Exh. Petitioner EJM-7

FLORENCE SUBSTATION NOISE ASSESSMENT

August 2021

VELCO

RSG
the science of insight

Report Title:

Florence Substation Noise Assessment

Report Prepared by:

RSG

Report Prepared for:

VELCO

For additional information regarding this report, or for questions about permissions or use of findings contained therein, please contact:

RSG (Headquarters)
55 Railroad Row
White River Junction, VT 05001
(802) 295-4999
www.rsginc.com

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

VELCO is planning upgrades to the Florence Substation located at 8040 Whipple Hollow Road in Pittsford, Vermont. In preparation for the upgrades, VELCO asked RSG to conduct a noise assessment of the changes. This assessment includes:

- A description of the substation, both in its existing and proposed form,
- Short- and long-term sound level monitoring procedures and results,
- Sound propagation modeling procedures and results, and
- Conclusions.

A primer describing terms that are used in this report is included in Appendix A.

2.0 SITE DESCRIPTION

The existing Florence substation is located 900 feet south of Whipple Hollow Road in Pittsford, Vermont. A map showing the substation and the area surrounding it is shown in Figure 1. An OMYA Inc. plant is located 300 meters (980 feet) to the east, which also has a railroad running through it. Florence Crushed Stone is located 1,166 meters (3,825 feet) to the northeast. A powerline runs from north to south along the west side of the substation. The area south and west of the substation are largely forested, with some residences and agricultural fields.

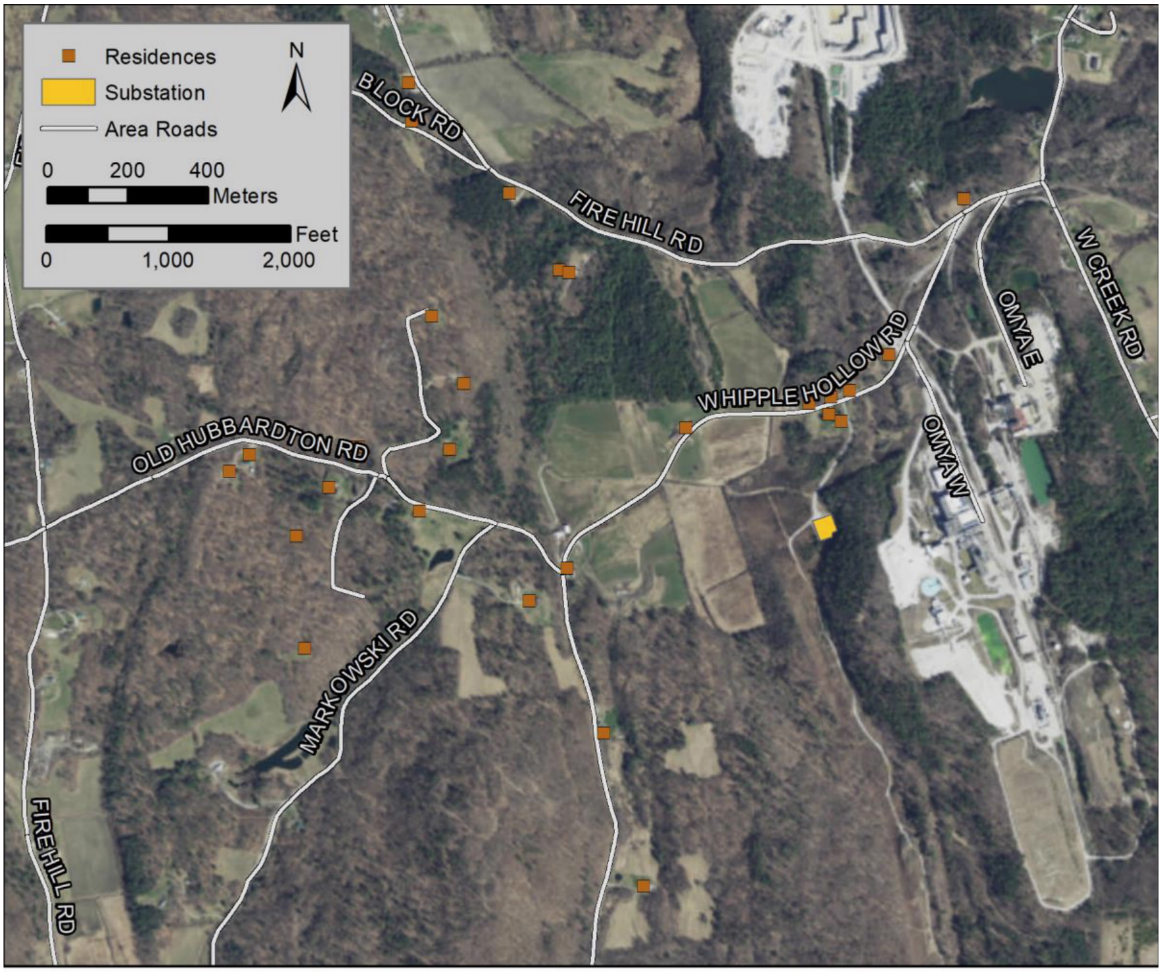

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FIGURE 1: MAP OF AREA SURROUNDING FLORENCE SUBSTATION

There is currently one 115/46 kV transformer at the substation and one 46 kV capacitor bank, although it is our understanding that the capacitor bank is only in-service infrequently. A map of the existing substation layout is provided in Figure 2. The proposed update to the substation will include:

- Shifting the footprint of the substation to the north,
- Replacing the transformer with a new 115/46 kV transformer,
- Installing a tuned capacitor bank that includes a capacitors, reactor, and resistors, and
- Constructing a new control building.

It is our understanding that the new tuned capacitor bank will be in-service infrequently (i.e. during a transformer outage). Breakers will also be installed, though these are not expected to be consistent sound sources. A map of the proposed substation layout is provided in Figure 3.

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FIGURE 2: MAP OF EXISTING SUBSTATION LAYOUT

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FIGURE 3: MAP OF PROPOSED SUBSTATION LAYOUT

3.0 SOUND LEVEL MONITORING

Short term and long-term monitoring were conducted at the substation. The short-term monitoring consisted of sound power measurement of the transformer under ONAN and ONAF conditions, as well as perimeter fence-line measurements under ONAN and ONAF conditions. The existing capacitor bank was not in-service during the short-term site visit, so no sound level measurements of the capacitor bank are included in this assessment. The long-term monitoring included one week of monitoring at a spot on the fence-line and at a nearby residence to determine substation sound emissions within the context of other area sources.

3.1 SHORT-TERM MONITORING

Short-term sound level measurements were collected for the transformer and at the fence-line to quantify sound emissions of existing equipment.

Measurements were collected between 2:30 and 3:45 PM on April 25, 2019, with a temperature of 7.8°C (46°F) and winds ranging from 0 to 2.5 m/s (5.6 mph). Measurements were collected with Cesva SC310 sound level meters which are ANSI/IEC Class 1 instruments. The meters were set to collect 1/3 octave band sound levels once per second and were calibrated before and after the measurements. The microphones were covered with 7-inch foam windscreens.

Fence-line Measurements

Fence-line measurements are used to establish a baseline sound level of the facility for future comparison. Since the fence is close to the sound sources, the influence of other background sounds is generally less than measurements made at more distant locations.

Measurements were made at intervals of approximately 50 to 60 feet (15 to 18 meters) with transformer fans on (Oil Natural Air Forced, ONAF) and off (Oil Natural Air Natural, ONAN). The sound level meters were mounted on tripods at a height of approximately 1.5-meters (5-feet). Measurement duration was approximately 2 minutes per location.

Fence-line measurement results are shown in Figure 4. Sound levels exceeded 90 percent of the time (L90) are shown to help filter out transient sounds. With transformer fans off (ONAN), sound levels ranged between 45 dBA and 57 dBA. The highest level occurred on the western fence-line. Under the ONAF condition (transformer fans on), sound levels ranged from 50 to 61 dBA. The highest level occurred at two locations on the western side and at one location on the north side of the fence-line.

