Environmental Design and Research

DIXON RUN SOLAR NOISE ASSESSMENT

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55 Railroad Row
White River Junction, VT 05001
802.295.4999
www.rsginc.com

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1.0 INTRODUCTION

Dixon Run Solar Project (the “Project”) is a proposed solar generation facility in Jackson County, Ohio. The Project area is approximately 2,046 acres, which are primarily wooded or agricultural with some rural residences. As part of the Ohio Power Siting Board (OPSB) permitting process, RSG was retained by Environmental Design and Research to perform a noise assessment of existing acoustical conditions in the area and the primary sound-producing project components, namely inverters and transformers. This report includes:

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

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 Jackson County, Ohio and is bounded by US 35 to the southwest, OH 327 to the northwest, Keystone Furnace Road to the north, and Dixon Run Road / Luther Jones Road to the east and southeast.

The area is primarily wooded and agricultural with some residences. A total of 264 receptors are included in this assessment, including primarily residences. Also included are a cemetery and six churches. The closest sensitive receptors along with Project elements are shown in Figure 1. The closest sensitive receptor is located 30 meters (100 feet) from the Project site and 130 meters (430 feet) from the nearest solar panel.

The primary operational sound sources include 40 inverter skids (Sunny Central 4200 kVA) spread throughout the Project area and a main high voltage transformer (157 MVA) at the Project substation. The Project substation location is located near the center of the Project area, 1,400 meters (4,600 feet) from the nearest residence. Each inverter skid includes an inverter and medium voltage transformer. The solar panels are of fixed tilt design, so trackers will not be used.

Sound 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 support. As such, it has been assumed for this assessment that all sources could operate at night.

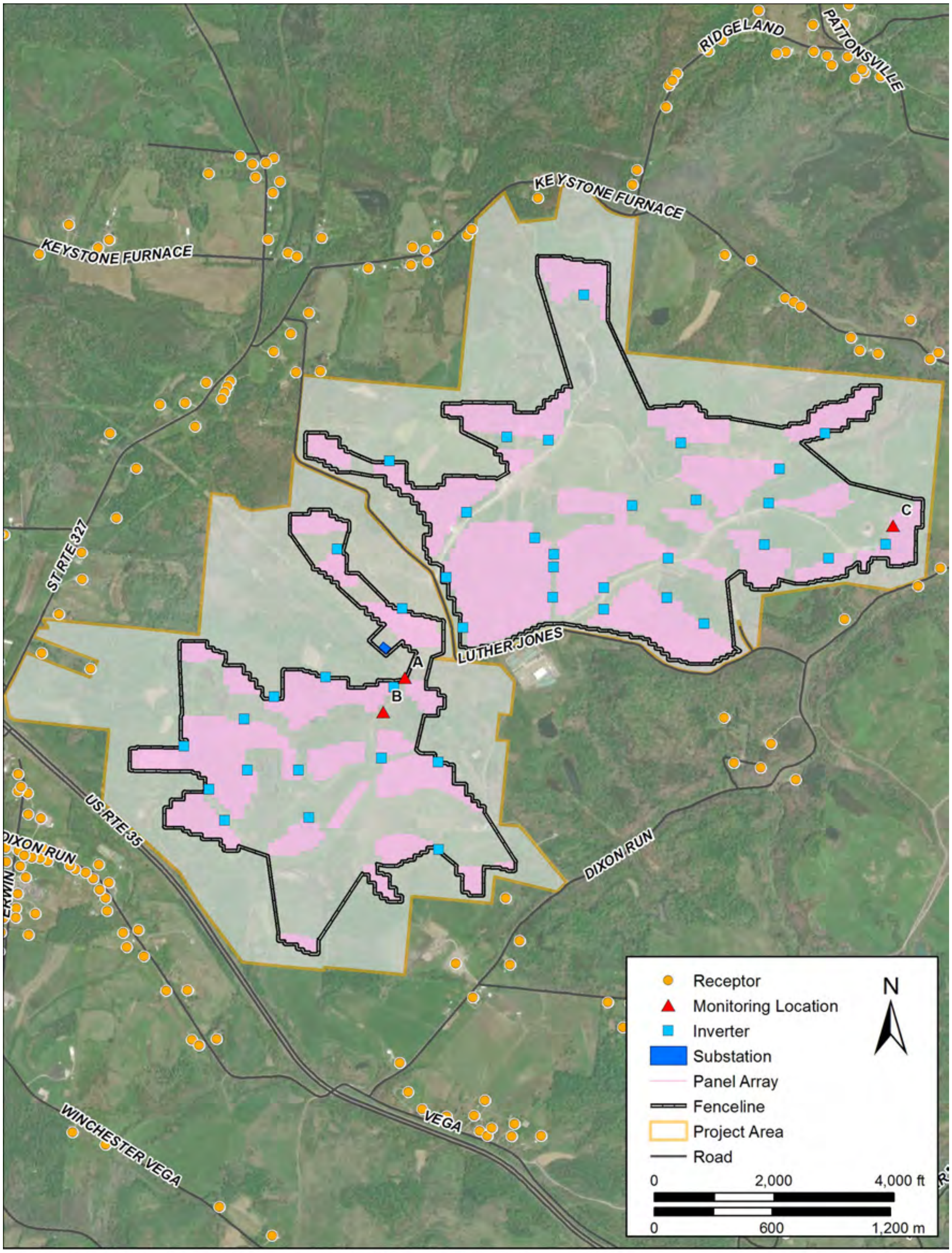

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FIGURE 1: PROJECT AREA MAP

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). This Section requires that information on noise be provided including:

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

Although there is a specific sound level limit for wind power projects within the OAC, there is not one for solar power projects. Nevertheless, we use the same procedure to establish a design threshold as if this were a wind project. Thus, 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 4.0), the average existing daytime and nighttime equivalent continuous sound levels (L_{eq}) in the area are 43 dBA and 42 dBA, respectively. This sets the daytime design threshold at 48 dBA and the nighttime design threshold at 47 dBA.

The OAC limits construction hours for wind farms to between the hours of 7 AM and 7 PM or until dusk when sunset occurs after 7 PM. Impact pile driving, hoe ram, and blasting operations, if required, are limited to the hours between 10 AM and 5 PM, Monday through Friday. The Applicant has committed to construction within these hours, as applicable. Note that solar array post driving equipment is significantly smaller and generates sound levels that are 15 to 20 dB lower than impact pile driving equipment used for large construction project such as high-rise buildings or bridges. As a result, the reduced construction hours for impact pile driving would not apply to solar array post driving.

4.0 SOUND LEVEL MONITORING

4.1 PROCEDURES

Background sound levels were measured at three locations representative of different soundscapes around the Project Area. A map showing all three monitor locations is provided in Figure 1 in Section 2.0. Monitoring was conducted from July 21 through July 28, 2021.

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 to external audio recorders (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 (5 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 meteorological data was taken from the National Weather Service ASOS station at the Greater Portsmouth Regional Airport in Portsmouth, Ohio (KPMH).

Location Descriptions

Monitor A

Monitor A was located toward the center of the Project area near the proposed substation. It was approximately 280 meters (900 feet) southwest of Luther Jones Road. The proposed substation would be approximately 160 meters (530 feet) northwest of the Monitor A location. The nearest residence to the monitor is approximately 1,200 meters (3,940 feet) to the southeast, closer to Dixon Run Road.

Monitor A measured a soundscape that is representative of rural residences not located along major roadways. A photograph of the monitor is provided in Figure 2 and a map of the monitor location is provided in Figure 3.

FIGURE 2: PHOTOGRAPH OF MONITOR A

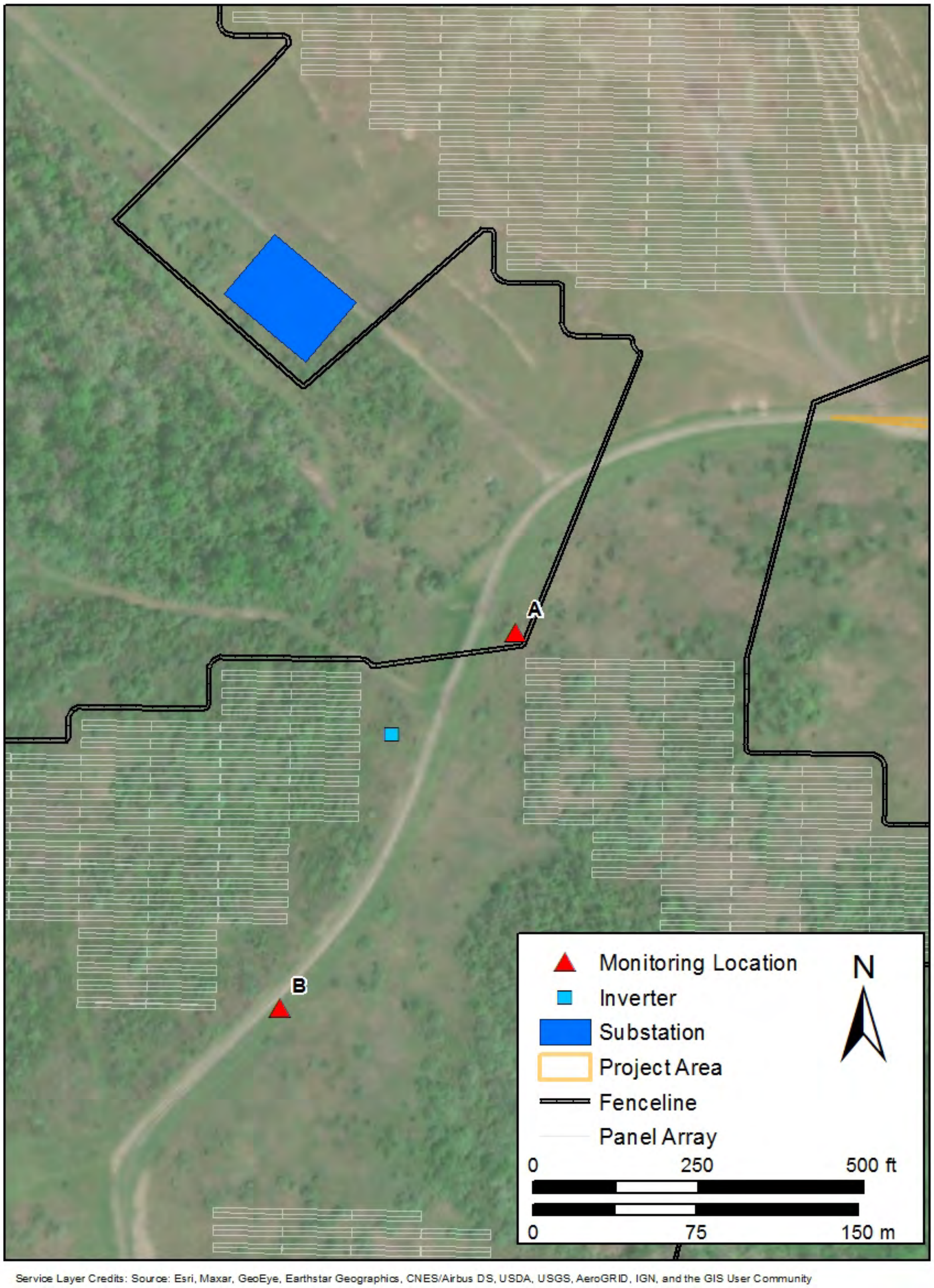

FIGURE 3: MAP OF MONITOR A LOCATION

Monitor B

Monitor B was located in the southcentral portion of Project area. It is approximately 450 meters (1,475 feet) southwest of Luther Jones Road. The proposed substation would be approximately 330 meters (1,080 feet) north of the Monitor B location. The nearest residence to the monitor is approximately 1,125 meters (3,690 feet) to the southeast, closer to Dixon Run Road.

