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December 7, 2022

***Via Electronic Filing***

Ms. Tanowa Troupe
Administration/Docketing
Public Utilities Commission of Ohio
180 East Broad Street, 11th Floor
Columbus, OH  43215-3793

**Re: Arche Energy Project, LLC, Case No 20-979-EL-BGN**

Dear Ms. Troupe:

On April 15, 2021, the Ohio Power Siting Board ("OPSB" or "Board") issued a certificate of environmental compatibility and public need to Arche Energy Project, LLC ("Arche") for the constructions, operation, and maintenance of a 107 MW solar generation facility located in Fulton County, Ohio.

As part of the Certificate, Arche must comply with various conditions related to the construction and operation of the facility. Certificate Condition No. 15 requires that:

> **If the inverters or substation transformer chosen for the project have a higher sound power output than the models used in the noise model, Arche shall submit at least 30 days prior to construction an updated noise study using noise data from the inverter and substation chosen for the project. The updated noise study shall show that sounds levels will not exceed the daytime ambient level plus five dBa at any nonparticipating sensitive receptor.**

In compliance with Condition No. 15, attached is Arche's updated Noise Assessment dated November 29, 2022. Please do not hesitate to contact me if you have any questions.

Sincerely,

Dylan F. Borchers

Attachment

Cc: Jim O'Dell (w/Attachment)

# LIGHTSOURCE BP

# ARCHE SOLAR

**Noise Assessment | November 29, 2022**


**PREPARED FOR:**
LIGHTSOURCE BP

**SUBMITTED BY:**
RSG

**IN COOPERATION WITH:**
ENVIRONMENTAL DESIGN & RESEARCH

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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, Lightsource BP, 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 71 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 (122 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, inverters may operate sometimes at night for VAR[1] support.

