

Verdantas

SOUND MODELING – SOUNDVIEW SOLAR

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1.0 INTRODUCTION

Greenskies Clean Energy, LLC is developing the 1.999 MWAC Soundview Solar power project (“Project”) proposed for Woodbridge, Connecticut. The engineer for the Project has asked RSG to perform sound propagation modeling to assess sound levels relative to State of Connecticut and local sound level limits. The report includes:

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

2.0 PROJECT DESCRIPTION

The Soundview Solar power project (“Project”) is a 1.999 MWAC photovoltaic facility located in the Town of Woodbridge, Connecticut. A map showing the Project in the context of the surrounding area is shown in Figure 1 and a map of the immediate site is shown in Figure 2. The proposed Project will be located approximately 700 feet west of Newtown Road and approximately 680 feet north of Penny Lane. The fenced-in area is proposed to be approximately 7.7 acres. The area is generally wooded with a number of nearby residences surrounding the Project area.

Project equipment is currently proposed to include panels, trackers to orient the panels towards the sun, 16 inverters to convert DC electricity to AC, and two transformers to step up the electricity to the line voltage. The inverters are currently planned to be Solectria SCG 1500 125 kW units. Each transformer will be a pad mounted 1,000 kVA unit.



FIGURE 1: PROJECT AREA MAP

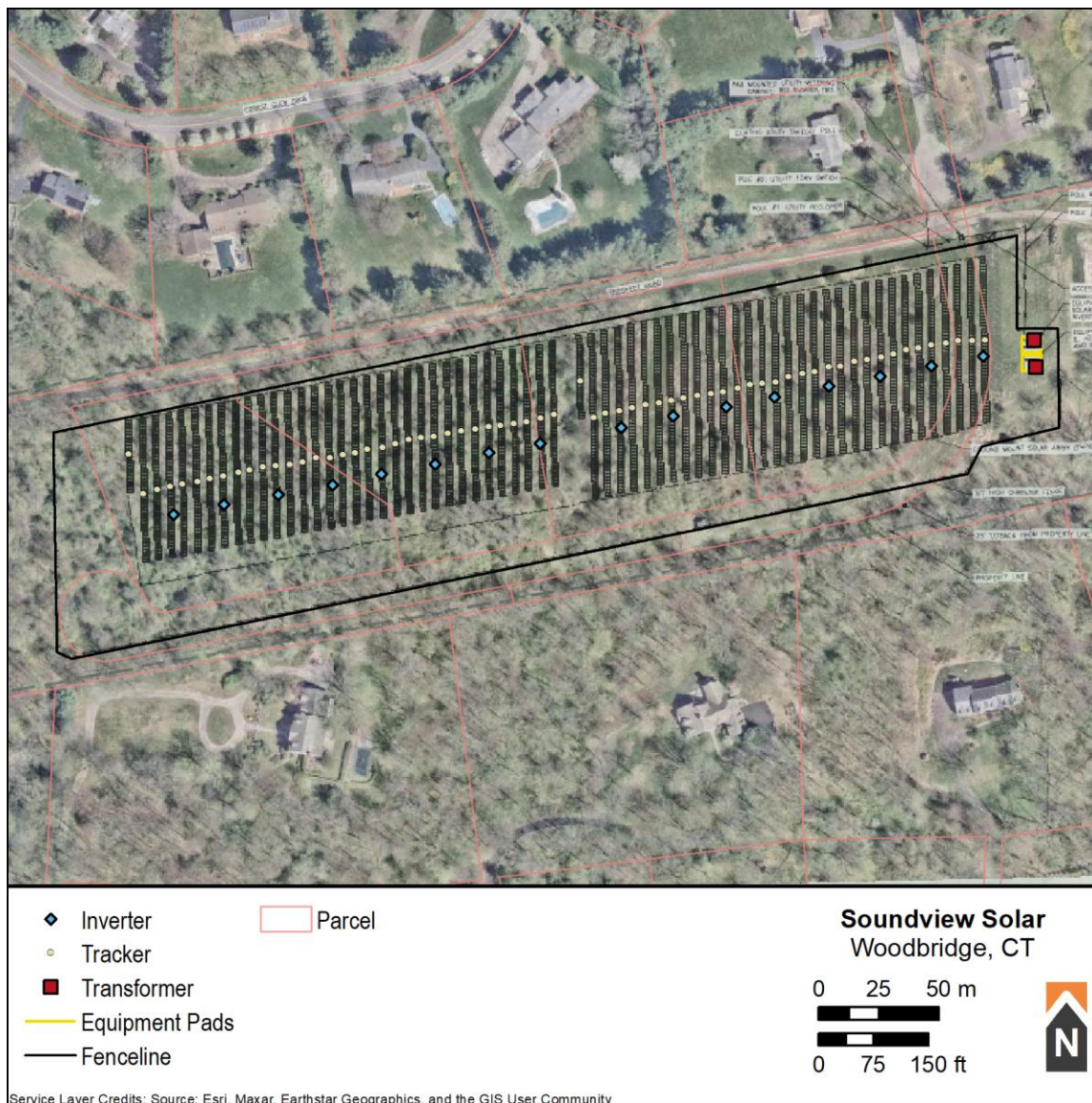


FIGURE 2: PROJECT SITE MAP

3.0 SOUND LEVEL LIMITS

3.1 WOODBRIDGE, CONNECTICUT

Sound level limits for the Town of Woodbridge are found in section 315-8. For situations where the sound source is in a residential noise district, the noise limits applicable at the property line are found in Table 1.

Since the entire area, including the Project parcel, is zoned residential, the noise limits are 55 dBA during the day and 45 dBA at night. Daytime is defined as 7 am to 8 pm.

TABLE 1: WOODBRIDGE PROPERTY LINE NOISE LIMITS IF THE EMITTING PARCEL IS IN A RESIDENTIAL NOISE DISTRICT

	Receptor			
	Business/Industrial Development	Business	Residential	
			Day	Night
	(dBA)	(dBA)	(dBA)	(dBA)
Residential emitter to	62	55	55	45

3.2 STATE OF CONNECTICUT

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

The Project parcel classifies as a Class A Noise Zone and is surrounded by more Class A Noise Zones. For Class A Noise Zone, the emitter cannot exceed the noise level limits at the adjacent Noise Zones provided in Table 2.

TABLE 2: CONNECTICUT CLASS A NOISE ZONE - LIMITS

