PL16-0097

RAMBOLL

ENVIRONMENT
& HEALTH

KRISTEN WALLACE

Senior Managing Consultant

Summary of Experience/Expertise
Kristen Wallace has more than 24 years of experience managing and conducting environmental noise studies. These studies have included compliance determinations, impact assessments, and investigations of mitigation measures for a variety of proposed developments and actions for private developers and government agencies. Projects have included evaluation of noise from power highway and transit sources, power generation facilities, mines, ports, industrial facilities, and urban centers. The results of these analyses have been included in documentation ranging from simple compliance assessment reports to monitoring and management plans, and various state (e.g., SEPA, CEQA) and National Environmental Policy Act (NEPA) environmental impact statements/reports.

EDUCATION

MS, Aerospace Engineering
University of Cincinnati, Cincinnati, Ohio, United States

BA, Mathematics and History
College of Idaho, Caldwell, Idaho, United States

EXPERIENCE

North Bend Gravel Operation EIS Review and Supplemental Analysis, Washington, USA
Asked by King County and URS to provide a third-party review of the noise analysis included in the DEIS and FEIS for the proposed North Bend Gravel Operation near North Bend, Washington. Subsequently conducted a supplemental noise analysis, which included additional sound level measurements, updated noise modeling of on-site noise sources, updated modeling of off-site truck traffic, and completion of a new noise section for an addendum to the EIS. Subsequent to the publishing of the EIS Addendum, provided assistance to King County's prosecuting attorney in responding to a challenge to the County's approval of a grading permit for the operation.

Maury Island Gravel Mine, Washington, USA
Conducted a noise analysis for the expansion of an existing sand and gravel pit on Maury Island, Washington. As part of the analysis, modeled future sound levels and suggested noise mitigation measures. The noise technical report was attached to an expanded SEPA checklist. Subsequently assisted in responding to public comments on the Maury Island Gravel Mine EIS, assessed the noise impacts of extending the length of the loading pier for a supplemental EIS, and provided testimony to the Shoreline Hearings Board regarding environmental noise issues.

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Snoqualmie Hard Rock, Washington, USA
Conducted the environmental noise analysis and oversaw the air quality analysis for the expansion of existing operations at the Glacier Northwest Snoqualmie Sand and Gravel Pit to include hard rock mining. The proposed action would add drilling, blasting, and rock screening to the existing crushing, screening, batch processing, and hauling. The results of both the air quality and noise studies were included in an expanded SEPA checklist. Provided testimony on noise issues at the permit hearing. Subsequently developed and implemented a noise monitoring plan in response to a condition imposed on the permit.

Gold Mine Expansion, Guerrero, Mexico
Conducted the noise and vibration analyses for a proposed expansion of an existing gold mine located in the state of Guerrero in Mexico. For the noise impact assessment, used baseline sound level data captured for the initial project to characterize the affected environment. Modeled the sound levels of the excavation activities and transport of materials at the nearest villages to the mine. The noise assessment was completed to assess compliance with the International Finance Corporation's performance standards for noise. The analysis included an assessment of potential ground-borne vibration impacts from blasting. Results of the analyses were included in a technical report provided to the client for use in ESIA documentation.

Gateway Pacific Terminal, Washington, USA
Conducted the environmental noise impact and mitigation analyses for the Gateway Pacific Terminal, a proposed multi-commodity export/import facility in northwest Washington. Modeled sound levels used the CadnaA model to consider future project-related sound levels to identify potential impacts and mitigation measures. The evaluation extensively considered rail and locomotive noise, including the use of wayside warning horns in lieu of locomotive-mounted warning horns.

Tacoma-to-Lakewood Commuter Rail Project (D to M Street), Washington, USA
Conducted the noise and vibration impact assessments for a new section of the Sound Transit Commuter Rail line between Tacoma and Lakewood. The noise impact assessment included 24-hour sound level measurements, CadnaA noise modeling for each alternative commuter rail route and for wayside horn noise at rail/road crossings, TNM noise modeling for realigned roadways in the project vicinity, and the assessment of noise impacts using Federal Transit Administration noise impact criteria. The ground-borne vibration assessment included a screening review of the project corridor and calculations using Federal Transit Administration "general assessment" procedures to consider ground-borne vibration from both construction and operational sources. Results of these analyses were reported in a series of technical memoranda that were summarized in the SEPA/NEPA documentation for the project.

Lake Oswego to Portland Streetcar Extension, TriMet, Portland, OR.
Performed the noise and vibration analyses for an extension of the Portland streetcar system from the south downtown area to Lake Oswego. For the impact assessment, initially conducted a screening review followed by modeling assessments of the environmental noise and ground-borne vibration implications of the proposal. The reviews included visual surveys of the entire project alignment, numerous multiday measurements of existing ambient sound levels near potentially affected sensitive receivers, review of noise source specifications, CadnaA noise modeling of the project alignment, evaluation of noise and vibration mitigation measures, detailed calculations regarding construction and operational vibration sources, and technical documentation for the project NEPA EIS.

Vancouver Energy Distribution Terminal, Washington, USA
Completed the noise section for the Washington Energy Facility Site Evaluation Council (EFSEC) application and conducted an environmental noise impact assessment to be used to inform the noise section for the SEPA EIS. Conducted extensive noise modeling using CadnaA of both on-site sources and on and off-site train activities to evaluate compliance with regulatory limits and the potential for noise impacts.

PROFESSIONAL AFFILIATIONS AND ACTIVITIES
Institute for Noise Control Engineering, Member

PL16-0097

Prepared for:

Miles Sand & Gravel Company

Prepared by:

Ramboll US Corporation
Lynnwood, Washington

Kristen Wallace

Date

November 21, 2018

GRIP ROAD MINE

UPDATED NOISE AND VIBRATION STUDY

RAMBOLL

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1. INTRODUCTION

Miles Sand & Gravel Company (Miles) is proposing to mine gravel from a 68 acre parcel located in unincorporated Skagit County near Sedro Woolley, Washington. The mine is completely surrounded by Natural Resource designated land (NRL) and is situated near the north end of 726 acres of contiguously owned property. The site is currently forested, but some of the site is proposed to be logged. All material from the mine would be sold as pit run or transported to other facilities for processing.

The following report reviews noise terminology, regulatory criteria applicable to the project, and the methods and findings of the analysis.

2. TERMINOLOGY AND BACKGROUND

2.1 Noise Level Terminology and Human Hearing

The human ear responds to a very wide range of sound intensities. The decibel scale (dB) used to describe sound is a logarithmic rating system which accounts for the large differences in audible sound intensities. This scale accounts for the human perception of a doubling of loudness as an increase of 10 dB. Therefore, a 70-dB sound level will sound about twice as loud as a 60-dB sound level. People generally cannot detect differences of 1 dB; in ideal laboratory situations, differences of 2 or 3 dB can be detected by people, but such a change probably would not be detectable in an average outdoor environment. A 5-dB change would probably be perceived under normal listening conditions.

When addressing the effects of noise on people, it is useful to consider the frequency response of the human ear. Sound-measuring instruments are therefore often programmed to weight measured sounds based on the way people hear. The frequency-weighting most often used is A-weighting because it approximates the frequency response of human hearing and is highly correlated to the effects of noise on people. Measurements from instruments using this system are reported in "A-weighted decibels" or dBA. All sound levels in this evaluation are reported in A-weighted decibels.

Distance from the source, the frequency of the sound, the absorbency of the intervening ground, obstructions, and duration of the noise-producing event all affect the transmission and perception of noise. The degree of this effect also depends on who is listening and on existing sound levels.

2.2 Vibration Terminology

Vibration is an oscillatory motion that can be measured and characterized by the frequency and amplitude of waves of motion. Because it takes time for the human body to perceive and respond to vibration signals, vibration amplitude (i.e., the size of the wave of motion) is usually characterized using a "smoothed" amplitude based on the root mean square (rms). Some methodologies used for assessing potential impacts from vibration consider vibration amplitude reported as rms velocity, converted to vibration decibel levels or VdB. The typical background level in residential areas is about 50 VdB, and most people generally cannot detect levels below about 65 VdB, and generally do not consider levels below 70 VdB to be of significance. However, the duration of a vibration event has an effect on human response. Generally, as the duration of a vibration event increases, the potential for adverse human response increases. Additionally, the rate of recurrence of events can also affect human response.

3. AFFECTED ENVIRONMENT

3.1 Skagit County Noise Regulations

The project site and surrounding properties are located in unincorporated Skagit County. Chapter 9.50 of the Skagit County Code (SCC 9.50) adopts regulations established in Chapter 173-60 of the Washington Administrative Code (WAC).

Chapter 173-60 of the WAC limits the levels and durations of noise crossing property boundaries (**Table 1**). Allowable "maximum permissible" sound levels depend on the Environmental Designation of Noise Abatement (EDNA) of the source of the noise and the EDNA of the receiving property. WAC 173-60-030 stipulates that EDNA land classification shall conform to land *uses* unless a local jurisdiction has adopted a program in which EDNA classifications are based on zoning. Generally, lands of residential use are considered Class A EDNAs, commercial properties are considered Class B EDNAs, and industrial areas are considered Class C EDNAs.

Table 1. WAC Maximum Permissible Sound Levels (dBA)

EDNA of Sound Source	EDNA of Receiving Property		
	Class A Day / Night	EDNA B	EDNA C
EDNA A	55 / 45	57	60
EDNA B	57 / 47	60	65
EDNA C	60 / 50	65	70

The limitations for noise received in a Class A EDNA are reduced by 10 dBA during nighttime hours, defined as between 10 PM and 7 AM.

Source: WAC 173-60-040

The "maximum permissible" environmental noise levels in **Table 1** may be exceeded for short periods as defined in WAC 173-60-040. The allowed short-term increases are as follows: 5 dBA for no more than 15 minutes in any hour, or 10 dBA for no more than 5 minutes of any hour, or 15 dBA for no more than 1.5 minutes of any hour. These allowed short-term increases can be described in terms of noise "metrics" that represent the percentage of time certain levels are exceeded. For example, the hourly L25 metric represents the sound level that is exceeded 25 percent of the time, or 15 minutes in an hour. Similarly, the L8.3 and L2.5 are the sound levels exceeded 5 and 1.5 minutes in an hour, respectively. The maximum permissible levels are not to be exceeded by more than 15 dBA at any time, and this limit is represented by the Lmax noise metric.

The Washington Administrative Code (173-60-050) identifies a number of noise sources or activities that are exempt from the maximum permissible sound levels. The following sources are among those exempt:

- Sounds created by motor vehicles on public roads when individual vehicles are subject to performance standards regulated by WAC 173-62 (motor vehicle fleet performance standards)
- Sounds caused by motor vehicles, licensed or unlicensed, when operated off public highways, except when such sounds are received in Class A EDNAs; and
- Sounds created by warning devices not operating continuously for more than five minutes (such as back-up alarms on vehicles).

3.2 FTA Vibration Impact Criteria

There are currently no applicable vibration limits or regulations established by Skagit County. Therefore, we are applying Federal Transit Administration (FTA) vibration impact criteria in this assessment to gauge the potential for vibration impacts from the proposed mining and material transport activities.

FTA vibration impact criteria vary depending on the type of receiver and the frequency of occurrence of vibration events. FTA categorizes receiving properties as Category 1 (e.g., most sensitive, such as research facilities with vibration sensitive equipment), Category 2 (e.g., residences), and Category 3 (e.g., institutional uses such as schools, churches, etc.). For this project, groundborne vibration would have the potential to primarily affect residences (Category 2 receiving properties), and these types of properties are the focus of this assessment. The FTA vibration impact criteria for Category 2 receivers are shown in **Table 2**. [1]

[1] Federal Transit Administration, *Transit Noise and Vibration Impact Assessment*, May 2006. FTA-VA-90-1003-06.

Table 2. FTA Vibration Impact Criteria

Land Use Category	Frequent Events	Occasional Events	Infrequent Events
Category 2 - Residential	72 VdB	75 VdB	80 VdB
"Frequent Events" is defined as more than 70 vibration events of the same source per day. "Occasional Events" is defined as between 30 and 70 vibration events of the same source per day. "Infrequent Events" is defined as fewer than 30 vibration events of the same kind per day. FTA, 2006.			

3.3 Land Uses and Zoning

The proposed mining area and surrounding properties are zoned RRv and RRc-NRL (Rural Reserve and Rural Resource, respectively). Skagit County does not specifically assign an EDNA based on zoning designations, so the EDNA classification of the site and surrounding properties are based on the uses of the properties. Mining uses are typically classified as Class C EDNA noise sources and residential uses are classified as Class A EDNAs.

The applicable noise limits for a Class C EDNA noise source affecting a Class A receiver are 60 dBA during daytime hours (7 AM to 10 PM) and 50 dBA during nighttime hours (10 PM to 7 AM). Allowable short-term increases to the above levels are as described previously. Operation of the mine is generally expected to occur between 7 AM and 5 PM, Monday through Friday, but the mine could potentially operate during weekends or at night, on occasion. The applicable noise limits at the nearby receivers from mining activities would be 60 dBA during standard daytime operation and 50 dBA during potential nighttime operation.

3.4 Existing Sound Levels

In January 2018, Ramboll measured day-long sound levels at three locations representative of residences nearest the proposed mining area and access drive. The measurements were taken using Larson Davis Class 1 sound level meters (Model LxT). The meters had been factory certified within the previous 12 months and were field calibrated immediately prior to the measurements. The microphones of the meters were fitted with wind screens and set approximately 5 feet above the ground (at a typical listening height).

The sound level measurements were taken at the following locations:

- **SLM1** –onsite near northern property boundary
- **SLM2** – near the southern property boundary at the entrance of the mine site, approximately 50 feet from Grip Road
- **SLM3** –approximately 0.3 miles northwest of the site along Wildlife Acres Lane

The measured sound levels are summarized in **Table 3**, and the sound level measurement locations are depicted in **Figure 1**. Details of hourly sound level measurements can be found in Appendix A.

Table 3. Measured Existing Sound Levels (dBA)

Location	Time of Day [a]	Range of Hourly Sound Levels (dBA) [b]				
		Leq	L25	L8.3	L2.5	Lmax
SLM1	Day	32-46	32-47	33-50	33-55	40-73
	Night	33-41	32-41	35-44	37-47	47-63
	7 AM - 5 PM	32-46	32-47	33-50	33-55	40-73
SLM2	Day	46-56	32-52	37-61	52-66	71-79 [c]
	Night	43-55	31-49	33-58	41-65	70-78 [c]
	7 AM - 5 PM	52-56	36-52	52-59	59-66	72-79 [c]
SLM3	Day	32-55	32-55	34-59	37-61	45-86 [d]
	Night	31-47	31-40	33-44	35-52	42-77 [d]
	7 AM - 5 PM	32-55	32-55	34-59	37-61	49-86 [d]

(a) "Day" refers to the hours between 7 AM and 10 PM and "Night" to the hours between 10 PM and 7 AM. 7 AM to 5 PM is the standard hours of operation.

(b) The Leq is the "energy-averaged" sound level. The Lmax is the-highest measured sound level. The L2.5, L8.3, and L25 levels are defined previously in this report in the discussion of the regulatory noise limits.

(c) Although the meter was not staffed during the entire measurement event, elevated Lmax levels are likely due to truck passbys on Grip Road or wildlife (e.g., birdcalls) very near the microphone.

(d) Although the meter was not staffed during the entire measurement event, elevated Lmax levels are likely due to nearby human activity, although wildlife activity (e.g., birdcalls) very near the microphone could also result in elevated levels.

