Technical Report
South Lake Union Streetcar Project

Noise and Vibration

March 24, 2005

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The City of Seattle Department of Transportation

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Chapter 1 Summary

The analysis of noise impacts in the project area is based on a comparison of noise exposure, with the noise caused by the project compared with existing noise levels to determine if a substantial noise increase would result. Construction noise impacts are described based on maximum noise levels of construction equipment published by the U.S. Environmental Protection Agency (EPA). Transit noise exposure is predicted at sensitive receptors based on projected operations using the Federal Transit Administration (FTA) noise assessment spreadsheet model. Mitigation measures are discussed, where appropriate, to avoid or reduce potential noise impacts.

Ambient noise levels were measured to describe the existing noise environment, determine the noise levels above which impacts would occur, and to identify major noise sources in the project area. Noise levels in South Lake Union are typical of an urban location. Project noise exposures that would result from the South Lake Union Streetcar project were modeled at noise-sensitive uses nearest the project alignment. Vibration impacts were evaluated qualitatively, based on the type of construction equipment likely to be used, the streetcar vehicle operating along the alignment, and nearby land uses.

Because substantial transportation-related (vehicular, bus transit, air via seaplanes from South Lake Union) service already exists in the South Lake Union project area, streetcar service would not result in an average increase in transportation noise. The frequency of noise peaks (L_{max} noise levels) may increase as transit operations increase in South Lake Union.

Noise exposure from the project for the year 2030 would range between 39 and 55 dBA L_{dn} at the modeled noise-sensitive land uses. Noise impacts under the FTA criteria are not predicted to occur at the six noise-sensitive locations analyzed as a result of the South Lake Union Streetcar Project.

Construction activities would generate noise and vibration during the construction period. Maximum (peak) noise levels from construction equipment would range from 69 to 106 dBA at 50 feet. Construction noise at locations farther away would decrease at a rate of 6 dBA per doubling of distance from the source. Because various equipment would be turned off, idling, or operating at less than full power at any time and because construction machinery is typically used to complete short-term tasks at any given location, average L_{eq} noise levels during the day would be less than the maximum noise levels and within City of Seattle construction noise limits.

Ground-borne vibration could be a concern for occupants of nearby buildings during construction activities associated with the proposed project. However, it is unusual for vibration from sources such as buses and trucks to be perceptible, even in locations close to major roads. Most common sources of ground-borne vibration are trains, buses on rough roads, and construction activities such as blasting, pile driving, and operating heavy earth-moving equipment.

Vibration impacts would only occur if vibration-sensitive land use occurs in the immediate vicinity of the project. The survey of nearby land uses did not include any vibration-sensitive uses within the immediate project area. Therefore, no substantial vibration impacts are predicted to occur as a result of the operation of this project.

Chapter 2 Introduction

This report describes the potential noise and vibration impacts associated with the proposed South Lake Union Streetcar Project. The project would provide a new streetcar line between the downtown Seattle commercial core and South Lake Union. The proposed route would follow Westlake Avenue north from Olive Way and continue east on Valley Street/Fairview Avenue N., ending near Ward Street. A portion of the route would also travel on Terry Avenue N. between Thomas and Valley streets. The approximate length of the proposed streetcar line would be 1.3 miles in each direction. The project would include associated stormwater and maintenance facilities.

Environmental noise is composed of many frequencies, each occurring simultaneously at its own sound pressure level. The range of magnitude from the faintest to the loudest sound the ear can hear is so large that sound pressure is expressed on a logarithmic scale in units called decibels (dB). The commonly used frequency weighting for environmental noise is A-weighting (dBA), which simulates how an average person hears sound.

A common noise descriptor for environmental noise is the equivalent sound level (L_{eq}). L_{eq} is a measure of total noise, a summation of all sounds during a period of time. L_{eq} measured over a one-hour period is the hourly L_{eq} (L_{eq} (h)). The day/night level (L_{dn}) is a descriptor of the daily noise environment, with a penalty for high noise levels at night.

For federally funded transit projects, noise impacts occur when predicted L_{eq}(h) or L_{dn} noise exposure generated by the project increase the overall noise in the area by between 1 and 10 dBA, depending on the existing noise level (FTA, 1995).

Ambient noise levels were measured at several locations near the project area to characterize the daily environmental noise environment. Measurements were taken according to Federal Highway Administration (FHWA) guidelines (1996). Sampling locations represent a variety of noise conditions and are representative of other receptors near the proposed project. Because most project-area noise was attributable to transportation sources, L_{dn} noise levels were estimated from a combination of L_{dn} and L_{eq}. At one residential site, one hotel, and one park, 24-hour noise measurements were taken and actual L_{eq} was calculated.

Project noise exposure levels (the quantity of noise that the project could cause) were modeled along the corridor. Noise exposure was modeled at various distances from the proposed alignment, to evaluate project effects at sensitive receptors that the project would potentially affect. FTANOISE, the FTA Transit Noise Assessment Spreadsheet Model (HMMH, 1995) was used to calculate noise levels generated by train operations and by supporting operations that would occur as a result of the proposed project. Predicted noise levels were based on projected daily transit operations for 2030, to estimate worst-case project noise levels.

Vibration is an oscillatory motion that can be described in terms of displacement, velocity, or acceleration. Displacement is the easiest descriptor to understand. For a vibrating floor, the displacement is simply the distance that a point on the floor moves away from its static position. The velocity represents the instantaneous speed of the floor movement, and acceleration is the rate of change of the speed. Transit vibration is virtually always characterized in terms of the root-mean-square (rms) velocity reported as VdB. It represents the average energy over a short time interval; a one-second interval is typically used to evaluate human response to vibration. RMS vibration velocity is considered the best available measure of potential human annoyance from ground-borne vibration.

Although the perceptibility threshold is about 65 VdB, human response to vibration is not usually substantial unless the vibration exceeds 70 VdB. This is a typical level 50 feet from a rapid transit or light rail system.

Ground-borne vibration could be a concern for occupants of nearby buildings during construction activities associated with the proposed project. However, it is unusual for vibration from sources such as buses and trucks to be perceptible, even in locations close to major roads. Most common sources of ground-borne vibration are heavy trains, buses on rough roads, and construction activities such as blasting, pile driving, and operating heavy earth-moving equipment.

The effects of ground-borne vibration include perceptible movement of building floors, rattling of windows, shaking of items on shelves or hanging on walls, and rumbling sounds. In extreme cases, the vibration can cause damage to buildings. Building damage is not a factor for normal transportation projects, with the occasional exception of pile driving, and demolition of structures that may occur during construction.

Vibration impacts were evaluated qualitatively, based on the type of construction equipment likely to be used, the streetcar vehicles operating along the project alignment, and nearby land uses

Chapter 3 Project Description

The City of Seattle, in cooperation with the U.S Department of Transportation Federal Transit Administration (FTA), proposes to construct a new streetcar line to serve the downtown, Denny Triangle and South Lake Union areas of Seattle. This line would provide local transit service, connect to the regional transit system, accommodate economic development, and contribute to neighborhood vitality. The project elements and construction are discussed in detail in the *South Lake Union Streetcar Project Description Memo* (Parsons Brinckerhoff, March 2005).

The proposed South Lake Union Streetcar would begin in the vicinity of the intersection of Westlake Avenue and Olive Way/5th Avenue in downtown Seattle (see Figure 3-1). It would extend north through the Denny Triangle and South Lake Union neighborhoods and terminate in the vicinity of Fairview Avenue N. and Ward Street near the Fred Hutchinson Cancer Research Center. The line would connect these neighborhoods and destinations with the regional transit hub at Westlake Center, which will be a major connection point for light rail, buses and monorail. The length of the proposed streetcar line is approximately 1.3 miles in each direction (2.6 track miles total) and the tracks and stops would be constructed entirely within existing right-of-way.

The streetcar would share the street with automobile traffic. Initially, the streetcar is expected to operate for 15 hours per day (roughly 6 AM to 9 PM), with fifteen minutes between cars. Ultimately, the system is expected to operate for 18 hours per day (roughly 5 AM to 11 PM), with ten minutes between cars.

As shown in Figure 3-1, streetcar stops would typically be side-platform corner-curb bulbs located within the parking lane at the far side of an intersection. Two stops would be center platform configurations: one within Fairview Avenue N. at the Fred Hutchinson campus and one in the railbank north of Valley Street adjacent to South Lake Union Park.

