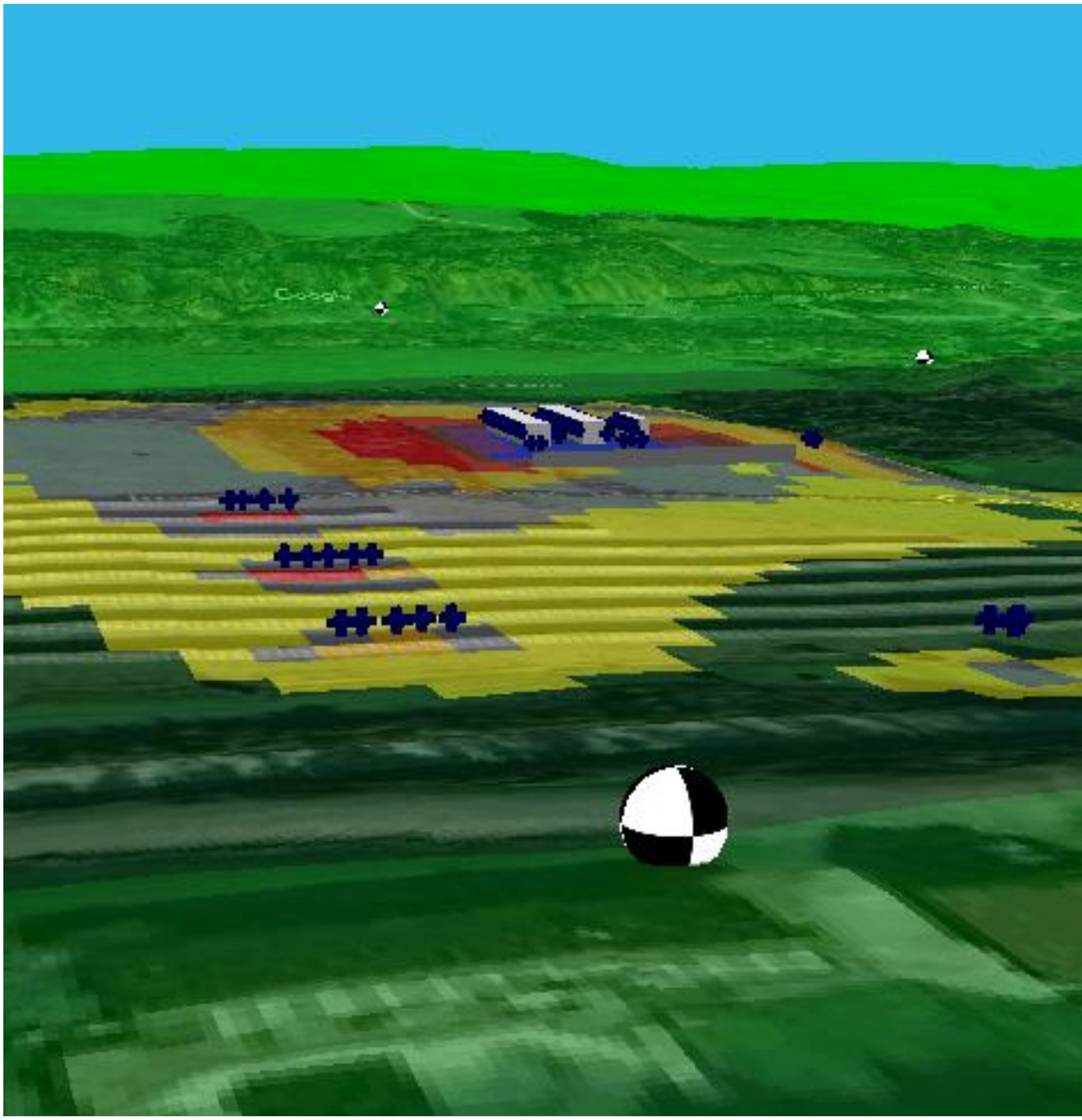
Exh. MRES-TK-6

MURPHY ROAD ENERGY STORAGE - SOUND MODELING STUDY



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Prepared for Encore Renewable Energy

Report Title:

Murphy Road Energy Storage - Sound Modeling Study

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1.0 EXECUTIVE SUMMARY

Encore Renewable Energy is proposing to construct the Murphy Road Energy Storage Project (Project), a 4.99 MW AC battery energy storage system (BESS) in Bennington, Vermont. The Project consists of 36 BESS cabinets, five inverters, two main transformers, auxiliary transformers, and other electrical control cabinets enclosed in a fence. The Project is sited adjacent to ER Paper Mill Village Solar Array, a 500 kW AC photovoltaic (PV) project.

To quantify noise impacts from the Project, sound emissions from each equipment type were quantified and sound pressure levels at 75 nearby residences were calculated. The manufacturer provided overall A-weighted sound pressure levels, measured at a specified distance from the equipment. With these and representative 1/3 octave band data of similar equipment, sound power levels for each piece of equipment were calculated. All source data indicate that the expected sound emissions from the Project are tonal. Noise with prominent discrete tones is more noticeable than broadband sound at the same overall level.

In lieu of local, state, and federal guidelines on noise limits, the project noise design goal is based on the WHO guideline of a 45 dBA equivalent average over an eight-hour nighttime period. Project equipment could run during daytime and nighttime hours, so there was no differentiation between day and night in the modeling. Due to the expected tonality of noise generated by the equipment, a 5 dB tonal penalty (per ANSI S12.9 Part 4) was assessed on the limit; the Project noise design goal was thus set to 40 dBA. For the Project noise design goal, rather than calculate the value over a night, the modeling calculates the one-hour equivalent average sound level (L_{1h}) of the Project and the adjacent PV project running at full capacity. The modeled Project incorporates all equipment planned to be installed initially plus an additional set of equipment (one inverter and four DC Blocks) for future augmentation that would be installed in approximately 10 years.

The maximum cumulative L_{1h} modeled at a residence was 40 dBA, directly to the south of the Project. The cumulative sound level is the sum of the PV project (30 dBA) and the proposed BESS project (39 dBA). An eight-foot-tall absorptive noise blanket is specified along the southern Project fenceline to achieve these sound levels. With this mitigation in place, we conclude that sound generated by the Project will not result in an undue adverse impact on air quality.

2.0 INTRODUCTION

This report describes and quantifies the expected sound levels emitted from the proposed Murphy Road Energy Storage Project in Bennington, Vermont.

A primer on acoustics is provided in Appendix A.

2.1 PROJECT DESCRIPTION

The Murphy Road Energy Storage Project is a proposed 4.99 MW battery energy storage system at 419 Murphy Road in Bennington, VT. The proposed site for the Project is adjacent to ER Paper Mill Village Solar Array, an existing 500 kW AC solar photovoltaic ("PV") project that was constructed in 2017. The Project will serve to assist the utility during periods of peak demand.

