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EXECUTIVE SUMMARY

This technical report documents the findings of potential noise and vibration impacts for the proposed Northwest Phase II Light Rail Extension Project in Phoenix, Arizona. The technical report and findings are in support of the Environmental Assessment (EA). The 1.55-mile proposed project, or Build Alternative, would extend the existing Valley Metro light rail line west along Dunlap Avenue and north along 25th Avenue before spanning I-17 and terminating at Metrocenter.

Noise concerns associated with a light rail system include light rail operations, effects from special trackwork, track curvature, audible warnings, traction power substations (TPSSs) and construction of the system. Vibration concerns associated with a light rail system include light rail operations, effects from special trackwork and construction of the system. More information about light rail noise and vibration concerns can be found in Section 1.0.

Noise and vibration has been assessed in accordance with guidelines specified in the Federal Transit Administration (FTA) Noise and Vibration Impact Assessment guidance manual (FTA Report FTA-VA-90-1003-06, May 2006; also referred to as FTA Guidance Manual). Specifics of criteria applied can be found in Section 2.0, and specifics of the prediction methodologies can be found in Section 3.0.

Potential impacts were examined for locations adjacent to the proposed alignment due to both transit operations and construction activities. Noise- and vibration-sensitive land uses along the alignment include single- and multi-family residences, hotels, schools and medical facilities. A full list of sensitive receivers and maps showing their locations can be found in Appendix F.

A noise and vibration measurement program was conducted to characterize the existing noise and vibration in the project area. The primary existing noise source in the area is vehicular traffic along the whole alignment with the highest noise levels due to traffic on I-17 and Dunlap Avenue. Normalized to a distance of 25 feet from the near travel lane, 24-hour noise levels (Ldn) ranged from 67 to 80 dBA; note that the Ldn metric applies penalties for nighttime noise to properly assess residential land uses and other uses, such as hotels, where people sleep. Also at a distance of 25 feet, short-term (up to 1 hour) noise levels ranged from 68 to 78 dBA Leq, representing the worst noise hour (highest traffic volumes during free-flowing traffic conditions). More information about the existing conditions and dBA noise descriptors can be found in Section 4.0.

The vibration test program included propagation tests to characterize efficiency of vibration propagation through the ground at several locations along the alignment. Vibration propagation was found to be very efficient along the whole alignment, with peak efficiency in the 40 to 50 Hz range. The existing vibration data were also measured and helped to confirm the validity of the propagation data. More information about vibration propagation can be found in Section 4.0.

SUMMARY OF NOISE IMPACTS

This section summarizes the results of the noise impact assessment for the Northwest Phase II Light Rail Extension Project (more details can be found in Section 5.0). The predicted noise levels for light rail operations include the noise from the steel wheels of
the light rail vehicle (LRV) rolling on the steel rails and the noise from special trackwork (such as crossovers and turnouts), train bells as the LRV arrives and departs from stations or passes through an intersection, crossing gate bells and TPSS units. The impact analysis does not include noise from warning horns because they would only be used in case of emergency. The TPSS units are the only ancillary noise source associated with the project.

The noise-sensitive receivers where potential impacts are predicted are presented in Table ES-1, along with noise limit exceedances and mitigation recommendations. Sensitive receivers are defined into three categories by the FTA. Category 1 includes receivers where quiet is an essential element in their intended purpose. Category 2 includes residences and buildings where people sleep. Category 3 includes institutional land uses with primarily daytime and evening use. No Category 1 receivers are identified on the alignment. The predicted impact exceedance is shown as amount above the FTA moderate impact level threshold. Only moderate impacts are predicted. There are no sensitive receivers where severe impact is predicted. For severe noise impact FTA assumes “that mitigation will be incorporated in the project unless there are truly extenuating circumstances which prevent it.” (FTA Guidance Manual, p. 3-11). For moderate impacts, FTA guidance states that project-specific factors must be considered to determine the need for mitigation. The reasonableness of providing mitigation is a factor when considering mitigation. A less than 1 dB change in noise level with the project is negligible given that 3 dB is considered the threshold at which an average listener can detect change. This assumption is reasonable. Therefore, for predicted exceedances less than 1 dB, mitigation is not recommended. For the Northwest Phase II Light Rail Extension Project, two residential sensitive receiver clusters (FTA Category 2) have potential impacts of <1 dB above the FTA moderate threshold; the impacts are described below.

