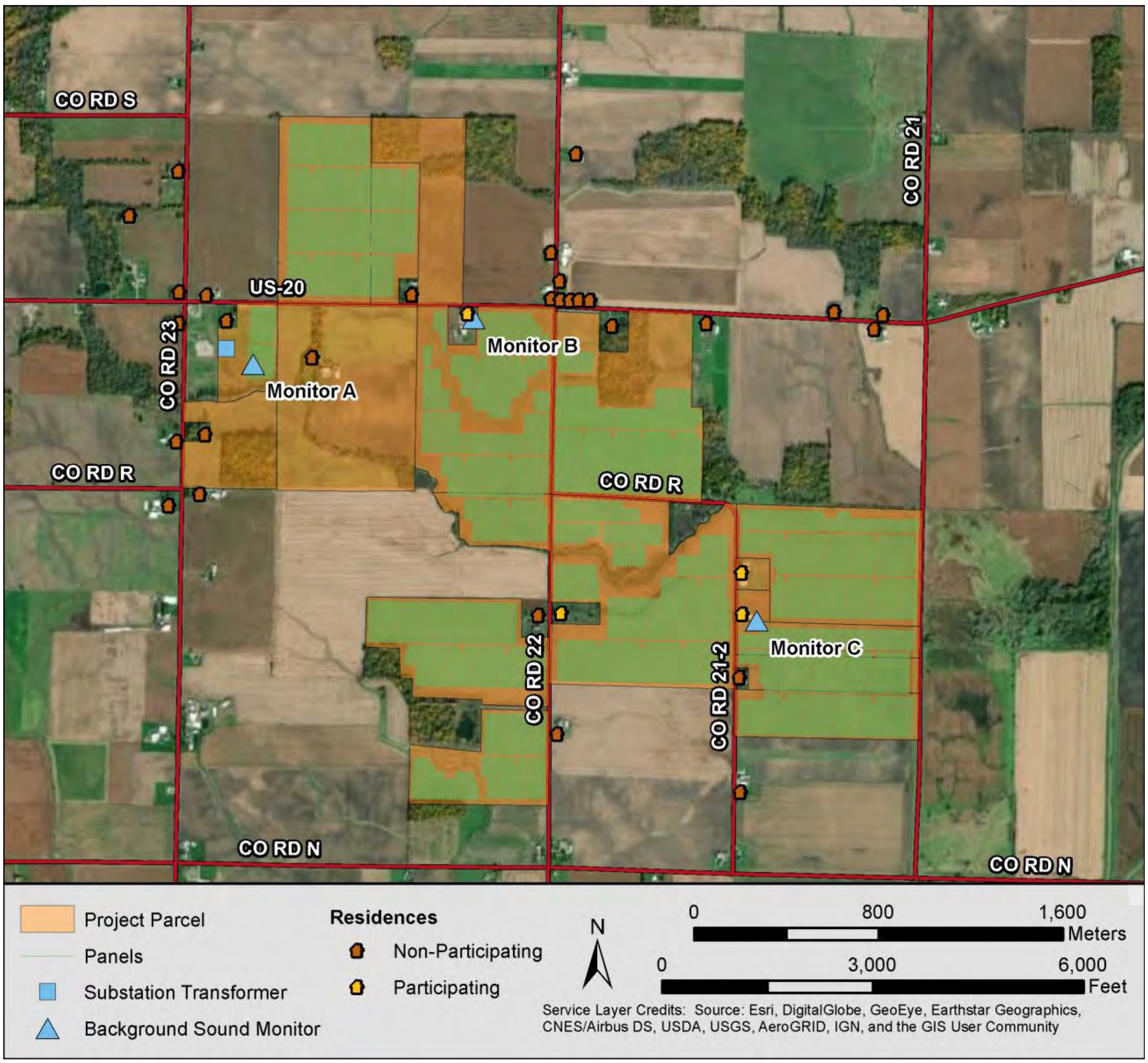

FIGURE 2: MAP OF MONITOR LOCATIONS

Equipment

Sound levels at each location were measured using a Cesva SC 310 sound level meter, which is an ANSI/IEC Class 1 instrument. All meters logged A-weighted and 1/3 octave band equivalent continuous sound levels once each second. Each sound level meter was attached an external audio recorder (Roland R-05) to aid in source identification and soundscape characterization.

Each sound level meter's microphone was mounted on a wooden stake at a height of approximately 1.5 meters (4.9 feet) and covered with a seven-inch weather-resistant windscreen. The windscreen reduces the influence of wind-induced self-noise on the measurements. The sound level meters were field-calibrated before and after each measurement period.

Wind data was logged at each site using an ONSET anemometer which recorded average wind speed and wind gust speed data once per minute and was installed at microphone height (1.5 meters). Other weather data such as temperature and precipitation were taken from the ASOS station for Wauseon, Ohio. Precipitation timing was also confirmed from audio files.

Data Process

Following collection of the meters, data was downloaded, processed, and summarized into 10-minute, overall day, overall night, and full monitoring-period length durations. For each 10-minute period, equivalent average (L_{eq}), upper 10th percentile (L_{10}), median (L_{50}), and lower 10th percentile (L_{90}) sound levels were also calculated.

During analysis, sound level data was removed from the dataset to maintain the integrity of the background sound levels during the periods that would cause false sound level readings or artificially high levels. These periods include:

- Wind speeds above 5 m/s (11 mph);
- Precipitation and thunderstorm events;
- Anomalous events; or
- Equipment interactions by RSG staff, other people, or animals.

Precipitation events were obtained from nearby airport data and were corroborated through both analysis of sound level spectrograms and from the audio recordings. There was just one brief period of rain that happened on the night between June 12 and June 13.

Notable anomalous events that were removed from the dataset include agricultural equipment in proximity to the monitors and lawn equipment operating in proximity to the monitors.

Location Descriptions

Monitor A

Monitor A was located in a field east of the existing substation on County Road 23, between the proposed substation location and a nearby residence to the east. The monitor was setback approximately 265 meters (869 feet) south of US-20 and 300 meters (984 feet) east of County Road 23. It measured a soundscape that is representative of residences on the western side of the Project Area, especially those that are near the existing substation. A photograph of the monitor is shown in Figure 3, and a map of the monitor location is provided in Figure 4.

FIGURE 3: MONITOR A LOCATION PHOTO

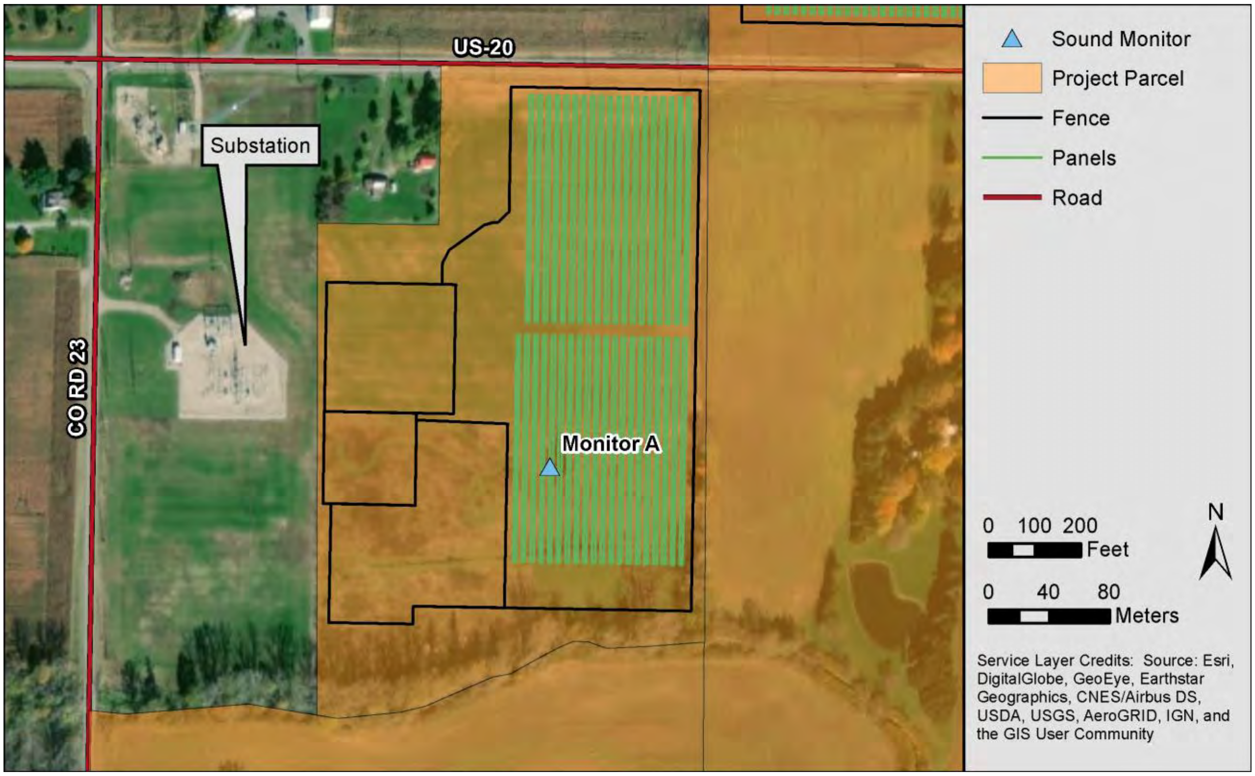

FIGURE 4: MONITOR A LOCATION MAP

Monitor B

Monitor B was located at a participating residence on the south side of US-20 on the edge of a field next to the residence. The monitor was setback approximately 55 meters (180 feet) south of US-20 and 350 meters (1,148 feet) west of County Road 22. It measured a soundscape that is representative of residences along US-20 which crosses the northern half of the Project Area. A photograph of the monitor is shown in Figure 5, and a map of the monitor location is provided in Figure 6.

FIGURE 5: MONITOR B LOCATION PHOTO

FIGURE 6: MONITOR B LOCATION MAP

Monitor C

Monitor C was located near a participating residence on the east side of County Road 21-2 on the edge of a field next to the residence. The monitor was setback approximately 95 meters (312 feet) east of County Road 21-2 and 1,080 meters (3,543 feet) north of County Road N. It measured a soundscape that is representative of residences in the southern portion of the project area that are further away from US-20. A photograph of the monitor is shown in Figure 7, and a map of the monitor location is provided in Figure 8.