The primary sources of operational sound from the proposed Project are the BESS cabinets, transformers, and inverters[1]. Representative images of the equipment are provided in Figure 1 and are discussed in further detail in Section 2.3.

Figure 2 shows the site plan of the Project in the context of the surrounding area, which includes a noise blanket mounted along the southern fenceline specified by this study. The closest residences to the Project are directly south and west from the Project site.

Source: KORE POWER — **(A)**

Source: EPC Power — **(B)**

Source: Prolec — **(C)**

FIGURE 1: REPRESENTATIVE IMAGES OF (A) A BESS CABINET, (B) TWO INVERTERS, AND (C) A PAD-MOUNTED TRANSFORMER

[1] The inverters are also called Power Converting Systems (PCS).

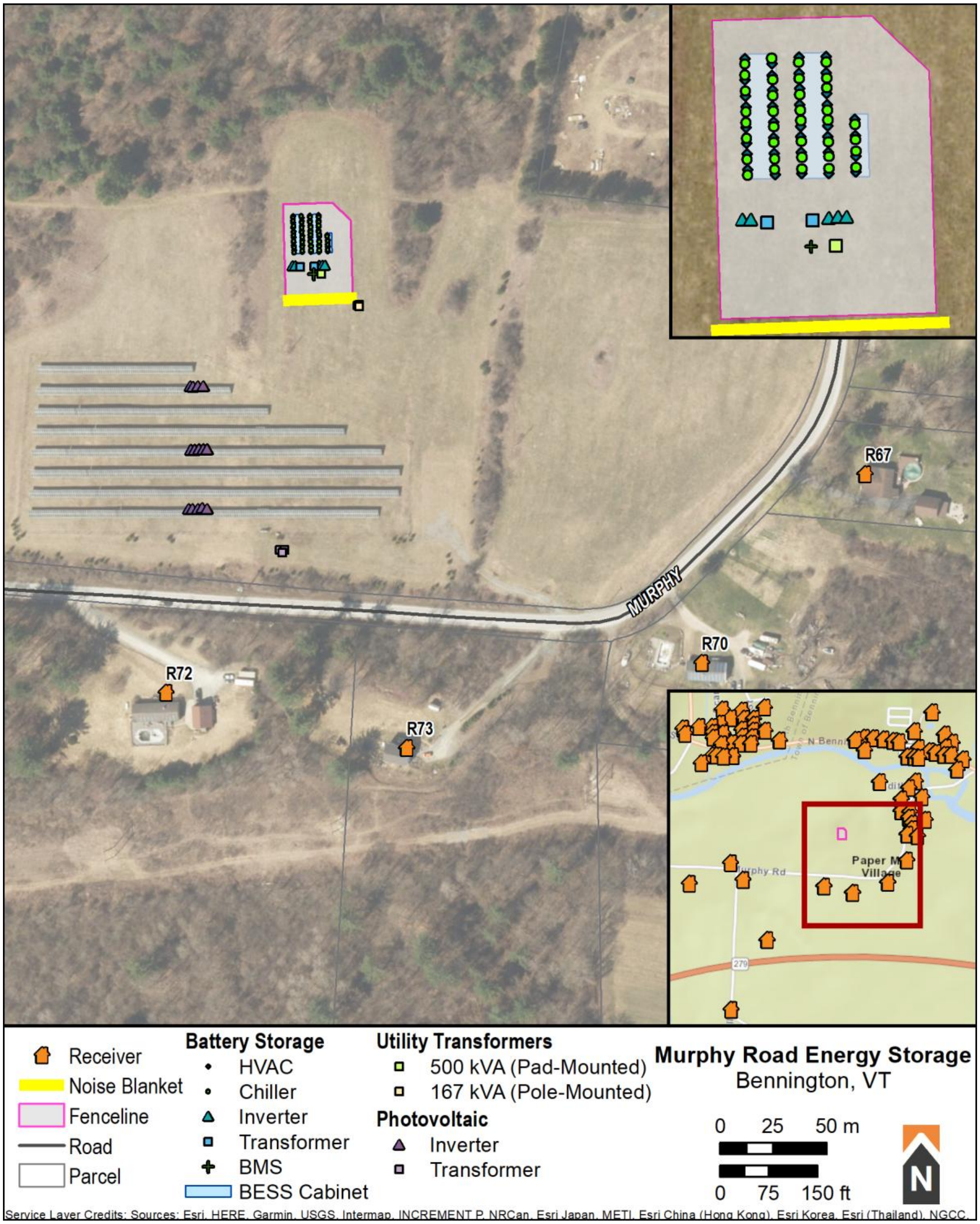

FIGURE 2: PROPOSED PROJECT LAYOUT AND VICINITY

2.2 NOISE IMPACT CRITERIA

The Project is being reviewed by the Public Utility Commission ("PUC") under Section 248 of Title 30. The PUC does not have quantitative noise limits that apply to battery storage projects and there are no Vermont statutes or regulations that establish quantitative noise standards applicable to the Project. The Section 248 Criteria document[2], published in October 2020, includes noise under "Air Pollution and Greenhouse Gas Impacts." It states that "[t]*he project will not result in undue air pollution, sound, or greenhouse gas emissions,"* and it specifically references 30 V.S.A. § 248(b)(5) and 10 V.S.A. § 6086(a)(1) ("Act 250 Criterion 1").

WHO Community Noise Guidelines

The WHO has adopted various noise guidelines to address health and aesthetic issues. In the WHO's Community Noise Guidelines (WHO Guidelines), [3] they write, "The scope of WHO's effort to derive guidelines for community noise is to consolidate actual scientific knowledge on the health impacts of community noise and to provide guidance to environmental health authorities and professional trying to protect people from the harmful effects of noise in non-industrial environments." The WHO Guidelines specify a sound level of 45 dBA averaged over an eight-hour night at a residence to protect against sleep disturbance (L_{8h}). Thus, limiting the Project to an operating sound level of 45 dBA or less ensures that the Project does not impart an unduly adverse impact on air quality with respect to noise.

Tonality

Although spectral data were not provided for the main project noise sources, manufacturer documentation for similar units and/or units measured by RSG indicate that the inverters and battery temperature regulation systems usually generate pure tones. It is important to note that these are sound levels measured close to the unit and measurements made at distant receivers may not be tonal due to influence from other (non-Project) sound sources or broadband noise from equipment fans.

Project Noise Design Goal

Operational sound levels are assessed as a one-hour equivalent average (L_{1h}) at maximum operations and a 5 dB tonal penalty[4] was applied to Project generated sound. The one-hour duration is used here instead of the WHO guideline's eight-hour duration to facilitate compliance assessments. Although the WHO guidelines do not require a penalty for tonality, this adaption of the WHO Guidelines for the Project sets the noise design goal to 40 dBA L_{1h} at a residence.