One potential impact is at the San Valiente Apartments, cluster NB-08; this impact is <1 dB and, although no mitigation for noise is recommended, this impact is removed with the implementation of a low-impact frog, as recommended for vibration purposes. The other potential impact is at the Acclaim Apartments, cluster SB-09; this impact is also <1 dB, with exceedance being related to the train bells. Although no mitigation is recommended, making sure the train bells are at their lowest safe level is recommended. This analysis applied a level of 80 dBA at 50 feet for train-mounted bells, a typical daytime level. It may be possible to use a lower level during the night when ambient noise is lower (for example, Sound Transit uses the same daytime level as applied here, but for hours between 10 pm and 6 am, a level of 72 dBA is used). Note that for all predictions and mitigation recommendations, it is assumed that the track and wheels would be maintained in a state of good repair (that is, rail corrugations and wheel flats would be minimized through maintenance procedures—rail grinding and wheel truing, as well as friction management). Wheel squeal is minimized with friction control. Two approaches to friction control are (1) applying a friction modifier to the rail head and/or the wheel tread or (2) applying lubricant to the gauge face of the rail or the wheel flange. Valley Metro vehicles are equipped with a lubrication system and are used on all track curvatures. All new light rail vehicles will also be equipped with a lubrication system. There are revenue service train movements through low-radius curves at the Dunlap Ave/25th Avenue intersection, the Mountain View Rd/25th Avenue intersection, and on the aerial structure south of the Metrocenter station.
TABLE ES-1: SUMMARY OF PREDICTED NOISE IMPACTS AND MITIGATION FOR LIGHT RAIL OPERATIONS

<table>
<thead>
<tr>
<th>FTA Category of Land Uses</th>
<th>ID</th>
<th>Desc.</th>
<th>Sensitive Receiver Location</th>
<th>Amount Exceeds FTA Impact Threshold (dB)</th>
<th># Impacted Units without Mitigation</th>
<th>Recommended Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>No Category 1 uses are located along the project alignment</td>
</tr>
<tr>
<td>Category 2</td>
<td>NB-08</td>
<td>MFR</td>
<td>San Valiente Apartments</td>
<td>&lt;1</td>
<td>24</td>
<td>Low-impact frog recommended for vibration impact would fully mitigate this impact (for special trackwork by 22nd Ave); see Table ES-2</td>
</tr>
<tr>
<td></td>
<td>SB-09A</td>
<td>MFR</td>
<td>Acclaim Apartments</td>
<td>&lt;1</td>
<td>50</td>
<td>Mitigation not recommended. Ensure train bells are at lowest safe level</td>
</tr>
<tr>
<td>Category 3</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>No Category 3 uses adversely affected; thus no mitigation is needed</td>
</tr>
</tbody>
</table>

The Northwest Phase II Light Rail Extension Project would involve some physical roadway changes; however, traffic volume differences between Build and No-Build Alternatives are minor. By evaluating the effect of shifting some of the travel lanes along various sections of the alignment using the Federal Highway Administration (FHWA) Traffic Noise Model (TNM), it is concluded that traffic changes would result in minimal or negligible sound level differences. As a result, these changes are not included in the project noise predictions.

The park-and-ride lots to be used for the project consist of one near the Metrocenter station in an existing Metrocenter parking lot and one on 25th Avenue (near the proposed Mountain View/25th Avenue station). Applying FTA procedures, no receivers are within the screening distance for either of the proposed park-and-ride lots (75 feet shielded, 125 feet unshielded). Therefore, these lots require no further consideration of noise impact.

Possible noise impacts have been predicted at two receivers. The predicted exceedance above the FTA threshold for moderate impact is less than 1 dB at all receivers. No mitigation is recommended at this time.

SUMMARY OF VIBRATION IMPACTS

This section summarizes the results of the vibration impact assessment for the Northwest Phase II Light Rail Extension Project (more details can be found in Section 5.0). The vibration-sensitive receivers where impact is predicted are presented.
in Table ES-2. Below is a summary of the predicted impacts and recommended mitigation.

