Exhibit Petitioner KHK-2

VERMONT ELECTRIC POWER CO., INC.

NEW HAVEN OPERATIONS FACILITY NOISE IMPACT STUDY

Report | November 14, 2019

PREPARED FOR:
VERMONT ELECTRIC POWER CO., INC.

SUBMITTED BY:
RSG

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

Cover images: Left, rendering of the generator building by BAW Architecture. Right, RSG photo of sound monitoring near the transmission line to the south.

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1.0 INTRODUCTION

Vermont Electric Power Company (VELCO) is proposing the VELCO New Haven Operations Facility (the “Project”) in New Haven, Vermont. Its primary use is as a backup to VELCO’s Rutland operations facility in case of emergency, and it will also be used for training and other administrative purposes. The New Haven Operations Facility will house internal offices, computer equipment, and redundant backup generators, chillers, and building transformers.

In preparation for Public Utility Commission filing, VELCO requested that RSG perform a noise assessment of the Project. Included in this report are:

- A description of the proposed project;
- Existing background sound levels;
- Descriptions of sound-generating equipment;
- Sound propagation modeling results; and
- Conclusions.

A primer on the science of sound included in Appendix A.

2.0 SITE DESCRIPTION

The Project site is located in New Haven Vermont on the south side of VT 14 just west of the Village. The site is accessed via the same road as VELCO's New Haven substation. However, the New Haven substation is not directly connected with the New Haven Operations Facility and there are no changes to the New Haven substation that is part of this project. A map showing the Project in relation to the general area is shown in Figure 1, and a map showing a closer view is shown in Figure 2.

The site is located just east of Forest Drive. The closest residence is 220 meters to the northeast at 1118 Main Street and 225 meters to the southeast at 538 Town Hill Road. The closest home to the west is 370 meters away at 690 Main Street.