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[2] https://puc.vermont.gov/sites/psbnew/files/doc_library/section-248-criteria_0.pdf

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

[4] This is consistent with recommendations found in ANSI S12.9 Part 4, *Quantities and procedures for description and measurement of environmental sound – Part 4: noise assessment and prediction of long-term community response.*

2.3 EQUIPMENT DESCRIPTION

The components of the Project that emit sound are the BESS cabinets, Inverter (PCS), Battery Management System (BMS), and transformers. Components of the adjacent PV system are also described in this section. Equipment locations are shown in Figure 1.

- ***BESS Cabinets***

The KORE P2 750 batteries are modular blocks that each require individual temperature regulation. Each BESS cabinet has two active temperature control systems: a chiller (BESS Chiller) and a ventilation unit (BESS HVAC), which are located on the door of each container. The temperature control systems primarily run during charging and discharging but may also run to keep the battery within a specified temperature range during cold and hot days.

The sound level guaranteed by the manufacturers for the chiller and the ventilation unit lead to sound power levels of 83 dBA for each, which combines to an effective sound power level of 86 dBA for each BESS cabinet. A separate BMS cabinet was modeled with 78 dBA sound power.

- ***Inverters (PCS)***

The EPC Power CAB1000 inverters convert between direct current (DC) power that is stored in the batteries and the alternating current (AC) power used on the grid. Inverters may be used for reactive power management and during frequency regulation. Inverter noise is characterized by the combination of mid to high-frequency electrical sounds and cooling fans. The inverter generates its maximum sound level during charging and discharging of the batteries. The maximum sound level specified by the manufacturer is 70 dBA at 3 meters, which translates to a sound power level of 91 dBA.

- ***Transformers***

Two pad-mounted three-phase transformers rated at 3,100 kVA will be mounted adjacent to groups of inverters. Additional transformers at the site include a smaller pad-mounted auxiliary transformer (500 kVA) and three 167 kVA pole-mounted transformers. The transformers will be energized at all times and none of them have cooling fans (ONAN only). Based on the NEMA TR-1 standard[5] and the size of each unit, Sound power levels of the transformers were calculated as 79, 70, and 65 dBA for the 3100 kVA, 500 kVA, and 167 kVA transformers, respectively. Transformer sound is tonal at 120 Hz and multiples thereof.

- ***PV Project Equipment***

Fourteen string inverters operate at the ER Paper Mill Village Solar Project. Three 167 kVA pole-mounted transformers are located toward the south of the site for utility interconnection (Figure 1). Specifications of the equipment are provided in Table 2.

[5] NEMA TR 1-2013 (R2019), *Transformers, Regulators and Reactors*. National Electrical Manufacturers Association.

Equipment Summary

A list of equipment specifications and associated sound levels are provided in Table 1 for Project noise sources. The Project, as represented herein, incorporates all equipment planned to be installed initially (four inverters and thirty-two DC Blocks) plus an additional set of equipment (one inverter and four DC Blocks) for future augmentation to be installed in approximately 10 years. Specifications of the noise sources associated with the adjacent PV project are provided in Table 2.

TABLE 1: MURPHY STREET ENERGY STORAGE NOISE SOURCE INFORMATION

EQUIPMENT	MAKE	MODEL	QTY.	SOUND POWER LEVEL (dBA)	NOISE SPEC.
BESS Controller	KORE	DCB-P1-B02	1	78	63 dBA at 5 feet
BESS DC Block	KORE	P2 750	36	n/a	n/a
BESS HVAC	nVent	G28	36	83	68 dBA at 1.5 meters
BESS Chiller	Envicool	EMW100HDNC1A	36	83	72 dBA at 1 meter
Inverter (PCS)	EPC	CAB1000	5	91	70 dBA at 3 meters
Main Transformer	Typical	3100 kVA	2	79	64 dBA at 0.3 meters
Aux. Transformer (pad)	Typical	500 kVA	1	70	57 dBA at 0.3 meters
Aux Transformer (pole)	Typical	167 kVA	3	65	57 dBA at 0.3 meters

TABLE 2: ER PAPER MILL VILLAGE SOLAR ARRAY NOISE SOURCE INFORMATION

EQUIPMENT	MAKE	MODEL	QTY.	SOUND POWER LEVEL (dBA)	NOISE SPEC.
PV Inverter	Solectra	PVI 28TL/36TL	14	71	60 dBA at 1 meter
Aux. Transformer (pole)	Typical	167 kVA	3	65	57 dBA at 0.3 meters

3.0 SOUND PROPAGATION MODELING

3.1 DESCRIPTION

Modeling for the assessment was conducted in accordance with the standard ISO 9613-2, “Acoustics – Attenuation of sound during propagation outdoors, Part 2: General Method of Calculation.” ISO 9613-2 is:

> “*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, ground factors, and terrain. ISO 9613-2 assumes downwind sound propagation between every source and every receiver. The acoustical modeling software used here was CadnaA, from Datakustik GmbH, a widely accepted acoustical propagation modeling tool.

The area within the fencline was conservatively modeled with hard ground (G = 0) within the fenceline and soft ground (G = 1) throughout the remainder of the area. Foliage attenuation was not included in the model. BESS cabinets were modeled as reflective (α = 0.1) and two orders of reflection for vertical surfaces were considered.

Sound levels at 75 discrete receivers[6] at 4-meters (13 feet) above ground level were evaluated to represent sound level impacts at nearby residences. Four meters above ground level represents a second story bedroom window. Additionally, a 5-meter by 5-meter grid of receivers was set up over a 250-acre area surrounding the proposed Project site. The grid was analyzed at 4-meters (13 feet) above ground level and also at 1.5-meter (5 foot) above ground level to represent the listening height of an average human.

3.2 NOISE SOURCES

The locations of the noise sources modeled are identified in Figure 1. Each noise source was modeled as a point source at the height of the highest surface radiating sound at maximum output conditions. Guaranteed overall sound levels (dBA) and source geometry from the manufacturer were used to calculate sound power levels for the modeled noise sources (see Table 1 and Table 2).

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[6] A receiver is a discrete point above the ground at which the model calculates a sound level.

For the model, the spectral shape of a similar unit from RSG's database was used to represent the spectral content of the sound emissions. According to these data and our experience, the sound emitted by all sound sources modeled usually produce prominent discrete tones. It is important to note that these are sound levels measured close to the unit and measurements made at distant receivers may not be tonal due to influence from other (non-Project) sound sources or sound level attenuation over distance.

3.3 NOISE MITIGATION

The nearest residence is about 200 meters south of Proposed project fenceline. To minimize sound from the Project propagating toward the closest residences to the east, an 8-foot noise barrier is prescribed along the Project's southern fenceline (see Figure 2)

The sound absorption of a typical noise blanket was applied to the interior surface of the fencline as a noise barrier (see Appendix B for an example product specification). The installed noise blanket, which spans about 34 linear meters (110 linear feet), should have sound absorption[7] and sound transmission loss[8] characteristics that are equal to or better than the example product specifications.