FIGURE 7: MONITOR C LOCATION PHOTO

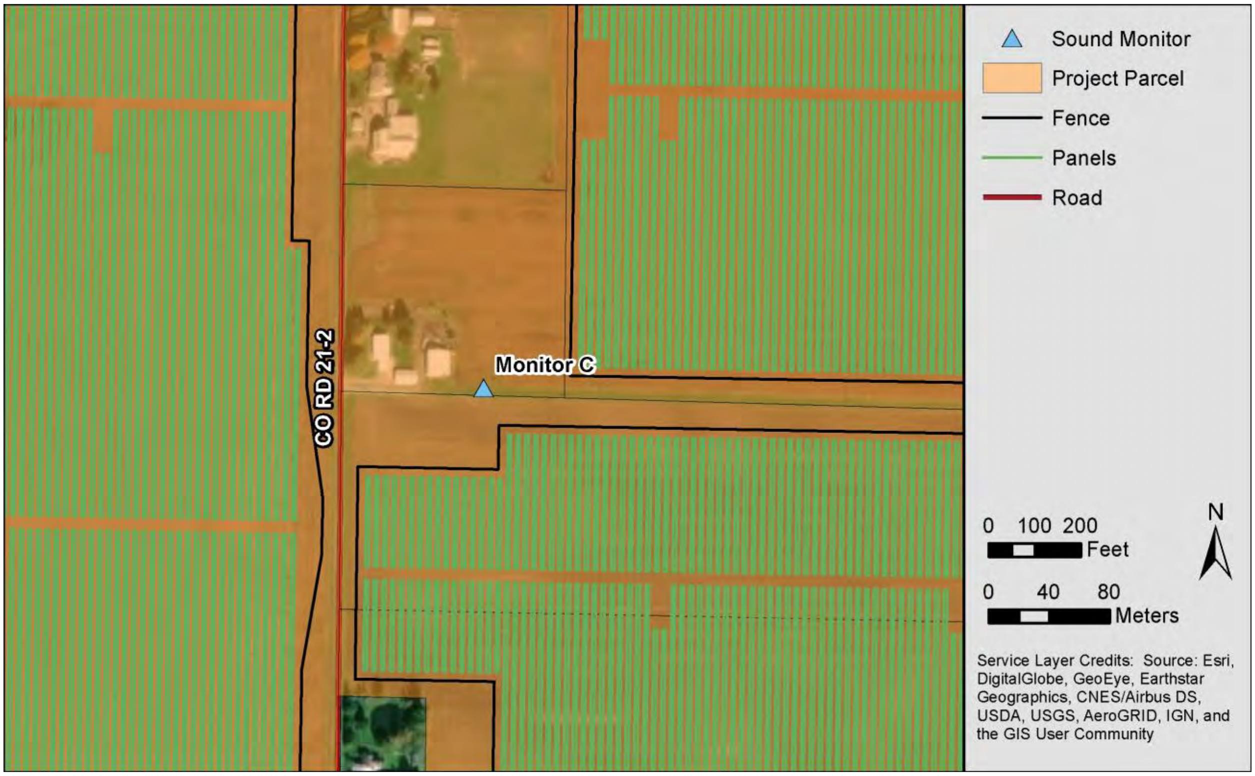

FIGURE 8: MONITOR C LOCATION MAP

4.2 BACKGROUND SOUND LEVEL SUMMARY

An overall summary of the monitor results is provided in this Section, followed by time-history graphs for each monitor in Section 4.3. Sound levels for each location are summarized into daytime, nighttime, and entire period levels in Table 1. It includes equivalent continuous average (L_{eq}), upper 10th percentile (L_{10}), median (L_{50}), and lower 10th percentile (L_{90}) sound levels. The nighttime L_{eq} across the Project Area is 42 dBA, and the daytime L_{eq} across the Project Area is 45 dBA. As discussed in Section 3.0, this sets the nighttime design threshold for nonparticipating sensitive receptors at 47 dBA and the daytime design threshold for non-participating sensitive receptors at 50 dBA.

TABLE 1: SOUND LEVEL MONITORING SUMMARY[2]

Monitor Location	Sound Pressure Level (dBA)			
	L_{EQ}	L_{90}	L_{50}	L_{10}
Overall				
Monitor A	45	30	40	48
Monitor B	53	26	42	55
Monitor C	35	25	30	37
Day				
Monitor A	45	33	41	49
Monitor B	54	34	45	56
Monitor C	36	26	32	38
Night				
Monitor A	43	27	37	46
Monitor B	50	23	35	51
Monitor C	34	24	28	37
Daytime Average	45			
Nighttime Average	42			

4.3 MONITOR RESULTS BY LOCATION

For display purposes, the one second data that was collected is displayed in 10-minute summarized values in the time history-graphs to show overall trends. Sound levels are plotted along with ambient temperature and wind speed to show relating trends. Time periods during which data was removed for the sound level summary presented in Section 4.2 are indicated with color-coded markers. Sound level data during periods where the entire 10-minute interval was excluded for wind, rain, or anomalies are still present in these graphs as lighter colors, with the darker colors representing 10-minute intervals where there were no data exclusions or only partial data exclusions.[3] The duration of each time history graph is one week, and each graph exhibits day/night shading where night is defined as 22:00 to 7:00 and shaded grey.

[2] High frequency biogenic sound was filtered out of the data during periods where it was present using an ANS weighting (defined in ANSI S12.100, “Methods to Define and Measure the Residual Sound in Protected Natural and Quiet Residential Areas”) which simply discounts sound levels above the 1 kHz 1/1/ octave band, the frequency range in which the biogenic sounds occur.

[3] For some 10-minute periods, shorter durations within the 10-minutes are excluded due to wind, rain, or anomalies, but the rest of the 10-minute interval is still used in the summary. These periods are shown in the darker colors (Leq and L90) as only some of the 10-minute period was excluded.

Monitor A

Time-history graphics for Monitor A are shown in Figure 9 and Figure 10. The daytime and nighttime equivalent average sound levels were 45 and 43 dBA[2] for the daytime and nighttime periods respectively. Sound levels exhibit a diurnal pattern, with consistently lower sound levels in the middle of the night than during the day. The consistent spread between the L_{EQ} and L_{90} indicates that there are transient sound sources during all periods of day or night.

Major sound sources at this location were birds, vehicles on nearby roads, aircraft, and agricultural equipment. Vehicle sound is a consistent presence, though it is not usually at the forefront of the soundscape.

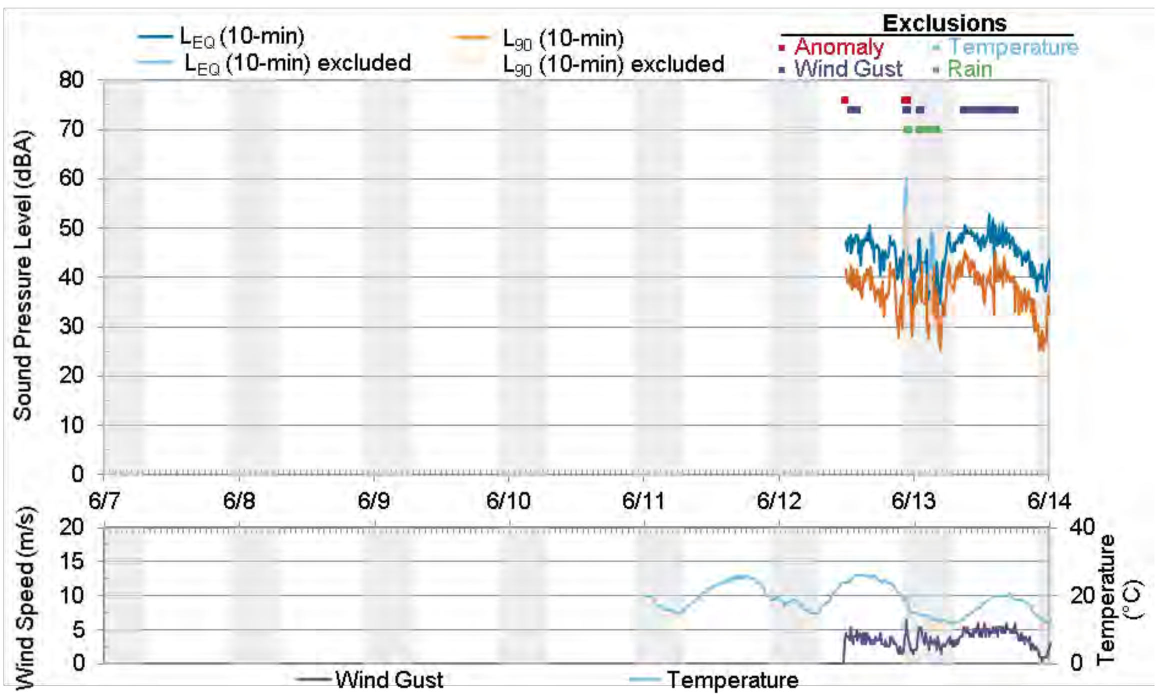

FIGURE 9: MONITOR A TIME-HISTORY RESULTS - PART 1

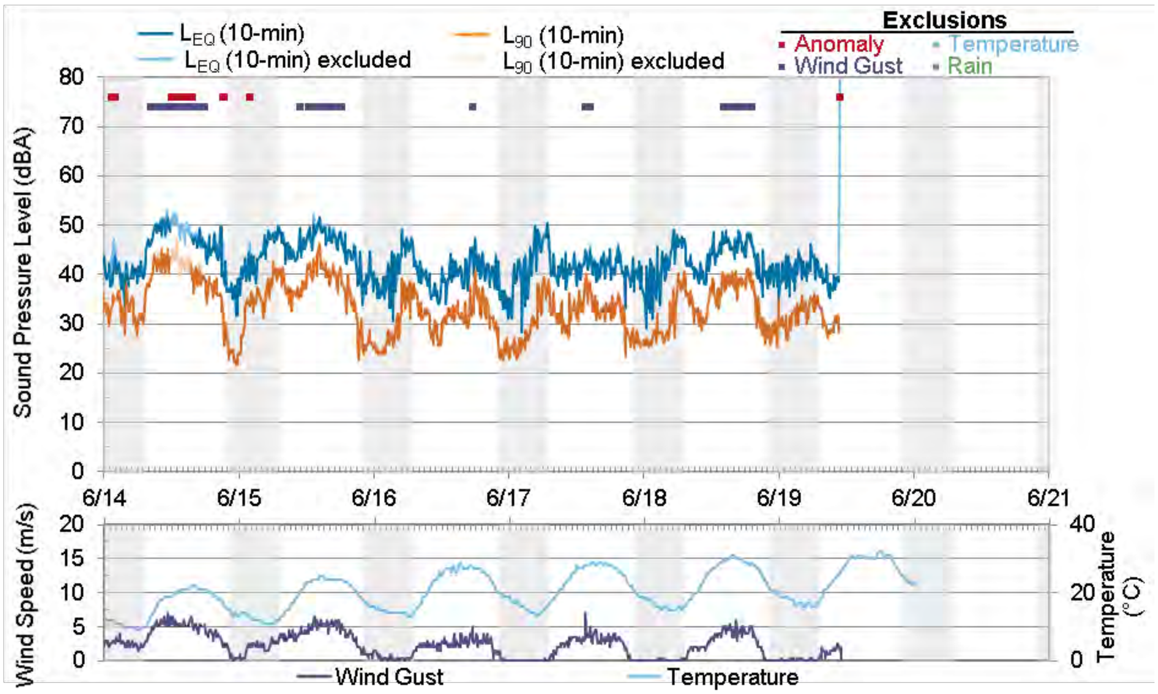

FIGURE 10: MONITOR A TIME-HISTORY RESULTS - PART 2

Monitor B

Time-history graphics for Monitor B are shown in Figure 11 and Figure 12. The daytime and nighttime equivalent average sound levels were 54 and 50 dBA[2] for the daytime and nighttime periods respectively. Sound levels exhibit a diurnal pattern, with consistently lower sound levels in the middle of the night than during the day. The consistent spread between the L_{EQ} and L_{90} indicates that there are transient sound sources during all periods of day or night. This is similar to Monitor A, but the difference between the L_{EQ} and L_{90} is generally larger and overall levels are higher.