Bi-directional, low-floor, single-car, articulated streetcars are proposed. They are typically 66 feet long, 11.5 feet high, and 8 feet wide and run on standard gauge tracks. The streetcar would be powered by an overhead electrical system similar to those used by streetcars in cities such as Tacoma, Washington and Portland, Oregon.

A maintenance facility at the southwest corner of Fairview Avenue N. and Valley Street is also planned as part of this project. The maintenance facility building would be approximately 100 x 70 feet. Two additional yard storage tracks would also be provided. Daily vehicle maintenance and inspections and minor repairs would be completed at the facility.

In the typical construction method for the streetcar track system, the top 12 to 18 inches of pavement would be removed and replaced with rail-embedded reinforced concrete slabs within a trench approximately eight feet wide. This project would also involve upgrading the stormwater detention system in several locations.

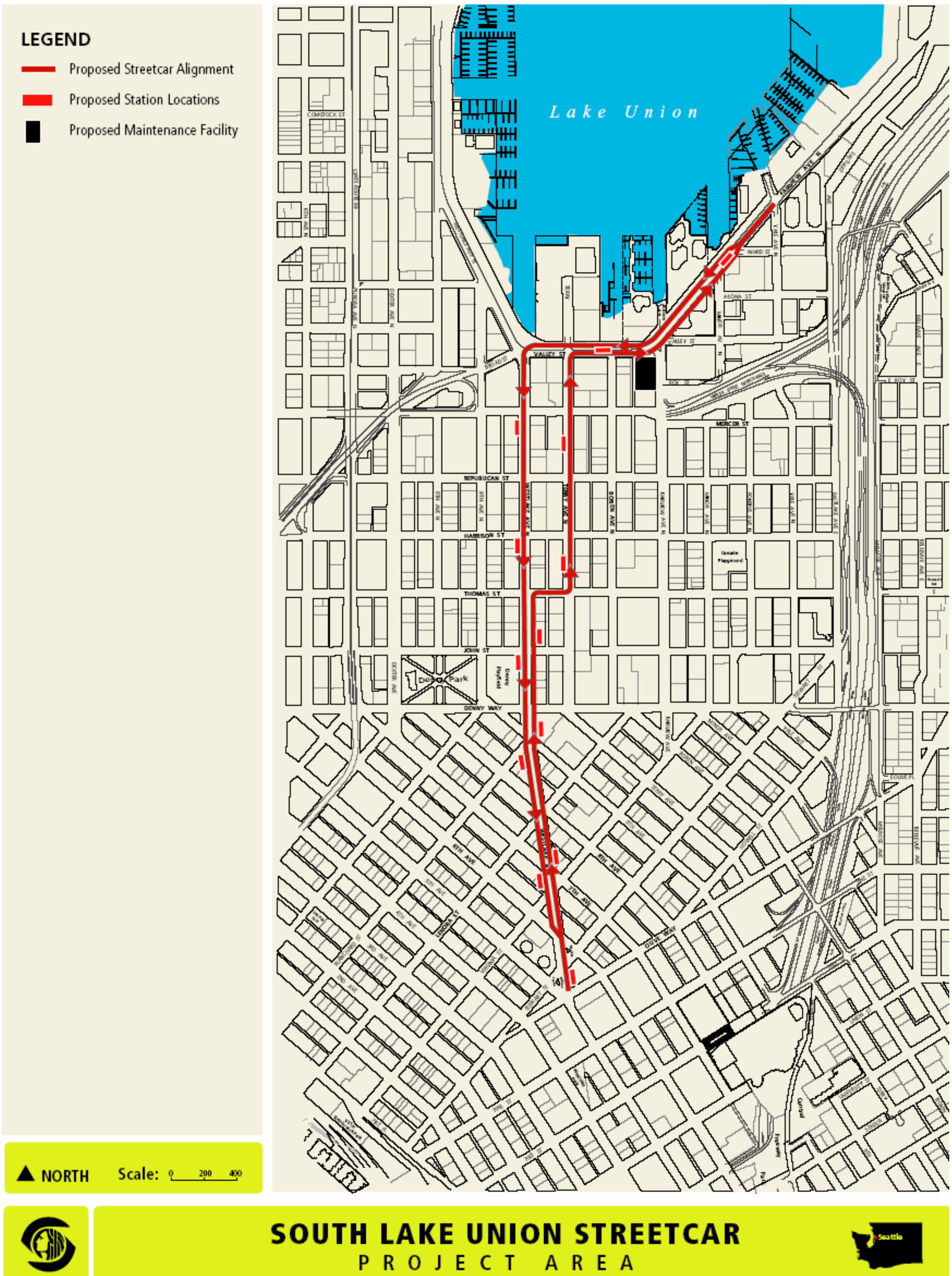


Figure 3-1: Project Area

4.1 Background and Characteristics of Noise

Sound is created when objects vibrate, resulting in a minute variation in surrounding atmospheric pressure called *sound pressure*. The human response to sound depends on the magnitude of a sound as a function of its frequency and time pattern (EPA, 1974). Magnitude measures the physical sound energy in the air. The range of magnitude, from the faintest to the loudest sound the ear can hear, is so large that sound pressure is expressed on a logarithmic scale in units called decibels (dB). *Loudness*, compared to physical sound measurement, refers to how people subjectively judge a sound and varies from person to person. Magnitudes of typical noise levels are presented in Table 4-1.

Humans respond to a sound's frequency or pitch. The human ear is very effective at perceiving sounds with a frequency between approximately 1,000 and 5,000 Hz, and efficiency decreases outside this range. Environmental noise is composed of many frequencies, each occurring simultaneously at its own sound pressure level. Frequency weighting, which is applied electronically by a sound level meter, combines the overall sound frequency into one sound level that simulates how an average person hears sounds. The commonly used frequency weighting for environmental noise is A-weighting (dBA), which is most similar to how humans perceive sounds of low to moderate magnitude.

Because of the logarithmic decibel scale, a doubling of the number of noise sources, such as the number of buses operating within a specified area, increases noise levels by 3 dBA. A ten-fold increase in the number of noise sources will add 10 dBA. As a result, a noise source emitting a noise level of 60 dBA combined with another noise source of 60 dBA yields a combined noise level of 63 dBA, not 120 dBA.

Noise levels from traffic and transit sources depend on volume, speed, and the type of vehicle. Generally, an increase in volume, speed, or vehicle size increases traffic noise levels. Vehicular noise is a combination of noises from engines, exhaust, and tires. Other conditions affecting traffic noise include defective mufflers, steep grades, terrain, vegetation, distance from the roadway, and shielding by barriers and buildings.

Noise levels decrease with distance from the noise source. For a line source such as a roadway, noise levels decrease 3 dBA over hard ground (concrete, pavement) or 4.5 dBA over soft ground (grass) for every doubling of distance between the source and the receptor. For a point source such as a transit center, noise levels will decrease between 6 and 7.5 dBA for every doubling of distance from the source.

Table 4-1: Typical Noise Levels

Transportation Sources	Noise Level (dBA)	Other Sources	Description
	130		Painfully loud
Jet takeoff (200 feet)	120		
Car horn (3 feet)			Maximum vocal effort
	110		
	100	Shout (.5 feet)	
			Very annoying
Heavy truck (50 feet)	90	Jack hammer (50 feet)	Loss of hearing with prolonged exposure
		Home shop tools (3 feet)	
Train on a structure (50 feet)	85	Backhoe (50 feet)	
City bus (50 feet)	80	Bulldozer (50 feet)	Annoying
		Vacuum cleaner (3 feet)	
Train (50 feet)	75	Blender (3 feet)	
City bus at stop (50 feet)			
Freeway traffic (50 feet)	70	Lawn mower (50 feet)	
		Large office	
Train in station (50 feet)	65	Washing machine (3 feet)	Intrusive
	60	TV (10 feet)	
Light traffic (50 feet)		Talking (10 feet)	
Light traffic (100 feet)	50		Quiet
		Refrigerator (3 feet)	
	40	Library	
	30	Soft whisper (15 feet)	Very quiet

Sources: FTA, 1995; EPA, 1971; EPA, 1974

4.2 Noise Level Descriptors

A widely-used descriptor for environmental noise is the equivalent sound level (L_{eq}). The L_{eq} can be considered a measure of the average noise level during a specified period of time. It is a measure of total noise, or a summation of all sounds during a time period. It places more emphasis on occasional high noise levels that accompany general background noise levels. L_{eq} is defined as the constant level that, over a given period of time, transmits to the receiver the same amount of acoustical energy as the actual time-varying sound. For example, two sounds, one of which contains twice as much energy but lasts only half as long, have the same L_{eq} noise levels.