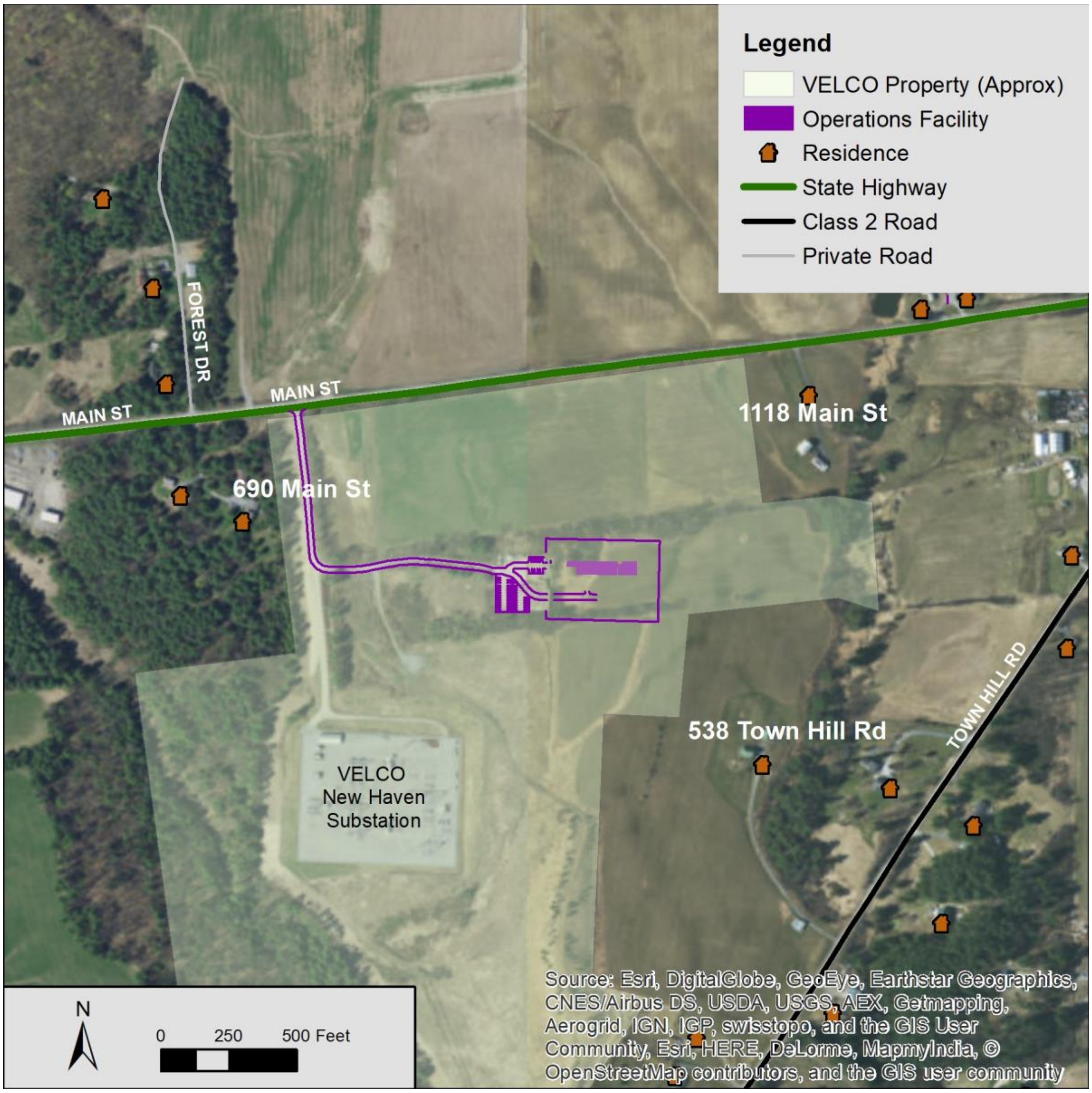

FIGURE 1: AREA MAP

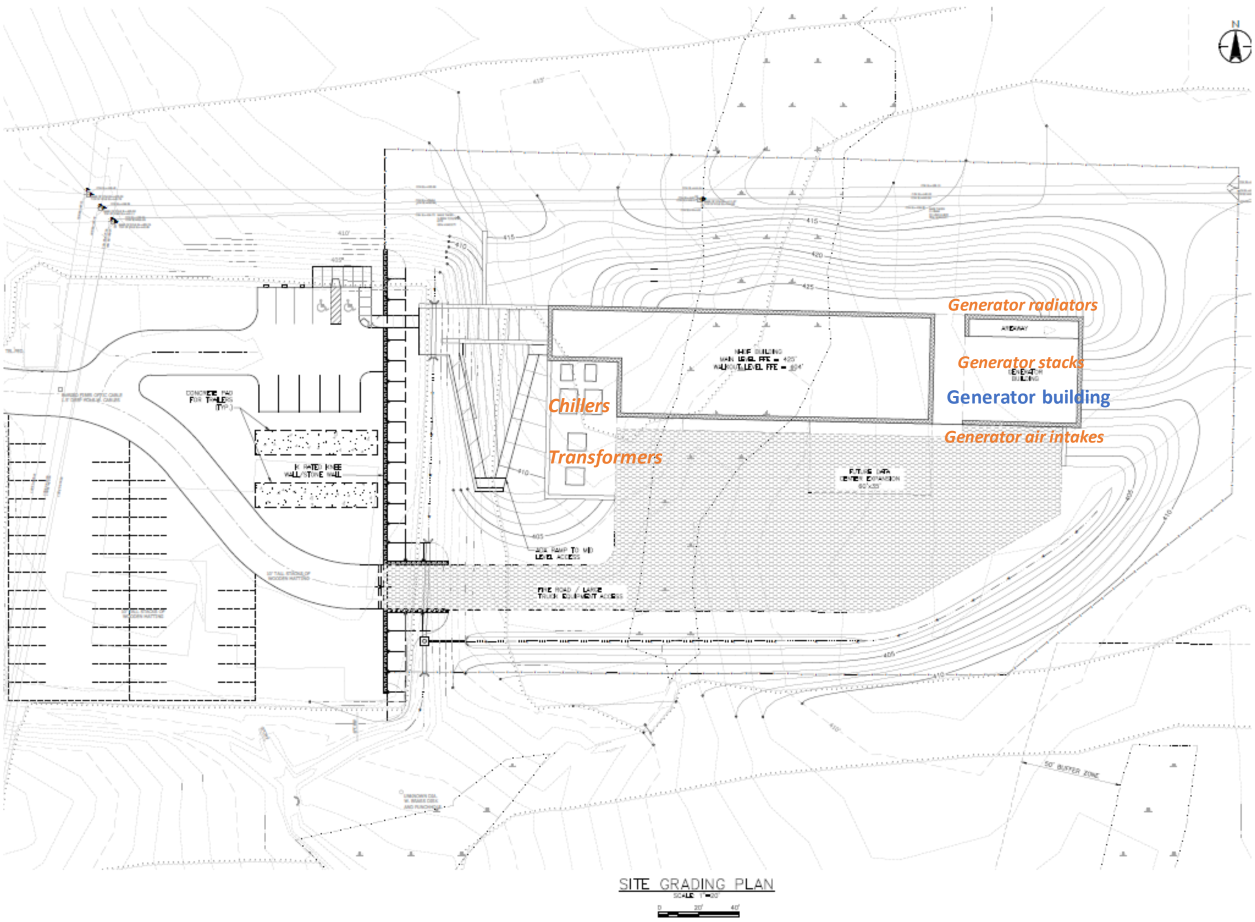

FIGURE 2: SITE PLAN WITH NOISE SOURCES OVERLAID

Base plan from Plan C-103, Stantec, 10/25/2019

3.0 NOISE STANDARDS

This facility is regulated by the Vermont Public Utilities Commission (PUC). The PUC has not set quantitative noise limits for operations facilities of this type. Similarly, there are no local, State, or Federal noise standards that this project is required to comply with. However, the PUC may take notice of local, State, and Federal standards in setting their own limits. In that regard, the most directly applicable limits are set by the Town of New Haven in their Zoning Ordinance and Town Plan. These are described below.

3.1 TOWN OF NEW HAVEN TOWN ZONING ORDINANCE

Performance standards for any land or building in any zoning district are set in Article VIII of the Town of New Haven Zoning Ordinance. Section 820 in this Article states that:

> "In all districts uses are not permitted which exceed any of the following standards measured at the individual property line:
>
> 1. Emit noise In excess of 70 decibels [sic]. …"

The standard is ambiguous, in that there is no sound level metric (L_{max}, L_{eq}, L_{50}, L_{90}), no weighting (A, C, or Z), and no averaging time. While the standard does not apply to the Project, we will interpret the standard as 70 dBA L_{1hr}, which is the maximum A-weighted equivalent continuous level measured over a one-hour period.

3.2 TOWN OF NEW HAVEN TOWN PLAN

The Town of New Haven Town Plan (adopted March 7, 2017) has language that is directly applicable to the noise impacts of Section 248 projects. This is as follows:

> "It is also the Town's policy to intervene in utility and other §248 project review processes for project proposed in other towns at locations near New Haven's borders, and to request that these same standards be applied to the extent that the proposed project would affect New Haven property, scenic views, historic and natural resources, or aesthetics from public roadways, recreational resources or New Haven residences.
>
> "• Noise. Strict noise limits must be imposed on any substations, converter stations, natural gas gate stations, generating plants, and any other utility or merchant §248 projects or infrastructure to avoid adverse impacts on the Town and its residents. To comply with this standard, noise levels at the property line, or the line of legal control for a project (whichever is lesser) cannot exceed 45dBa between 8 a.m. and 5 p.m. Monday through Friday and 40dBa at all other times. Such standards must be imposed in an enforceable manner requiring reasonable monitoring and timelines for compliance."

4.0 SOUND LEVEL MONITORING

4.1 SOUND MONITORING METHODOLOGY

Sound monitoring was conducted around the site in April and May 2013, as part of the post-construction sound monitoring for the New Haven Substation shunt reactor project.[1] No substantive changes have occurred in the area since that time, so these sound measurements are still representative of the existing background sound level.

Sound monitoring took place at five locations, shown in Figure 3. Monitors A and B are along Forest Drive, Monitor C represents the closest home to the west. Monitor D is along VT 17, and Monitor E is closer to the homes along Town Hill Road.

The monitoring took place from April 25 to May 4, 2013 for Monitors A, and C through E. Monitor B suffered a power failure during this time period and was set-up again to run from May 7 to May 16, 2013. The measurements were conducted with ANSI/IEC Type I sound level meters. All meters were calibrated before and after the measurements, and all microphones were fitted with windscreens. Each meter measured equivalent average A-weighted and 1/3 octave band sound levels at one-second intervals. During the monitoring, temperatures ranged from 25°F to 61°F. There were no periods of significant wind or precipitation.

4.2 BACKGROUND SOUND LEVELS

The overall, daytime, and nighttime sound levels for each sound monitoring station are shown in Table 1.

TABLE 1: BROADBAND BACKGROUND SOUND LEVELS (dBA)

	Overall				Day				Night			
	L_{eq}	L_{90}	L_{50}	L_{10}	L_{eq}	L_{90}	L_{50}	L_{10}	L_{eq}	L_{90}	L_{50}	L_{10}
Site A	48	30	38	47	49	33	39	45	44	28	36	49
Site B	48	31	40	47	51	36	42	47	42	29	37	46
Site C	42	32	38	45	44	35	41	46	40	30	35	43
Site D	48	30	40	51	49	35	43	52	47	29	35	50
Site E	41	30	38	45	42	34	39	45	40	28	34	44

As shown, equivalent continuous sound levels (L_{eq}) ranged from 42 dBA to 51 dBA during the day and 40 dBA to 47 dBA during the night. The sound level exceeded 90 percent of the time (L_{90}) ranged from 33 dBA to 36 dBA during the day and 28 to 30 dBA during the night.

[1] "Post-construction sound monitoring: VELCO New Haven Substation," RSG, July 2013, Docket 7730.