3.4 RESULTS

Modeling results for the discrete receivers are provided in Table 3, which is arranged by the cumulative sound level. Modeled sound levels at all surrounding residences are listed in Table 4 Appendix C. The results tables provide partial sound levels from each project (PV and BESS), as well as the cumulative sound level from the energy projects (PV + BESS). The highest modeled operational cumulative sound level (L_{1h}) is 40 dBA, with the BESS only modeled sound level of 39 dBA.

A map of the overall cumulative sound level results with sound level isolines (contours) is provided in Figure 3. Sound levels are represented as solid lines for the grid with a 4-meter receiver height and as dashed lines for ground-based receivers (1.5-meter). Sound levels are about 1 dB higher at 4-meters above ground level compared to 1.5-meters due to less impact from ground absorption and barrier geometry. All results include a noise blanket on the southern fenceline, as described in Section 3.3 and shown in Figure 2 and Figure 3.

[7] Overall Noise Reduction Coefficient (NRC) $\geq$ 0.65
[8] Overall Sound Transmission Class (STC) $\geq$ 29

TABLE 3: SOUND LEVEL MODELING RESULTS (L_{1h}) (4-METER RECEIVER HEIGHT)

RECEIVER ID	E911 ADDRESS	MODELED SOUND PRESSURE LEVEL (dBA)		
		PV Only	BESS Only	Total (Both)
R72	558 MURPHY RD	30	39	40
R73	480 MURPHY RD	27	37	37
R54	111 EDITH RD	15	36	36
R58	243 MURPHY RD	19	35	35
R64	268 MURPHY RD	20	34	34
R57	187 MURPHY RD	18	34	34
R70	380 MURPHY RD	23	34	34
R67	334 MURPHY RD	20	34	34
R60	228 MURPHY RD	19	34	34
R59	214 MURPHY RD	19	33	34
R63	256 MURPHY RD	19	33	33
R62	238 MURPHY RD	18	33	33
R65	272 MURPHY RD	19	32	32
R61	248 MURPHY RD	14	30	30
R55	42 EDITH RD	13	29	29
R53	23 EDITH RD	12	27	27

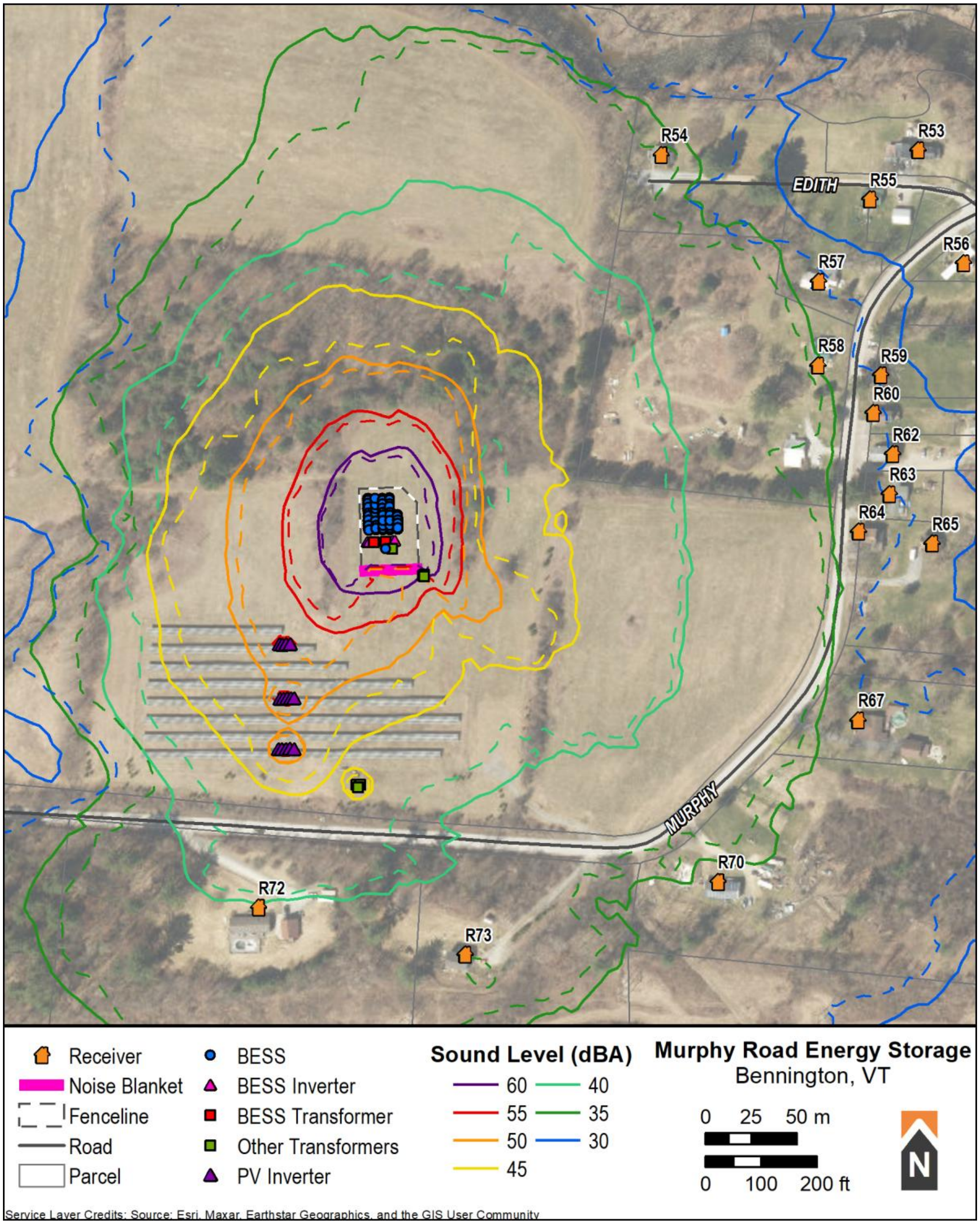


FIGURE 3: SOUND LEVEL CONTOUR MAP WITH ALL EQUIPMENT OPERATING (L_{1h}), 4 METERS ABOVEGROUND LEVEL (SOLID) AND 1.5 METERS ABOVE GROUND LEVEL (DASHED).

4.0 CONCLUSION

RSG performed a sound modeling study of Encore Renewable Energy's proposed Murphy Road Energy Storage Project in Bennington, VT. The full build out of the site includes 36 battery cabinets with associated temperature regulation devices, five inverters, two main transformers, and other auxiliary electrical equipment.