[1] volt-ampere reactive

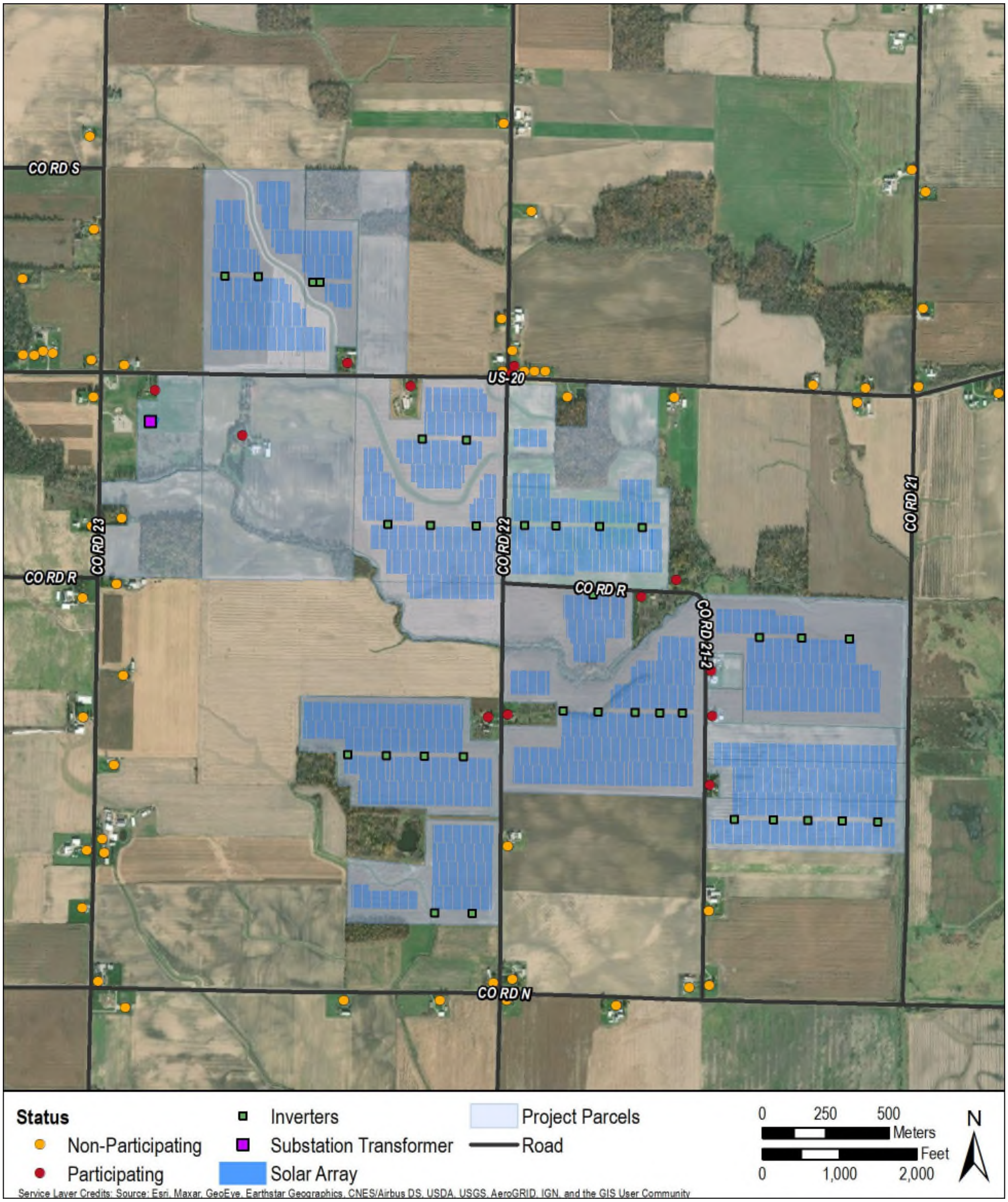


**FIGURE 1: PROJECT AREA MAP**

# 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.

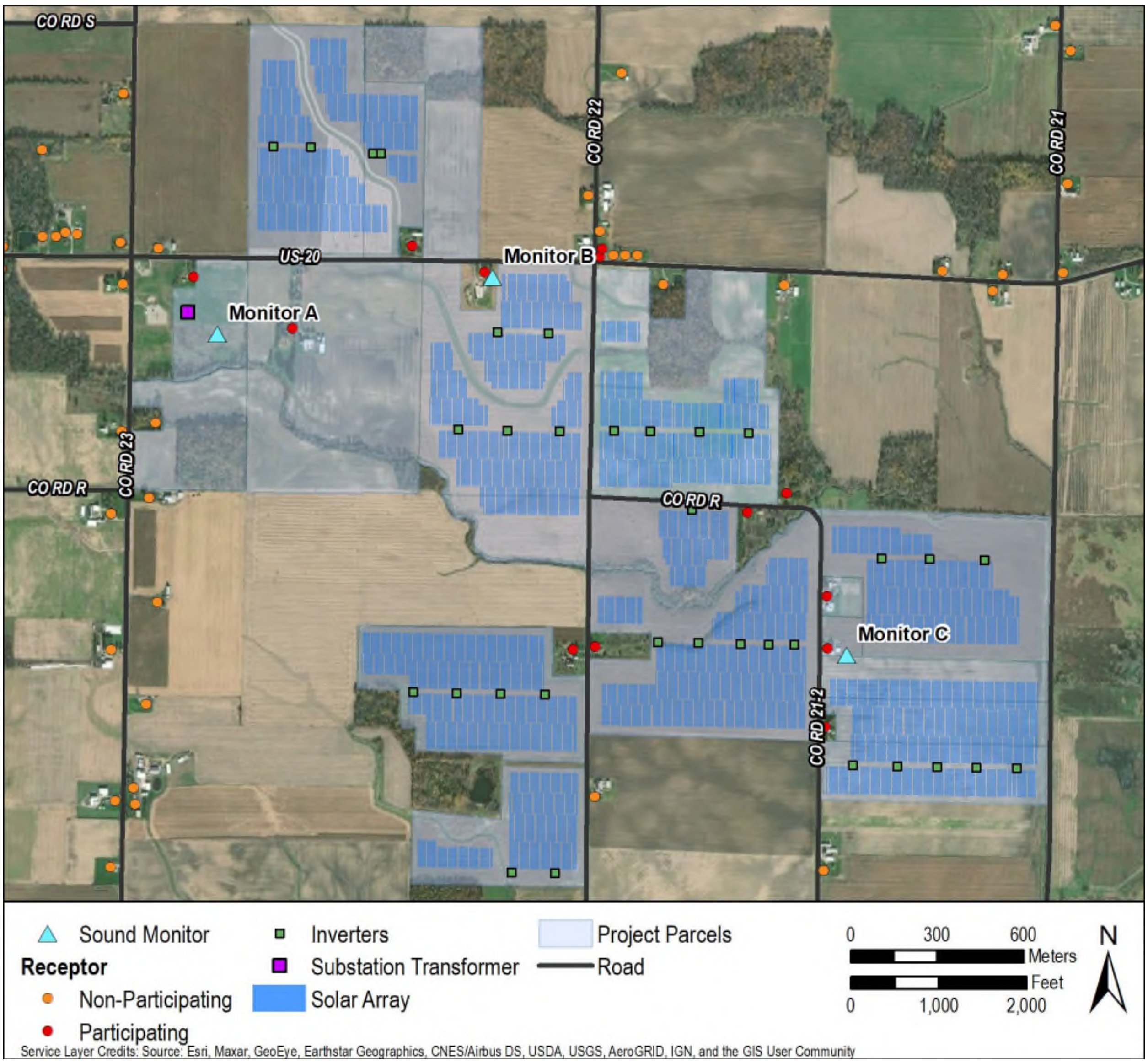


**FIGURE 2: MAP OF MONITOR LOCATIONS**

## 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 $10^{th}$ percentile ($L_{10}$), median ($L_{50}$), and lower $10^{th}$ 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 10$^{th}$ percentile ($L_{10}$), median ($L_{50}$), and lower 10$^{th}$ 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.

