Verdantas

SOUND MODELING – SUNSET SOLAR

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1.0 INTRODUCTION

1.1 PURPOSE

Greenskies Clean Energy, LLC is developing the 5 MW AC Sunset Solar project ("Project") proposed for Ellington, Connecticut. RSG has been asked by Verdantas to perform sound propagation modeling to assess sound levels relative to State of Connecticut and local sound level limits. The report includes:

- A description of the Project,
- A discussion of sound level limits applicable to the Project,
- Sound propagation modeling procedures and results, and
- Conclusions.

A primer of acoustical terms used in this report is included in Appendix A.

1.2 PROJECT DESCRIPTION

The Sunset Solar project ("Project") is a 5 MW AC photovoltaic facility located in the Town of Ellington, Connecticut. The Project is bordered by the town of Stafford, Connecticut to the north. A map showing the Project site in the context of the surrounding area is shown in Figure 1.

The Project is proposed to be located off of Schoolhouse Road, approximately 1.2 kilometers (0.75 miles) north of Route 140. Boyer Road runs approximately 430 meters (1,410 feet) north of the Project fenceline. The Project is set in a rural area where land use is primarily agricultural and residential. The nearest sensitive receiver is an orchard building approximately 130 meters (427 feet) west of the Project fenceline.

The Project is proposed to be composed of approximately 19 acres of solar panels and two equipment pads, each pad containing 20 inverters and one 2,750 kVA transformer.