Monitor B measured a soundscape that is representative of rural areas of the project, not located near major roadways; most residences are closer to busier roadways and would likely experience background sound levels that are higher than those measured at this monitor. A photograph of the monitor is provided in Figure 4, and map of the monitor location is provided in Figure 5.

FIGURE 4: PHOTOGRAPH OF MONITOR B

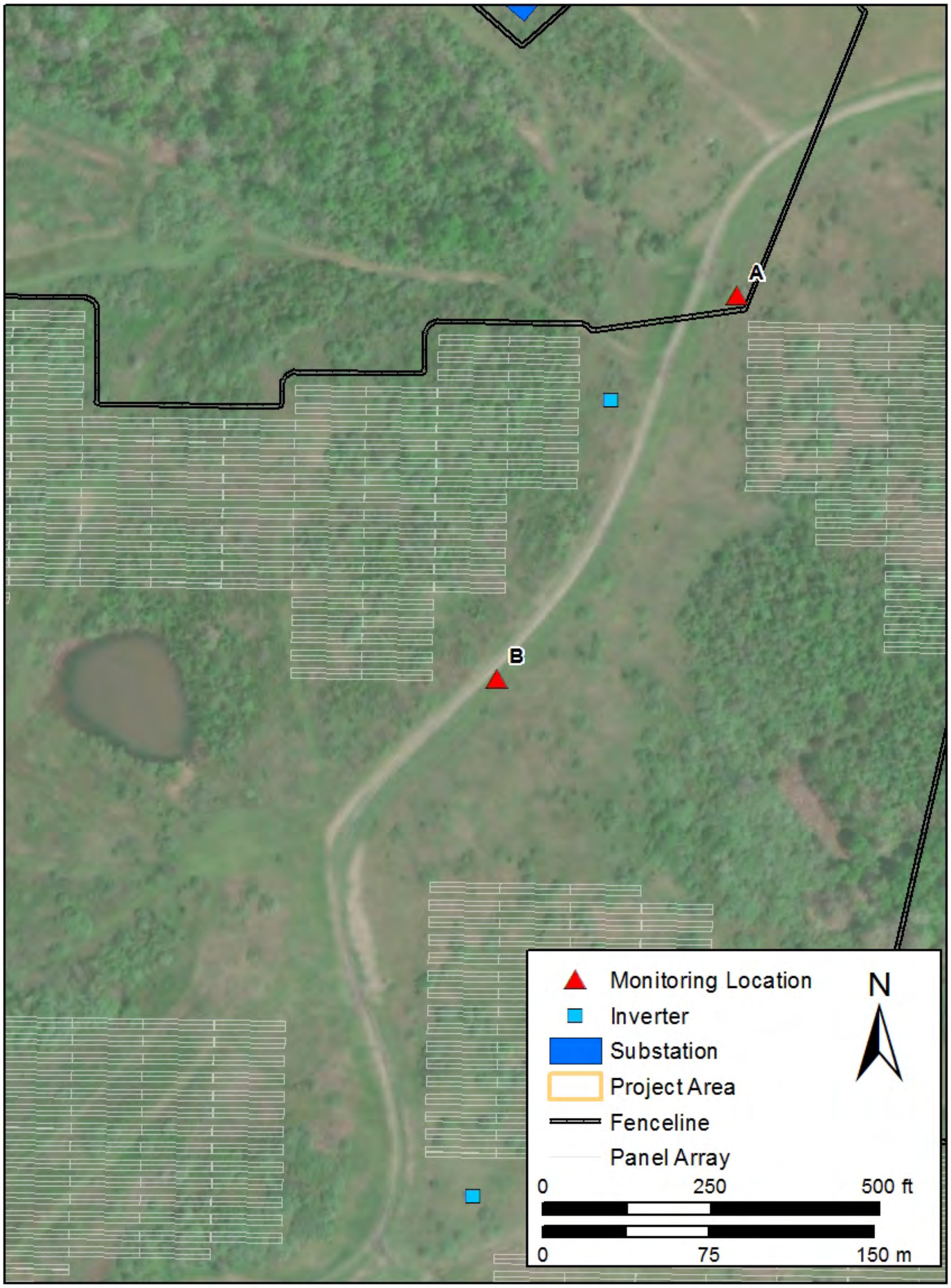

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FIGURE 5: MAP OF MONITOR B LOCATION

Monitor C

Monitor C was located in the eastern region of the Project area, approximately 300 meters (1,000 feet) east of Dixon Run Road. The nearest residence to the monitor location is approximately 175 meters (560 feet) to the southwest.

Monitor C measured a soundscape that is representative of residences set back from Dixon Run Road. A photograph of the monitor is provided in Figure 6, and map of the monitor location is provided in Figure 7.

FIGURE 6: PHOTOGRAPH OF MONITOR C

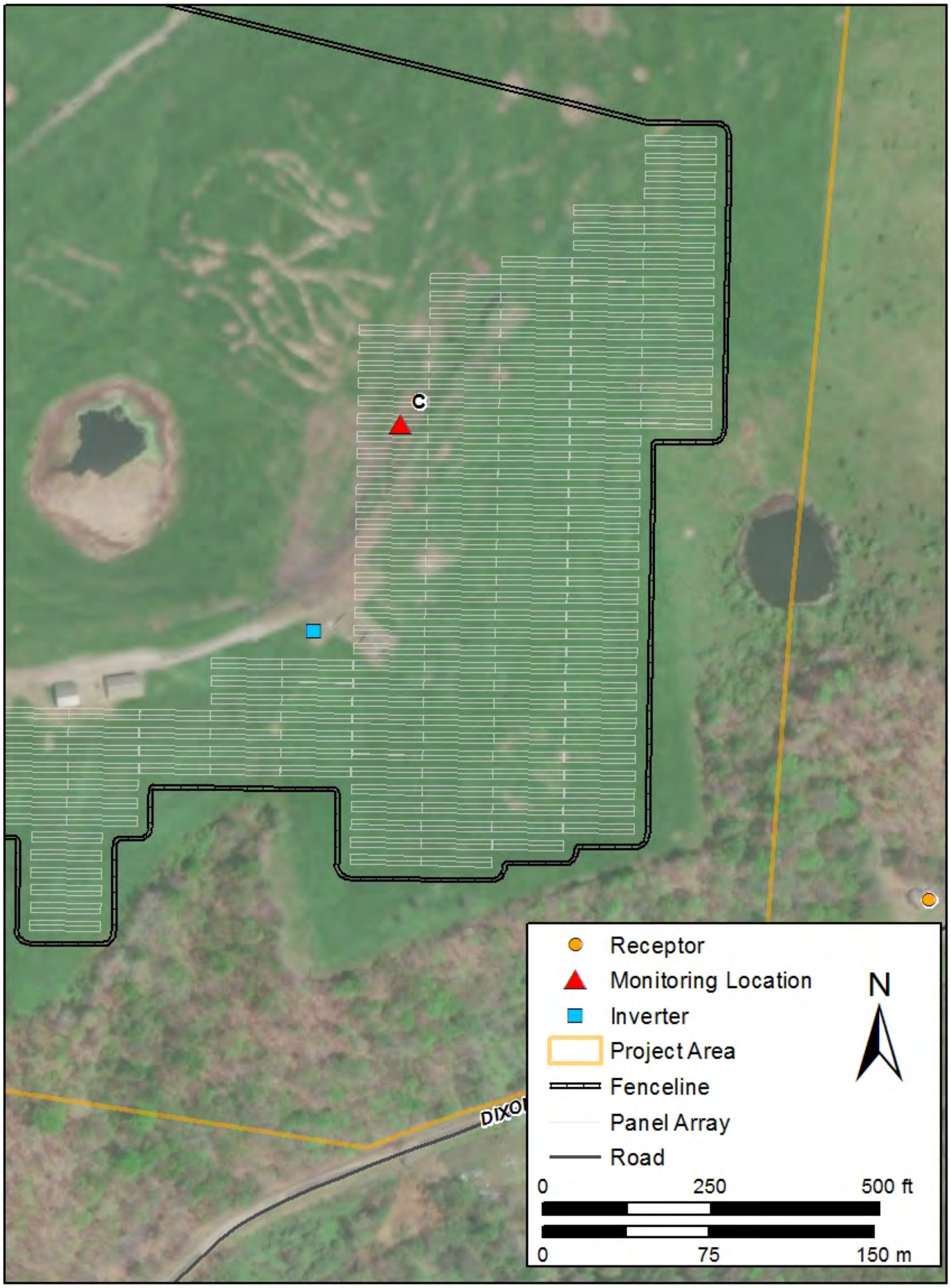


FIGURE 7: MAP OF MONITOR C LOCATION

Data Processing

Following the collection of the sound level 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.

To maintain the integrity of the background sound levels data, conditions that would cause false sound level readings or artificially high levels were excluded from the data. These periods include:

- Wind speeds above 5 m/s (11 mph);
- Precipitation and thunderstorm events;
- Anomalous events;
- Temperatures below -10°C (14°F); and,
- Equipment interactions by RSG staff, other people, or animals.

4.2 BACKGROUND SOUND LEVEL SUMMARY

An overall summary of the monitoring 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 for sound level metrics including the 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 43 dBA. As discussed in Section 3.0, this sets the nighttime project design threshold at 47 dBA and the daytime project design threshold at 48 dBA.

TABLE 1: SUMMARY OF BACKGROUND SOUND LEVELS

Site	Sound Pressure Level (dBA)			
	L_{eq}	L_{90}	L_{50}	L_{10}
Overall				
A	42	29	37	45
B	44	31	40	47
C	41	27	35	45
Day				
A	43	29	37	46
B	44	30	39	47
C	41	27	35	45
Daytime Average	**43**			
Daytime Limit	**48**			
Night				
A	42	30	37	44
B	44	33	40	48
C	40	28	35	44
Nighttime Average	**42**			
Nighttime Limit	**47**			

4.3 MONITOR RESULTS BY LOCATION

For display purposes, the one-second data that was collected is displayed in 10-minute levels 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 4.1 are indicated with color-coded markers at the bottom of each sound level graph. Sound level data during periods when 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.[1] Each graph exhibits day/night shading where night is defined as 22:00 to 7:00 and shaded grey.

[1] 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 (L_{eq} and L_{90}) as only some of the 10-minute period was excluded.