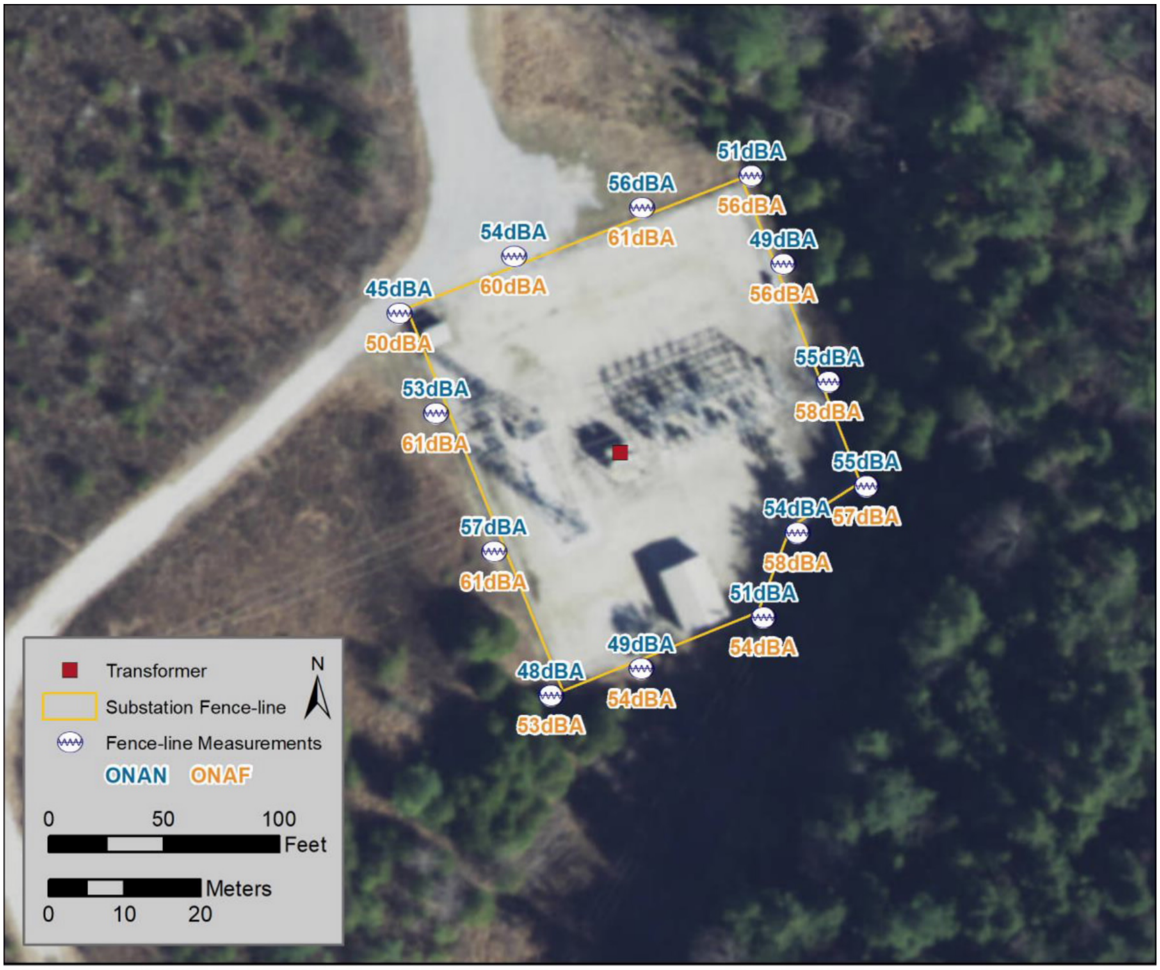

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FIGURE 4: FENCE-LINE SOUND LEVEL MEASUREMENT RESULTS

Figures 5 and 6 show the L90 spectrum and tonal prominence from the most tonal fence-line location. At the fence-line, sound levels exhibit tonal prominence in the 125, 250, and 630 Hz 1/3 octave bands.

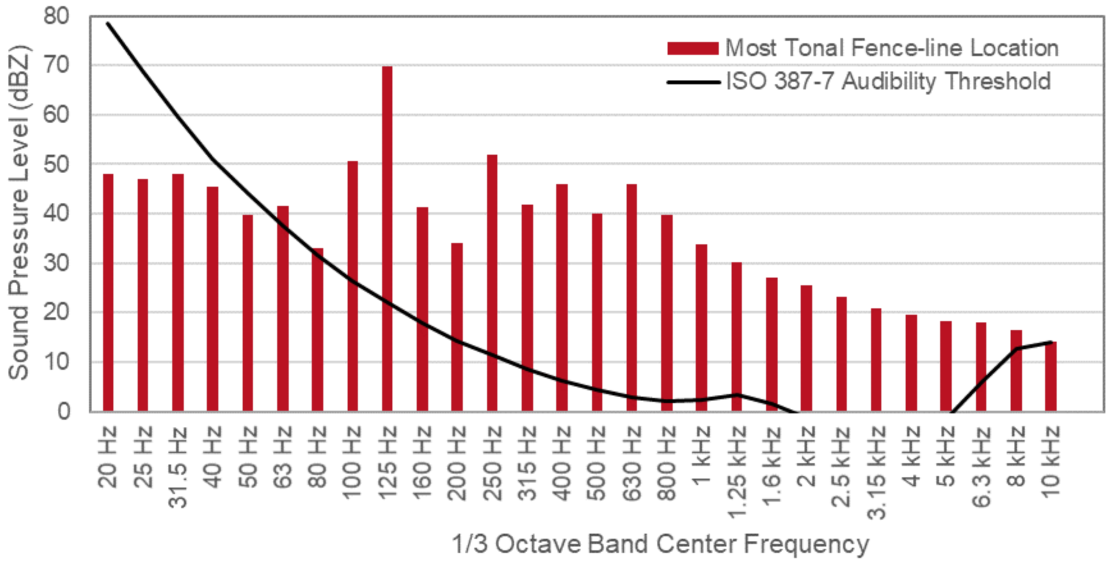

FIGURE 5: SOUND LEVEL AT THE MOST TONAL ONAN FENCE-LINE MEASUREMENT LOCATION

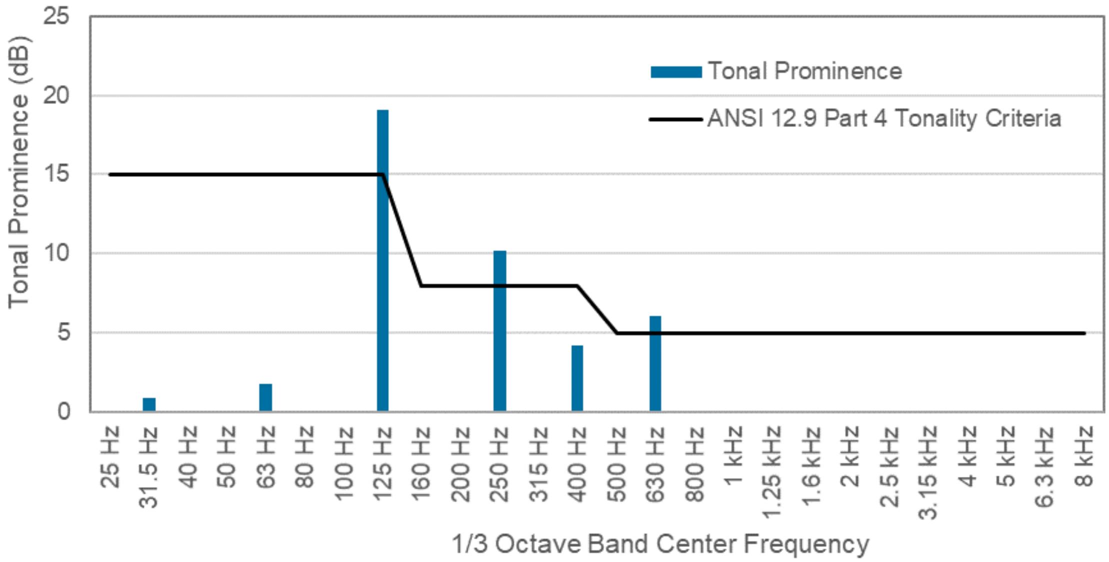

FIGURE 6: TONAL PROMINENCE AT THE MOST TONAL ONAN FENCE-LINE LOCATION

Transformer Measurements

The “sound power level” is the intrinsic sound emissions of a source. A sound pressure level measurement was conducted for the transformer and then converted into a sound power level.

Measurements were made of the transformer in accordance with IEEE C57.12.90-2010 Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

During measurements, microphones were mounted at 1/3 and 2/3 of the transformer height, or at 1.5 and 3 meters (5 and 10 feet). With transformer fans off, measurements were made every 0.9 meters (3 feet) at a distance of 0.3 meters (1 foot) from the transformer. With the fans on, the measurements were repeated in the same manner, except near the transformer cooling fans, where measurements were made at a 2-meter distance (6.6 feet) from the fans. Measurement duration at each position around the transformer was approximately 25 seconds.

Overall transformer measurement results are displayed in Table 1, and the spectra for the transformer are provided in Figure 7. The measured sound pressure levels for the transformer were 76 dBA ONAN and 77 dBA ONAF, corresponding to sound power levels of 96 dBA and 98 dBA respectively. The transformer has tonal prominence in the 125 Hz and 250 Hz 1/3 octave bands under the ONAN condition, and in the 125 Hz 1/3 octave band under the ONAF condition.

TABLE 1: TRANSFORMER SOUND PRESSURE AND SOUND POWER LEVEL RESULTS

Transformer Mode	Measured Sound Pressure Level (dBA)	Sound Power Level (dBA)
ONAN	76	96
ONAF	77	98

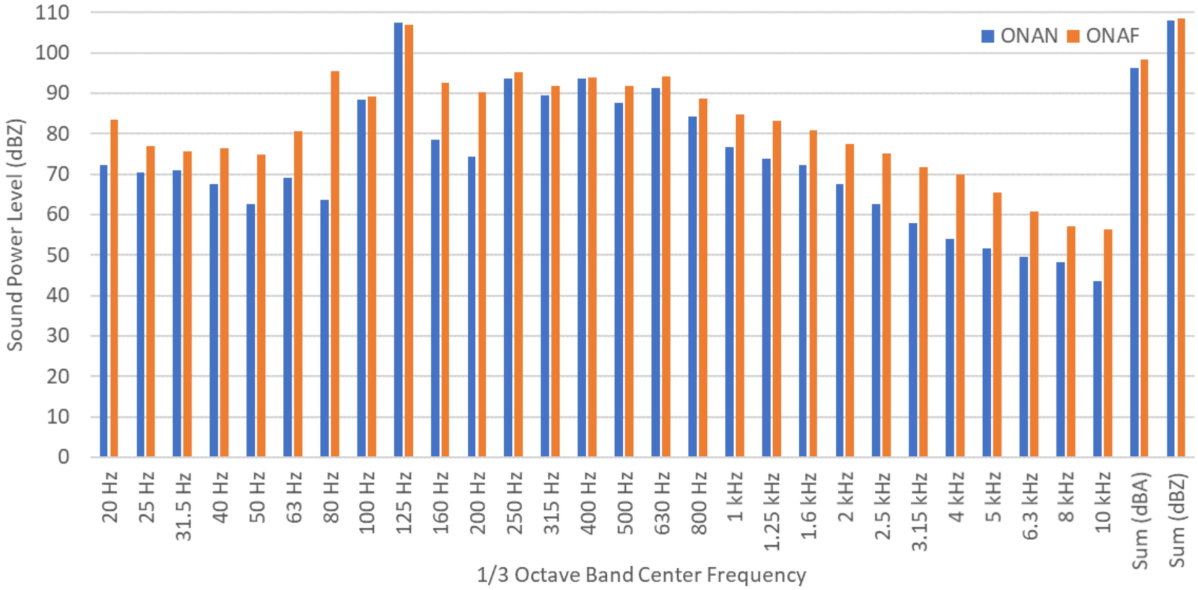

FIGURE 7: TRANSFORMER SOUND POWER SPECTRA

3.2 LONG-TERM MONITORING

Procedures

Long-term measurements were taken at two locations near the substation. At the substation, a monitor was placed on the northeast portion of the fence-line (“Substation Monitor”). Additionally, a long-term monitor was placed at the closest residence to the substation, 8040 Whipple Hollow Road (“Residence Monitor”). The locations are shown in Figure 8, and photographs of the monitors are provided in Figure 9.