A single vibration impact is predicted at a multi-family residential cluster NB-08, San Valiente Apartments. The vibration impact is predicted because of the proximity of special trackwork (approximately 80 feet). The recommended mitigation is the use of a low-impact frog combined with low-vibration rail boot or to move the special trackwork farther away. The gaps in the rail associated with standard frogs can cause vibration levels to increase by up to 10 decibels. Low-impact frogs can reduce vibration levels by creating a smoother transition through the gap in the rails at the special trackwork. Examples of low-impact frogs include monoblock frogs, flange-bearing frogs, moveable point frogs or spring rail frogs. Where possible, special trackwork may also be relocated farther away from the receiver. More information on low-impact frogs is included in Appendix G. Using low-impact frogs at this location would reduce the predicted levels, but would not reduce the levels below the FTA Criteria; the predicted groundborne vibration would be less than 1 dB above the FTA Criteria. Additional mitigation could be achieved by relocating the crossover.

Groundborne noise is also analyzed here. The predicted groundborne noise is derived from the predicted groundborne vibration and is compared to FTA criteria of 35 dBA for Category 2 and 40 dBA for Category 3 receivers. (FTA Guidance Manual, Table 8-1) The alignment is fully at or above grade through its entire length, which means that airborne noise may dominate the levels generated at a receiver. Therefore, the predicted groundborne noise is also compared to existing noise levels as well as predicted noise from train operations to determine if impact should be predicted. No groundborne noise impacts are predicted for the project.

Note that historic structures that do not fall into the FTA land use categories are not included in the assessment for vibration impact from light rail operations. The vibration impact thresholds are based on annoyance, and the primary concern for historic structures is the risk of damage. The recommended limit in the FTA Guidance Manual for buildings extremely susceptible to damage is 90 VdB, which is 18 decibels higher than the limit for Category 2 (residential) land uses.

A single groundborne vibration impact is predicted for Phase II of the Northwest Extension. It is recommended that low-impact special trackwork be used at the crossovers immediately east of 22nd Avenue. This will lower the predicted levels to within 1 dB of the FTA Criteria, but not below the FTA Criteria. In addition to low-vibration frogs, a vibration isolating rail boot may be used in this area. Rail boots designed with thicker than standard rubber can achieve 1-2 dB vibration reduction. The use of low-impact frogs and vibration isolating rail boot brings the predicted level below 72 VdB.
### TABLE ES-2: SUMMARY OF VIBRATION MITIGATION FOR SENSITIVE RECEIVER

<table>
<thead>
<tr>
<th>ID</th>
<th>Desc.</th>
<th>Sensitive Receiver Location</th>
<th>GBV (VdB)&lt;sup&gt;c,d&lt;/sup&gt;</th>
<th>Predicted</th>
<th>Predicted w/ mitigation</th>
<th>GBN (dBA)&lt;sup&gt;c,e&lt;/sup&gt;</th>
<th>Predicted</th>
<th>Predicted w/ mitigation</th>
<th># of Units</th>
<th>Recommended Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB-08</td>
<td>MFR</td>
<td>San Valiente Apartments</td>
<td>72</td>
<td>76</td>
<td>&lt;72</td>
<td>36</td>
<td>31</td>
<td>27</td>
<td>24</td>
<td>Low-impact frog, Low-vibration rail boot</td>
</tr>
</tbody>
</table>

<sup>a</sup> ID identifies sensitive receivers as shown in the maps in Appendix F. NB = northbound side, SB = southbound side.
<sup>b</sup> MFR = multifamily residential,
<sup>c</sup> Levels are reported to the nearest decibel. These numbers represent fractional exceedances of less than 1 dB (still considered an impact).
<sup>d</sup> Levels for GBV are maximum 1/3 octave band
<sup>e</sup> Groundborne noise predictions and criteria for this receiver based on indoor noise levels using the Ldn metric.

### SUMMARY OF CONSTRUCTION NOISE AND VIBRATION

#### Construction Noise

Construction noise levels were predicted using estimates of the types of equipment likely to be used during the noisiest periods of track construction. The predicted construction noise level exceeds the FTA impact threshold for construction noise by 4 decibels at 50 feet. Given that some residences in the project area are within 50 feet of the alignment, construction noise impacts are likely unless the contractor is required to implement noise control measures when working near residences.

Listed below are some typical approaches to reducing noise levels associated with the construction phase of major projects. Requiring the contractor to employ these methods should leave the contractor with enough flexibility to perform the work without undue financial or logistical burdens while protecting adjacent noise sensitive receivers from excessive construction noise levels.