Monitor A Results

Background sound level monitoring results for Monitor A are shown in Figure 8. The primary sources of sound at this monitor location are geophonic sounds such as wind blowing over obstacles (i.e. tree branches and leaves, grass, etc.) and biogenic sounds such as insects and birds. Traffic sounds are minimal. As shown in Figure 8, there were very few periods that necessitated exclusion from the dataset.

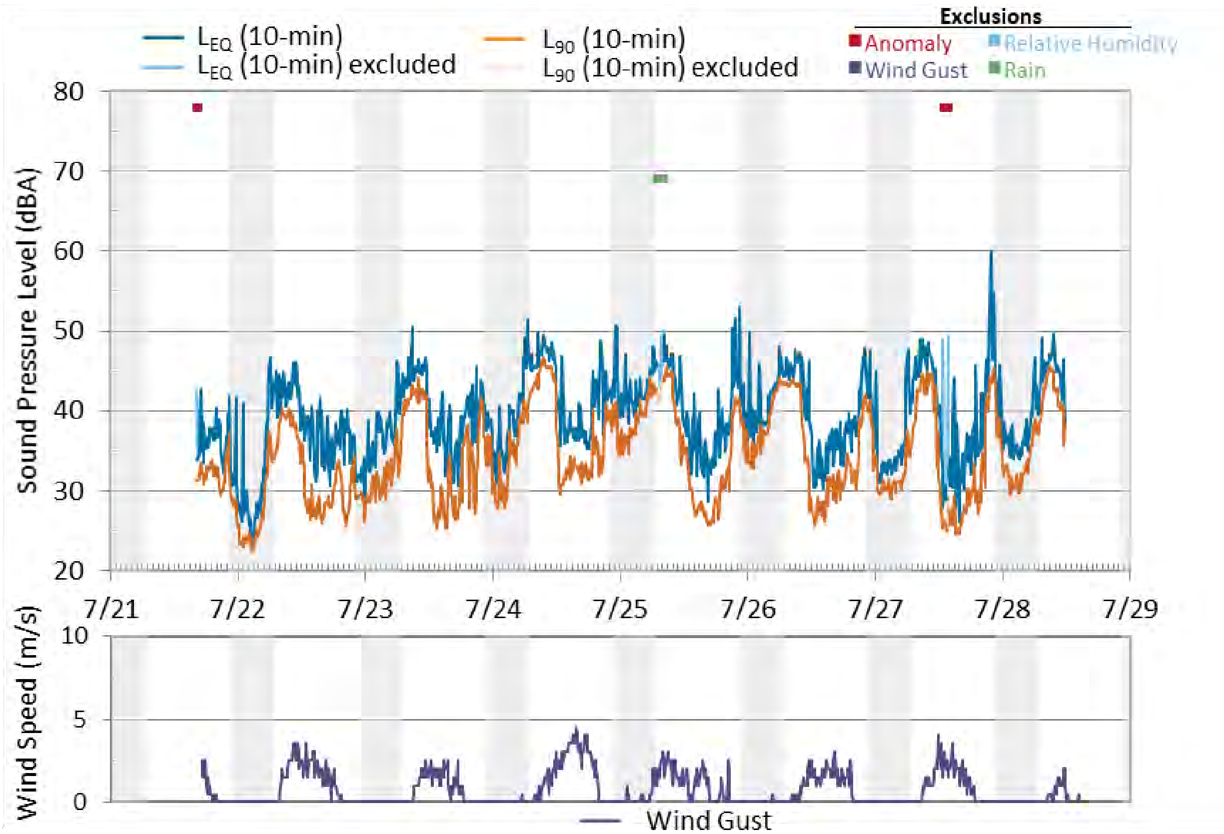


FIGURE 8: SOUND PRESSURE LEVELS OVER TIME - MONITOR A, JULY 21 TO 28, 2021

Monitor B Results

Background sound level monitoring results for Monitor B are provided in Figure 9**Error! Reference source not found.**. The primary sound sources at this location are geophonic and biogenic sounds. Traffic along US 35 is audible at this location; however, traffic sounds are not a significant contributor to the sound levels. Similar to Monitor A, there were very few periods that necessitated exclusion from the dataset.

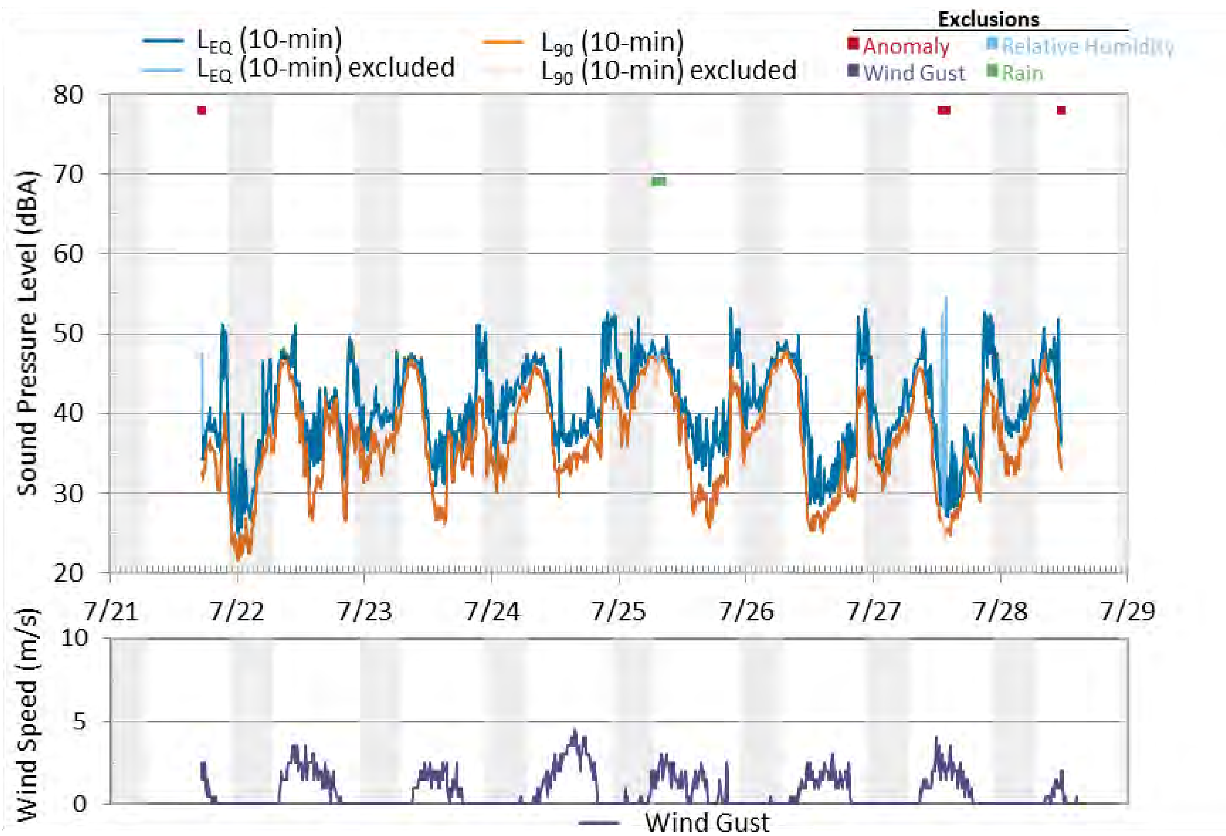


FIGURE 9: SOUND PRESSURE LEVELS OVER TIME - MONITOR B, JULY 21 TO 28, 2021

Monitor C Results

Background sound level monitoring results for Monitor C are shown in Figure 10. Like Monitors A and B, traffic sounds are minimal at this location. The primary sources of sound at this monitor location were geophonic and biogenic sounds. There were a few periods of high winds that were excluded from the data analysis.

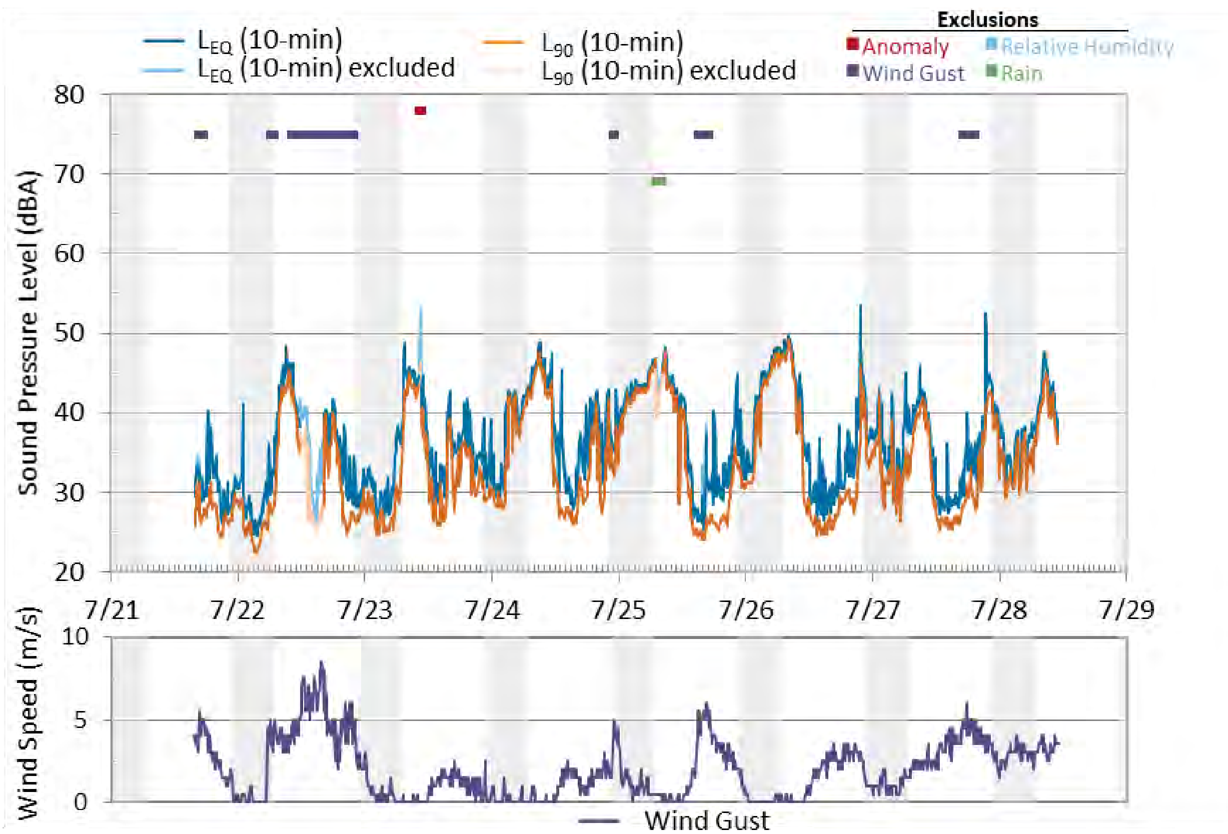


FIGURE 10: SOUND PRESSURE LEVELS OVER TIME - MONITOR C, JULY 21 TO 28, 2021

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 246 discrete receivers within one mile of the Project were placed at a height of 1.5 and 4 meters (5 and 13 feet) above ground level to represent ground level and upper story sensitive receptors. In addition, a grid of receivers spaced 10 meters by 10 meters was setup at a height of 1.5 meters above ground covering approximately 59 sq. km. (23 sq. mi.) around the Project area.