L_{eq} measured over a one-hour period is the hourly L_{eq} ($L_{eq(h)}$), which is used for highway noise impact and abatement analyses and transit noise analysis for noise-sensitive sites with daytime use only. Daily averaged noise levels that rank noise that occurs during the evening or night more heavily are also considered in transportation noise analysis. The L_{dn} adds 10 dBA to noise levels that occur between 10 p.m. and 7 a.m. L_{dn} is used for transit noise impact and abatement analyses to residential uses and other locations where people sleep. Short-term noise levels, such as those from a single bus pass-by, can be described by either the total noise energy or the highest instantaneous noise level that occurs during the event. The sound exposure level (SEL) is a measure of total sound energy from an event, and is useful in determining what the L_{eq} would be over a period in time when several noise events occur. The maximum sound level (L_{max}) is the greatest short-duration sound level that occurs during a single event. L_{max} is related to impacts on speech interference and sleep disruption. In comparison, L_{min} is the minimum sound level during a period of time.

An individual's response to sound depends greatly upon the range that the sound varies in a given environment. People will generally find a moderately high, constant sound level more tolerable than a quiet background level interrupted by frequent high-level noise intrusions. For example, steady traffic noise from a highway is normally less bothersome than occasional aircraft flyovers in a relatively quiet area. To account for this subjective response, it is often useful to look at a statistical distribution of sound levels over a given time period, in addition to the average sound level. These distributions identify the sound level exceeded and the percentage of time exceeded, and therefore, allow for a more thorough description of the range of sound levels during the given measurement period. These distributions are identified with an L_n, where *n* is the percentage of time that the levels are exceeded. For example, the L_{10} level is the noise level that is exceeded 10 percent of the time.

Transit noise assessment is calculated in terms of a noise exposure level. The noise exposure level is the noise level (in dBA) that the project would cause. To calculate the total noise level, the noise exposure level is added to the background noise level that would exist without the project.

4.3 Effects of Noise

Environmental noise at high intensities directly affects human health by causing the disease of hearing loss. Although scientific evidence is not currently conclusive, noise is suspected of causing or aggravating other diseases. Environmental noise indirectly affects human welfare by interfering with sleep, thought, and conversation.

4.4 Noise Regulations and Impact Criteria

Applicable noise regulations and guidelines provide a basis for evaluating potential noise impacts. As indicated previously, the FTA has established impact criteria for federally funded transit projects. Under the FTA criteria, noise impacts occur when predicted L_{eq}(h) or L_{dn} noise levels caused by the project increase the overall noise by between 1 and 10 dBA, depending on the land use and existing noise level (FTA, 1995). In general, the higher the existing noise level, the less a project may increase the overall noise level without causing a noise impact under the FTA criteria. There are three categories of sensitive land use (Table 4-2) that may be impacted by noise. Other uses such as retail and industrial are generally not noise-sensitive.

Table 4-2: Noise-Sensitive Land Uses

Land Use Category	Noise Metric (dBA)	Description of Land Use Category
1	Outdoor Leq (h)*	Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, and such land uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with substantial outdoor use.
2	Outdoor Ldn	Residences and buildings where people normally sleep. This category includes homes, hospitals and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.
3	Outdoor Leq (h)*	Institutional land uses with primary daytime and evening use. This category includes schools, libraries, and churches where it is important to interference with such activities as speech, meditation, and concentration on reading material. Buildings with interior spaces where quiet is important such as medical offices, conference rooms, recording studios and concert halls fall into this category. Places for meditation or study associated with cemeteries, monuments, and museums. Certain historical sites, parks and recreational facilities are also included.

Source: FTA, 1995
* Leq for the noisiest hour of transit-related activity during hours of noise sensitivity

The project noise exposure levels that define impacts from transit facilities under the FTA criteria are presented in Figure 4-1. The noise exposure levels shown in Figure 4-1 include only noise generated by the project and not other noise sources that contribute to the overall noise level in the project area. For example, if a project is located in a residential area with an average L_{dn} of 50 dBA, the project can generate up to 54 dBA L_{dn} without causing any impact and up to 59 dBA L_{dn} without causing a severe impact. For noise-sensitive commercial areas, impacts are determined by peak-hour L_{eq}, so if the average L_{eq} is 50 dBA, the project can generate up to 59 dBA L_{eq} without causing any impact and up to 64 dBA L_{eq} without causing a severe impact. Severe impacts generally meet the definition of a significant adverse impact under the National Environmental Policy Act (NEPA).

The City of Seattle limits noise levels at property lines of neighboring properties (SMC 25.08.410). The maximum permissible sound level depends on the land uses of both the source noise and receiving property (Table 4-3). The maximum permissible sound levels apply to construction activities only if they occur between 10 p.m. and 7 a.m. on weekdays and 10 p.m. and 9 a.m. on weekends. The maximum allowed noise levels for daytime construction in the City of Seattle is 99 dBA L_{eq} for 7.5 minutes an hour. Performance of construction activities during nighttime hours that would exceed these levels requires a noise variance from the City of Seattle.

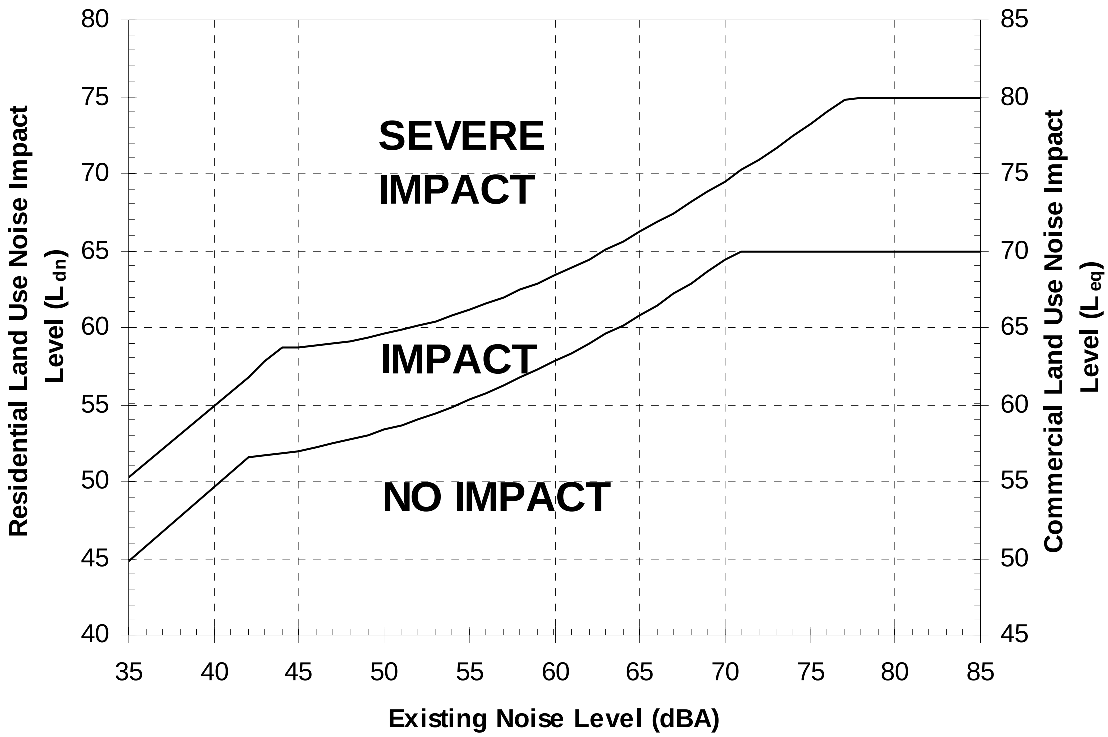


Figure 4-1: Project Noise Exposure Impact Criteria for Transit Projects

Table 4-3: City of Seattle Maximum Permissible Sound Levels (dBA)

District of Noise Source	District of Receiving Property			
	Residential[a]		Commercial	Industrial
	Day	Night		
Residential	55	45	57	60
Commercial	57	47	60	65
Industrial	60	50	65	70

[a] The maximum permissible sound level is reduced by 10 dBA for residential receiving properties between 10 p.m. and 7 a.m.

Source: Seattle Municipal Code 25.08.410.