- Avoid nighttime construction when possible. If nighttime construction is necessary, develop nighttime noise limits.
- Use specialty equipment with enclosed engines and/or high-performance mufflers.
- Locate equipment and staging areas as far from noise-sensitive receivers as possible.
- Limit unnecessary idling of equipment.
- Install temporary noise barriers. This approach can be particularly effective for stationary noise sources such as compressors and generators.
- Reroute construction-related truck traffic away from local residential streets.
• Avoid impact pile driving where possible. Where geological conditions permit, the use of drilled piles or a vibratory pile driver is generally quieter.

Specific measures to be employed to mitigate construction noise impacts should be developed by the contractor and presented in the form of a Noise Control Plan.

**Construction Vibration**

The primary concern regarding construction vibration is potential damage to structures. The thresholds for potential damage are much higher than the thresholds for evaluating potential annoyance used to assess impact from operational vibration. At a distance of 50 feet from buildings, the predicted vibration levels from construction are below the damage risk criteria for even those buildings most sensitive to damage. At a distance of 25 feet, the vibration level from high-vibration-generating equipment, such as a vibratory roller, is predicted to exceed the potential risk for damage impact threshold for timber and masonry buildings and those buildings most susceptible to damage. A structure eligible for historic listing is the Souper Salad building in Metrocenter. This building was constructed in the 1970’s and is unlikely to be considered a fragile structure. The property of the Royal Palm Mobile Home Park is also eligible to be listed as historic; there are no buildings that would likely be considered fragile on this property. There are no other properties along the alignment where buildings are expected to be considered to be fragile.

It is unlikely that high-vibration-generating equipment, such as a vibratory roller, would be operated closer than 25 feet of the nearest buildings. However, the following precautionary vibration mitigation strategies should be implemented to minimize the potential for damage to any structures in the corridor:

1. **Preconstruction Survey:** The survey should include inspecting building foundations and taking photographs of preexisting conditions. The survey can be limited to buildings within 25 feet of high-vibration-generating construction activities. The only exception is if an important and potentially fragile historic resource is located within approximately 200 feet of construction, in which case it should be included in the survey. As previously stated, no fragile buildings are likely to be located anywhere along the project alignment.

2. **Vibration Limits:** The FTA Guidance Manual suggests vibration limits in terms of peak particle velocity ranging from 0.12 inches/second for “buildings extremely susceptible to vibration damage” to 0.5 inches/second for “Reinforced-concrete, steel or timber” buildings. The contract specifications should limit construction vibration to a maximum of 0.5 inches/second for all buildings in the corridor. Should the preconstruction survey identify any buildings that are particularly sensitive to vibration, these structures should be assessed by an architect to determine appropriate vibration limits.

3. **Vibration Monitoring:** In locations within 25 feet of buildings (the distance where there is a potential risk for damage) and at locations where the building owners or occupants have complained about high vibration levels, vibration monitoring should be conducted when high-vibration construction generating equipment is used.
4. **Alternative Construction Procedures**: If construction vibration levels exceed limits specified in the contract, then alternative procedures may be needed. Examples of such procedures include use of nonvibratory compaction in limited areas or use of a concrete saw instead of a hoe ram to break up pavement.
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1.0 INTRODUCTION

This Noise and Vibration Technical Report has been prepared to support the Environmental Assessment (EA) for the proposed Northwest Phase II Light Rail Extension Project in Phoenix, Arizona. The proposed project, or Build Alternative, consists of an extension of the existing Valley Metro light rail line west along Dunlap Avenue, north on 25th Avenue, west on Mountain View Road, then crosses over Interstate 17 (I-17) and terminates at Metrocenter in northwest Phoenix. The total length of the Project is approximately 1.55 miles.

In addition to the main text that addresses the regulatory framework, noise and vibration prediction methodologies, the affected environment, potential noise and vibration impacts and mitigation for operations and construction, the document includes the following appendices:

- Appendix A: Fundamentals of Noise and Vibration
- Appendix B: Force Density Measurement Results
- Appendix C: Noise Source Level
- Appendix D: Vibration Propagation Test Results
- Appendix E: Ambient Noise and Vibration Measurement Sites
- Appendix F: Sensitive Receiver Inventory
- Appendix G: Vibration Mitigation for Switches

The remainder of this section discusses the No-Build and Build Alternatives for the project, including specific project features. In addition, a brief review of potential noise and vibration concerns related to the project is provided.