Major sound sources at this location were birds, vehicles on nearby roads, aircraft, and agricultural equipment. Vehicle sound is also consistent at this location, though it tends to be more at the forefront of the soundscape than at Monitor A.

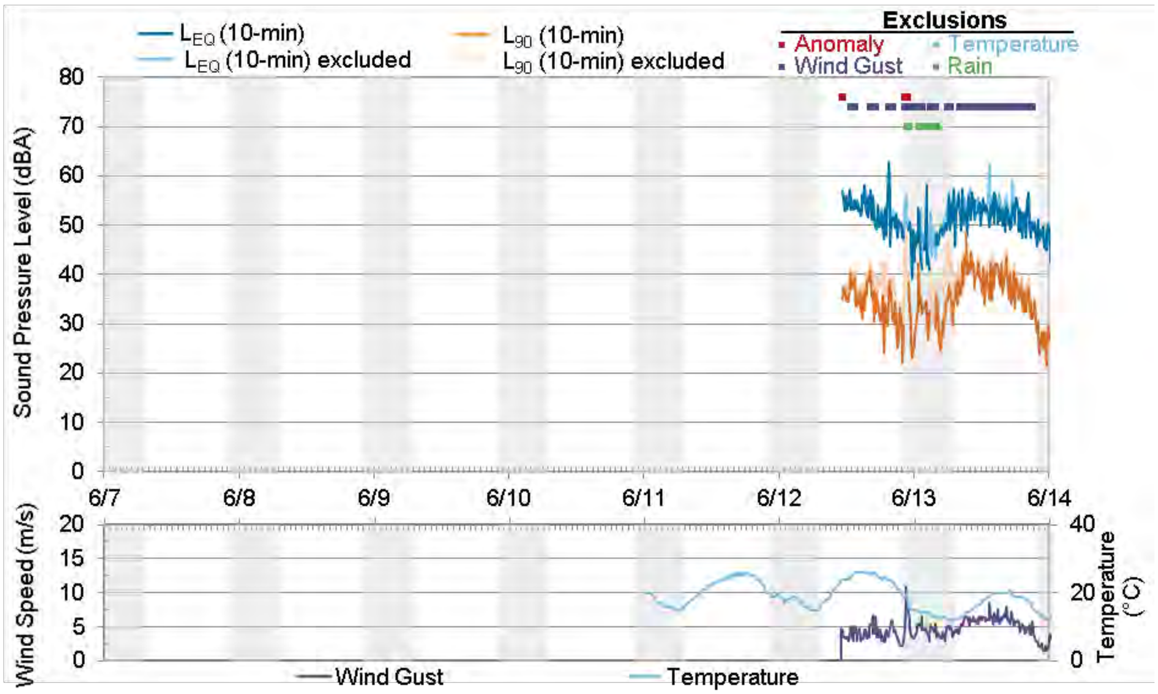

FIGURE 11: MONITOR B TIME-HISTORY RESULTS - PART 1

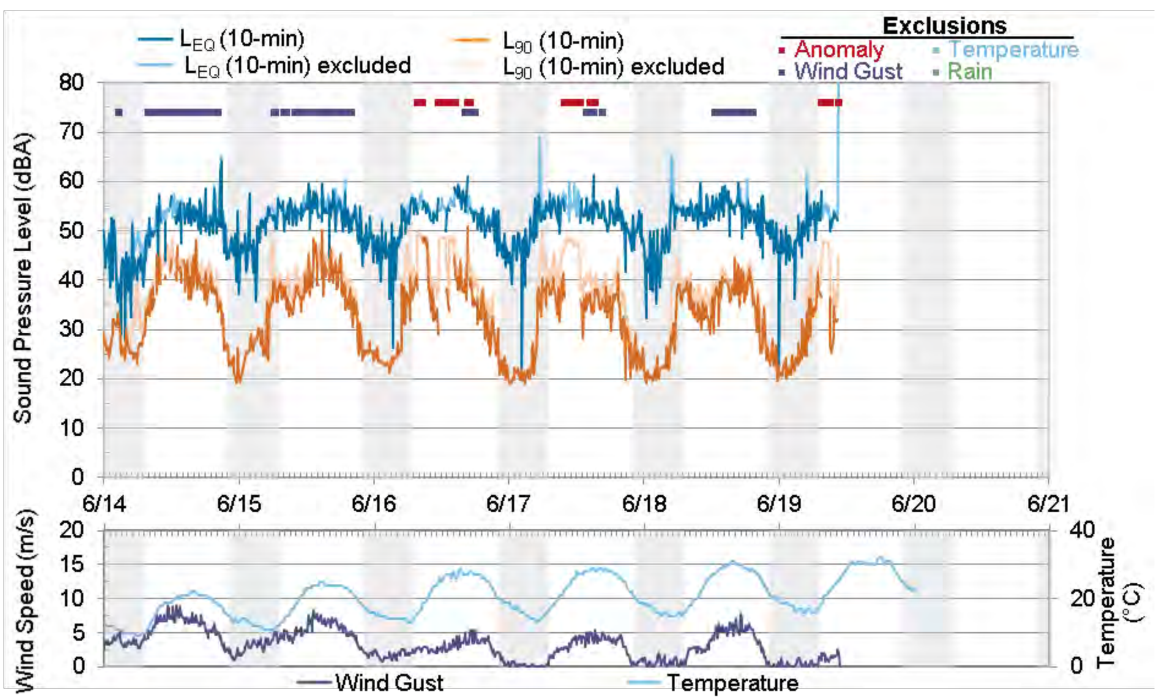

FIGURE 12: MONITOR B TIME-HISTORY RESULTS - PART 2

Monitor C

Time-history graphics for Monitor C are shown in Figure 13 and Figure 14. The daytime and nighttime equivalent average sound levels were 36 and 34 dBA[2] for the daytime and nighttime periods respectively. Sound levels exhibit a diurnal pattern, with consistently lower sound levels in the middle of the night than during the day, though this is less dramatic than at Monitors A and B. The spread is also less consistent, with L_{EQ} and L_{90} levels converging at night. This is due to more infrequent transient sound sources.

Major sound sources at this location were birds, vehicles on nearby roads, aircraft, and agricultural equipment. Vehicle sound was much less consistent and prominent at this location than at Monitors A and B, which means other sound sources are more prominent.

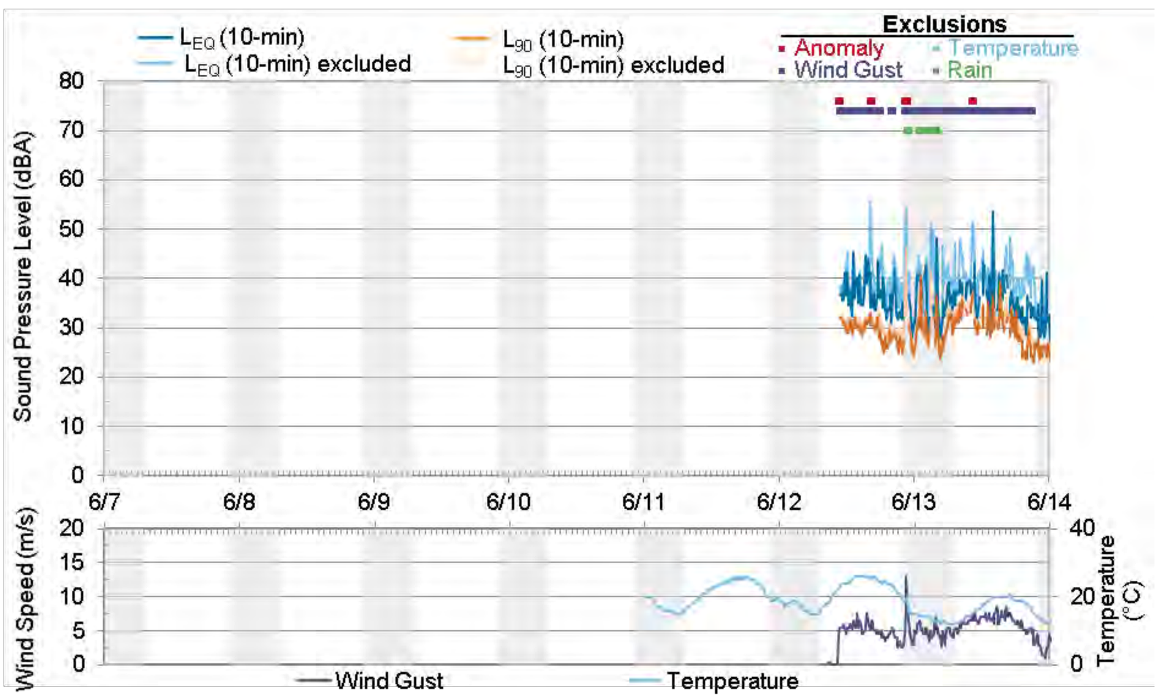

FIGURE 13: MONITOR C TIME-HISTORY RESULTS - PART 1

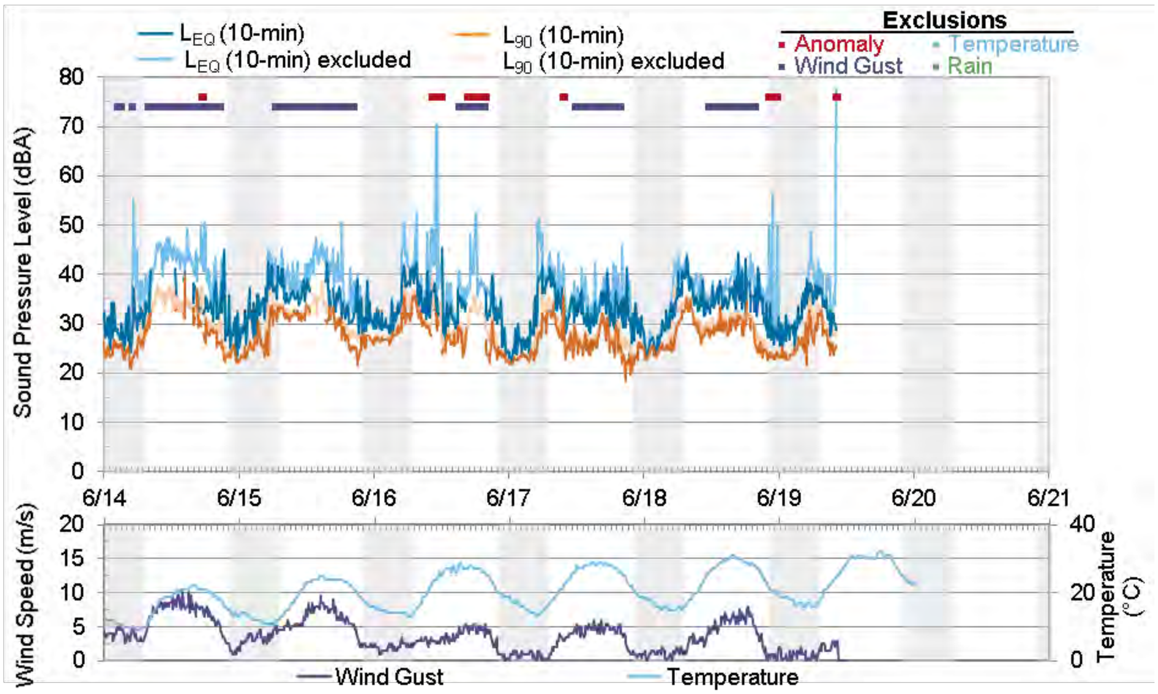

FIGURE 14: MONITOR C TIME-HISTORY RESULTS - PART 2

5.0 SOUND PROPAGATION MODELING

5.1 PROCEDURES

Modeling for the Project was in accordance with the standard ISO 9613-2, "Acoustics – Attenuation of sound during propagation outdoors, Part 2: General Method of Calculation." The ISO standard states,

> This part of ISO 9613 specifies an engineering method for calculating the attenuation of sound during propagation outdoors in order to predict the levels of environmental noise at a distance from a variety of sources. The method predicts the equivalent continuous A-weighted sound pressure level … under meteorological conditions favorable to propagation from sources of known sound emissions. These conditions are for downwind propagation … or, equivalently, propagation under a well-developed moderate ground-based temperature inversion, such as commonly occurs at night.