Short-term exceedances above the permissible sound level are allowed for any noise source. The maximum level may be exceeded by 5 dBA for a total of 15 minutes, by 10 dBA for a total of 5 minutes, or by 15 dBA for a total of 1.5 minutes during any one-hour period. These allowed exceptions are referred to in terms of the percentage of time a certain level is exceeded; L_{25} is the noise level that is exceeded 15 minutes during an hour. Therefore, the permissible L_{25} would be 5 dBA greater than the values in Table 4-3, provided that the noise level is below the permissible level in Table 4-3 for the rest of the hour and never exceeds the permissible level by more than 5 dBA. An hourly L_{eq} of approximately 2 dBA higher than the values in Table 4-3 is an equivalent sound level to the permissible levels, including the allowed short-term excursions. Using this example, an L_{eq}(h) of 59 dBA corresponds approximately to a noise level of 57 dBA for 45 minutes and 62 dBA for 15 minutes, which is the maximum permissible noise level created by a source in a commercial zone and received by a property in a residential zone.

Construction activities carried out between 7 a.m. and 10 p.m. on weekdays and between 9 a.m. and 10 p.m. on weekends are allowed to exceed the property line standards per the following limits, measured at 50 feet or the property line, whichever is further (SMC 25.08.425):

- Earthmoving or other large construction equipment may exceed the applicable property line limit by 25 dBA
- Portable powered equipment may exceed the limit by 20 dBA
- Impact equipment, such as jackhammers, may not exceed an L_{eq}(h) of 90 dBA or an L_{eq}(7.5 min) of 99 dBA

4.5 Characteristics of Vibration

Vibration is an oscillatory motion, which can be described in terms of the displacement, velocity, or acceleration. Because the motion is oscillatory, there is no net movement of the vibration element and the average of any of the motion descriptors is zero. Displacement is the easiest descriptor to understand. For a vibrating floor, the displacement is simply the distance that a point on the floor moves away from its static position. The velocity represents the instantaneous speed of the floor movement, and acceleration is the rate of change of the speed. Although displacement is easier to understand than velocity or acceleration, it is rarely used for describing ground-borne vibration. This is because most transducers used for measuring ground-borne vibration use either velocity or acceleration, and even more important, the response of humans, buildings, and equipment to vibration is more accurately described using velocity or acceleration.

4.6 Vibration Descriptors

Ground-borne vibration is usually characterized in terms of the vibration velocity because, over the frequency range relevant to ground-borne vibration (about I to 200 Hz), both human and building response tends to be more proportional to velocity than either displacement or acceleration. Vibration velocity is usually given in terms of either inches per second or decibels. The following equation defines the relationship between vibration velocity in inches per second and decibels:

$$L_v = 20 \times \log (V/V_{ref})$$

V is the velocity amplitude in inches/second, V_{ref} is 10^{-6} inches/second, and is the velocity level in decibels. The abbreviation VdB is used here for vibration decibels to minimize confusion with sound decibels.

Train vibration is virtually always characterized in terms of the root-mean-square (rms) amplitude. RMS is a widely used but sometimes confusing method of characterizing vibration and other oscillating phenomena. It represents the average energy over a short time interval; a one-second interval is typically used to evaluate human response to vibration. RMS vibration velocity is considered the best available measure of potential human annoyance from ground-borne vibration.

4.7 Typical Vibration Levels

In contrast to airborne noise, ground-borne vibration is not a phenomenon that most people experience every day. The background vibration velocity level in residential areas is usually 50 VdB or lower, well below the threshold of perception for humans which is around 65 VdB (Figure 4-2). Most perceptible indoor vibration is caused by sources within buildings such as operation of mechanical equipment, movement of people, or slamming of doors. Typical outdoor sources of perceptible ground-borne vibration are construction equipment, steel-wheeled trains, and traffic on rough roads. Pile driving is one of the greatest common sources of vibration. If the roadway is smooth, the vibration from traffic is rarely perceptible. The range of interest is from approximately 50 VdB to 100 VdB.

Background vibration is usually well below the threshold of human perception and is of concern only when the vibration affects very sensitive manufacturing or research equipment. Electron microscopes and high-resolution lithography equipment are typical of equipment that is highly sensitive to vibration and may be disturbed by vibration levels greater than approximately 65 VdB. Although the perceptibility threshold is about 65 VdB, human response to vibration is not usually substantial unless the vibration exceeds 70 VdB. This is a typical level 50 feet from a rapid transit or light rail system. Buses and trucks rarely create vibration that exceeds 70 VdB unless there are bumps in the road.

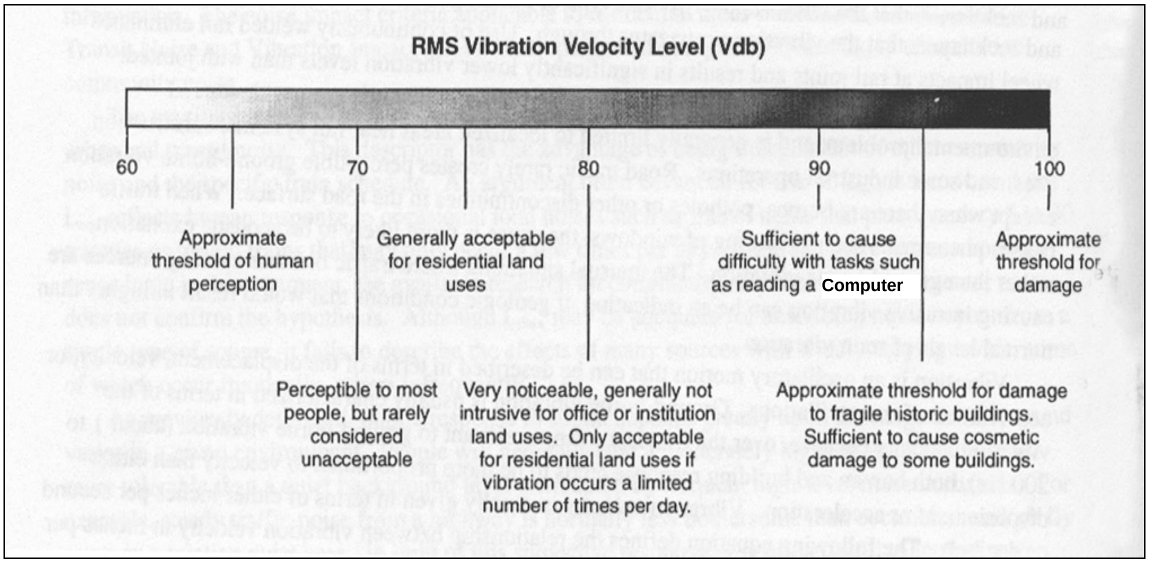


Figure 4-2: Typical Levels of Ground-Borne Vibration

4.8 Effects of Vibration

Ground-borne vibration could be a concern for occupants of nearby buildings during construction activities associated with the proposed project. However, it is unusual for vibration from sources such as buses and trucks to be perceptible, even in locations close to major roads. Most common sources of ground-borne vibration are trains, buses on rough roads, and construction activities such as blasting, pile driving, and operating heavy earth-moving equipment.

The effects of ground-borne vibration include perceptible movement of the building floors, rattling of windows, shaking of items on shelves or hanging on walls, and rumbling sounds. In extreme cases, the vibration can cause damage to buildings. Building damage is not a factor for normal transportation projects, with the occasional exception of blasting, pile driving, and demolition of structures that may occur during construction.

4.9 Vibration Impact Criteria

The FTA has developed impact criteria for acceptable levels of ground-borne noise and vibration (US DOT, *DOT-T-95-16*, 1995). Experience with ground-borne vibration from rail systems and other common vibration sources suggests the following:

- Ground-borne vibration from transit trains should be characterized in terms of the RMS vibration velocity amplitude. A one-second RMS time constant is assumed. This is in contrast to vibration from blasting and other construction procedures that have the potential of causing building damage. When looking at the potential for building damage, ground-borne vibration is usually expressed in terms of the peak particle velocity (PPV).

- The threshold of vibration perception for most humans is around 65 VdB, levels in the 70 to 75-VdB range are often noticeable but acceptable, and levels greater than 80 VdB are often considered unacceptable.
- For urban transit systems (streetcar) with 10 to 20 trains per hour throughout the day, limits for acceptable levels of residential ground-borne vibration are usually between 70 and 75 VdB.
- For human annoyance, there is some relationship between the number of events and the degree of annoyance caused by the vibration. It is intuitive to expect that more frequent vibration events, or events that last longer, will be more annoying to building occupants. Because of the limited amount of information available, there is no clear basis for defining this tradeoff.
- Ground-borne vibration from any type of train operations will rarely be high enough to cause any sort of building damage, even minor cosmetic damage. The only real concern is that the vibration would be intrusive to building occupants or interfere with vibration-sensitive equipment.

