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CASHMAN GALES FERRY INTERMODAL, LLC INDUSTRIAL REGRADING SOUND STUDY

September 2024

Prepared for Gales Ferry Intermodal, LLC

Report Title:

Cashman Gales Ferry Intermodal, LLC Industrial Regrading Sound Study

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1.0 INTRODUCTION

Gales Ferry Intermodal is an intermodal industrial facility in Ledyard, CT. To accommodate industrial sites on the property, stone must be removed from the southern portion of the site. This stone removal will involve the drilling, blasting, processing and transporting of the stone material. As part of the local permitting process, RSG was retained to perform an assessment of this stone removal with respect to the Connecticut noise standard. This report[1] includes:

- A project description
- Noise limits applicable to the Project
- Background sound level monitoring procedures and results
- Sound propagation modeling procedures and results
- Recommended noise mitigation, and
- Conclusions.

2.0 PROJECT DESCRIPTION

The Project is located in Ledyard, CT just west of Route 12 (Military Highway), across from Thames View Pentway and between River Drive and Chapman Lane. The western boundary of the property is adjacent to the Thames River. The Project's immediate surroundings are mostly residentially zoned, with some commercial and industrial activity nearby.

The applicant is proposing regrading to create building area for future industrial development. This will be conducted in five phases, with each phase being 10 acres or less of disturbed land. According to the civil engineering plans, regrading will require the removal of topsoil, removal of bedrock, and final site grading suitable for future industrial buildings and/or uses.

The site is zoned industrial and has current and historical industrial uses. Dow Chemical formally had a factory on the site and currently a Styrofoam manufacturer, Americas Styrenics, is a tenant. The facility has a port which has historically been used for importing raw material utilized in the manufactures of Styrofoam and other products. In addition, the facility has access to Route 12 (Military Highway) which is used for trucking access and a rail siding with service provided by the Genesee and Wyoming Railroad.

The bedrock extraction will generate sound from various activities. Sources will include, but may not be limited to, loaders, excavators, haul trucks, dump trucks, rock crushers, screening decks, tracked rock drills, and hydraulic hammers. There will also be minor sources of sound operating on the site including conveyors, skid-steer loaders, automobiles, etc. Both dump trucks and barges are anticipated to be used to haul material from the site. A maximum of 100 truck trips (50 round trips) are anticipated per day. The facility will employee approximately 30 people. Hours of operation are 7:30 am to 5:30 pm Monday through Friday and 9 am to 5:30 on Saturday. Blasting will only occur between the hours of 11:00 am and 4:00 pm on Mondays through Fridays.

A map of the Project area the site and surrounding parcels is shown in Figure 1.

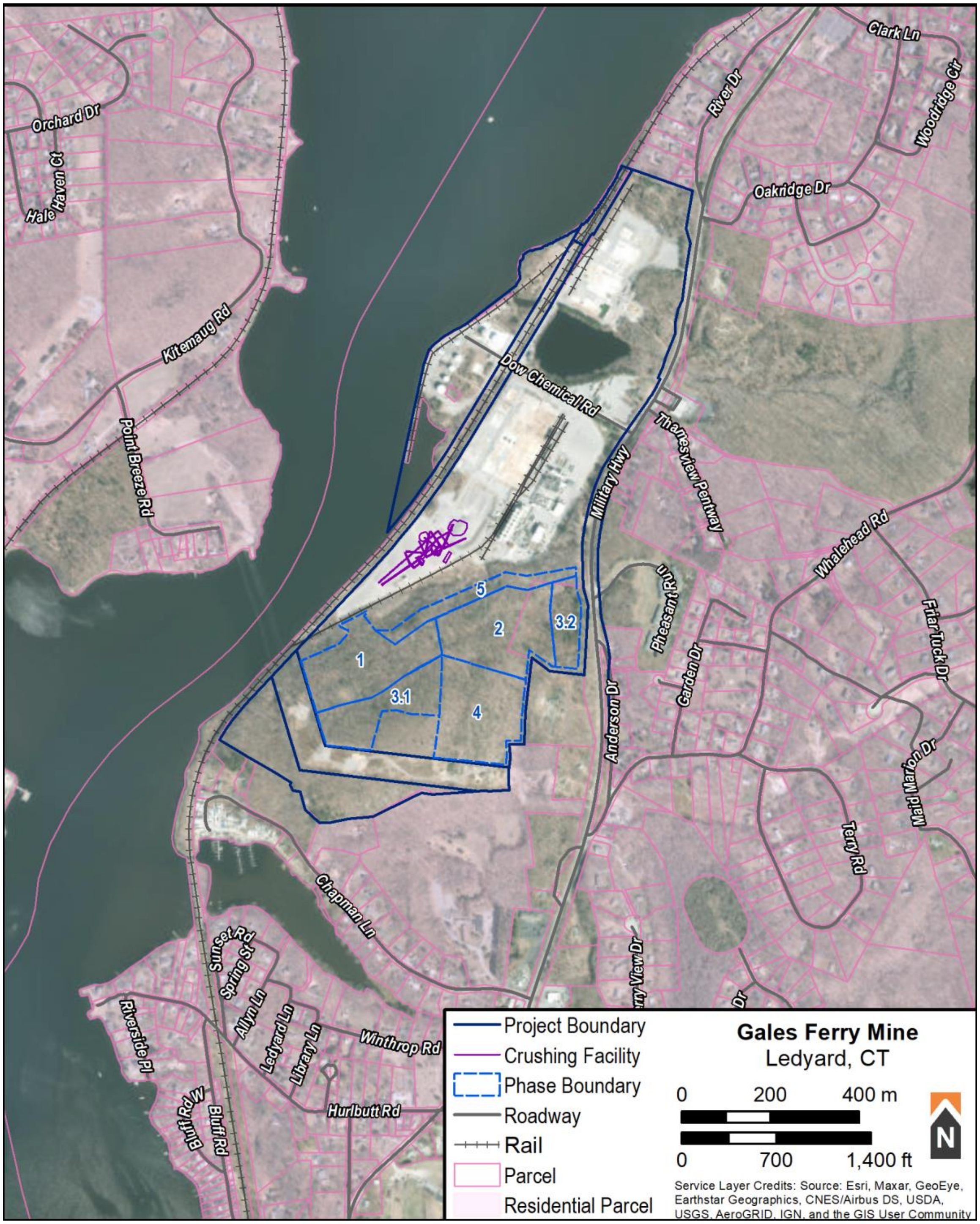

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FIGURE 1: PROJECT AREA MAP

3.0 NOISE STANDARD

The Project is located in Ledyard, Connecticut. The town of Ledyard zoning ordinance does not specify permissible noise limits for industrial activities. It does require wind energy projects to comply at the nearest property line with the requirements of the Connecticut Regulations for the Control of Noise and Connecticut General Statutes Title 22a Chapter 442.

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

The Project parcel classifies as a Class C Noise Zone and is surrounded by a mix of other Class C and Class A Noise Zones. For Class C Noise Zone, the emitter cannot exceed the noise level limits at the adjacent Noise Zones provided in Table 1.

TABLE 1: CONNECTICUT CLASS C NOISE ZONE - LIMITS

	RECEPTOR NOISE ZONE			
	C	**B**	**A/DAY**	**A/NIGHT**
Class C Emitter	70 dBA	66 dBA	61 dBA	51 dBA

Daytime is defined as 7:00 am to 10:00 pm and nighttime is defined as 10:00 pm to 7:00 am. The Project will not operate at night, so the Project design goal is 61 dBA at the property line of Class A Noise Zones.

4.0 SOUND MONITORING

4.1 PROCEDURES

Background sound levels were measured at four locations around the study area during June 2024. A map of the monitoring locations is provided in Figure 2.

Equipment

Sound levels were measured using ANSI/IEC Class 1 sound level meters (Table 2). Audio recordings were also made at each location to aid in source identification and soundscape characterization. All sound level meters logged A-weighted and 1/3 octave band equivalent sound levels once each second continuously throughout the monitoring period (

Table 3).