The Substation Monitor was located approximately 35 meters (115 feet) northeast of the transformer. It was approximately 282 meters (925 feet) west of the OMYA building and 265 meters (869 feet) south of Whipple Hollow Road. The Residence Monitor was in the yard of a house on Whipple Hollow Road. It was approximately 255 meters (836 feet) north-northeast of the transformer, and 60 meters (197 feet) south of Whipple Hollow Road. The monitor was 40 meters (131 feet) south of the primary residence building, and approximately 13 meters (43 feet) away from an outbuilding.

Long term levels were collected using ANSI/IEC Class 1 Cesva SC310 sound level meters. They recorded 1/3 octave band sound levels once per second. Audio recorders were fed a signal from the sound level meter to aid with sound source identification. Microphones were covered with 7-inch hydrophobic windscreens and mounted on wooden stakes at a height of 1.4 meters (4.6 feet). Onset HOBO anemometers were situated adjacent to the sound level meters to collect local wind speed. Additional meteorological data was obtained from Rutland-Southern Vermont Regional Airport.

Data was summarized into 10-minute periods for daytime, nighttime, and overall categories. Data was excluded if there was measurable precipitation or wind speeds exceeding 5 m/s (11 mph). Additionally, sound levels that were due to animal or human interaction with equipment, or are seasonally present (lawn mowing, snow removal, etc.), or were anomalous (atypical for the site) were removed from the dataset.

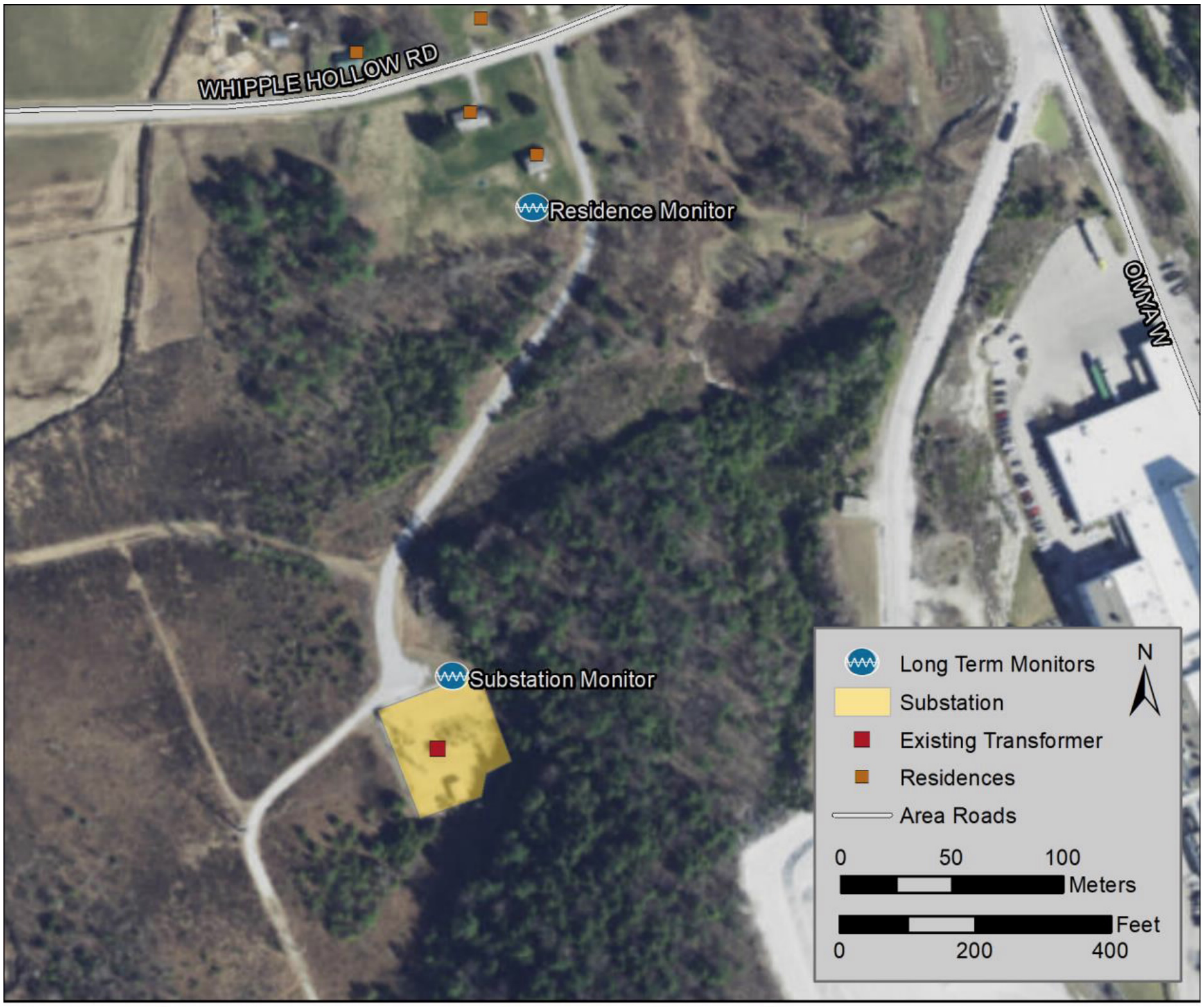

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FIGURE 8: MAP OF LONG-TERM MONITOR LOCATIONS

FIGURE 9: PHOTOGRAPHS OF THE SUBSTATION MONITOR (LEFT) & RESIDENCE MONITOR (RIGHT)

Results

Long-term monitoring took place from April 25, 2019 to May 2, 2019. Temperatures ranged from -2 to 16.6° C during this time (28 to 62 °F). Precipitation occurred on April 26, 27, and May 2. Wind speeds ranged from calm to 8.5 m/s (19 mph).

Substation Monitor

Overall and statistical sound levels for the Substation Monitor are shown in Table 2, and time-history results are provided in Figure 10. The substation was the primary noise source at this location. Additional noise sources included birds, spring peepers, and occasional distant train horns. While geographically close, the nearby OMYA plant is situated behind a hill relative to the substation, and thus was not a significant sound source. The daytime, nighttime, and overall L_{eq} were all the same at 54 dBA, demonstrating the substation was the dominant source as the overall levels did not exhibit a diurnal pattern, which can be readily observed in the time-history graph. Similarly, the daytime, nighttime, and overall L_{90} were each 53 dBA.

TABLE 2: SUBSTATION MONITOR - OVERALL AND STATISTICAL SOUND LEVEL RESULTS

Period	Sound Pressure Level (dBA)			
	L_{Aeq}	L_{A90}	L_{A50}	L_{A10}
Day	54	53	54	55
Night	54	53	54	55
Total	54	53	54	55