Table 4-4 summarizes the FTA impact criteria for ground-borne vibration. These criteria are based on previous standards, criteria, and design goals including ANSI S3.29 (Acoustical Society of America, 1993) and the noise and vibration guidelines of the American Public Transit Association (APTA, 1981). Some buildings, such as concert halls, TV and recording studios, and theaters, can be very sensitive to vibration 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 4-4: FTA Ground-Borne Vibration Impact Criteria

Land Use Category	Ground-Borne Vibration Impact Levels (VdB re 1 micro inch/sec)	
	Frequent Events[1]	**Infrequent Events[2]**
Category 1: Buildings where low ambient vibration is essential for interior operations.	65VdB[3]	65VdB[3]
Category 2: Residences and buildings where people normally sleep.	72 VdB	80 VdB
Category 3: Institutional land uses with primarily daytime use.	75 VdB	83 VdB

Notes:

1. "Frequent Events" is defined as more than 70 vibration events per day.
2. "Infrequent Events" is defined as fewer than 70 vibration events per day. This category includes most commuter rail systems.
3. This criterion 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 system and stiffened floors.

Source: Transit Noise and Vibration Impact Assessment, FTA, April 1995.

4.10 Geology and Soils

A detailed discussion of the geologic setting of the project area is presented in the *South Lake Union Streetcar Project – Geology and Soils Technical Report*. The information presented in this section provides a general background of geology and soils in the South Lake Union Streetcar Project Area.

The project site is located within an area delineated as a liquefaction hazard. This liquefaction hazard area is located along Valley Street, Fairview Avenue, and Westlake Avenue between Valley and Mercer streets. Units of compressible soils underlie the project area north of Harrison Street between Westlake and Fairview avenues. These soils include very soft to medium-stiff silts, organic silts, and units of peat and wood chips.

For this study, a design earthquake associated with a probability of exceedance of 10 percent in a 50-year period was evaluated. An earthquake with a 10 percent probability of exceedance corresponds to an earthquake recurrence interval of 475 years. The design earthquake event corresponding to this recurrence interval consists of an earthquake with a Richter magnitude of 6.81 and a peak horizontal ground acceleration of approximately 0.33g.

Based on a review of the available subsurface information, the areas delineated as liquefaction hazard areas on the City of Seattle sensitive areas maps were determined to have a substantial potential for liquefaction during a magnitude 6.81 design earthquake with a horizontal ground acceleration of 0.33g. The affected areas include Valley Street, Fairview Avenue, and Westlake Avenue between Valley and Mercer streets. These areas are underlain by up to approximately 30 feet of fill consisting of loose to medium-dense granular soils. Liquefaction of these soils may result in ground settlement. Typically, this is manifested as hummocky features resulting from differential settlement along the ground surface. Ground loss due to sand boils is also likely in these materials. Although the engineering analysis is not yet complete, it appears that ground settlement could range from 2 to 8 inches during a design-level earthquake.

Based on the potential for liquefaction along the south shore of Lake Union, the potential for lateral spreading would be substantial during a design-level earthquake for the few areas located within about 300 feet of the shoreline. These include the intersection of Westlake Avenue and Valley Street, the intersection of Fairview Avenue and Valley Street, and along Fairview Avenue near Ward Street.

Chapter 5 Methodology

Ambient noise levels were measured at several locations near the project area to characterize the daily environmental noise environment. Measurements were taken according to Federal Highway Administration (FHWA) guidelines (1996). Sampling locations represent a variety of noise conditions and are representative of other receptors near the proposed project. Because most project area noise was attributable to transportation sources, L_{dn} noise levels were estimated from a combination of L_{dn} and L_{eq}. At one residential site, one hotel, and one park, 24-hour noise measurements were taken and actual L_{dn} was calculated. At other locations where only L_{eq} measurements were take, L_{dn} noise levels were estimated from the L_{eq} measurements based on the 224-hour noise patterns taken at the nearest L_{dn} measurement sites.

Project noise exposure levels (the quantity of noise caused by the project) were modeled along the corridor. Noise exposure was modeled at various distances from the proposed alignment to evaluate project effects at sensitive receptors that would be potentially affected by the project. The FTA Transit Noise Assessment Spreadsheet Model (HMMH, 1995) was used to calculate noise levels generated by train operations and supporting operations that would occur as a result of the proposed project. Predicted noise levels were based on projected daily transit operations for 2030 to estimate worst-case project noise levels. Streetcar vehicle noise reference levels for the year 2030 are described in Table 5-1 and the 2030 streetcar schedule used for noise projections is described in Table 5-2.

Table 5-1: 2030 Streetcar Vehicle Noise Reference Levels

Reference Sound Level:	**82 dBA**
Conditions	
Speed:	30 mph
Length:	1 vehicle (66 feet)
Distance from Track Centerline:	50 feet
Track Type:	Embedded in pavement

Table 5-2: 2030 Streetcar Schedule Used for Noise Projections

Period	**Number of Hours**		**Period**	**Headway***	**Train Length**
	Day	**Night**			
5:30-7:00	0	2	off-peak	10	1-car
7:00-22:00	15	0	peak	10	1-car
Note: *Headway is the time, in minutes, between trains.					

Vibration impacts were evaluated qualitatively, based on the type of construction equipment likely to be used, the streetcar vehicles operating along the project alignment, and nearby land uses.

Chapter 6 Affected Environment

The proposed project would take place within Seattle's downtown commercial core and the Denny Triangle and South Lake Union neighborhood areas. The downtown area consists primarily of retail and commercial buildings densely occupying city streets. The Denny Triangle and South Lake Union neighborhoods are north of downtown and consist of a variety of retail, commercial and residential buildings.

Land use in the project vicinity is typical of a mixed-use urban downtown area. Zoning in the area includes commercial and residential areas (Figure 6-1). Uses surrounding the South Lake Union Streetcar Project area include street level retail, office, and parking. There are no Category 1 (see Table 4-2) land uses in the project vicinity. Residential uses and the Westin and Marriott hotels, which are a Category 2 noise-sensitive land use, are the primary noise-sensitive receptors in the study area. There are also Category 3 uses, including South Lake Union Park, the Denny Playfield, and the Washington Library for the Blind adjacent to the project alignment. The location of current noise-sensitive uses near the proposed layover locations are shown in Figure 6-2.

The project site is located within an area delineated as a liquefaction hazard. This liquefaction hazard area is located along Valley Street, Fairview Avenue, and Westlake Avenue between Valley and Mercer streets. Units of compressible soils underlie the project area north of Harrison Street between Westlake and Fairview avenues. These soils include very soft to medium-stiff silts, organic silts, and units of peat and wood chips.

6.1 Existing Conditions

Ambient noise levels were measured to describe the existing noise environment, determine the noise levels above which impacts would occur, and identify major noise sources in the project area. Existing noise levels were measured for a 24-hour period at three locations (Table 6-1) and shorter-duration (15-minute) measurements were taken at an additional three locations (Table 6-2). L_{dn} noise levels were calculated for each of the 24-hour measurements. For the three short-duration measurement locations, L_{dn} noise levels were estimated by comparing the noise measurement at that location to the measurement during the same time period at the most similar 24-hour measurement locations, and adjusting the L_{dn} by the difference between the locations.

Noise measurements were taken between January 5 and January 26, 2005 to characterize existing weekday noise levels during various times of the day. Sampling locations are representative of other receptors near the proposed project.