TABLE 2: SOUND LEVEL METERS AT EACH LOCATION

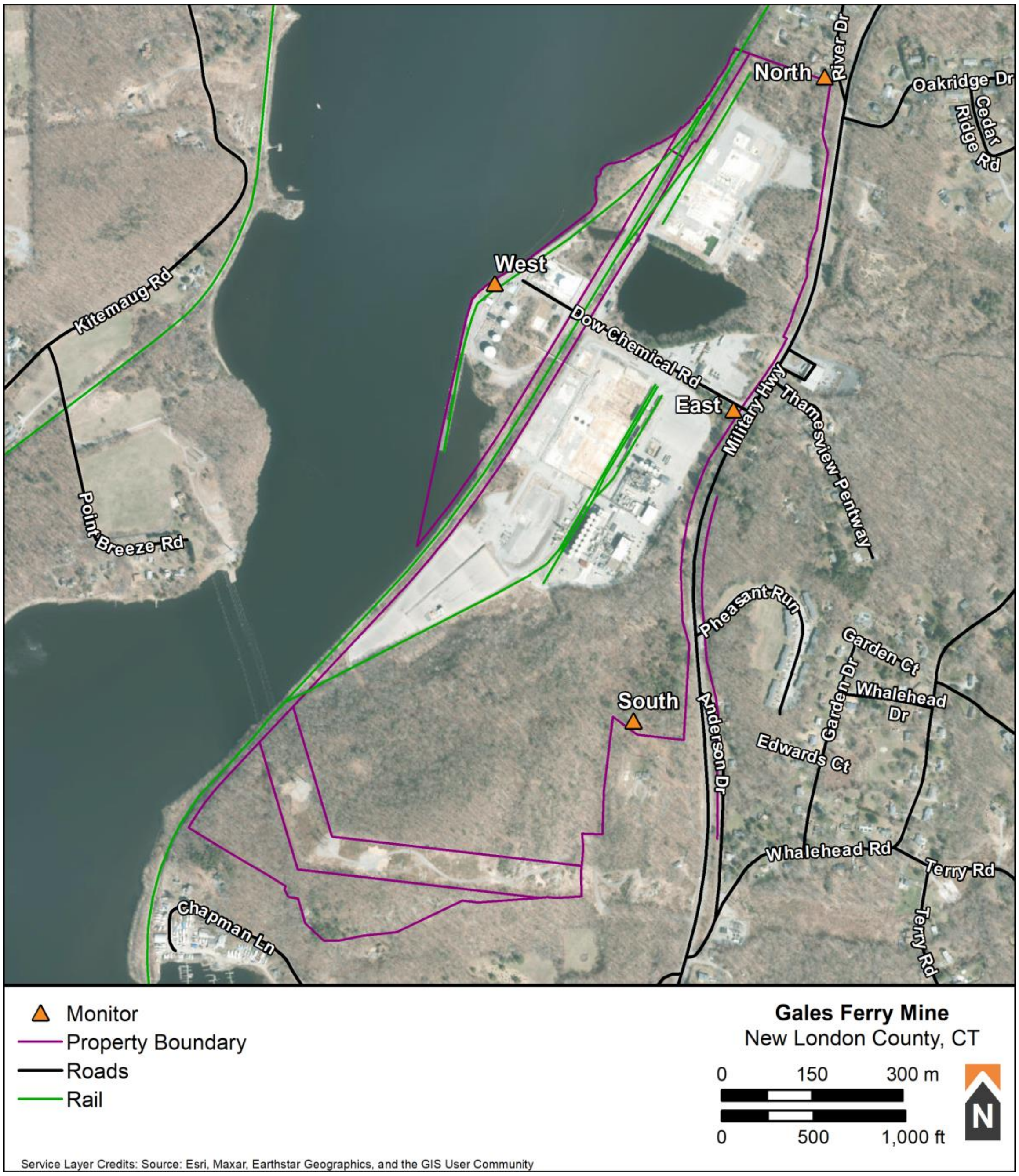
Location	Manufacturer	Model	Serial number	Last NIST-Traceable Calibration
Entrance	Cesva	SC310	T231914	04/04/2024
House	Svantek	977	97548	10/27/2024
River	Cirrus	CR171B	G303004	10/02/2023
Woods	Cesva	SC310	T235260	04/05/2024

Each sound level meter microphone was mounted on a wooden stake at a height of approximately 1.2 meters (4 feet) and covered with a seven-inch weather-resistant windscreen. The windscreen reduces the influence of wind-induced self-noise on the measurements. The sound level meters were field calibrated before and after each measurement period. Further, all calibrators were ANSI/IEC Class 1 and calibrated in a NIST-traceable lab within one year of the deployment.

Wind data was logged at each site using ONSET anemometers which recorded average wind speed and wind gust speed every minute and was installed within 20 feet of each microphone and at microphone height (~1.2 meters). Other meteorological data was taken from the National Weather Service ASOS Station at the Groton – New London Airport in Groton, Connecticut, approximately 8 miles south.

TABLE 3: SOUND MONITORING START, END, AND DURATION AT EACH LOCATION

Location	Start	End	Duration
Entrance	06/07/2024	06/20/2024	13.0 days
House	06/07/2024	06/21/2024	13.9 days
River	06/07/2024	06/17/2024	9.6 days
Woods	06/07/2024	06/16/2024	9.4 days



Service Layer Credits: Source: Esri, Maxar, Earthstar Geographics, and the GIS User Community

FIGURE 2: BACKGROUND SOUND MONITORING LOCATIONS

4.2 MONITORING LOCATIONS

Sound monitors were set up at locations on the north, south, east, and west property boundaries.

The goal in selecting monitoring locations was to capture representative soundscapes in the proposed project area, which is primarily affected by varying traffic volumes and land uses.

The characteristics of the four selected sound monitoring locations are as follows.

Entrance Monitor

The Entrance Monitor was located on the eastern property boundary, at the intersection of Dow Chemical Road, 10 meters north, and the heavily travelled Route 12, 20 meters east (Figure 3). The surrounding area is the commercial project area to the west and a wooded residential area to the east, the nearest residence being 50 meters east of the monitor. The nearest train tracks are 300 meters northwest.

The soundscape was primarily composed of passing vehicles, industrial noise, and bird and insect noise. While there were passing vehicles at all hours, there was a higher volume of vehicles during the day, especially during morning and evening rush hour. Because of the stoplight, vehicles at this location were observed idling at red lights and accelerating during both yellow and green light changes. Many of the vehicles observed along Dow Chemical Road were commercial vehicles, including 18-wheelers and work trucks. The industrial noise included machine operations at the Americas Styrenics (“AmSty”) plant on the property and vehicles’ backup alarms. The nearby trees and tall grasses could be heard on windy days. There was an audible train that passed one or two times at night, and all instances were scrubbed from the data analysis.

FIGURE 3: ENTRANCE MONITOR, FACING NORTHEAST

House Monitor

The House Monitor was located on the northern property boundary at 3 River Drive, Gales Ferry, CT. This monitor was placed adjacent to the fence to the south of the residence (Figure 4) and had a direct line of site to both River Drive, 20 meters east, and the heavily travelled Route 12, which is 35 meters east. The surrounding area is primarily wooded area to the south and residential property to the north, the nearest residence being 30 meters north of the monitor location. The nearest train tracks are 140 meters west.

The soundscape was primarily comprised of passing vehicles and bird and insect noise. Most of the passing vehicles were from Route 12, and while there were passing vehicles at all hours, there was a higher volume of vehicles during the day, especially during morning and evening rush hour. The trees could often be heard rustling in the wind. There was no observed industrial noise from the property. There was an audible train that passed one or two times at night, and all instances were removed from the data analysis.

FIGURE 4: HOUSE MONITOR, FACING EAST

River Monitor

The River Monitor was located on the western property boundary of the site, between the train tracks and the river (Figure 5). The Thames River is east of the monitor location, and the commercial project area is to the east, with the nearest stacks from AmSty being 450 meters southeast. The nearest train tracks are 140 meters northwest.

The soundscape was comprised of bird and insect sound, boats passing along the Thames, industrial noise, waves on the river on windier days, and work operations at the dock. When workers entered the dock area the motorized gate was audible, and work trucks were often left idling in the area. The site ran crane operations at the dock on June 12th and 13th, which was removed from the data analysis. According to the Gales Ferry Intermodal representative on site, the owner’s affiliate has loading/unloading crane operations once a month, and AmSty has crane operations two to three times per month. There was an audible train that passed one or two times at night, and all instances were removed from the data analysis.

FIGURE 5: RIVER MONITOR, FACING SOUTHWEST

Woods Monitor

The Woods monitor was located on the southern property boundary of the site, closest to the proposed regrading site. The monitor was north of the rock wall that marked the property boundary and was in the middle of a moderately forested area (Figure 6). The nearest train tracks are 440 meters west. Route 12 is 110 meters to the east, and the residence that shares the southern property line is 85 meters away from the monitor location.

The soundscape was primarily comprised of bird and insect noise, wind through the trees, and industrial noise during the day. Route 12 was also audible from this location. There was an audible train that passed one or two times at night, and all instances were removed from the data analysis.

FIGURE 6: WOODS MONITOR, FACING SOUTH

4.3 DATA ANALYSIS

Data were excluded under the following conditions:

- Wind gust speeds above 5 m/s (11 mph)
- Temperatures below -10° C (14° F) (outside the specification of the sound level meters)
- Precipitation in the form of rain, sleet, or ice
- Thunder
- Humidity outside the specifications of the sound level meter
- Anomalous sounds that were out of character for the area being monitored
- Seasonal sound sources such as harvesting equipment, lawn mowers, and snow removal equipment, and

- Equipment interactions by field staff during microphone calibration and maintenance.

Precipitation events were obtained from Groton – New London Airport and were corroborated through both analysis of sound level spectrograms and from audio recordings.

The remaining one-second sound level data from each monitor were energy-averaged into 10-minute periods and summarized over the entire monitoring period. Statistical levels were calculated from the one-second equivalent continuous sound level (L_{eq}) data.

Results

An overall summary of the long-term sound monitoring results is provided in Table 4, for the A-weighted sound levels. Sound levels for each location are summarized into overall, daytime, and nighttime levels for the equivalent continuous (L_{eq}),[1] lower 10th percentile (L_{90}), median (L_{50}), and upper 10th percentile (L_{10}).