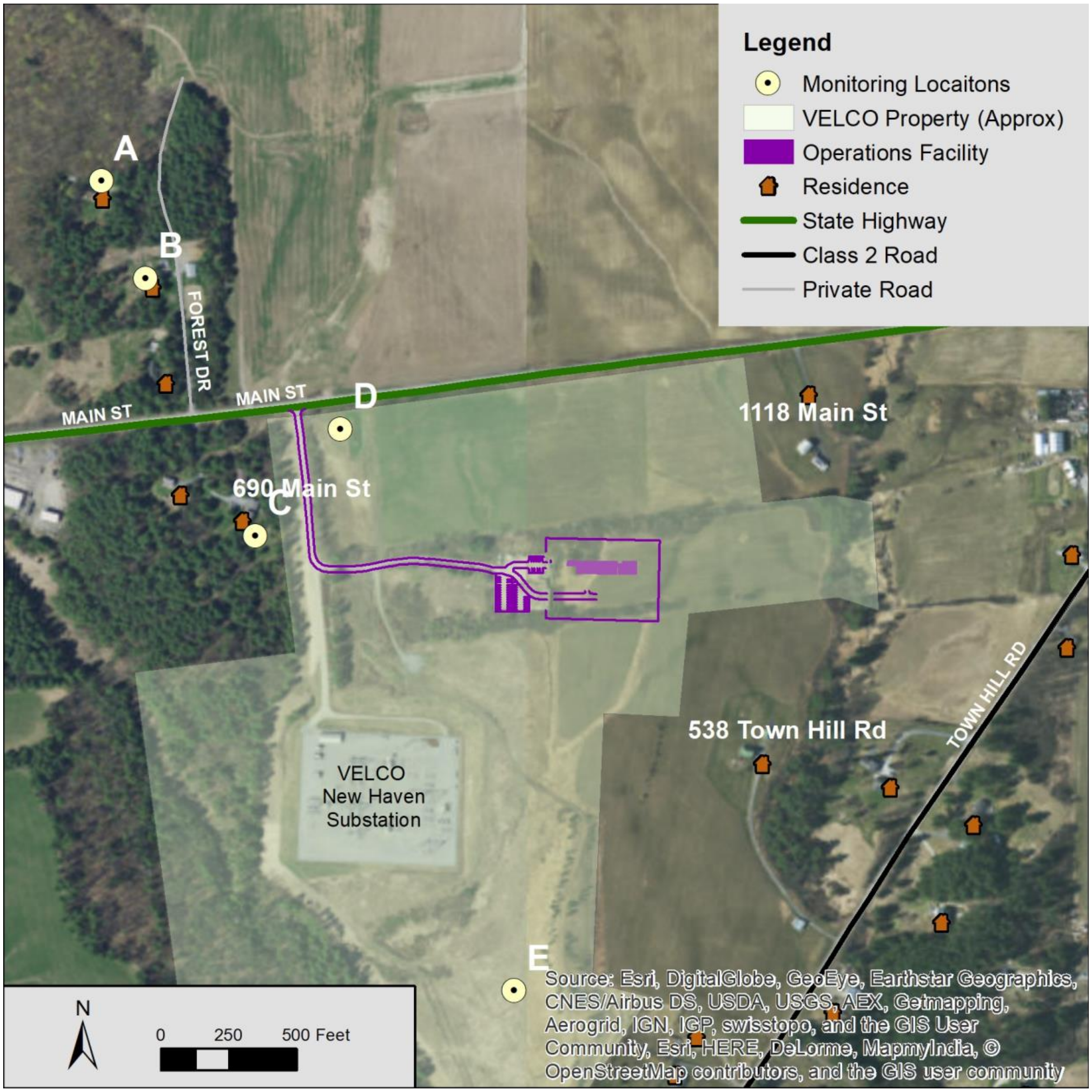

FIGURE 3: BACKGROUND SOUND MONITORING LOCATIONS

Figure 4 shows the median nighttime sound levels by 1/3 octave band. Site D is closest to VT 17, so it shows a spectral shape that is indicative of highway traffic. Sites A, B, C, and E show some discontinuity at the 125 Hz 1/3 octave band, which is indicative of transformer-type sound at a fundamental frequency of 120 Hz. The sound monitoring also shows a rise in levels at and above 2 kHz, which is most likely due to biogenic sound sources, including birds, insects, and amphibians.

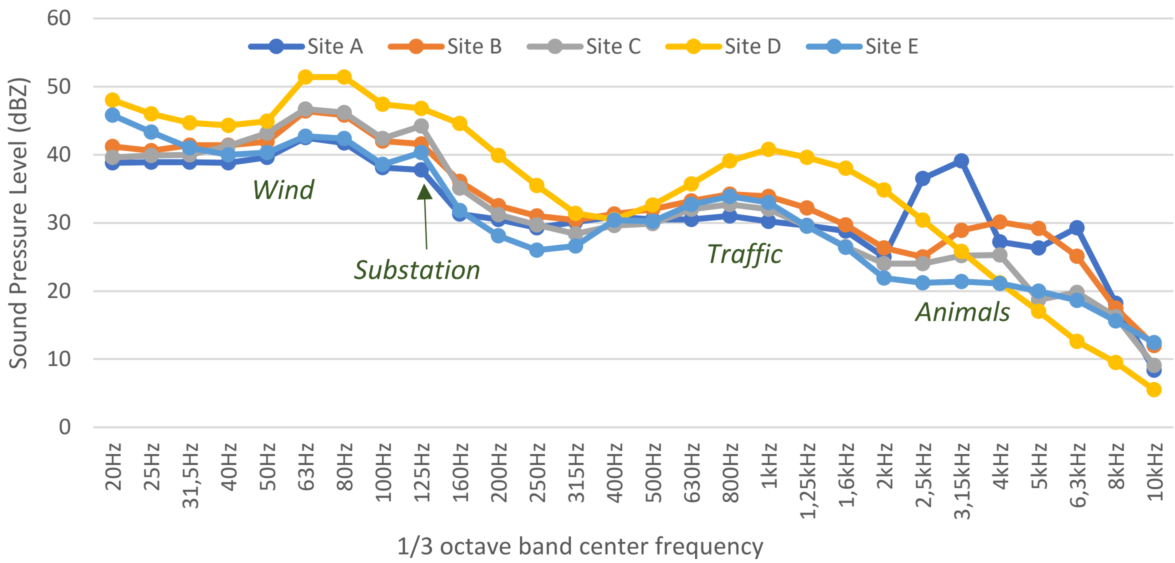

FIGURE 4: MEDIAN NIGHTTIME SOUND LEVELS BY 1/3 OCTAVE BAND

Overall, the soundscape in the area is dominated by highway traffic on both VT 17 and Town Hill Road. However, further from the highway, other sources of sound can be made out, particularly wind-induced sound, animals, and low-frequency substation sound.

5.0 EQUIPMENT

5.1 DESCRIPTION

The proposed New Haven Operations Facility will house offices and computer equipment required for both emergency operations, training, and other administrative support. In that regard, the noise noises are similar to a typical office building, with the exception that all mechanical systems are redundant, and the facility operates a backup emergency generator.

As such, the primary noise sources are:

1) Two three-module (six-fan) 15.82-ton chillers located outside to the southwest of the main building.
2) Two building transformers, 12.47/7.2 KV with a secondary voltage of 480/277 V, rated at 95 kV BIL.
3) Two diesel emergency generators, currently assumed to be Kohler KD1000s, rated at 1,000 kW standby.

Note that the units are redundant, so that only one of each would operate at any one time. The exception is that each transformer will likely remain energized, with only one loaded at one time.

The sound power for the transformer was calculated using standard NEMA TR-1.

The model also included sound levels from the existing New Haven substation. These include four transformers and two shunt reactors.

The unmitigated sound power levels for these devices are shown in Table 2.

TABLE 2: SOUND POWER LEVELS

Name	Weight	1/3 octave band center frequency (Hz)										
		31.5	63	125	250	500	1000	2000	4000	8000	dBA	dBZ
Existing Substation												
Transformer T1 fans off	A	43	50	88	85	89	74	64	62	55	93	105
Transformer T1 fans on	A	49	62	88	87	93	92	89	82	71	97	105
Transformer T2 fans off	A	42	52	88	86	91	75	66	64	58	93	105
Transformer T2 fans on	A	57	64	87	87	93	92	89	82	71	97	106
Transformer T3 fans off	A	43	47	78	69	70	67	66	64	62	79	94
Transformer T3 fans on	A	48	55	76	71	74	72	69	66	64	80	94
Transformer T4 fans off	A	43	50	68	79	82	79	62	60	54	85	92
Transformer T4 fans on	A	44	65	78	86	89	89	86	77	66	94	100
Shunt Reactor Fans On	A	39	53	80	82	81	69	62	57	50	86	98
Shunt Reactor fans off	A	32	52	79	81	82	66	58	54	48	86	97
New Haven Operations Facility												
Kohler KD1000 Radiator Loaded	A	n/a	66	82	96	96	97	98	95	93	104	108
Kohler KD1000 Radiator Unloaded	A	n/a	64	82	94	94	94	94	91	84	101	106
Kohler KD1000 Exhaust Loaded	A	n/a	110	116	123	129	128	130	128	124	135	140
Kohler KD1000 Exhaust Unloaded	A	n/a	98	106	119	113	116	112	107	103	122	130
Kohler KD100 Intake Loaded	A	n/a	66	82	96	96	97	98	95	93	104	108
Kohler KD100 Intake Unloaded	A	n/a	64	82	94	94	94	94	91	84	101	106
Transformer	A	25	38	56	58	72	65	59	49	42	73	78
Multistack ASP030X Chiller	Z	n/a	97	109	104	105	100	96	91	82	106	112
Multistack Chiller w/Sound Attenuation	Z	n/a	99	92	94	93	86	96	81	71	94	102