For each source type (i.e., inverter, HVAC, transformer), spectral shapes for similar equipment from RSG's source library were applied to the overall sound power levels provided by the manufacturers. Sound emission data for the transformers was derived from manufacturer-specified overall sound pressure levels, dimensions, and the spectrum of RSG measurement of similar equipment. Only 32 DC blocks and four inverters will be installed initially, an additional four DC blocks and one inverter were included in the model and analysis herein to account for future augmentation that will be installed in approximately ten years.

All components of the Project are expected to generate tonal sound. As a result, the 45 dBA L_{8h} WHO nighttime noise guideline is decreased to 40 dBA for sound that has prominent discrete tones. Further conservative measures in the model included assessing the maximum one-hour equivalent average sound level (as opposed to the WHO guideline of an eight-hour average) and considering the cumulative sound from proposed Project and the existing adjacent PV project.

The model demonstrated that with a noise blanket spanning the southern fenceline of the Project, cumulative modeled sound levels will be 40 dBA L_{1h} or less at all area residences when all equipment is operating at maximum capacity. Given this, we conclude that the sound generated by the Project will not result in an undue adverse impact on air quality.

APPENDIX A. ACOUSTICS PRIMER

Expressing Sound Levels in Decibels

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”).[9] 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.

[9] 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.

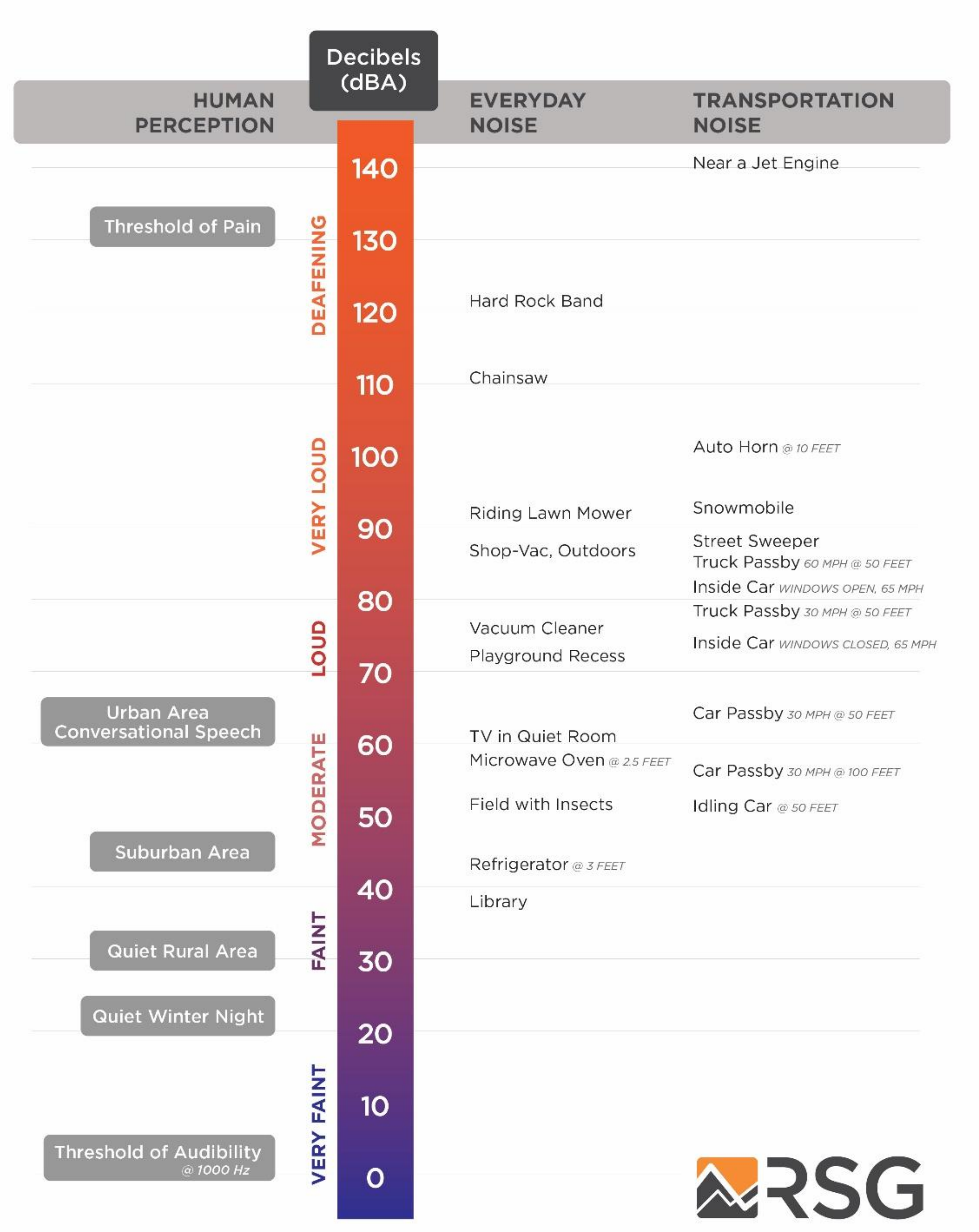


FIGURE 4: A SCALE OF SOUND PRESSURE LEVELS FOR TYPICAL SOUND SOURCES

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.

The Spectrogram

One method of viewing the spectral sound level is to look at a spectrogram of the sound. As shown in Figure 5, the spectrogram shows the level, frequency spectra, and time in one graph. That is, the horizontal axis represents time, the vertical axis is frequency, and the intensity of the color is proportional to the intensity of the sound.

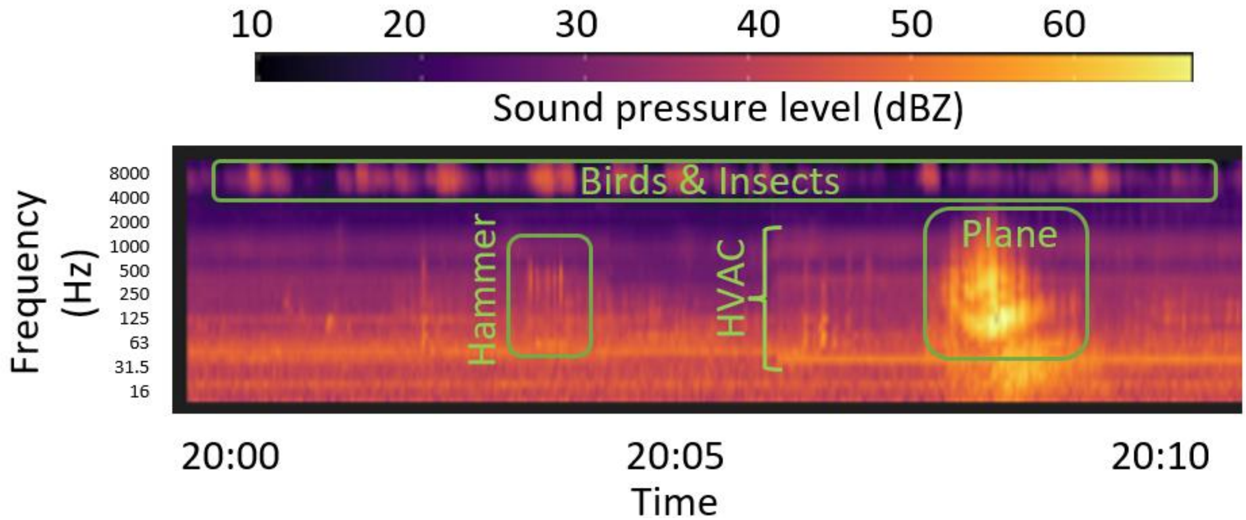


FIGURE 5: AN EXAMPLE OF A SOUND SPECTROGRAM WITH ANNOTATIONS

The spectrogram is useful for identifying the sources of sound. For example, birds show short bursts of high frequency sound, while airplanes are mostly low frequency sound and show slow rise and fall times. In the example above, we can see several of these events.