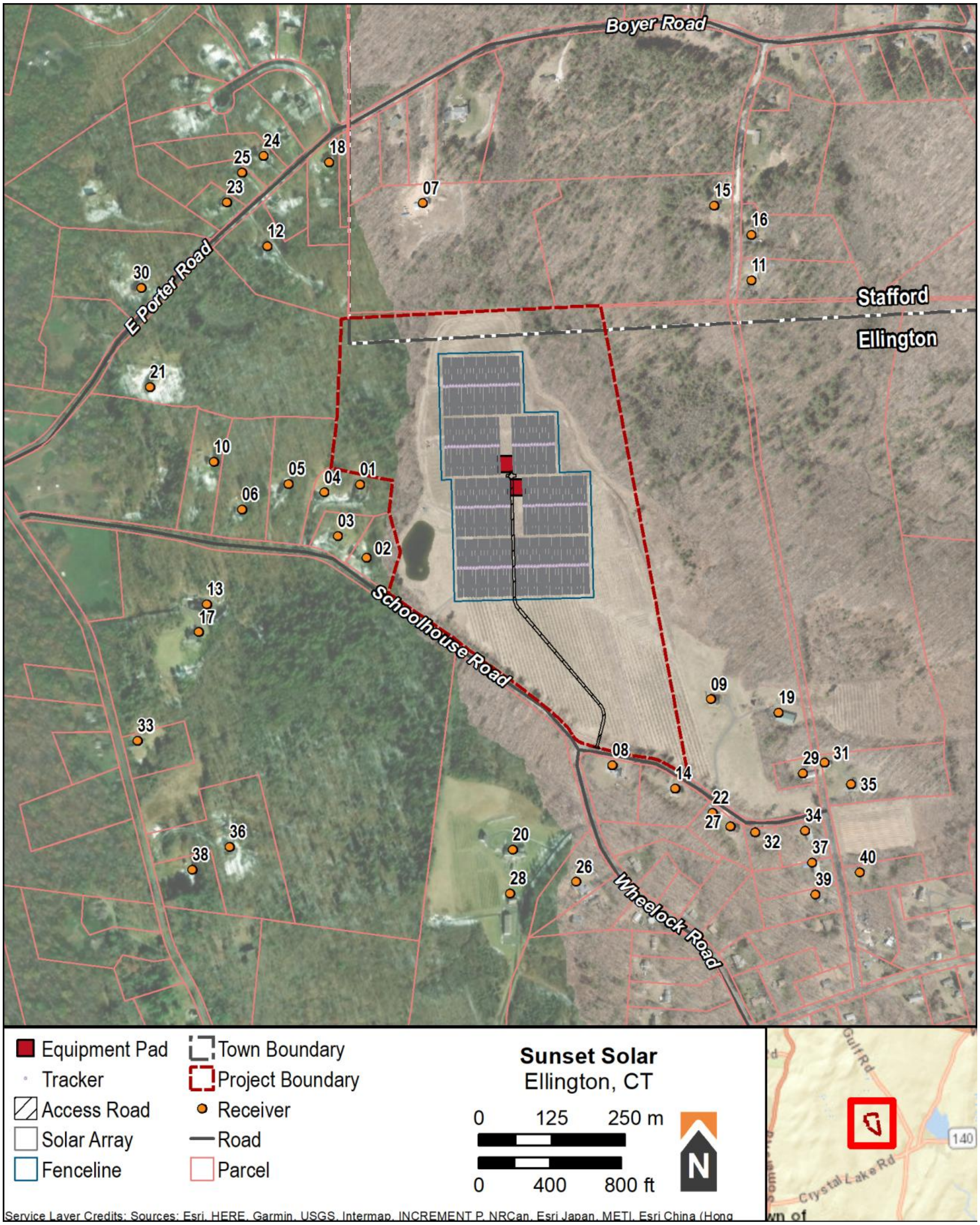

FIGURE 1: PROJECT AREA

2.0 SOUND LEVEL LIMITS

2.1 STATE OF CONNECTICUT

The State of Connecticut noise limits are classified by land use. Both the noise emitter and receptors are classified into Noise Zones as described in Section 22a-69-2 of the State of Connecticut Regulations. A Class A Noise Zone is residential or where humans tend to sleep, a Class B Noise Zone is intended for commercial or institutional uses, and a Class C Noise Zone is industrial.

The Project parcel classifies as Rural Agricultural Residential per the Town of Ellington zoning. It is currently being used for "Agriculture" (an orchard) which would be Class B. Solar power projects are not listed, except maybe as "Transportation, Communications and Utilities", which is Class C. This is based on designations in Section 22a-69-2 of the State of Connecticut Regulations. Within a Class A Noise Zone, an emitter cannot cause an exceedance of the noise level limits at the adjacent Noise Zones provided in Table 1. Zones surrounding the Project are similarly zoned as Rural Agricultural Residential and classified as Class A.

TABLE 1: CONNECTICUT CLASS A AND C NOISE ZONE - LIMITS

	Receptor Noise Zone			
	C	**B**	**A/Day**	**A/Night**
Class A Emitter	62 dBA	55 dBA	55 dBA	45 dBA
Class B Emitter	62 dBA	62 dBA	55 dBA	45 dBA
Class C Emitter	70 dBA	66 dBA	61 dBA	51 dBA

Daytime is defined as 7:00 am to 10:00 pm and nighttime is defined as 10:00 pm to 7:00 am. There is a tonal penalty based on 1/3 octave band sound levels.

2.2 TOWN OF ELLINGTON

The Town of Ellington, Connecticut does not quantify sound level limits for photovoltaic facilities but states the following requirement in Article 7 Special Regulations Section 7.15.7 Ground-Mounted Primary Use and Other – All Zones. Paragraph D. *"Transformers and inverters shall be located 200' or greater from all property lines and soundproofed."* This sets a minimum distance between transformers and inverters and the property lines and requires that both will be "sound proofed." There isn't really an acoustical definition for what "sound proofed" means. Even substantial mitigation applied to the transformers and inverters will result in some sound emissions. As a result mitigation will be applied, if it is necessary to comply with State of Connecticut sound level limits.

2.3 TOWN OF STAFFORD

The town of Stafford, Connecticut regulates solar facilities producing greater than 100 kW in Article VII Special Regulations Section 7.18 Solar Energy Systems Part J but does not quantify or specify sound level limits or regulations.

2.4 WHO GUIDELINES

There are no local noise limits set for sound levels at nearby residences, but per the guidelines set by the World Health Organization ("WHO Guidelines")[1], levels from a development should remain below 70 dBA, aggregated over a 24-hour period, to minimize hearing damage, and below 45 dBA, aggregated over an 8-hour period, at nighttime to minimize the risk of sleep disturbance. This is generally applied at residences. The daytime guideline is 50 dBA averaged over the daytime to prevent moderate annoyance.

2.5 PROJECT NOISE DESIGN LIMITS

The noise design limit of the Project during daytime hours, as defined to be from 7:00 am to 10:00 pm, is 50 dBA at the property line, based on WHO guidelines. The design limit during nighttime hours, as defined to be from 10:00 pm to 7:00 am, is 45 dBA at the property line based on State of Connecticut limits. This assumes current land use (Class B), though that will change if the Project is built. After the project is built, the use will change to Class C, resulting in limits of 61 dBA during the day and 51 dBA at night.

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[1] "Guidelines for Community Noise," Edited by Birgitta Berglund, Thomas Lindvall, Dietrich H. Schwela, World Health Organization, Geneva, 2000.

3.0 SOUND PROPAGATION MODELING

3.1 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 considers 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® V4.4, 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. The ground was modeled as soft (G=1), that is, suitable for vegetation growth. Equipment pads, roadways, and the pond to the west of the Project fenceline were modeled as hard ground (G=0). The Project access road was modeled as mixed ground (G=0.6).