5.2 MITIGATION

Several mitigation measures for the New Haven Operations Facility sources were implemented in the sound propagation model. These include:

- An 11-foot high solid wall on the west side of the building and extending approximately 20 meters (65 feet) south. This wall helps to reduce sound from the chillers and transformer from propagating to the west.
- A hospital-grade exhaust silencer. This type of silencer reduces exhaust noise by 34 to 43 dBA.
- Air intake acoustic louvers. These louvers would be placed on the air intake side of the generators to attenuate generator mechanical noise emissions to the outside.
- Radiator acoustic louvers. These louvers would be placed on the radiator side of the generators to attenuate generator radiator noise emissions to the outside.

- Sound attenuation package on the chillers. The sound package includes low-noise fans, acoustic wraps around the compressors, 36-inch fan discharge silencers, and upper frame acoustic intake louvers.
- Acoustic treatment to the interior of the generator room, representing an average noise reduction coefficient of 0.30.

6.0 SOUND MODELING

6.1 METHODOLOGY

Modeling for the project was in accordance with the standard ISO 9613-2, "Acoustics – Attenuation of sound during propagation outdoors, Part 2: General Method of Calculation." The ISO standard states,

> This part of ISO 9613 specifies an engineering method for calculating the attenuation of sound during propagation outdoors in order to predict the levels of environmental noise at a distance from a variety of sources. The method predicts the equivalent continuous A-weighted sound pressure level … under meteorological conditions favorable to propagation from sources of known sound emissions. These conditions are for downwind propagation … or, equivalently, propagation under a well-developed moderate ground-based temperature inversion, such as commonly occurs at night.

The model takes into account source sound power levels, surface reflection and absorption, atmospheric absorption, geometric divergence, meteorological conditions, walls, barriers, berms, and terrain. The acoustical modeling software used here was CadnaA, from Datakustik GmbH. CadnaA is a widely accepted acoustical propagation modeling tool, used by many noise control professionals in the United States and internationally.

Model configuration parameters are listed in Appendix B.

A 10-meter by 10-meter grid of receivers[2] was set up at a height of 4.0 m (13 ft) in the model, covering approximately 2.17 square kilometers (537 acres) around the New Haven Operations Facility. In addition to the grid, the 13 closest homes were included as discrete receptors in the model.

6.2 SOUND MODELING RESULTS

Six scenarios of sound modeling were conducted. These are:

1) **Substation Only Fans Off** – The VELCO New Haven substation operating with all transformer and shunt reactor fans off. No Project operations.
2) **Substation Only Fans On** – The VELCO New Haven substation operating with all transformer and shunt reactor fans on. No Project operations.
3) **Project Chillers Only** – The Project chillers operating at 100% fan speed,[3] plus both transformers energized. No substation sources or emergency generator. This would be a worst-case condition for typical operations.
4) **Project Chillers + Generator** – Scenario 3 plus a generator operating unloaded under routine exercising.

[2] A receiver is a point above the ground at which the computer model calculates a sound level.
[3] This is a worst-case chiller scenario, as the chillers operate with a variable frequency drive and will only operate at 100% fans speed under extreme conditions.

5) **Substation + Project Chillers –** Scenario 2 plus Scenario 3.

6) **Substation + Project Chillers and Generator –** Scenario 2 plus Scenario 4

The model results for these scenarios, along with the measured nighttime background sound levels are shown in Table 3 for the closest receptors and in Figures 5 through 8 for the nearby community (Scenarios 3 through 6 only).

As shown, existing nighttime background sound levels range from 34 dBA L_{50} to 47 dBA L_{eq}.

With the chillers and transformers operating at 100 percent, the Project sound levels at the nearest homes range from 14 to 28 dBA. At the nearest property line, the sound level from these sources is modeled at 37 dBA. The sound is generally greatest to the southeast. Under normal operations, the chiller and transformer sound levels are below the existing nighttime median sound level (L_{50}).

When the generator is being exercised (i.e., unloaded), the sound levels increase to 29 to 34 dBA at the nearest homes and 45 dBA at the closest property line to the southeast. [4] The generator sound is greatest at homes to the southeast and northeast. During these periods, the generator sound level is modeled to be below the existing nighttime L_{50} at 690 Main St and within 1 dB of the existing nighttime L_{50} at 1118 Main St and 538 Town Hill Rd.

TABLE 3: MEASURED BACKGROUND SOUND LEVELS AND SOUND MODELING RESULTS (dBA)

Receptor	Measured Approx. Existing Night Leq	Measured Approx. Existing Night L50	Modeled Existing Substation OA	Modeled Existing Substation FOA	Modeled Project Chiller	Modeled Project Chiller + Generator	Modeled Substation + Project Chiller	Modeled Substation + Project Chiller and Generator
690 Main St	40	35	33	36	27	29	37	37
1118 Main St	47	35	28	30	14	34	31	36
538 Town Hill Rd	40	34	31	34	28	34	35	37
Closest Property Line	40	34	31	34	37	45	39	46

[4] Under emergency operation, the generators would be fully loaded, resulting in an approximate 5 to 7 dB increase in the A-weighted sound level at the nearby receptors, compared to the results in Table 3.