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 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.

A relatively new standard weighting is the ANS weight. ANS stands for A-weighted, natural sounds. The ANS weight is the same as the A-weighting, but it filters out all sound above the 1,000 Hz octave band. Thus, it removes the impact of many high frequency biogenic sounds such as insects, birds, and amphibians. The ANS weighting is often used to eliminate the effects of seasonality of sound, as there are fewer insects and birds during the winter than the summer.

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.[10] 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 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.

[10] 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.

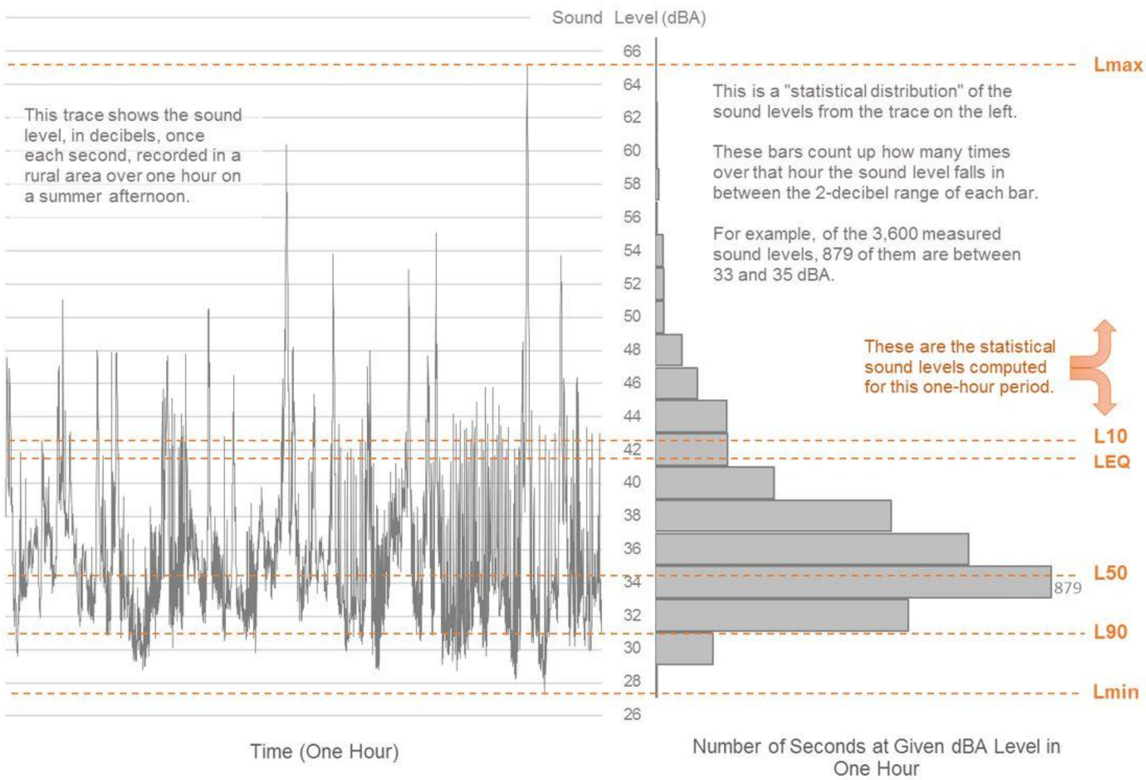


FIGURE 6: EXAMPLE OF DESCRIPTIVE TERMS OF SOUND MEASUREMENT OVER TIME

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.

Sound Levels from Multiple Sources: Adding Decibels

Because of the way that sound levels in decibels are calculated, the sounds from more than one source do not add arithmetically. Instead, two sound sources that are the same decibel level increase the total sound level by 3 dB. For example, suppose the sound from an industrial blower registers 80 dB at a distance of 2 meters (6.6 feet). If a second industrial blower is operated next to the first one, the sound level from both machines will be 83 dB, not 160 dB. Adding two more blowers (a total of four) raises the sound level another 3 dB to 86 dB. Finally, adding four more blowers (a total of eight) raises the sound level to 89 dB. It would take eight total blowers, running together, for a person to judge the sound as having “doubled in loudness”.

Recall from the explanation of sound levels that a difference of 10 decibels is a factor of 20 in sound pressure and a factor of 10 in sound power. (The difference between sound pressure and sound power is described in the next Section.) If two sources of sound differ individually by 10 decibels, the louder of the two generates *ten times* more sound. This means that the loudest source(s) in any situation always dominates the total sound level. Looking again at the industrial blower running at 80 decibels, if a small ventilator fan whose level alone is 70 decibels were operated next to the industrial blower, the total sound level increases by only 0.4 decibels, to 80.4 decibels. The small fan is only 10% as loud as the industrial blower, so the larger blower completely dominates the total sound level.

The Difference Between Sound Pressure and Sound Power

The human ear and microphones respond to variations in sound *pressure*. However, in characterizing the sound emitted by a specific source, it is proper to refer to sound *power*. While sound pressure induced by a source can vary with distance and conditions, the power is the same for the source under all conditions, regardless of the surroundings or the distance to the nearest listener. In this way, sound power levels are used to characterize noise sources because they act like a “fingerprint” of the source. An analogy can be made to light bulbs. The bulb emits a constant amount of light under all conditions, but its perceived brightness diminishes as one moves away from it.

Both sound power and sound pressure levels are described in terms of decibels, but they are not the same thing. Decibels of sound pressure are related to 20 micropascals, as explained at the beginning of this primer. Sound power is a measure of the acoustic power emitted or radiated by a source; its decibels are relative to one picowatt.

Sound Propagation Outdoors

As a listener moves away from a source of sound, the sound level decreases due to “geometrical divergence”: the sound waves spread outward like ripples in a pond and lose energy. For a sound source that is compact in size, the received sound level diminishes or attenuates by 6 dB for every doubling of distance: a sound whose level is measured as 70 dBA at 100 feet from a source will have a measured level of 64 dBA at 200 feet from the source and 58 dBA at 400 feet. Other factors, such as walls, berms, buildings, terrain, atmospheric absorption, and intervening vegetation will also further reduce the sound level reaching the listener.