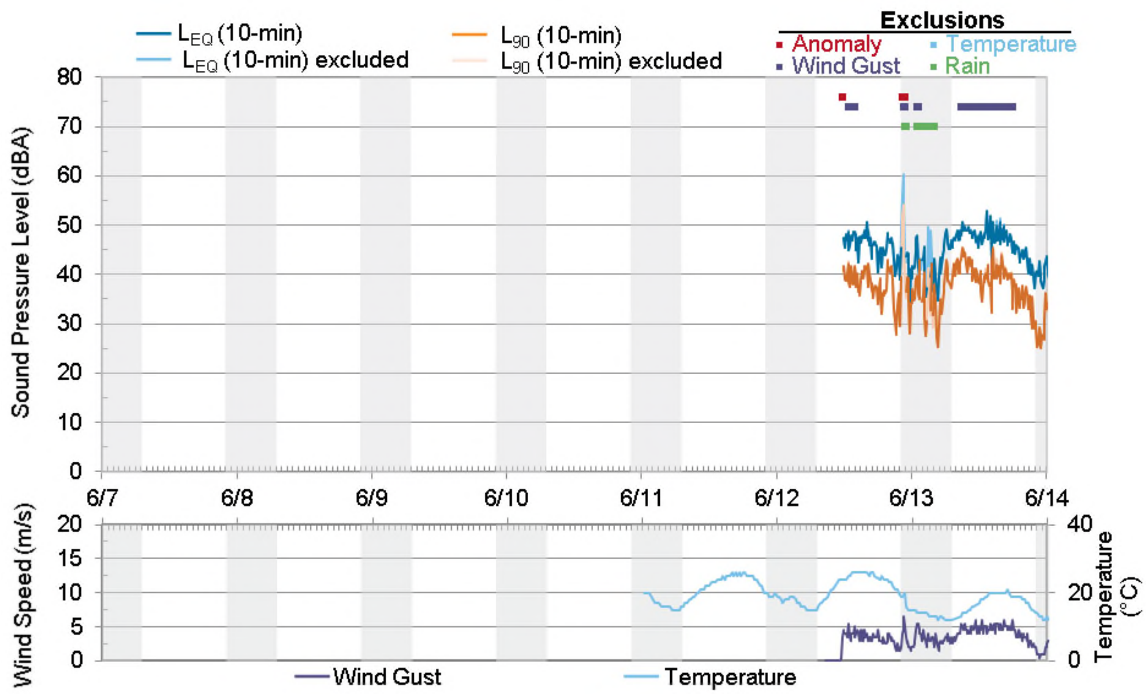


**FIGURE 9: MONITOR A TIME-HISTORY RESULTS - PART 1**

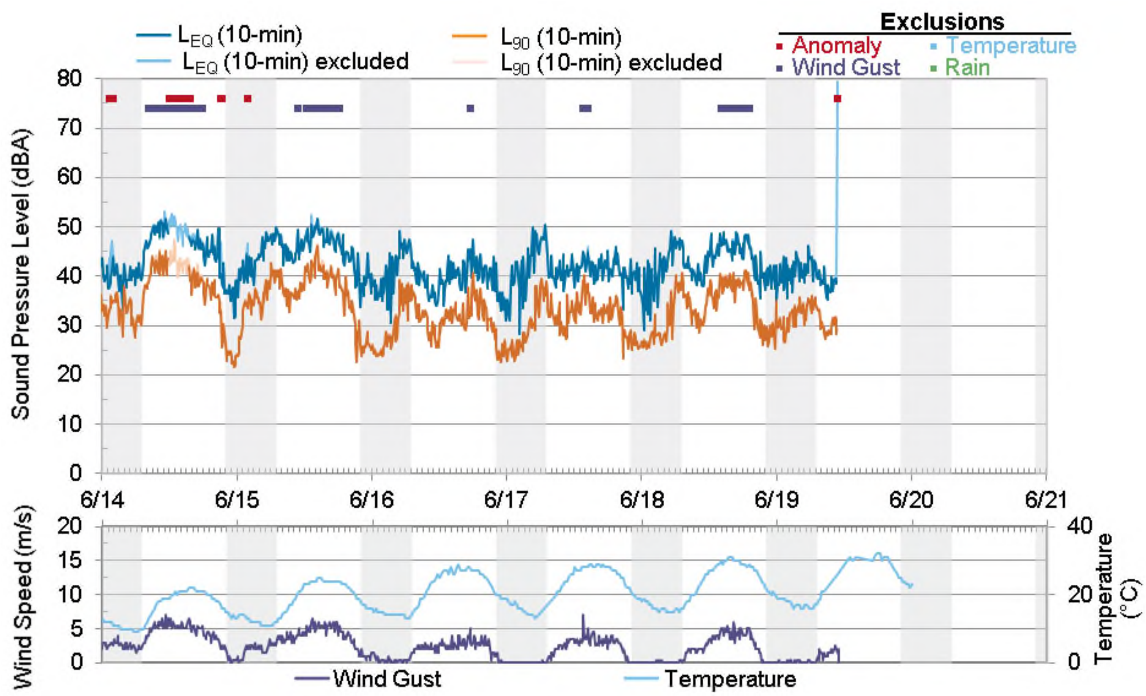


FIGURE 10: MONITOR A TIME-HISTORY RESULTS - PART 2

## 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.

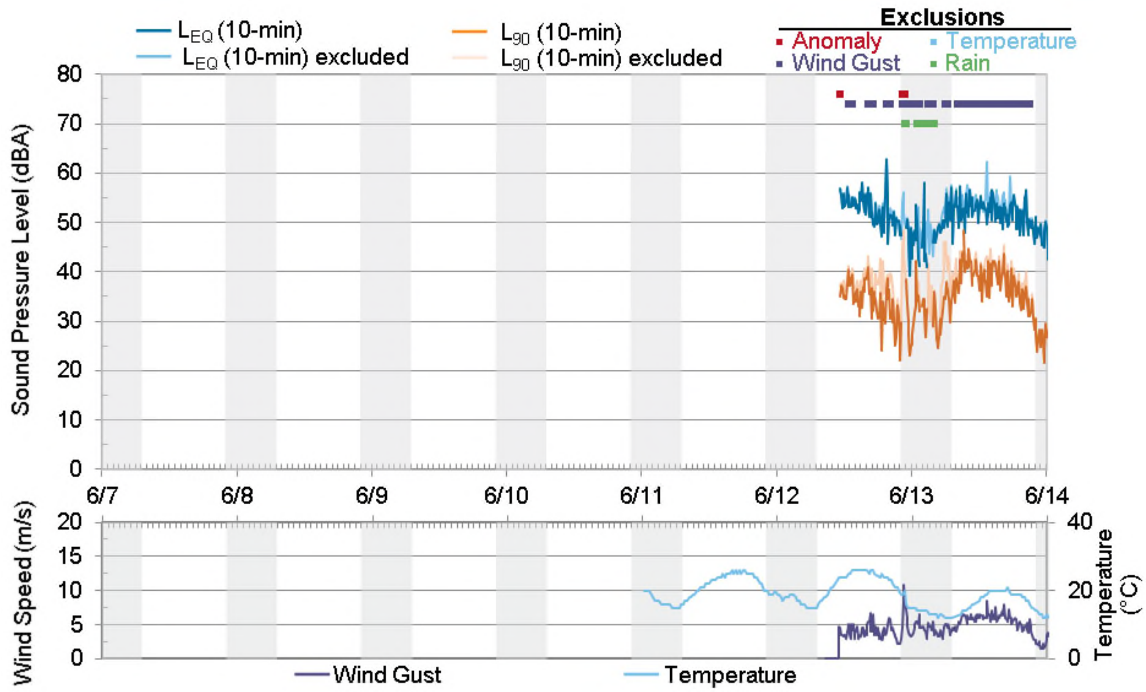


**FIGURE 11: MONITOR B TIME-HISTORY RESULTS - PART 1**

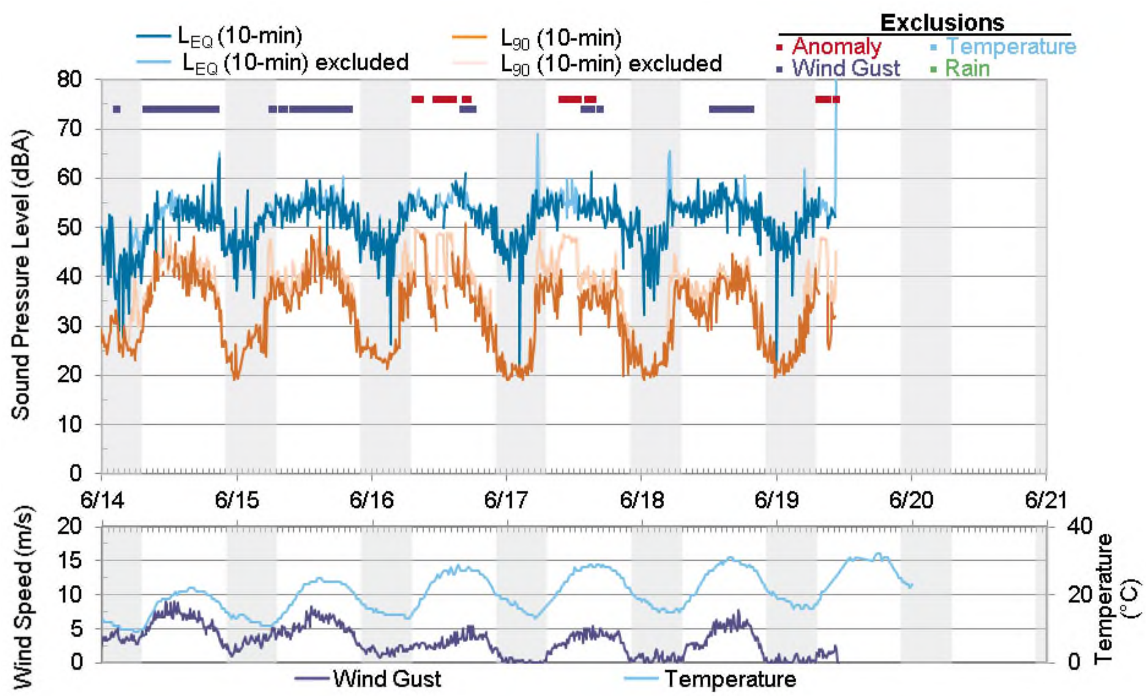


**FIGURE 12: MONITOR B TIME-HISTORY RESULTS - PART 2**

## 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.

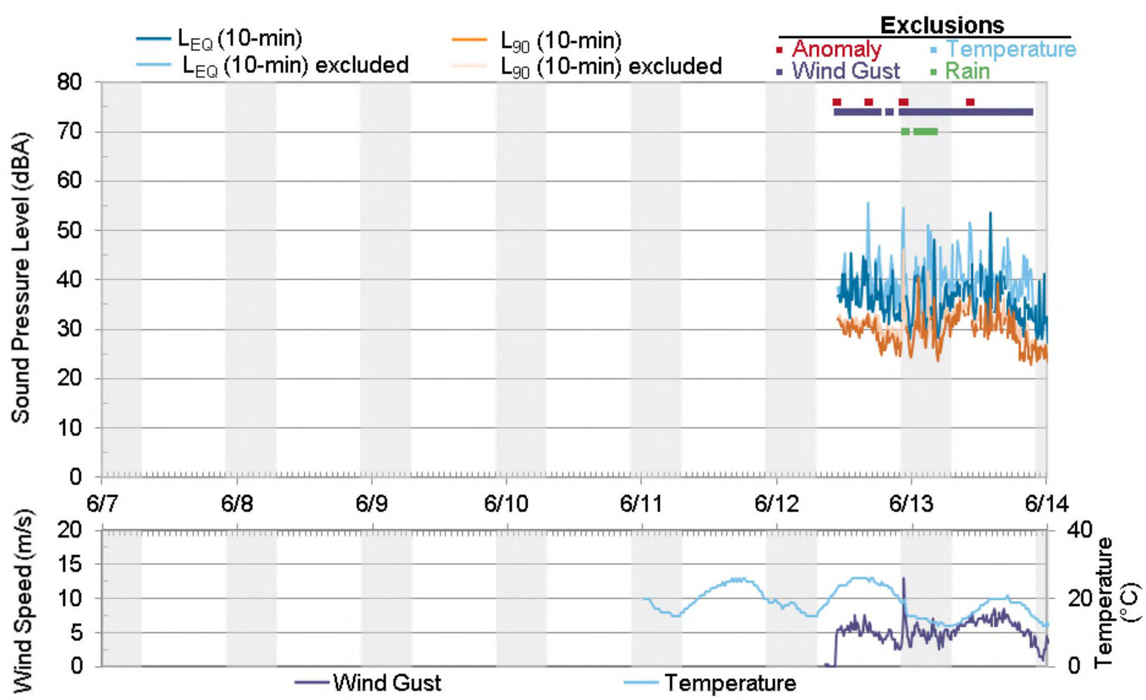


**FIGURE 13: MONITOR C TIME-HISTORY RESULTS - PART 1**

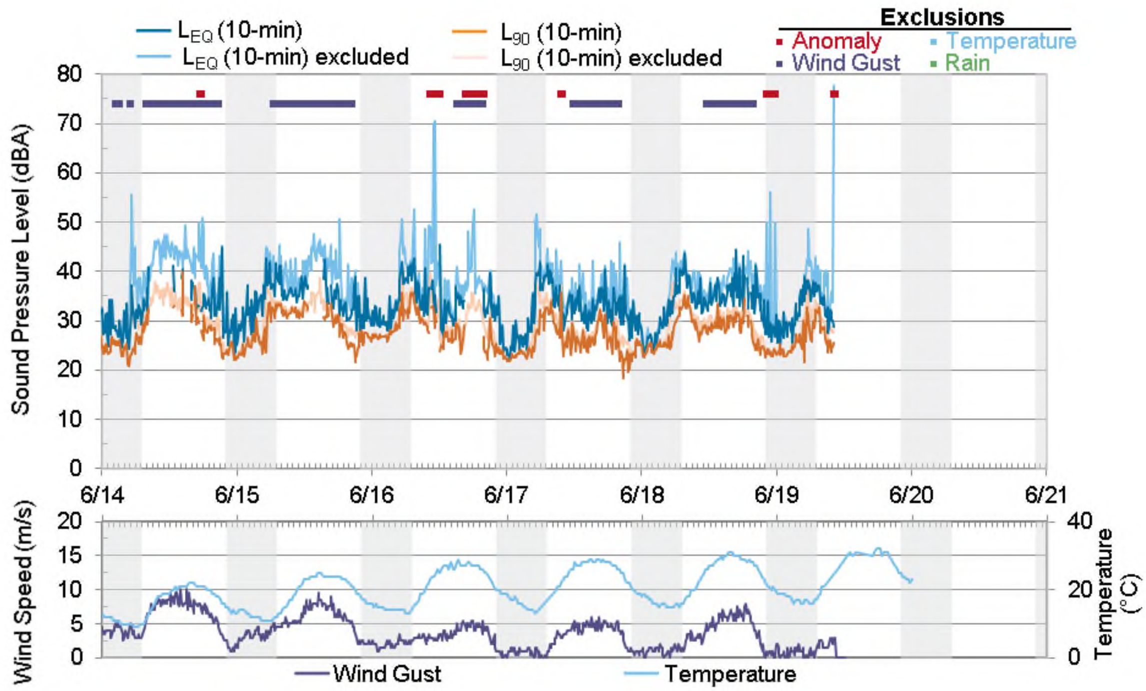


**FIGURE 14: MONITOR C TIME-HISTORY RESULTS - PART 2**

# 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 Inputs and Assumptions

Model input parameters are listed in Appendix B including the modeled sound power spectra for each source. A total of 71 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.

Modeled equipment includes the following:

- Array Inverter Skids – There are 33 inverter skids scattered throughout the Project. Each skid includes an inverter and a medium voltage transformer (MVT). These convert the DC electricity generated by the solar panels to low-voltage AC power to medium-voltage AC power for transmission to the substation. The inverters have fans whose speed is a function of temperature and load. Inverter fans were assumed to operate simultaneously at 100 percent during the daytime. In addition, some inverters would operate at night for

VAR support. During VAR support, inverter fans would operate at 70 percent, resulting in a sound level reduction of about 6 dB from full operations. As a conservative measure, this assessment assumes that all inverters operate continuously at night at 70 percent for VAR support. Each inverter skid, including the sound generated by both the inverter and the MVT, is modeled with a sound power level of 99.6 dBA during the daytime and 93.6 dBA during the nighttime.