Figures 7 through 10 show the time-history for each sound monitoring location. For display purposes, the one second data that was collected is displayed in 10-minute summarized values in the time history-graphs to show overall trends. Sound levels are plotted along with ambient temperature and wind speed to show relating trends. Time periods during which data was removed for the sound level summary presented in are indicated with color-coded markers. Sound level data during periods when the entire 10-minute interval was excluded for wind, rain, or anomalies are still present in these graphs as lighter colors, with the darker colors representing 10-minute intervals where there were no data exclusions or only partial data exclusions.[2] The duration of each time history graph is one week, and each graph exhibits day/night shading where night is defined as 22:00 to 7:00 and shaded grey.

TABLE 4: SUMMARY OF BACKGROUND SOUND LEVELS BY MONITOR

Monitor	Sound Level (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}
Entrance	64	49	58	68	65	52	62	68	61	48	51	65
House	56	40	53	59	57	47	55	60	52	37	44	56
River	43	36	40	44	44	38	41	45	41	36	38	43
Woods	47	44	46	48	47	44	46	49	45	43	45	46
Average	52	42	49	55	53	45	51	55	50	41	44	53

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[1] The equivalent continuous level is level based on the pressure average across the time period.

[2] For some 10-minute periods, shorter durations within the 10-minutes are excluded due to wind, rain, or anomalies, but the rest of the 10-minute interval is still used in the summary. These periods are shown in the darker colors (L_{eq} and L_{90}) as only some of the 10-minute period was excluded.