1.1 ALTERNATIVES

The Environmental Assessment (EA) for this project includes two alternatives for evaluation. They include a No-Build Alternative and a Build Alternative. Both alternatives are summarized below. Because FTA noise and vibration criteria require comparison of the Build Alternative to current existing conditions, rather than future No-Build conditions to determine impact, the No-Build Alternative is not considered for the Noise and Vibration Technical Report. The Build Alternative has been identified as the preferred alternative and is the focus of this noise and vibration analysis.

1.1.1 No-Build Alternative

The No-Build Alternative represents the case where the Northwest Phase II Light Rail Extension Project is not built. The No-Build Alternative includes the existing transit and roadway system, as well as programmed transportation improvement projects. The No-Build Alternative is not considered for the Noise and Vibration Technical Report for the reasons previously mentioned.
1.1.2 **Build Alternative**

The Build Alternative, shown in Figure 1, would consist of an approximately 1.5-mile northwestern extension of the existing Valley Metro light rail line from its current terminus at Dunlap and 19th Avenues to Metrocenter on the western side of I-17. The Northwest Phase II Light Rail Extension is scheduled to begin operations in 2023. A summary of the proposed project is provided below. Refer to Chapter 2 of the Northwest Phase II Light Rail Extension EA for a more detailed description of the Build Alternative and Appendix A of the EA for detailed drawings.

The light rail extension begins just west of the existing Dunlap Ave/19th Avenue Station and continues west on Dunlap Avenue to 25th Avenue where the track turns north to continue along 25th Avenue to Mountain View Road. At Mountain View Road, the route turns west and crosses over I-17. On the western side of I-17, the tracks turn north above the I-17 southbound frontage road and continue to a location north of Cheryl Drive within Metrocenter.

The bi-directional tracks would be primarily at grade, with the exception of the aerial structure and retained fill extending from Mountain View Road over I-17 to the end-of-line station at Metrocenter. Most of the guideway would be exclusively reserved for light rail vehicles (LRVs), physically separated from automobile traffic by a barrier such as a trackway curb. Exceptions to this occur at traffic intersections along the alignment and two at grade crossings west of the existing end-of-line Dunlap Ave/19th Avenue Station and the proposed Dunlap Ave/25th Avenue Station. The alignment transitions from side-running to median-running near both stations.
Special trackwork for this project would include installation of three crossovers at the following locations:

- Dunlap Avenue just east of 22nd Avenue
- Elevated structure just east of I-17 crossing
- Turnouts just south of the two end-of-line platforms

The crossovers will facilitate train movements to the opposite track.

Three new light rail stations would be provided at:

- Dunlap Ave/25th Avenue (at grade)
- Mountain View Rd/25th Avenue (at grade)
- Metrocenter (elevated)

The Build Alternative would connect with the existing light rail tracks just west of the existing Dunlap Ave/19th Avenue Station to allow interlining of the proposed extension with the existing light rail system.
Park-and-ride would be provided at two locations:

- Near the end-of-line Metrocenter Station. Approximately 260 parking spaces would be located near the end-of-line station within the existing parking area for Dillard’s department store inside the existing ring road of Metrocenter.

- Near the Mountain View Rd/25th Avenue Station. Approximately 179 spaces will be added to the existing parking lot along 25th Avenue at Rose Mofford Sports Complex. Recreational users would be able to use all the existing and additional spaces. A parking area within the lot will be designated for both light rail and recreational users. Additional parking will be added to the Rose Mofford Dog Park as well. 33 spaces will be added to the south end of this parking lot.

The existing transit center located in the southwest quadrant of Metrocenter would be relocated adjacent to the proposed end-of-line Metrocenter Station to better facilitate passenger transfers between transportation modes thereby creating a substantially improved multi-modal center. The Metrocenter Station platform and relocated transit center would be designed to accommodate a potential future pedestrian bridge over I-17 freeway to connect the Metrocenter land uses to the west and office park, educational institutions and Rose Mofford Sports Complex to the east of the freeway. The pedestrian bridge would not be part of this project but could be built in the future when demand warrants.

Traction power substations (TPSS) would be installed to provide electricity to power the LRVs. Three sites are being considered, but only two would be needed and selected for the project. All three potential sites are evaluated in this report. The sites are located at:

- Southern side of Dunlap Avenue west of 25th Avenue within an empty parcel.
- Northwestern quadrant of the intersection of 25th Avenue and Mountain View Road within an existing parking lot.
- Metrocenter – Within the proposed park-and-ride lot near Dillard’s department store.