5.2 MODEL 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 receiver. This Project assumed that all residences were non-participating. As shown in Table 2, all sensitive receptors are projected to be less than the daytime and nighttime design thresholds of 48 and 47 dBA, respectively.

TABLE 2: SUMMARY OF MODELED SOUND PRESSURE LEVELS

	DAYTIME (GROUND LEVEL)			NIGHTTIME (GROUND LEVEL)			NIGHTTIME (UPPER STORY)		
	AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX
Residences (245)	14 dBA	4 dBA	22 dBA	12 dBA	4 dBA	22 dBA	15 dBA	7 dBA	24 dBA
Churches (6)	16 dBA	9 dBA	19 dBA	15 dBA	8 dBA	17 dBA	17 dBA	11 dBA	19 dBA
Cemetery (1)	18 dBA			17 dBA			19 dBA		

During both day and night, the highest modeled sound levels at ground level sensitive receivers are 22 dBA at sensitive receptors located east of the Project (R-65 and R-120). The highest modeled sound levels at the upper story of these receivers is 24 dBA (also at R-65 and R-120). During the day, the substation transformer is modeled at stage two cooling (ONAF) which would involve cooling fans operating. At night, under ONAN cooling, which does not involve cooling fan operation. The maximum projected sound levels are well below the daytime and nighttime design thresholds discussed in Section 3.0.

A map of the projected daytime sound levels throughout the Project area, including at the Project boundary, is provided in Figure 11, and the projected nighttime sound levels with VAR support are shown in Figure 12. The highest projected sound level at the Project boundary is 31 dBA, which occurs at southeastern property line of the northern section of the Project area, near sensitive receptor R-120 (see Figure 11 and Figure 18).

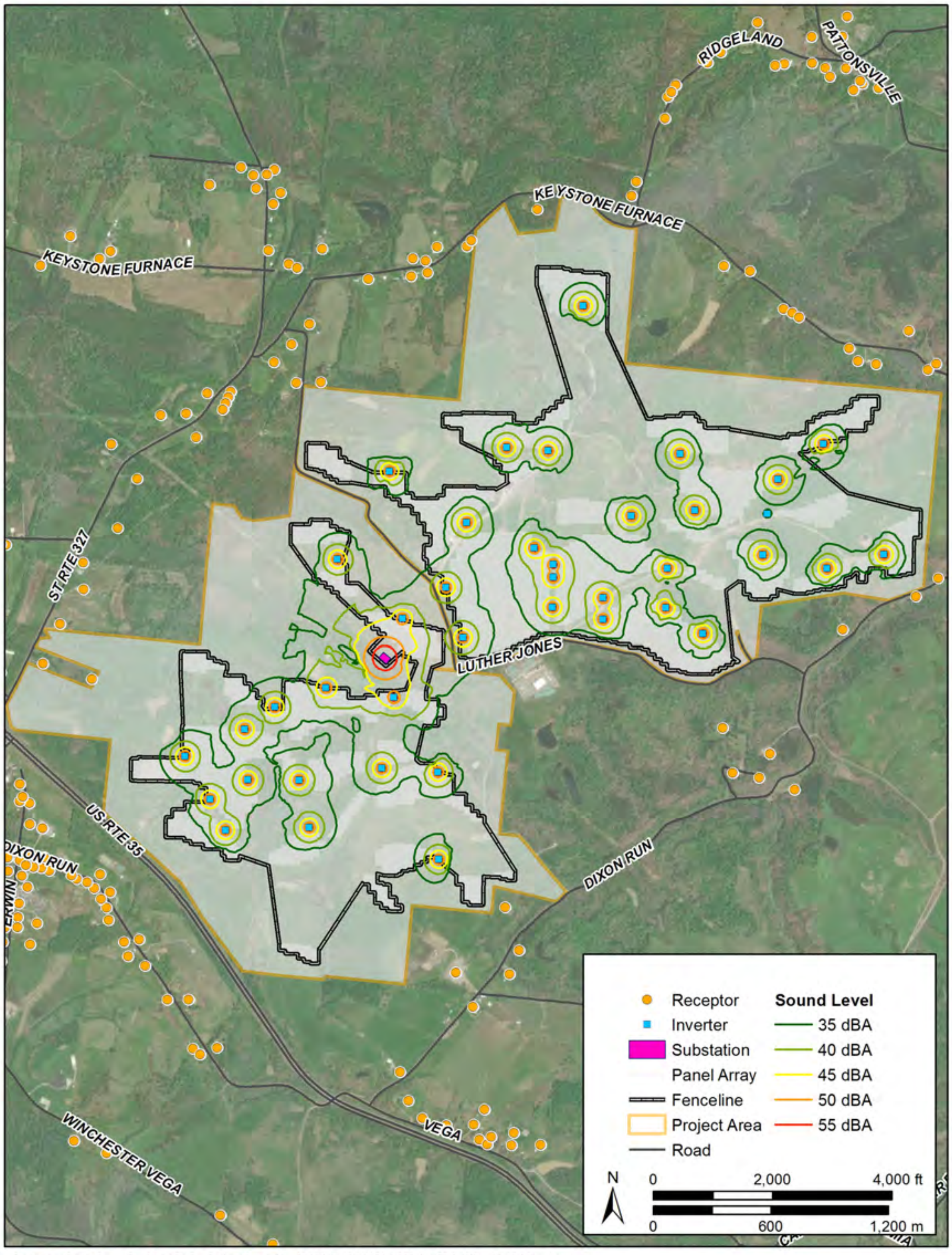


FIGURE 11: DAYTIME MODEL RESULTS

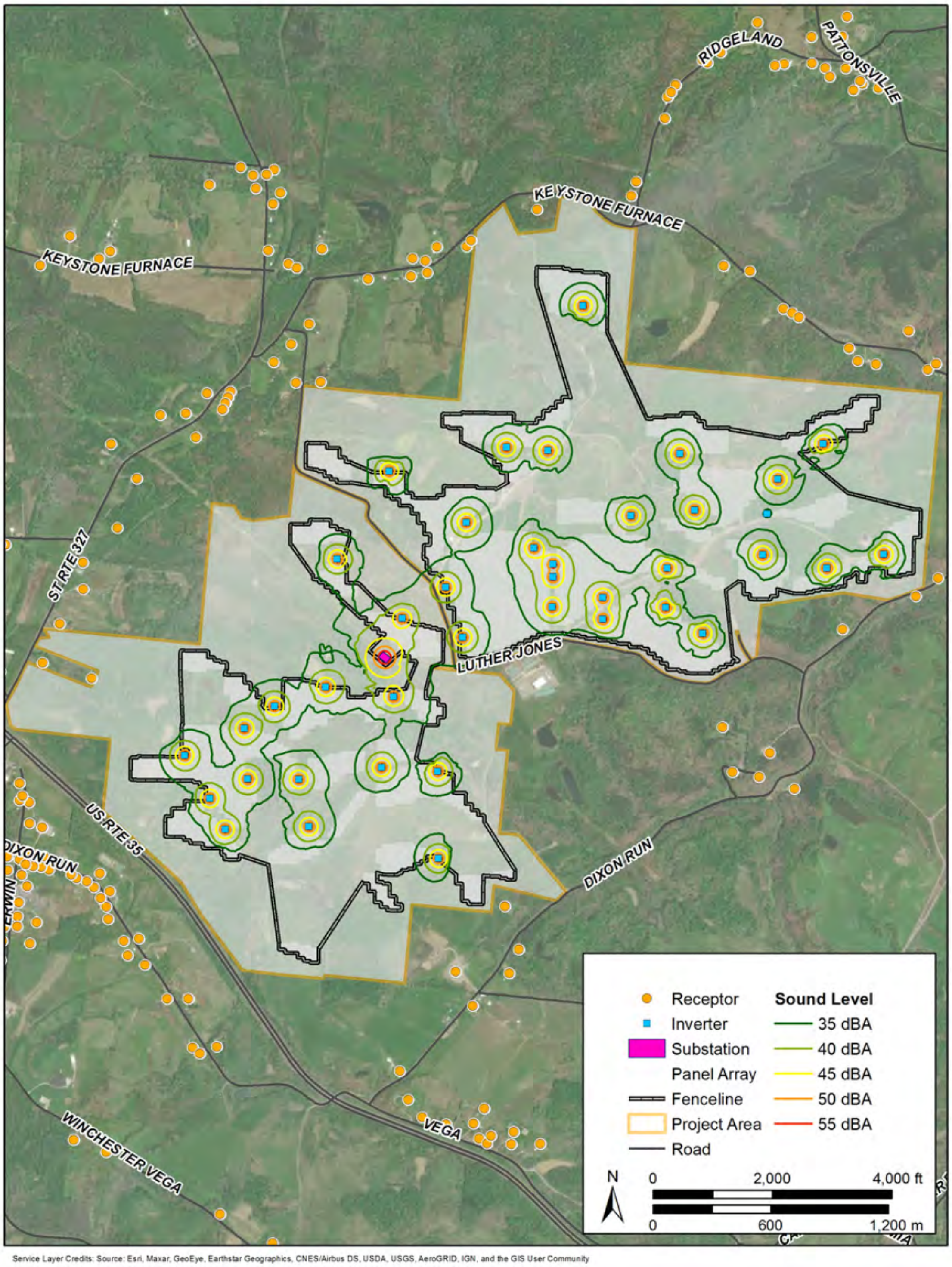


FIGURE 12: NIGHTTIME MODEL RESULTS WITH VAR SUPPORT

6.0 CONSTRUCTION NOISE

Construction activities include road construction, substation construction, trenching, inverter and transformer installation, piling and racking. In any given area, construction will be relatively short in duration, particularly for road construction, trenching, piling, and racking. Construction of substations 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. Lastly, piling and racking will take place throughout the solar arrays.

Construction that involves increasing sound above ambient levels will take place between 7 AM and 7 PM or dusk, whichever is later. Pile driving for solar arrays utilizes pile driving equipment that is much smaller than that utilized for construction of foundations for large construction projects such as high-rise buildings or bridges. The solar array post driving equipment is similar in sound level to other 'typical' construction equipment and on the order of 15 to 20 dB lower in sound level than traditional larger scale impact pile driving. As a result, solar array post driving should not be expected to result in impacts that are greater than other construction activities when occurring during normal construction hours (7 AM and 7 PM or dusk).

Construction equipment will be fitted with exhaust systems and mufflers to reduce exhaust noise. 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 back alarms.