	Receptor Noise Zone			
	C	B	A/Day	A/Night
Class A 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.

The Project will not operate at night, so the Project design goal is 61 dBA at the property line of Class A Noise Zones. There is a tonal penalty based on 1/3 octave band sound levels.

3.3 PROJECT NOISE DESIGN LIMITS

The difference between Woodbridge and the State of Connecticut is how the noise zones are defined. Woodbridge focuses on how the land is zoned and Connecticut focuses on how it's used. Since the Woodbridge limits are more conservative (i.e. lower), those are what the Project will be evaluated against. This is a limit of 45 dBA at night and 55 dBA during the day at the Project property line.

4.0 SOUND PROPAGATION MODELING

4.1 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® 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. The exception is for the inverter and transformer pads, which were modeled as hard ($G=0$). Sound levels were calculated at 20 property line receivers and over an area of 1.9 square miles (5 square kilometers) with a grid spacing of 49 feet by 49 feet (15 meters by 15 meters). Both the receivers and the grid were calculated at a height of 1.5 meters (4.9 feet).

Modeled sound sources included 16 Solectria SCG 1500 125 kW, two 1,000 kVA transformers and 65 tracking motors. Data for the inverters was obtained from a manufacturer test. For the transformers it was based on sound emissions from the NEMA TR-1 standard along with data we have monitored from similar size transformers. Data for the trackers came from 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 frequently tonal. A five dB penalty was added to both types of sources to reflect this.

Modeling included two different operational conditions. The first is the “daytime” condition with all sources operating simultaneously at full capacity. This is the acoustical worst-case condition. The “nighttime” condition has only the transformers operating since they will still be energized at night, but without load, while the inverters and trackers will not be operating. Since daytime is defined by Woodbridge as being from 7 am to 8 pm and the earliest sunrise in the area is near 5:30 am, there will be some situations where the inverters will start up before 7 am. Day and Night in the modeling sense here refers to the operational conditions. The nighttime ordinance period may sometimes overlap with the daytime operational condition, but this will be over a confined period in the spring and summer.