1.2 NOISE CONCERNS ASSOCIATED WITH THE LIGHT RAIL SYSTEM

The following list summarizes most of the major noise sources associated with operating light rail systems:

**Light Rail Operations:** This is the normal noise from the operation of LRVs and includes noise from steel wheels rolling on steel rails (wheel/rail noise) and from propulsion motors, air conditioning and other auxiliary equipment on the vehicles. At the time of this study the maximum operating speed considered for the light rail ranges from 25 to 35 miles per hour (mph), depending on the section of the alignment. A key assumption in the noise predictions is that the optimal wheel and rail profiles would be maintained through periodic truing of the wheels and rail grinding.

**Traffic Noise:** Light rail shares the right-of-way with vehicular traffic, and the proposed project would result in a few physical changes to the road in the project area. A noise analysis as conducted to determine whether lane shifts along Dunlap Avenue, 25th Avenue and Mountain View Road would affect noise levels. The conclusion is that minimal changes in sound levels are expected from the potential changes to the roadways.
Audible Warnings: The LRVs are equipped with horns and bells as audible warning devices. The horns would be used in the same manner as on the buses along the alignment to alert pedestrians and motor vehicles of a potential safety risk. The horns are not expected to be used frequently enough to have any effect on the noise exposure. Therefore, horn noise has not been included in the noise analysis. Because the train bells would be used on a regular basis at stations and traffic signals, bell noise was included in the analysis for all noise-sensitive receivers near the alignment. Since a railroad gate would be included on Dunlap Avenue as part of the project, bells for crossing gates were also included in the analysis. Parameters that affect these stationary bells include the level at which the bells would sound, the time the bells are sounding and whether or not a shroud is in place to provide directional sounding/shielding (analysis assumed no shrouds).

Special Trackwork: The Build Alternative would be constructed of continuously welded track, which eliminates the *clickety-clack* noise associated with older rail systems. The one exception is the special trackwork for crossovers, where two rails must cross. A fixture called a *frog* is used where rails must cross. The wheel impacts at the gaps in the rails of a standard frog cause noise levels near special trackwork to increase by approximately 10 decibels (dB) at a distance of 35 feet or closer. Low-impact frogs are available that smooth the transition through the gap in the rail and can be used as a mitigation measure where the noise from special trackwork results in a predicted impact. Examples of low-impact frogs include flange-bearing frogs, monoblock frogs, spring-rail frogs and moveable point frogs. More information on frogs can be found in Appendix G.

Wheel Squeal: Wheel squeal is generated when steel-wheel transit vehicles traverse tight radius curves. It is very difficult to predict when and where wheel squeal will occur. A general guideline is that there is the potential for wheel squeal at any curve with a radius that is less than approximately 600 feet. Common approaches to controlling wheel squeal include (1) applying a friction modifier to the railhead and/or the wheel tread, (2) applying lubricant to the gauge face of the rail or the wheel flange and (3) optimizing the wheel and rail profiles. Using resilient wheels and maintaining the tracks would help control wheel squeal; also, periodically truing wheels would maintain an optimum profile and can help minimize wheel squeal.

Ancillary Equipment: The only ancillary equipment associated with the proposed project with potential for creating noise impacts are the TPSS units. Although two TPSS locations are required for the light rail system, three potential locations have been identified. A general guideline is that locating the TPSS at least 50 feet from the closest residential land use would avoid noise impacts.

Construction: All the sources discussed above are associated with the operation of the proposed project. The use of heavy equipment during project construction has the potential to result in substantial but temporary increases in local noise levels along the corridor. Potential construction noise impacts are discussed in Section 6.0.

### 1.3 VIBRATION CONCERNS ASSOCIATED WITH THE LIGHT RAIL SYSTEM

The following list summarizes the significant vibration sources associated with operating light rail systems:

**Light Rail Operations:** Light rail operations create groundborne vibration that can be intrusive to occupants of buildings close to the tracks. This is particularly important for
residential land uses that are located within 75 feet of LRVs operating at 30 mph. Note that the FTA impact criteria for vibration is based on annoyance, and the predicted levels of light rail vibration at all receivers are well below the thresholds used to protect sensitive and fragile historic structures from damage. The potential for vibration from light rail operations to be annoying to occupants of historic structures is based on the appropriate vibration impact criteria for the current use of the building. A key assumption in the vibration predictions is that the optimal wheel and rail profiles would be maintained through periodic truing of the wheels and rail grinding.