The model takes into account source sound power levels, surface reflection and absorption, atmospheric absorption, geometric divergence, meteorological conditions, walls, barriers, berms, and terrain. The acoustical modeling software used here was CadnaA, from Datakustik GmbH. CadnaA is a widely accepted acoustical propagation modeling tool, used by many noise control professionals in the United States and internationally.

ISO 9613-2 also assumes downwind sound propagation between every source and every receiver, consequently, all wind directions, including the prevailing wind directions, are taken into account.

Model input parameters are listed in Appendix B including the modeled sound power spectra for each source. A total of 33 discrete receivers were modeled at residences surrounding the Project Area at a height of 4 meters (13 feet) above ground level. In addition, a grid of receivers spaced 10 meters by 10 meters was setup in the model at a height of 1.5 meters above ground covering approximately 16 sq. km. (6 sq. mi.) around the Project Area.

Mitigation, in the form of barriers next to some of the inverters, has been incorporated into the model and is discussed further in Section 6.0.

5.2 RESULTS

A summary of the sound propagation model results is provided in Table 2, and Appendix C provides a list of the calculated overall sound pressure levels at each discrete receiver. As shown in Table 2, all non-participating residences are projected at 47 dBA or less which is equal to or less than the nighttime Project design threshold of 47 dBA.

TABLE 2: SUMMARY OF MODELED SOUND PRESSURE LEVELS ACCOUNTING FOR MITIGATION IN SECTION 6.0 (dBA)

	DAYTIME			NIGHTTIME		
	AVG	MIN	MAX	AVG	MIN	MAX
Non-Participating Residence	43	36	47	43	36	47
Participating Residence	49	46	51	49	46	51

The highest non-participating residence during the day is at 47dBA and is located north of the proposed substation on US-20, which is the closest receptor to the substation. This is due primarily to the transformer at the substation which was modeled during the daytime scenario at stage two cooling (ONAF) which would involve cooling fans operating. At night, under ONAN cooling which does not involve cooling fan operation, the closest receptor to the substation would be at 46 dBA. The highest non-participating residence at night is on County Road 21-2 in the southeast corner of the project area which is at 47 dBA. This is due to the inverters operating at night for VAR control. It is not anticipated that the inverters will operate at night all of the time, but since it is a possibility, they are included in the nighttime operation scenario. A map of the daytime projected sound levels is provided in Figure 15, and the nighttime projected sound levels are provided in Figure 16.

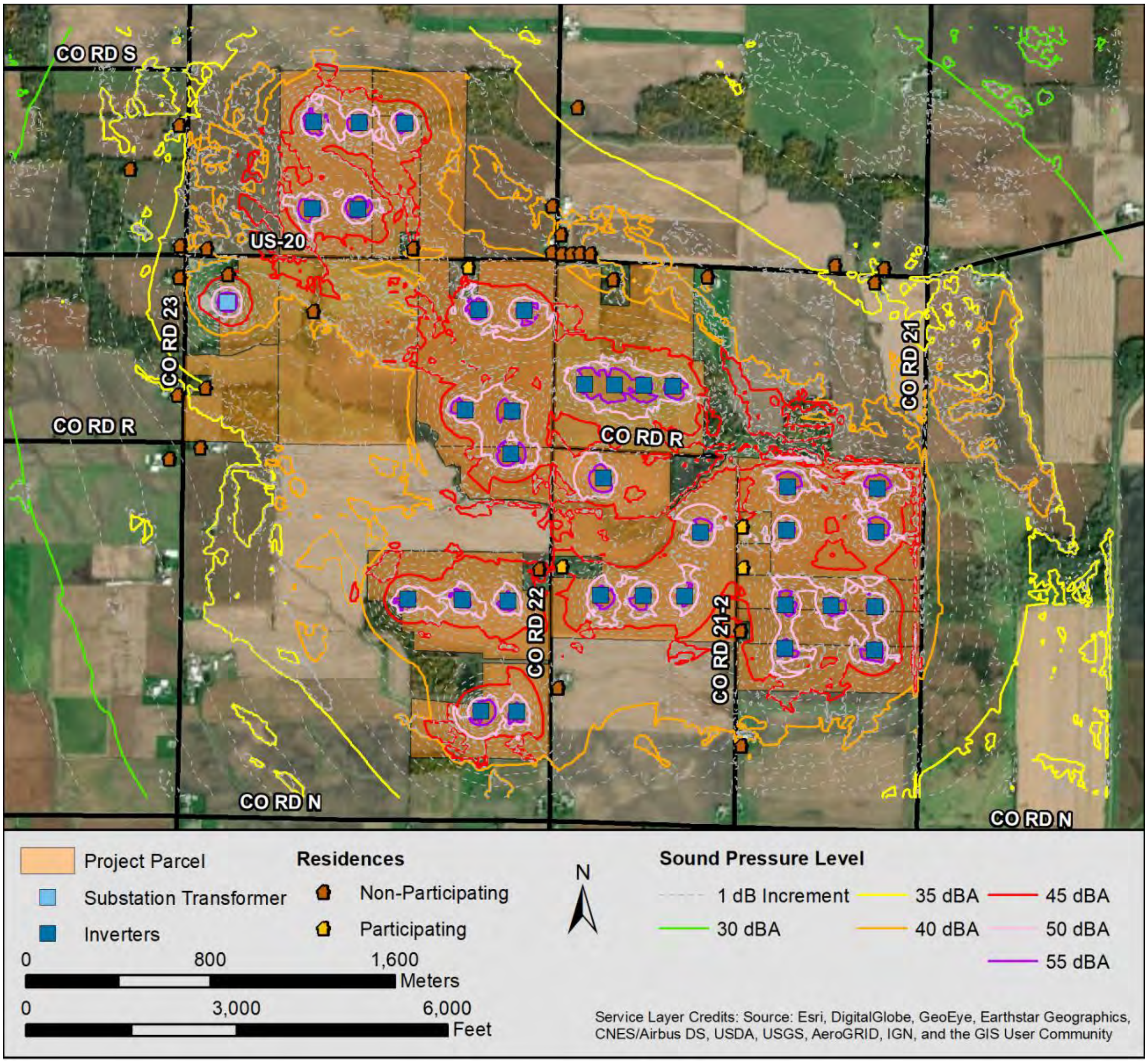

FIGURE 15: DAYTIME SOUND PROPAGATION MODEL RESULTS ACCOUNTING FOR MITIGATION IN SECTION 6.0

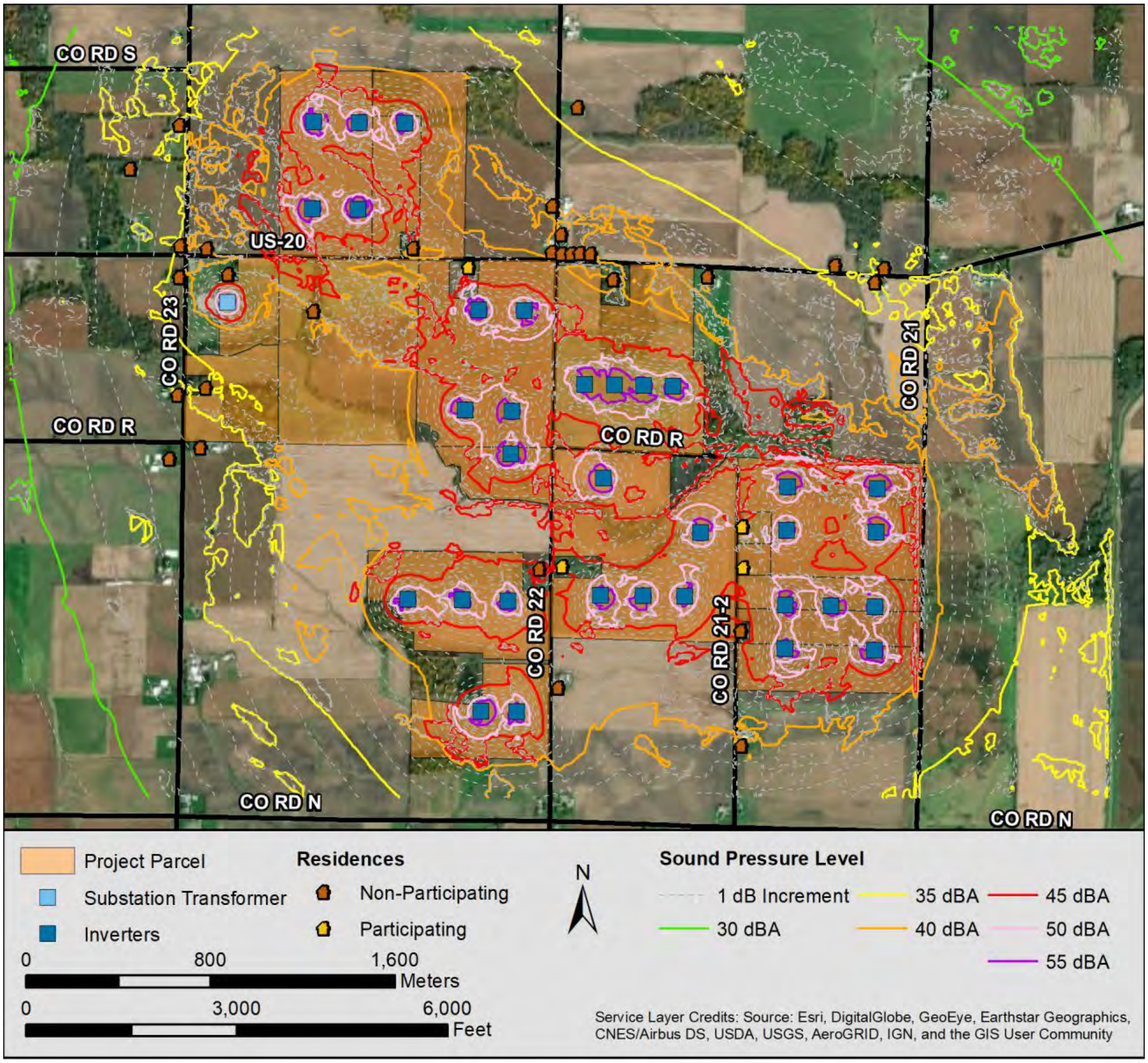

FIGURE 16: NIGHTTIME SOUND PROPAGATION MODEL RESULTS WITH VAR SUPPORT ACCOUNTING FOR MITIGATION IN SECTION 6.0

6.0 MITIGATION

To reduce the sound level at some non-participating receptors on County Road 22 and County Road 21-2 below the nighttime design threshold of 47 dBA mitigation is needed for some of the current inverter locations. Eight barriers were incorporated into the sound propagation model for select inverters to reduce the sound level at nearby non-participating receptors. The inverters where the barriers are located are shown in Figure 17. Each barrier[4] is:

- "L" shaped such that it shields two sides of the inverter;
- 16 meters (52 feet) in length;
- 3 meters (10 feet) high; and
- Setback 2 meters from the inverter pad.