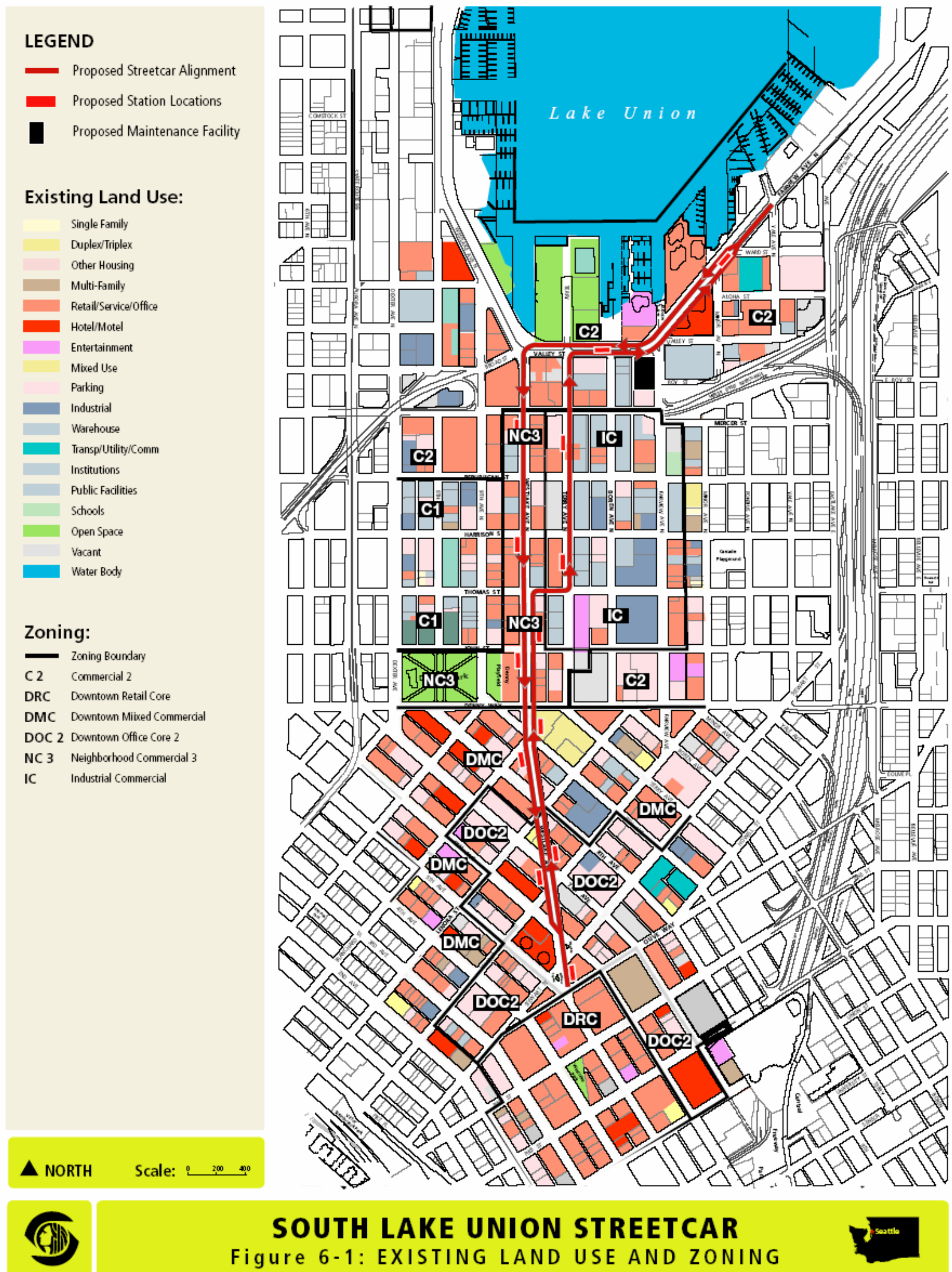


Figure 6-1: Existing Land Use and Zoning

Figure 6-2: Noise Measurement Locations

Table 6-1: Measured 24-Hour Noise Levels

Location		Date	Loudest Daytime Hour (L_{eq})	Quietest Nighttime Hour (L_{eq})	L_{dn}
1	South Lake Union Park	1/4,5/05	87	60	69
2	Marriott Residence Inn	1/25,26/05	66	53	66
3	Larned Apartments	1/25,26/05	68	57	69

Table 6-2: Measured Short-Duration Noise Levels

Location		L_{eq}	L_{max}	Date	Time
4	Washington Library for the Blind	67	84	1/25/05	15:20
5	Westin Hotel	69	83	1/25/05	15:45
6	Denny Playfield	62	73	1/25/05	16:05

6.1.1 Description of Measurement Locations

Receptor 1 was located near the center of South Lake Union Park, approximately 200 feet north of Valley Street. Noise sources at this location included fairly heavy traffic, construction trucks, buses, limited aircraft noise, and cars in a nearby parking lot. One-hour L_{eq} noise levels were measured at this location over a 24-hour period.

Receptor 2 was located on the ground-floor building exterior walkway along the western side of the Marriott Residence Inn. Noise sources at this location included moderate traffic, adjacent driveway traffic with delivery trucks, buses, and limited aircraft noise. A noise meter was placed at this location to measure one-hour L_{eq} noise levels over a 24-hour period.

Receptor 3 was located outside of a third-floor building window of the Larned Apartments, facing Westlake Avenue. Noise sources at this location included fairly heavy traffic, buses, and limited aircraft noise. One-hour L_{eq} noise levels were measured at this location over a 24-hour period.

Receptor 4 was located at street level on Lenora Street at the Washington Library for the Blind building. Noise sources at this location included moderate traffic, limited aircraft noise, and a large construction site located at 10th Avenue and Denny Way, approximately 200 feet from this measurement location. The maximum noise levels at this location were caused by the nearby construction site.

Receptor 5 was located at street level at the intersection of Westlake Avenue and Stewart Street at the Westin Hotel. Noise sources at this location included fairly heavy traffic and limited aircraft noise. The maximum noise levels at this location were caused by adjacent traffic on Westlake Avenue.

Receptor 6 was located in the center of Denny Playfield, approximately 200 feet north of Denny Way and 200 feet west of Westlake Avenue. Noise sources at this location included fairly heavy traffic on Westlake Avenue, Denny Way, and 9th Avenue, limited aircraft noise, and an adjacent construction site located at the northwest corner of the intersection of Westlake Avenue and Denny Way, approximately 100 feet from the measurement location. The maximum noise levels at this location were caused by traffic on the surrounding streets, as this measurement was taken after the construction day had ended.

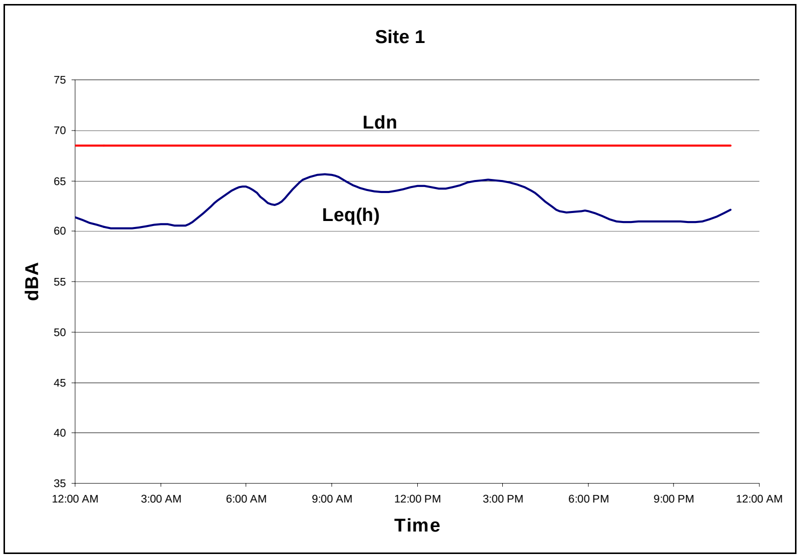
The day/night noise level (L_{dn}) for the three 24-hour measurements ranged between 66 and 69 dBA. The measured daily sound patterns for the sites are shown in Table 6-3. Ldn and Leq(h) values for the three 24-hour noise measurements are presented in Figure 6-3.