- Substation Transformer – There will be one substation transformers which step up the medium voltage AC power to the high voltage of the transmission line. The substation transformer is modeled with a sound power level of 105 dBA with cooling fans on and 102 dBA with cooling fans off. The fans typically will operate only during daylight.

The sources operating under each scenario are shown in Table 2. The highest sound levels occur during the daytime scenario, as all equipment would be operating at their maximum sound output at the same time.

**TABLE 2: EQUIPMENT OPERATION SCENARIOS**

| Sound Source | Operation Scenario | |
|---|---|---|
| | Daytime | Nighttime |
| Inverter Skids (Inverters & MVT) | 100% | 70% |
| Substation Transformer[4] | ONAF | ONAN |

Model input parameters are listed in Appendix B including the modeled sound power spectra for each source.

## 5.2 RESULTS

A summary of the sound propagation model results is provided in Table 3 and Appendix C provides a list of the calculated overall sound pressure levels at each discrete receiver. As shown in Table 3, all non-participating residences are projected at 42 dBA or less during the nighttime and 48 dBA or less during the daytime which is less than the nighttime and daytime Project design thresholds of 47 dBA and 50 dBA, respectively.

**TABLE 3: SUMMARY OF MODELED SOUND PRESSURE LEVELS (dBA)**

| | DAYTIME | | | NIGHTTIME | | |
|---|---|---|---|---|---|---|
| | AVG | MIN | MAX | AVG | MIN | MAX |
| Non-Participating Residence | 39 | 30 | 48 | 34 | 24 | 42 |
| Participating Residence | 49 | 46 | 53 | 43 | 40 | 47 |

[4] ONAN – Oil Natural Air Natural (Fans off), ONAF – Oil Natural Air Forced (Fans On)

The highest non-participating residence is 48 dBA during the day and 42 dBA during the night and is located on US-22. A map of the daytime projected sound levels is provided in Figure 15, and the nighttime projected sound levels are provided in Figure 16.