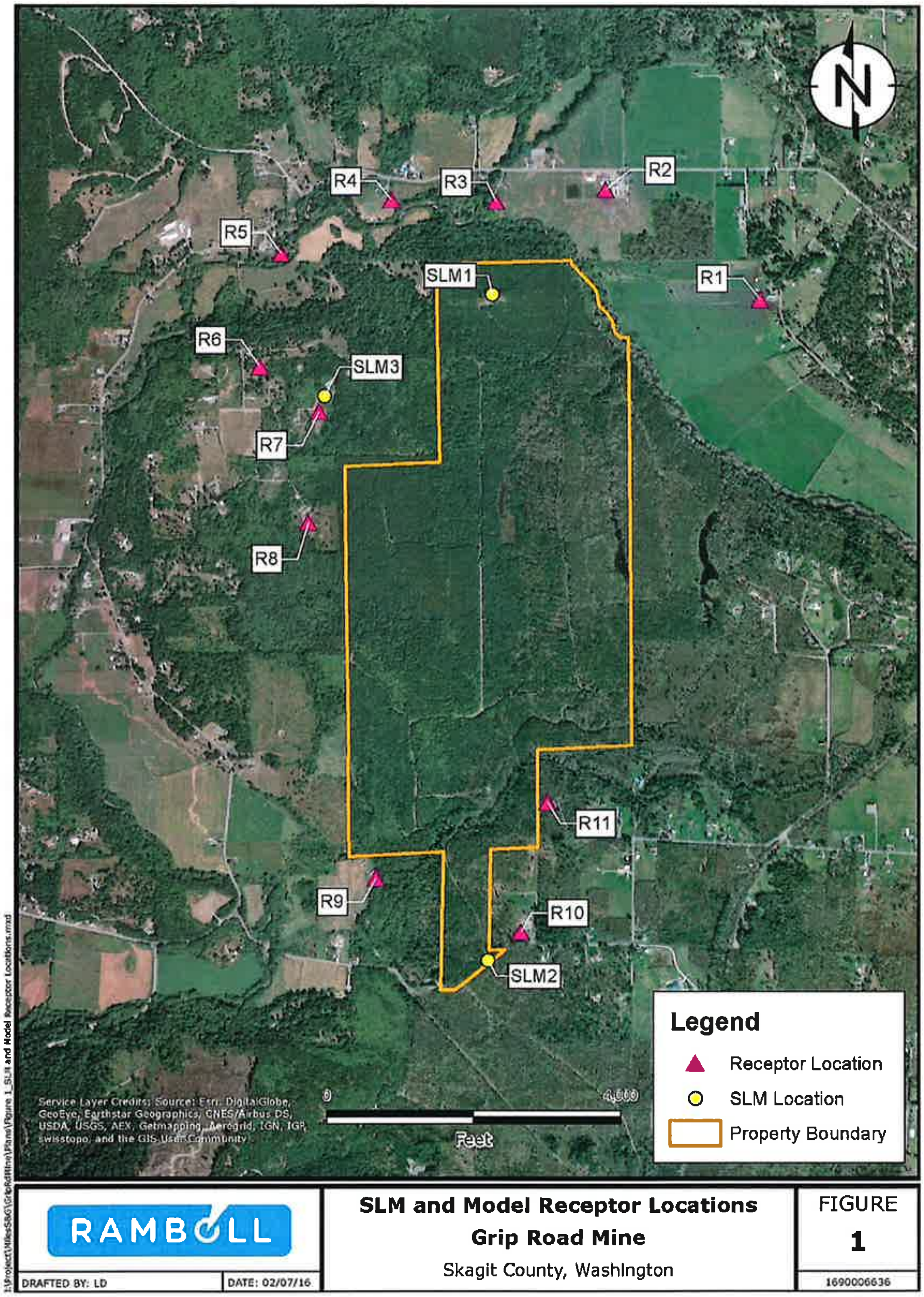

Figure 1. Sound Level Measurement and Model Receptor Locations

4. OPERATIONAL NOISE IMPACT

4.1 Noise Sources

The primary noise sources introduced by the proposal would be a front-end loader, a dozer, and/or an excavator used to excavate material from the floor of the pit in the expansion area and haul/dump trucks used to export the pit run. No crushing or processing is proposed on the site. Trucks would travel on an on-site road south to Grip Road to exit the site.

4.2 Noise Model Used

Noise modeling of on-site sources was completed using the CadnaA noise model. CadnaA is a computer tool that calculates sound levels after considering the noise reductions or enhancements caused by distance, topography, varying ground surfaces, atmospheric absorption, and meteorological conditions. For the loader and truck in the mine, the model uses algorithms that comply with the international standards in ISO-9613-2:1996.

The modeling process includes the following steps: (1) characterizing the noise sources, (2) creating 3-dimensional maps of the site and vicinity to enable the model to evaluate effects of distance and topography on noise attenuation, and (3) assigning equipment and activity sound levels to appropriate locations on the site. CadnaA then constructs topographic cross sections to calculate sound levels in the vicinity of a project site.

4.3 Modeling Assumptions

The following assumptions were used in our assessment:

- A front-end loader, dozer, and excavator were assumed to operate concurrently in the mine, with haul/dump trucks. Long-term, concurrent operation of the loader, dozer, and excavator may occur occasionally and is representative of a conservative scenario.
- When excavating the southern half of the site, the equipment was assumed to be operating at existing elevation. This is likely to occur only at the beginning of mining, after which the equipment would be expected to work at a lower excavation, with the slopes of the mine acting somewhat as a noise barrier. Therefore, this is a conservative assumption.
- When excavating the northern half of the site, the dozer was assumed to be operating on the mining slope while the loader, excavator, and trucks were assumed to be operating on the floor of the mine.
- All equipment was assumed to work continuously in the same general area for a one-hour period, with equipment locations assumed to be in the southwest, southeast, northwest, and northeast quadrants of the mine. The worst-case southern location and worst-case northern location for each receptor location were used to assess compliance and potential noise impacts.

- A truck would arrive in proximity to the loader and wait to be loaded. A waiting truck was assumed to be present continuously over the hour.
- The sound levels of the loader, excavator, and dozer were assumed to be 75, 75, and 76 dBA, respectively, at a distance of 100 feet. The sound level of the waiting truck was assumed to be 60 dBA at 100 feet.
- In addition to the waiting trucks, we considered noise from 12 trucks per hour traveling on the on-site access road to and from the mine. This estimated number of hourly trucks was based on the estimated average number of 8 trucks, with an additional 50% increase to ensure a conservative noise estimate. Trucks traveling on the onsite road were modeled using the TNM module of CadnaA.[2]
- The proposed mine site and contiguous property surrounding the mine had been logged. Although there are plans to log some of the site, there are currently no plans to log the entire site, so this is a conservative assumption.
- The model-calculated sound levels represent hourly L_{eq}s. For most mining operations, the L_{eq}s are very similar to the L_{25}s. Therefore, the modeled hourly L_{eq}s are used to assess compliance with the State's L_{25} noise limit.

4.4 Noise Modeling Results

4.4.1 Compliance Assessment

As part of the noise assessment, Ramboll first considered the potential for onsite noise to comply with the applicable WAC noise limits. For this assessment, Ramboll considered the potential sound levels from two working scenarios; 1) equipment operating at existing grade in the southern half of the site, and 2) equipment operating on the mine slope and mine floor in the northern half of the site. The resulting model-calculated sound levels for each scenario were compared to the applicable noise limits to assess potential compliance with the WAC noise limits.

The resulting model-calculated sound levels are displayed in **Table 4**. As can be seen by the values in **Table 4**, sound levels from the Grip Road Mine are expected to easily comply with the State's daytime noise limit during excavation. In addition, if mining activities were to occur at night, they would be expected to easily comply with the stricter nighttime limit.

[2] The CadnaA noise model includes a module that applies the FHWA's Traffic Noise Model (TNM) traffic noise emission levels and noise attenuation algorithms.

Table 4. Model-Calculated Sound Levels (Leq/L25, dBA)

Model Receptor	Southern Scenario	Northern Scenario	Daytime/Nighttime Noise Limit[a]
R1	42	40	60/50
R2	45	42	60/50
R3	40	41	60/50
R4	40	41	60/50
R5	39	43	60/50
R6	40	41	60/50
R7	36	37	60/50
R8	34	36	60/50
R9	36	36	60/50
R10	40	39	60/50
R11	41	41	60/50

[a] Daytime refers to the hours between 7 AM and 10 PM. Nighttime refers to the hours between 10 PM and 7 AM.

Source: Ramboll

4.4.2 Increases Over Existing Noise Levels From Project Sources

In addition to evaluating the potential compliance of onsite sources, Ramboll considered potential noise impacts caused by project-related increases over existing background sound levels. For the existing background sound level, we used the period Leq (energy-average sound level) between 7 AM and 5 PM to represent the existing baseline sound levels, since this represents the typical hours of operation.

Table 5. Calculated Increases over Existing Levels (Leq, dBA)

Receptor	Existing[(a)]	Southern Scenario			Northern Scenario		
		Project	Cumulative[(b)]	Increase	Project	Cumulative[(b)]	Increase
R1	43	42	46	3	40	45	2
R2	43	45	47	4	42	45	2
R3	43	40	45	2	41	45	2
R4	43	40	45	2	41	45	2
R5	43	39	45	1	43	46	3
R6	49	40	49	1	41	49	1
R7	49	36	49	0	37	49	0
R8	49	34	49	0	36	49	0
R9	54	36	54	0	36	54	0
R10	54	40	54	0	39	54	0
R11	54	41	54	0	41	54	0

Notes:

(a) The existing sound level shown is the period Leq between 7 AM and 5 PM. When identifying existing sound levels, the sound levels measured at SLM1 were assumed to represent receptors R1-R5, the levels at SLM3 represent R6-R8, and the levels at SLM2 represent R9-R11.

(b) Cumulative levels represent the existing measured sound levels + the modeled project-related sound levels.

Source: Ramboll

As can be seen in **Table 5**, the model-calculated sound levels of all equipment operating at the existing grade in the southern half of the mine site increase by 0 to 4 dBA at the nearest residential receivers to the site. Increases of 0-2 dBA would generally be not perceptible or barely perceptible. Increases of 3 to 4 dBA may be readily perceptible but would not be characterized as a substantial increase. Also, it should be noted that these levels were modeled using conservative assumptions that all equipment would be operating concurrently for at least an hour and would be operating at the existing grade. Soon after mining begins, the equipment would be working below the existing grade in a pit, and the walls of the mine would begin to act as a noise barrier to residences north of the site. This would reduce potential increases over existing sound levels.

When mining in the northern half of the site, the estimated increases over existing levels range from 0 to 3 dBA. An increase of 3 dBA may be perceptible but would not be characterized as a substantial increase. Furthermore, the analysis was based upon the conservative assumption that all equipment (loader, excavator, dozer, and haul trucks) would operate concurrently and continuously over an hour, which is only expected to occur occasionally. Therefore, any impacts due to increases over existing levels would be slight.

5. OPERATIONAL VIBRATION IMPACT

Although most gravel mining operations do not typically result in perceptible vibrations at offsite locations (unless blasting is required), vibration was mentioned as a source of concern by residents in the project vicinity. Therefore, Ramboll evaluated the potential for vibration impacts from the project. The proposed onsite mining operations and haul road would be located more than 500 feet (and generally much farther) from the nearest residential structures, and there is no potential for impacts from groundborne vibration due to these onsite activities. Therefore, this assessment focused on the potential for vibration impacts from trucks traveling between the site and Old Highway 99 via Grip Road and Prairie Road. For this assessment, we used FTA vibration assessment methods in conjunction with the FTA vibration impact criteria identified earlier in this report.

1.1 FTA Vibration Screening Procedure

FTA guidance includes a screening procedure to identify locations where there is little possibility of vibration impacts related to facility operations. Based on specific screening distances for various types of sources, the screening review applies the principle that if no sensitive receivers are identified within the screening distance, no vibration impacts would be expected, and no further assessment is necessary. Ramboll employed this screening procedure as the first step in the review of ground-borne vibration related to the Project. As per FTA guidance, the screening distance for rubber-tired vehicles affecting residences is 50 feet. Therefore, any residential structures farther than 50 feet from Grip Road or Prairie Road are not expected to be affected by vibration from trucks traveling to and from the site.

Ramboll identified all residential structures located within 50 feet of the nearest and farthest lanes of Grip Road and Prairie Road, west of the mine entrance. The following two residences were identified for additional consideration:

- A residential property to the west of the mine entrance along Grip Road, approximately 48 feet from the westbound lanes of the road
- A residential property along Prairie Road, approximately 41 feet from the westbound lanes of the road

1.2 FTA General Vibration Assessment

Based on the findings of the FTA vibration impact screening procedure it was necessary to conduct a more detailed "general vibration assessment" for the two residential properties identified. Ramboll conducted a general vibration assessment as described below.

The FTA guidance manual includes a chart used to estimate potential vibration levels (VdB) based on a reference travel speed, a general transit vehicle type (e.g., rubber-tired vehicles), and distance from the lane of travel. Using these reference vibration levels, adjustments can be made to account for variations in speed. Using this method, Ramboll estimated the future vibration levels at each of the two locations, as detailed below.

Residential Property Along Grip Road – There is a single residential structure that is approximately 48 feet from the westbound travel lane of Grip Road. (The eastbound lane is more than 50 feet from the residence, is beyond the screening distance, and is not considered further.) The reference vibration level for a rubber-tired vehicle traveling 30 mph at a distance of 48 feet is 64 VdB, and this reference vibration level was adjusted by +2.5 VdB to account for the higher posted speed limit of 40 mph on this section of Grip Road. With the speed adjustment, the estimated vibration level at the residential structure along Grip Road is approximately 67 VdB. The FTA impact criterion for frequent events (i.e., more than 70 events per day) affecting residential structures is 72 Vdb, and no vibration impacts are anticipated. It should be noted that the number of trucks per day traveling in the westbound lane is expected to be less than 70.

Residential Property Along Prairie Road – There is a single residential structure that is approximately 41 feet from the westbound travel lane of Prairie Road. (The eastbound lane is more than 50 feet from the residence, is beyond the screening distance, and is not considered further.) The reference vibration level for a rubber-tired vehicle traveling 30 mph at a distance of 41 feet is 65 VdB, and this reference vibration level was adjusted by +4.4 VdB to account for the higher posted speed limit of 50 mph on this section of Prairie Road. With the speed adjustment, the estimated vibration level at the residential structure along Prairie Road is approximately 69 VdB. The FTA impact criterion for frequent events (i.e., more than 70 events per day) affecting residential structures is 72 Vdb, and no vibration impacts are anticipated. As noted above, the number of trucks per day traveling in the westbound lane is expected to be less than 70.

6. CONCLUSION

Model-calculated sound levels from onsite mining equipment and haul trucks are well below both the daytime noise limit of 60 dBA (applicable between 7 AM and 10 PM) and the nighttime limit of 50 dBA (applicable between 10 PM and 7 AM. Therefore, the mine is expected to easily comply with the applicable noise limits. Furthermore, estimated increases over existing levels range from 0 to 4 dBA and would be less than 3 dBA during the vast majority of mining activities. Therefore, noise impacts from onsite mining operations would be slight.

In addition to noise impacts, the potential for vibration impacts from haul trucks traveling along Grip Road and Prairie Road were considered. Using FTA vibration impact methods and criteria, we found that there would be no impacts to residences from trucks traveling to and from the site on these roads.