To evaluate sound levels at the Project property line, a grid of receivers spaced 10 meters by 10 meters (33 feet by 33 feet) was calculated and four discrete receivers were positioned in critical locations. The isoline and property line receivers were modeled at 1.5 meters. Sound levels at nearby buildings were modeled at 4-meter (13 foot) heights, representative of the height of a two-story bedroom window.

Modeled sound sources include 40 Solectria SCG 1500 125 kW inverters, two 2,750 kVA transformers and 138 tracking motors. Data for the inverters was obtained from measurements provided by the manufacturer. Sound power levels of the transformers were calculated based on sound emissions from the NEMA TR-1 standard and data that RSG has monitored from similar size transformers. Data for the trackers came from manufacturer data for a similar unit.

Sound emissions were prorated to reflect that trackers only operate a small percentage of the time as they track the sun throughout the day. For modeling, they were assumed to operate eight percent of the time. Transformers and inverters are assumed to be tonal. A five dB penalty was added to both sources to reflect this.

During daytime operation, all equipment is modeled to operate. During nighttime operation, it is assumed that only the transformers will operate.

3.2 RESULTS

Sound levels from expected daytime operations along the Project property line are a maximum of 42 dBA, which occurs at location on the southwest. This meets Connecticut daytime limits for Class B and Class C emitters. It even meets the 45 dBA Class B emitter nighttime limit. The maximum sound level at a building outside of the Project property line is 40 dBA at Receiver 01. Sound level contours for daytime operational conditions are provided in Figure 2. The limit based on the State of Connecticut Regulations of 61 dBA along the Project property line is shown in dotted pink and is located roughly 15 meters from the equipment pads.

Expected nighttime operations of the Project produce a maximum sound level of 25 dBA along the Project property line and 23 dBA at a nearby building (Receiver 01). Sound level contours for nighttime operational conditions are provided in Figure 3. The Connecticut limit of 51 dBA along the Project property line, shown as a dotted pink line, is not visible as it is approximately 5 meters from each equipment pad.

Expected Project sound levels are below the limits specified by the State of Connecticut Regulations for both Class B and Class C emitters, and below the advised sound levels according to WHO Guidelines. Therefore, the Project, as represented in this report herein, is expected to meet the noise regulations specified by the State of Connecticut.