The type of ground over which sound is propagating can have a strong influence on sound levels. Harder ground, pavement, and open water are very reflective, while soft ground, snow cover, or grass is more absorptive. In general, sounds of higher frequency will attenuate more over a given distance than sounds of lower frequency: the “boom” of thunder can be heard much further away than the initial “crack”.

Atmospheric and meteorological conditions can enhance or attenuate sound from a source in the direction of the listener. Wind blowing from the source toward the listener tends to enhance sound levels; wind blowing away from the listener toward the source tends to attenuate sound levels. Normal temperature profiles (typical of a sunny day, where the air is warmer near the ground and gets colder with increasing altitude) tend to attenuate sound levels; inverted profiles (typical of nighttime and some overcast conditions) tend to enhance sound levels.

APPENDIX B. EXAMPLE NOISE BLANKET SPECIFICATION

Acoustical® SOLUTIONS
For every environment of your life

2420 Grenoble Road
Richmond, VA 23294
Toll Free: 800-782-5742

PRIVACYSHIELD® OUTDOOR ABSORPTIVE SOUNDPROOFING BLANKET DATA SHEET

TECHNICAL CHARACTERISTICS

SIZE: 54" x 96", Up to 54" x 20'

THICKNESS: 1", 2" (actual size may vary after quilt); 4" (special order)

CONTRUCTION: UV resistant heavy-duty vinyl coated polyester faced quilted fiberglass backed with a one pound per square foot reinforced mass loaded vinyl sound barrier

FACING COLOR: Grey, Tan (standard)
Black, Off-White (special order)

BARRIER COLOR: Grey, Tan (standard)

WEIGHT (P.S.F.): 1.2 (1"), 1.45 (2"), 2.9 (4")

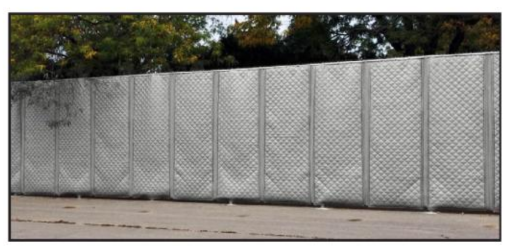
TEMP RANGE: -20 to 180 degrees F

DESCRIPTION

The PrivacyShield® Outdoor Absorptive Soundproofing Blanket (formerly ABBC-13EXT) is a barrier backed panel used to block and absorb sound for exterior applications.

The blanket is an exterior grade barrier backed composite (BBC), consisting of UV and tear resistant vinyl coated polyester facing. The facing is quilted on environmentally sustainable 1-2 inch fiberglass batting with Gore® Tenara® thread. It also has a reinforced 1 lb./sq. ft. mass loaded vinyl barrier bonded to one side.

These blankets are a combination of sound blocking and sound absorbing material. The sound attenuation blankets are constructed with grommets across the top and Velcro® along the vertical edges of the blankets for easy installation and layering. The exterior grade blanket is great for use in outdoor environments where extended lifespan and durability are required.



SOUND ABSORPTION (ASTM C 423)

Thickness	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	NRC
1"	0.18	0.68	0.74	0.72	0.42	0.29	0.65
2"	0.45	0.96	0.87	0.66	0.47	0.28	0.75
4"	0.67	1.05	0.97	0.84	0.86	0.52	0.95

SOUND TRANSMISSION LOSS (ASTM E90 & E413)

Thickness	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	STC
1"	15	17	28	40	45	52	29
2"	14	20	32	41	42	41	33
4"	16	21	30	41	52	56	34

as-privacyshield-outdoor-absorptive-soundproofing-blanket-data-sheet *2022-04-13*

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APPENDIX C. DISCRETE RECEIVER RESULTS

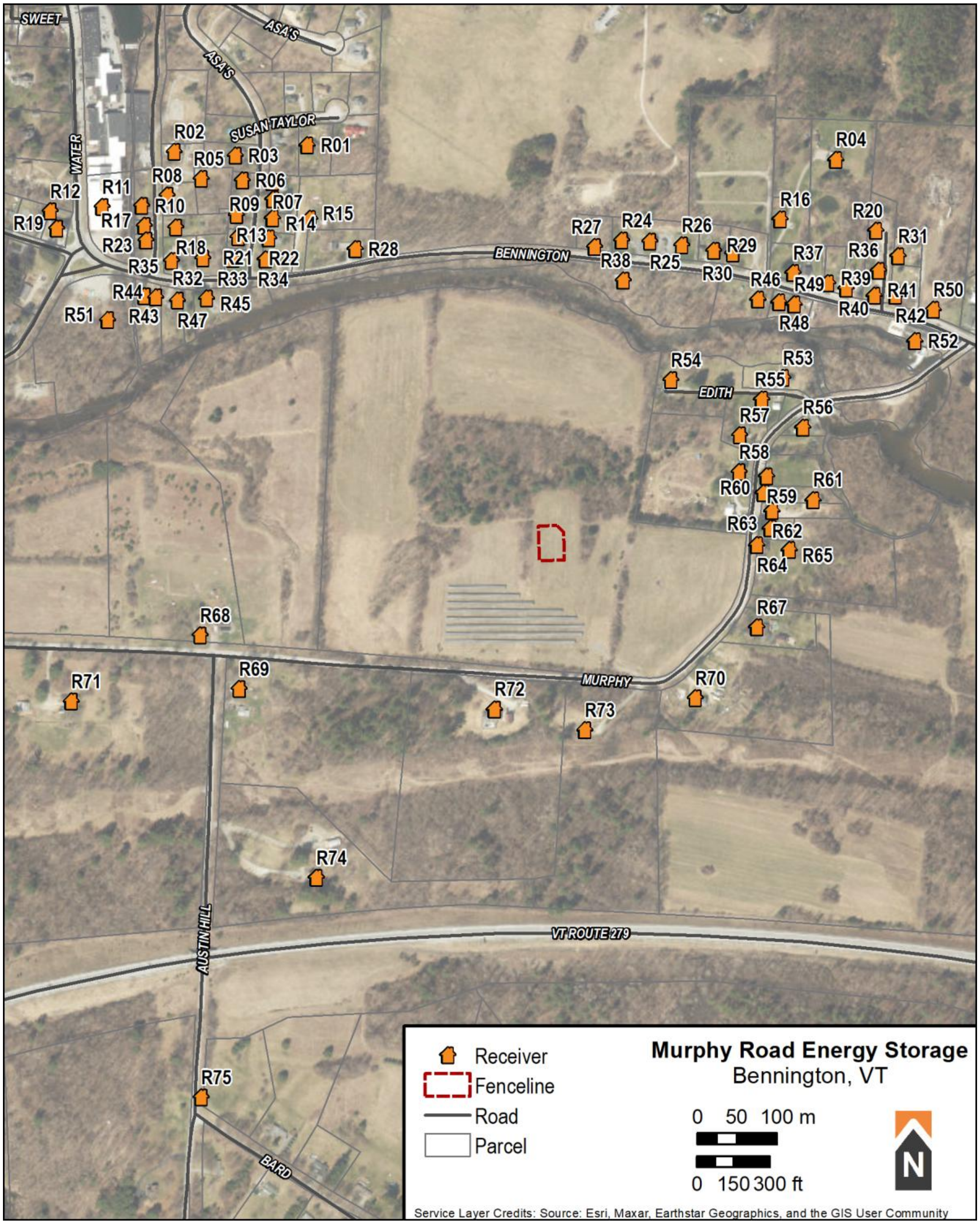

FIGURE 7: RECEIVER ID KEY

TABLE 4: DISCRETE RECEIVER SOUND LEVEL RESULTS (dBA)