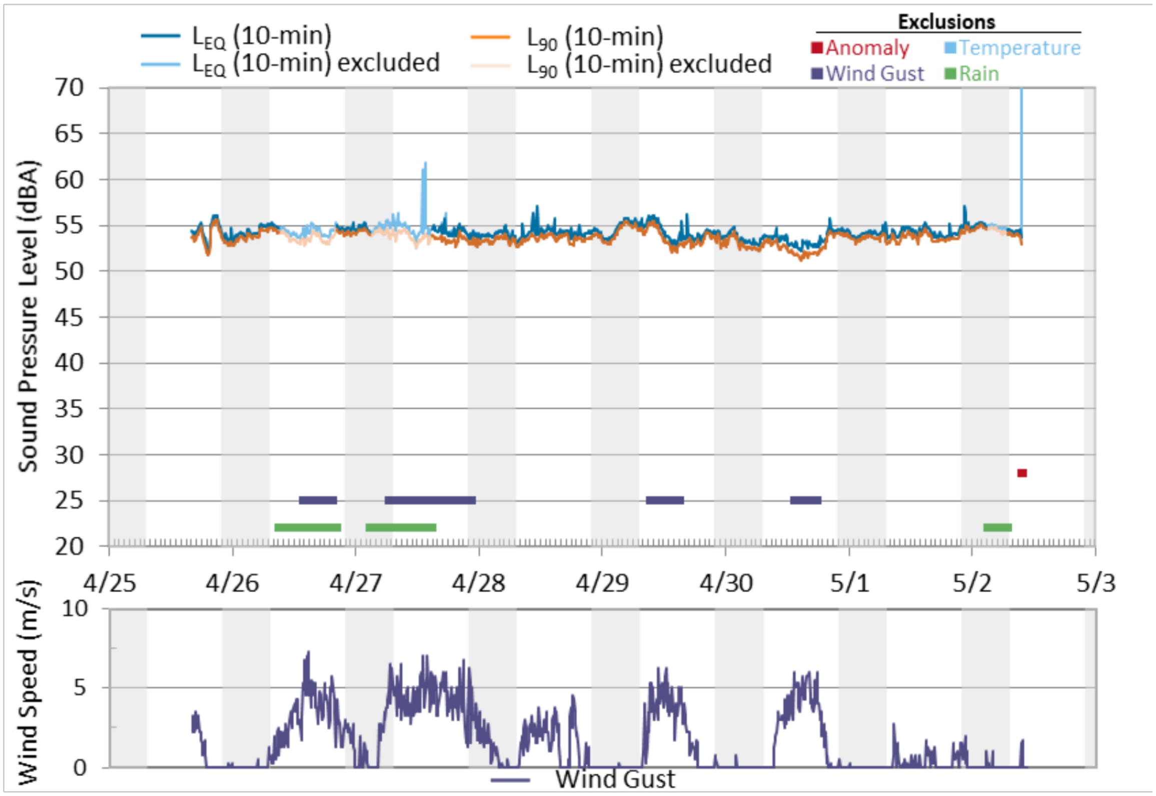

FIGURE 10: SUBSTATION MONITOR TIME-HISTORY RESULTS

Residence Monitor

Overall and statistical sound levels for the Residence Monitor on Whipple Hollow Road are shown in Table 3, and time-history results are provided in Figure 11. The primary sound sources at this location were traffic on Whipple Hollow Road, trains, birds, spring peepers, as well truck traffic entering and exiting the OMYA facility. The daytime L_{eq} at this location was 52 dBA and the nighttime L_{eq} was 47 dBA. They daytime L90 was 38 dBA and the nighttime L90 was 39 dBA. Relative to the substation monitor, this location exhibited a more diurnal pattern as a result of many of the sources mentioned above being more abundant during the day.

TABLE 3: RESIDENCE MONITOR - OVERALL AND STATISTICAL SOUND LEVEL RESULTS

Period	Sound Pressure Level (dBA)			
	L_{Aeq}	L_{A90}	L_{A50}	L_{A10}
Day	52	38	44	50
Night	47	39	44	48
Overall	51	39	44	49

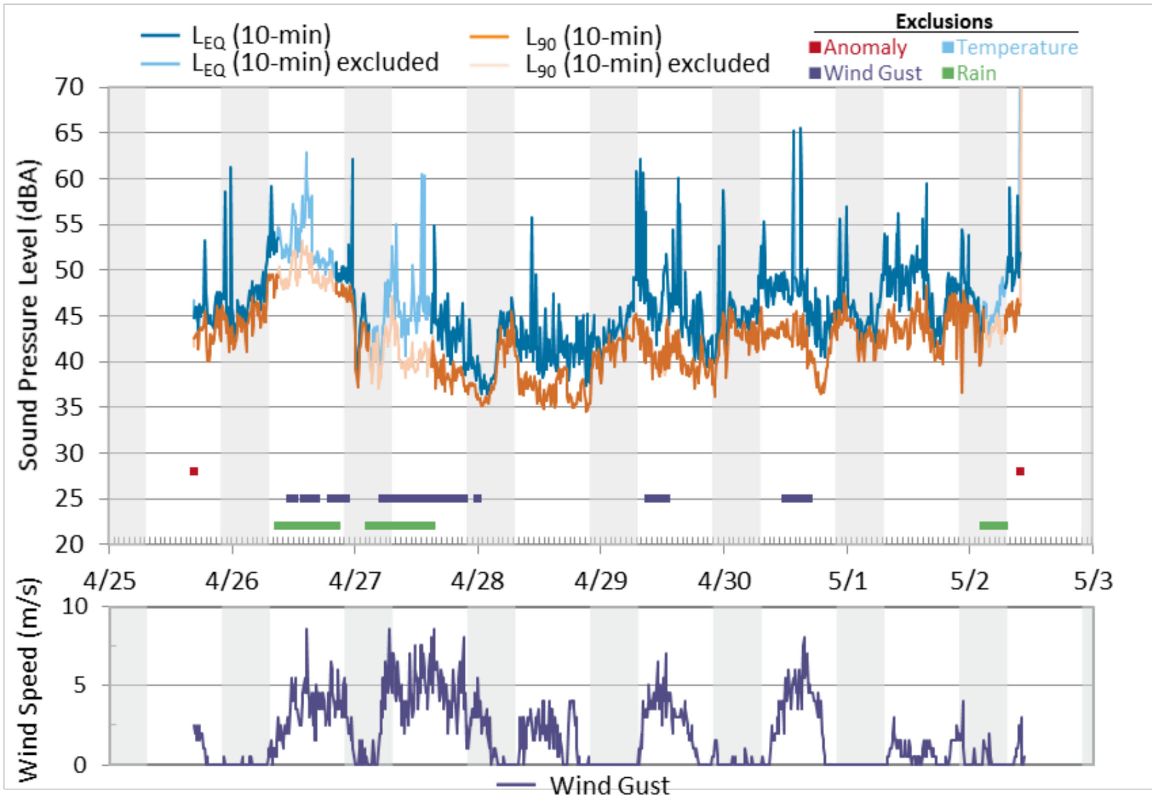

FIGURE 11: RESIDENCE MONITOR - TIME HISTORY RESULTS

4.0 SOUND PROPAGATION MODELING

4.1 METHODOLOGY

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.” 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, ground factors, and terrain. The acoustical modeling software used here was CadnaA, from Datakustik GmbH. CadnaA is a widely accepted acoustical propagation modeling tool, used by many noise control professionals in the United States and internationally. It has also been accepted for many years as a reliable noise modeling methodology by the Vermont Public Utility Commission, Act 250 District Commissions, the Environmental Board, the Vermont Superior Court Environmental Division, and the Vermont Supreme Court.

ISO 9613-2 assumes downwind sound propagation between every source and every receiver, consequently, all wind directions, including prevailing wind directions, are taken into account. The effect of this set of assumptions is to make the modelling results conservative. For this study, we used spectral ground attenuation, with soft ground (G=1) throughout the area, except for the substation which was modeled as mixed ground (G=0.6). Additional model input data is provided in Appendix B.

A 32-foot by 32-foot (10-meter by 10-meter) grid of 1.5-meter-high receivers was set up in the model, covering approximately 9 square kilometers (3.5 square miles) around the site. A receiver is a point above the ground at which the computer model calculates a sound level. In addition, 30 discrete receivers were modeled at nearby residences.

A total of five scenarios were modeled:

1. Existing substation ONAN
2. Existing substation ONAF

3. Proposed substation ONAN
4. Proposed Substation ONAF
5. Proposed Substation, tuned capacitor bank only (reactor and capacitor)

Sound power levels for new equipment were based on manufacturer specifications and are summarized in Table 4 below. The sound power level of the new transformer is 14 dB less than the existing transformer that will be removed from the site.

TABLE 4: SOUND EMISSIONS OF NEW EQUIPMENT

Equipment	Manufacturer Specified Sound Pressure Level (dBA)	Calculated Sound Power Level (dBA)
New Transformer ONAN	61 per IEEE C57.12.90	82
New Transformer ONAF	62 per IEEE C57.12.90	84
Tuned Capacitor Bank	88 at 2 meters	99

4.2 RESULTS

Sound propagation modeling results for the existing scenarios are provided in Figure 12 for the fans off condition (ONAN) and Figure 13 for the fans on condition (ONAF). The highest projected sound level at nearby residence from the existing substation is 31 dBA (ONAN) and 33 dBA (ONAF). Results for the proposed scenarios are provided in Figure 14 for ONAN and Figure 15 for ONAF. The highest project sound level at a nearby residence for the proposed substation from the transformer is 24 dBA (ONAN) and 26 dBA (ONAF). Across all modeled receptors sound levels from the substation are expected to decrease by 6 to 15 dB. Finally, the model results for when the tuned capacitor bank is in-service are provided in Figure 16. The highest projected sound level at a nearby residence from the tuned capacitor bank is 41 dBA. Projected sound levels for all modeled receptors for each scenario are provided in Appendix C.