APPENDIX A: SOUND LEVEL MEASUREMENT DATA

Table A- 1. Measured Sound Levels at SLM1 (dBA)

Date	Time	Leq	Lmax	L2.5	L8.3	L25	L90
22/01/2018	13:00:00	32.9	48.6	37.0	34.3	32.7	31.4
22/01/2018	14:00:00	31.8	40.1	33.0	32.5	32.0	31.3
22/01/2018	15:00:00	32.6	52.9	34.3	33.4	32.6	31.4
22/01/2018	16:00:00	42.2	71.4	48.7	38.8	34.5	32.0
22/01/2018	17:00:00	35.6	45.3	39.0	37.8	36.3	33.2
22/01/2018	18:00:00	36.3	47.7	40.8	39.1	36.9	33.2
22/01/2018	19:00:00	35.5	49.2	41.4	38.4	35.6	32.0
22/01/2018	20:00:00	34.6	47.5	40.3	37.3	34.7	31.7
22/01/2018	21:00:00	33.8	50.2	38.5	36.0	33.8	31.6
22/01/2018	22:00:00	33.2	46.8	37.3	34.8	33.3	31.4
22/01/2018	23:00:00	33.0	48.4	37.2	34.7	32.9	31.4
23/01/2018	00:00:00	33.4	51.1	38.7	35.5	33.1	31.2
23/01/2018	01:00:00	34.1	51.0	41.0	36.0	32.4	31.2
23/01/2018	02:00:00	34.5	48.1	40.2	37.3	34.3	31.6
23/01/2018	03:00:00	37.0	55.8	44.0	42.3	35.7	31.7
23/01/2018	04:00:00	35.0	50.4	39.8	37.7	35.5	32.4
23/01/2018	05:00:00	37.5	58.0	43.4	40.2	36.9	33.2
23/01/2018	06:00:00	41.2	63.3	47.1	43.6	40.9	36.6
23/01/2018	07:00:00	46.2	67.9	54.5	50.3	44.6	36.7
23/01/2018	08:00:00	45.8	63.7	51.4	49.2	46.5	38.9
23/01/2018	09:00:00	45.8	64.6	52.2	48.6	45.4	40.7
23/01/2018	10:00:00	44.9	69.9	52.3	47.5	43.1	37.8
23/01/2018	11:00:00	43.0	72.9	48.0	45.0	42.9	38.4
23/01/2018	12:00:00	42.4	64.4	48.0	44.8	42.0	37.4

Table A- 2. Measured Sound Levels at SLM2 (dBA)

Date	Time	Leq	Lmax	L2.5	L8.3	L25	L90
22/01/2018	13:00:00	52.8	72.5	63.6	54.6	39.5	30.6
22/01/2018	14:00:00	51.8	74.4	62.1	52.3	35.7	30.7
22/01/2018	15:00:00	53.0	71.5	64.0	56.2	40.8	30.5
22/01/2018	16:00:00	55.5	73.7	66.2	59.3	46.8	31.2
22/01/2018	17:00:00	55.9	74.2	66.4	60.8	47.9	31.0
22/01/2018	18:00:00	54.2	77.1	64.7	56.8	39.6	30.2
22/01/2018	19:00:00	51.5	73.4	61.7	51.0	33.0	29.9
22/01/2018	20:00:00	51.2	74.0	60.5	47.1	33.2	30.1
22/01/2018	21:00:00	45.9	71.0	52.0	37.3	32.0	29.8
22/01/2018	22:00:00	45.8	70.4	52.5	37.3	32.2	29.8
22/01/2018	23:00:00	45.3	73.8	46.5	34.7	31.4	29.7
23/01/2018	00:00:00	44.7	72.0	45.6	34.4	31.1	29.4
23/01/2018	01:00:00	46.9	76.8	40.6	32.6	32.0	29.9
23/01/2018	02:00:00	43.5	70.3	41.3	34.8	32.5	30.3
23/01/2018	03:00:00	43.1	71.5	46.7	44.1	38.0	32.2
23/01/2018	04:00:00	47.4	71.9	54.1	43.2	39.9	34.5
23/01/2018	05:00:00	53.7	78.1	62.8	53.9	45.7	37.8
23/01/2018	06:00:00	55.0	74.4	65.2	58.3	49.4	40.8
23/01/2018	07:00:00	54.4	76.7	64.6	57.0	49.0	39.9
23/01/2018	08:00:00	56.0	79.2	65.4	58.6	52.0	43.1
23/01/2018	09:00:00	54.7	74.4	63.4	56.9	51.6	44.3
23/01/2018	10:00:00	51.9	72.5	59.4	53.8	50.0	42.1
23/01/2018	11:00:00	52.1	72.0	60.7	53.2	48.8	41.5
23/01/2018	12:00:00	53.1	74.9	62.4	54.0	46.7	41.0

Table A- 3. Measured Sound Levels at SLM3 (dBA)

Date	Time	Leq	Lmax	L2.5	L8.3	L25	L90
22/01/2018	13:00:00	34.3	55.0	40.5	37.3	33.8	30.2
22/01/2018	14:00:00	32.5	48.8	37.0	33.8	32.3	30.3
22/01/2018	15:00:00	38.3	52.7	47.2	43.9	34.6	30.5
22/01/2018	16:00:00	43.6	69.9	49.7	46.8	42.6	31.2
22/01/2018	17:00:00	33.6	47.9	37.5	35.1	33.6	31.7
22/01/2018	18:00:00	33.1	46.6	36.8	34.6	33.2	31.3
22/01/2018	19:00:00	33.4	44.5	36.8	35.2	33.8	31.5
22/01/2018	20:00:00	33.6	49.9	38.0	35.9	33.9	31.4
22/01/2018	21:00:00	33.3	48.6	37.9	35.0	33.3	31.1
22/01/2018	22:00:00	32.4	46.7	36.4	34.3	32.4	30.5
22/01/2018	23:00:00	32.3	46.9	36.9	33.9	32.3	30.3
23/01/2018	00:00:00	32.3	46.5	36.4	34.7	32.7	30.0
23/01/2018	01:00:00	31.0	42.1	34.8	32.7	30.8	29.8
23/01/2018	02:00:00	31.8	47.1	35.3	33.4	31.8	29.9
23/01/2018	03:00:00	36.4	63.8	43.1	40.5	32.7	30.3
23/01/2018	04:00:00	35.0	66.7	38.5	35.6	33.7	31.3
23/01/2018	05:00:00	36.5	63.0	40.8	38.0	36.1	32.2
23/01/2018	06:00:00	47.4	77.4	51.9	44.0	40.4	35.9
23/01/2018	07:00:00	48.4	77.9	51.5	47.2	43.4	36.5
23/01/2018	08:00:00	54.5	83.1	61.4	58.6	54.6	42.6
23/01/2018	09:00:00	48.7	76.2	54.3	49.8	46.0	40.3
23/01/2018	10:00:00	46.4	72.7	52.1	47.2	42.9	38.0
23/01/2018	11:00:00	52.7	86.2	53.9	50.5	47.1	38.8
23/01/2018	12:00:00	46.6	65.4	54.2	51.5	46.9	37.5

Prepared for:

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Date

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GRIP ROAD MINE

UPDATED NOISE AND VIBRATION STUDY

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1. INTRODUCTION

Miles Sand & Gravel Company (Miles) is proposing to mine gravel from a 68 acre parcel located in unincorporated Skagit County near Sedro Woolley, Washington. The mine is completely surrounded by Natural Resource designated land (NRL) and is situated near the north end of 726 acres of contiguously owned property. The site is currently forested, but some of the site is proposed to be logged. All material from the mine would be sold as pit run or transported to other facilities for processing.

The following report reviews noise terminology, regulatory criteria applicable to the project, and the methods and findings of the analysis.

2. TERMINOLOGY AND BACKGROUND

2.1 Noise Level Terminology and Human Hearing

The human ear responds to a very wide range of sound intensities. The decibel scale (dB) used to describe sound is a logarithmic rating system which accounts for the large differences in audible sound intensities. This scale accounts for the human perception of a doubling of loudness as an increase of 10 dB. Therefore, a 70-dB sound level will sound about twice as loud as a 60-dB sound level. People generally cannot detect differences of 1 dB; in ideal laboratory situations, differences of 2 or 3 dB can be detected by people, but such a change probably would not be detectable in an average outdoor environment. A 5-dB change would probably be perceived under normal listening conditions.

When addressing the effects of noise on people, it is useful to consider the frequency response of the human ear. Sound-measuring instruments are therefore often programmed to weight measured sounds based on the way people hear. The frequency-weighting most often used is A-weighting because it approximates the frequency response of human hearing and is highly correlated to the effects of noise on people. Measurements from instruments using this system are reported in "A-weighted decibels" or dBA. All sound levels in this evaluation are reported in A-weighted decibels.

Distance from the source, the frequency of the sound, the absorbency of the intervening ground, obstructions, and duration of the noise-producing event all affect the transmission and perception of noise. The degree of this effect also depends on who is listening and on existing sound levels.

2.2 Vibration Terminology

Vibration is an oscillatory motion that can be measured and characterized by the frequency and amplitude of waves of motion. Because it takes time for the human body to perceive and respond to vibration signals, vibration amplitude (i.e., the size of the wave of motion) is usually characterized using a "smoothed" amplitude based on the root mean square (rms). Some methodologies used for assessing potential impacts from vibration consider vibration amplitude reported as rms velocity, converted to vibration decibel levels or VdB. The typical background level in residential areas is about 50 VdB, and most people generally cannot detect levels below about 65 VdB, and generally do not consider levels below 70 VdB to be of significance. However, the duration of a vibration event has an effect on human response. Generally, as the duration of a vibration event increases, the potential for adverse human response increases. Additionally, the rate of recurrence of events can also affect human response.

3. AFFECTED ENVIRONMENT

3.1 Skagit County Noise Regulations

The project site and surrounding properties are located in unincorporated Skagit County. Chapter 9.50 of the Skagit County Code (SCC 9.50) adopts regulations established in Chapter 173-60 of the Washington Administrative Code (WAC).

Chapter 173-60 of the WAC limits the levels and durations of noise crossing property boundaries (Table 1). Allowable "maximum permissible" sound levels depend on the Environmental Designation of Noise Abatement (EDNA) of the source of the noise and the EDNA of the receiving property. WAC 173-60-030 stipulates that EDNA land classification shall conform to land *uses* unless a local jurisdiction has adopted a program in which EDNA classifications are based on zoning. Generally, lands of residential use are considered Class A EDNAs, commercial properties are considered Class B EDNAs, and industrial areas are considered Class C EDNAs.

Table 1. WAC Maximum Permissible Sound Levels (dBA)

EDNA of Sound Source	EDNA of Receiving Property		
	Class A Day / Night	EDNA B	EDNA C
EDNA A	55 / 45	57	60
EDNA B	57 / 47	60	65
EDNA C	60 / 50	65	70

The limitations for noise received in a Class A EDNA are reduced by 10 dBA during nighttime hours, defined as between 10 PM and 7 AM.
Source: WAC 173-60-040

The "maximum permissible" environmental noise levels in Table 1 may be exceeded for short periods as defined in WAC 173-60-040. The allowed short-term increases are as follows: 5 dBA for no more than 15 minutes in any hour, or 10 dBA for no more than 5 minutes of any hour, or 15 dBA for no more than 1.5 minutes of any hour. These allowed short-term increases can be described in terms of noise "metrics" that represent the percentage of time certain levels are exceeded. For example, the hourly L_{25} metric represents the sound level that is exceeded 25 percent of the time, or 15 minutes in an hour. Similarly, the $L_{8.3}$ and $L_{2.5}$ are the sound levels exceeded 5 and 1.5 minutes in an hour, respectively. The maximum permissible levels are not to be exceeded by more than 15 dBA at any time, and this limit is represented by the L_{max} noise metric.

The Washington Administrative Code (173-60-050) identifies a number of noise sources or activities that are exempt from the maximum permissible sound levels. The following sources are among those exempt:

- Sounds created by motor vehicles on public roads when individual vehicles are subject to performance standards regulated by WAC 173-62 (motor vehicle fleet performance standards)
- Sounds caused by motor vehicles, licensed or unlicensed, when operated off public highways, except when such sounds are received in Class A EDNAs; and
- Sounds created by warning devices not operating continuously for more than five minutes (such as back-up alarms on vehicles).

3.2 FTA Vibration Impact Criteria

There are currently no applicable vibration limits or regulations established by Skagit County. Therefore, we are applying Federal Transit Administration (FTA) vibration impact criteria in this assessment to gauge the potential for vibration impacts from the proposed mining and material transport activities.

FTA vibration impact criteria vary depending on the type of receiver and the frequency of occurrence of vibration events. FTA categorizes receiving properties as Category 1 (e.g., most sensitive, such as research facilities with vibration sensitive equipment), Category 2 (e.g., residences), and Category 3 (e.g., institutional uses such as schools, churches, etc.). For this project, groundborne vibration would have the potential to primarily affect residences (Category 2 receiving properties), and these types of properties are the focus of this assessment. The FTA vibration impact criteria for Category 2 receivers are shown in Table 2.

Table 2. FTA Vibration Impact Criteria

Land Use Category	Frequent Events	Occasional Events	Infrequent Events
Category 2 - Residential	72 VdB	75 VdB	80 VdB
"Frequent Events" is defined as more than 70 vibration events of the same source per day. "Occasional Events" is defined as between 30 and 70 vibration events of the same source per day. "Infrequent Events" is defined as fewer than 30 vibration events of the same kind per day.			

3.3 Land Uses and Zoning

The proposed mining area and surrounding properties are zoned RRv and RRc-NRL (Rural Reserve and Rural Resource, respectively). Skagit County does not specifically assign an EDNA based on zoning designations, so the EDNA classification of the site and surrounding properties are based on the uses of the properties. Mining uses are typically classified as Class C EDNA noise sources and residential uses are classified as Class A EDNAs.

The applicable noise limits for a Class C EDNA noise source affecting a Class A receiver are 60 dBA during daytime hours (7 AM to 10 PM) and 50 dBA during nighttime hours (10 PM to 7 AM). Allowable short-term increases to the above levels are as described previously. Operation of the mine is generally expected to occur between 7 AM and 5 PM, Monday through Friday, but the mine could potentially operate during weekends or at night, on occasion. The applicable noise limits at the nearby receivers from mining activities would be 60 dBA during standard daytime operation and 50 dBA during potential nighttime operation.

3.4 Existing Sound Levels

In January 2018, Ramboll measured day-long sound levels at three locations representative of residences nearest the proposed mining area and access drive. The measurements were taken using Larson Davis Class 1 sound level meters (Model LxT). The meters had been factory certified within the previous 12 months and were field calibrated immediately prior to the measurements. The microphones of the meters were fitted with wind screens and set approximately 5 feet above the ground (at a typical listening height).

The sound level measurements were taken at the following locations:

- **SLM1** –onsite near northern property boundary
- **SLM2** –approximately 0.3 miles northwest of the site along Wildlife Acres Lane
- **SLM3** – near the southern property boundary at the entrance of the mine site, approximately 50 feet from Grip Road

The measured sound levels are summarized in Table 3, and the sound level measurement locations are depicted in Figure 1. Details of hourly sound level measurements can be found in Appendix A.

Table 3. Measured Existing Sound Levels (dBA)

Location	Time of Day [a]	Range of Hourly Sound Levels (dBA) [b]				
		L_{eq}	L_{25}	$L_{8.3}$	$L_{2.5}$	L_{max}
SLM1	Day	32-46	32-47	33-50	33-55	40-73
	Night	33-41	32-41	35-44	37-47	47-63
	7 AM - 5 PM	32-46	32-47	33-50	33-55	40-73
SLM2	Day	46-56	32-52	37-61	52-66	71-79
	Night	43-55	31-49	33-58	41-65	70-78
	7 AM - 5 PM	52-56	36-52	52-59	59-66	72-79
SLM3	Day	32-55	32-55	34-59	37-61	45-86
	Night	31-47	31-40	33-44	35-52	42-77
	7 AM - 5 PM	32-55	32-55	34-59	37-61	49-86

(a) "Day" refers to the hours between 7 AM and 10 PM and "Night" to the hours between 10 PM and 7 AM. 7 AM to 5 PM is the standard hours of operation.

(b) The L_{eq} is the "energy-averaged" sound level. The L_{max} is the-highest measured sound level. The $L_{2.5}$, $L_{8.3}$, and L_{25} levels are defined previously in this report in the discussion of the regulatory noise limits.