4.2 RESULTS

Sound propagation modeling results are shown in Figure 3 for the daytime condition and Figure 4 for the nighttime condition. Discrete property line receiver results are shown in Table 6 in Appendix C; all results include the 5 dB penalty for tonal sources. Results show sound levels of up to 49 dBA at a residential property in the daytime configuration and 32 dBA in the nighttime configuration.

While daytime and nighttime operations will meet their respective noise limits, the nighttime ordinance period may sometimes overlap with the daytime operational condition over a confined period (from about 5:30 to 7:00 am) in the spring and summer, causing a modeled exceedance in the nighttime noise limit. Although inverters will be operating during this period, it will be at a reduced output of not more than 70 percent. The exact sound emissions from this inverter model at a reduced output are not provided. Data from a different inverter shows sound levels decrease by 7.5 dB as output decreases from 100 to 70 percent. A separate inverter shows an 11 dB decrease from 80 percent to 50 percent output. On top of this, sound screening from the solar panels will reduce sound levels at the property line to some extent. This means that although modeling shows an overage of up to four dB for this time period, this is unlikely to happen in practice.

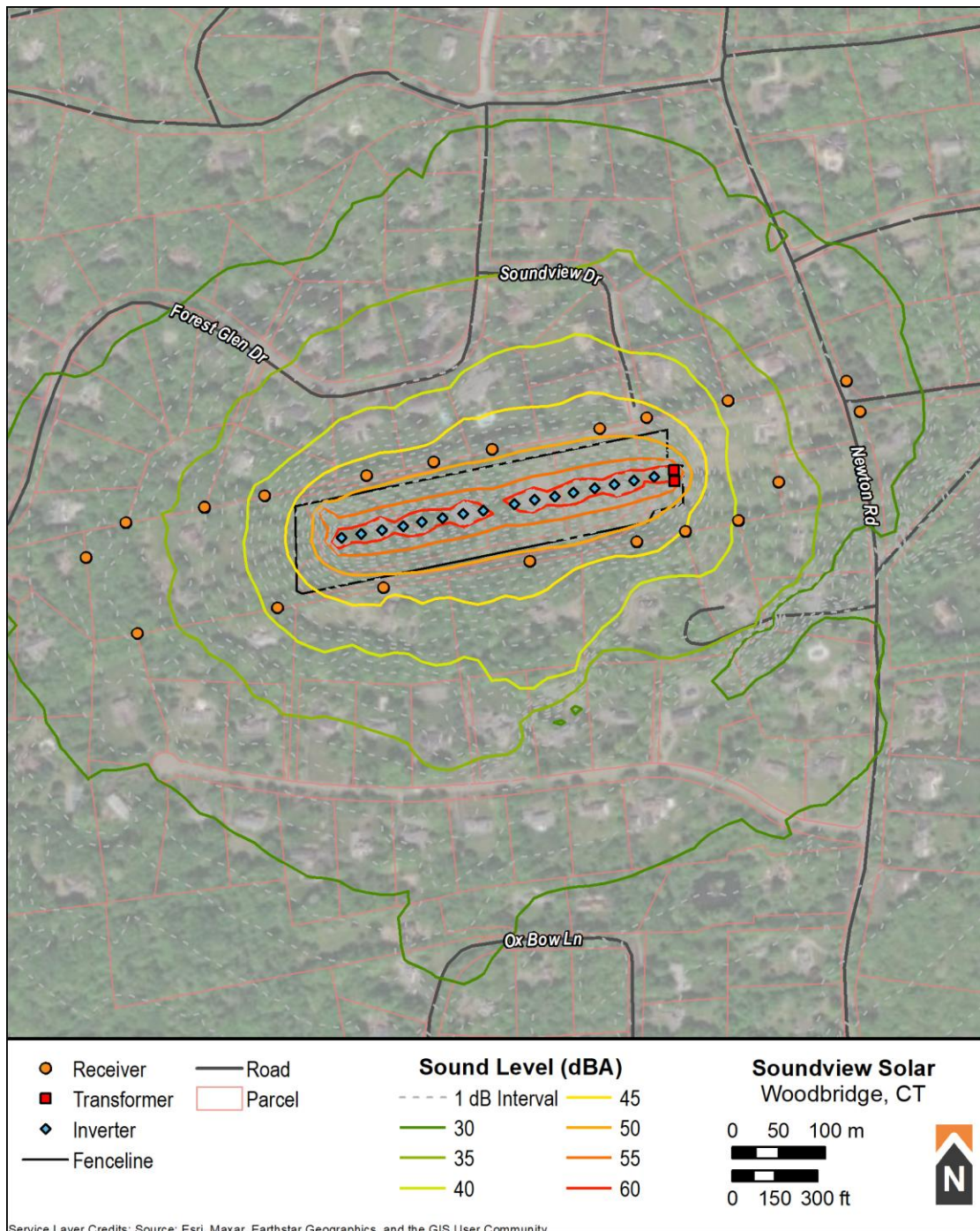


FIGURE 3: SOUND PROPAGATION MODELING RESULTS - DAYTIME CONDITION¹

¹ Due to the number of them, trackers are not shown specifically.