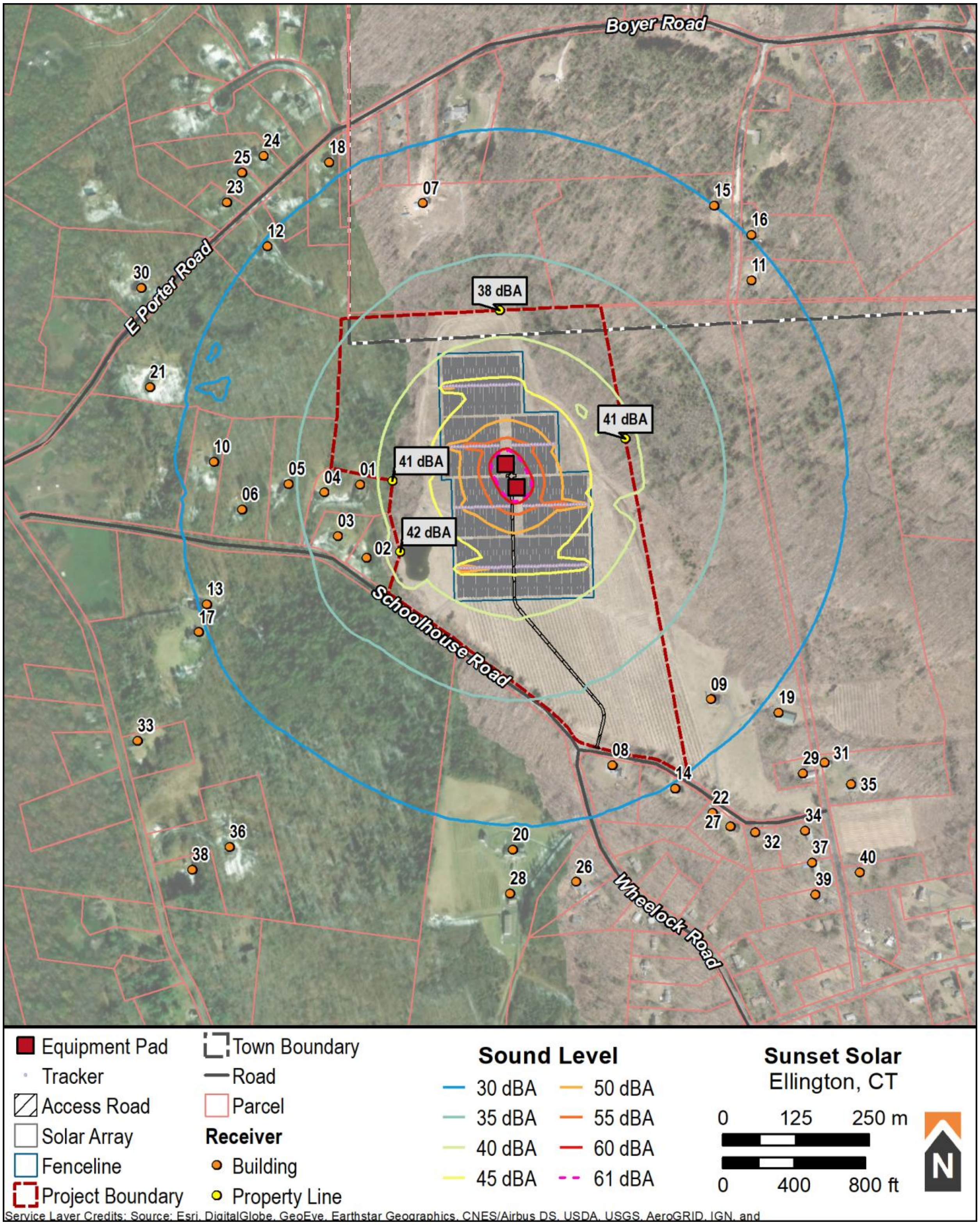

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FIGURE 2: SOUND PROPAGATION MODELING RESULTS – DAYTIME OPERATION

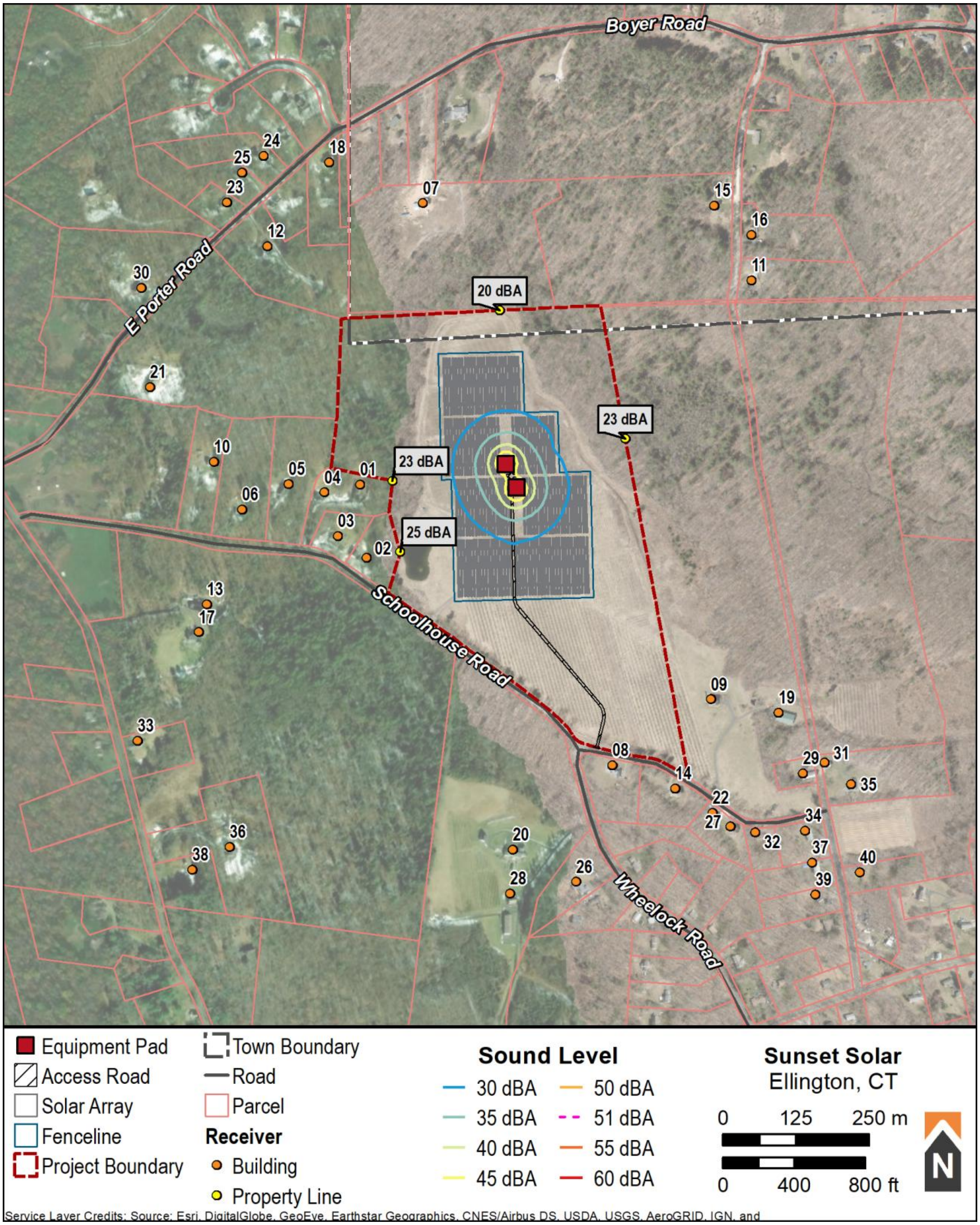

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FIGURE 3: SOUND PROPAGATION MODELING RESULTS - NIGHTTIME OPERATION

4.0 CONCLUSIONS

Greenskies Clean Energy, LLC is in the process of developing the 5 MW AC Sunset Solar power project, proposed for Ellington, Connecticut. Verdantas, the engineering company for the project, asked RSG to model sound levels of the Project and compare them to noise limits of the State of Connecticut, and local noise ordinances. Conclusions are as follows:

- The noise limits applicable to the Project are based on Section 22a-69-2 of the State of Connecticut Regulations and WHO Guidelines and are categorized by daytime and nighttime hours. State regulations require the Project to not exceed 61 dBA along the property line during the daytime and 51 dBA at nighttime if the Project parcel has a Class C Land use, which would include utilities. The current use of the Project parcel is agriculture, which is Class B. This has limits of 55 dBA during the day and 45 dBA at night on the property line. According to WHO Guidelines, Project sound levels should not exceed 50 dBA at a residence during daytime hours to minimize the risk of annoyance and 45 dBA at nighttime to minimize the risk of sleep disturbance. There are no quantitative town regulations applicable to the Project.
- Sound propagation modeling was performed using Datakustik's CadnaA implementation of the ISO 9613-2 sound propagation modeling algorithm.
- The primary sound producing sources include a total of 40 string inverters and two transformers. The inverters and transformers are designed to be installed on two equipment pads towards the center of the Project area. Both inverters and transformers are assumed to be tonal. Secondary sound-producing equipment includes the tracking motors which are mounted at the center of each solar rack.
- Daytime operation assumes that trackers, inverters, and transformers are operating at full power capacity. Nighttime operation assumes that only the transformers are operating.
- The maximum sound levels from the Project during daytime operations are 42 dBA along the Project property line and 40 dBA at a nearby building. Expected nighttime operations produce maximum sound levels of 25 dBA along the Project property line and 23 dBA at a nearby building. Project sound levels are below the State of Connecticut limits and WHO Guidelines.

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").[2] 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 4.

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.

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[2] 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.