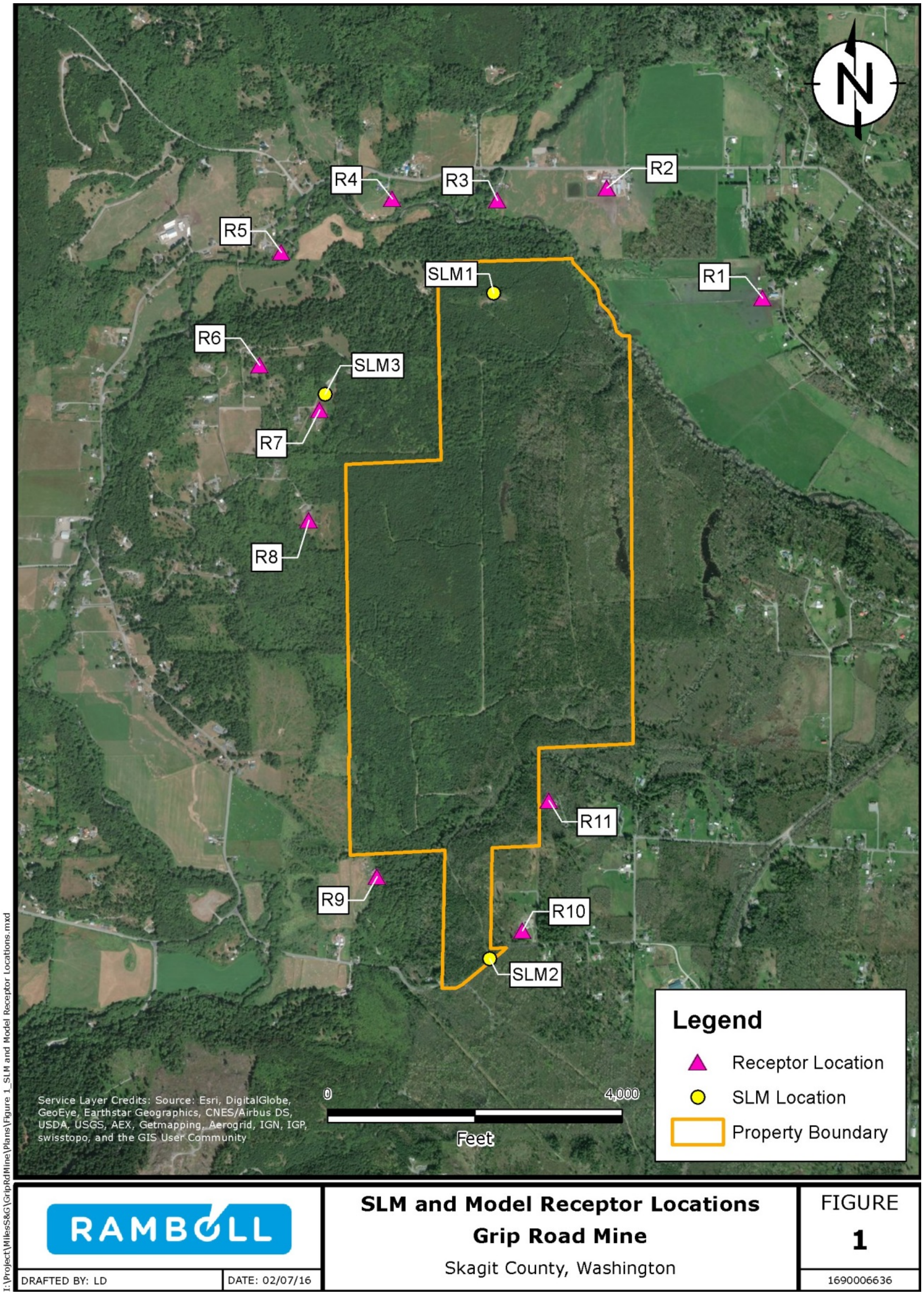

Figure 1. Sound Level Measurement and Model Receptor Locations

4. OPERATIONAL NOISE IMPACT

4.1 Noise Sources

The primary noise sources introduced by the proposal would be a front-end loader, a dozer, and/or an excavator used to excavate material from the floor of the pit in the expansion area and haul/dump trucks used to export the pit run. No crushing or processing is proposed on the site. Trucks would travel on an on-site road south to Grip Road to exit the site.

4.2 Noise Model Used

Noise modeling of on-site sources was completed using the CadnaA noise model. CadnaA is a computer tool that calculates sound levels after considering the noise reductions or enhancements caused by distance, topography, varying ground surfaces, atmospheric absorption, and meteorological conditions. For the loader and truck in the mine, the model uses algorithms that comply with the international standards in ISO-9613-2:1996.

The modeling process includes the following steps: (1) characterizing the noise sources, (2) creating 3-dimensional maps of the site and vicinity to enable the model to evaluate effects of distance and topography on noise attenuation, and (3) assigning equipment and activity sound levels to appropriate locations on the site. CadnaA then constructs topographic cross sections to calculate sound levels in the vicinity of a project site.

4.3 Modeling Assumptions

The following assumptions were used in our assessment:

- A front-end loader, dozer, and excavator were assumed to operate concurrently in the mine, with haul/dump trucks. Long-term, concurrent operation of the loader, dozer, and excavator may occur occasionally and is representative of a conservative scenario.
- When excavating the southern half of the site, the equipment was assumed to be operating at existing elevation. This is likely to occur only at the beginning of mining, after which the equipment would be expected to work at a lower excavation, with the slopes of the mine acting somewhat as a noise barrier. Therefore, this is a conservative assumption.
- When excavating the northern half of the site, the dozer was assumed to be operating on the mining slope while the loader, excavator, and trucks were assumed to be operating on the floor of the mine.
- All equipment was assumed to work continuously in the same general area for a one-hour period, with equipment locations assumed to be in the southwest, southeast, northwest, and northeast quadrants of the mine. The worst-case southern location and worst-case northern location for each receptor location were used to assess compliance and potential noise impacts.

- A truck would arrive in proximity to the loader and wait to be loaded. A waiting truck was assumed to be present continuously over the hour.
- The sound levels of the loader, excavator, and dozer were assumed to be 75, 75, and 76 dBA, respectively, at a distance of 100 feet. The sound level of the waiting truck was assumed to be 60 dBA at 100 feet.
- In addition to the waiting trucks, we considered noise from 12 trucks per hour traveling on the on-site access road to and from the mine. This estimated number of hourly trucks was based on the estimated average number of 8 trucks, with an additional 50% increase to ensure a conservative noise estimate. Trucks traveling on the onsite road were modeled using the TNM module of CadnaA.[1]
- The proposed mine site and contiguous property surrounding the mine had been logged. Although there are plans to log some of the site, there are currently no plans to log the entire site, so this is a conservative assumption.
- The model-calculated sound levels represent hourly L_{eq}s. For most mining operations, the L_{eq}s are very similar to the L_{25}s. Therefore, the modeled hourly L_{eq}s are used to assess compliance with the State's L_{25} noise limit.

4.4 Noise Modeling Results

4.4.1 Compliance Assessment

As part of the noise assessment, Ramboll first considered the potential for onsite noise to comply with the applicable WAC noise limits. For this assessment, Ramboll considered the potential sound levels from two working scenarios; 1) equipment operating at existing grade in the southern half of the site, and 2) equipment operating on the mine slope and mine floor in the northern half of the site. The resulting model-calculated sound levels for each scenario were compared to the applicable noise limits to assess potential compliance with the WAC noise limits.

The resulting model-calculated sound levels are displayed in **Table 4**. As can be seen by the values in **Table 4**, sound levels from the Grip Road Mine are expected to easily comply with the State's daytime noise limit during excavation. In addition, if mining activities were to occur at night, they would be expected to easily comply with the stricter nighttime limit.

[1] The CadnaA noise model includes a module that applies the FHWA's Traffic Noise Model (TNM) traffic noise emission levels and noise attenuation algorithms.

Table 4. Model-Calculated Sound Levels (L_{eq}/L_{25}, dBA)

Model Receptor	Southern Scenario	Northern Scenario	Daytime/Nighttime Noise Limit[a]
R1	42	40	60/50
R2	45	42	60/50
R3	40	41	60/50
R4	40	41	60/50
R5	39	43	60/50
R6	40	41	60/50
R7	36	37	60/50
R8	34	36	60/50
R9	36	36	60/50
R10	40	39	60/50
R11	41	41	60/50

[a] Daytime refers to the hours between 7 AM and 10 PM. Nighttime refers to the hours between 10 PM and 7 AM.

Source: Ramboll

4.4.2 Increases Over Existing Noise Levels From Project Sources

In addition to evaluating the potential compliance of onsite sources, Ramboll considered potential noise impacts caused by project-related increases over existing background sound levels. For the existing background sound level, we used the period L_{eq} (energy-average sound level) between 7 AM and 5 PM to represent the existing baseline sound levels, since this represents the typical hours of operation.

Table 5. Calculated Increases over Existing Levels (L_{eq}, dBA)

Receptor	Existing[a]	Southern Scenario			Northern Scenario		
		Project	Cumulative[b]	Increase	Project	Cumulative[b]	Increase
R1	43	42	46	3	40	45	2
R2	43	45	47	4	42	45	2
R3	43	40	45	2	41	45	2
R4	43	40	45	2	41	45	2
R5	43	39	45	1	43	46	3
R6	49	40	49	1	41	49	1
R7	49	36	49	0	37	49	0
R8	49	34	49	0	36	49	0
R9	54	36	54	0	36	54	0
R10	54	40	54	0	39	54	0
R11	54	41	54	0	41	54	0

Notes:

[a] The existing sound level shown is the period L_{eq} between 7 AM and 5 PM. When identifying existing sound levels, the sound levels measured at SLM1 were assumed to represent receptors R1-R5, the levels at SLM3 represent R6-R8, and the levels at SLM2 represent R9-R11.

[b] Cumulative levels represent the existing measured sound levels + the modeled project-related sound levels.

Source: Ramboll

As can be seen in **Table 5**, the model-calculated sound levels of all equipment operating at the existing grade in the southern half of the mine site increase by 0 to 4 dBA at the nearest residential receivers to the site. Increases of 0-2 dBA would generally be not perceptible or barely perceptible. Increases of 3 to 4 dBA may be readily perceptible but would not be characterized as a substantial increase. Also, it should be noted that these levels were modeled using conservative assumptions that all equipment would be operating concurrently for at least an hour and would be operating at the existing grade. Soon after mining begins, the equipment would be working below the existing grade in a pit, and the walls of the mine would begin to act as a noise barrier to residences north of the site. This would reduce potential increases over existing sound levels.

When mining in the northern half of the site, the estimated increases over existing levels range from 0 to 3 dBA. An increase of 3 dBA may be perceptible but would not be characterized as a substantial increase. Furthermore, the analysis was based upon the conservative assumption that all equipment (loader, excavator, dozer, and haul trucks) would operate concurrently and continuously over an hour, which is only expected to occur occasionally. Therefore, any impacts due to increases over existing levels would be slight.

5. OPERATIONAL VIBRATION IMPACT

Although most gravel mining operations do not typically result in perceptible vibrations at offsite locations (unless blasting is required), vibration was mentioned as a source of concern by residents in the project vicinity. Therefore, Ramboll evaluated the potential for vibration impacts from the project. The proposed onsite mining operations and haul road would be located more than 500 feet (and generally much farther) from the nearest residential structures, and there is no potential for impacts from groundborne vibration due to these onsite activities. Therefore, this assessment focused on the potential for vibration impacts from trucks traveling between the site and Old Highway 99 via Grip Road and Prairie Road. For this assessment, we used FTA vibration assessment methods in conjunction with the FTA vibration impact criteria identified earlier in this report.

1.1 FTA Vibration Screening Procedure

FTA guidance (2006) includes a screening procedure to identify locations where there is little possibility of vibration impacts related to facility operations. Based on specific screening distances for various types of sources, the screening review applies the principle that if no sensitive receivers are identified within the screening distance, no vibration impacts would be expected, and no further assessment is necessary. Ramboll employed this screening procedure as the first step in the review of ground-borne vibration related to the Project. As per FTA guidance, the screening distance for rubber-tired vehicles affecting residences is 50 feet. Therefore, any residential structures farther than 50 feet from Grip Road or Prairie Road are not expected to be affected by vibration from trucks traveling to and from the site.

Ramboll identified all residential structures located within 50 feet of the nearest and farthest lanes of Grip Road and Prairie Road, west of the mine entrance. The following two residences were identified for additional consideration:

- A residential property to the west of the mine entrance along Grip Road, approximately 48 feet from the westbound lanes of the road
- A residential property along Prairie Road, approximately 41 feet from the westbound lanes of the road

1.2 FTA General Vibration Assessment

Based on the findings of the FTA vibration impact screening procedure it was necessary to conduct a more detailed "general vibration assessment" for the two residential properties identified. Ramboll conducted a general vibration assessment as described below.

The FTA guidance manual includes a chart used to estimate potential vibration levels (VdB) based on a reference travel speed, a general transit vehicle type (e.g., rubber-tired vehicles), and distance from the lane of travel. Using these reference vibration levels, adjustments can be made to account for variations in speed. Using this method, Ramboll estimated the future vibration levels at each of the two locations, as detailed below.

Residential Property Along Grip Road – There is a single residential structure that is approximately 48 feet from the westbound travel lane of Grip Road. The eastbound lane is more than 50 feet from the residence and is beyond the screening distance. The reference vibration level for a rubber-tired vehicle traveling 30 mph at a distance of 48 feet is 64 VdB. The posted speed limit on this section of Grip Road is 40 mph, and the reference vibration level is adjusted by +2.5 VdB to account for the higher travel speed. With this adjustment, the estimated vibration level at the residential structure along Grip Road is approximately 67 VdB. There would be approximately 23 trucks per day traveling in the westbound lane, and the calculated vibration level of 67 VdB is well below the 80-VdB FTA impact criterion for infrequent events (i.e., fewer than 30 per day), and no vibration impacts are anticipated.

Residential Property Along Prairie Road – There is a single residential structure that is approximately 41 feet from the westbound travel lane of Prairie Road. The eastbound lane is more than 50 feet from the residence and is beyond the screening distance. The reference vibration level for a rubber-tired vehicle traveling 30 mph at a distance of 41 feet is 65 VdB. The posted speed limit on this section of Prairie Road is 50 mph, and the reference vibration level is adjusted by +4.4 VdB to account for the higher travel speed. With this adjustment, the estimated vibration level at the residential structure along Grip Road is approximately 69 VdB. With approximately 23 trucks per day traveling in the westbound lane, the calculated vibration level of 69 VdB is well below the 80-VdB FTA impact criterion for infrequent events (i.e., fewer than 30 per day), and no vibration impacts are anticipated.

6. CONCLUSION

Model-calculated sound levels from onsite mining equipment and haul trucks are well below both the daytime noise limit of 60 dBA (applicable between 7 AM and 10 PM) and the nighttime limit of 50 dBA (applicable between 10 PM and 7 AM. Therefore, the mine is expected to easily comply with the applicable noise limits. Furthermore, estimated increases over existing levels range from 0 to 4 dBA and would be less than 3 dBA during the vast majority of mining activities. Therefore, noise impacts from onsite mining operations would be slight.

In addition to noise impacts, the potential for vibration impacts from haul trucks traveling along Grip Road and Prairie Road were considered. Using FTA vibration impact methods and criteria, we found that there would be no impacts to residences from trucks traveling to and from the site on these roads.