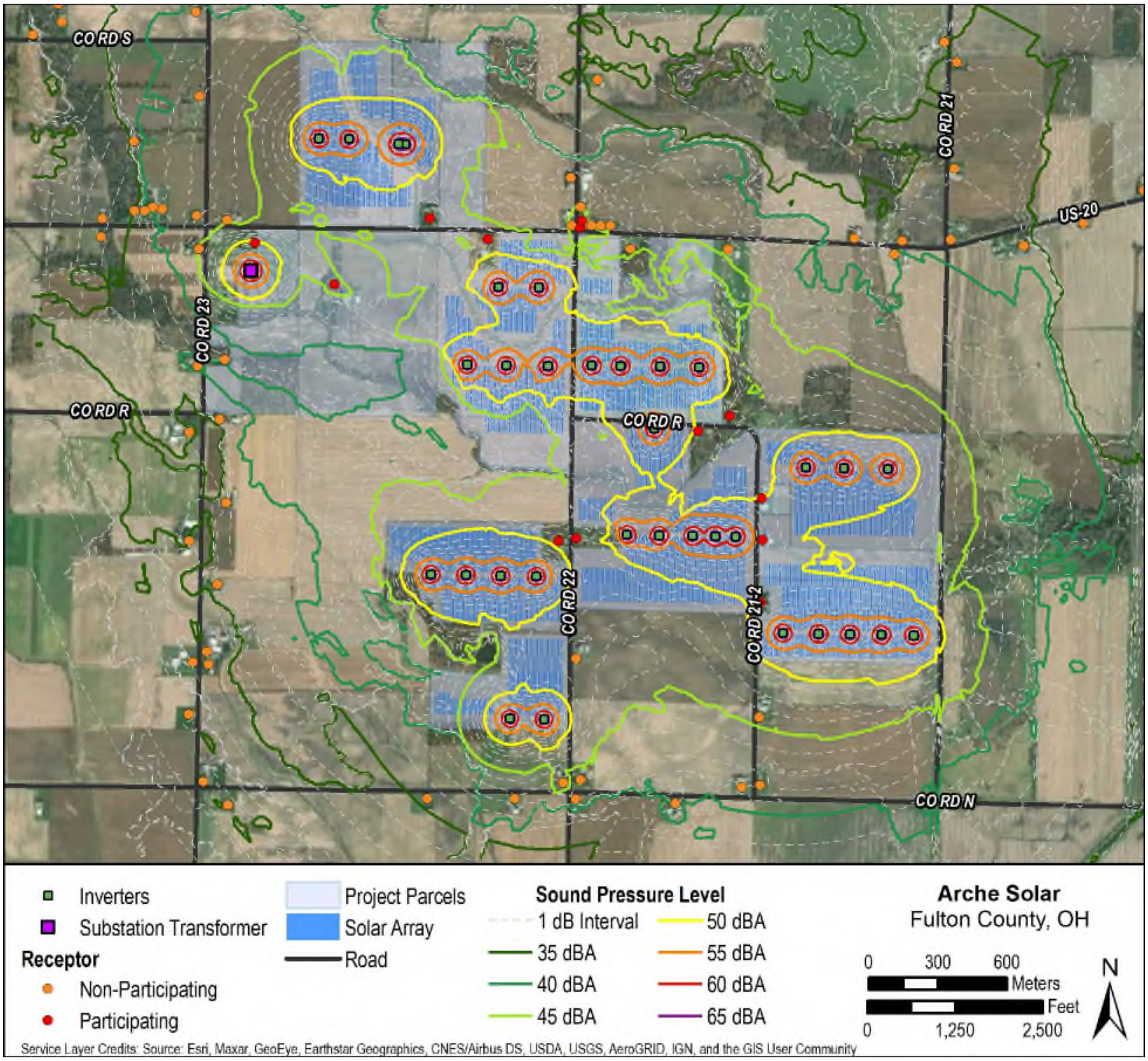


**FIGURE 15: DAYTIME SOUND PROPAGATION MODEL RESULTS**

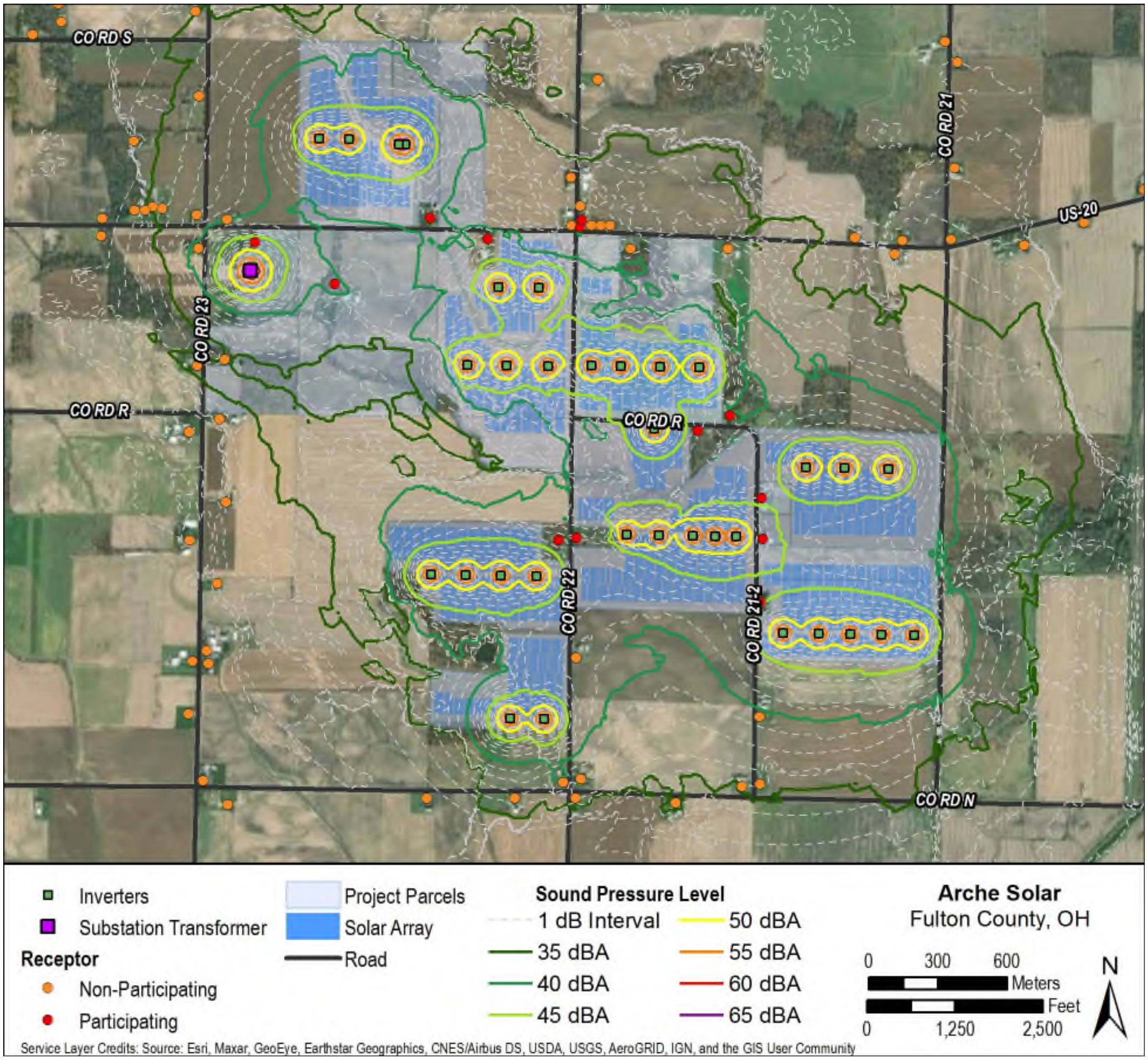


**FIGURE 16: NIGHTTIME SOUND PROPAGATION MODEL RESULTS WITH VAR SUPPORT**

# 6.0 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[5] are shown in Table 4 along with the approximate maximum sound pressure levels at 15 meters (50 feet) and 50 meters (165 feet) the closest distance between a nonparticipating residence and a solar array where racking and piling will take place.

[5] 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 50 meters (165 feet) (dBA)[6] | Maximum Sound Pressure Level at 15 meters (50 feet) (dBA) |
|---|---|---|
| Excavator | 75 | 85 |
| Dozer | 75 | 85 |
| Grader | 75 | 85 |
| Roller | 75 | 85 |
| Dump Truck | 74 | 84 |
| Concrete Mixing Truck | 75 | 85 |
| Concrete Pumper Truck | 72 | 82 |
| Man-lift | 75 | 85 |
| Flatbed Truck | 74 | 84 |
| Large Crane | 75 | 85 |
| Small Crane | 73 | 83 |
| Trencher | 73 | 83 |
| Compactor | 70 | 80 |
| Forklift | 75 | 85 |
| Boom Truck | 74 | 84 |
| Small Pile Driver | 74 | 84 |

[6] 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.

# 7.0 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. During daytime, this assessment conservatively assumed:
    a. The substation transformer would operate under ONAF cooling mode (fans on),
    b. All inverter fans would operate at 100 percent during the day, and
    c. Evaluated the projected sound levels from those sources against the nighttime threshold of 50 dBA for non-participating residences.
4. 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. The substation transformer would operate under ONAN cooling mode (fans off),
    b. All inverter fans would operate at 70 percent during the night, and
    c. Evaluated the projected sound levels from those sources against the nighttime threshold of 47 dBA for non-participating residences.

5. Sound propagation modeling was conducted in accordance with ISO 9613-2 at 71 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. Sound levels due to construction are summarized in Section 6.0.

# 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").[7] 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 17.

## 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.

[7] 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 17: 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.[8] 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 18. 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

[8] 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 18, 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.