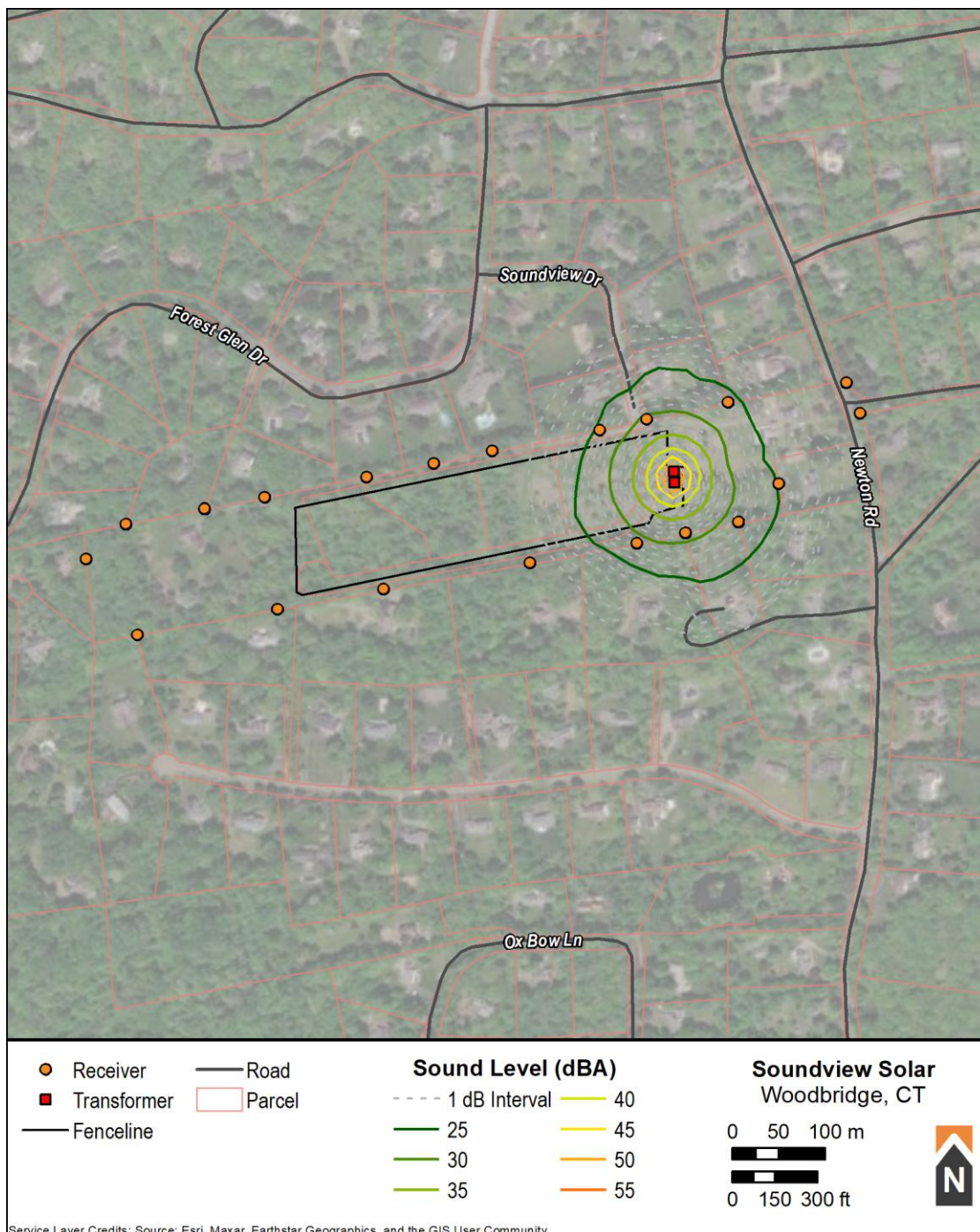


FIGURE 4: SOUND PROPAGATION MODELING RESULTS - NIGHTTIME CONDITION

5.0 CONCLUSIONS

Greenskies Clean Energy, LLC is in the process of developing the 1.999 MW AC Soundview Solar power project (“Project”), proposed for Woodbridge, Connecticut. Verdantas, the engineering company for the project, asked RSG to assess sound levels of the Project relative to noise limits of the State of Connecticut and Woodbridge. Conclusions are as follows:

- Both Connecticut and Woodbridge have noise limits. Connecticut limits are based on land use and Woodbridge limits are based on zoning. This results in Woodbridge having lower limits of 55 dBA during the day and 45 dBA at night, assessed at Project property lines. There is also a tonal penalty for Connecticut.
- Sound propagation modeling was performed using Datakustik’s Cadna/A implementation of the ISO 9613-2 sound propagation modeling algorithm. The sound producing sources are the inverters, trackers, and transformers.
- The highest daytime operations sound levels at a property line were 49 dBA and the highest nighttime operations sound levels were 32 dBA, meeting the Town of Woodbridge noise limits. These sound levels both include the 5 dB tonal penalty on tonal sources.

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 5.

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.

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.