APPENDIX A: SOUND LEVEL MEASUREMENT DATA

Table A- 1. Measured Sound Levels at SLM1 (dBA)

Date	Time	L_{eq}	L_{max}	$L_{2.5}$	$L_{8.3}$	L_{25}	L_{90}
22/01/2018	13:00:00	32.9	48.6	37.0	34.3	32.7	31.4
22/01/2018	14:00:00	31.8	40.1	33.0	32.5	32.0	31.3
22/01/2018	15:00:00	32.6	52.9	34.3	33.4	32.6	31.4
22/01/2018	16:00:00	42.2	71.4	48.7	38.8	34.5	32.0
22/01/2018	17:00:00	35.6	45.3	39.0	37.8	36.3	33.2
22/01/2018	18:00:00	36.3	47.7	40.8	39.1	36.9	33.2
22/01/2018	19:00:00	35.5	49.2	41.4	38.4	35.6	32.0
22/01/2018	20:00:00	34.6	47.5	40.3	37.3	34.7	31.7
22/01/2018	21:00:00	33.8	50.2	38.5	36.0	33.8	31.6
22/01/2018	22:00:00	33.2	46.8	37.3	34.8	33.3	31.4
22/01/2018	23:00:00	33.0	48.4	37.2	34.7	32.9	31.4
23/01/2018	00:00:00	33.4	51.1	38.7	35.5	33.1	31.2
23/01/2018	01:00:00	34.1	51.0	41.0	36.0	32.4	31.2
23/01/2018	02:00:00	34.5	48.1	40.2	37.3	34.3	31.6
23/01/2018	03:00:00	37.0	55.8	44.0	42.3	35.7	31.7
23/01/2018	04:00:00	35.0	50.4	39.8	37.7	35.5	32.4
23/01/2018	05:00:00	37.5	58.0	43.4	40.2	36.9	33.2
23/01/2018	06:00:00	41.2	63.3	47.1	43.6	40.9	36.6
23/01/2018	07:00:00	46.2	67.9	54.5	50.3	44.6	36.7
23/01/2018	08:00:00	45.8	63.7	51.4	49.2	46.5	38.9
23/01/2018	09:00:00	45.8	64.6	52.2	48.6	45.4	40.7
23/01/2018	10:00:00	44.9	69.9	52.3	47.5	43.1	37.8
23/01/2018	11:00:00	43.0	72.9	48.0	45.0	42.9	38.4
23/01/2018	12:00:00	42.4	64.4	48.0	44.8	42.0	37.4

Table A- 2. Measured Sound Levels at SLM2 (dBA)

Date	Time	L_{eq}	L_{max}	$L_{2.5}$	$L_{8.3}$	L_{25}	L_{90}
22/01/2018	13:00:00	52.8	72.5	63.6	54.6	39.5	30.6
22/01/2018	14:00:00	51.8	74.4	62.1	52.3	35.7	30.7
22/01/2018	15:00:00	53.0	71.5	64.0	56.2	40.8	30.5
22/01/2018	16:00:00	55.5	73.7	66.2	59.3	46.8	31.2
22/01/2018	17:00:00	55.9	74.2	66.4	60.8	47.9	31.0
22/01/2018	18:00:00	54.2	77.1	64.7	56.8	39.6	30.2
22/01/2018	19:00:00	51.5	73.4	61.7	51.0	33.0	29.9
22/01/2018	20:00:00	51.2	74.0	60.5	47.1	33.2	30.1
22/01/2018	21:00:00	45.9	71.0	52.0	37.3	32.0	29.8
22/01/2018	22:00:00	45.8	70.4	52.5	37.3	32.2	29.8
22/01/2018	23:00:00	45.3	73.8	46.5	34.7	31.4	29.7
23/01/2018	00:00:00	44.7	72.0	45.6	34.4	31.1	29.4
23/01/2018	01:00:00	46.9	76.8	40.6	32.6	32.0	29.9
23/01/2018	02:00:00	43.5	70.3	41.3	34.8	32.5	30.3
23/01/2018	03:00:00	43.1	71.5	46.7	44.1	38.0	32.2
23/01/2018	04:00:00	47.4	71.9	54.1	43.2	39.9	34.5
23/01/2018	05:00:00	53.7	78.1	62.8	53.9	45.7	37.8
23/01/2018	06:00:00	55.0	74.4	65.2	58.3	49.4	40.8
23/01/2018	07:00:00	54.4	76.7	64.6	57.0	49.0	39.9
23/01/2018	08:00:00	56.0	79.2	65.4	58.6	52.0	43.1
23/01/2018	09:00:00	54.7	74.4	63.4	56.9	51.6	44.3
23/01/2018	10:00:00	51.9	72.5	59.4	53.8	50.0	42.1
23/01/2018	11:00:00	52.1	72.0	60.7	53.2	48.8	41.5
23/01/2018	12:00:00	53.1	74.9	62.4	54.0	46.7	41.0

Table A- 3. Measured Sound Levels at SLM3 (dBA)

Date	Time	L_{eq}	L_{max}	$L_{2.5}$	$L_{8.3}$	L_{25}	L_{90}
22/01/2018	13:00:00	34.3	55.0	40.5	37.3	33.8	30.2
22/01/2018	14:00:00	32.5	48.8	37.0	33.8	32.3	30.3
22/01/2018	15:00:00	38.3	52.7	47.2	43.9	34.6	30.5
22/01/2018	16:00:00	43.6	69.9	49.7	46.8	42.6	31.2
22/01/2018	17:00:00	33.6	47.9	37.5	35.1	33.6	31.7
22/01/2018	18:00:00	33.1	46.6	36.8	34.6	33.2	31.3
22/01/2018	19:00:00	33.4	44.5	36.8	35.2	33.8	31.5
22/01/2018	20:00:00	33.6	49.9	38.0	35.9	33.9	31.4
22/01/2018	21:00:00	33.3	48.6	37.9	35.0	33.3	31.1
22/01/2018	22:00:00	32.4	46.7	36.4	34.3	32.4	30.5
22/01/2018	23:00:00	32.3	46.9	36.9	33.9	32.3	30.3
23/01/2018	00:00:00	32.3	46.5	36.4	34.7	32.7	30.0
23/01/2018	01:00:00	31.0	42.1	34.8	32.7	30.8	29.8
23/01/2018	02:00:00	31.8	47.1	35.3	33.4	31.8	29.9
23/01/2018	03:00:00	36.4	63.8	43.1	40.5	32.7	30.3
23/01/2018	04:00:00	35.0	66.7	38.5	35.6	33.7	31.3
23/01/2018	05:00:00	36.5	63.0	40.8	38.0	36.1	32.2
23/01/2018	06:00:00	47.4	77.4	51.9	44.0	40.4	35.9
23/01/2018	07:00:00	48.4	77.9	51.5	47.2	43.4	36.5
23/01/2018	08:00:00	54.5	83.1	61.4	58.6	54.6	42.6
23/01/2018	09:00:00	48.7	76.2	54.3	49.8	46.0	40.3
23/01/2018	10:00:00	46.4	72.7	52.1	47.2	42.9	38.0
23/01/2018	11:00:00	52.7	86.2	53.9	50.5	47.1	38.8
23/01/2018	12:00:00	46.6	65.4	54.2	51.5	46.9	37.5

DEPARTMENT OF TRANSPORTATION · UNITED STATES OF AMERICA

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Federal Transit Administration

TRANSIT NOISE AND VIBRATION IMPACT ASSESSMENT

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13. ABSTRACT (Maximum 200 words)

This report is the second edition of a guidance manual originally issued in 1995 which presents procedures for predicting and assessing noise and vibration impacts of proposed mass transit projects. All types of bus and rail projects are covered. Procedures for assessing noise and vibration impacts are provided for different stages of project development, from early planning before mode and alignment have been selected through preliminary engineering and final design. Both for noise and vibration, there are three levels of analysis described. The framework acts as a screening process, reserving detailed analysis for projects with the greatest potential for impacts while allowing a simpler process for projects with little or no effects.

This updated guidance contains noise and vibration impact criteria that are used to assess the magnitude of predicted impacts. A range of mitigation measures are described for dealing with adverse noise and vibration impacts. There is a discussion of noise and vibration during the construction stage and also discussion of how the technical information should be presented in the Federal Transit Administration's environmental documents. This guidance will be of interest not only to technical specialists who conduct the analyses but also to transit agency staff, federal agency reviewers, and members of the general public who may be affected by the projects.

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TRANSIT NOISE AND VIBRATION IMPACT ASSESSMENT

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8. VIBRATION IMPACT CRITERIA

Because of the relatively rare occurrence of annoyance due to ground-borne vibration and noise, there has been only limited sponsored research of human response to building vibration and structure-borne noise. However, with the construction of new rail rapid transit systems in the past 30 years, considerable experience has been gained as to how people react to various levels of building vibration. This experience, combined with the available national and international standards,[1,2,3] represents a good foundation for predicting annoyance from ground-borne noise and vibration in residential areas as well as interference with vibration-sensitive activities.

The criteria for environmental impact from ground-borne vibration and noise are based on the maximum root-mean-square (rms) vibration levels for repeated events of the same source. The criteria presented in Table 8-1 account for variation in project types as well as the frequency of events, which differ widely among transit projects. Most experience is with the community response to ground-borne vibration from rail rapid transit systems with typical headways in the range of 3 to 10 minutes and each vibration event lasting less than 10 seconds. It is intuitive that when there will be many fewer events each day, as is typical for commuter rail projects, it should take higher vibration levels to evoke the same community response. This is accounted for in the criteria by distinguishing between projects with varying numbers of events, where *Frequent Events* are defined as more than 70 events per day, *Occasional Events* range between 30 and 70 events per day, and *Infrequent Events* are fewer than 30 events per day. Most commuter rail branch lines will fall into the infrequent events category, although the trunk lines of some commuter rail lines serving major cities are in the occasional events category.

The criteria are primarily based on experience with passenger train operations with only limited experience from freight train operations. The difference is that passenger train operations, whether rapid transit, commuter rail, or intercity passenger railroad, create vibration events that last less than about 10 seconds. A typical line-haul freight train is about 5000 feet long. At a speed of 30 mph, it will take a 5000-foot freight train approximately two minutes to pass. Even though the criteria are primarily based on experience with shorter vibration events and this manual is oriented to transit projects, there will be situations where potential impacts from freight train ground-borne vibration will need to be evaluated. The prime example is when freight train tracks must be relocated to provide space for a transit project within a railroad right-of-way. Some guidelines for applying these criteria to freight train operations are given later in this chapter.

8.1 VIBRATION IMPACT CRITERIA FOR GENERAL ASSESSMENT

8.1.1 Sensitive-Use Categories

The criteria for acceptable ground-borne vibration are expressed in terms of rms velocity levels in decibels and the criteria for acceptable ground-borne noise are expressed in terms of A-weighted sound levels. The limits are specified for the three land-use categories defined below:

- **Vibration Category 1 - High Sensitivity:** Included in Category 1 are buildings where vibration would interfere with operations within the building, including levels that may be well below those associated with human annoyance. Concert halls and other special-use facilities are covered separately in Table 8-2. Typical land uses covered by Category 1 are: vibration-sensitive research and manufacturing, hospitals with vibration-sensitive equipment, and university research operations. The degree of sensitivity to vibration will depend on the specific equipment that will be affected by the vibration. Equipment such as electron microscopes and high resolution lithographic equipment can be very sensitive to vibration, and even normal optical microscopes will sometimes be difficult to use when vibration is well below the human annoyance level. Manufacturing of computer chips is an example of a vibration-sensitive process.

  The vibration limits for Vibration Category 1 are based on acceptable vibration for moderately vibration-sensitive equipment such as optical microscopes and electron microscopes with vibration isolation systems. Defining limits for equipment that is even more sensitive requires a detailed review of the specific equipment involved. This type of review is usually performed during the Detailed Analysis associated with the final design phase and not as part of the environmental impact assessment. Mitigation of transit vibration that affects sensitive equipment typically involves modification of the equipment mounting system or relocation of the equipment rather than applying vibration control measures to the transit project.

  Note that this category does not include most computer installations or telephone switching equipment. Although the owners of this type of equipment often are very concerned about the potential of ground-borne vibration interrupting smooth operation of their equipment, it is rare for computer or other electronic equipment to be particularly sensitive to vibration. Most such equipment is designed to operate in typical building environments where the equipment may experience occasional shock from bumping and continuous background vibration caused by other equipment.

- **Vibration Category 2 - Residential:** This category covers all residential land uses and any buildings where people sleep, such as hotels and hospitals. No differentiation is made between different types of residential areas. This is primarily because ground-borne vibration and noise are experienced indoors and building occupants have practically no means to reduce their exposure. Even in a noisy urban area, the bedrooms often will be quiet in buildings that have effective noise insulation and tightly closed windows. Moreover, street traffic often abates at night when transit continues to operate. Hence, an occupant of a bedroom in a noisy urban area is likely to be just as exposed to ground-borne noise and vibration as someone in a quiet suburban area. The criteria apply to the transit-generated ground-borne vibration and noise whether the source is subway or surface running trains.

- **Vibration Category 3 - Institutional:** Vibration Category 3 includes schools, churches, other institutions, and quiet offices that do not have vibration-sensitive equipment, but still have the potential for activity interference. Although it is generally appropriate to include office buildings in this category, it is not appropriate to include all buildings that have any office space. For example, most industrial buildings have office space, but it is not intended that buildings primarily for industrial use be included in this category.

Table 8-1. Ground-Borne Vibration (GBV) and Ground-Borne Noise (GBN) Impact Criteria for General Assessment

Land Use Category	GBV Impact Levels (VdB re 1 micro-inch /sec)			GBN Impact Levels (dB re 20 micro Pascals)		
	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]
Category 1: Buildings where vibration would interfere with interior operations.	65 VdB[4]	65 VdB[4]	65 VdB[4]	N/A[4]	N/A[4]	N/A[4]
Category 2: Residences and buildings where people normally sleep.	72 VdB	75 VdB	80 VdB	35 dBA	38 dBA	43 dBA
Category 3: Institutional land uses with primarily daytime use.	75 VdB	78 VdB	83 VdB	40 dBA	43 dBA	48 dBA

Notes:
1. "Frequent Events" is defined as more than 70 vibration events of the same source per day. Most rapid transit projects fall into this category.
2. "Occasional Events" is defined as between 30 and 70 vibration events of the same source per day. Most commuter trunk lines have this many operations.
3. "Infrequent Events" is defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.
4. This criterion limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. Vibration-sensitive manufacturing or research will require detailed evaluation to define the acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the HVAC systems and stiffened floors.
5. Vibration-sensitive equipment is generally not sensitive to ground-borne noise.

There are some buildings, such as concert halls, TV and recording studios, and theaters, that can be very sensitive to vibration and noise but do not fit into any of the three categories. Because of the sensitivity of these buildings, they usually warrant special attention during the environmental assessment of a transit project. Table 8-2 gives criteria for acceptable levels of ground-borne vibration and noise for various types of special buildings.

Table 8-2. Ground-Borne Vibration and Noise Impact Criteria for Special Buildings

Type of Building or Room	Ground-Borne Vibration Impact Levels (VdB re 1 micro-inch/sec)		Ground-Borne Noise Impact Levels (dB re 20 micro-Pascals)	
	Frequent [1] Events	Occasional or Infrequent [2] Events	Frequent [1] Events	Occasional or Infrequent [2] Events
Concert Halls	65 VdB	65 VdB	25 dBA	25 dBA
TV Studios	65 VdB	65 VdB	25 dBA	25 dBA
Recording Studios	65 VdB	65 VdB	25 dBA	25 dBA
Auditoriums	72 VdB	80 VdB	30 dBA	38 dBA
Theaters	72 VdB	80 VdB	35 dBA	43 dBA

Notes:
1."Frequent Events" is defined as more than 70 vibration events per day. Most rapid transit projects fall into this category.
2."Occasional or Infrequent Events" is defined as fewer than 70 vibration events per day. This category includes most commuter rail systems.
3.If the building will rarely be occupied when the trains are operating, there is no need to consider impact. As an example, consider locating a commuter rail line next to a concert hall. If no commuter trains will operate after 7 pm, it should be rare that the trains interfere with the use of the hall.

The criteria in Tables 8-1 and 8-2 are related to ground-borne vibration causing human annoyance or interfering with use of vibration-sensitive equipment. It is extremely rare for vibration from train operations to cause any sort of building damage, even minor cosmetic damage. However, there is sometimes concern about damage to fragile historic buildings located near the right-of-way. Even in these cases, damage is unlikely except when the track will be very close to the structure. Damage thresholds that apply to these structures are discussed in Section 12.2.2.

8.1.2 Existing Vibration Conditions

One factor not incorporated in the criteria is how to account for existing vibration. In most cases, the existing environment does not include a significant number of perceptible ground-borne vibration or noise events. The most common example of needing to account for the pre-existing vibration is when the project will be located in an existing rail corridor. When the project will cause vibration more than 5 VdB greater than the existing source, the existing source can be ignored and the standard vibration criteria applied to the project. Following are methods of handling representative scenarios:

1. *Infrequently-used rail corridor (fewer than 5 trains per day):* Use the general vibration criteria, Tables 8-1 and 8-2.