These details are shown in Figure 18 using Barrier 8-1 as an example, and the design details for each barrier is provided in Table 3.

TABLE 3: INVERTER BARRIER DESIGN DETAILS

Barrier ID	Side of Inverter	Total Length (m)	Height (m)	Setback Distance from Inverter Pad (m)
8-1	East & North	16	3	2
8-2	East & North	16	3	2
9-1	East & North	16	3	2
10-1	West & North	16	3	2
10-3	West & South	16	3	2
11-1	West & South	16	3	2
11-2	West & North	16	3	2
11-3	West & South	16	3	2

Barriers are not needed to meet the design thresholds at locations other than those shown in Table 3 and Figure 17. Alternatively, barriers would not be necessary at the identified locations if the inverter manufacturer can provide inverter specific mitigation that will reduce the overall sound emissions of the inverter skid by at least 6 dB. Based on manufacturer data and as shown in Appendix B, the sound power level[5] of the inverter used in the model is 99.6 dBA, with much of that acoustical energy in the 63 Hz octave band. If the inverter manufacturer can

[4] The barriers should be flush with the ground, containing no air gaps, and have a surface weight of a least 4 pounds per square foot.
[5] Sound power level is a measure of the amount of acoustical energy emitted by a specific source which is independent of the environmental conditions in which that source is located. It should not be confused with sound pressure level which can be measured with a sound level meter and varies with distance and environmental conditions.

provide a mitigation solution for their system that reduces the total sound power level to 93.6 dBA or less and reducing the amount of acoustical energy in the 63 Hz octave band, it would be as effective as the barrier mitigation described above, effectively negating the need for the barrier mitigation.

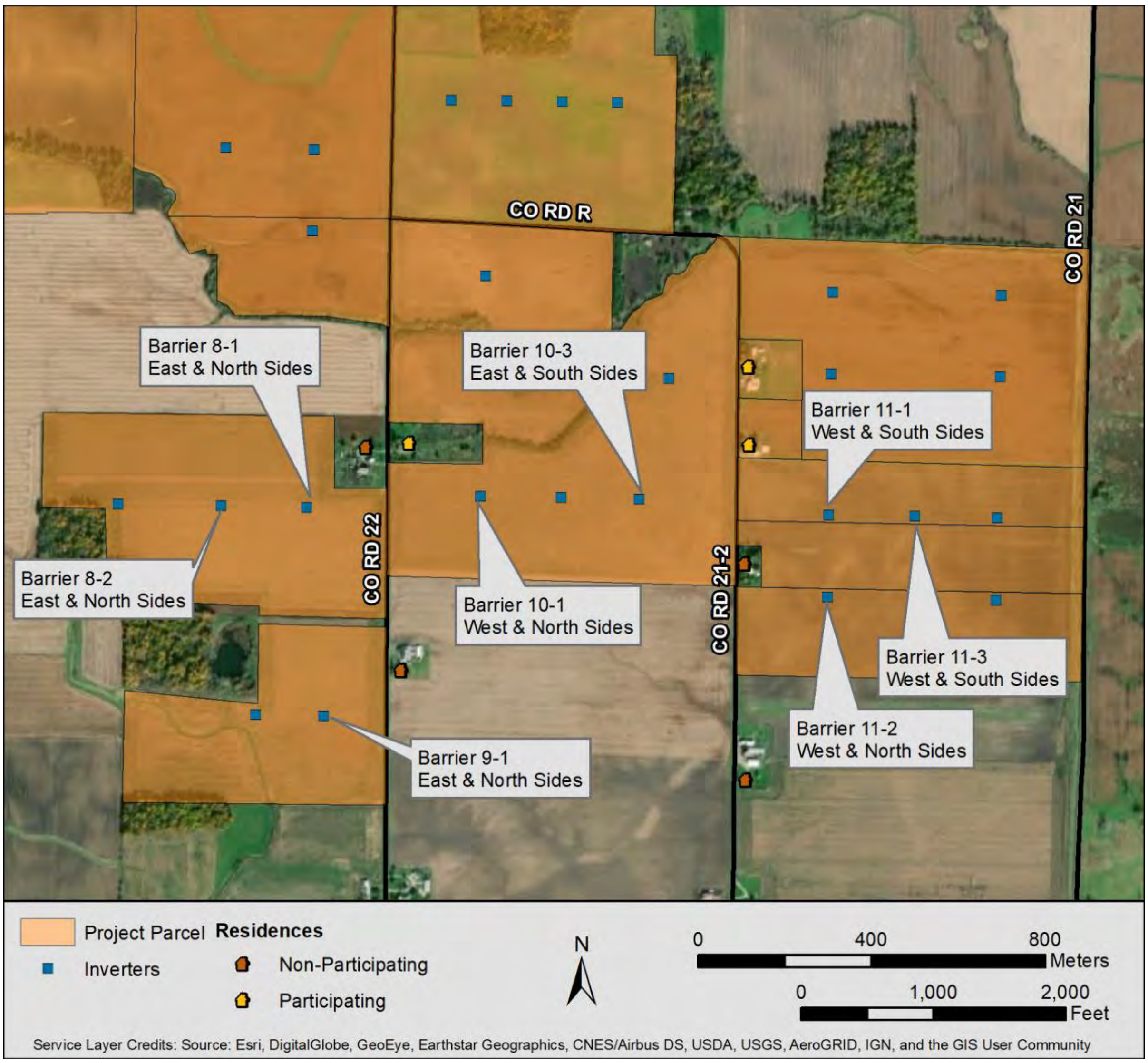

FIGURE 17: MAP OF MODELED NOISE BARRIERS

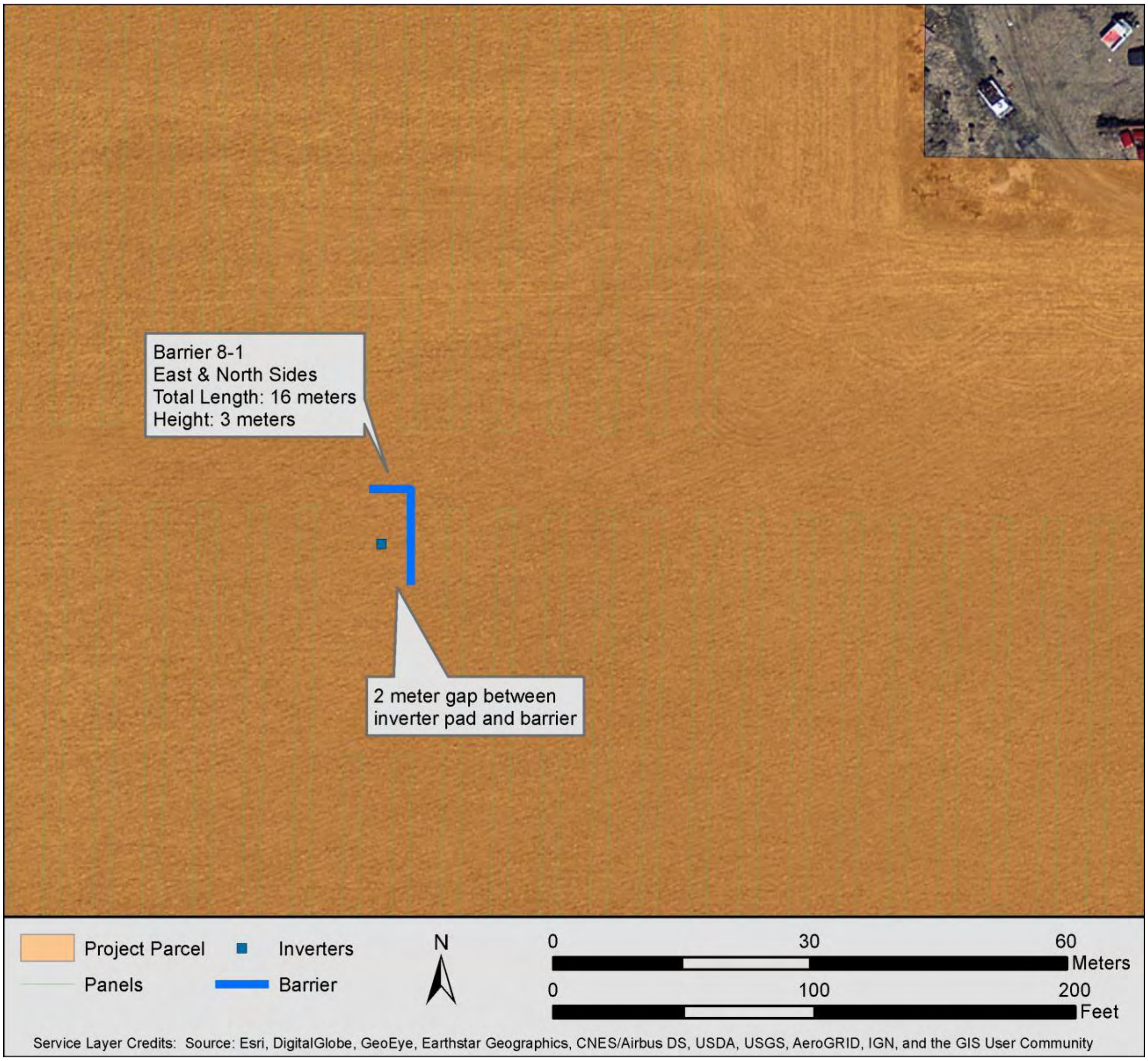

FIGURE 18: EXAMPLE BARRIER MAP, BARRIER 8-1

7.0 CONSTRUCTION NOISE

Construction activities include road construction, substation construction, trenching, inverter installation, piling and racking. In any given area, construction will be relatively short in duration, particularly for road construction, trenching, piling, and racking. Substation construction typically lasts longer than these other activities. Road construction would take place within and adjacent to the solar arrays. Trenching would take place along the underground collection line routes. Inverter installation would take place at each inverter pad location. And piling and racking will take place throughout the solar arrays.

Construction of the Facility will result in sound above ambient levels and will occur between 7 AM and 7 PM or dusk, whichever is later. For areas of the Project within 500 feet of a non-participating residence, pile driving will be limited to the hours of 8 AM to 6 PM, Monday through Saturday. In addition, the material staging areas will be located away from sensitive receptors when feasible. To the extent possible, circular vehicular movements will be established to minimize the use of backup alarms.

Equipment used for each activity will vary. Some of the louder pieces of equipment[6] are shown in Table 4 along with the approximate maximum sound pressure levels at 15 meters (50 feet) and 40 meters (131 feet) the closest distance between a nonparticipating residence and a solar array where racking and piling will take place.

[6] Sound source information was obtained from FHWA's Roadway Construction Noise Model and manufacturer data.