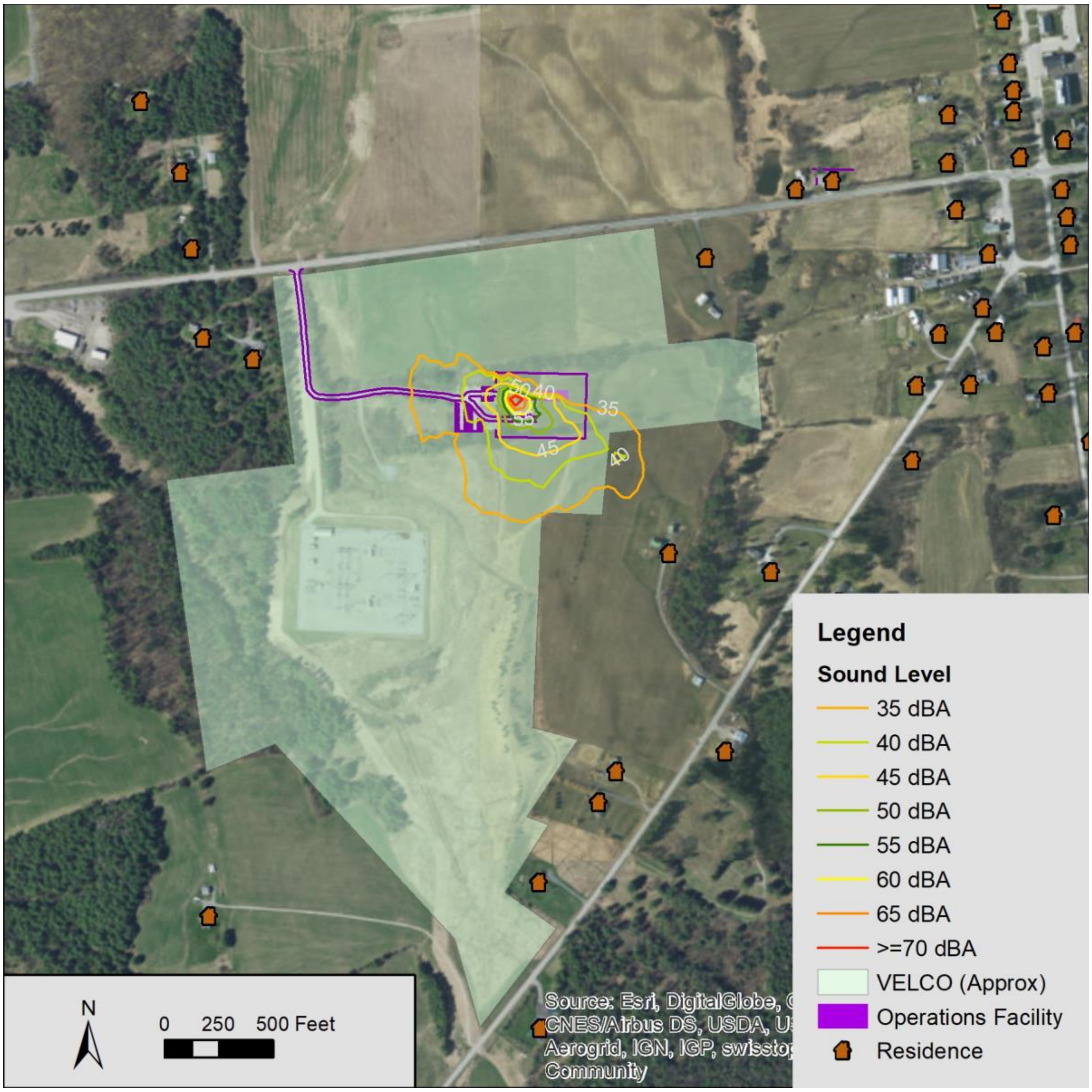

FIGURE 5: SOUND MODELING RESULTS: PROJECT CHILLER AT 100 PERCENT

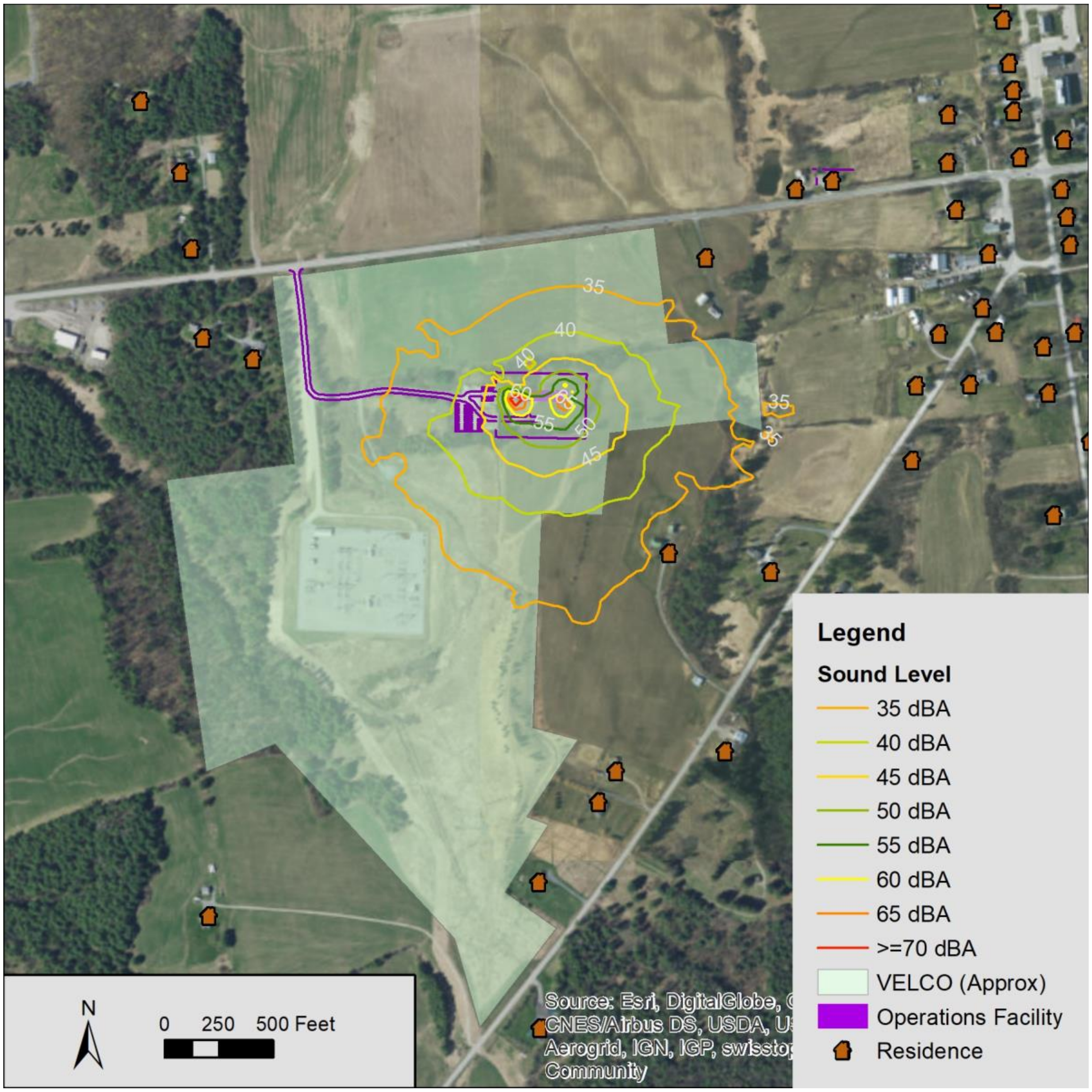

FIGURE 6: SOUND MODELING RESULTS: PROJECT CHILLER AT 100 PERCENT AND GENERATOR EXERCISING

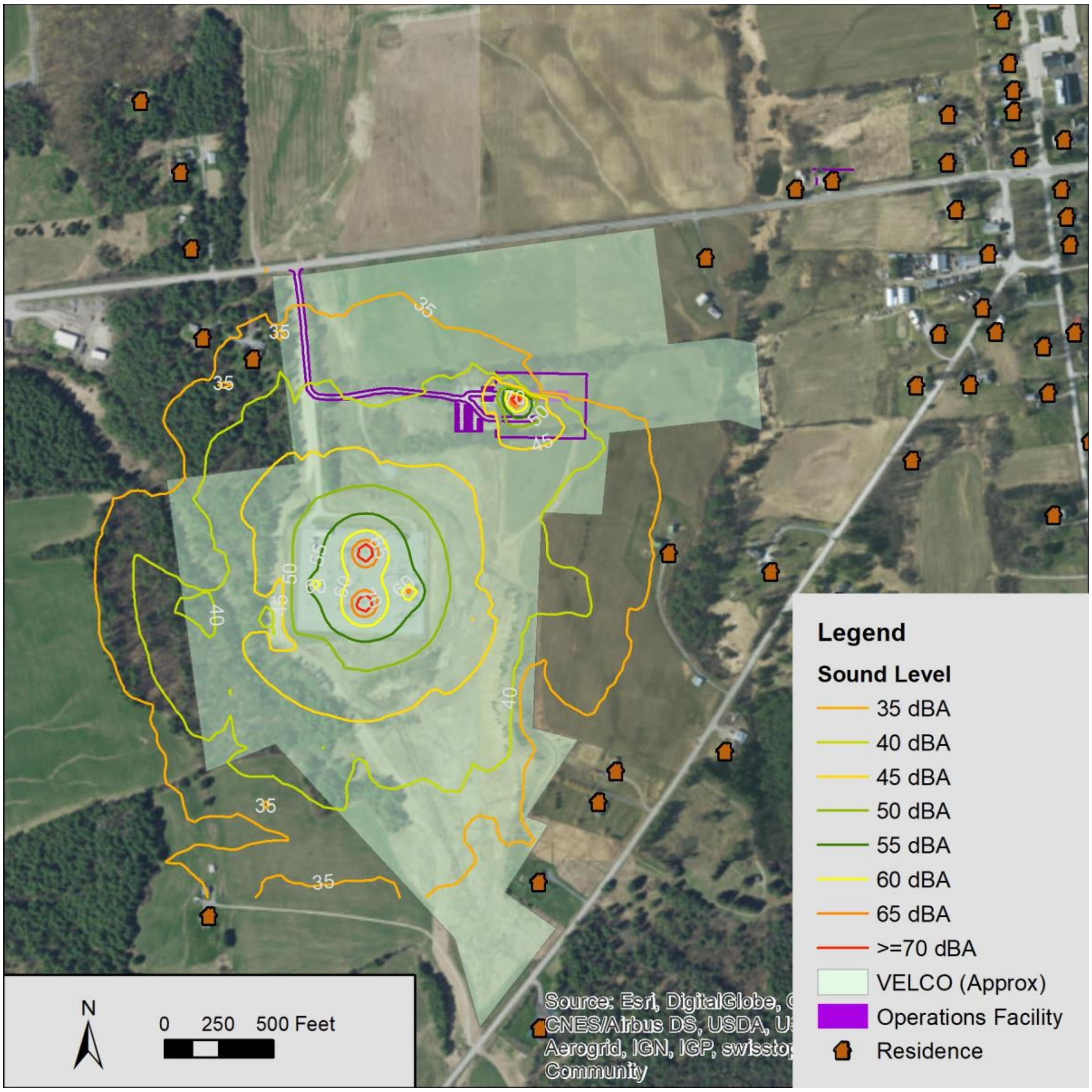

FIGURE 7: SOUND MODELING RESULTS: PROJECT CHILLERS AT 100 PERCENT PLUS NEW HAVEN SUBSTATION WITH ALL FANS OPERATING

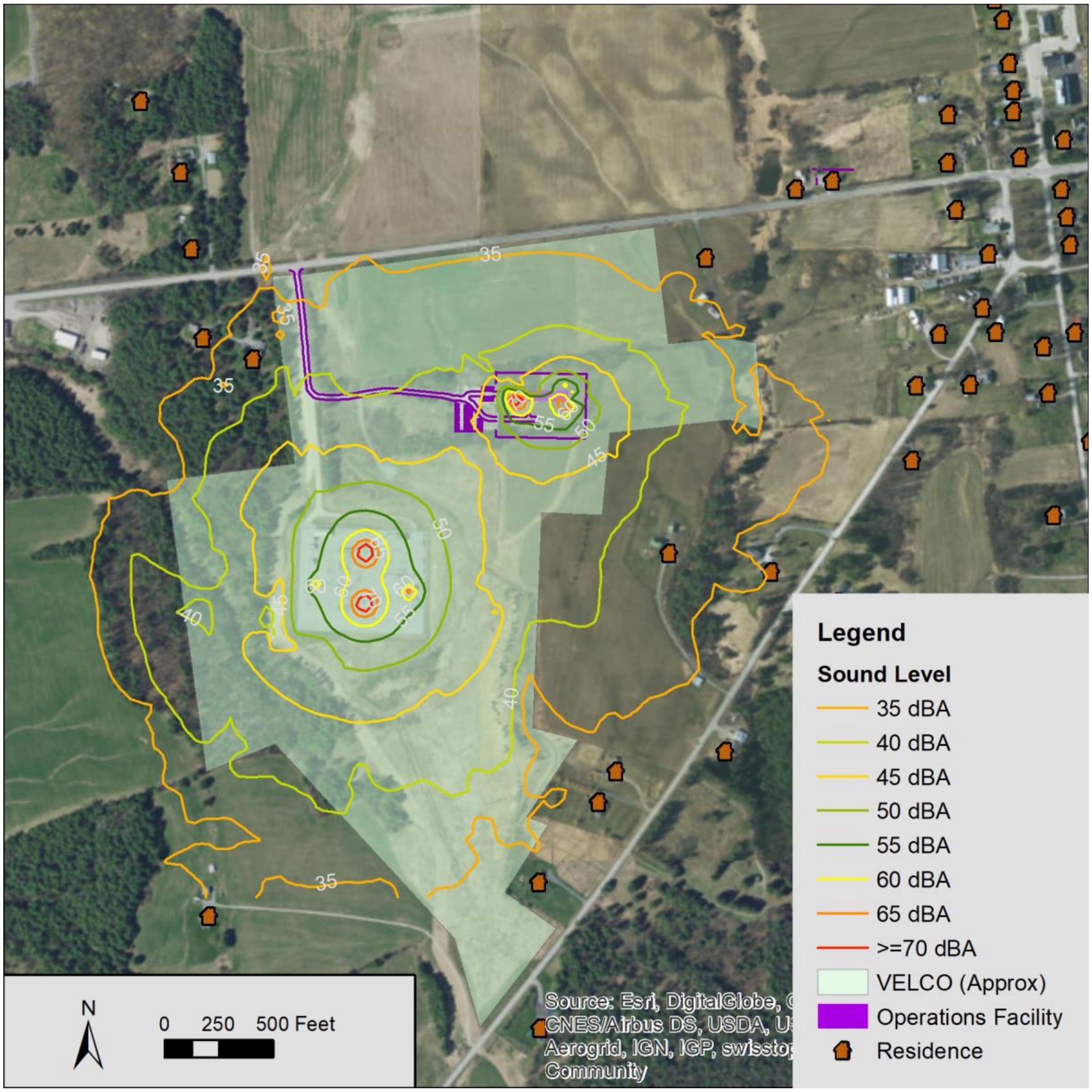

FIGURE 8: SOUND MODELING RESULTS: PROJECT CHILLERS AT 100 PERCENT, GENERATOR EXERCISING, AND NEW HAVEN SUBSTATION WITH ALL FANS OPERATING

6.3 ALTERNATIVE CONFIGURATION

As an alternative cooling system, VELCO is also considering a primary geothermal system with a backup chiller. Under this configuration, the six dual fan chiller units would be reduced to two-dual fan units. This single unit would be placed in the same Mechanical Systems Area. At the same time, the transformers would be moved adjacent to the building, where the removed chillers were. The retaining wall immediately to the west of the Mechanical Systems Area would be lowered to follow the terrain to the west, with a maximum height of approximately six feet.

Under this scenario the sound levels would be approximately the same (±1 dB) as the chiller-only scenario described in Table 3. The sound level grid is shown in Figure 9.