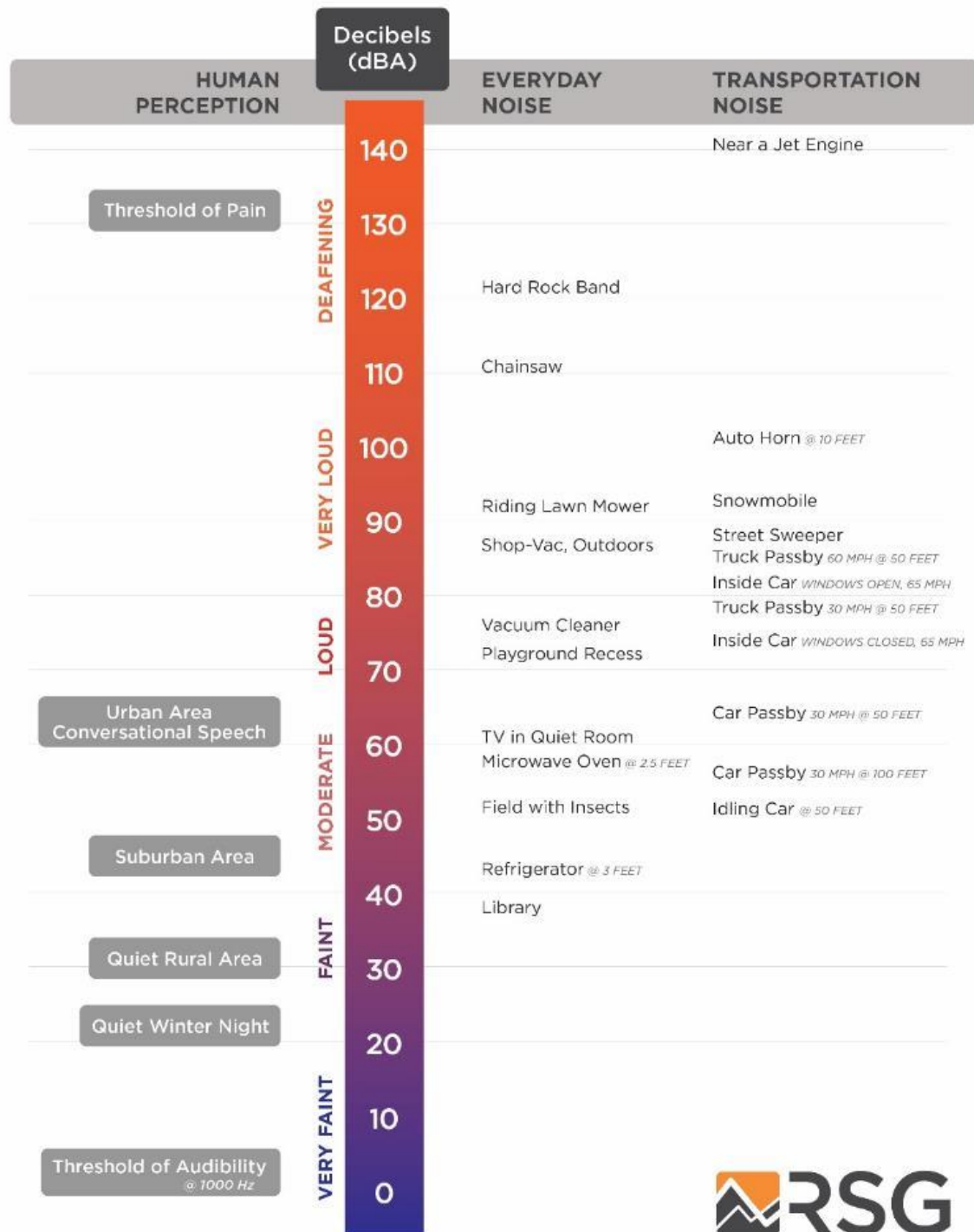


FIGURE 5: A SCALE OF SOUND PRESSURE LEVELS FOR TYPICAL SOUND SOURCES

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 6. 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

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.

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 6, 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.