RECEIVER ID	E911 ADDRESS	MODELED SOUND PRESSURE LEVEL (dBA)			COORDINATES (NAD84 UTM 18N)		
		PV ONLY	BESS ONLY	TOTAL (BOTH)	X (M)	Y (M)	Z (M)
R01	37 SUSAN TAYLOR LN	11	24	24	439329	46392	190
R02	11 SCAREY LN	7	18	19	439163	46384	178
R03	17 ROYAL ST	9	23	23	439239	46379	188
R04	1641 N BENNINGTON RD	8	24	24	439991	46374	179
R05	9 SCAREY LN	8	22	22	439196	46350	181
R06	9 ROYAL ST	9	23	24	439248	46348	185
R07	10 ROYAL ST	10	24	24	439286	46346	185
R08	7 SCAREY LN	8	20	21	439154	46329	174
R09	8 ROYAL ST	10	24	24	439286	46324	183
R10	22 SCAREY LN	7	20	20	439122	46316	171
R11	1030 WATER ST	7	19	19	439072	46314	171
R12	3 HILLSIDE ST	6	18	19	439007	46309	175
R13	5 ROYAL ST	9	23	23	439241	46305	180
R14	6 ROYAL ST	10	24	25	439286	46300	181
R15	2009 N BENNINGTON RD	10	25	25	439333	46300	178
R16	1639 N BENNINGTON RD	10	26	26	439921	46299	175
R17	20 SCAREY LN	8	20	20	439125	46291	171
R18	5 SCAREY LN	8	21	21	439165	46289	174
R19	1043 WATER ST	7	19	19	439016	46288	175
R20	60 WILKIE WAY	10	24	25	440041	46285	172
R21	3 ROYAL ST	9	23	23	439242	46276	177
R22	4 ROYAL ST	10	24	24	439281	46275	178
R23	18 SCAREY LN	8	20	21	439127	46273	172
R24	1749 N BENNINGTON RD	11	30	30	439723	46273	174
R25	1729 N BENNINGTON RD	12	30	30	439758	46271	174
R26	1703 N BENNINGTON RD	12	30	30	439798	46267	174
R27	1789 N BENNINGTON RD	12	31	31	439689	46264	174
R28	1955 N BENNINGTON RD	11	26	27	439390	46261	172
R29	1681 N BENNINGTON RD	12	29	29	439838	46260	173
R30	1653 N BENNINGTON RD	11	29	29	439861	46256	173
R31	1517 N BENNINGTON RD	11	24	24	440069	46253	172
R32	2079 N BENNINGTON RD	9	22	22	439199	46250	173
R33	1 ROYAL ST	10	23	23	439236	46250	174
R34	2 ROYAL ST	10	24	24	439277	46249	173
R35	1 SCAREY LN	9	21	21	439159	46247	174
R36	16 WILKIE WAY	11	25	25	440044	46235	172
R37	1617 N BENNINGTON RD	10	27	27	439938	46232	172
R38	1752 N BENNINGTON RD	12	32	32	439725	46223	171

RECEIVER ID	E911 ADDRESS	MODELED SOUND PRESSURE LEVEL (dBA)			COORDINATES (NAD84 UTM 18N)		
		PV ONLY	BESS ONLY	TOTAL (BOTH)	X (M)	Y (M)	Z (M)
R39	1589 N BENNINGTON RD	10	26	27	439981	46219	172
R40	1575 N BENNINGTON RD	10	26	26	440004	46212	172
R41	8 WILKIE WAY	10	25	25	440039	46203	172
R42	1535 N BENNINGTON RD	10	25	25	440066	46203	172
R43	2118 N BENNINGTON RD	9	21	21	439125	46203	171
R44	2112 N BENNINGTON RD	9	21	22	439140	46201	174
R45	2074 N BENNINGTON RD	10	22	23	439204	46200	171
R46	1644 N BENNINGTON RD	11	29	29	439893	46199	171
R47	2092 N BENNINGTON RD	10	22	22	439167	46198	173
R48	1626 N BENNINGTON RD	11	29	29	439920	46195	171
R49	1614 N BENNINGTON RD	11	28	28	439939	46193	171
R50	1505 N BENNINGTON RD	8	24	24	440113	46186	172
R51	34 RIVER RD	9	20	20	439079	46173	170
R52	1514 N BENNINGTON RD	9	22	22	440090	46146	170
R53	23 EDITH RD	12	27	27	439925	46100	173
R54	111 EDITH RD	15	36	36	439784	46098	172
R55	42 EDITH RD	13	29	29	439898	46073	174
R56	158 MURPHY RD	12	27	27	439950	46039	175
R57	187 MURPHY RD	18	34	34	439870	46028	178
R58	243 MURPHY RD	19	35	35	439870	45983	182
R59	214 MURPHY RD	19	33	34	439904	45977	178
R60	228 MURPHY RD	19	34	34	439900	45956	179
R61	248 MURPHY RD	14	30	30	439963	45948	176
R62	238 MURPHY RD	18	33	33	439911	45934	178
R63	256 MURPHY RD	19	33	33	439909	45912	179
R64	268 MURPHY RD	20	34	34	439892	45891	182
R65	272 MURPHY RD	19	32	32	439933	45885	179
R67	334 MURPHY RD	20	34	34	439892	45788	182
R68	765 MURPHY RD	14	24	25	439195	45778	184
R69	791 AUSTIN HILL RD	15	25	26	439244	45711	186
R70	380 MURPHY RD	23	34	34	439815	45700	186
R71	882 MURPHY RD	10	20	21	439034	45695	182
R72	558 MURPHY RD	30	39	40	439564	45686	199
R73	480 MURPHY RD	27	37	37	439677	45660	202
R74	609 AUSTIN HILL RD	13	25	26	439341	45475	209
R75	475 AUSTIN HILL RD	6	16	17	439197	45199	230

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