2. *Moderately-used rail corridor (5 to 12 trains per day):* If the existing train vibration exceeds the impact criteria given in Tables 8-1 and 8-2, there will be no impact from the project vibration if the levels estimated using the procedures outlined in either Chapter 10 or 11 are at least 5VdB less than the existing train vibration. Otherwise, vibration criteria in Tables 8-1 and 8-2 apply to the project. The existing train vibration can be either measured or estimated using the General Assessment procedures in Chapter 10. It is usually preferable to measure vibration from existing train traffic.

3. *Heavily-used rail corridor (more than 12 trains per day):* If the existing train vibration exceeds the impact criteria given in Tables 8-1 and 8-2, the project will cause additional impact if the project significantly increases the number of vibration events. Approximately doubling the number of events is required for a significant increase.

   If there is not a significant increase in vibration events, there will be additional impact only if the project vibration, estimated using the procedures of Chapters 10 or 11, will be 3 VdB or more higher than the existing vibration. An example of a case with no additional impact would be an automated people mover system planned for a corridor with an existing rapid transit service with 220 trains per day. On the other hand, there could be impact if it is a new commuter rail line planned to share a corridor with the rapid transit system. In this latter case, the project vibrations are likely to be higher than the existing vibrations by 3 VdB or more.

4. *Moving existing tracks:* Another scenario where existing vibration can be significant is when a new transit project will use an existing railroad right-of-way and result in shifting the location of existing railroad tracks. The track relocation and reconstruction can result in lower vibration levels, in which case this aspect of the project represents a benefit, not an adverse impact. If the track relocation will cause higher vibration levels at sensitive receptors, then the projected vibration levels must be compared to the appropriate impact criterion to determine if there will be new impacts. If impact is judged to have existed prior to moving the tracks, new impact will be assessed only if the relocation results in more than a 3 VdB increase in vibration level.

8.1.3 Application to Freight Trains

The impact thresholds given in Tables 8-1 and 8-2 are based on experience with vibration from rail transit systems. They have been used to assess vibration from freight trains since no specific impact criteria exist for freight railroads. However, the significantly greater length, weight and axle loads of freight trains make it problematic to use these impact criteria for freight rail. Nevertheless, in shared right-of-way situations where the proposed transit alignment causes the freight tracks to be moved closer to sensitive sites, these impact criteria will have to be used. In assessing the freight train vibration, a dual approach is recommended with separate consideration of the locomotive and rail car vibration. Because the locomotive vibration only lasts for a very short time, the few-event criterion is appropriate for fewer than 30 events per day. However, for a typical line-haul freight train where the rail car vibration lasts for several minutes, the many-event limits should be applied to the rail car vibration. Some judgment must be exercised to make sure that the approach is reasonable. For example, some spur rail lines carry very little rail traffic (sometimes only one train per week) or have short trains, in which case the criteria may be disregarded altogether.

Finally, it should be pointed out that the vibration control measures developed for rail transit systems are not effective for freight trains. Consequently, any decision to relocate freight tracks closer to sensitive sites should be made with the understanding that the increased vibration impact due to freight rail will be very difficult, if not impossible, to mitigate.

8.2 VIBRATION IMPACT CRITERIA FOR DETAILED ANALYSIS

8.2.1 Ground-Borne Vibration

Specification of mitigation measures requires more detailed information and more refined impact criteria than what were used in the General Assessment. A frequency distribution, or spectrum, of the vibration energy determines whether the vibrations are likely to generate a significant response in a receiving building or structure. The Detailed Analysis method in this manual provides an estimate of building response in terms of a one-third octave band frequency spectrum. This section provides criteria for assessing the potential for interference or annoyance from building response and for determining the performance of vibration reduction methods.

International standards have been developed for the effects of vibration on people in buildings with ratings related to annoyance and interference with activities based on frequency distribution of acceptable vibrations.[2] These criteria have been supplemented by industry standards for vibration-sensitive equipment.[3] Both sets of criteria are expressed in terms of one-third octave band velocity spectra, with transient events like train passbys described in terms of the maximum rms vibration velocity level with a one-second averaging time. The measurement point is specified as the floor of the receiving building at the location of the prescribed activity.

The vibration impact criteria are shown in Figure 8-1 where the international standard curves and the industry standards are plotted on the same figure. Interpretations of the various levels are presented in Table 8-3. Detailed Analysis results in one-third octave band spectra levels that are plotted over the curves shown in Figure 8-1. Band levels that exceed a particular criterion curve indicate the need for mitigation and the frequency range within which the treatment needs to be effective.

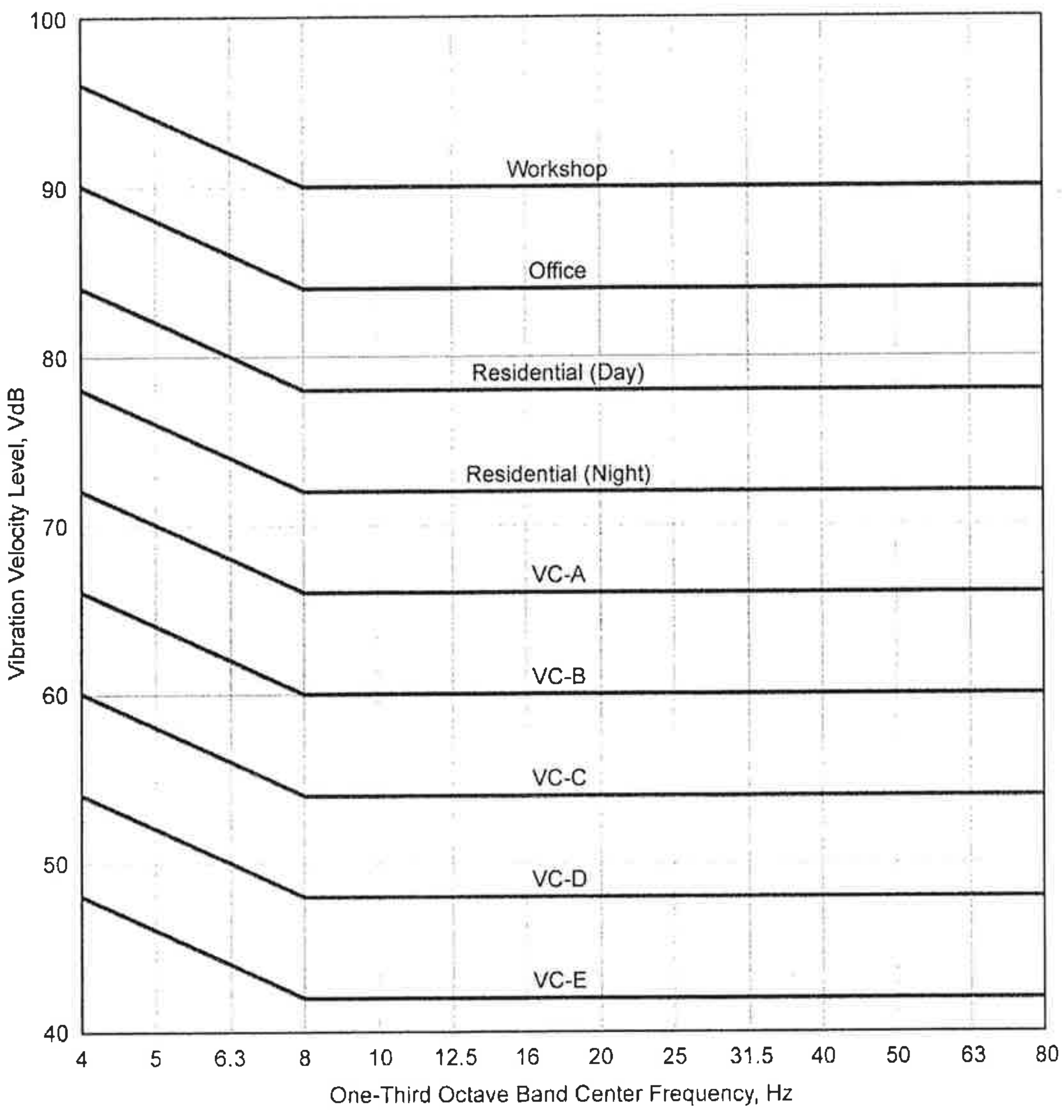

Figure 8-1. Criteria for Detailed Vibration Analysis

Table 8-3. Interpretation of Vibration Criteria for Detailed Analysis		
Criterion Curve[1] (See Figure 8-1)	**Max L_v (VdB)[2]**	**Description of Use**
Workshop	90	Distinctly feelable vibration. Appropriate to workshops and non-sensitive areas.
Office	84	Feelable vibration. Appropriate to offices and non-sensitive areas.
Residential Day	78	Barely feelable vibration. Adequate for computer equipment and low-power optical microscopes (up to 20X).
Residential Night, Operating Rooms	72	Vibration not feelable, but ground-borne noise may be audible inside quiet rooms. Suitable for medium-power optical microscopes (100X) and other equipment of low sensitivity.
VC-A	66	Adequate for medium- to high-power optical microscopes (400X), microbalances, optical balances, and similar specialized equipment.
VC-B	60	Adequate for high-power optical microscopes (1000X), inspection and lithography equipment to 3 micron line widths.
VC-C	54	Appropriate for most lithography and inspection equipment to 1 micron detail size.
VC-D	48	Suitable in most instances for the most demanding equipment, including electron microscopes operating to the limits of their capability.
VC-E	42	The most demanding criterion for extremely vibration-sensitive equipment.

[1]Descriptors on curves are those provided by References 2 and 3.
[2]As measured in 1/3-octave bands of frequency over the frequency range 8 to 80 Hz.

These criteria use a frequency spectrum because vibration-related problems generally occur due to resonances of the structural components of a building or vibration-sensitive equipment. Resonant response is frequency-dependent. A Detailed Analysis can provide an assessment that identifies potential problems resulting from resonances.

The detailed vibration criteria are based on generic cases when people are standing or equipment is mounted on the floor in a conventional manner. Consequently, the criteria are less stringent at very low frequencies below 8 Hz. Where special vibration isolation has been provided in the form of pneumatic isolators, the resonant frequency of the isolation system is very low. Consequently, in this special case, the curves may be extended flat at lower frequencies.

8.2.2 Ground-Borne Noise

Ground-borne noise impacts are assessed based on criteria for human annoyance and activity interference. The results of the Detailed Analysis provide vibration spectra inside a building. These vibration spectra can be converted to sound pressure level spectra in the occupied spaces using the method described in Section 11.2.2. For residential buildings, the criteria for acceptability are given in terms of the A-weighted sound pressure level in Table 8-1. For special buildings listed in Table 8-2, a single-valued level may not be sufficient to assess activity interference at the Detailed Analysis stage. Each special building may have a unique specification for acceptable noise levels. For example, a recording studio may have stringent requirements for allowable noise in each frequency band. Therefore, the ground-borne noise criteria for each sensitive building in this category will have to be determined on a case-by-case basis.

REFERENCES

1. Acoustical Society of America, "American National Standard: Guide to Evaluation of Human Exposure to Vibration in Buildings," ANSI S3.29-1983 (ASA 48-1983).

2. International Organization for Standardization, "Evaluation of Human Exposure to Whole-Body Vibration, Part 2: Continuous and Shock-Induced Vibrations in Buildings (1-80Hz)," ISO-2361-2, 1989.

3. Institute of Environmental Sciences and Technology, "Considerations in Clean Room Design," RR-CC012.1, 1993.

9. VIBRATION SCREENING PROCEDURE

The vibration screening procedure is designed to identify projects that have little possibility of creating significant adverse impact. If the screening procedure does not identify any potential problem areas, it is usually safe to eliminate further consideration of vibration impact from the environmental analysis.

9.1 STEPS IN SCREENING PROCEDURE

The steps in the vibration screening procedure are summarized in Figure 9-1 in a flow chart format. Following is a summary of the steps:

Initial Decision: If the project includes any type of steel-wheeled/steel-rail vehicle, there is potential for vibration impact. Proceed directly to the evaluation of screening distances. Transit projects that do not involve vehicles, such as a station rehabilitation, do not have potential for vibration impact unless the track system will be modified (e.g., tracks moved or switches modified). Rail systems include urban rapid transit, light rail transit, commuter rail, and steel-wheel intermediate capacity transit systems. For projects that involve rubber-tire vehicles, vibration impact is unlikely except in unusual situations. Three specific factors shown in Figure 9-1 should be checked to determine if there is potential vibration impact from bus projects or any other projects that involve rubber-tire vehicles:

1. Will there be expansion joints, speed bumps, or other design features that result in unevenness in the road surface near vibration-sensitive buildings? Such irregularities can result in perceptible ground-borne vibration at distances up to 75 feet away.
2. Will buses, trucks or other heavy vehicles be operating close to a sensitive building? Research using electron microscopes and manufacturing of computer chips are examples of vibration-sensitive activities.

3. Does the project include operation of vehicles inside or directly underneath buildings that are vibration-sensitive? Special considerations are often required for shared-use facilities such as a bus station located inside an office building complex.

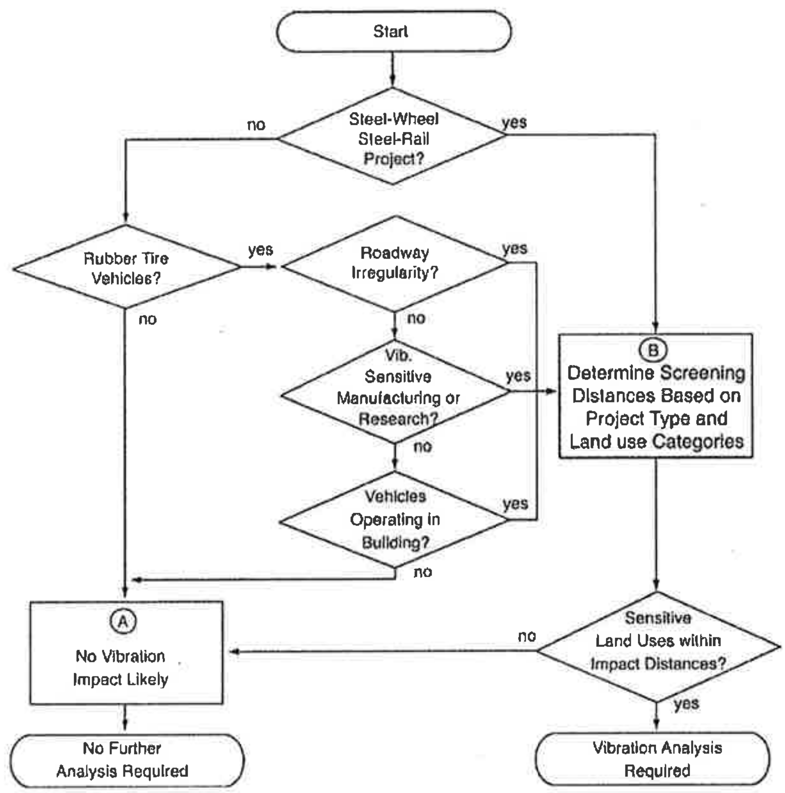

Figure 9-1. Flow Chart of Vibration Screening Process

No Impact (Box A): The decisions in step 1 lead to either box A, "No vibration impact likely," or box B. Reaching box A indicates that further analysis is not required. The majority of smaller FTA-assisted projects, such as bus terminals and park-and-ride lots, will be eliminated from further consideration of ground-borne vibration impact in the first step.

Screening Distances (Box B): If the result of the first step is that there is potential for vibration impact, determine if any vibration-sensitive land uses are within the screening zones. Vibration-sensitive land uses are identified in Chapter 8. Tables 9-1 and 9-2 are used to determine the applicable vibration screening distances for the project.

Impact: If there are any vibration-sensitive land uses within the screening distances, there is the potential for vibration impact. The result of the screening procedure is that a General Vibration Assessment should be done as part of the environmental analysis.

9.2 SCREENING DISTANCES

9.2.1 Project Categories

The vibration screening procedure is applicable to all types of FTA-assisted projects. The project categories for the vibration screening procedure are summarized in Table 9-1 for four types of rail transit. The fifth category includes all bus projects. Any project that does not include some type of vehicle is not likely to cause vibration impact.