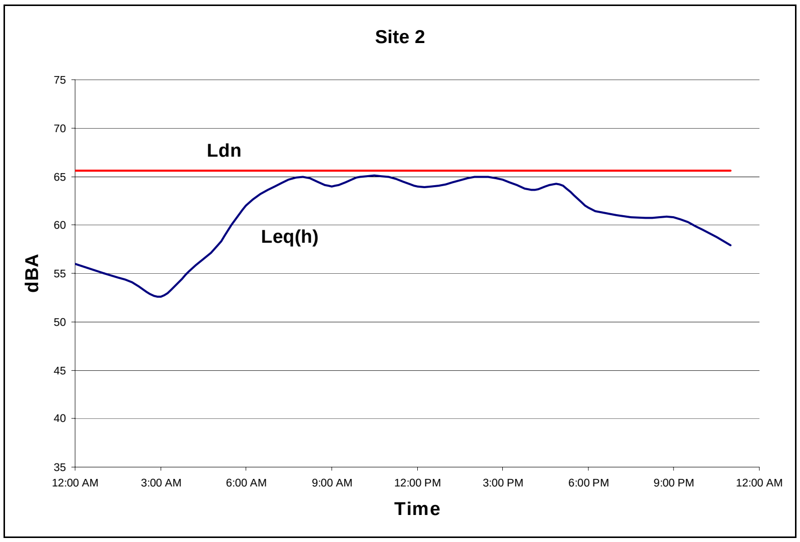
Table 6-3: Measured and Estimated Existing Ldn Noise Levels

Location		Ldn
1	South Lake Union Park	69
2	Marriott Residence Inn	66
3	Larned Apartments	69

6.1.2 Vibration

Existing vibration levels in the South Lake Union Streetcar Project area are typical of an urban environment, with trucks and buses operating on city streets. Current vibration levels are not known to cause disturbance to residents and businesses in the project area.





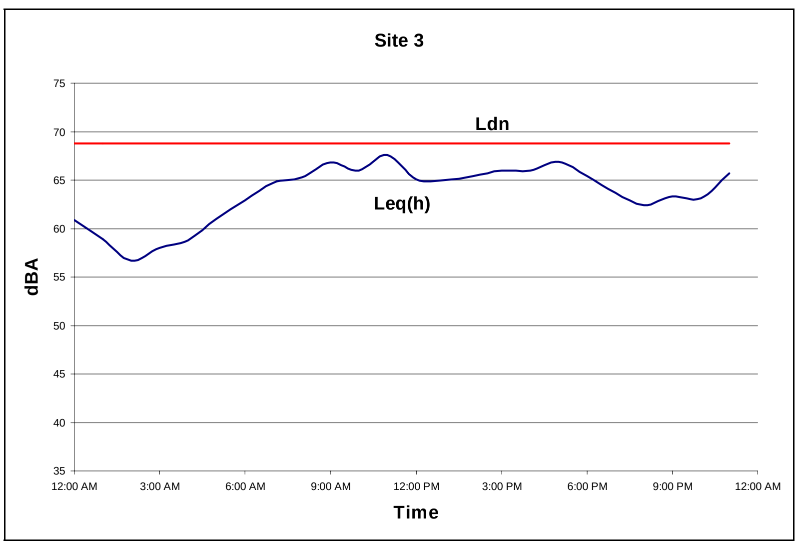


Figure 6-3: Noise Measurement Results

Chapter 7 Environmental Consequences

7.1 Operation

7.1.1 Noise

Noise exposure levels (the noise level that would be generated by the project, not including other noise sources) were predicted for the six monitored locations (see Figure 6-2 in Chapter 6). Future noise levels are not predicted to increase in noise-sensitive locations as a result of increased transit operation in the South Lake Union Streetcar Project area. Because transit service and other urban noise sources already exist in the project area, the addition of streetcar transit service would result in no increases in noise levels at all noise-sensitive locations. Streetcar operations in 2030 are projected to increase by 32 percent during daytime and evening hours relative to 2007 operations to 6 cars per hour. These increases in transit operations would result in no average increase in transit noise exposure near transit routes.

Noise exposure from the project for the year 2030 would range between 39 and 55 dBA L_{dn} at the modeled noise-sensitive land uses (Table 7-1).

Table 7-1: Predicted Noise Exposure

	Existing Noise Level[1]		Noise Impact Criteria[2]		Project Noise Exposure[3]		Impact	
Location	**L_{eq}**	**L_{dn}**	**Impact**	**Severe**	**2030 Build**	**No Action**	**2030 Build**	**No Action**
1	66		67	72	50	0	No Impact	No Impact
2		66	62	67	52	0	No Impact	No Impact
3		69	64	69	55	0	No Impact	No Impact
4	66		67	72	39	0	No Impact	No Impact
5		69	64	69	52	0	No Impact	No Impact
6	62		64	69	44	0	No Impact	No Impact

Notes:
1) Existing L_{dn} is reported for residential areas; L_{eq} is reported for other noise-sensitive areas
2) FTA Noise Impact Criteria are L_{dn} or L_{eq} values as appropriate, calculated from Figure 4-1 in Chapter 4
3) Future Noise Exposure includes noise from the increased future transit noise associated with project operations
Non-project-related noise sources are not included.

For the year 2030, noise impacts under the FTA criteria are not predicted to occur at the six locations analyzed as a result of the South Lake Union Streetcar Project. Although the project would cause no increase in average noise levels, there may be an increase in the frequency of noise peaks caused by transit operations near the station locations. The highest transit noise associated with this project would occur at Sites 2, 3, and 5 along Westlake Avenue, south of Denny, and along Fairview Avenue, due to the sites' relative distances to the project alignment.

The values in Table 7-1 are the noise levels that would be generated by transit operations for the year 2030. They do not include existing transit operations or other noise sources. Future noise levels at each of the residential locations, including the project, existing transit operations, and other background noise sources, are predicted to range between 66 and 69 dBA L_{dn} (Table 7-2), assuming that the proposed project would be the only change to the local noise environment. These noise levels represent no increase over existing noise levels.

Future noise levels at daytime use areas, reflecting the project, existing transit operations, and other background noise sources, are predicted to range between 62 and 66 dBA L_{eq} (Table 7-3), assuming that the proposed project would be the only change to the local noise environment. These levels represent no increase over existing levels.

Table 7-2: Predicted Future Ldn Noise Levels at Residential Uses

Location		Existing L_{dn}	Predicted Future L_{dn}	
			2030 Build	No Action
2	Marriott Residence Inn	66	66	66
3	Larned Apartments, 3rd Floor	69	69	69
5	Westin Hotel	69	69	69

Table 7-3: Predicted Future Leq Noise Levels at Daytime Sensitive Uses

Location		Existing L_{eq}	Predicted Future L_{eq}	
			2030 Build	No Action
1	South Lake Union Park	66	66	66
4	Washington Library for the Blind	66	66	66
6	Denny Playfield	62	62	62

A park (Receptor 1) and a hotel (Receptor 2) are both located approximately 500 feet from eh proposed maintenance facility. The facility is anticipated to operate two shifts, with louder activities occurring during daytime hours. The noise exposure levels in Table 7-1 include the noise generated from the maintenance facility at these two receptors.

While streetcars are generally less susceptible to wheel squeal than long-wheelbase subway cars, wheel squeal can occur where turn radii are less than 1,000 feet. Squeal is irritating to people nearby because it includes high-frequency noise and can generate an Lmax noise level around 100 dBA at 50 feet from the tracks. It can be eliminated by increasing curve radius or reduced with several measures discussed under mitigation. With incorporation of appropriate mitigation measures, substantial squeal is not anticipated from the streetcar.

7.1.2 Vibration

Vibration impacts would only occur if vibration-sensitive land use occurs in the immediate vicinity of the project. Because the streetcars would operate at low speed (30 miles per hour), vibration levels are expected to be below 70 VdB at 50 feet from the tracks. The survey of nearby land uses did not include any vibration-sensitive uses within the 50 feet of the tracks. Therefore, no substantial vibration impacts are predicted to occur as a result of the operation of this project. At the sidewalk, approximately 10 feet from the curb lane, and 20 to 25 feet from the tracks, vibration levels experienced when a train passes by would be similar to those currently experienced when a truck or bus passes in the curb lane. At greater distances from the tracks, the vibration level would be less.

7.2 Construction

Nearby receptors would experience temporary noise impacts during project construction. No vibration impacts are expected.

7.2.1 Noise

Construction activities would generate noise and vibration during the construction period. The most prevalent noise source at the construction site would be the internal combustion engine. Engine-powered equipment includes earth-moving equipment, material-handling equipment, and stationary equipment. Mobile equipment operates in a cyclic fashion, while stationary equipment, such as generators and compressors, operates at sound levels fairly constant over time. Since trucks would not be confined to the project site, noise from trucks could affect more receptors. Other noise sources would include impact equipment and tools such as jackhammers. Impact tools could be pneumatically powered, hydraulic, or electric. Pavement cutting and jackhammering are likely to be the loudest construction activities.