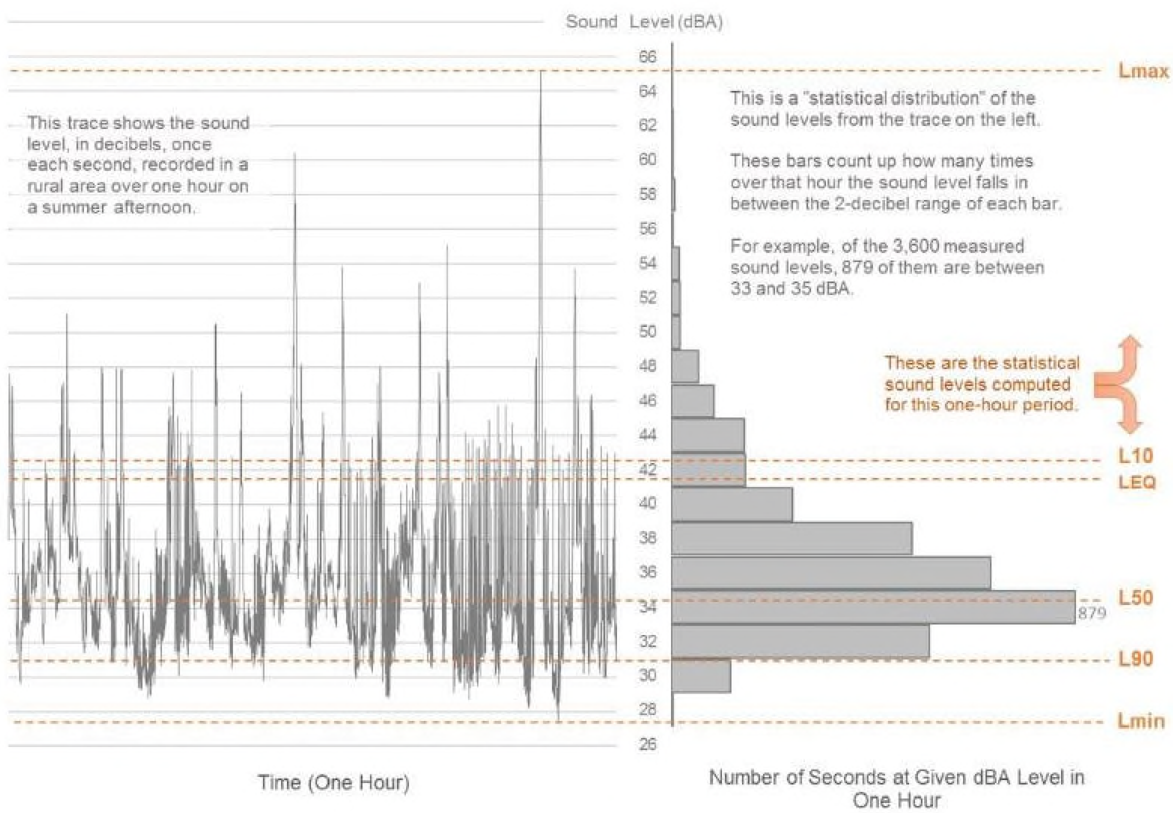


**FIGURE 18: EXAMPLE OF DESCRIPTIVE TERMS OF SOUND MEASUREMENT OVER TIME**

### *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 | 51 | 66 | 97 | 100 | 99 | 97 | 94 | 88 | 77 | 105 | 115 | Calculated from Arche Solar provided specs[9] |
| Substation Transformer ONAN | 48 | 63 | 94 | 97 | 96 | 94 | 91 | 85 | 74 | 102 | 112 | Calculated from Arche Solar provided specs[9] |
| Power Electronics HEM 100% | 124 | 124 | 105 | 96 | 90 | 86 | 84 | 77 | 77 | 100 | 127 | Manufacturer test data |
| Power Electronics HEM 70% | 118 | 118 | 99 | 90 | 84 | 80 | 78 | 71 | 71 | 94 | 121 | Manufacturer test data |

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

### TABLE 7: SOURCE INPUT DATA

| Source | Daytime Sound Power Level (dBA) | Nighttime Sound Power Level (dBA) | Relative Height (m) | Coordinates UTM NAD83 Z17N | | Absolute Elevation (m) |
|---|---|---|---|---|---|---|
| | | | | X (m) | Y (m) | |
| Sub Transformer (ONAF/ONAN) | 105 | 102 | 2.1 | 224851 | 4618676 | 235 |
| Inverter01 | 99.6 | 93.6 | 1.5 | 225148 | 4619251 | 234 |
| Inverter02 | 99.6 | 93.6 | 1.5 | 225278 | 4619248 | 233 |
| Inverter03 | 99.6 | 93.6 | 1.5 | 225522 | 4619226 | 232 |
| Inverter04 | 99.6 | 93.6 | 1.5 | 225494 | 4619226 | 232 |
| Inverter05 | 99.6 | 93.6 | 1.5 | 225926 | 4618607 | 231 |
| Inverter06 | 99.6 | 93.6 | 1.5 | 226102 | 4618603 | 231 |
| Inverter07 | 99.6 | 93.6 | 1.5 | 225790 | 4618269 | 231 |
| Inverter08 | 99.6 | 93.6 | 1.5 | 225960 | 4618266 | 229 |
| Inverter09 | 99.6 | 93.6 | 1.5 | 226140 | 4618263 | 231 |
| Inverter10 | 99.6 | 93.6 | 1.5 | 226627 | 4618261 | 229 |
| Inverter11 | 99.6 | 93.6 | 1.5 | 226797 | 4618258 | 228 |
| Inverter12 | 99.6 | 93.6 | 1.5 | 226601 | 4617991 | 228 |
| Inverter13 | 99.6 | 93.6 | 1.5 | 225633 | 4617359 | 232 |
| Inverter14 | 99.6 | 93.6 | 1.5 | 225784 | 4617356 | 231 |
| Inverter15 | 99.6 | 93.6 | 1.5 | 225936 | 4617353 | 231 |
| Inverter16 | 99.6 | 93.6 | 1.5 | 226090 | 4617350 | 231 |
| Inverter17 | 99.6 | 93.6 | 1.5 | 226483 | 4617531 | 227 |
| Inverter18 | 99.6 | 93.6 | 1.5 | 226622 | 4617529 | 226 |
| Inverter19 | 99.6 | 93.6 | 1.5 | 226768 | 4617526 | 229 |
| Inverter20 | 99.6 | 93.6 | 1.5 | 226866 | 4617525 | 228 |
| Inverter21 | 99.6 | 93.6 | 1.5 | 226955 | 4617523 | 227 |
| Inverter22 | 99.6 | 93.6 | 1.5 | 227260 | 4617823 | 224 |
| Inverter23 | 99.6 | 93.6 | 1.5 | 227426 | 4617820 | 224 |
| Inverter24 | 99.6 | 93.6 | 1.5 | 227616 | 4617816 | 223 |
| Inverter25 | 99.6 | 93.6 | 1.5 | 227160 | 4617104 | 225 |
| Inverter26 | 99.6 | 93.6 | 1.5 | 227314 | 4617101 | 224 |
| Inverter27 | 99.6 | 93.6 | 1.5 | 227451 | 4617099 | 224 |
| Inverter28 | 99.6 | 93.6 | 1.5 | 227588 | 4617097 | 224 |
| Inverter29 | 99.6 | 93.6 | 1.5 | 227727 | 4617094 | 223 |
| Inverter30 | 99.6 | 93.6 | 1.5 | 225976 | 4616733 | 225 |
| Inverter31 | 99.6 | 93.6 | 1.5 | 226124 | 4616730 | 228 |
| Inverter32 | 99.6 | 93.6 | 1.5 | 226456 | 4618264 | 229 |
| Inverter33 | 99.6 | 93.6 | 1.5 | 226330 | 4618266 | 230 |