TABLE 4: MAXIMUM SOUND LEVELS FROM VARIOUS TYPES OF CONSTRUCTION EQUIPMENT ASSUMING NO ATTENUATION FROM TREES OR TERRAIN

Equipment	Maximum Sound Pressure Level at 40 meters (131 feet) (dBA)[7]	Maximum Sound Pressure Level at 15 meters (50 feet) (dBA)
Excavator	70	85
Dozer	70	85
Grader	70	85
Roller	70	85
Dump Truck	69	84
Concrete Mixing Truck	70	85
Concrete Pumper Truck	67	82
Man-lift	70	85
Flatbed Truck	69	84
Large Crane	70	85
Small Crane	68	83
Trencher	68	83
Compactor	65	80
Forklift	70	85
Boom Truck	69	84
Small Pile Driver	69	84

[7] Assumes hard ground around construction site, and ISO 9613-2 propagation with no vegetation reduction. Actual sound levels will likely be lower given the prevalence of vegetation and soft ground around the site.

8.0 CONCLUSIONS

RSG conducted a sound level assessment of the Project that included background sound level monitoring of the existing environment in and around the Project Area and sound propagation modeling to predict operational sound levels at nearby residences.

Summary and conclusions are as follows:

1. Sound sources in the existing soundscape include agricultural activities, traffic noise from both local and through traffic, aircraft overflights, and biogenic and geophonic sounds.
    a. Background sound levels varied across the site and were largely a function of distance from US-20. Monitor B had the highest sound levels and was representative of houses located along US-20. Monitor A was setback further from US-20 and had lower sound levels than Monitor B, and Monitor C was even further from US-20 in the southern portion of the project area where background sound levels were lowest.
    b. The average daytime L_{eq} across the Project Area was 45 dBA.
    c. The average nighttime L_{eq} across the Project Area was 42 dBA.
2. Based on OPSB precedents, a Project design threshold of 5 dB above existing L_{eq} was established, creating a daytime threshold of 50 dBA and a nighttime threshold of 47 dBA for non-participating residences.
3. While the Project transformers are typically the only sources that operate at night from a solar project, there may be times that the inverters for this Project will operate at night for VAR support. As such, this assessment conservatively assumed:
    a. All inverters would operate at night, and
    b. Evaluated the projected sound levels from those sources against the nighttime threshold of 47 dBA.
4. Daytime sound levels were also modeled, with the only difference between daytime and nighttime operational sound levels being that the cooling mode on the substation transformer, ONAF for the daytime scenario and ONAN for the nighttime scenario.
5. Sound propagation modeling was conducted in accordance with ISO 9613-2 at 33 residences throughout the Project Area, using the planned inverter for the Project, Power Electronics HEM.

6. Model results are summarized in Section 5.2, and provided in tabular format in Appendix C. All non-participating receptors are less than 50 dBA during the day and less than 47 dBA during the night, meeting the daytime and nighttime design thresholds.
7. Either barriers, inverter relocation, or manufacturer provided mitigation will be needed to meet the nighttime design thresholds for non-participating residences on County Road 22 and County Road 21-2. Mitigation was incorporated into the sound propagation model in the form of barriers as discussed in Section 6.0.
8. Sound levels due to construction are summarized in Section 7.0.

APPENDIX A. ACOUSTICS PRIMER

Expressing Sound in Decibel Levels

The varying air pressure that constitutes sound can be characterized in many different ways. The human ear is the basis for the metrics that are used in acoustics. Normal human hearing is sensitive to sound fluctuations over an enormous range of pressures, from about 20 micropascals (the "threshold of audibility") to about 20 pascals (the "threshold of pain").[8] This factor of one million in sound pressure difference is challenging to convey in engineering units. Instead, sound pressure is converted to sound "levels" in units of "decibels" (dB, named after Alexander Graham Bell). Once a measured sound is converted to dB, it is denoted as a level with the letter "L".

The conversion from sound pressure in pascals to sound level in dB is a four-step process. First, the sound wave's measured amplitude is squared and the mean is taken. Second, a ratio is taken between the mean square sound pressure and the square of the threshold of audibility (20 micropascals). Third, using the logarithm function, the ratio is converted to factors of 10. The final result is multiplied by 10 to give the decibel level. By this decibel scale, sound levels range from 0 dB at the threshold of audibility to 120 dB at the threshold of pain.

Typical sound sources, and their sound pressure levels, are listed on the scale in Figure 19.

Human Response to Sound Levels: Apparent Loudness

For every 20 dB increase in sound level, the sound pressure increases by a *factor* of 10; the sound *level* range from 0 dB to 120 dB covers 6 factors of 10, or one million, in sound *pressure*. However, for an increase of 10 dB in sound *level* as measured by a meter, humans perceive an approximate doubling of apparent loudness: to the human ear, a sound level of 70 dB sounds about "twice as loud" as a sound level of 60 dB. Smaller changes in sound level, less than 3 dB up or down, are generally not perceptible.

[8] The pascal is a measure of pressure in the metric system. In Imperial units, they are themselves very small: one pascal is only 145 millionths of a pound per square inch (psi). The sound pressure at the threshold of audibility is only 3 one-billionths of one psi: at the threshold of pain, it is about 3 one-thousandths of one psi.

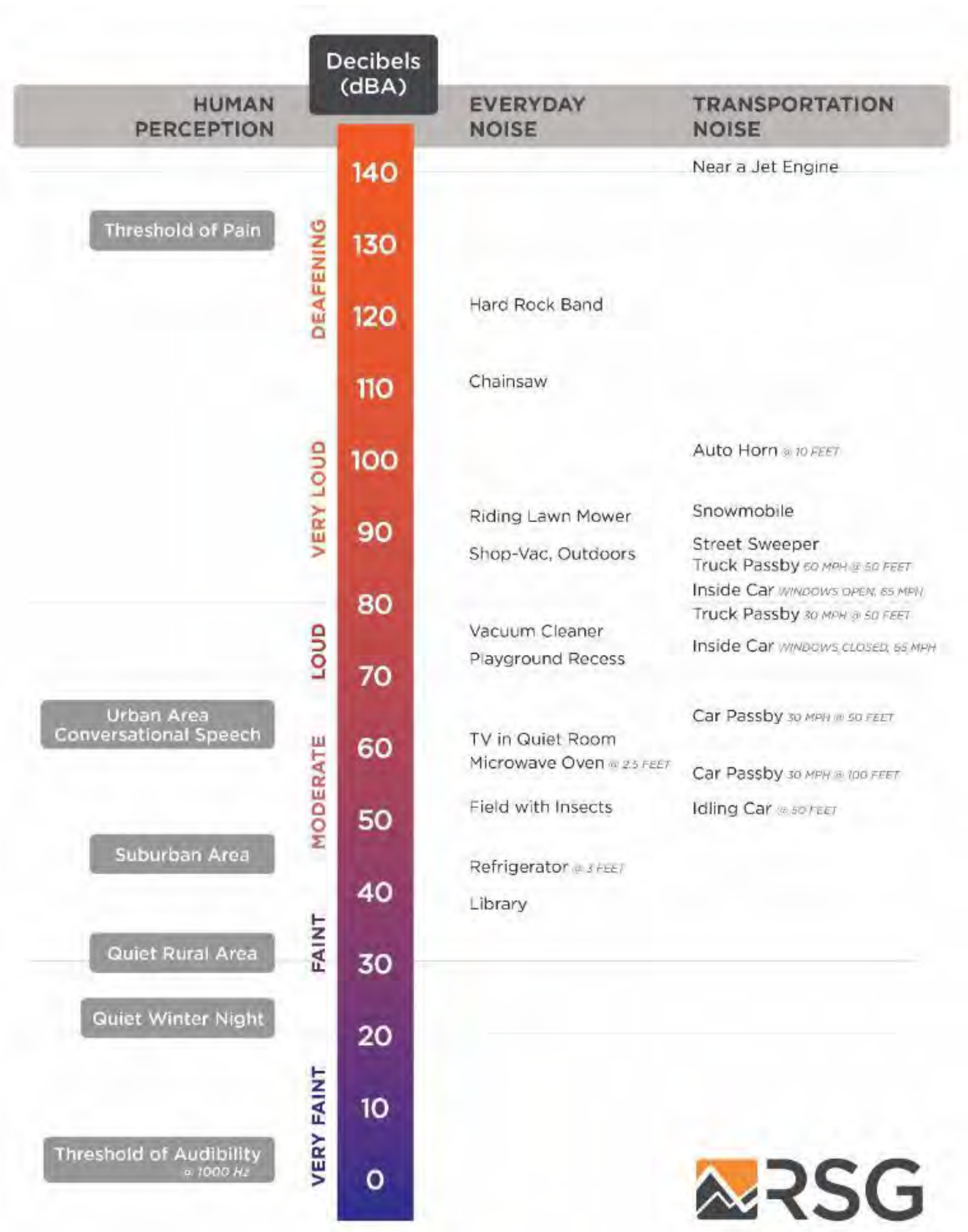

FIGURE 19: A SCALE OF SOUND PRESSURE LEVELS FOR TYPICAL SOUND SOURCES

Frequency Spectrum of Sound

The "frequency" of a sound is the rate at which it fluctuates in time, expressed in Hertz (Hz), or cycles per second. Very few sounds occur at only one frequency: most sound contains energy at many different frequencies, and it can be broken down into different frequency divisions, or bands. These bands are similar to musical pitches, from low tones to high tones. The most common division is the standard octave band. An octave is the range of frequencies whose upper frequency limit is twice its lower frequency limit, exactly like an octave in music. An octave band is identified by its center frequency: each successive band's center frequency is twice as high (one octave) as the previous band. For example, the 500 Hz octave band includes all sound whose frequencies range between 354 Hz (Hertz, or cycles per second) and 707 Hz. The next band is centered at 1,000 Hz with a range between 707 Hz and 1,414 Hz. The range of human hearing is divided into 10 standard octave bands: 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz, 4,000 Hz, 8,000 Hz, and 16,000 Hz. For analyses that require finer frequency detail, each octave-band can be subdivided. A commonly-used subdivision creates three smaller bands within each octave band, or so-called 1/3-octave bands.

Human Response to Frequency: Weighting of Sound Levels

The human ear is not equally sensitive to sounds of all frequencies. Sounds at some frequencies seem louder than others, despite having the same decibel level as measured by a sound level meter. In particular, human hearing is much more sensitive to medium pitches (from about 500 Hz to about 4,000 Hz) than to very low or very high pitches. For example, a tone measuring 80 dB at 500 Hz (a medium pitch) sounds quite a bit louder than a tone measuring 80 dB at 60 Hz (a very low pitch). The frequency response of normal human hearing ranges from 20 Hz to 20,000 Hz. Below 20 Hz, sound pressure fluctuations are not "heard", but sometimes can be "felt". This is known as "infrasound". Likewise, above 20,000 Hz, sound can no longer be heard by humans; this is known as "ultrasound". As humans age, they tend to lose the ability to hear higher frequencies first; many adults do not hear very well above about 16,000 Hz. Most natural and man-made sound occurs in the range from about 40 Hz to about 4,000 Hz. Some insects and birdsongs reach to about 8,000 Hz.