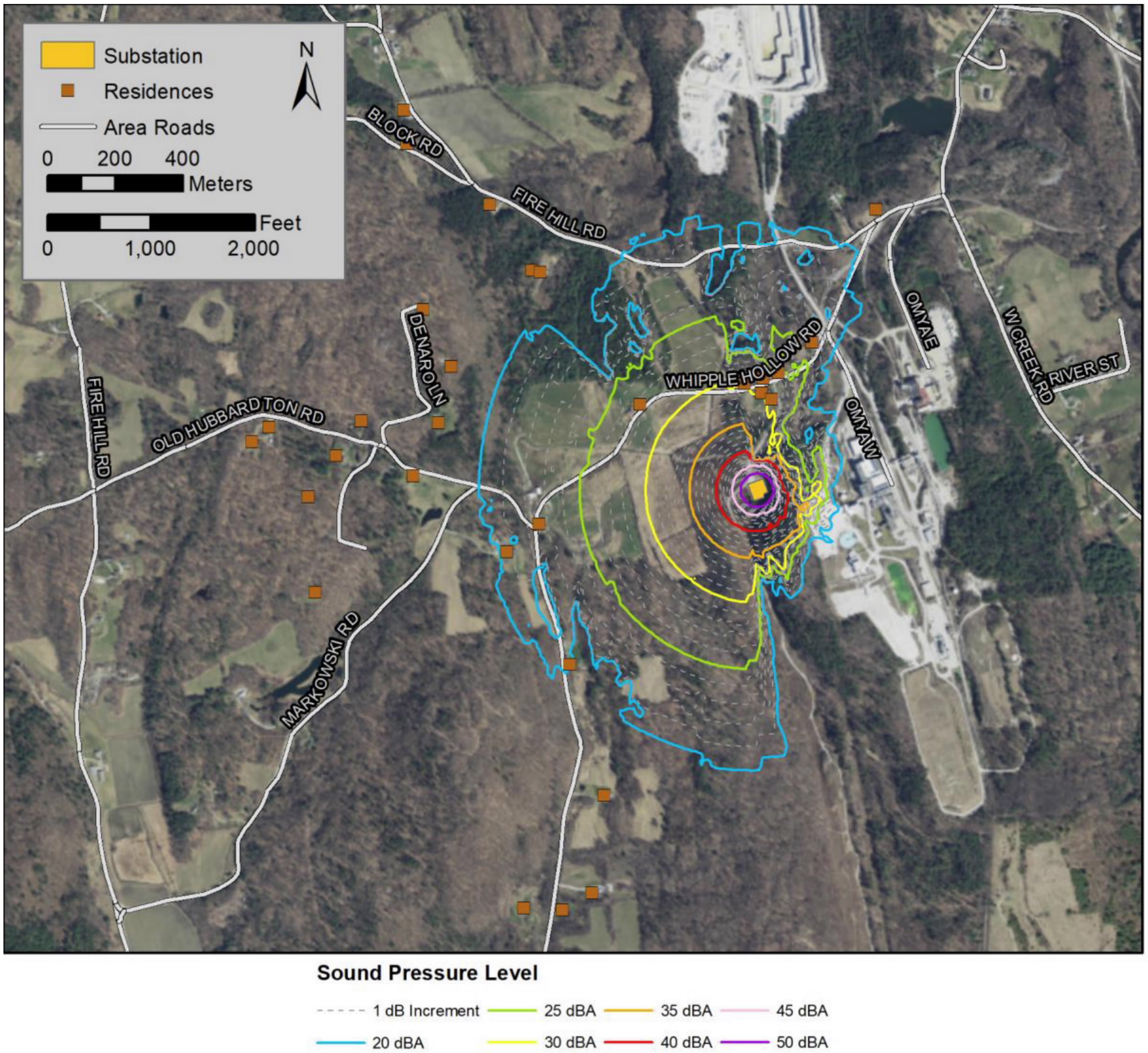

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FIGURE 12: SOUND PROPAGATION MODEL RESULTS OF THE EXISTING SUBSTATION – TRANSFORMER FANS OFF (ONAN)

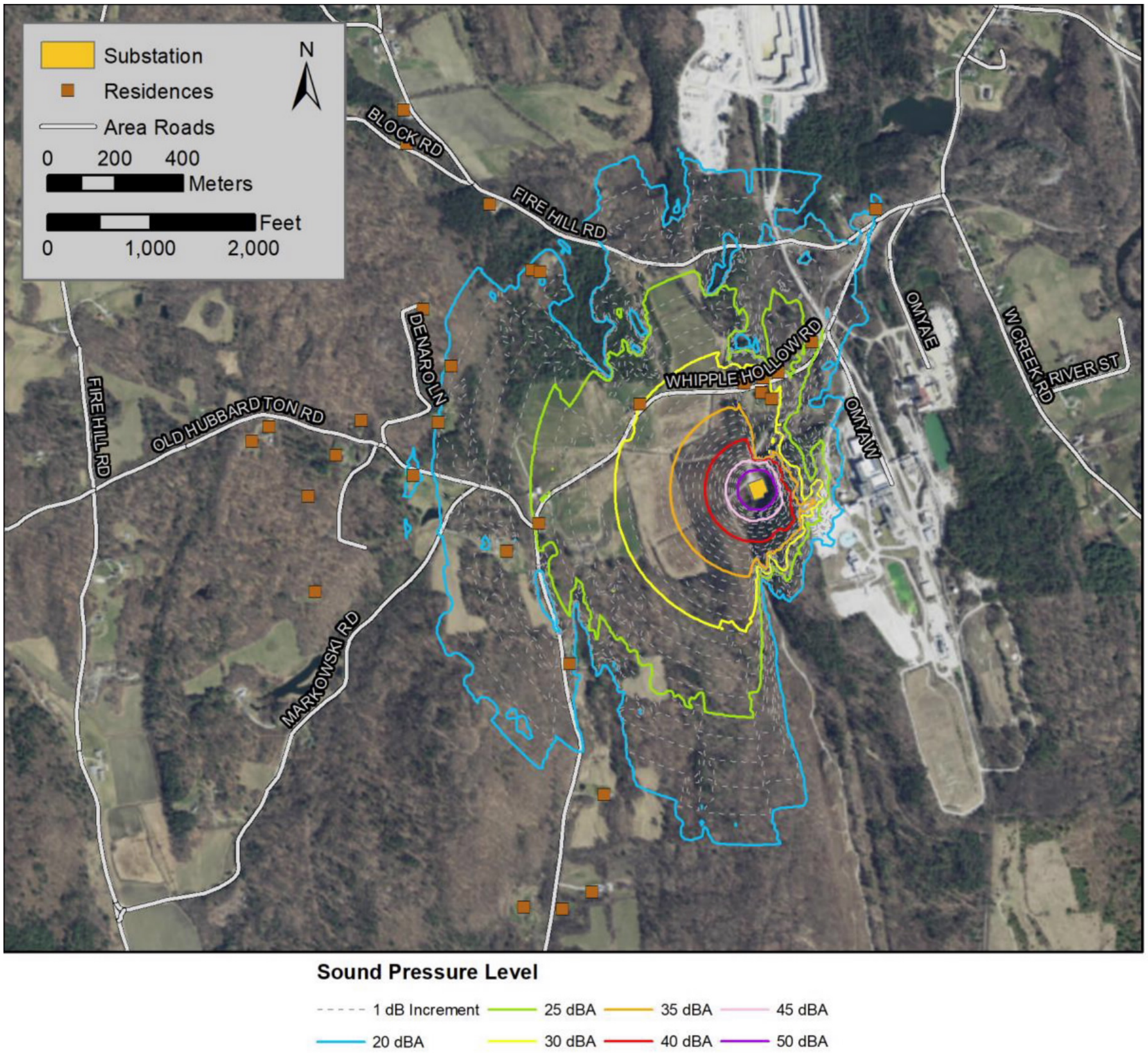

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FIGURE 13: SOUND PROPAGATION MODEL RESULTS OF THE EXISTING SUBSTATION – TRANSFORMER FANS ON (ONAF)

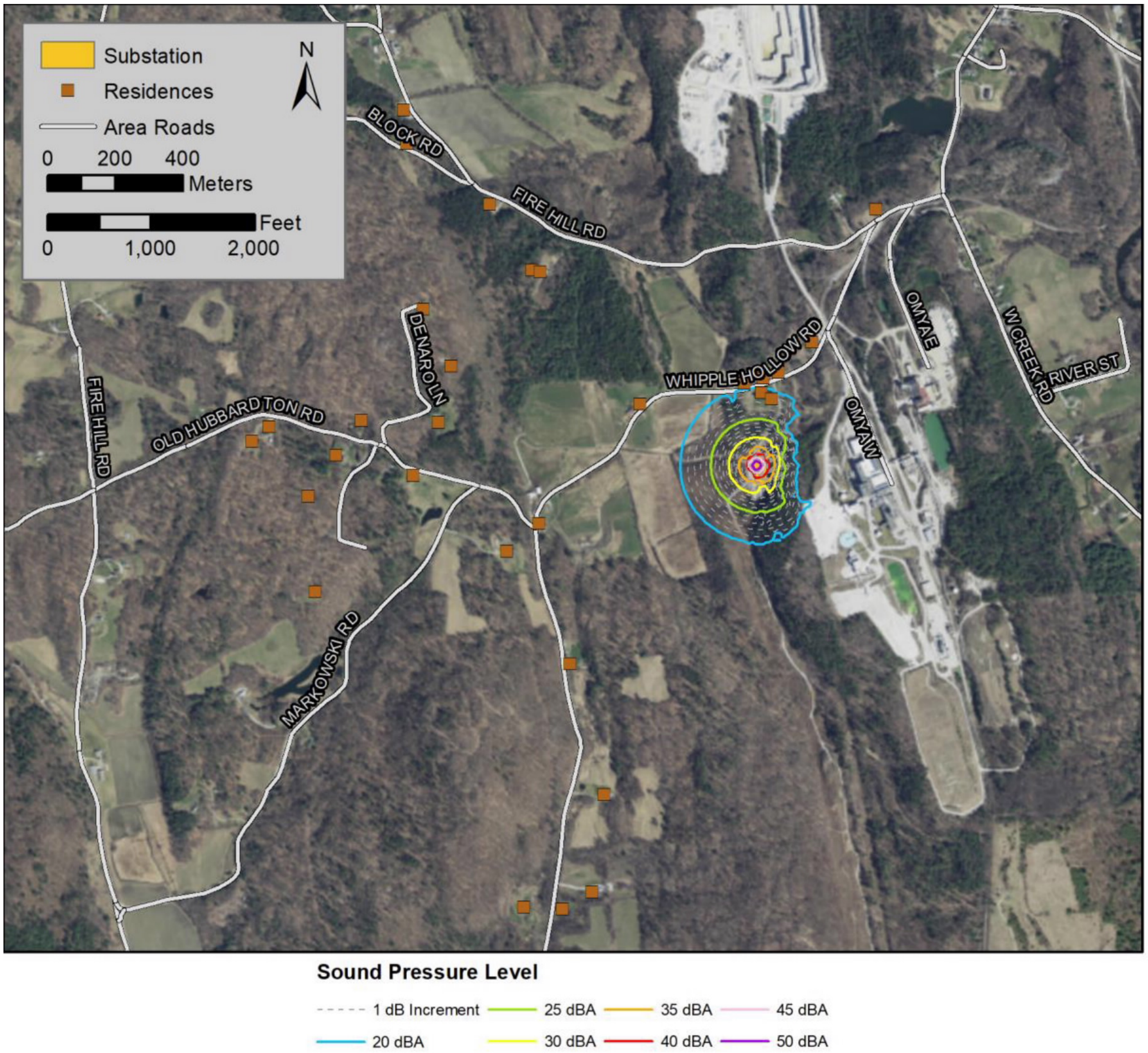

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FIGURE 14: SOUND PROPAGATION MODEL RESULTS OF THE PROPOSED SUBSTATION – TRANSFORMER FANS OFF (ONAN)