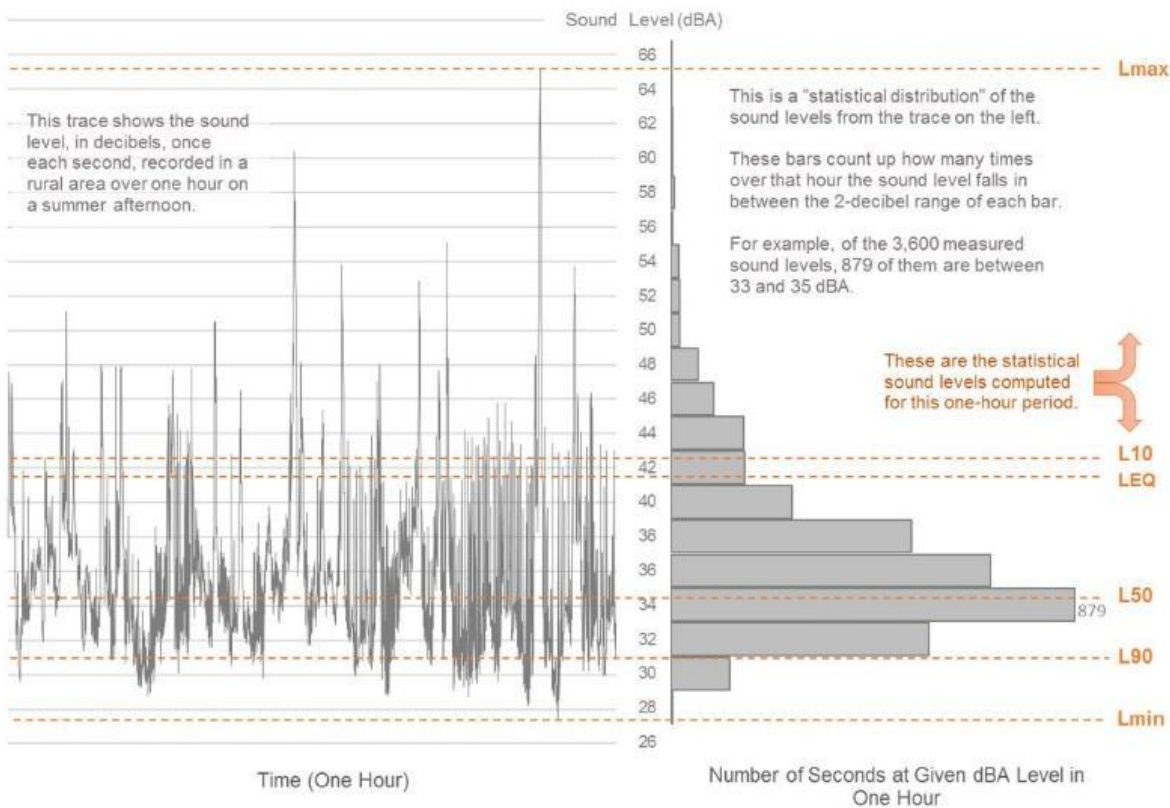


FIGURE 6: EXAMPLE OF DESCRIPTIVE TERMS OF SOUND MEASUREMENT OVER TIME

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 3: SOUND PROPAGATION MODELING PARAMETERS

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

TABLE 4: 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 SCG 1500-125 kW	80	75	79	72	79	82	76	78	77	85	88	
Transformer - 1000kVA	71	76	82	81	71	67	58	50	43	75	85	
NexTracker					70					67	70	

TABLE 5: SOUND SOURCE INFORMATION

Source ID	Equipment Type	Modeled Sound Power (dBA)	Relative Height (m)	Coordinates (UTM NAD83 Z18N)		
				X (m)	Y (m)	Z (m)
Tr1	Transformer	80	1.7	666331	4581497	142
Tr2	Transformer	80	1.7	666332	4581486	141
Inv01	Inverter	90	1.6	666203	4581469	141
Inv02	Inverter	90	1.6	666181	4581465	140
Inv03	Inverter	90	1.6	666160	4581460	141
Inv04	Inverter	90	1.6	665973	4581424	139
Inv05	Inverter	90	1.6	665995	4581428	140
Inv06	Inverter	90	1.6	666017	4581433	142
Inv07	Inverter	90	1.6	666040	4581437	142
Inv08	Inverter	90	1.6	666060	4581441	143
Inv09	Inverter	90	1.6	666082	4581445	142
Inv10	Inverter	90	1.6	666105	4581450	142
Inv11	Inverter	90	1.6	666126	4581454	140
Inv12	Inverter	90	1.6	666224	4581473	142
Inv13	Inverter	90	1.6	666246	4581478	142
Inv14	Inverter	90	1.6	666267	4581482	142

Source ID	Equipment Type	Modeled Sound Power (dBA)	Relative Height (m)	Coordinates (UTM NAD83 Z18N)		
				X (m)	Y (m)	Z (m)
Inv15	Inverter	90	1.6	666289	4581486	142
Inv16	Inverter	90	1.6	666310	4581490	142