# APPENDIX C. MODEL RESULTS FOR EACH RECEPTOR

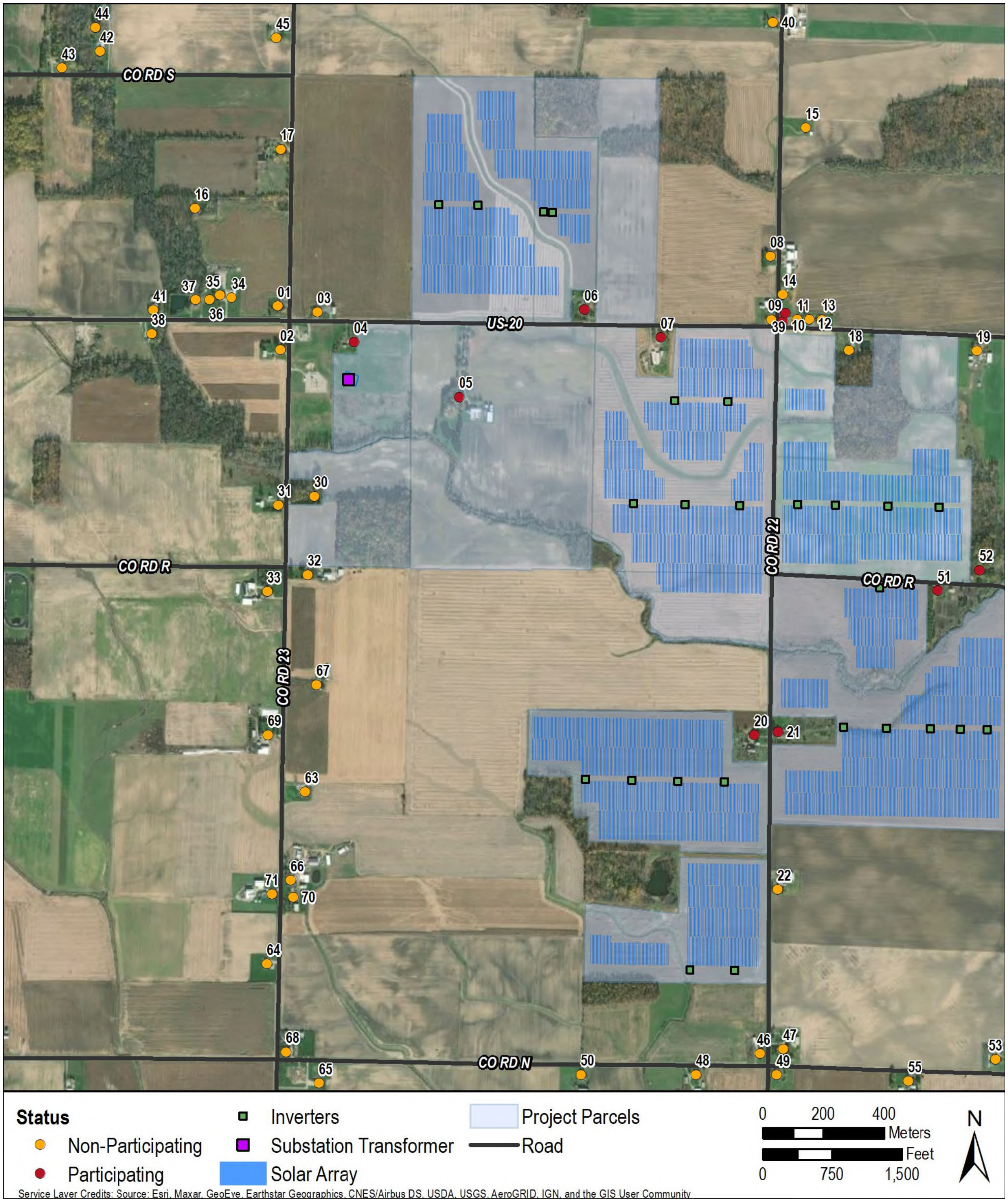


**FIGURE 19: MAP OF RECEIVER IDS - WESTERN AREA**

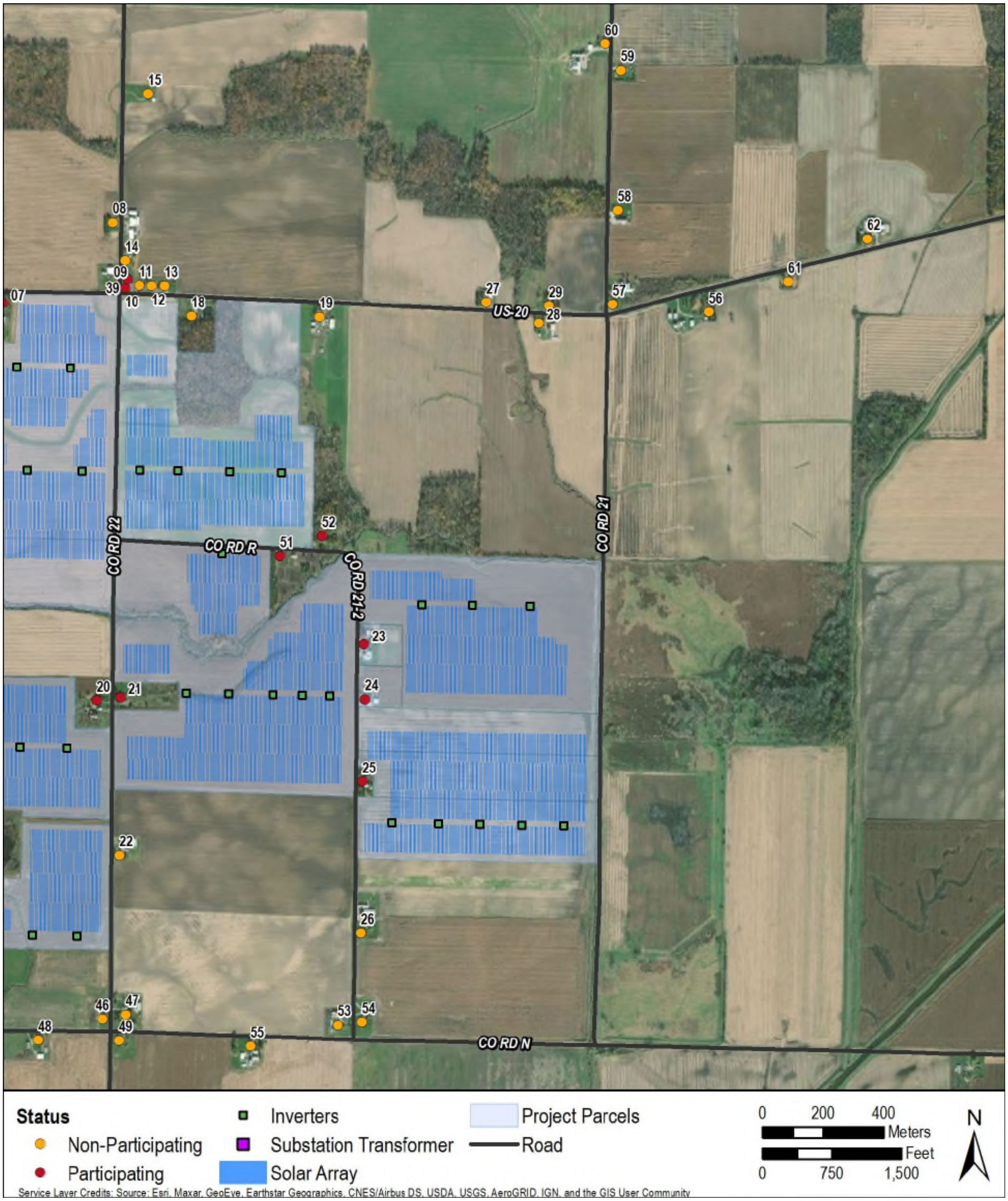


**FIGURE 20: MAP OF RECEIVER IDS - EASTERN AREA**

TABLE 8: MODEL RESULTS & RECEIVER COORDINATES

| Receiver ID | Participation Status | Modeled Sound Level (dBA) | | Relative Height (m) | Coordinates UTM NAD83 Z17N | | Absolute Elevation (m) |
|---|---|---|---|---|---|---|---|
| | | Daytime | Nighttime | | X (m) | Y (m) | |
| 1 | Non-Participating | 43 | 38 | 4 | 224618 | 4618917 | 240 |
| 2 | Non-Participating | 45 | 41 | 4 | 224626 | 4618773 | 240 |
| 3 | Non-Participating | 45 | 40 | 4 | 224749 | 4618897 | 239 |
| 4 | Participating | 51 | 47 | 4 | 224870 | 4618798 | 240 |
| 5 | Participating | 46 | 41 | 4 | 225216 | 4618618 | 239 |
| 6 | Participating | 47 | 41 | 4 | 225629 | 4618905 | 234 |
| 7 | Participating | 48 | 42 | 4 | 225880 | 4618814 | 236 |
| 8 | Non-Participating | 45 | 39 | 4 | 226241 | 4619081 | 237 |
| 9 | Non-Participating | 46 | 40 | 4 | 226244 | 4618872 | 235 |
| 10 | Participating | 46 | 40 | 4 | 226281 | 4618866 | 235 |
| 11 | Non-Participating | 45 | 39 | 4 | 226329 | 4618873 | 234 |
| 12 | Non-Participating | 45 | 39 | 4 | 226369 | 4618873 | 234 |
| 13 | Non-Participating | 45 | 39 | 4 | 226412 | 4618872 | 234 |
| 14 | Non-Participating | 45 | 39 | 4 | 226282 | 4618955 | 236 |
| 15 | Non-Participating | 35 | 29 | 4 | 226357 | 4619505 | 234 |
| 16 | Non-Participating | 38 | 33 | 4 | 224345 | 4619239 | 240 |
| 17 | Non-Participating | 42 | 36 | 4 | 224628 | 4619435 | 242 |
| 18 | Non-Participating | 45 | 39 | 4 | 226500 | 4618772 | 231 |
| 19 | Non-Participating | 45 | 39 | 4 | 226922 | 4618770 | 234 |
| 20 | Participating | 49 | 43 | 4 | 226188 | 4617505 | 233 |
| 21 | Participating | 49 | 43 | 4 | 226265 | 4617516 | 232 |
| 22 | Non-Participating | 48 | 42 | 4 | 226263 | 4616995 | 232 |
| 23 | Participating | 51 | 45 | 4 | 227069 | 4617689 | 229 |
| 24 | Participating | 53 | 47 | 4 | 227073 | 4617510 | 230 |
| 25 | Participating | 51 | 45 | 4 | 227063 | 4617238 | 229 |
| 26 | Non-Participating | 46 | 40 | 4 | 227058 | 4616739 | 227 |
| 27 | Non-Participating | 38 | 32 | 4 | 227471 | 4618818 | 229 |
| 28 | Non-Participating | 40 | 34 | 4 | 227645 | 4618748 | 229 |
| 29 | Non-Participating | 40 | 34 | 4 | 227679 | 4618806 | 229 |
| 30 | Non-Participating | 40 | 36 | 4 | 224739 | 4618291 | 237 |
| 31 | Non-Participating | 40 | 36 | 4 | 224621 | 4618262 | 240 |
| 32 | Non-Participating | 39 | 34 | 4 | 224717 | 4618032 | 238 |
| 33 | Non-Participating | 38 | 32 | 4 | 224584 | 4617977 | 238 |
| 34 | Non-Participating | 41 | 36 | 4 | 224467 | 4618945 | 240 |