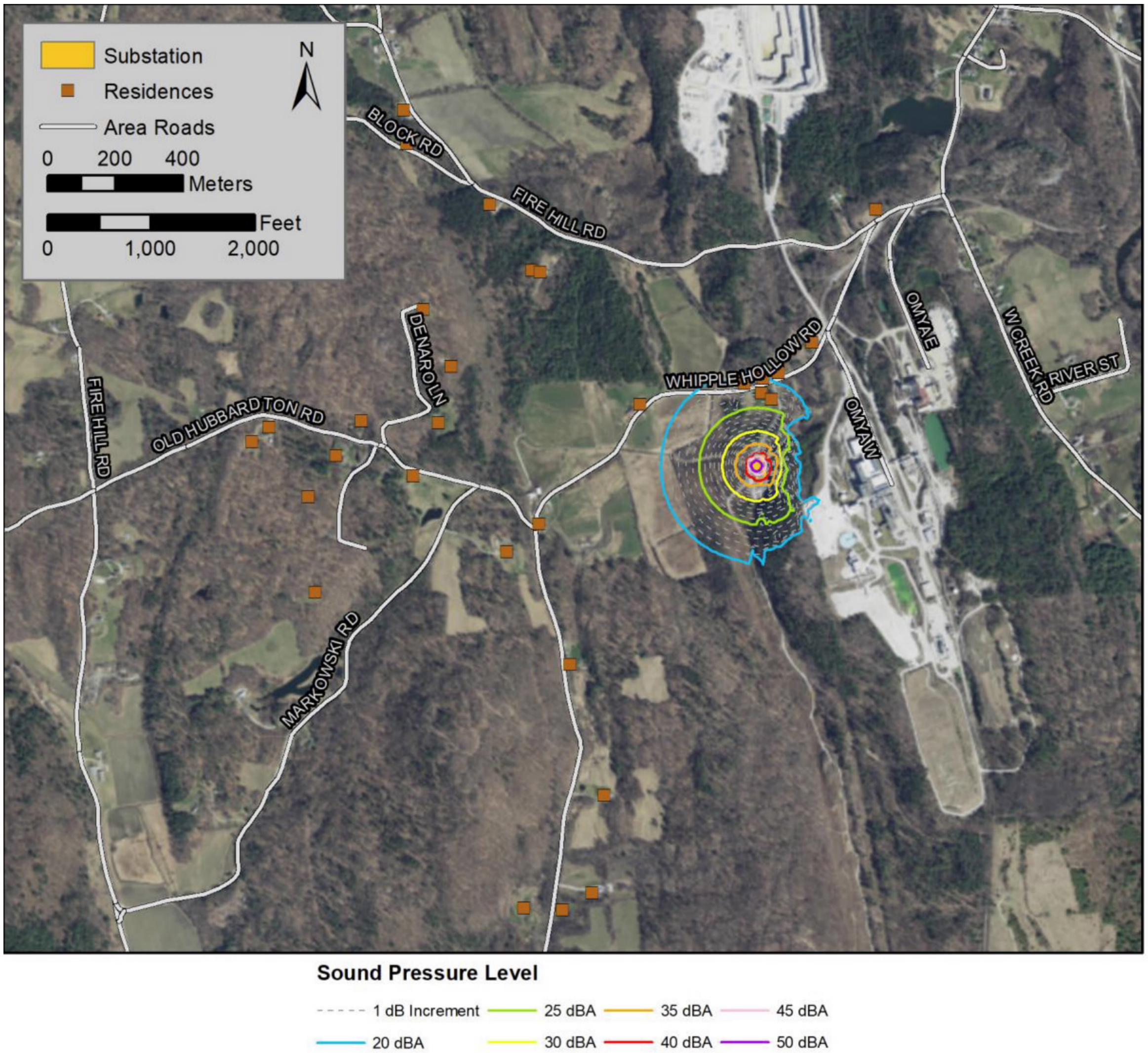

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FIGURE 15: SOUND PROPAGATION MODEL RESULTS OF THE PROPOSED SUBSTATION – TRANSFORMER FANS ON (ONAF)

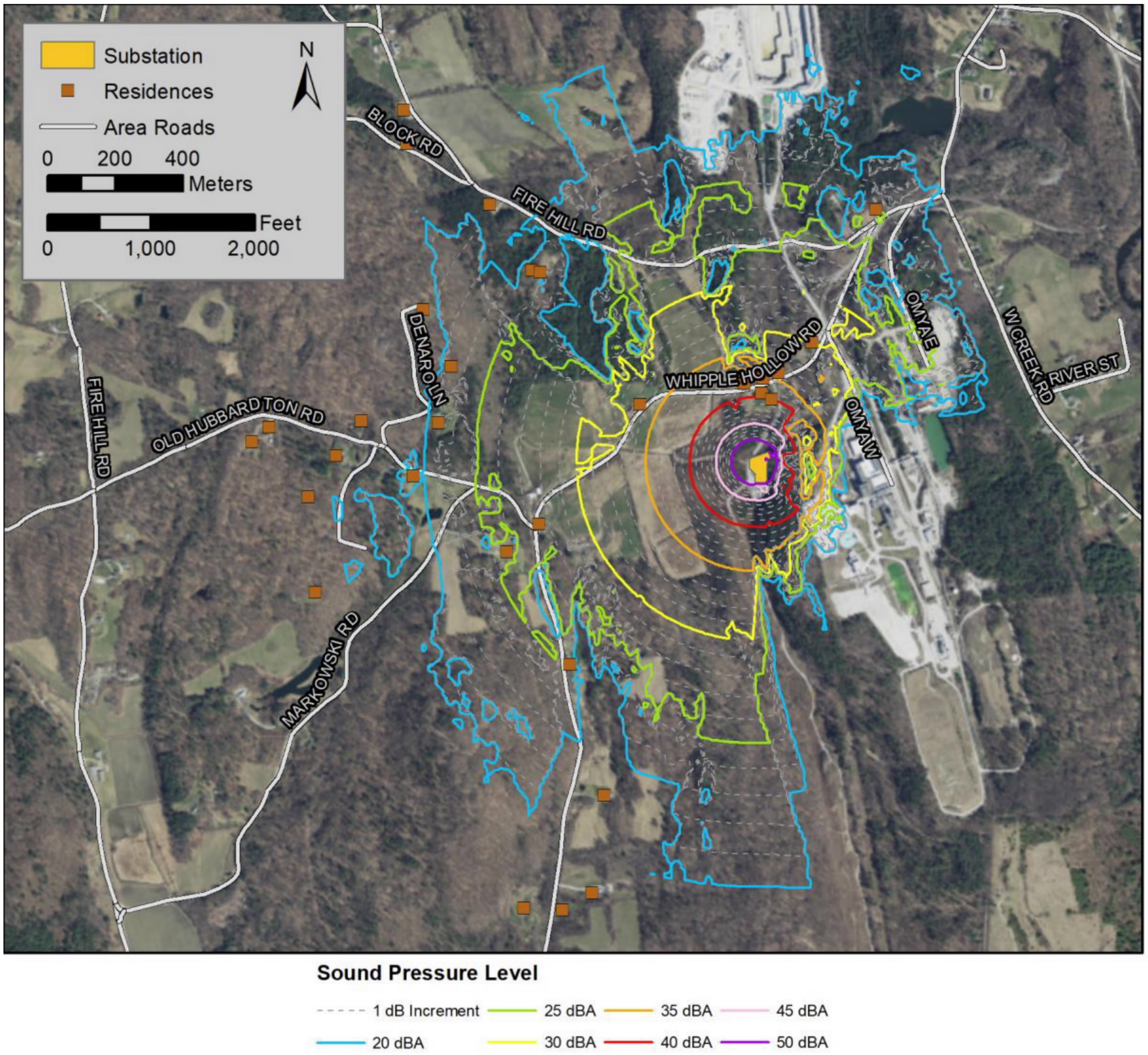

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FIGURE 16: SOUND PROPAGATION MODEL RESULTS OF THE PROPOSED SUBSTATION – TUNE CAPACITOR BANK ONLY

5.0 SUMMARY & CONCLUSIONS

RSG conducted a preconstruction noise assessment in preparation for updates to VELCO's Florence Substation on Whipple Hollow Road in Pittsford, Vermont. Updates include shifting the substation footprint to the north, construction of a new control building, replacing the transformer with a new transformer, and installing a new tuned capacitor bank.

For the assessment, RSG took short-term and long-term sound level measurements in and around the existing substation. Sound propagation modeling was completed for existing and proposed substation scenarios to determine the projected sound levels at nearby residences and throughout the area.

Our conclusions are as follows:

1. Long-term sound level measurements indicated that the primary source of sound at the substation fence-line, where sound levels were consistently between 53 and 55 dBA, is the existing transformer.
2. Long-term sound level measurements at the closest residence to the substation, 8040 Whipple Hollow Road, indicated that the primary sources of sound in that area were traffic on Whipple Hollow Road, trains, birds, spring peepers, as well truck traffic entering and exiting the OMYA facility. The average sound level at the Residence Monitor was 52 dBA during the day and 47 dBA during the night, although when there were no intermittent source of background sound, the sound level was around 39 dBA (L_{90}).
3. The proposed transformer has a sound power level that is 14 dB less than the existing transformer. Projected sound levels presented in Section 4.2 and Appendix C show that sound levels at area residences due to the substation transformer will be 6 to 15 dB less than existing transformer sound levels.
4. The highest projected sound levels at nearby residences due to the tuned capacitor bank is 41 dBA and occurs at 8018 and 8040 Whipple Hollow Road. This is below the average daytime and nighttime sound levels in the area, and sound from the tuned capacitor bank is expected to occur infrequently.