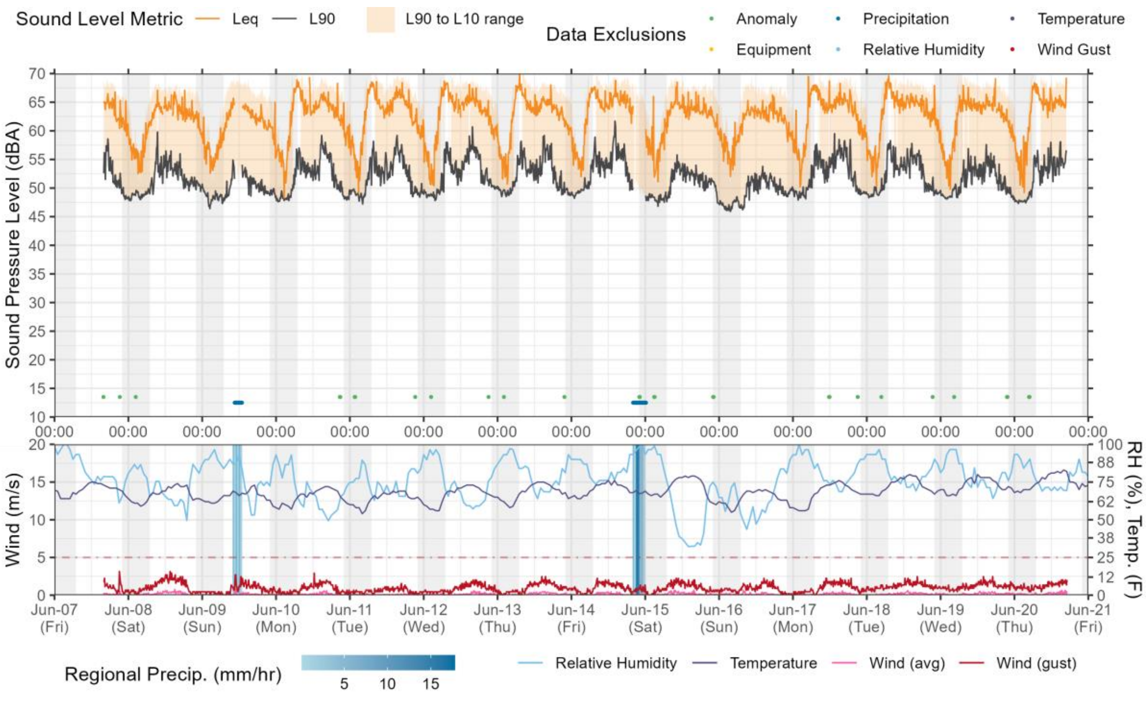

FIGURE 7: ENTRANCE MONITOR SOUND LEVELS AND METEOROLOGY

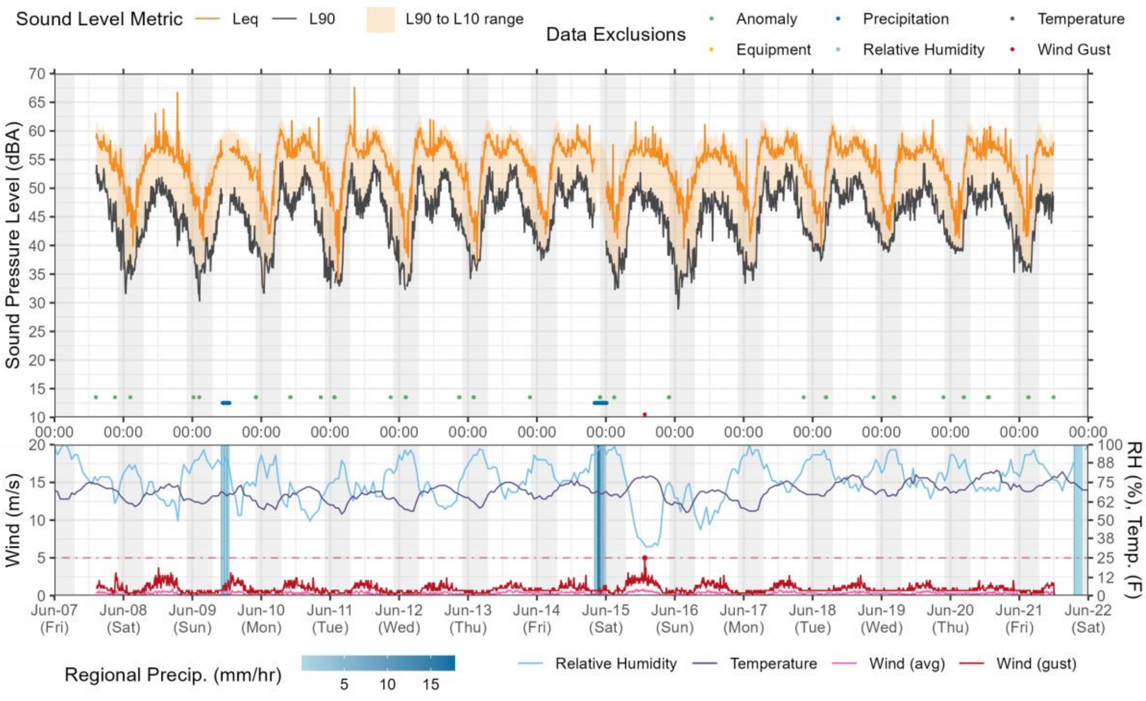

FIGURE 8: HOUSE MONITOR SOUND LEVELS AND METEOROLOGY

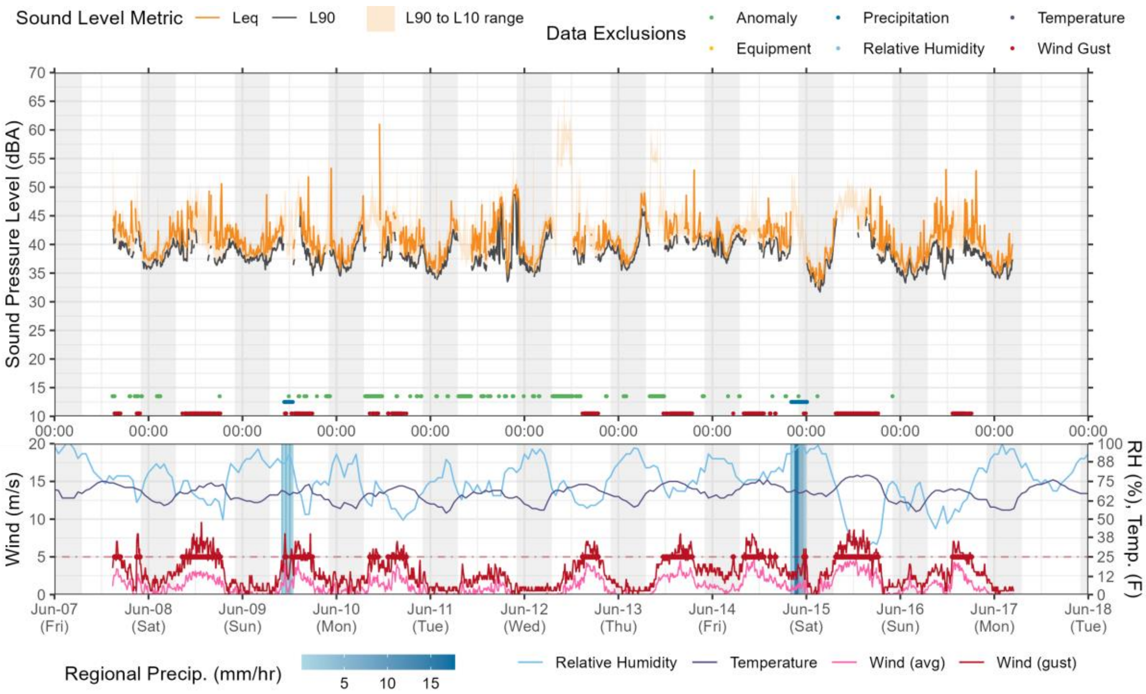

FIGURE 9: RIVER MONITOR SOUND LEVELS AND METEOROLOGY

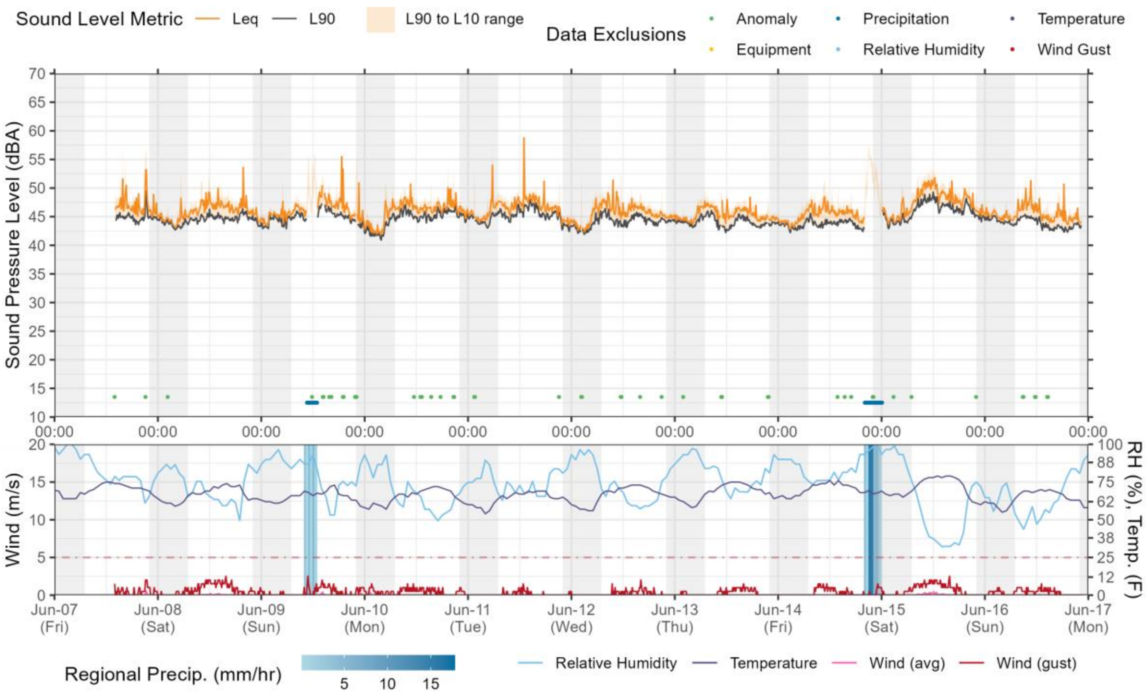

FIGURE 10: WOODS MONITOR SOUND LEVELS AND METEOROLOGY

5.0 SOUND PROPAGATION MODELING

5.1 MODELING PROCEDURE

Modeling for the project was completed using the International Standards Organization ISO 9613-2 standard, “Acoustics – Attenuation of sound during propagation outdoors, Part 2: General Method of Calculation,” as implemented in the Cadna/A acoustical modeling software. ISO 9613-2 is an internationally accepted acoustics standard, used by many other noise control professionals in the United States and abroad.

> 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 methodology takes into account source sound power levels, surface reflection and absorption, atmospheric absorption, geometric divergence, meteorological conditions, walls, barriers, berms, and terrain.

For this study, we modeled sound propagation in accordance with ISO 9613-2 with spectral ground attenuation, with reflective ground (G=0) within the extraction and processing areas and over the river, and porous ground (G=1) elsewhere.

A 10-meter by 10-meter (33-foot by 33-foot) grid of 1.5 meter (4 foot) high receivers was set up in the model, covering approximately 3,300 acres (5.2 square mile) around the site. A receiver is a point above the ground at which the computer model calculates a sound level.

We assumed the following equipment in the extraction area would be operating at maximum capacity simultaneously:

- A crushing plant, containing one jaw crusher, two cone crushers and three screening decks, along with conveyance and loaders.[3] After Phase 1, the primary jaw crusher is located within the excavation area.
- At the stockpiles, a loader loading the crusher and moving to and from the stockpiles,

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[3] The sound power levels of the secondary and tertiary crushers are based on a measurement that included both crushers operating with screening and loading. Each crusher was conservatively modeled with this sound power level. The sound power level of the jaw crusher was similar based on a measurement with loading and screening occurring simultaneously.

- A tracked top-hammer rock drill. In each modeled phase, the drill was placed at the highest representative location within the phase.
- At the floor of the excavation, a loader, excavator, and an excavator mounted rock hammer.
- Dump trucks on the internal roads.

In addition, we included the stockpiles of processed materials, at an average height of 6.1 meters as berms in the model.

The sound power levels (sound emissions) from each source are derived from measurements taken by RSG or other consultants of similar equipment operating for other projects. The exception is the sound emissions from a dump truck and loader were taken from the Federal Highway Administration's Roadway Construction Noise Model. A table of sound power levels are provided in Appendix B.

5.2 MODEL RESULTS

The results of the sound propagation modeling are shown for seven phases of industrial regrading operations:

- The start of Phase 1 (Figure 11)
- The start of Phase 2 (Figure 12)
- The start of Phase 3a (Figure 13)
- The start of Phase 3b (Figure 14)
- The start of Phase 4 (Figure 15)
- The start of Phase 5 (Figure 16), and
- The end of Phase 5 (Figure 17).

In each figure, the projected sound levels are represented by colored isolines expressed in A-weighted decibels (dBA). The 70 dBA isoline, which represents the Connecticut noise limit for industrial lands is shown in dark red. The 61 dBA isoline is shown as a dashed pink line. In all cases, the 61 dBA contour does not encroach into residential lands. This indicates that the Connecticut noise limit is modeled to be met at and within all residentially zoned property boundaries.