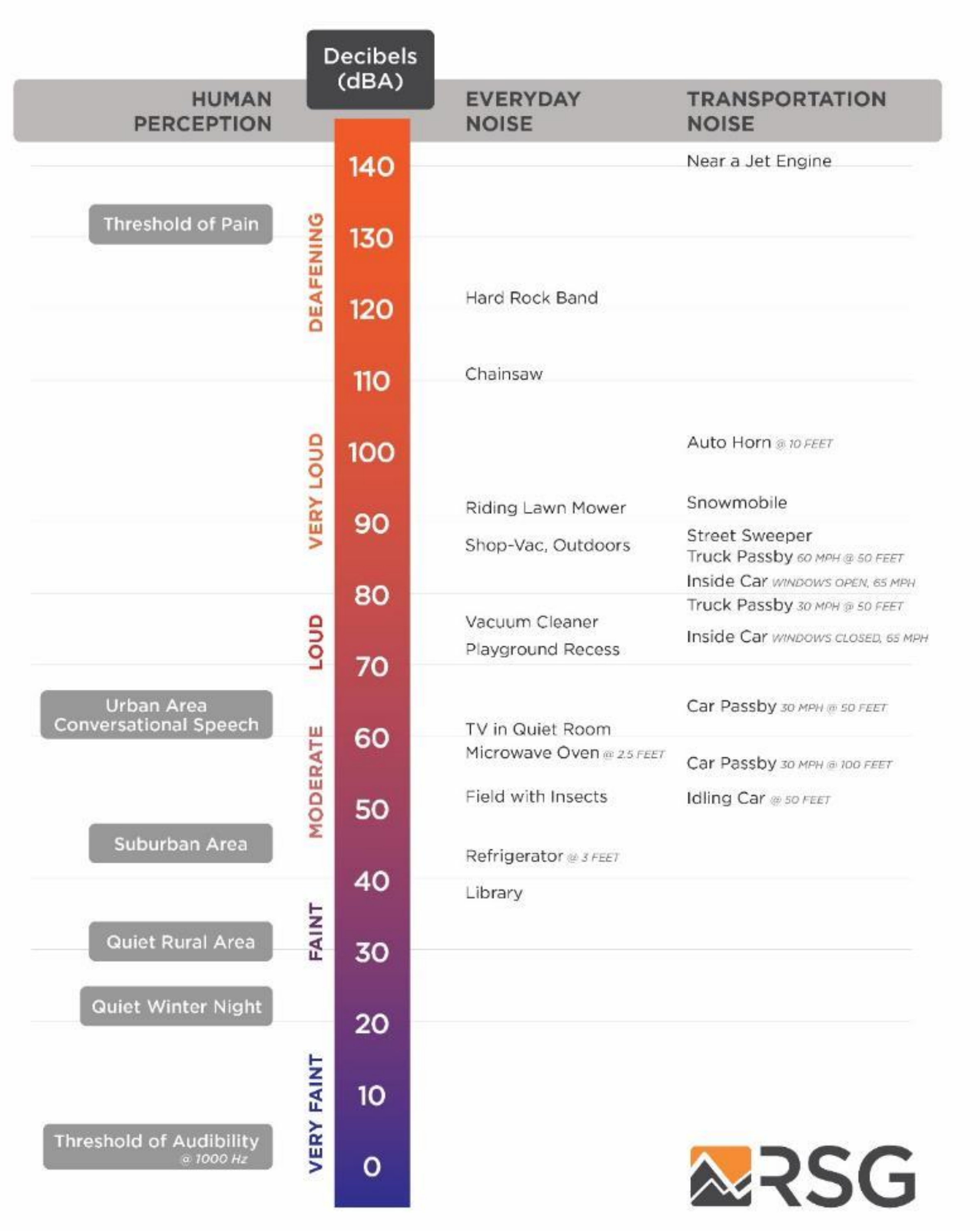

FIGURE 4: A SCALE OF SOUND PRESSURE LEVELS FOR TYPICAL SOUND SOURCES

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.[3] 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 $L_{eq,max}$.

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 5. 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 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

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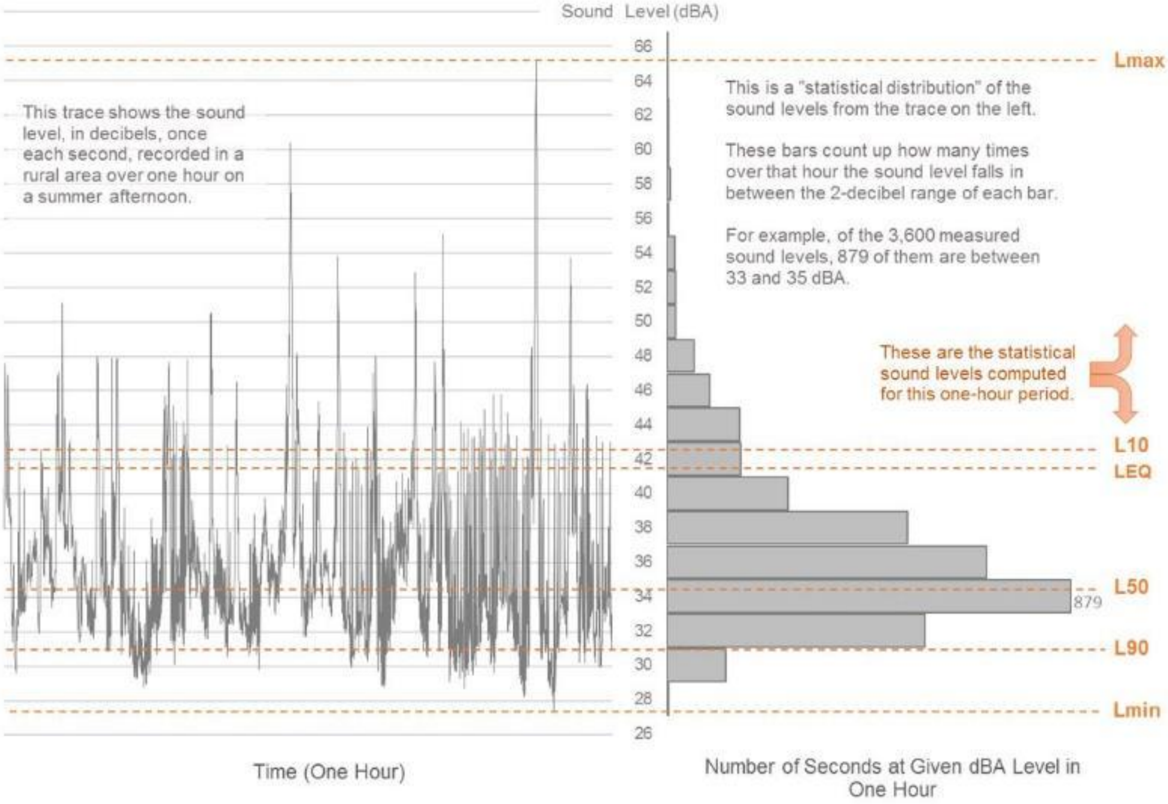
[3] There is a third time response defined by standards, the “Impulse” response. This response was defined to enable use of older, analog meters when measuring very brief sounds; it is no longer in common use.