With respect to Project Type 5, the rubber-tire vehicle category, most complaints about vibration caused by buses and trucks are related to rattling of windows or items hung on the walls. These vibrations are usually the result of airborne noise and not ground-borne vibration. In the case where ground-borne vibration is the source of the problem, the vibration can usually be related to potholes, some sort of bump in the road, or other irregularities.

Table 9-1. Project Types for Vibration Screening Procedure

Project Type	Description
1. Conventional Commuter Railroad	Both the locomotives and the passenger vehicles create significant vibration. The highest vibration levels are usually created by the locomotives. Electric commuter rail vehicles create levels of ground-borne vibration that are comparable to electric rapid transit vehicles.
2. Rail Rapid Transit	Ground-borne vibration impact from rapid transit trains is one of the major environmental issues for new systems. For operation in subway, the ground-borne vibration is usually a significant environmental impact. It is less common for at-grade and elevated rapid transit lines to create intrusive ground-borne vibration.
3. Light Rail Transit	The ground-borne vibration characteristics of light rail systems are very similar to those of rapid transit systems. Because the speeds of light rail systems are usually lower, the typical vibration levels usually are lower. Steel-wheel/steel-rail Automated Guideway Transit (AGT) will fall into either this category or the Intermediate Capacity Transit category depending on the level of service and train speeds.
4. Intermediate Capacity Transit	Because of the low operating speeds of most ICT systems, significant vibration problems are not common. However, steel-wheel ICT systems that operate close to vibration-sensitive buildings have the potential of causing intrusive vibration. With a stiff suspension system, an ICT system could create intrusive vibration.
5. Bus and Rubber-Tire Transit Projects	This category encompasses most projects that do not include steel-wheel trains of some type. Examples are diesel buses, electric trolley buses, and rubber-tired people movers. Most projects that do not include steel-wheel trains do not cause significant vibration impact.

9.2.2 Distances

The screening distances are given in Table 9-2. These distances are based on the criteria presented in Chapter 8, with a 5-decibel factor of safety included. The distances have been determined using vibration prediction procedures that are summarized in Chapter 10 assuming "normal" vibration propagation. As discussed in Chapter 10, efficient vibration propagation can result in substantially higher vibration levels.

Because of the 5-decibel safety factor, even with efficient propagation, the screening distances will identify most of the potentially impacted areas. By not specifically accounting for the possibility of efficient vibration propagation, there is some possibility that some potential impact areas will not be identified in the screening process. When there is evidence of efficient propagation, such as previous complaints about existing transit facilities or a history of problems with construction vibration, the distances in Table 9-2 should be increased by a factor of 1.5.

Table 9-2. Screening Distances for Vibration Assessment

Type of Project	Critical Distance for Land Use Categories* Distance from Right-of-Way or Property Line		
	Cat. 1	Cat. 2	Cat. 3
Conventional Commuter Railroad	600	200	120
Rail Rapid Transit	600	200	120
Light Rail Transit	450	150	100
Intermediate Capacity Transit	200	100	50
Bus Projects (if not previously screened out)	100	50	--

* The land-use categories are defined in Chapter 8. Some vibration-sensitive land uses are not included in these categories. Examples are: concert halls and TV studios which, for the screening procedure, should be evaluated as Category 1; and theaters and auditoriums which should be evaluated as Category 2.

10. GENERAL VIBRATION ASSESSMENT

This chapter outlines procedures that can be used to develop generalized predictions of ground-borne vibration and noise. This manual includes three different levels of detail for projecting ground-borne vibration:

- **Screening:** The screening procedure is discussed in Chapter 9. A standard table of impact distances is used to determine if ground-borne vibration from the project may affect sensitive land uses. More detailed analysis is required if any sensitive land uses are within the screening distances. The screening procedure does not require any specific knowledge about the vibration characteristics of the system or the geology of the area. If different propagation conditions are known to be present, a simple adjustment is provided.

- **General Assessment:** The general level of assessment, as described in this chapter, is an extension of the screening procedure. It uses generalized data to develop a curve of vibration level as a function of distance from the track. The vibration levels at specific buildings are estimated by reading values from the curve and applying adjustments to account for factors such as track support system, vehicle speed, type of building, and track and wheel condition. The general level deals only with the overall vibration velocity level and the A-weighted sound level. It does not consider the frequency spectrum of the vibration or noise.

- **Detailed Analysis:** Discussed in Chapter 11, the Detailed Analysis involves applying all of the available tools for accurately projecting the vibration impact at specific sites. The procedure outlined in this manual includes a test of the vehicle (or similar vehicle) to define the forces generated by the vibration source and tests at the site in question to define how the local geology affects vibration propagation. It is considerably more complex to develop detailed projections of ground-borne vibration than it is to develop detailed projections of airborne noise. Accurate projections of ground-borne vibration require professionals with experience in performing and interpreting vibration propagation tests. As such, detailed vibration predictions are usually performed during the final design phase of a project when there is sufficient reason to suspect adverse vibration impact from the project. The procedure for Detailed Vibration Analysis presented in Chapter 11 is based on measurements to characterize vibration propagation at specific sites.

There is not always a clear distinction between general and detailed predictions. For example, it is often appropriate to use several representative measurements of vibration propagation along the planned alignment in developing generalized propagation curves. Other times, generalized prediction curves may be sufficient for the majority of the alignment, but with Detailed Analysis applied to particularly sensitive buildings such as a concert hall. The methods for analyzing transit vibration in this manual are consistent with those described in recognized handbooks and international standards.[1, 2]

The purpose of the General Assessment is to provide a relatively simple method of developing estimates of the overall levels of ground-borne vibration and noise that can be compared to the acceptability criteria given in Chapter 8. For many projects, particularly when comparing alternatives, this level of detail will be sufficient for the environmental impact assessment. Where there are potential problems, the Detailed Analysis is then undertaken during final design of the selected alternative to accurately define the level of impact and design mitigation measures. A Detailed Analysis usually will be required when designing special track-support systems such as floating slabs or ballast mats. Detailed Analysis is not usually required if, as is often the case, the mitigation measure consists of relocating a crossover or turnout. Usually, the General Assessment is adequate to determine whether a crossover needs to be relocated.

The basic approach for the General Assessment is to define a curve, or set of curves, that predicts the overall ground-surface vibration as a function of distance from the source, then apply adjustments to these curves to account for factors such as vehicle speed, building type, and receiver location within the building. Section 10.1 includes curves of vibration level as a function of distance from the source for the common types of vibration sources such as rapid transit trains and buses. When the vehicle type is not covered by the curves included in this section, it will be necessary to define an appropriate curve either by extrapolating from existing information or performing measurements at an existing facility.

10.1 SELECTION OF BASE CURVE FOR GROUND SURFACE VIBRATION LEVEL

The base curves for three standard transportation systems are defined in Figure 10-1. This figure shows typical ground-surface vibration levels assuming equipment in good condition and speeds of 50 mph for the rail systems and 30 mph for buses. The levels must be adjusted to account for factors such as different speeds and different geologic conditions than assumed. The adjustment factors are discussed in Section 10.2.

The curves in Figure 10-1 are based on measurements of ground-borne vibration at representative North American transit systems. The top curve applies to trains that are powered by diesel or electric locomotives. It includes intercity passenger trains and commuter rail trains. The curve for rapid transit rail cars covers both heavy and light-rail vehicles on at-grade and subway track. It is somewhat surprising that subway and at-grade track can be represented by the same curve since ground-borne vibration created by a train operating in a subway has very different characteristics than vibration from at-grade track. However, in spite of these differences, the overall vibration velocity levels are comparable. Subways tend to have more vibration problems than at-grade track. This is probably due to two factors: (1) subways are usually located in more densely developed areas, and (2) the airborne noise is usually a more serious problem for at-grade systems than the ground-borne vibration. Another difference between subway and at-grade track is that the ground-borne vibration from subways tends to be higher frequency than the vibration from at-grade track, which makes the ground-borne noise more noticeable.

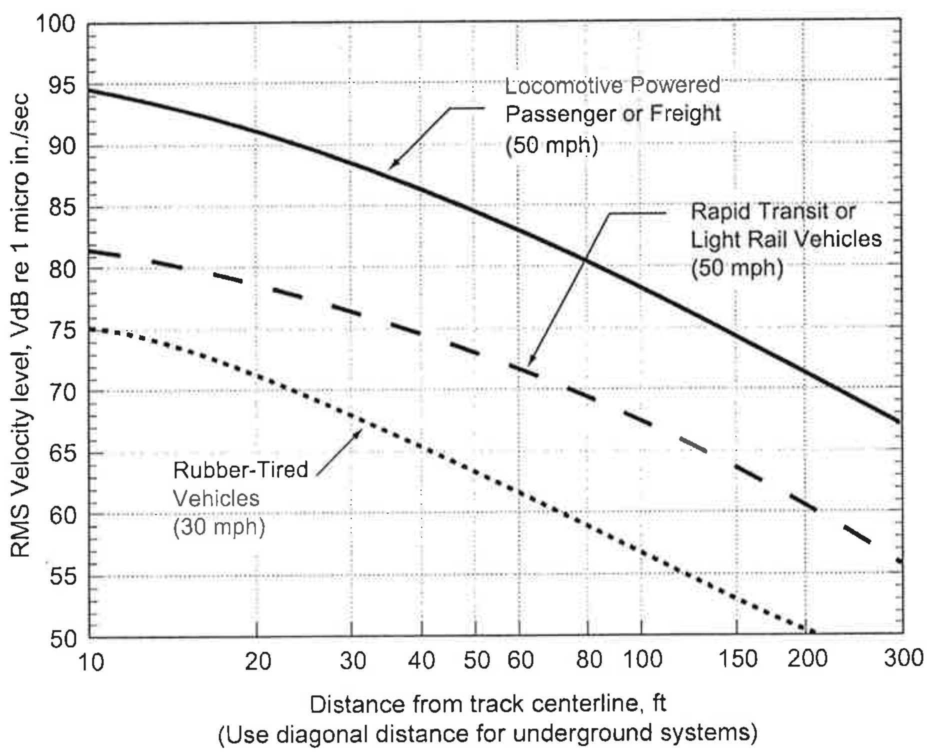

Figure 10-1. Generalized Ground Surface Vibration Curves

The curves in Figure 10-1 were developed from many measurements of ground-borne vibration. Experience with ground-borne vibration data is that, for any specific type of transit mode, a significant variation in vibration levels under apparently similar conditions is not uncommon. The curves in Figure

10-1 represent the upper range of the measurement data from well-maintained systems. Although actual levels fluctuate widely, it is rare that ground-borne vibration will exceed the curves in Figure 10-1 by more than one or two decibels unless there are extenuating circumstances, such as wheel- or running-surface defects.

One approach to dealing with the normal fluctuation is to show projections as a range. For example, the projected level from Figure 10-1 for an LRT system with train speeds of 50 mph is about 72 VdB at a distance of 60 feet from the track centerline, just at the threshold for acceptable ground-borne vibration for residential land uses. To help illustrate the normal fluctuation, the projected level of ground-borne vibration might be given as 67 to 72 VdB. This approach is not recommended since it tends to confuse the interpretation of whether or not the projected vibration levels exceed the impact threshold. However, because actual levels of ground-borne vibration will sometimes differ substantially from the projections, some care must be taken when interpreting projections. Some guidelines are given below:

1. Projected vibration is below the impact threshold. Vibration impact is unlikely in this case.
2. Projected ground-borne vibration is 0 to 5 decibels greater than the impact threshold. In this range there is still a significant chance that actual ground-borne vibration levels will be below the impact threshold. In this case, the impact would be reported in the environmental document as exceeding the applicable threshold and a commitment would be made to conduct more detailed studies to refine the vibration impact analysis during final design and determine appropriate mitigation, if necessary. A site-specific Detailed Analysis may show that vibration control measures are not needed.
3. Projected ground-borne vibration is 5 decibels or more greater than the impact threshold. Vibration impact is probable and Detailed Analysis will be needed during final design to help determine appropriate vibration control measures.

The two most important factors that must be accounted for in a General Assessment are the type of vibration source (the mode of transit) and the vibration propagation characteristics. It is well known that there are situations where ground-borne vibration propagates much more efficiently than normal. The result is unacceptable vibration levels at distances two to three times the normal distance. Unfortunately, the geologic conditions that promote efficient propagation have not been well documented and are not fully understood. Shallow bedrock or stiff clay soil often are involved. One possibility is that shallow bedrock acts to keep the vibration energy near the surface. Much of the energy that would normally radiate down is directed back towards the surface by the rock layer with the result that the ground surface vibration is higher than normal.

The selection of a base curve depends on the mode of rail transit under consideration. Appropriate correction factors are then added to account for any unusual propagation characteristics. For less common modes such as magnetically-levitated vehicles (maglev), monorail, or automated guideway transit (AGT), it is necessary to either make a judgment about which curve and adjustment factors best fit the mode or to develop new estimates of vibration level as a function of distance from the track. For example, the vibration from a rubber-tire monorail that will be operating on aerial guideway can be approximated using the bus/rubber tire systems with the appropriate adjustment for the aerial structure. Another example is a magnetic levitation system. Most of the data available on the noise and vibration characteristics of maglev vehicles comes from high-speed systems intended for inter-city service. Even though there is no direct contact between the vehicle and the guideway, the dynamic loads on the guideway can generate ground-borne vibration. Measurements on a German high-speed maglev resulted in ground-borne vibrations at 75 mph comparable to the base curve for rubber-tired vehicles at 30 mph.[3] Considerations for selecting a base curve are discussed below:

- **Intercity Passenger Trains:** Although intercity passenger trains can be an important source of environmental vibration, it is rare that they are significant for FTA-funded projects unless a new transit mode will use an existing rail alignment. When a new transit line will use an existing rail alignment, the changes in the intercity passenger traffic can result in either positive or negative impacts. Unless there are specific data available on the ground-borne vibration created by the train operations, the upper curve in Figure 10-1 should be used for intercity passenger trains.

- **Locomotive-Powered Commuter Rail:** The locomotive curve from Figure 10-1 should be used for any commuter rail system powered by either diesel or electric locomotives. The locomotives often create vibration levels that are 3 to 8 decibels higher than those created by the passenger cars. Self-powered electric commuter rail trains can be considered to be similar to rapid transit vehicles. Although they are relatively rare in the U.S., self-powered diesel multiple units (DMU's) create vibration levels somewhere between rapid transit vehicles and locomotive-powered passenger trains. When the axle loads and suspension parameters of a particular DMU are comparable to typical rapid transit vehicles, the rapid transit curve in Figure 10-1 can be used for that mode.

- **Subway Heavy Rail:** Complaints about ground-borne vibration are more common near subways than near at-grade track. This is not because subways create higher vibration levels than at-grade systems - rather it is because subways are usually located in high-density areas in close proximity to building foundations. When applied to subways, the rapid transit curve in Figure 10-1 assumes a relatively lightweight bored concrete tunnel in soil. The vibration levels will be lower for heavier subway structures such as cut-and-cover box structures and stations.

- **At-Grade Heavy Rail or LRT:** The available data show that heavy rail and light rail transit vehicles create similar levels of ground-borne vibration. This is not surprising since the vehicles have similar suspension systems and axle loads. Light-rail systems tend to have fewer problems with ground-borne vibration because of the lower operating speeds. Similar to the subway case, an adjustment factor must be used if the transit vehicle has a primary suspension that is stiff in the vertical direction.

- **Intermediate Capacity Transit:** The vibration levels created by an intermediate capacity transit system or an AGT system will depend on whether the vehicles have steel wheels or rubber wheels. If they have steel wheels, the transit car curve in Figure 10-1 should be used with appropriate adjustments for operating speed. The bus/rubber tire curve should be used for rubber-tired ICT systems.

- **Bus/Rubber Tire:** Rubber-tire vehicles rarely create ground-borne vibration problems unless there is a discontinuity or bump in the road that causes the vibration. The curve in Figure 10-1 shows the vibration level for a typical bus operating on smooth roadway.