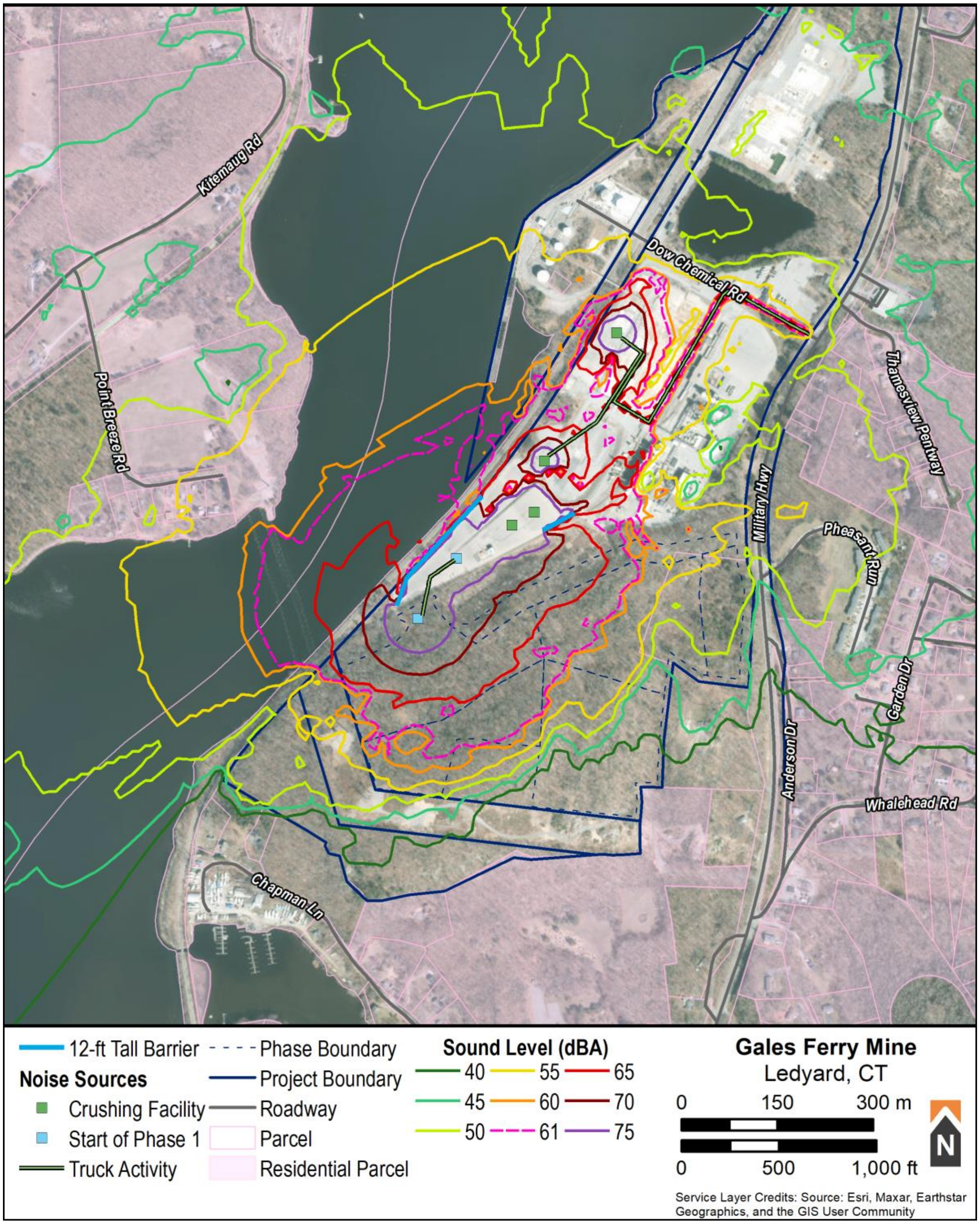

FIGURE 11: SOUND MODELING RESULTS – START OF PHASE 1

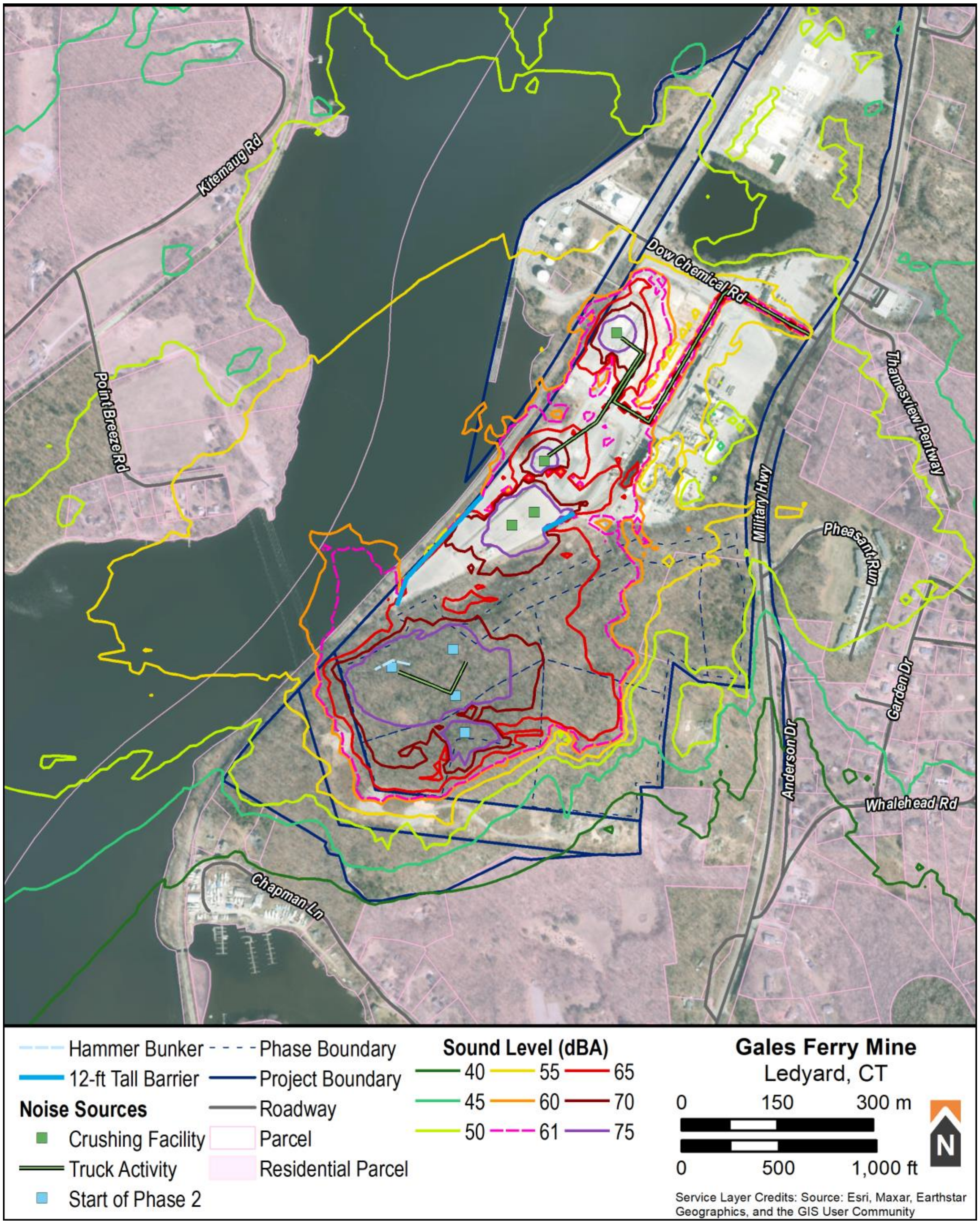

FIGURE 12: SOUND MODELING RESULTS – START OF PHASE 2

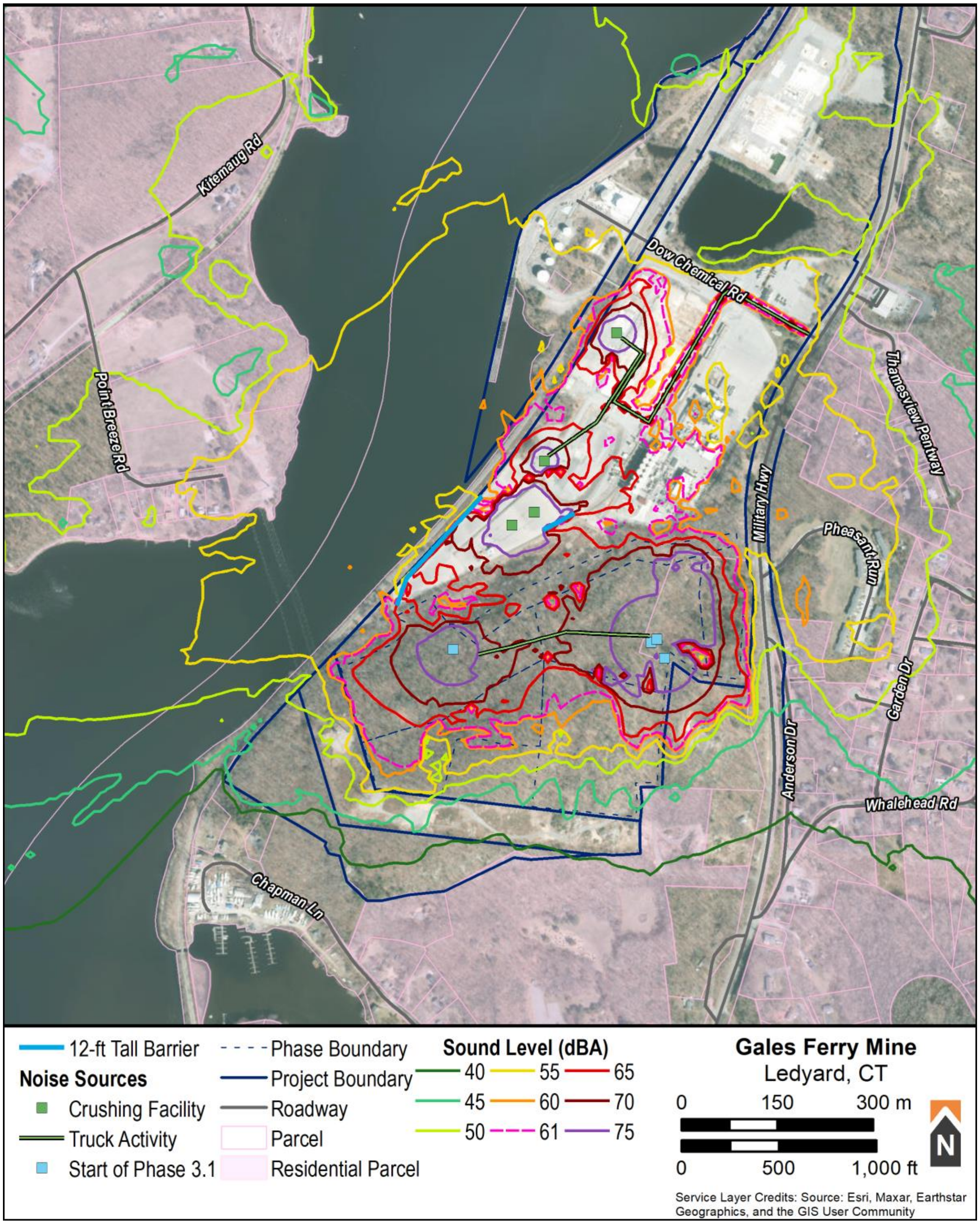

FIGURE 13: SOUND MODELING RESULTS – START OF PHASE 3.1

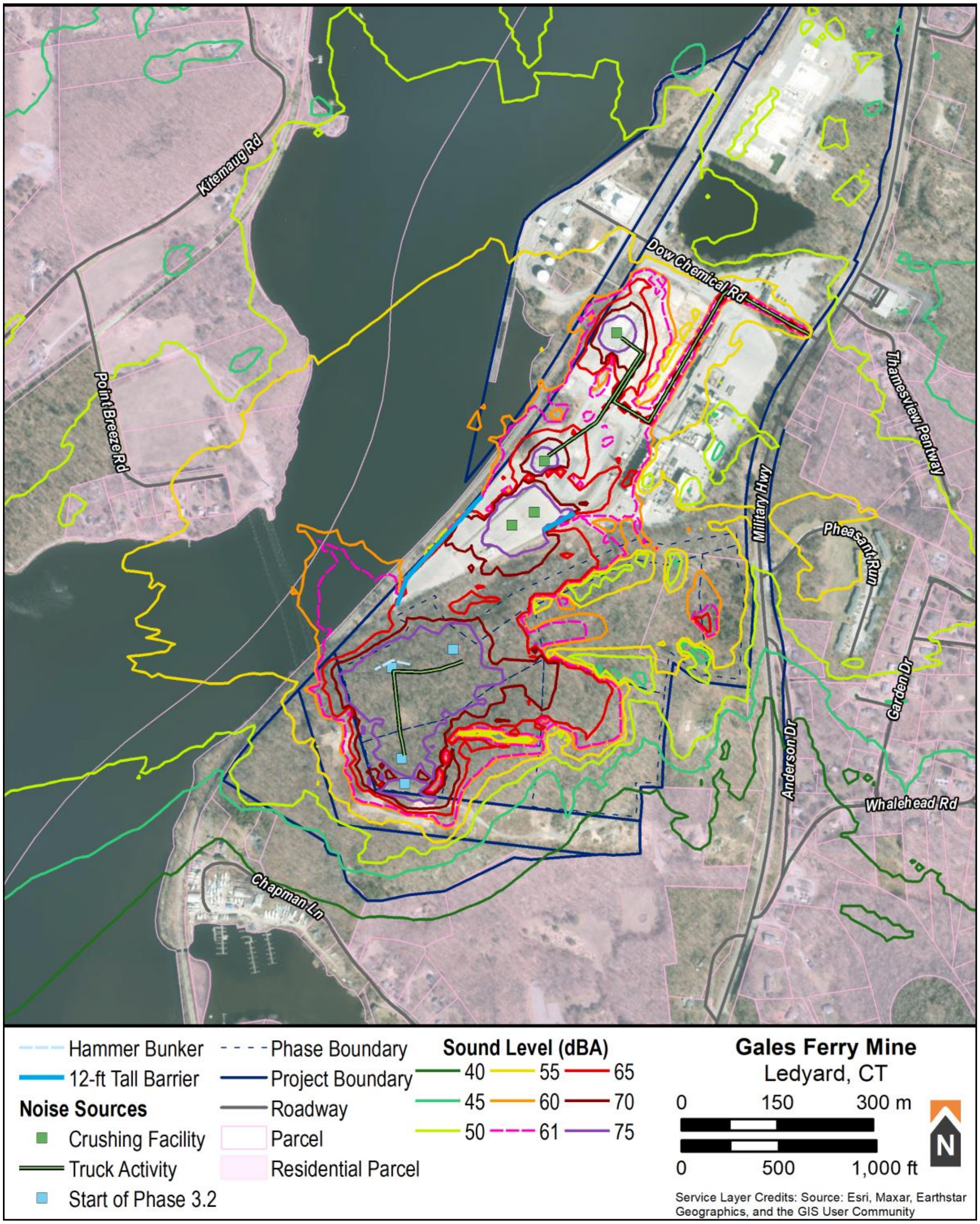

FIGURE 14: SOUND MODELING RESULTS – START OF PHASE 3.2

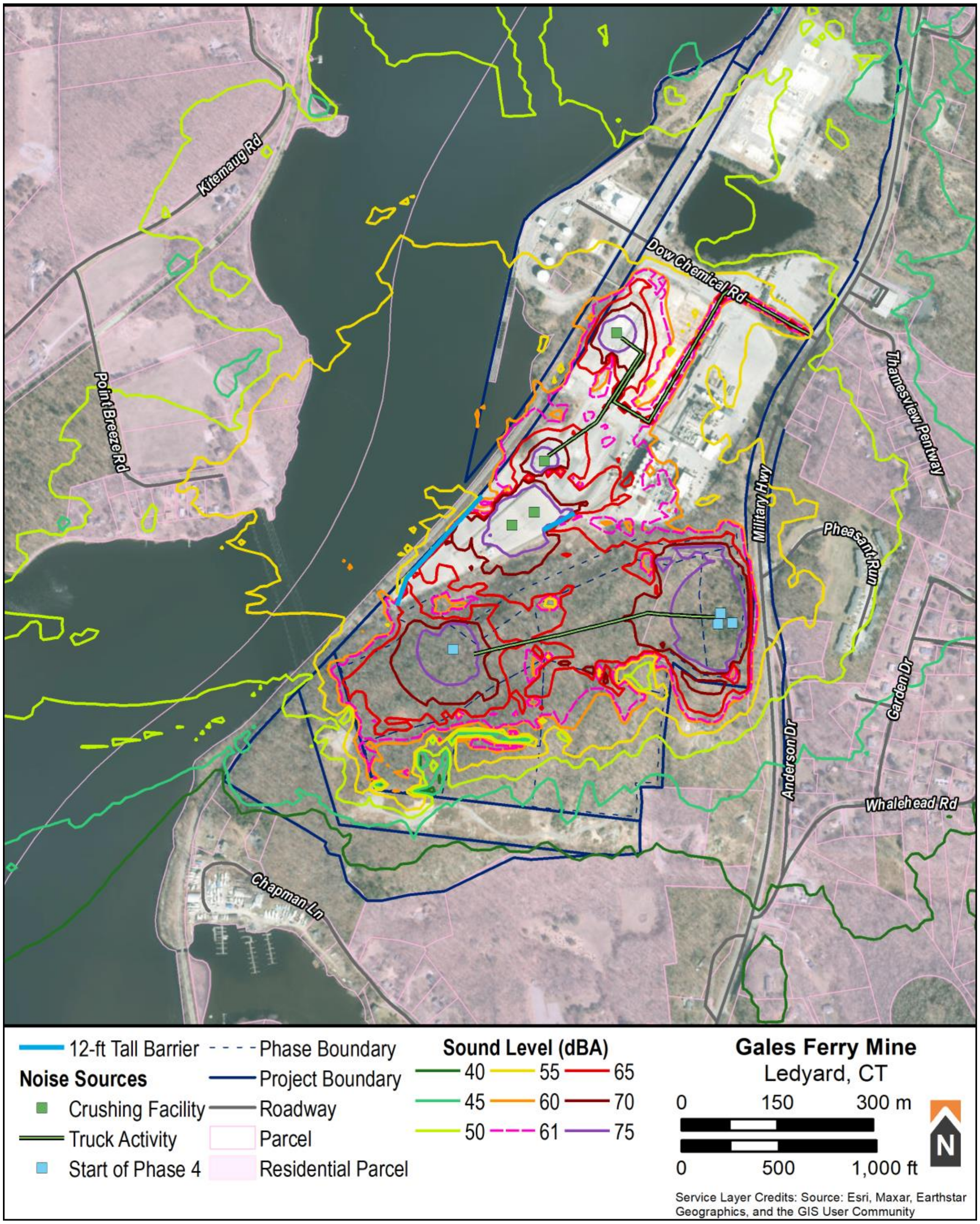

FIGURE 15: SOUND MODELING RESULTS – START OF PHASE 4

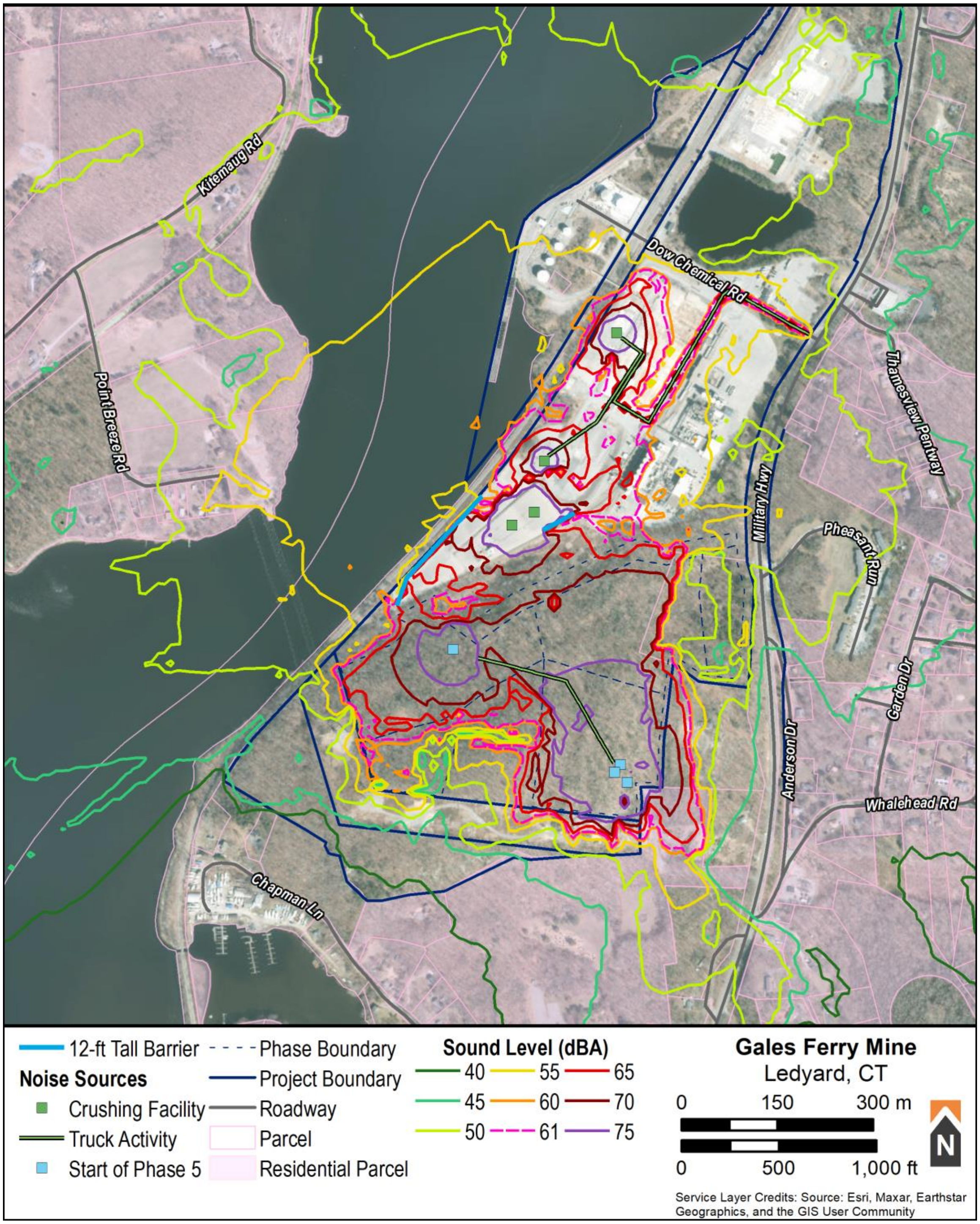

FIGURE 16: SOUND MODELING RESULTS – START OF PHASE 5

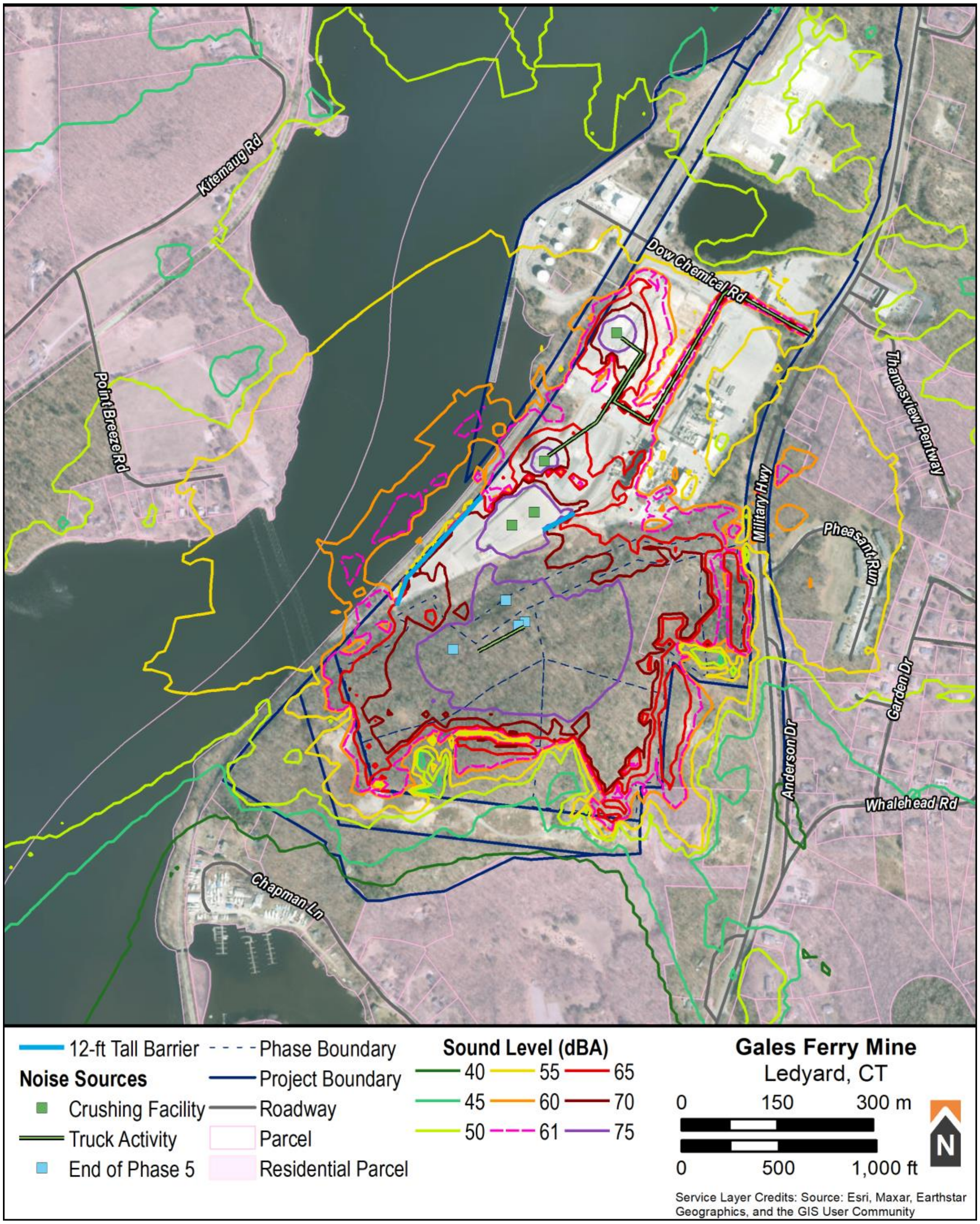

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FIGURE 17: SOUND MODELING RESULTS – END OF PHASE 5

6.0 RECOMMENDED MITIGATION

There are several mitigation measures that have been included in the model that are required to meet the 61 dBA noise limit at residential lands.

1. Provide a 12-foot high sound barrier along a portion of the railroad tracks to the west of the crushing area.
2. During Phases 1 and 3.1, provide a bunkered area for rock hammering. The bunker would have 12-foot high noise barrier on the side facing the river.
3. During Phase 5 provide a 16-foot high berm west of Route 12 (Military Highway).

In addition, several steps can be taken to minimize noise impacts, including:

1) Fitting on-site equipment with “white-noise” or similar low-impact backup alarms (such as radar activated or variable loudness), to the extent allowed by MSHA. These backup alarms make a high-frequency broadband sound that is more directional and attenuate faster with distance than conventional tonal alarms.