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 5, 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.



This trace shows the sound level, in decibels, once each second, recorded in a rural area over one hour on a summer afternoon.

This is a "statistical distribution" of the sound levels from the trace on the left.

These bars count up how many times over that hour the sound level falls in between the 2-decibel range of each bar.

For example, of the 3,600 measured sound levels, 879 of them are between 33 and 35 dBA.

These are the statistical sound levels computed for this one-hour period.

FIGURE 5: 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 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. SOUND SOURCE INFORMATION

TABLE 2: SOUND PROPAGATION MODELING PARAMETERS

Parameter	Setting
Ground Absorption	Spectral for all sources, soft ground (G=1), hard ground (G=0) for equipment pads, ponds, and roadways, mixed ground (G=0.6) for gravel access road
Atmospheric Attenuation	Based on 10 Celsius, 70% relative humidity
Receiver Height	1.5 meters for property line receivers and isoline contours, 4 meters for residences
Search Distance	3,000 meters

TABLE 3: EQUIPMENT SOUND POWER

Sound Source	1/1 Octave Band Center Frequency Sound Power (dBZ)									Sum (dBA)	Sum (dBZ)
	31.5 Hz	63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz		
Solectria XGI 1500-125kW (1 ct.)	67	67	69	65	74	76	70	71	79	82	83
2750 kVA Transformer	74	78	82	77	76	71	65	62	57	77	85
NexTracker					70					67	70

TABLE 4: SOUND SOURCE INFORMATION

Source ID	Equipment Type	Modeled Sound Power (dBA)	Relative Height (m)	Coordinates (UTM NAD83 Z18N)		
				X (m)	Y (m)	Z (m)
Inverter Rack 1 (20 ct.)	Inverter	101	1.5	715176	4646305	236
Inverter Rack 2 (20 ct.)	Inverter	101	1.5	715194	4646274	238
Transformer 01	Transformer	82	2.0	715176	4646312	236
Transformer 02	Transformer	82	2.0	715194	4646266	238
Tracker		67	1.5	Center of each solar rack		