Equipment used for each activity will vary. Some of the louder pieces of equipment are shown in Table 3 along with the approximate maximum sound pressure levels at a reference distance of 15 meters (50 feet) and 132 meters (435 feet), the closest distance between a sensitive receptor and a solar array where racking and piling will take place.

TABLE 3: MAXIMUM SOUND LEVELS FROM VARIOUS TYPES OF CONSTRUCTION EQUIPMENT ASSUMING NO ATTENUATION FROM TREES OR TERRAIN

Equipment	Maximum Sound Pressure Level at 132 meters (435 feet) (dBA)[2]	Maximum Sound Pressure Level at 15 meters (50 feet) (dBA)[3]
Excavator	57	76
Dozer	61	80
Grader	59	78
Roller	63	82
Dump Truck	63	82
Concrete Mixing Truck	62	81
Concrete Pumper Truck	65	84
Flatbed Truck	55	74
Crane	55	74
Trencher	64	83
Compactor (Plate)	56	75
Forklift	69	88
Small Pile Driver	65	84

[2] 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.
[3] Sound source information was obtained from National Cooperative Highway Research Program (NCHRP) Project 25-49 (September 2018). Modeling procedures generally followed guidelines in the FHWA's Highway Construction Noise Handbook, where appropriate and where data was available. For the pile driving equipment, noise data for a representative solar array post driver was used.

7.0 CONCLUSIONS

RSG conducted an 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 sensitive receptors. Summary and conclusions are as follows:

1. Sound sources in the existing soundscape include geophonic and biogenic sounds, and local traffic noise.
    a. The average daytime L_{eq} across the Project Area was 43 dBA.
    b. The average nighttime L_{eq} across the Project Area was 42 dBA.
2. A project design threshold of 5 dB above existing L_{eq} was established, creating a daytime threshold of 48 dBA and a nighttime threshold of 47 dBA for non-participating sensitive receptors. The Project assumed that all residences were non-participating.
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 will operate at night for VAR support. As such, this assessment conservatively assumed all inverters would operate both day and night.
4. Both daytime and nighttime sound levels were modeled, with the only difference between operational sound levels being the cooling mode on the substation transformer; ONAF was assumed for the daytime scenario and ONAN for the nighttime scenario.
5. Sound propagation modeling was conducted in accordance with ISO 9613-2 at 264 receptors within 1 mile of the Project, using the planned inverter for the Project, Sunny Central 4200 kVA.
6. Model results are summarized in Section 5.2, and provided in tabular format in Appendix C. The highest modeled sensitive receptors (R-65 and R-120) are 22 dBA for the daytime and nighttime at ground level (1.5 m) and 24 dBA for daytime and nighttime at upper story height (4 m). These sensitive receptors are both about 130 meters (430 feet) from the nearest solar panel. This sound exposure is well below the design thresholds.
7. The highest modeled sound level at a property line from operation of the Project is 31 dBA, which occurs at the southeastern property line of the northern section of the Project area, near sensitive receptor R-120.
8. 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”).[4] 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 13.

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.

[4] 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.

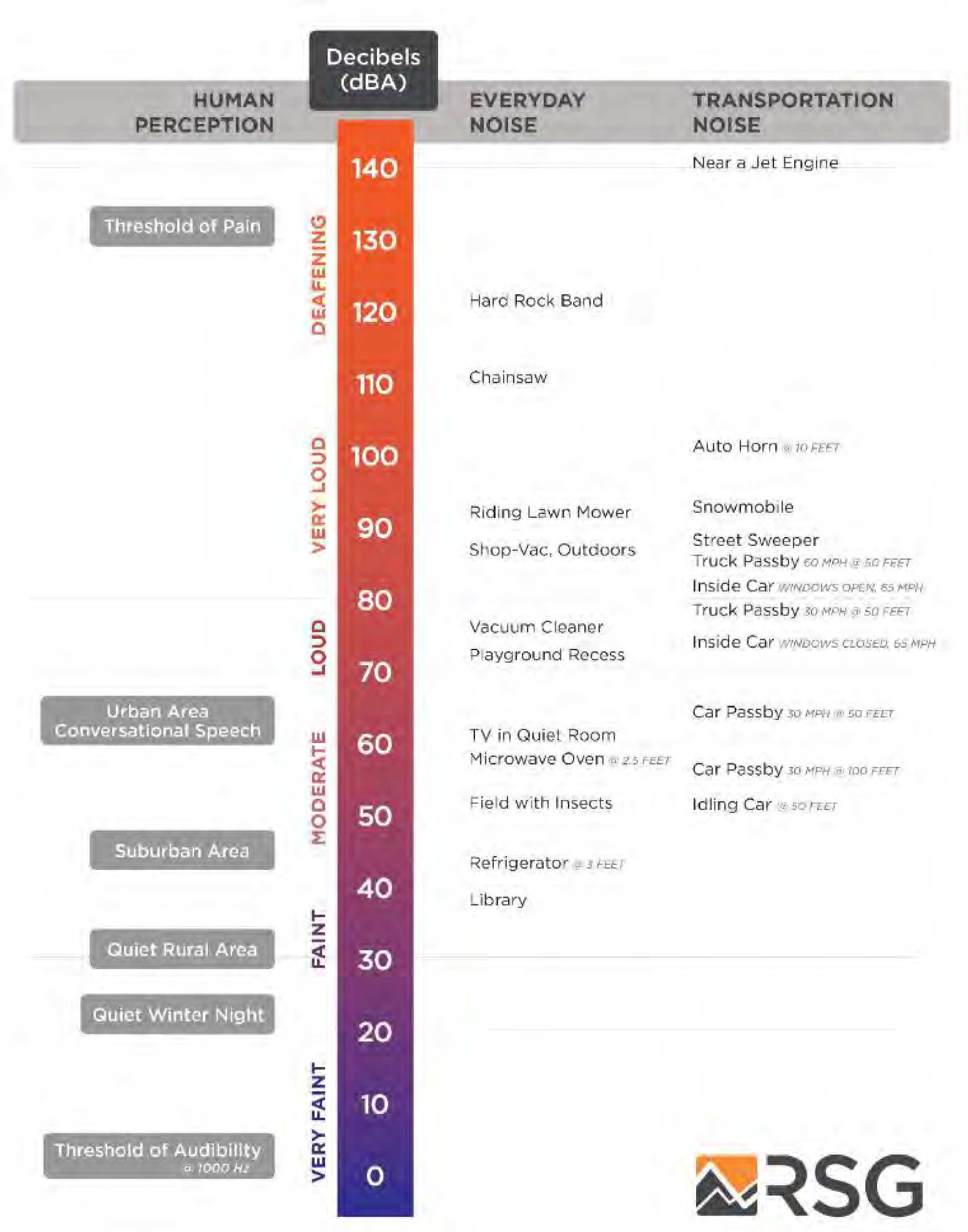


FIGURE 13: A SCALE OF SOUND PRESSURE LEVELS FOR TYPICAL SOUND SOURCES

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.[5] 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 14. 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

[5] 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 14, 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.

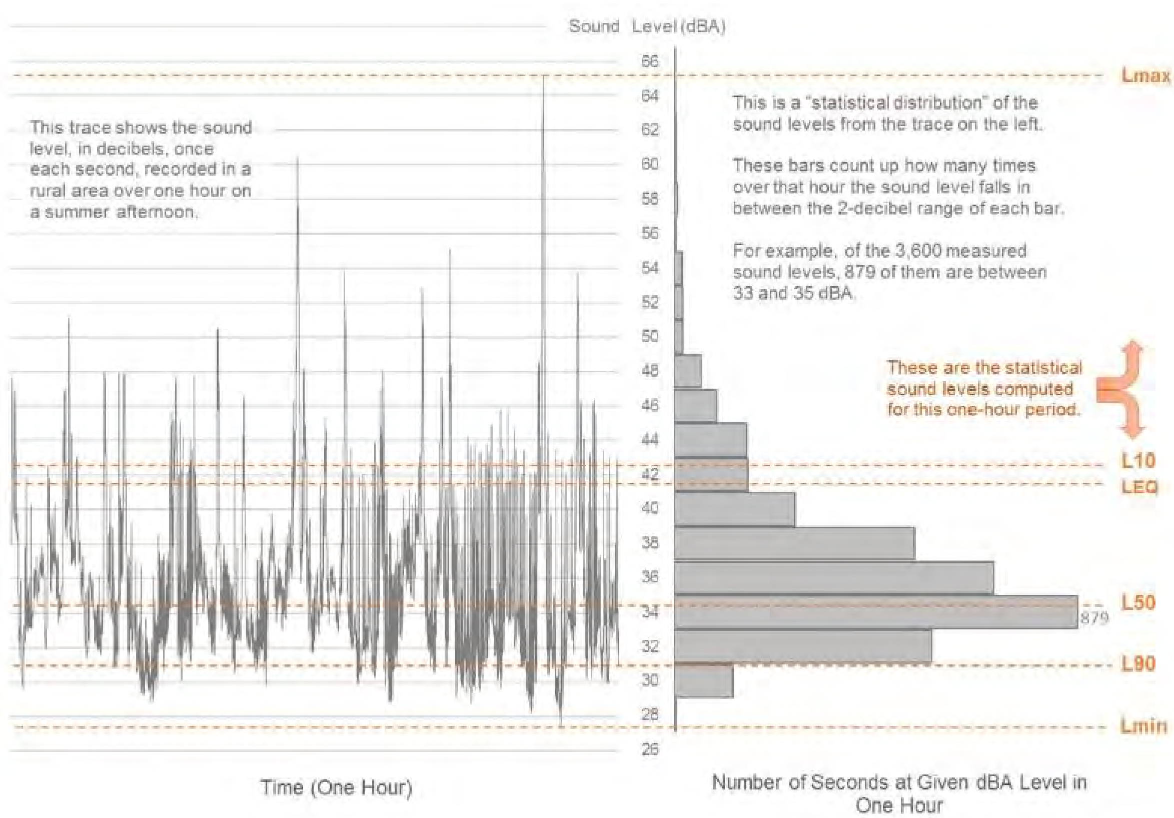


FIGURE 14: EXAMPLE OF DESCRIPTIVE TERMS OF SOUND MEASUREMENT OVER TIME

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 4: 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=1
Receiver Height	1.5 meters for sound level isolines, 1.5 and 4 m for discrete receptors
Search Radius	4,000 meters from each source

TABLE 5: 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	52	67	98	101	100	98	95	88	78	103	106	NEMA TR-1[6]
Substation Transformer ONAN	41	58	98	99	98	84	78	70	63	97	102	NEMA TR-1[8]
Inverter	25	54	64	72	78	79	76	86	81	91	94	Manufacturer test data (Sunny Central 4200 kVA)
Medium Voltage Transformer	23	41	54	57	62	60	55	51	45	66	74	Test report

TABLE 6: SOURCE INPUT DATA

Source	Overall Sound Power Level (dBA)	Relative Height (m)	Coordinates UTM NAD83 Z17N X (m)	Y (m)	Absolute Elevation (m)
Inverter 1	91	1.8	370498	4318210	250
Inverter 2	91	1.8	368856	4317834	256
Inverter 3	91	1.8	368943	4317577	268
Inverter 4	91	1.8	369307	4318034	266