To adjust measured sound pressure levels so that they mimic human hearing response, sound level meters apply filters, known as "frequency weightings", to the signals. There are several defined weighting scales, including "A", "B", "C", "D", "G", and "Z". The most common weighting scale used in environmental noise analysis and regulation is A-weighting. This weighting represents the sensitivity of the human ear to sounds of low to moderate level. It attenuates sounds with frequencies below 1000 Hz and above 4000 Hz; it amplifies very slightly sounds between 1000 Hz and 4000 Hz, where the human ear is particularly sensitive. The C-weighting scale is sometimes used to describe louder sounds. The B- and D- scales are seldom used. All of these frequency weighting scales are normalized to the average human hearing response at

1000 Hz: at this frequency, the filters neither attenuate nor amplify. When a reported sound level has been filtered using a frequency weighting, the letter is appended to “dB”. For example, sound with A-weighting is usually denoted “dBA”. When no filtering is applied, the level is denoted “dB” or “dBZ”. The letter is also appended as a subscript to the level indicator “L”, for example “L_A” for A-weighted levels.

Time Response of Sound Level Meters

Because sound levels can vary greatly from one moment to the next, the time over which sound is measured can influence the value of the levels reported. Often, sound is measured in real time, as it fluctuates. In this case, acousticians apply a so-called “time response” to the sound level meter, and this time response is often part of regulations for measuring sound. If the sound level is varying slowly, over a few seconds, “Slow” time response is applied, with a time constant of one second. If the sound level is varying quickly (for example, if brief events are mixed into the overall sound), “Fast” time response can be applied, with a time constant of one-eighth of a second.[9] The time response setting for a sound level measurement is indicated with the subscript “S” for Slow and “F” for Fast: L_S or L_F. A sound level meter set to Fast time response will indicate higher sound levels than one set to Slow time response when brief events are mixed into the overall sound, because it can respond more quickly.

In some cases, the maximum sound level that can be generated by a source is of concern. Likewise, the minimum sound level occurring during a monitoring period may be required. To measure these, the sound level meter can be set to capture and hold the highest and lowest levels measured during a given monitoring period. This is represented by the subscript “max”, denoted as “L_{max}”. One can define a “max” level with Fast response L_{Fmax} (1/8-second time constant), Slow time response L_{Smax} (1-second time constant), or Continuous Equivalent level over a specified time period L_{EQmax}.

Accounting for Changes in Sound Over Time

A sound level meter’s time response settings are useful for continuous monitoring. However, they are less useful in summarizing sound levels over longer periods. To do so, acousticians apply simple statistics to the measured sound levels, resulting in a set of defined types of sound level related to averages over time. An example is shown in Figure 20. The sound level at each instant of time is the grey trace going from left to right. Over the total time it was measured (1 hour in the figure), the sound energy spends certain fractions of time near various levels, ranging from the minimum (about 27 dB in the figure) to the maximum (about 65 dB in the figure). The simplest descriptor is the average sound level, known as the Equivalent Continuous

[9] There is a third time response defined by standards, the “Impulse” response. This response was defined to enable use of older, analog meters when measuring very brief sounds; it is no longer in common use.

Sound Level. Statistical levels are used to determine for what percentage of time the sound is louder than any given level. These levels are described in the following sections.

Equivalent Continuous Sound Level - L_{eq}

One straightforward, common way of describing sound levels is in terms of the Continuous Equivalent Sound Level, or L_{EQ}. The L_{EQ} is the average sound pressure level over a defined period of time, such as one hour or one day. L_{EQ} is the most commonly used descriptor in noise standards and regulations. L_{EQ} is representative of the overall sound to which a person is exposed. Because of the logarithmic calculation of decibels, L_{EQ} tends to favor higher sound levels: loud and infrequent sources have a larger impact on the resulting average sound level than quieter but more frequent sounds. For example, in Figure 20, even though the sound levels spends most of the time near about 34 dBA, the L_{EQ} is 41 dBA, having been "inflated" by the maximum level of 65 dBA and other occasional spikes over the course of the hour.

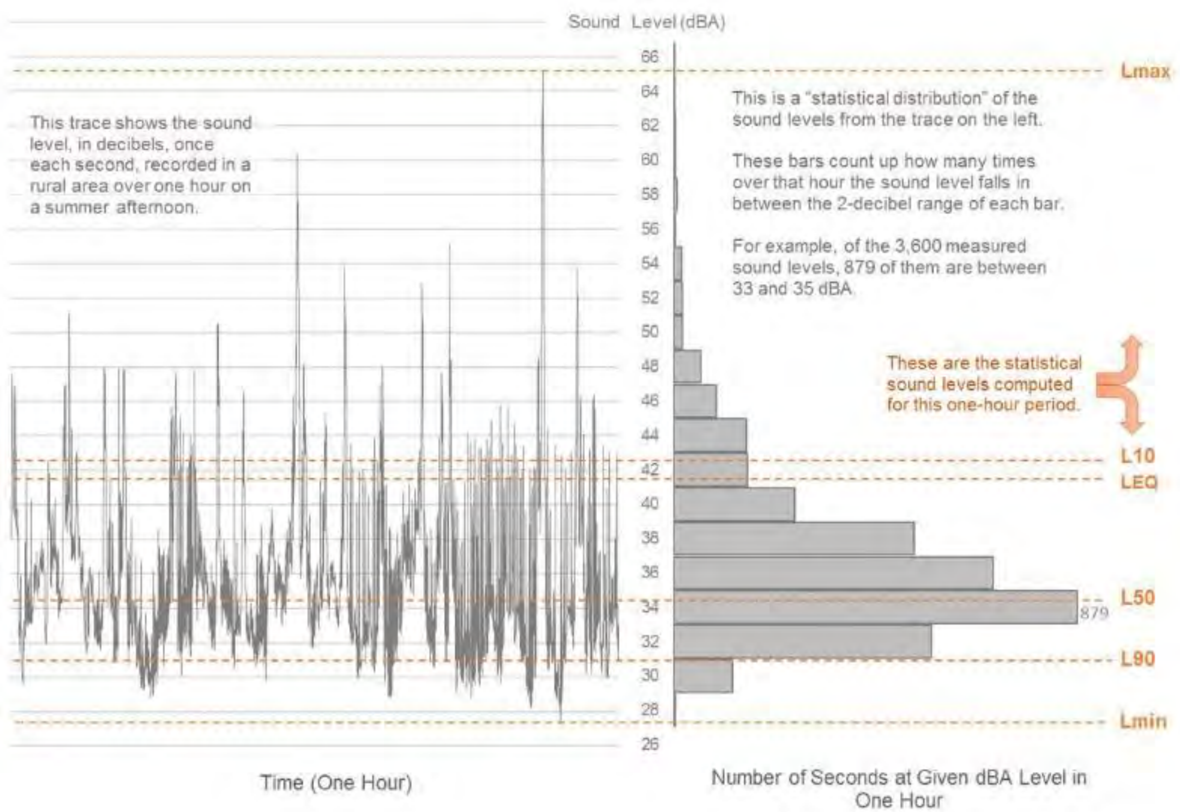

FIGURE 20: EXAMPLE OF DESCRIPTIVE TERMS OF SOUND MEASUREMENT OVER TIME

Percentile Sound Levels – L_n

Percentile sound levels describe the statistical distribution of sound levels over time. "L_N" is the level above which the sound spends "N" percent of the time. For example, L_{90} (sometimes called the "residual base level") is the sound level exceeded 90% of the time: the sound is louder than L_{90} most of the time. L_{10} is the sound level that is exceeded only 10% of the time. L_{50} (the "median level") is exceeded 50% of the time: half of the time the sound is louder than L_{50}, and half the time it is quieter than L_{50}. Note that L_{50} (median) and L_{EQ} (mean) are not always the same, for reasons described in the previous section.

L_{90} is often a good representation of the "ambient sound" in an area. This is the sound that persists for longer periods, and below which the overall sound level seldom falls. It tends to filter out other short-term environmental sounds that aren't part of the source being investigated. L_{10} represents the higher, but less frequent, sound levels. These could include such events as barking dogs, vehicles driving by and aircraft flying overhead, gusts of wind, and work operations. L_{90} represents the background sound that is present when these event sounds are excluded.

Note that if one sound source is very constant and dominates the soundscape in an area, all of the descriptive sound levels mentioned here tend toward the same value. It is when the sound is varying widely from one moment to the next that the statistical descriptors are useful.

APPENDIX B. MODEL INPUT DATA

TABLE 5: MODEL PARAMETER SETTINGS

Model Parameter	Setting
Atmospheric Absorption	Based on 10°C and 70% RH
Foliage	No Foliage Attenuation
Ground Absorption	ISO 9613-2 spectral, G=0 on concrete equipment pads, G=0.6 at substation, and G=1 elsewhere
Receiver Height	1.5 meters for sound level isolines and 4.0 meters discrete receptors
Search Radius	10,000 meters from each source

TABLE 6: MODELED SOUND POWER SPECTRA, dBZ UNLESS OTHERWISE NOTED

Source	Octave Band Center Frequency (Hz)									Overall Sound Power Level		Reference
	31.5	63	125	250	500	1000	2000	4000	8000	dBA	dBZ	
Substation Transformer ONAF	85	88	108	104	98	92	88	82	73	100	110	Calculated from Arche Solar provided specs[10]
Power Electronics HEM	124	124	105	96	90	86	84	77	77	100	127	Manufacturer test data

TABLE 7: SOURCE INPUT DATA

Source	Overall Sound Power Level (dBA)	Relative Height (m)	Coordinates UTM NAD83 Z17N		Absolute Elevation (m)
			X (m)	Y (m)	
Sub Transformer	100	2.1	224835.5	4618666.5	234.7
Inverter01	99.6	1.5	225209.5	4619448.4	233.8
Inverter02	99.6	1.5	225406.9	4619445.2	235.1
Inverter03	99.6	1.5	225604.3	4619441.5	235.1
Inverter04	99.6	1.5	225202.9	4619072.5	233.2
Inverter05	99.6	1.5	225400.4	4619069.0	231.7
Inverter06	99.6	1.5	225924.4	4618632.6	230.7

[10] Spectrum based on RSG measurements of similarly sized transformer

Source	Overall Sound Power Level (dBA)	Relative Height (m)	Coordinates UTM NAD83 Z17N		Absolute Elevation (m)
			X (m)	Y (m)	
Inverter07	99.6	1.5	226122.0	4618629.5	231.1
Inverter08	99.6	1.5	226768.5	4618302.2	228.5
Inverter09	99.6	1.5	226640.9	4618304.5	229.6
Inverter10	99.6	1.5	226513.2	4618306.6	228.6
Inverter11	99.6	1.5	226385.4	4618308.9	229.4
Inverter12	99.6	1.5	226068.9	4618194.3	231.0
Inverter13	99.6	1.5	225865.7	4618198.3	232.1
Inverter14	99.6	1.5	226065.5	4618006.7	226.6
Inverter15	99.6	1.5	226465.0	4617903.8	226.0
Inverter16	99.6	1.5	227653.9	4617858.9	223.2
Inverter17	99.6	1.5	227265.0	4617865.9	224.2
Inverter18	99.6	1.5	227650.5	4617670.9	223.6
Inverter19	99.6	1.5	227261.6	4617677.7	225.5
Inverter20	99.6	1.5	226887.2	4617666.8	227.2
Inverter21	99.6	1.5	226818.4	4617389.9	227.2
Inverter22	99.6	1.5	226638.5	4617393.2	229.1
Inverter23	99.6	1.5	226452.7	4617396.5	229.8
Inverter24	99.6	1.5	226052.3	4617371.1	230.7
Inverter25	99.6	1.5	225855.0	4617374.6	231.4
Inverter26	99.6	1.5	225616.9	4617378.7	232.0
Inverter27	99.6	1.5	226090.7	4616890.5	229.2
Inverter28	99.6	1.5	225934.1	4616893.3	225.9
Inverter29	99.6	1.5	227255.9	4617352.8	225.2
Inverter30	99.6	1.5	227453.3	4617349.6	224.5
Inverter31	99.6	1.5	227644.7	4617345.7	224.0
Inverter32	99.6	1.5	227641.4	4617157.8	223.3
Inverter33	99.6	1.5	227252.5	4617164.6	225.0