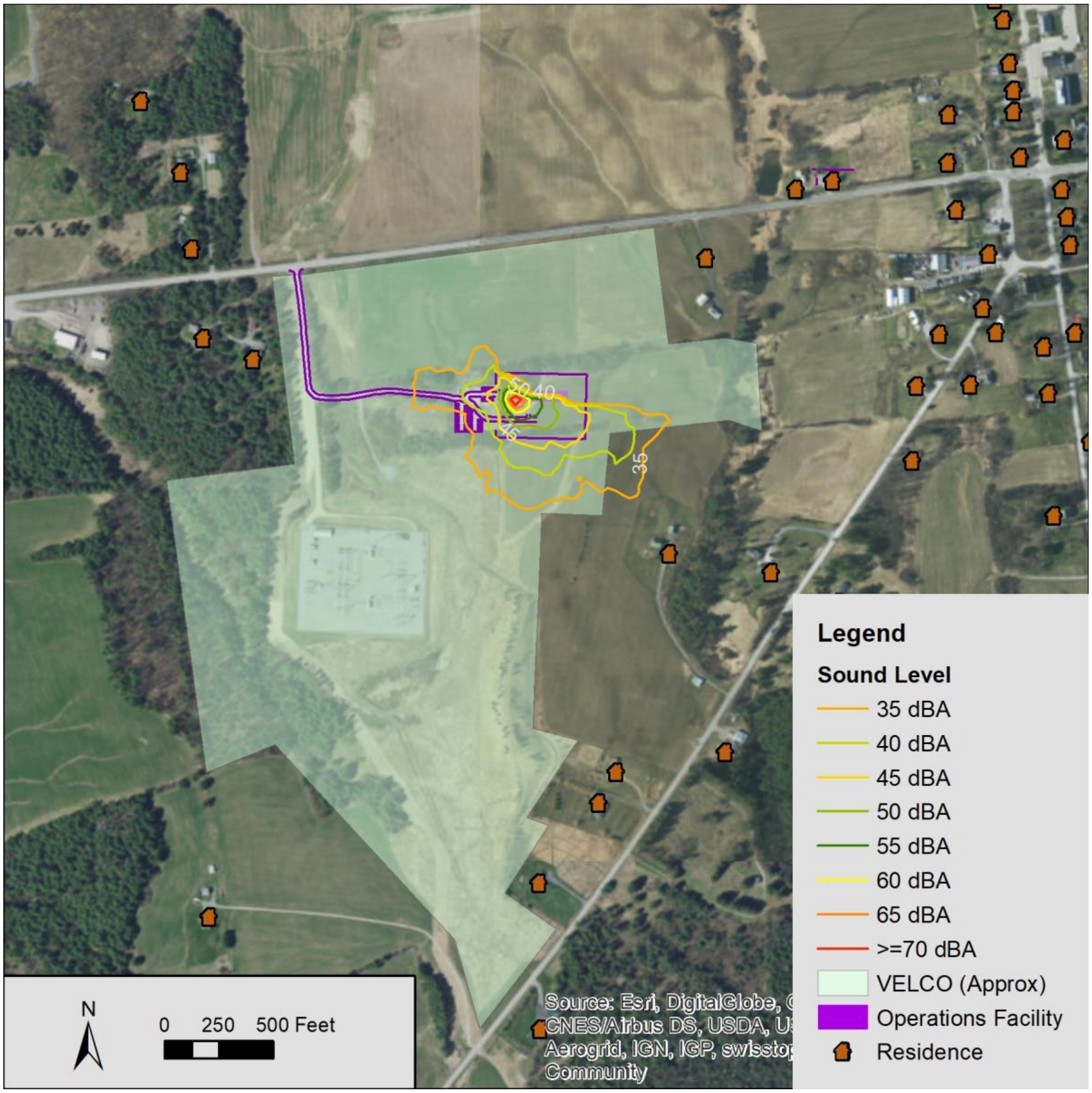

FIGURE 9: SOUND MODELING RESULTS: GEOTHERMAL SCENARIO AT MAXIMUM COOLING LOAD

7.0 RECOMMENDATIONS

The modeling described above incorporates several mitigation features. These include:

- An 11-foot high solid wall extending from the west side of the building and going approximately 20 meters (65 feet) south. This wall helps to reduce sound from the chillers and transformer from propagating to the west.
- A hospital-grade exhaust silencer. This type of silencer reduces exhaust noise by 34 to 43 dBA.
- Air intake acoustic louvers. These louvers would be placed on the air intake side of the generators to attenuate generator mechanical noise emissions to the outside.
- Radiator acoustic louvers. These louvers would be placed on the radiator side of the generators to attenuate generator radiator noise emissions to the outside
- A “sound attenuation module” to the chillers to further reduce noise. According to the manufacturer, this module has oversized condenser coils and VFD-controlled condenser fan motors that modulate to maintain head pressure for precise fan speed control. Fans have acoustically optimized blades utilizing a composite material. Compressors would be wrapped with high-temperature acoustic covers consisting of a dense-design fabric exterior with quilted acoustical fiberglass interior and open edges sealed with silicone coated fabric with hook and loop closure.
- Treatment of the interior of the generator room with acoustically absorptive materials such that the average noise reduction coefficient[5] across all surfaces is 0.30.

[5] The noise reduction coefficient is the average absorption coefficient for the 250 Hz through 2000 Hz octave bands.

8.0 CONCLUSIONS

The results of this study show that the proposed project will not create unduly adverse impacts on aesthetics with regard to noise. In coming to this conclusion, we consider the following:

1) The impacts may be adverse, since the types of sounds generated by the project are new to the area. While chiller and transformer sound levels are expected to be below the existing A-weighted median nighttime sound levels at the nearest neighbors, the generator will be above.
2) However, the impacts are not unduly adverse due to the following facts:
    a. The maximum sound level for routine operations is 28 dBA at any home. This is below the WHO community noise guideline of 45 dBA for an 8-hour night and 50 dBA averaged over a day.[6]
    b. The maximum sound level at any property line for routine operations is 37 dBA. This is below the Town of New Haven Zoning Ordinance limit of 70 dB and below the Town Plan recommendation of 45 dBA during the day and 40 dBA during the night.
    c. The generators and chillers should not generate pure tones as measured at any home.
    d. The generators will be exercised approximately 30 minutes per week each. The exercising will only be conducted during weekday daytimes when residents are less likely to be home. The exercising of a generator is modeled at 34 dBA at the worst-case home and 45 dBA at the property line.
    e. Under emergency conditions, the generator could be fully loaded, resulting in an approximate 6 dB increase in Project sound levels above the typical exercising sound level. This would only occur during power emergencies when both GMP distribution sources of power at the New Haven Operations Facility are down.
    f. The project incorporates reasonably available mitigation, including:
        i. Chillers will have variable frequency drives to operate the fans and an acoustical module that incorporates low-noise fans and acoustically isolated condenser.
        ii. The generator will incorporate acoustical louvers for air intakes and radiators, acoustical absorption within the generator room, and hospital-grade silencers on the exhaust.
        iii. The noise will further be reduced by an 11-foot high wall immediately to the west of the chillers.

[6] World Health Organization, “Guidelines for Community Noise,” 1999

g. These noise impacts are approximately the same with an optional geothermal cooling system. Under this scenario, there would be a reduction in the number of chillers and a commensurate lowering of the height of the retaining wall to the west of the mechanical area.

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”).[7] 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 10.

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.

[7] 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.