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

Source	Overall Sound Power Level (dBA)	Relative Height (m)	Coordinates UTM NAD83 Z17N X (m)	Coordinates UTM NAD83 Z17N Y (m)	Absolute Elevation (m)
Inverter 5	91	1.8	369400	4317732	250
Inverter 6	91	1.8	369404	4317885	255
Inverter 7	91	1.8	369405	4317950	260
Inverter 8	91	1.8	369979	4317730	271
Inverter 9	91	1.8	369659	4317670	261
Inverter 10	91	1.8	370169	4317598	262
Inverter 11	91	1.8	369658	4317780	262
Inverter 12	91	1.8	369803	4318199	262
Inverter 13	91	1.8	369987	4317931	254
Inverter 14	91	1.8	370128	4318227	258
Inverter 15	91	1.8	370552	4318385	237
Inverter 16	91	1.8	370051	4318517	255
Inverter 17	91	1.8	370785	4318567	231
Inverter 18	91	1.8	370803	4317930	262
Inverter 19	91	1.8	370475	4317999	263
Inverter 20	91	1.8	371094	4318002	251
Inverter 21	91	1.8	367650	4316754	249
Inverter 22	91	1.8	367845	4316853	237
Inverter 23	91	1.8	367522	4316974	248
Inverter 24	91	1.8	367828	4317112	250
Inverter 25	91	1.8	368105	4316852	238
Inverter 26	91	1.8	367729	4316596	240
Inverter 27	91	1.8	368590	4317274	258
Inverter 28	91	1.8	368528	4316913	250
Inverter 29	91	1.8	368815	4316893	249
Inverter 30	91	1.8	368819	4316447	248
Inverter 31	91	1.8	368157	4316610	241
Inverter 32	91	1.8	367981	4317226	255
Inverter 33	91	1.8	368243	4317324	258
Inverter 34	91	1.8	368961	4318165	261
Inverter 35	91	1.8	368568	4318427	254
Inverter 36	91	1.8	369377	4318531	241
Inverter 37	91	1.8	369166	4318548	251
Inverter 38	91	1.8	369557	4319272	242
Inverter 39	91	1.8	368633	4317674	268
Inverter 40	91	1.8	368302	4317978	255
Substation Transformer	ONAF 103 ONAN 97	3	368543	4317475	260