2) Providing a one-way circulation plan for loading trucks to avoid the sounding of backup alarms.
3) Using “down-the-hole” drills when practical to reduce drilling noise. While quieter, these drills can only be used in specific terrain and thus are not practical for use at all times during the life of the extraction.
4) Providing neighbors that request it the name and phone number of a site supervisor to report noise complaints.

7.0 SUMMARY AND CONCLUSIONS

Gales Ferry Intermodal, LLC is proposing to excavate stone at an intermodal industrial facility in Ledyard, CT. RSG conducted sound monitoring and sound propagation modeling to forecast the Project's operational sound levels.

Our summary and conclusions are as follows:

1. Sound monitoring was conducted at four locations over nine to thirteen days to quantify the existing sound levels across the Project area. The primary sound sources in the existing soundscape include vehicle traffic along Route 12, existing industrial activity in the Project parcel along Dow Chemical Road, and bird and insect noise. The highest average daytime sound levels were along Route 12 at 65 dBA and the lowest was along the river at 44 dBA.
2. The primary sound sources from the proposed excavation include truck and loader activity, a rock drill, a rock hammer, machine crusher, and the crushing facility, which include primary, secondary, and tertiary, crushers and screening decks as well as material loading, storage, and transport.
3. The project incorporates several design features to minimize noise impacts, including an excavation direction that maximizes the effectiveness of the existing terrain to attenuate sound, placing topsoil and processed material storage areas to attenuate sound transmission to the community, and incorporating low-impact backup alarms on all operator-owned equipment, to the extent allowed by MSHA.
4. In addition, we recommend the construction of a bunker for rock hammering during the early phases of the project and two 12-foot noise walls along portions of the exterior of the crushing area, and a berm along portions Route 12 during the final phases of excavation.
5. With these mitigation steps in place, sound propagation modeling of the proposed excavation was conducted in accordance with the international standard, ISO 9613-2.
6. The results show that all residential properties are modeled to have project sound levels at or below Connecticut's 61 dBA daytime residential noise limit.

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”).[4] 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 18.

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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[4] 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 18: 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 19, 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.