APPENDIX C. RECEIVER INFORMATION

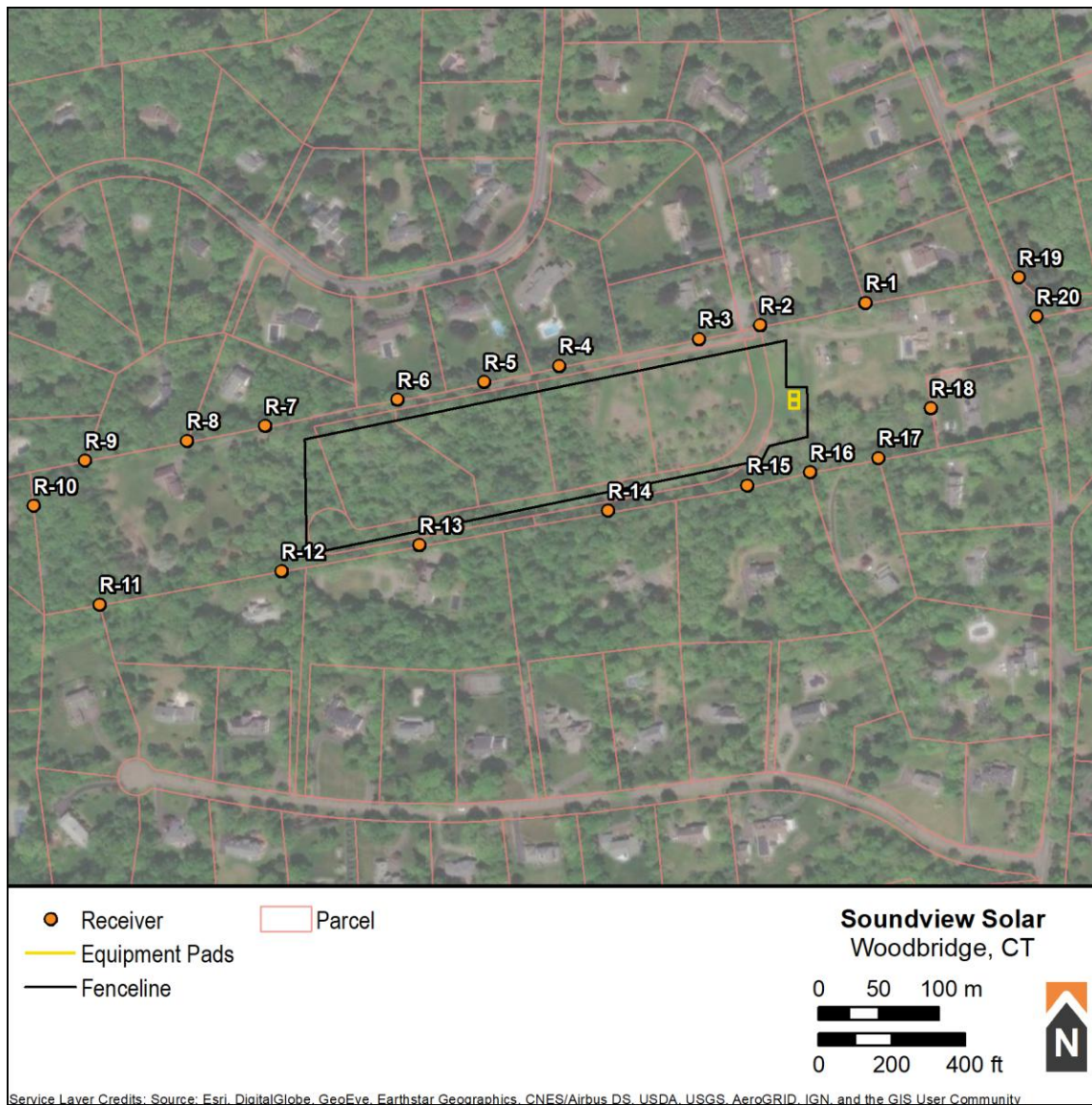


FIGURE 7: PROPERTY LINE RECEIVER LOCATIONS

TABLE 6: DISCRETE PROPERTY LINE RECEIVERS

Receiver ID	Type	Sound Pressure Level (dBA)		Relative Height (m)	Coordinates (UTM NAD83 Z18N)		
		Day	Night		X (m)	Y (m)	Z (m)
R-01	Property Line	39	26	1.5	666390	4581572	141
R-02	Property Line	47	31	1.5	666302	4581554	145
R-03	Property Line	49	26	1.5	666252	4581542	145
R-04	Property Line	49	18	1.5	666135	4581520	144
R-05	Property Line	49	16	1.5	666072	4581506	145
R-06	Property Line	48	13	1.5	666000	4581491	142
R-07	Property Line	41	10	1.5	665890	4581469	136
R-08	Property Line	37	8	1.5	665825	4581457	133
R-09	Property Line	33	7	1.5	665740	4581441	128
R-10	Property Line	32	6	1.5	665698	4581403	126
R-11	Property Line	33	7	1.5	665753	4581321	125
R-12	Property Line	41	10	1.5	665904	4581349	132
R-13	Property Line	47	13	1.5	666019	4581370	137
R-14	Property Line	49	19	1.5	666176	4581399	137
R-15	Property Line	47	28	1.5	666292	4581420	138
R-16	Property Line	45	32	1.5	666344	4581431	136
R-17	Property Line	40	28	1.5	666401	4581443	133
R-18	Property Line	37	25	1.5	666445	4581484	133
R-19	Property Line	32	18	1.5	666518	4581593	133
R-20	Property Line	32	18	1.5	666533	4581560	131