Construction noise would be intermittent (varying with the time of day and stage of construction) over the duration of the project. Construction noise impacts would depend on the type, amount, and location of construction activities. The type of construction methods would establish the maximum noise levels of construction equipment used. The highest construction noise levels would likely be associated with the demolition phase, when several pieces of machinery could be operating to break up pavement, remove the rubble, and truck it away from the project area. The location of construction equipment relative to adjacent properties would determine any effects of distance in reducing construction noise levels. The maximum noise levels of construction equipment working on this project under all build alternatives would be similar to typical maximum construction equipment noise levels presented in Figure 7-1.

As shown in Figure 7-1, maximum noise levels from construction equipment would range from 69 to 106 dBA at 50 feet. Construction noise at locations farther away would decrease at a rate of 6 dBA per doubling of distance from the source. Therefore, at 100 feet, peak construction noise levels would range from 63 to 100 dBA. Because various equipment would be turned off, idling, or operating at less than full power at any time and because construction machinery is typically used to complete short-term tasks at any given location, average L_{eq} noise levels during the day would be less than the maximum noise levels presented in Figure 7-1. The maximum allowed noise levels for daytime construction in the City of Seattle is 99 dBA L_{eq}, for 7.5 minutes a hour.

Construction workers would also be subject to construction noise while working on the site. Construction noise levels would be reduced by the construction practices identified in the following section (*Mitigation*).

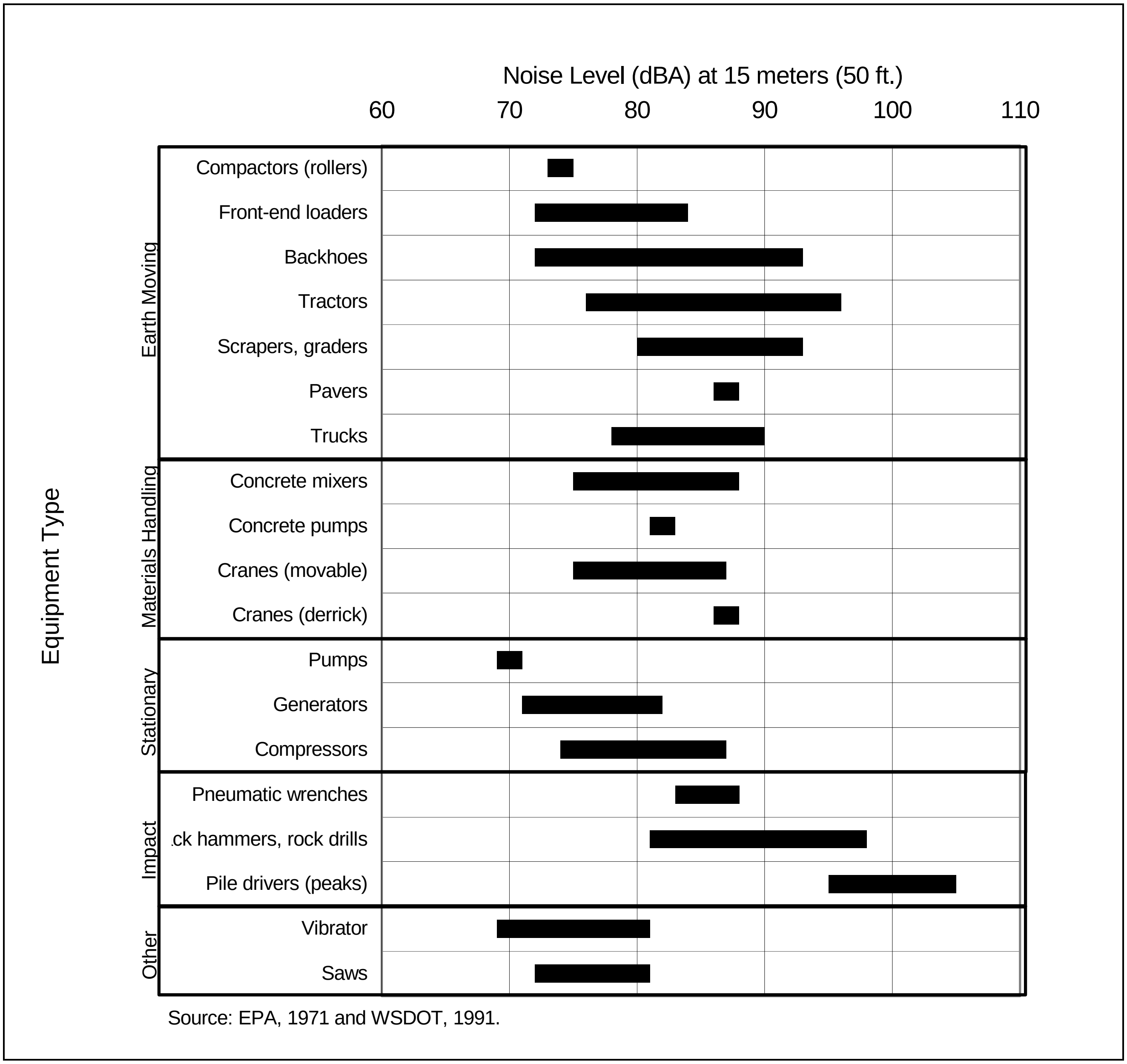


Figure 7-1: Construction Equipment Noise Ranges

7.2.2 Vibration

Vibration is usually measured as a root-mean-square velocity level L_v, which is reported in velocity decibels (VdB) referenced to a vibration level of 1 micro inch/second. Humans can perceive vibration levels above approximately 65 VdB. The threshold for minor damage to fragile buildings is approximately 100 VdB. Buses and trucks frequently generate approximately 65 VdB at 25 feet. Heavy construction equipment such as large bulldozers and loaded trucks frequently generate between 85 and 87 VdB at 25 feet. Pavement replacement would occur approximately 20 to 25 feet from the William O. McKay Ford Dealership building. No pavement breakers would be used within 25 feet of the building. No other potentially fragile buildings are located within 25 feet of proposed construction activities; therefore, no vibration damage is expected to buildings during construction. Any cast-iron water mains within 100 feet or other fragile utility lines within 25 feet could be affected by vibrations caused by impact equipment, such as pavement breakers (jackhammers). Limits on construction activities discussed in Chapter 8, Mitigation would minimize the risk of vibration damage during construction.

Chapter 8 Mitigation

8.1 Operation

8.1.1 Noise

No mitigation measures are identified for the project because no impacts (and no severe impacts) would be created by the project. For the year 2030, noise exposure levels (the noise level that would be generated by the project, not including other noise sources) were not predicted to increase existing noise levels.

If final track design includes curves with radii less than 1,000 feet, measures should be considered to reduce wheel squeal. Vehicle specification and discussions with the vehicle manufacturer should evaluate options that accommodate the curve radii anticipated for the South Lake Union streetcar project. The use of resilient, damped, or profiled wheels can substantially reduce squeal. The rail material used in tight curve areas may also be changed to eliminate squeal. If wheel squeal is experienced after project operation begins, rail lubrication would be implemented on the curves, but it is not anticipated to be required.

8.1.2 Vibration

No mitigation is proposed because no impacts are anticipated.

8.2 Construction

8.2.1 Noise

Because construction is expected to be completed during daytime hours (7 a.m. to 10 p.m. weekdays and 9 a.m. to 10 p.m. weekends) and within City of Seattle construction noise limits, mitigation would not be required.

8.2.2 Vibration

Impact equipment should not be used for pavement removal or placement of piles within 100 feet of known fragile cast-iron water mains or within 25 feet of other fragile underground utilities or historic buildings.

Chapter 9 Secondary/Cumulative Impacts

The proposed project may contribute to secondary and cumulative impacts from projects and development that may occur in and near the project area. Generally, secondary impacts are indirect impacts that may result from a proposed action, and cumulative impacts are the effects from a proposed project's actions combined with those of other project actions in the area.

The City has planned several transportation projects that may affect downtown traffic conditions, including some located within portions of or near the proposed streetcar project area. Construction noise from several projects could be occurring at the same time as construction noise for the streetcar project. Construction of the South Lake Union Park project (proposed construction between 2007 and 2009) would produce noise the northern portion of the proposed streetcar line. The Mercer Corridor Project would be completed by 2010 and would cross the northern portion of the streetcar project area near Lake Union. The Seattle Monorail construction is proposed from 2006 to 2009 and could cause construction noise near Westlake Avenue and Olive Way. The Link Light Rail project between downtown and Sea-Tac would be completed by 2010 and may also cause construction noise near the southern streetcar area.

Development projects may also take place on land parcels adjacent to the proposed streetcar line, and could contribute to cumulative noise in the project area.

Chapter 10 References

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