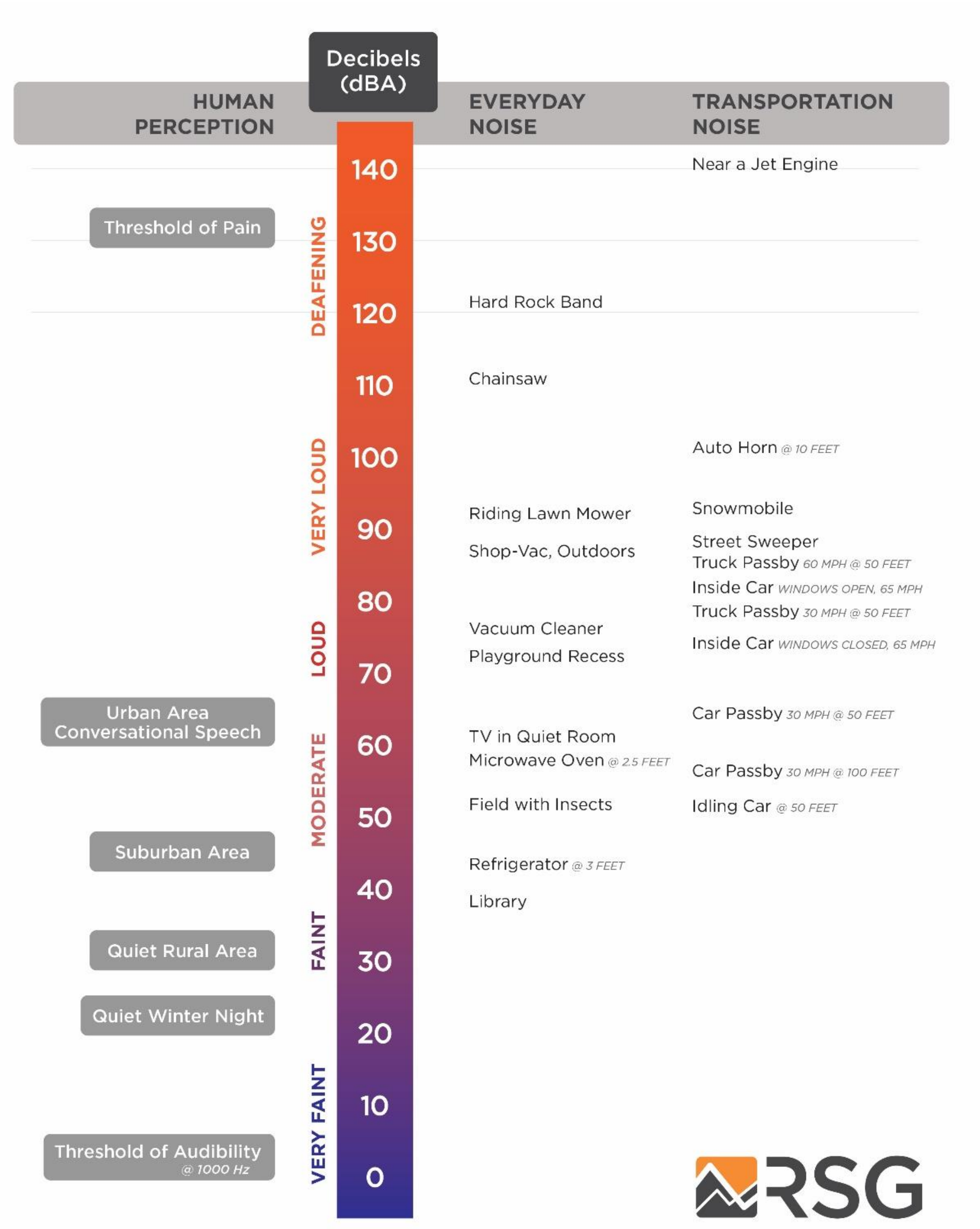

FIGURE 10: A SCALE OF SOUND PRESSURE LEVELS FOR TYPICAL SOUND SOURCES

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.[8] 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 11. 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.

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 11, 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.

[8] 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.

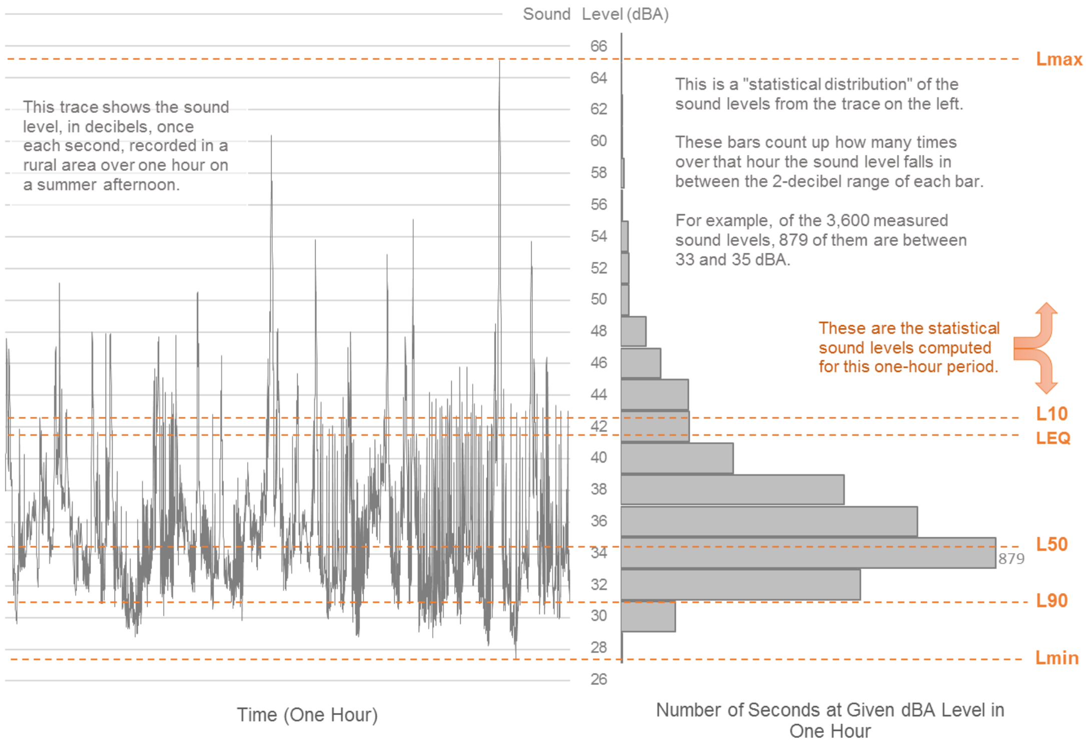

FIGURE 11: EXAMPLE OF DESCRIPTIVE TERMS OF SOUND MEASUREMENT OVER TIME

Percentile Sound Levels – L_n

Percentile sound levels describe the statistical distribution of sound levels over time. "L_N" is the level above which the sound spends "N" percent of the time. For example, L_{90} (sometimes called the "residual base level") is the sound level exceeded 90% of the time: the sound is louder than L_{90} most of the time. L_{10} is the sound level that is exceeded only 10% of the time. L_{50} (the "median level") is exceeded 50% of the time: half of the time the sound is louder than L_{50}, and half the time it is quieter than L_{50}. Note that L_{50} (median) and L_{eq} (mean) are not always the same, for reasons described in the previous Section.

L_{90} is often a good representation of the "ambient sound" in an area. This is the sound that persists for longer periods, and below which the overall sound level seldom falls. It tends to filter out other short-term environmental sounds that 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. MODELING INFORMATION

TABLE 4: SOUND PROPAGATION MODELING PARAMETERS

Parameter	Setting
Ground Absorption	ISO 9613-2 Spectral, G=0.6 in substation, G=0 for asphalt, G=1.0 elsewhere
Atmospheric Absorption	Based on 10 Degrees Celsius, 70% relative humidity
Refelction	2 orders
Receiver Height	4 meters (13 feet) for residences, 1.5 meters (5 feet) for grid

TABLE 5: MODELED SOUND SOURCES

Sound Source	Modeled Sound Power (dBA)	Height (m)	Coordinates (Vermont State Plane NAD 83)		
			X (m)	Y (m)	Z (m)
Generator Stack Loaded	101	9	447,011	180,355	132.15
Generator Stack Unloaded	92	9	447,019	180,355	132.15
Chiller	106	2	446,949	180,349	125.14
Transformer	73	2	446,950	180,343	125.14
Transformer	73	2	446,949	180,338	125.14
1-unit Chiller	92	2	446,949	180,349	125.14
Generator Intake Loaded	101	5.57	447,016	180,346	128.89
Generator Intake Unloaded	92	5.57	447,016	180,346	128.89
Generator Radiator Loaded	101	2.6	447,016	180,362	133.5
Generator Radiator Unloaded	92	2.6	447,016	180,362	133.5
Substation T1 OA	93	3.68	446,738	180,139	116.46
Substation T4 OA	85	2.94	446,671	180,105	115.72
Substation T3 OA	79	3.28	446,670	180,090	116.06
Substation SR OA	86	3	446,799	180,083	115.78
Substation T1 FOA	97	3.68	446,738	180,139	116.46
Substation T3 FOA	80	3.28	446,671	180,090	116.06
Substation T2 OA	93	3.68	446,737	180,067	116.46
Substation SR FOA	97	3.68	446,737	180,067	116.46

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