Proposed updates to the VELCO Florence substation are not expected to cause an undue adverse impact on the surrounding area due to the fact that when the tuned capacitor bank is not in-service, sound levels are expected to be 6 to 15 dB less at nearby residential receptors due to sound from the substation.

APPENDIX A. ACOUSTICS PRIMER

Sound consists of tiny, repeating fluctuations in ambient air pressure. The strength, or amplitude, of these fluctuations determines the sound pressure level. “Noise” can be defined as “a sound of any kind, especially when loud, confused, indistinct, or disagreeable.”

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”).[1] 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 sources of noise, and their sound pressure levels, are listed on the scale in Figure 17.

Human Response to Sound Levels: Apparent Loudness

For every 20 dB increase in sound level, the sound pressure increases by a *factor* of 10; the sound *level* range from 0 dB to 120 dB covers 6 factors of 10, or one million, in sound *pressure*. However, for an increase of 10 dB in sound *level* as measured by a meter, humans perceive an approximate doubling of apparent loudness: to the human ear, a sound level of 70 dB sounds about “twice as loud” as a sound level of 60 dB. Smaller changes in sound level, less than 3 dB up or down, are generally not perceptible.

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[1] The pascal is a measure of pressure in the metric system. In Imperial units, they are themselves very small: one pascal is only 145 millionths of a pound per square inch (psi). The sound pressure at the threshold of audibility is only 3 one-billionths of one psi: at the threshold of pain, it is about 3 one-thousandths of one psi.

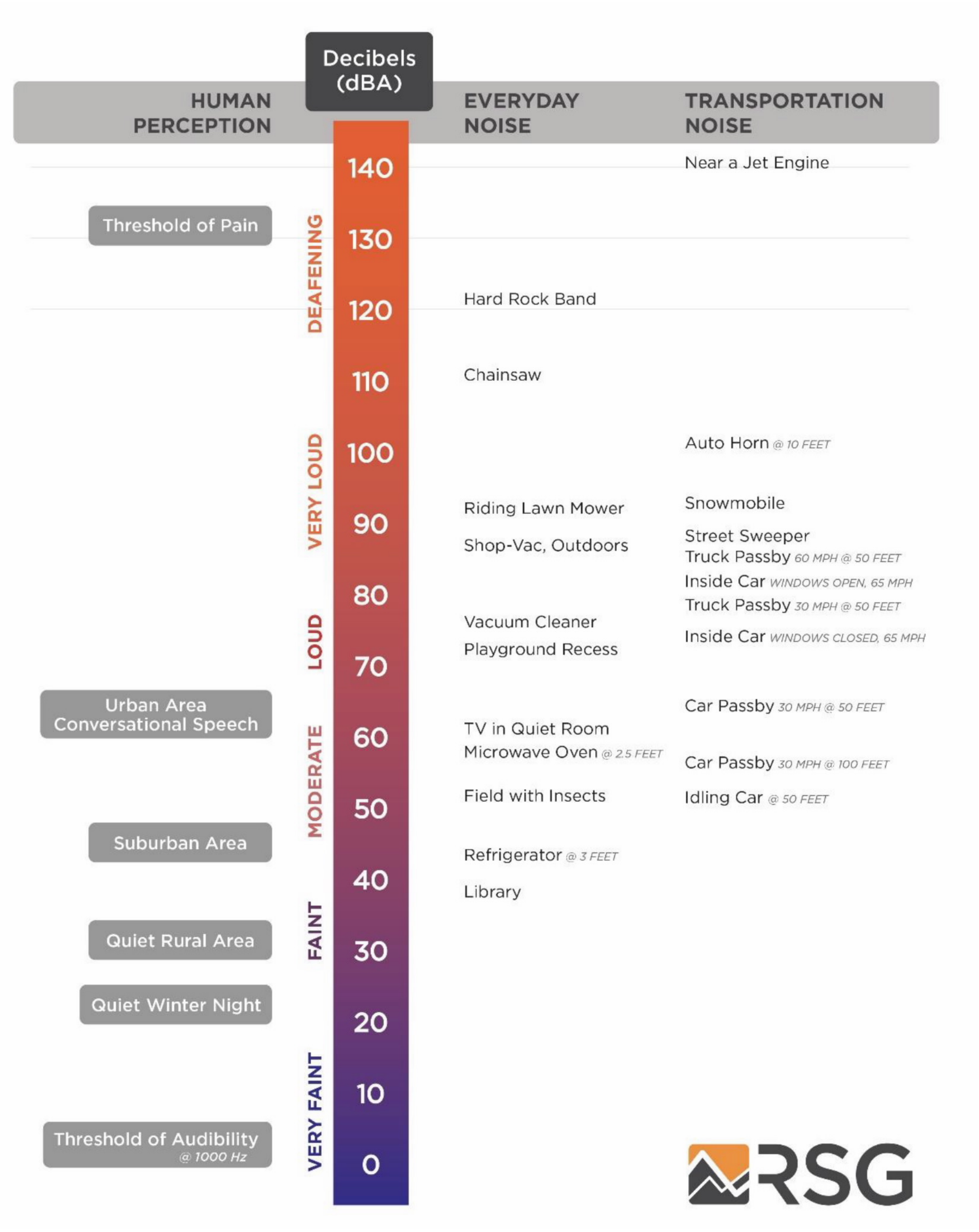

FIGURE 17: A SCALE OF SOUND PRESSURE LEVELS FOR TYPICAL SOUND SOURCES

Frequency Spectrum of Sound

The “frequency” of a sound is the rate at which it fluctuates in time, expressed in Hertz (Hz), or cycles per second. Very few sounds occur at only one frequency: most sound contains energy at many different frequencies, and it can be broken down into different frequency divisions, or bands. These bands are similar to musical pitches, from low tones to high tones. The most common division is the standard octave band. An octave is the range of frequencies whose upper frequency limit is twice its lower frequency limit, exactly like an octave in music. An octave band is identified by its center frequency: each successive band's center frequency is twice as high (one octave) as the previous band. For example, the 500 Hz octave band includes all sound whose frequencies range between 354 Hz (Hertz, or cycles per second) and 707 Hz. The next band is centered at 1,000 Hz with a range between 707 Hz and 1,414 Hz. The range of human hearing is divided into 10 standard octave bands: 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1,000 Hz, 2,000 Hz, 4,000 Hz, 8,000 Hz, and 16,000 Hz. For analyses that require finer frequency detail, each octave band can be subdivided. A commonly used subdivision creates three smaller bands within each octave band, or so-called 1/3-octave bands.

Human Response to Frequency: Weighting of Sound Levels

The human ear is not equally sensitive to sounds of all frequencies. Sounds at some frequencies seem louder than others, despite having the same decibel level as measured by a sound level meter. In particular, human hearing is much more sensitive to medium pitches (from about 500 Hz to about 4,000 Hz) than to very low or very high pitches. For example, a tone measuring 80 dB at 500 Hz (a medium pitch) sounds quite a bit louder than a tone measuring 80 dB at 60 Hz (a very low pitch). The frequency response of normal human hearing ranges from 20 Hz to 20,000 Hz. Below 20 Hz, sound pressure fluctuations are not "heard", but sometimes can be "felt". This is known as "infrasound". Likewise, above 20,000 Hz, sound can no longer be heard by humans; this is known as "ultrasound". As humans age, they tend to lose the ability to hear higher frequencies first; many adults do not hear very well above about 16,000 Hz. Most natural and man-made sound occurs in the range from about 40 Hz to about 4,000 Hz. Some insects and birdsongs reach to about 8,000 Hz.

To adjust measured sound pressure levels so that they mimic human hearing response, sound level meters apply filters, known as "frequency weightings", to the signals. There are several defined weighting scales, including "A", "B", "C", "D", "G", and "Z". The most common weighting scale used in environmental noise analysis and regulation is A-weighting. This weighting represents the sensitivity of the human ear to sounds of low to moderate level. It attenuates sounds with frequencies below 1000 Hz and above 4000 Hz; it amplifies very slightly sounds between 1000 Hz and 4000 Hz, where the human ear is particularly sensitive. The C-weighting scale is sometimes used to describe louder sounds. The B- and D- scales are seldom used. All of these frequency weighting scales are normalized to the average human hearing response at 1000 Hz: at this frequency, the filters neither attenuate nor amplify. When a reported sound level has been filtered using a frequency weighting, the letter is appended to "dB". For example, sound with A-weighting is usually denoted "dBA". When no filtering is applied, the level is denoted “dB” or “dBZ”. The letter is also appended as a subscript to the level indicator “L”, for example “L_A” for A-weighted levels.

Time Response of Sound Level Meters

Because sound levels can vary greatly from one moment to the next, the time over which sound is measured can influence the value of the levels reported. Often, sound is measured in real time, as it fluctuates. In this case, acousticians apply a so-called “time response” to the sound level meter, and this time response is often part of regulations for measuring sound. If the sound level is varying slowly, over a few seconds, “Slow” time response is applied, with a time constant of one second. If the sound level is varying quickly (for example, if brief events are mixed into the overall sound), “Fast” time response can be applied, with a time constant of one-eighth of a second.[2] The time response setting for a sound level measurement is indicated with the subscript “S” for Slow and “F” for Fast: L_S or L_F. A sound level meter set to Fast time response will indicate higher sound levels than one set to Slow time response when brief events are mixed into the overall sound, because it can respond more quickly.