APPENDIX C. MODEL RESULTS FOR EACH RECEPTOR

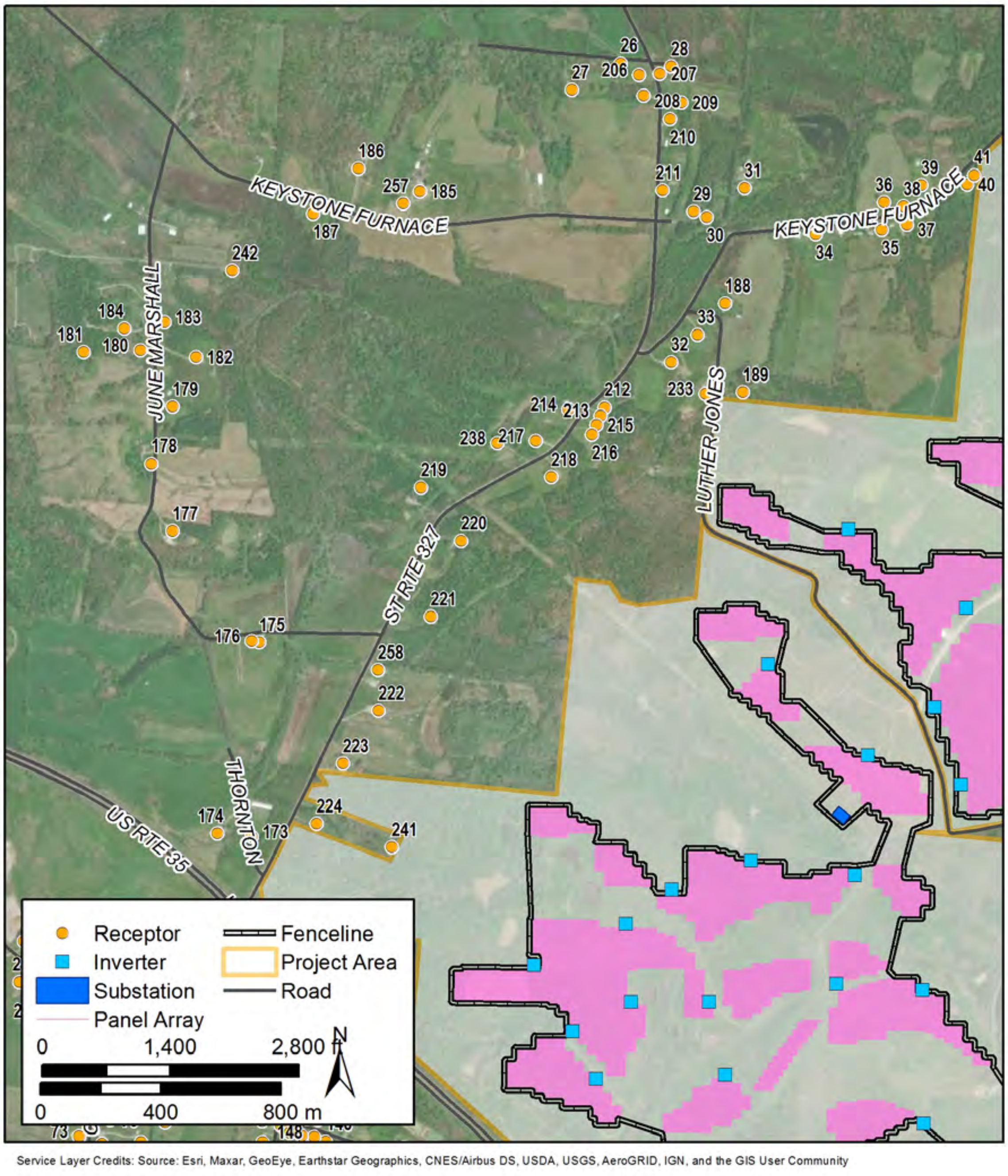


FIGURE 15: MAP OF RECEPTORS, NW QUADRANT

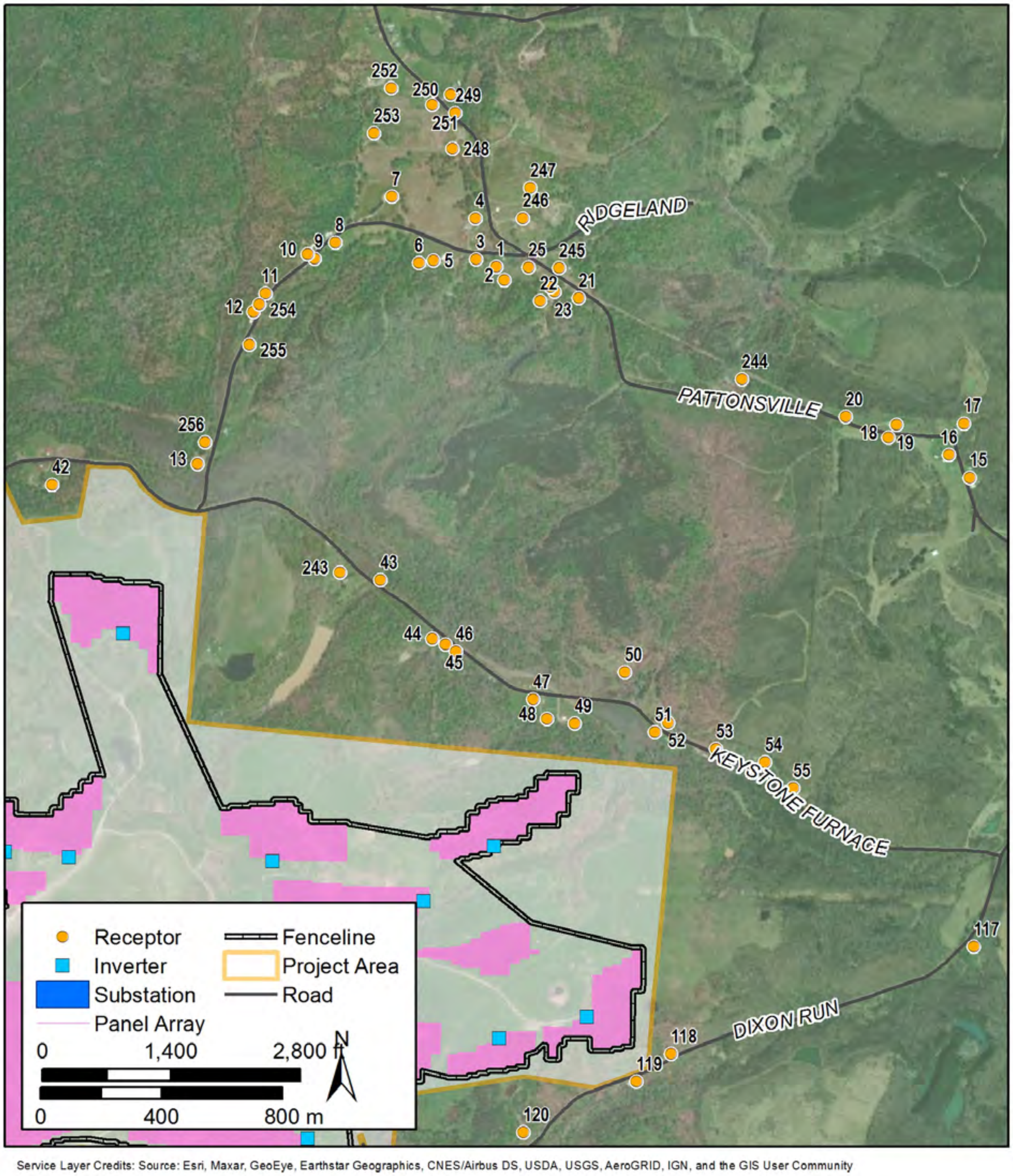
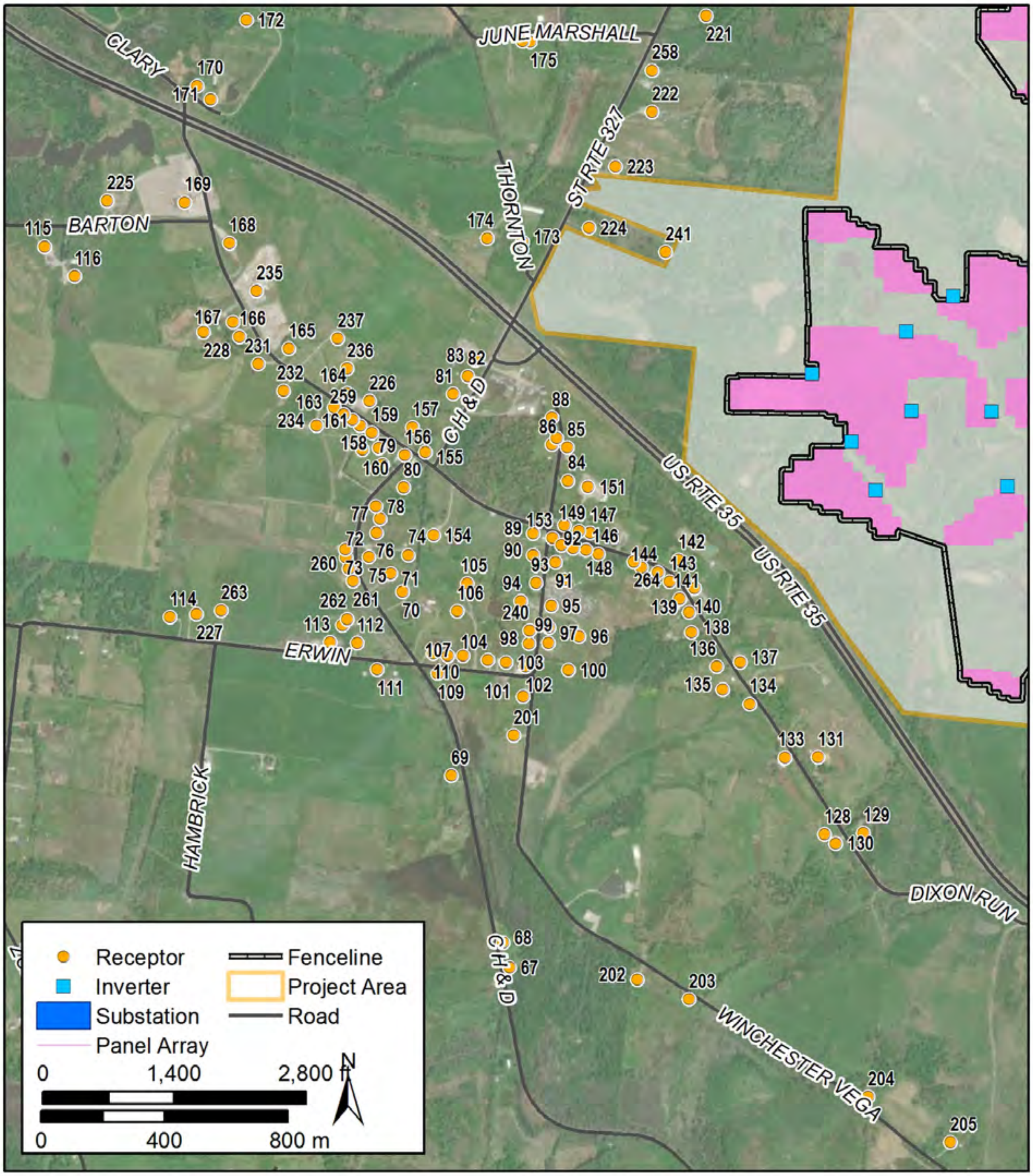
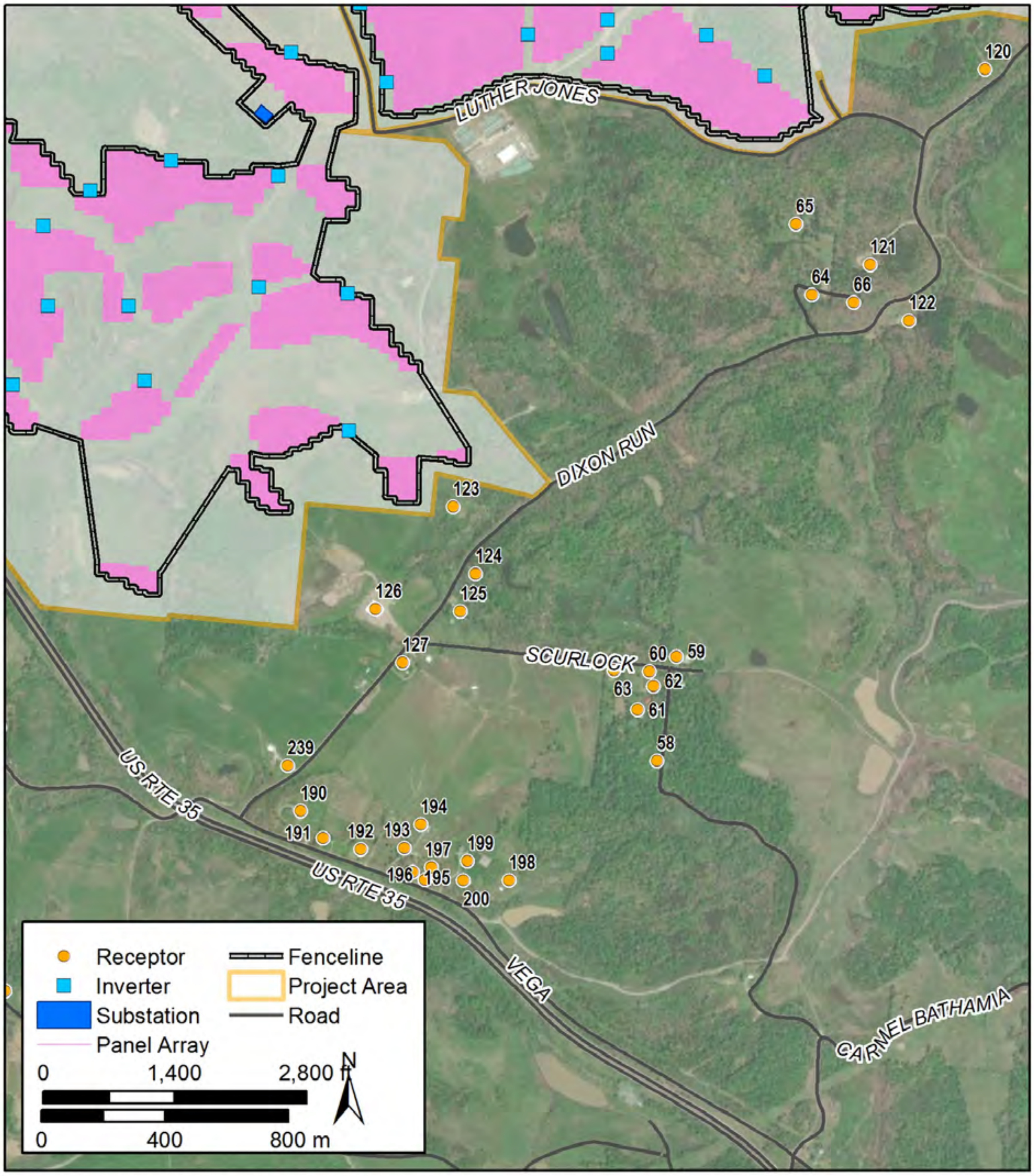


FIGURE 16: MAP OF RECEPTORS, NE QUADRANT



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

FIGURE 17: MAP OF RECEPTORS, SW QUADRANT



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

FIGURE 18: MAP OF RECEPTORS, SE QUADRANT

TABLE 7: MODEL RESULTS & RECEIVER COORDINATES

Receptor ID	Land Use	Daytime Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Upper Story	Coordinates UTM NAD83 Z17N		Ground Elevation (m)
					X (m)	Y (m)	
1	Residential	10	9	12	370794	4320487	253
2	Residential	10	10	12	370819	4320442	254
3	Residential	10	10	12	370727	4320511	248
4	Residential	9	8	10	370724	4320646	242
5	Residential	11	10	13	370585	4320507	257
6	Residential	10	9	13	370538	4320500	257
7	Residential	10	9	12	370448	4320719	263
8	Residential	11	10	13	370261	4320567	256
9	Residential	11	11	13	370192	4320513	254
10	Residential	11	11	13	370169	4320528	255
11	Residential	12	11	14	370030	4320399	241
12	Residential	13	12	14	369990	4320338	239
13	Residential	13	13	15	369805	4319832	203
14	Residential	8	7	10	372564	4319600	259
15	Residential	8	7	10	372362	4319788	264
16	Residential	8	8	10	372293	4319864	268
17	Residential	7	7	10	372342	4319968	271
18	Church	9	8	11	372093	4319921	269
19	Residential	8	7	10	372118	4319964	265
20	Residential	8	8	11	371950	4319990	264
21	Residential	10	9	12	371067	4320383	257
22	Residential	10	9	12	370938	4320373	246
23	Residential	10	10	12	370986	4320405	254
24	Residential	10	10	12	370973	4320419	254
25	Residential	10	9	12	370900	4320484	254
26	Residential	13	11	14	367809	4319978	212
27	Residential	13	12	14	367648	4319889	233
28	Residential	13	12	14	367979	4319968	201
29	Residential	16	15	17	368052	4319484	204
30	Residential	16	15	17	368096	4319465	203
31	Residential	16	15	17	368223	4319562	205
32	Residential	19	17	19	367978	4318983	209

[7] Assuming inverters may operate at times at night for VAR support.

Receptor ID	Land Use	Daytime Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Upper Story	Coordinates UTM NAD83 Z17N		Ground Elevation (m)
					X (m)	Y (m)	
33	Residential	19	17	19	368067	4319075	209
34	Residential	17	16	18	368460	4319408	206
35	Residential	17	16	18	368679	4319423	209
36	Residential	17	16	18	368686	4319514	207
37	Residential	17	16	18	368763	4319440	209
38	Residential	17	16	18	368751	4319501	206
39	Residential	17	16	18	368811	4319573	205
40	Residential	16	16	18	368964	4319575	210
41	Residential	16	15	18	368986	4319606	212
42	Residential	8	8	11	369323	4319764	217
43	Residential	14	13	15	370410	4319449	197
44	Residential	10	10	12	370581	4319255	198
45	Residential	9	9	11	370626	4319235	197
46	Residential	9	9	10	370660	4319212	197
47	Residential	14	14	16	370916	4319054	197
48	Residential	14	13	16	370962	4318989	200
49	Residential	10	10	13	371054	4318973	204
50	Residential	14	14	16	371220	4319143	196
51	Residential	15	14	17	371319	4318944	199
52	Residential	15	15	17	371362	4318976	205
53	Residential	15	15	17	371521	4318889	197
54	Residential	14	13	16	371683	4318846	198
55	Residential	13	13	15	371776	4318760	201
56	Residential	7	7	10	372869	4317974	198
57	Residential	4	4	7	372636	4318102	204
58	Residential	15	13	16	369820	4315375	266
59	Residential	15	13	15	369882	4315714	236
60	Residential	15	14	16	369793	4315666	234
61	Residential	15	13	16	369756	4315542	241
62	Residential	15	13	16	369807	4315618	239
63	Residential	16	14	16	369679	4315670	235
64	Residential	20	19	21	370321	4316888	226
65	Residential	22	22	24	370270	4317117	235
66	Residential	19	19	21	370457	4316863	231
67	Residential	10	9	11	366541	4315048	213
68	Residential	10	9	11	366520	4315128	213
69	Residential	12	11	13	366351	4315671	216