APPENDIX C. MODEL RESULTS FOR EACH RECEPTOR

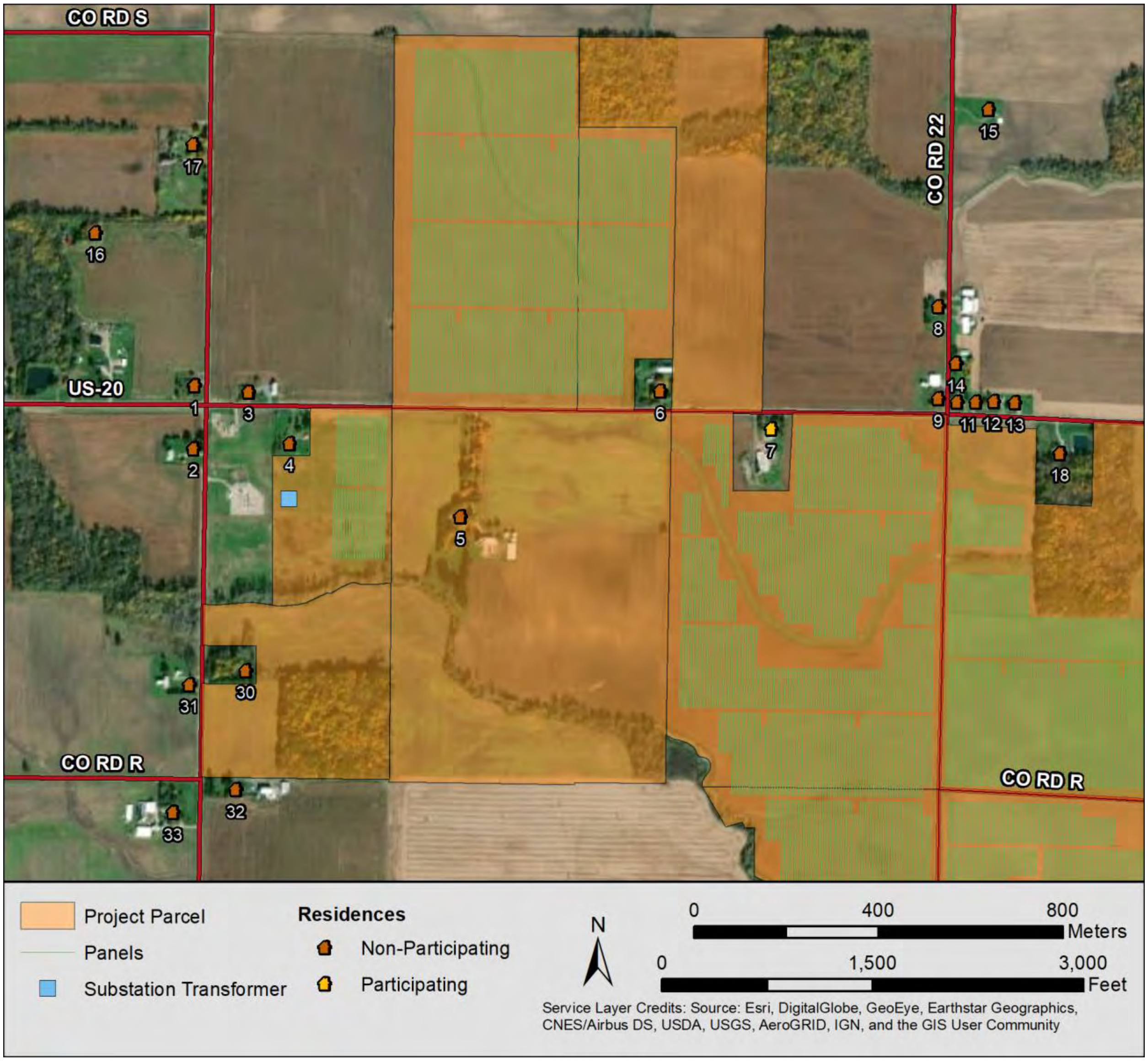

FIGURE 21: MAP OF RECEIVER IDS - WESTERN AREA

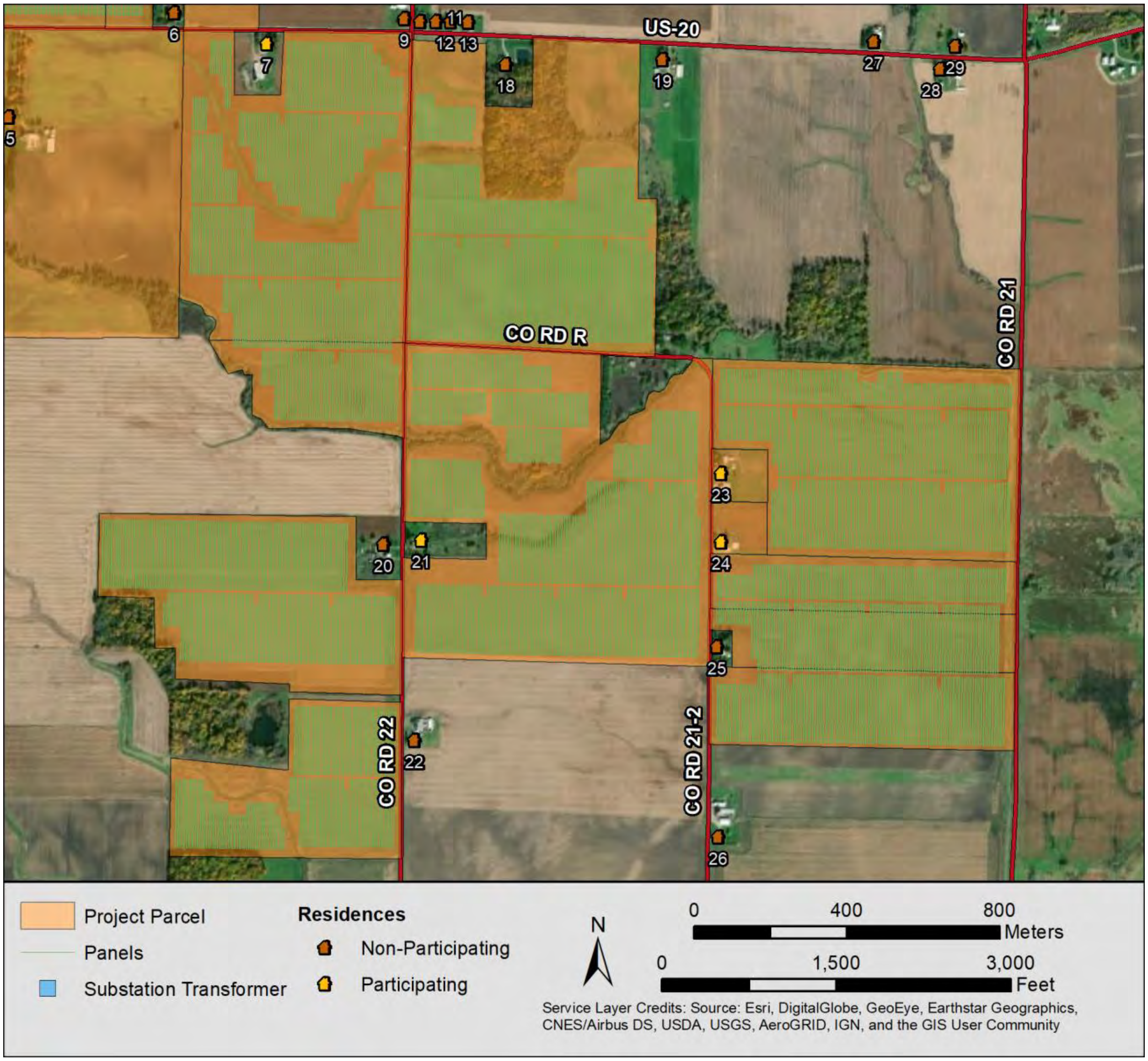

FIGURE 22: MAP OF RECEIVER IDS - EASTERN AREA

TABLE 8: MODEL RESULTS & RECEIVER COORDINATES

Receiver ID	Participation Status	Daytime Modeled Sound Level (dBA)	Daytime Modeled Sound Level (dBA)	Relative Height (m)	Coordinates UTM NAD83 Z17N X (m)	Y (m)	Absolute Elevation (m)
1	NonParticipating	42	42	4	224630.8	4618912.0	239.6
2	NonParticipating	43	42	4	224627.9	4618775.7	239.9
3	NonParticipating	43	43	4	224747.6	4618898.8	239.1
4	NonParticipating	47	46	4	224836.8	4618787.2	239.8
5	NonParticipating	46	46	4	225207.9	4618627.3	238.9
6	NonParticipating	46	46	4	225640.5	4618900.6	234.2
7	Participating	49	49	4	225882.3	4618818.4	235.6
8	NonParticipating	44	44	4	226244.1	4619083.6	237.1
9	NonParticipating	45	45	4	226243.2	4618884.2	234.8
10	NonParticipating	45	45	4	226284.4	4618877.3	235.1
11	NonParticipating	44	44	4	226325.6	4618876.4	233.9
12	NonParticipating	44	44	4	226364.6	4618877.7	233.6
13	NonParticipating	44	44	4	226410.5	4618875.5	234.0
14	NonParticipating	44	44	4	226282.3	4618960.0	235.8
15	NonParticipating	36	36	4	226353.1	4619511.8	234.3
16	NonParticipating	40	40	4	224414.5	4619244.1	239.8
17	NonParticipating	43	43	4	224627.0	4619435.2	241.5
18	NonParticipating	45	45	4	226508.4	4618765.4	231.3
19	NonParticipating	44	44	4	226918.4	4618777.5	233.4
20	NonParticipating	46	46	4	226188.1	4617509.1	232.6
21	Participating	46	46	4	226287.9	4617519.5	232.1
22	NonParticipating	46	46	4	226269.7	4616995.4	232.1
23	Participating	51	51	4	227071.3	4617693.7	229.1
24	Participating	50	50	4	227071.9	4617515.5	229.7
25	NonParticipating	47	47	4	227061.8	4617240.3	229.1
26	NonParticipating	43	43	4	227064.6	4616743.4	227.2
27	NonParticipating	38	38	4	227471.5	4618825.2	228.9
28	NonParticipating	39	39	4	227645.4	4618752.5	229.0
29	NonParticipating	39	39	4	227684.8	4618812.4	229.2
30	NonParticipating	38	38	4	224741.7	4618294.1	236.6
31	NonParticipating	40	40	4	224619.1	4618263.7	239.8
32	NonParticipating	35.0		4	321753.0	4373745.5	220.3
33	Participating	40.5		4	325416.4	4373688.3	215.4

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