In some cases, the maximum sound level that can be generated by a source is of concern. Likewise, the minimum sound level occurring during a monitoring period may be required. To measure these, the sound level meter can be set to capture and hold the highest and lowest levels measured during a given monitoring period. This is represented by the subscript “max”, denoted as “L_{max}”. One can define a “max” level with Fast response L_{Fmax} (1/8-second time constant), Slow time response L_{Smax} (1-second time constant), or Continuous Equivalent level over a specified time period L_{EQmax}.

Accounting for Changes in Sound Over Time

A sound level meter’s time response settings are useful for continuous monitoring. However, they are less useful in summarizing sound levels over longer periods. To do so, acousticians apply simple statistics to the measured sound levels, resulting in a set of defined types of sound level related to averages over time. An example is shown in Figure 18. The sound level at each instant of time is the grey trace going from left to right. Over the total time it was measured, the sound energy spends certain fractions of time near various levels, ranging from the minimum (about 28 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.

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[2] 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 noises; it is no longer in common use.

Equivalent Continuous Sound Level - Leq

One straightforward, common way of describing sound levels is in terms of the Continuous Equivalent Sound Level, or L_{eq}. The L_{eq} is the average sound pressure level over a defined period of time, such as one hour or one day. L_{eq} is the most commonly used descriptor in noise standards and regulations. L_{eq} is representative of the overall sound to which a person is exposed. Because of the logarithmic calculation of decibels, L_{eq} tends to favor higher sound levels: loud and infrequent sources have a larger impact on the resulting average sound level than quieter but more frequent sounds. For example, in Figure 18, even though the sound levels spends most of the time near about 34 dBA, the L_{eq} is 41 dBA, having been "inflated" by the maximum level of 65 dBA.

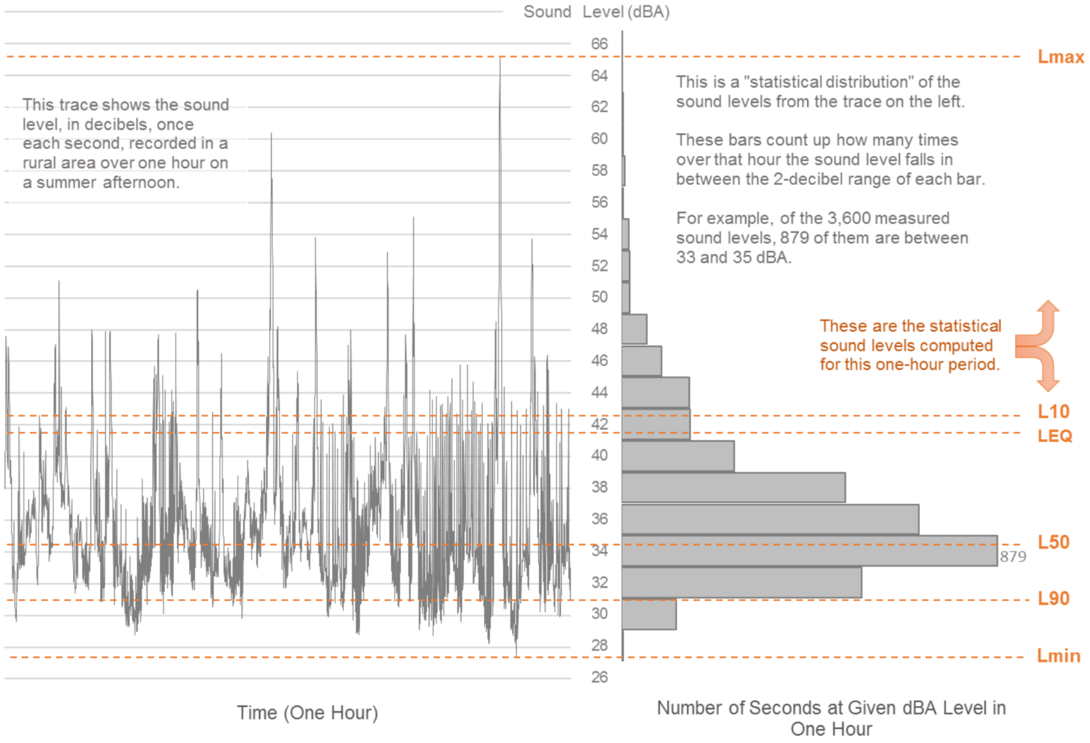

FIGURE 18: EXAMPLE OF DESCRIPTIVE TERMS OF SOUND MEASUREMENT OVER TIME

Percentile Sound Levels – Ln

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 the L_{90} most of the time. L_{10} is the sound level that is exceeded only 10% of the time. L_{50} (the "median level") is exceeded 50% of the time: half of the time the sound is louder than L_{50}, and half the time it is quieter than L_{50}. Note that L_{50} (median) and L_{eq} (mean) are not always the same, for reasons described in the previous Section.

L_{90} is often a good representation of the "ambient sound" in an area. This is the sound that persists for longer periods, and below which the overall sound level seldom falls. It tends to filter out other short-term environmental sounds that are not 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 noises are excluded.

Note that if one sound source is very constant and dominates the sound 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 is generating *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 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. MODEL INPUT DATA

TABLE 5: SOUND PROPAGATION MODELING PARAMETERS

Parameter	Setting
Ground Absorption	ISO 9613-2 Spectral, G=0.6 in substation, G=1.0 elsewhere
Atmospheric Absorption	Based on 10 Degrees Celsius, 70% relative humidity
Search Radius	4,000 meters from each source (2.5 miles)
Receiver Height	4 meters (13 feet) for residences and 1.5 meters (4.9 feet) for isolines

TABLE 6: SOUND SOURCE LOCATIONS

Sound Source	Modeled Sound Power (dBA)	Relative Height (m)	Coordinates (VT State Plane NAD83)		Elevation + Height (m)
			X (m)	Y (m)	
Exist. Trans. ONAN	96	3.4	454273	134429	132
Prop. Trans. ONAN	82	3.1	454272	134501	133
Exist. Trans. ONAF	98	3.4	454273	134429	132
Prop. Trans. ONAF	84	3.1	454272	134501	133
Tuned Capacitor Bank	99	5	454264	134427	135

APPENDIX C. RECEIVER INFORMATION AND MODEL RESULTS

Receptor	Modeled Sound Pressure Level (dBA)					Relative Height (m)	Coordinates (VT State Plane)		Height (Relative + Ground Elevation) (m)
	Existing Substation ONAN	Existing Substation ONAF	Future Substation ONAN	Future Substation ONAF	Future Substation Tuned Capacitor Bank Only		X (m)	Y (m)	
981 FIRE HILL RD	14	16	0	2	15	4	453233	135547	148
142 BLOCK RD	14	16	1	2	16	4	453242	135450	167
755 FIRE HILL RD	16	17	2	4	18	4	453485	135270	147
8421 WHIPPLE HOLLOW RD	19	21	7	9	27	4	454624	135255	138
587 FIRE HILL RD	19	21	6	7	22	4	453610	135077	155
585 FIRE HILL RD	19	21	6	8	22	4	453635	135070	147
352 DENARO LN	17	19	3	5	19	4	453291	134962	252
8163 WHIPPLE HOLLOW RD	25	26	14	16	32	4	454436	134864	133
206 DENARO LN	22	24	8	10	25	4	453372	134793	239
8053 WHIPPLE HOLLOW RD	28	30	19	22	38	4	454338	134774	133

Receptor	Modeled Sound Pressure Level (dBA)					Relative Height (m)	Coordinates (VT State Plane)		Height (Relative + Ground Elevation) (m)
	Existing Substation ONAN	Existing Substation ONAF	Future Substation ONAN	Future Substation ONAF	Future Substation Tuned Capacitor Bank Only		X (m)	Y (m)	
8027 WHIPPLE HOLLOW RD	29	31	21	23	39	4	454292	134758	135
7991 WHIPPLE HOLLOW RD	30	32	22	24	40	4	454236	134742	135
8018 WHIPPLE HOLLOW RD	31	32	23	25	41	4	454287	134716	134
8040 WHIPPLE HOLLOW RD	30	32	24	26	41	4	454317	134697	135
7797 WHIPPLE HOLLOW RD	30	33	17	20	35	4	453929	134681	135
242 OLD HUBBARDTON RD	16	17	1	3	16	4	453108	134632	200
136 DENARO LN	22	24	8	10	25	4	453336	134627	214
407 OLD HUBBARDTON RD	14	16	0	2	15	4	452835	134614	208
409 OLD HUBBARDTON RD	14	16	0	2	15	4	452785	134572	211
249 OLD HUBBARDTON RD	16	18	2	4	17	4	453034	134531	202
117 OLD HUBBARDTON RD	21	24	8	10	24	4	453261	134471	193
126 HAWK RIDGE DR	16	18	3	5	20	4	452951	134410	207

Receptor	Modeled Sound Pressure Level (dBA)					Relative Height (m)	Coordinates (VT State Plane)		Height (Relative + Ground Elevation) (m)
	Existing Substation ONAN	Existing Substation ONAF	Future Substation ONAN	Future Substation ONAF	Future Substation Tuned Capacitor Bank Only		X (m)	Y (m)	
7496 WHIPPLE HOLLOW RD	26	28	12	14	29	4	453630	134329	144
237 MARKOWSKI RD	24	26	9	12	27	4	453536	134247	175
221 HAWK RIDGE DR	18	21	4	6	21	4	452972	134128	228
7230 WHIPPLE HOLLOW RD	21	23	7	8	22	4	453723	133915	162
7002 WHIPPLE HOLLOW RD	18	20	4	5	19	4	453822	133530	176
6816 WHIPPLE HOLLOW RD	16	17	1	3	21	4	453788	133243	208
6723 WHIPPLE HOLLOW RD	15	16	0	2	15	4	453586	133199	205
6776 WHIPPLE HOLLOW RD	15	17	1	2	16	4	453699	133193	210

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