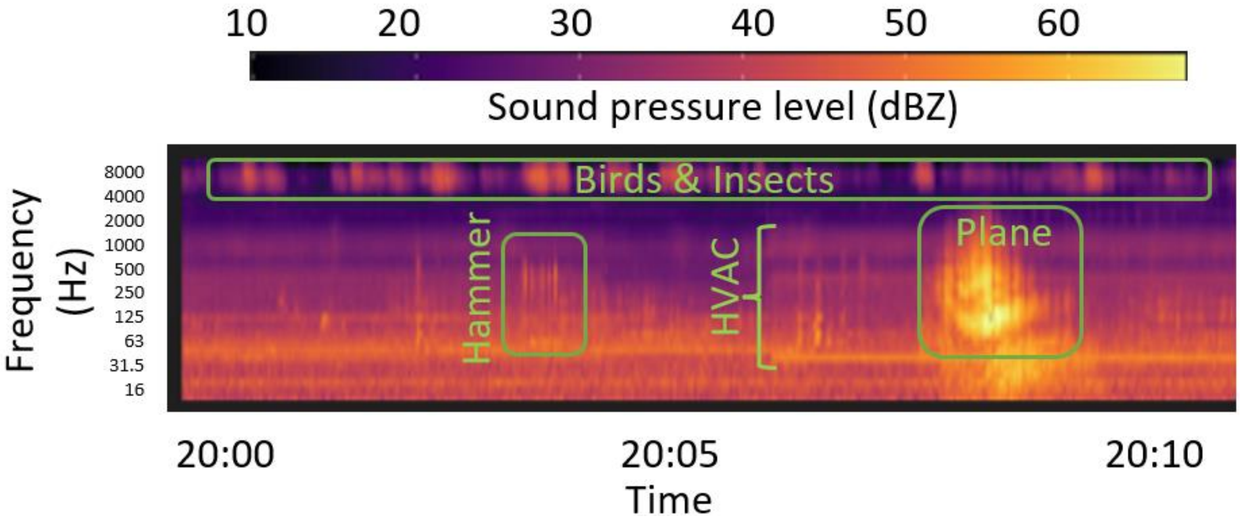

FIGURE 19: AN EXAMPLE OF A SOUND SPECTROGRAM WITH ANNOTATIONS

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.[5] 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 20. The sound level at each instant of time is the grey trace going from left to right. Over the total time it was measured (1 hour in the figure), the sound energy spends certain fractions of time near various levels, ranging from the minimum (about 27 dB in the figure) to the maximum (about 65 dB in the figure). The simplest descriptor is the average sound level, known as the Equivalent Continuous Sound Level. Statistical levels are used to determine for what percentage of time the sound is louder than any given level. These levels are described in the following sections.

Equivalent Continuous Sound Level - L_{eq}

One straightforward, common way of describing sound levels is in terms of the Continuous Equivalent Sound Level, or L_{eq}. The L_{eq} is the average sound pressure level over a defined period of time, such as one hour or one day. L_{eq} is the most commonly used descriptor in noise

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

standards and regulations. L_{eq} is representative of the overall sound to which a person is exposed. Because of the logarithmic calculation of decibels, L_{eq} tends to favor higher sound levels: loud and infrequent sources have a larger impact on the resulting average sound level than quieter but more frequent sounds. For example, in Figure 20, even though the sound levels spends most of the time near about 34 dBA, the L_{eq} is 41 dBA, having been “inflated” by the maximum level of 65 dBA and other occasional spikes over the course of the hour.

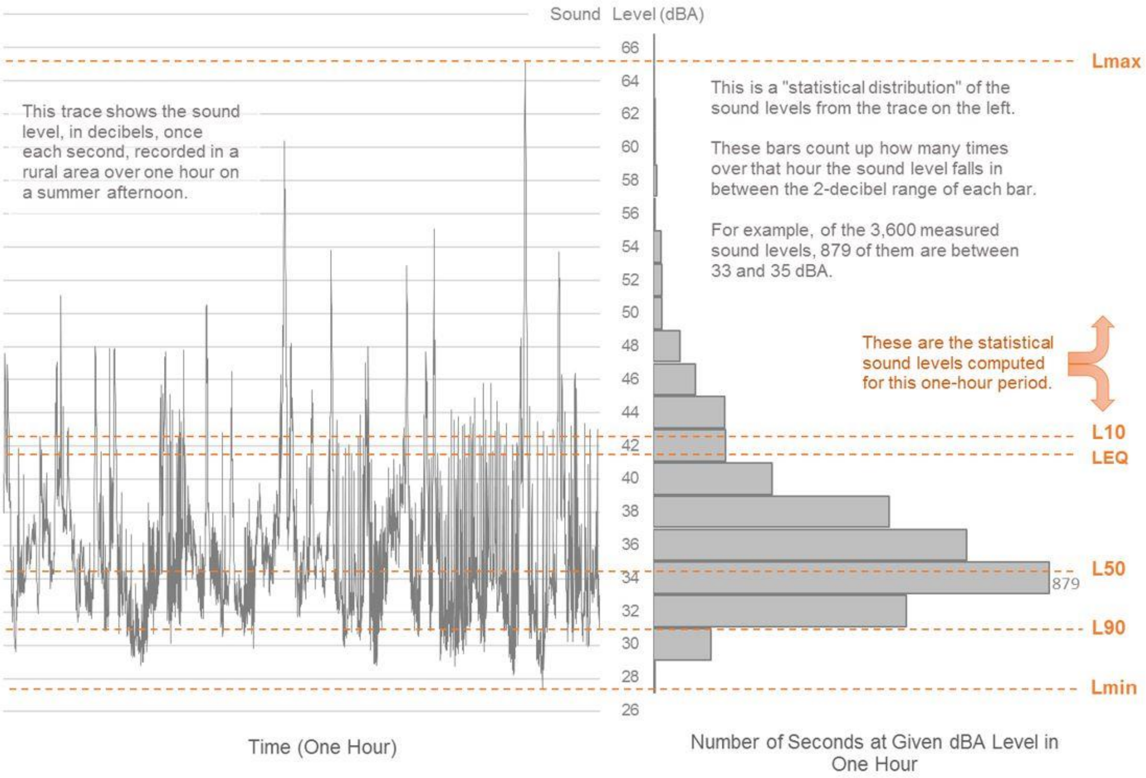

FIGURE 20: EXAMPLE OF DESCRIPTIVE TERMS OF SOUND MEASUREMENT OVER TIME

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. MODEL INPUT DATA

TABLE 5: MODEL PARAMETER SETTING

Model Parameter	Setting
Atmospheric Absorption	Based on 10°C and 70% RH
Foliage	No Foliage Attenuation
Ground Absorption	ISO 9613-2 spectral, G=0 for water and extraction and processing areas and G=1 elsewhere
Receiver Height	1.5 meters for sound level isolines and discrete receptors
Search Radius	2,000 meters from each source

TABLE 6: MODELED L_{eq} SOUND POWER SPECTRA

SOURCE	SOUND POWER (dBZ) BY OCTAVE BAND CENTER FREQUENCY (Hz)									OVERALL SOUND POWER LEVEL		REFERENCE
	31.5	63	125	250	500	1000	2000	4000	8000	dBA	dBZ	
Primary Crusher	106	120	122	119	115	113	110	103	94	118	126	RSG Measured Data
Crushing Facility: 2 cone crushers w/ screening	76	91	99	104	106	112	112	110	105	117	117	J. Slade Measured Data
Haul Truck	106	114	114	102	103	105	104	98	89	110	118	RSG Measured Data
Excavator	108	113	116	112	110	108	107	101	91	113	120	RSG Measured Data
Rock Hammer	145	138	133	13	122	118	115	112	106	126	146	RSG Measured Data
Rock Drill	66	83	87	95	106	108	116	117	118	122	122	J.Slade Measured Data
Loader: Loading	104	114	115	117	110	104	100	96	90	112	121	RSG Measured Data
Dump Truck: Driving	32	60	78	90	99	14	103	98	89	108	109	FHWA RCNM
Loader: Driving	66	80	91	102	99	103	98	93	87	106	107	FHWA RCNM

TABLE 7: POINT SOURCES BY PHASE

SOURCE	PHASE	X	Y	Z
Jaw Crusher and Loader	1	743564	4591636	8.9
	2 to 5	743472	4591442	8.6
Secondary Crusher/Screener/Loader	All	743564	4591636	8.9
Tertiary Crusher/Screener	All	743599	4591656	9.8
Haul Truck, stockpiles	All	743614	4591736	5.2
Excavator	2	743476	4591369	9.7
	3.1	743782	4591452	12.9
	3.2	743391	4591271	11.1
	4	743886	4591482	12.8
	5 beginning	743584	4591485	9.9
	5 end	743733	4591261	13.4
Rock Hammer	2	743376	4591413	7.1
	3.1	743791	4591457	11.2
	3.2	743376	4591413	7.1
	4	743890	4591498	11.8
	5 beginning	743725	4591249	12.4
	5 end	743574	4591479	8.9
Rock Drill	1	743416	4591490	14.1
	2	743490	4591312	60.1
	3.1	743803	4591427	43.6
	3.2	743396	4591231	58.9
	4	743909	4591483	28.4
	5 beginning	743744	4591233	43.6
	5 end	743554	4591518	24.6
Storage Pile Loader	All	743728	4591937	11.4

TABLE 8: LINE SOURCES

SOURCE	LOCATION
Dump Trucks	Processed material stockpiles to Route 12
Loader	Excavation face to crusher and hammer bunker (phases 2 beginning, 3.2 beginning)
Loader	From crusher stockpiles to processed material stockpiles