| 35 | Non-Participating | 41 | 35 | 4 | 224426 | 4618953 | 240 |
| 36 | Non-Participating | 39 | 34 | 4 | 224393 | 4618937 | 238 |
| 37 | Non-Participating | 35 | 31 | 4 | 224347 | 4618938 | 236 |

| Receiver ID | Participation Status | Modeled Sound Level (dBA) | | Relative Height (m) | Coordinates UTM NAD83 Z17N | | Absolute Elevation (m) |
|---|---|---|---|---|---|---|---|
| | | Daytime | Nighttime | | X (m) | Y (m) | |
| 38 | Non-Participating | 34 | 29 | 4 | 224203 | 4618826 | 236 |
| 39 | Participating | 46 | 40 | 4 | 226290 | 4618894 | 235 |
| 40 | Non-Participating | 37 | 31 | 4 | 226248 | 4619852 | 238 |
| 41 | Non-Participating | 34 | 29 | 4 | 224208 | 4618903 | 237 |
| 42 | Non-Participating | 30 | 25 | 4 | 224032 | 4619757 | 238 |
| 43 | Non-Participating | 36 | 30 | 4 | 223907 | 4619701 | 244 |
| 44 | Non-Participating | 30 | 25 | 4 | 224017 | 4619835 | 239 |
| 45 | Non-Participating | 41 | 35 | 4 | 224613 | 4619801 | 243 |
| 46 | Non-Participating | 46 | 40 | 4 | 226207 | 4616455 | 230 |
| 47 | Non-Participating | 44 | 38 | 4 | 226283 | 4616470 | 230 |
| 48 | Non-Participating | 43 | 37 | 4 | 225996 | 4616386 | 230 |
| 49 | Non-Participating | 44 | 38 | 4 | 226261 | 4616385 | 229 |
| 50 | Non-Participating | 35 | 29 | 4 | 225617 | 4616386 | 229 |
| 51 | Participating | 49 | 43 | 4 | 226793 | 4617981 | 229 |
| 52 | Participating | 47 | 41 | 4 | 226930 | 4618047 | 229 |
| 53 | Non-Participating | 42 | 36 | 4 | 226982 | 4616436 | 226 |
| 54 | Non-Participating | 42 | 36 | 4 | 227061 | 4616445 | 226 |
| 55 | Non-Participating | 42 | 36 | 4 | 226694 | 4616366 | 227 |
| 56 | Non-Participating | 39 | 33 | 4 | 228206 | 4618786 | 233 |
| 57 | Non-Participating | 39 | 33 | 4 | 227888 | 4618811 | 229 |
| 58 | Non-Participating | 38 | 32 | 4 | 227905 | 4619120 | 230 |
| 59 | Non-Participating | 37 | 31 | 4 | 227916 | 4619582 | 231 |
| 60 | Non-Participating | 35 | 29 | 4 | 227862 | 4619669 | 231 |
| 61 | Non-Participating | 31 | 25 | 4 | 228466 | 4618885 | 229 |
| 62 | Non-Participating | 30 | 24 | 4 | 228726 | 4619027 | 229 |
| 63 | Non-Participating | 37 | 31 | 4 | 224707 | 4617317 | 236 |
| 64 | Non-Participating | 35 | 29 | 4 | 224583 | 4616752 | 235 |
| 65 | Non-Participating | 35 | 29 | 4 | 224753 | 4616358 | 234 |
| 66 | Non-Participating | 32 | 27 | 4 | 224661 | 4617025 | 234 |
| 67 | Non-Participating | 40 | 34 | 4 | 224744 | 4617670 | 238 |
| 68 | Non-Participating | 35 | 29 | 4 | 224645 | 4616461 | 235 |
| 69 | Non-Participating | 35 | 30 | 4 | 224586 | 4617506 | 236 |
| 70 | Non-Participating | 32 | 27 | 4 | 224668 | 4616969 | 234 |
| 71 | Non-Participating | 35 | 29 | 4 | 224599 | 4616980 | 235 |

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