APPENDIX C. RECEIVER INFORMATION

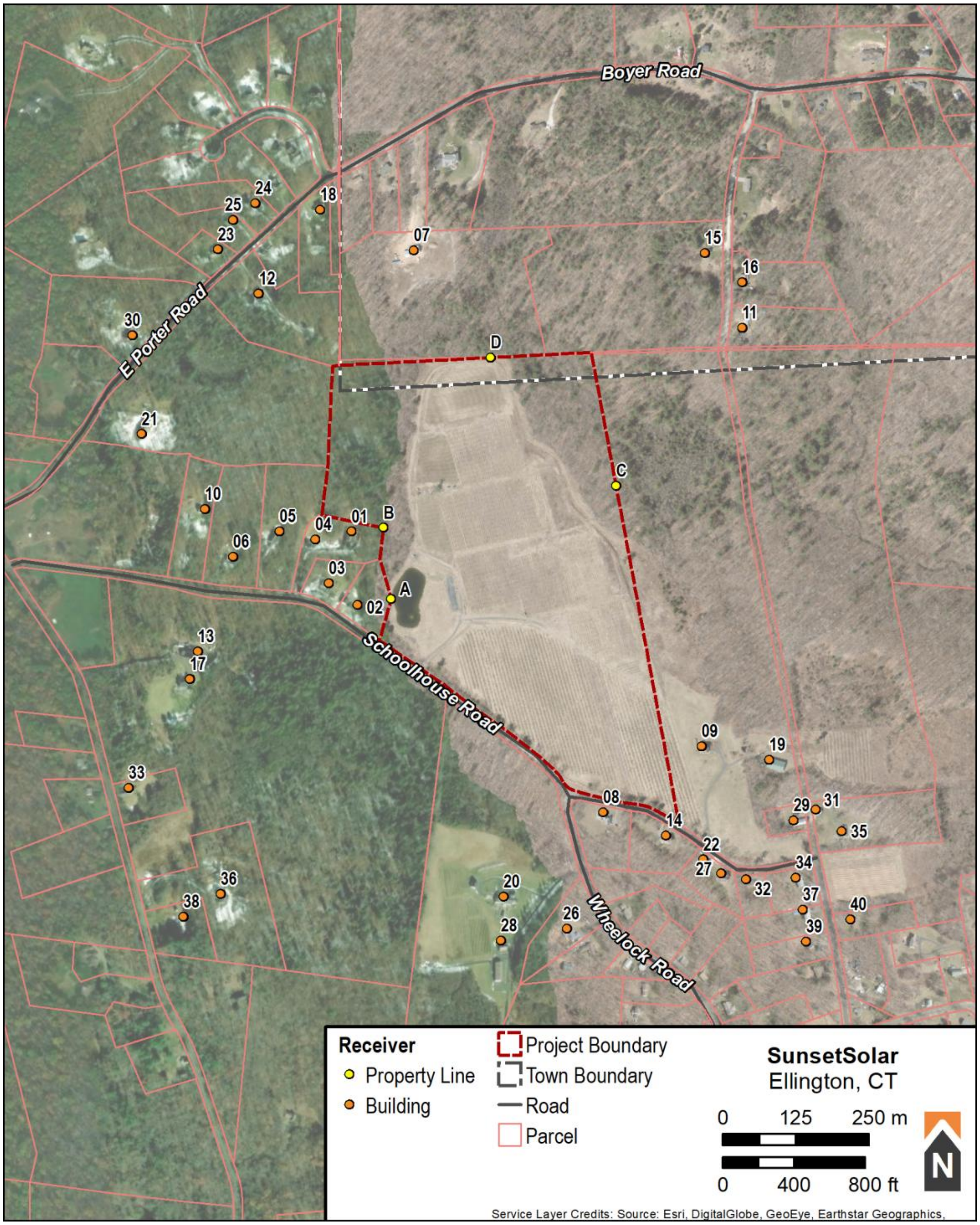


FIGURE 6: RECEIVER LOCATIONS

TABLE 5: DISCRETE RECEIVER RESULTS

Receiver ID	Sound Level (dBA)		Relative Height (m)	Coordinates (UTM NAD83 Z18N)		
	Daytime	Nighttime		X (m)	Y (m)	Z (m)
Property Line A	42	25	1.5	714995	4646159	232
Property Line B	41	23	1.5	714981	4646281	229
Property Line C	41	23	1.5	715381	4646352	221
Property Line D	38	20	1.5	715165	4646572	227
1	40	23	4	714927	4646274	236
2	39	22	4	714937	4646148	236
3	38	21	4	714888	4646186	238
4	37	21	4	714865	4646260	239
5	36	19	4	714804	4646275	250
6	33	17	4	714724	4646231	252
7	33	17	4	715034	4646755	233
8	33	16	4	715358	4645794	256
9	33	16	4	715527	4645906	257
10	32	16	4	714676	4646313	253
11	32	16	4	715597	4646623	231
12	31	15	4	714768	4646682	241
13	31	15	4	714664	4646069	240
14	31	15	4	715465	4645754	257
15	31	15	4	715533	4646751	232
16	31	15	4	715596	4646701	231
17	31	15	4	714650	4646021	237
18	31	14	4	714874	4646826	248
19	31	14	4	715643	4645884	256
20	30	14	4	715187	4645649	259
21	30	14	4	714567	4646441	245
22	30	13	4	715530	4645713	259
23	29	13	4	714698	4646757	245
24	29	13	4	714762	4646837	247
25	29	13	4	714724	4646808	246
26	29	13	4	715296	4645594	258
27	29	13	4	715560	4645689	260
28	29	13	4	715183	4645574	259
29	29	13	4	715684	4645780	260
30	29	13	4	714552	4646610	238
31	29	12	4	715722	4645798	259
32	28	12	4	715603	4645679	261
33	28	12	4	714545	4645836	225
34	28	12	4	715688	4645682	261
35	28	12	4	715767	4645761	260
36	27	12	4	714703	4645654	233
37	27	11	4	715701	4645627	261
38	26	11	4	714639	4645615	223
39	26	10	4	715706	4645572	260
40	26	10	4	715782	4645610	263