Receptor ID	Land Use	Daytime Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Upper Story	Coordinates UTM NAD83 Z17N X (m)	Y (m)	Ground Elevation (m)
70	Residential	13	12	14	366193	4316266	225
71	Residential	13	11	14	366154	4316325	226
72	Residential	12	10	13	366010	4316379	216
73	Residential	12	11	13	366008	4316405	216
74	Residential	13	12	14	366213	4316386	228
75	Residential	12	11	13	366084	4316380	219
76	Residential	12	11	13	366109	4316458	220
77	Residential	13	11	14	366121	4316503	219
78	Residential	13	11	14	366108	4316544	218
79	Residential	13	12	14	366128	4316680	217
80	Residential	13	12	14	366196	4316605	219
81	Residential	15	14	16	366357	4316908	219
82	Residential	15	14	16	366404	4316966	219
83	Residential	16	14	16	366429	4317018	217
84	Residential	17	16	18	366731	4316627	228
85	Church	18	17	19	366728	4316734	230
86	Church	18	16	19	366679	4316744	231
87	Cemetery	18	17	19	366694	4316765	233
88	Residential	17	16	18	366679	4316832	226
89	Residential	16	14	17	366617	4316455	223
90	Residential	16	14	16	366618	4316385	224
91	Residential	16	15	18	366689	4316362	232
92	Residential	16	15	17	366680	4316441	227
93	Residential	16	15	17	366626	4316295	231
94	Residential	15	13	16	366577	4316236	223
95	Residential	16	15	17	366676	4316221	223
96	Residential	16	15	17	366767	4316121	217
97	Residential	15	14	17	366669	4316150	217
98	Residential	15	14	16	366603	4316099	216
99	Residential	15	14	16	366667	4316100	216
100	Residential	15	14	16	366732	4316012	215
101	Residential	14	13	15	366584	4315927	214
102	Residential	14	13	16	366591	4316025	215
103	Residential	14	13	15	366528	4316037	215
104	Residential	14	13	15	366471	4316045	215
105	Residential	14	13	15	366403	4316293	223
106	Residential	14	12	15	366371	4316204	220

Receptor ID	Land Use	Daytime Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Upper Story	Coordinates UTM NAD83 Z17N X (m)	Y (m)	Ground Elevation (m)
107	Residential	13	12	15	366390	4316060	216
108	Residential	13	12	14	366339	4316059	215
109	Residential	13	12	14	366307	4316001	214
110	Residential	13	12	14	366293	4316067	215
111	Residential	12	10	13	366110	4316014	216
112	Residential	11	10	13	366046	4316101	214
113	Residential	11	10	12	365959	4316102	216
114	Residential	9	8	10	365439	4316184	224
115	Residential	8	6	9	365032	4317387	244
116	Residential	8	7	10	365130	4317291	247
117	Residential	9	9	11	372376	4318234	197
118	Residential	11	11	13	371372	4317879	202
119	Residential	17	17	19	371257	4317787	201
120	Residential	22	22	24	370883	4317619	225
121	Residential	19	18	21	370511	4316985	228
122	Residential	14	14	16	370637	4316804	205
123	Residential	19	18	20	369159	4316201	224
124	Residential	19	18	20	369230	4315982	228
125	Residential	18	17	19	369181	4315861	224
126	Industrial	19	17	20	368906	4315867	227
127	Residential	18	17	19	368994	4315694	231
128	Residential	16	14	17	367562	4315479	229
129	Residential	16	15	17	367688	4315483	230
130	Commercial	15	14	16	367600	4315450	226
131	Residential	17	15	18	367541	4315730	229
133	Residential	17	15	18	367434	4315729	221
134	Residential	18	17	19	367320	4315903	219
135	Residential	18	17	19	367232	4315951	217
136	Residential	18	17	19	367213	4316024	217
137	Residential	19	18	20	367290	4316037	218
138	Residential	18	17	19	367132	4316135	215
139	Residential	19	18	20	367123	4316199	218
140	Exempt	19	18	20	367141	4316278	220
141	Exempt	19	18	20	367093	4316243	218
142	Residential	19	19	21	367089	4316370	223
143	Residential	19	18	20	367060	4316300	219
144	Residential	19	18	20	367022	4316329	222

Receptor ID	Land Use	Daytime Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Upper Story	Coordinates UTM NAD83 Z17N		Ground Elevation (m)
					X (m)	Y (m)	
145	Residential	18	17	20	366969	4316346	224
146	Residential	18	17	19	366829	4316389	231
147	Residential	18	17	19	366802	4316458	234
148	Residential	17	17	19	366790	4316403	233
149	Residential	17	16	19	366766	4316463	233
150	Residential	17	16	18	366747	4316407	233
151	Church	18	17	19	366795	4316606	233
152	Residential	16	15	18	366709	4316417	230
153	Residential	17	16	18	366718	4316483	230
154	Residential	14	13	15	366294	4316451	237
155	Residential	14	13	15	366268	4316721	218
156	Residential	14	12	15	366200	4316710	217
157	Residential	14	13	15	366225	4316800	217
158	Residential	13	12	14	366116	4316734	217
159	Residential	13	12	14	366094	4316783	218
160	Residential	13	12	14	366064	4316727	217
161	Residential	13	12	14	366055	4316806	218
162	Residential	13	12	14	366030	4316824	218
163	Residential	13	11	13	365972	4316864	217
164	Residential	13	11	14	366014	4316911	218
165	Residential	12	10	13	365823	4317055	219
166	Residential	11	10	12	365664	4317095	228
167	Residential	11	9	12	365644	4317142	226
168	Commercial	11	9	12	365631	4317398	224
169	Commercial	10	9	11	365487	4317530	226
170	Residential	10	8	11	365527	4317908	232
171	Residential	10	9	11	365571	4317864	232
172	Residential	10	9	12	365687	4318122	249
173	Residential	17	15	17	366582	4317402	212
174	Residential	16	14	16	366468	4317413	216
175	Residential	16	14	16	366607	4318050	214
176	Residential	16	14	16	366582	4318053	213
177	Residential	14	12	15	366317	4318420	231
178	Residential	12	11	13	366247	4318645	224
179	Residential	12	10	13	366319	4318835	216
180	Residential	11	9	12	366211	4319021	215
181	Residential	10	9	11	366022	4319017	235

Receptor ID	Land Use	Daytime Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Upper Story	Coordinates UTM NAD83 Z17N		Ground Elevation (m)
					X (m)	Y (m)	
182	Residential	12	10	12	366396	4318999	210
183	Residential	11	9	12	366291	4319117	208
184	Residential	11	9	11	366158	4319094	216
185	Residential	13	12	14	367142	4319551	228
186	Residential	12	10	13	366938	4319628	222
187	Residential	12	10	13	366786	4319478	208
188	Residential	18	17	19	368158	4319179	208
189	Residential	19	18	20	368218	4318882	212
190	Residential	15	14	16	368664	4315213	240
191	Residential	14	12	15	368735	4315125	232
192	Residential	14	12	15	368858	4315089	230
193	Residential	15	13	15	368999	4315092	245
194	Residential	14	13	15	369053	4315169	244
195	Residential	13	11	14	369026	4315014	235
196	Residential	12	11	13	369066	4314990	231
197	Residential	13	11	13	369088	4315029	232
198	Residential	12	10	12	369340	4314988	241
199	Residential	13	12	14	369204	4315050	246
200	Residential	13	11	14	369190	4314987	242
201	Residential	13	12	14	366553	4315800	213
202	Residential	11	10	12	366955	4315008	226
203	Residential	11	10	12	367123	4314945	215
204	Residential	11	10	12	367703	4314628	221
205	Residential	10	9	11	367972	4314481	236
206	Residential	13	12	14	367871	4319938	206
207	Residential	13	12	14	367941	4319943	202
208	Residential	13	12	14	367887	4319871	209
209	Residential	14	13	15	368012	4319848	203
210	Residential	14	13	15	367975	4319791	207
211	Residential	16	14	16	367950	4319554	207
212	Residential	18	16	18	367757	4318832	212
213	Residential	19	16	18	367743	4318804	214
214	Residential	18	16	18	367635	4318825	212
215	Residential	19	17	19	367730	4318774	216
216	Residential	19	17	19	367715	4318741	218
217	Residential	18	16	18	367528	4318720	217
218	Church	19	17	19	367580	4318600	219

Receptor ID	Land Use	Daytime Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Upper Story	Coordinates UTM NAD83 Z17N		Ground Elevation (m)
					X (m)	Y (m)	
219	Residential	17	15	17	367146	4318565	231
220	Residential	18	16	18	367279	4318388	228
221	Residential	19	17	19	367179	4318135	230
222	Commercial	19	17	19	367004	4317823	211
223	Residential	18	17	19	366885	4317647	220
224	Residential	18	16	18	366798	4317447	213
225	Commercial	9	7	10	365234	4317536	230
226	Church	13	12	14	366085	4316886	218
227	Residential	9	8	10	365524	4316195	220
228	Industrial	10	9	11	365548	4317109	229
229	Commercial	17	16	18	366718	4316305	228
230	Residential	11	10	12	365998	4316158	215
231	Residential	11	10	12	365726	4317006	224
232	Residential	12	10	13	365808	4316919	218
233	Residential	19	18	20	368092	4318877	215
234	Residential	12	11	13	365913	4316806	216
235	Commercial	11	10	12	365720	4317243	222
236	Residential	13	12	14	366014	4316990	218
237	Residential	13	11	14	365983	4317087	221
238	Residential	18	16	18	367399	4318713	216
239	Residential	15	14	16	368622	4315360	229
240	Residential	15	14	16	366606	4316141	217
241	Residential	20	18	21	367047	4317368	226
242	Residential	11	10	12	366516	4319287	210
243	Residential	14	14	16	370275	4319475	208
244	Residential	9	9	11	371606	4320115	239
245	Residential	9	8	12	371001	4320482	253
246	Residential	9	8	11	370882	4320648	252
247	Residential	9	8	11	370906	4320748	252
248	Residential	8	7	9	370649	4320878	238
249	Residential	5	5	9	370658	4320996	234
250	Residential	6	6	8	370642	4321058	235
251	Residential	5	5	8	370581	4321023	240
252	Residential	5	5	8	370446	4321079	240
253	Residential	8	7	10	370388	4320929	254
254	Residential	12	12	14	370007	4320363	240
255	Residential	13	13	15	369975	4320229	231

Receptor ID	Land Use	Daytime Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Ground Level	Nighttime[7] Modeled Level (dBA) Upper Story	Coordinates UTM NAD83 Z17N		Ground Elevation (m)
					X (m)	Y (m)	
256	Residential	13	13	15	369828	4319906	199
257	Residential	13	11	14	367086	4319512	222
258	Residential	18	17	18	367002	4317958	210
259	Residential	13	11	14	366003	4316841	217
260	Residential	12	10	13	366019	4316342	216
261	Residential	12	10	13	366032	4316301	215
262	Residential	11	10	13	366013	4316178	214
263	Residential	10	8	11	365604	4316205	218
264	Residential	18	17	19	366944	4316364	225

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White River Junction, VT 05001
802.295.4999
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