10.2 ADJUSTMENTS

Once the base curve has been selected, the adjustments in Table 10-1 can be used to develop vibration projections for specific receiver positions inside buildings. All of the adjustments are given as single numbers to be added to, or subtracted from, the base level. The adjustment parameters are speed, wheel and rail type and condition, type of track support system, type of building foundation, and number of floors above the basement level. It should be recognized that many of these adjustments are strongly dependent on the frequency spectrum of the vibration source and the frequency dependence of the vibration propagation. The single number values are suitable for generalized evaluation of the vibration impact and vibration mitigation measures since they are based on typical vibration spectra. However, the single number adjustments are not adequate for detailed evaluations of impact of sensitive buildings or for detailed specification of mitigation measures. Detailed Analysis requires consideration of the relative importance of different frequency components.

Table 10-1. Adjustment Factors for Generalized Predictions of Ground-Borne Vibration and Noise

Source Factor	Adjustment to Propagation Curve			Comment
Factors Affecting Vibration Source				
		Reference Speed		
Speed	Vehicle Speed	50 mph	30 mph	Vibration level is approximately proportional to $20 * \log(speed/speed_{ref})$. Sometimes the variation with speed has been observed to be as low as 10 to 15 $\log(speed/speed_{ref})$.
	60 mph	+1.6 dB	+6.0 dB	
	50 mph	0.0 dB	+4.4 dB	
	40 mph	-1.9 dB	+2.5 dB	
	30 mph	-4.4 dB	0.0 dB	
	20 mph	-8.0 dB	-3.5 dB	
Vehicle Parameters (not additive, apply greatest value only)				
Vehicle with stiff primary suspension	+8 dB			Transit vehicles with stiff primary suspensions have been shown to create high vibration levels. Include this adjustment when the primary suspension has a vertical resonance frequency greater than 15 Hz.
Resilient Wheels	0 dB			Resilient wheels do not generally affect ground-borne vibration except at frequencies greater than about 80 Hz.
Worn Wheels or Wheels with Flats	+10 dB			Wheel flats or wheels that are unevenly worn can cause high vibration levels. This can be prevented with wheel truing and slip-slide detectors to prevent the wheels from sliding on the track.
Track Conditions (not additive, apply greatest value only)				
Worn or Corrugated Track	+10 dB			If both the wheels and the track are worn, only one adjustment should be used. Corrugated track is a common problem. Mill scale on new rail can cause higher vibration levels until the rail has been in use for some time.
Special Trackwork	+10 dB			Wheel impacts at special trackwork will significantly increase vibration levels. The increase will be less at greater distances from the track.
Jointed Track or Uneven Road Surfaces	+5 dB			Jointed track can cause higher vibration levels than welded track. Rough roads or expansion joints are sources of increased vibration for rubber-tire transit.
Track Treatments (not additive, apply greatest value only)				
Floating Slab Trackbed	-15 dB			The reduction achieved with a floating slab trackbed is strongly dependent on the frequency characteristics of the vibration.
Ballast Mats	-10 dB			Actual reduction is strongly dependent on frequency of vibration.
High-Resilience Fasteners	-5 dB			Slab track with track fasteners that are very compliant in the vertical direction can reduce vibration at frequencies greater than 40 Hz.

Table 10-1. Adjustment Factors for Generalized Predictions of Ground-Borne Vibration and Noise (Continued)

Factors Affecting Vibration Path				
Path Factor	**Adjustment to Propagation Curve**			**Comment**
Resiliently Supported Ties	-10 dB			Resiliently supported tie systems have been found to provide very effective control of low-frequency vibration.
Track Configuration (not additive, apply greatest value only)				
Type of Transit Structure	Relative to at-grade tie & ballast: Elevated structure -10 dB Open cut 0 dB			The general rule is the heavier the structure, the lower the vibration levels. Putting the track in cut may reduce the vibration levels slightly. Rock-based subways generate higher-frequency vibration.
	Relative to bored subway tunnel in soil: Station -5 dB Cut and cover -3 dB Rock-based - 15 dB			
Ground-borne Propagation Effects				
Geologic conditions that promote efficient vibration propagation	Efficient propagation in soil +10 dB			Refer to the text for guidance on identifying areas where efficient propagation is possible.
	Propagation in rock layer	<u>Dist.</u> 50 ft 100 ft 150 ft 200 ft	<u>Adjust.</u> +2 dB +4 dB +6 dB +9 dB	The positive adjustment accounts for the lower attenuation of vibration in rock compared to soil. It is generally more difficult to excite vibrations in rock than in soil at the source.
Coupling to building foundation	Wood Frame Houses -5 dB 1-2 Story Masonry -7 dB 3-4 Story Masonry -10 dB Large Masonry on Piles -10 dB Large Masonry on Spread Footings -13 dB Foundation in Rock 0 dB			The general rule is the heavier the building construction, the greater the coupling loss.
Factors Affecting Vibration Receiver				
Receiver Factor	**Adjustment to Propagation Curve**			**Comment**
Floor-to-floor attenuation	1 to 5 floors above grade: -2 dB/floor 5 to 10 floors above grade: -1 dB/floor			This factor accounts for dispersion and attenuation of the vibration energy as it propagates through a building.
Amplification due to resonances of floors, walls, and ceilings	+6 dB			The actual amplification will vary greatly depending on the type of construction. The amplification is lower near the wall/floor and wall/ceiling intersections.
Conversion to Ground-borne Noise				
Noise Level in dBA	Peak frequency of ground vibration: Low frequency (<30 Hz): -50 dB Typical (peak 30 to 60 Hz): -35 dB High frequency (>60 Hz): -20 dB			Use these adjustments to estimate the A-weighted sound level given the average vibration velocity level of the room surfaces. See text for guidelines for selecting low, typical or high frequency characteristics. Use the high-frequency adjustment for subway tunnels in rock or if the dominant frequencies of the vibration spectrum are known to be 60 Hz or greater.

Without careful consideration of the shape of the actual vibration spectra, an inappropriate vibration control measure may be selected that could actually cause an increase in the vibration levels.

The following guidelines are used to select the appropriate adjustment factors. Note that the adjustments for wheel and rail condition are not cumulative. The general rule-of-thumb to use when more than one adjustment may apply is to apply only the largest adjustment. For example: the adjustment for jointed track is 5 decibels and the adjustment for wheel flats is 10 decibels. In an area where there is jointed track and many vehicles have wheel flats, the projected vibration levels should be increased by 10 decibels, not 15 decibels.

- **Train Speed:** The levels of ground-borne vibration and noise vary approximately as 20 times the logarithm of speed. This means that doubling train speed will increase the vibration levels approximately 6 decibels and halving train speed will reduce the levels by 6 decibels. Table 10-1 tabulates the adjustments for reference vehicle speeds of 30 mph for rubber-tired vehicles and 50 mph for steel-wheel vehicles. The following relationship should be used to calculate the adjustments for other speeds.

$$adjustment(dB) = 20 \times \log\left(\frac{speed}{speed_{ref}}\right)$$

- **Vehicle:** The most important factors for the vehicles are the suspension system, wheel condition, and wheel type. Most new heavy rail and light rail vehicles have relatively soft primary suspensions. However, experience in Atlanta, New York, and other cities has demonstrated that a stiff primary suspension (vertical resonance frequency greater than 15 Hz) can result in higher than normal levels of ground-borne vibration. Vehicles for which the primary suspension consists of a rubber or neoprene "donut" around the axle bearing usually have a very stiff primary suspension with a vertical resonance frequency greater than 40 Hz.

  Deteriorated wheel condition is another factor that will increase vibration levels. It can be assumed that a new system will have vehicles with wheels in good condition. However, when older vehicles will be used on new track, it may be appropriate to include an adjustment for wheel condition. The reference curves account for wheels without defects, but wheels with flats or corrugations can cause vibration levels that are 10 VdB higher than normal. Resilient wheels will reduce vibration levels at frequencies greater than the effective resonance frequency of the wheel. Because this resonance frequency is relatively high, often greater than 80 Hz, resilient wheels usually have only a marginal effect on ground-borne vibration.

  It is important to use only one of the adjustments in this category, the greatest one that applies.

- **Track System and Support:** This category includes the type of rail (welded, jointed or special trackwork), the track support system, and the condition of the rail. The base curves all assume good-condition welded rail. Jointed rail causes higher vibration levels than welded rail; the amount higher depends on the condition of the joints. The wheel impacts at special trackwork, such as frogs at crossovers, create much higher vibration forces than normal. Because of the higher vibration levels at special trackwork, crossovers often end up being the principal areas of vibration impact on new systems. Modifying the track support system is one method of mitigating the vibration impact. Special track support systems such as ballast mats, high-resilience track fasteners, resiliently supported ties, and floating slabs have all been shown to be effective in reducing vibration levels.

  The condition of the running surface of the rails can strongly affect vibration levels. Factors such as corrugations, general wear, or mill scale on new track can cause vibration levels that are 5 to 15 decibels higher than normal. Mill scale will usually wear off after some time in service; however, the track must be ground to remove corrugations or to reduce the roughness from wear.

  Again, apply only one of the adjustments.

  Roadway surfaces in the case of rubber-tired systems are assumed to be smooth. Rough washboard surfaces, bumps or uneven expansion joints are the types of running surface defects that cause increased vibration levels over the smooth road condition.

- **Transit Structure:** The weight and size of a transit structure affects the vibration radiated by that structure. The general rule-of-thumb is that vibration levels will be lower for heavier transit structures. Hence, the vibration levels from a cut-and-cover concrete double-box subway can be assumed to be lower than the vibration from a lightweight concrete-lined bored tunnel. The vibration from elevated structures is lower than from at-grade track because of the mass and damping of the structure and the extra distance that the vibration must travel before it reaches the receiver. Elevated structures in automated guideway transit applications sometimes are designed to bear on building elements. These are a special case and may require detailed design considerations.

- **Propagation Characteristics:** In the General Assessment it is necessary to make a selection among the general propagation characteristics. For a subway, the selection is a fairly straightforward choice of whether or not the subway will be founded in bedrock. Bedrock is considered to be hard rock. It is usually appropriate to consider soft siltstone and sandstone to be more similar to soil than hard rock. As seen in Table 10-1, whether the subway is founded in soil or rock can be a 15 VdB difference in the vibration levels.

  When considering at-grade vibration sources, the selection is between "normal" vibration propagation and "efficient" vibration propagation. Efficient vibration propagation results in approximately 10 decibels higher vibration levels. This more than doubles the potential impact zone for ground-borne vibration. One of the problems with identifying the cause of efficient propagation is the difficulty in determining whether higher than normal vibration levels are due to geologic conditions or due to special source conditions (e.g. rail corrugations or wheel flats).

  Although it is known that geologic conditions have a significant effect on the vibration levels, it is rarely possible to develop more than a broad-brush understanding of the vibration propagation characteristics for a General Assessment. The conservative approach would be to use the 10-decibel adjustment for efficient propagation to evaluate all potential vibration impact. The problem with this approach is that it tends to greatly overstate the potential for vibration impact. Hence, it is best to review available geological data and any complaint history from existing transit lines and major construction sites near the transit corridor to identify areas where efficient propagation is possible. If there is any reason to suspect efficient propagation conditions, then a Detailed Analysis during final design would include vibration propagation tests at the areas identified as potentially efficient propagation sites.

Some geologic conditions are repeatedly associated with efficient propagation. Shallow bedrock, less than 30 feet below the surface, is likely to have efficient propagation. Other factors that can be important are soil type and stiffness. In particular, stiff clayey soils have sometimes been associated with efficient vibration propagation. Investigation of soil boring records can be used to estimate depth to bedrock and the presence of problem soil conditions.

A factor that can be particularly complex to address is the effect of vibration propagation through rock. There are three factors from Table 10-1 that need to be included when a subway structure will be founded in rock. First is the -15 decibel adjustment in the "Type of Transit Structure" category. Second is the adjustment based on the propagation distance in the "Geologic Conditions" category. This positive adjustment is applied to the distances shown in Figure 10-1; the adjustment increases with distance because vibration attenuates more slowly in rock than in the soil used as a basis for the reference curve. The third factor is in the "Coupling to Building" category. When a building foundation is directly on the rock layer, there is no "coupling loss" due to the weight and stiffness of the building. Use the standard coupling factors if there is at least a 10-foot layer of soil between the building foundation and the rock layer.

- **Type of Building and Receiver Location in Building:** Since annoyance from ground-borne vibration and noise is an indoor phenomenon, the effects of the building structure on the vibration must be considered. Wood frame buildings, such as the typical residential structure, are more easily excited by ground vibration than heavier buildings. In contrast, large masonry buildings with spread footings have a low response to ground vibration.

  Vibration generally reduces in level as it propagates through a building. As indicated in Table 10-1, a 1- to 2-decibel attenuation per floor is usually assumed. Counteracting this, resonances of the building structure, particularly the floors, will cause some amplification of the vibration. Consequently, for a wood-frame structure, the building-related adjustments nearly cancel out. The adjustments for the first floor assuming a basement are: -5 decibels for the coupling loss; -2 decibels for the propagation from the basement to the first floor; and +6 decibels for the floor amplification. The total adjustment in this case is -1 decibel.

- **Vibration to Ground-Borne Noise Adjustment**: It is possible to estimate the levels of radiated noise given the average vibration amplitude of the room surfaces (floors, walls and ceiling), and the total acoustical absorption in the room. The unweighted sound pressure level is approximately equal to the vibration velocity level when the velocity level is referenced to $1x10^{-6}$ inches/second.

However, to estimate the A-weighted sound level from the velocity level, it is necessary to have some information about the frequency spectrum. The A-weighting adjustment drops rapidly at low frequencies, reflecting the relative insensitivity of human hearing to low frequencies. For example, A-weighting is -16 dB at 125 Hz, -26 dB at 60 Hz and -40 dB at 30 Hz. Table 10-1 provides adjustments for vibration depending on whether it has low-frequency, typical or high-frequency characteristics. Some general guidelines for classifying the frequency characteristics are:

- Low Frequency: Low-frequency vibration characteristics can be assumed for subways surrounded by cohesiveless sandy soil or whenever a vibration isolation track support system will be used. Low-frequency characteristics can be assumed for most surface track.
- Typical: The typical vibration characteristic is the default assumption for subways. It should be assumed for subways until there is information indicating that one of the other assumptions is appropriate. It should be used for surface track when the soil is very stiff with a high clay content.
- High Frequency: High-frequency characteristics should be assumed for subways whenever the transit structure is founded in rock or when there is very stiff clayey soil.

10.3 INVENTORY OF VIBRATION-IMPACTED LOCATIONS

This chapter includes generalized curves for surface vibration for different transit modes along with adjustments to apply for specific operating conditions and buildings. The projected levels are then compared with the criteria in Chapter 8 to determine whether vibration impact is likely. The results of the General Assessment are expressed in terms of an inventory of all sensitive land uses where either ground-borne vibration or ground-borne noise from the project may exceed the impact thresholds. The General Assessment may include a discussion of mitigation measures which would likely be needed to reduce vibration to acceptable levels.

The purpose of the procedure is to develop a reasonably complete inventory of the buildings that may experience ground-borne vibration or noise that exceed the impact criteria. At this point, it is preferable to make a conservative assessment of the impact. That is, it is better to include some buildings where ground-borne vibration may be below the impact threshold than to exclude buildings where it may exceed the impact threshold. The inventory should be organized according to the categories described in Chapter 8. For each building where the projected ground-borne vibration or noise exceeds the applicable impact threshold, one or more of the vibration control options from Section 11.5 should be considered for applicability. See Section 11.4 for a more complete description of how the General Vibration Assessment fits into the overall procedure.

REFERENCES

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2. International Organization for Standardization, "Mechanical vibration – Ground-borne noise and vibration arising from rail systems," ISO/FDIS 14837-1:2005.

3. U.S. Department of Transportation, Volpe National Transportation Systems Center, "Vibration Characteristics of the Transrapid TR08 Maglev System," Report No. DOT-VNTSC-FRA-02-06, March 2002.