Special Trackwork: Turnouts and crossovers, where two rails cross, are the primary type of special trackwork on the alignment. This type of special trackwork is sometimes referred to as a frog. Standard frogs have gaps, and the train wheels must “jump” across the gap. The wheels striking the ends of the gap increase vibration levels as well as noise levels. The groundborne vibration levels near special trackwork increase by approximately 10 VdB because of wheel impacts at the gaps in the rails. Similar to noise, low-impact frogs can be used as a mitigation measure where the vibration from special trackwork results in a predicted vibration impact. More information on low-impact frogs can be found in Appendix G.

Construction: Construction of a light rail project entails relatively less use of heavy equipment compared to other rail projects. Nevertheless, the construction activities of the project would generate perceptible vibration levels. Potential construction vibration impacts are discussed in Section 6.0.

2.0 REGULATORY FRAMEWORK

Noise and vibration impact criteria that apply to this project are described below. As part of the regulatory framework discussion, typical terminology for noise and vibration are used; for more information on the basics of noise and vibration, including terminology, refer to Appendix A.

2.1 STATE AND LOCAL NOISE AND VIBRATION LIMITS

No state statutes related to noise and vibration apply to the operation of the proposed project. The FTA Noise and Vibration guidelines are used for this evaluation. The FTA guidelines, analysis methods and criteria reflect the best available research on the topic. Construction noise limits are discussed in Section 6.1 as part of the construction noise impact assessment.

2.2 FTA NOISE IMPACT CRITERIA

The noise impact criteria for use on federally funded transit projects are defined in the FTA Noise and Vibration Impact Assessment guidance manual (2006; also referred to as FTA Guidance Manual). The FTA criteria are based on the best available research on community response to noise. This research shows that characterizing the overall noise environment using measures of noise exposure provides the best correlation with human annoyance. Noise exposure characterizes noise levels over a period of time.

FTA provides different thresholds for different land uses. Table 1 lists the three FTA land-use categories and the applicable noise metric for each category. For Category 2
land uses (residential areas where people sleep), noise exposure is characterized using Ldn. In calculating Ldn, noise generated during nighttime hours is more heavily weighted than daytime noise to reflect residents’ greater sensitivity to noise during those hours. For Category 1 and Category 3 land uses (areas with primarily daytime use), noise exposure is characterized using the peak hour Leq, which is a time-averaged sound level over the noisiest hour of transit-related activity. Appendix A provides background information on the Ldn and Leq noise descriptors.

**TABLE 1: FTA LAND USE CATEGORIES AND NOISE METRICS**

<table>
<thead>
<tr>
<th>Land Use Category</th>
<th>Noise Metric (dBA)</th>
<th>Description of Land Use Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Outdoor Leq(h)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>A tract of land where quiet is an essential element of the 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 significant outdoor use. Also included are recording studios and concert halls.</td>
</tr>
<tr>
<td>2</td>
<td>Outdoor Ldn&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Residences and buildings in which people sleep. This category includes homes, hospitals and hotels, where a nighttime sensitivity to noise is assumed to be of utmost importance.</td>
</tr>
<tr>
<td>3</td>
<td>Outdoor Leq(h)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Institutional land uses with primarily daytime and evening use. This category includes schools, libraries and churches, where it is important to avoid interference with such activities as speech, meditation and concentration on reading material. Places for meditation or study associated with cemeteries, monuments, museums, campgrounds and recreational facilities can also be considered to be in this category. Certain historical sites and parks are also included.</td>
</tr>
</tbody>
</table>

Source: Federal Transit Administration (2006)

<sup>a</sup> Leq for the noisiest hour of transit-related activity during hours of noise sensitivity.

<sup>b</sup> Ldn is a measure that counts for full 24 hours of noise, with penalties for noise at night, which is defined as 10 PM to 7 AM.

The FTA noise impact threshold is a sliding scale based on existing noise exposure and land use of sensitive receivers. The basic concept of the FTA noise impact criteria is that more project noise is allowed in areas where existing noise is higher. However, in areas where existing noise exposure is higher, the allowable increase above the existing noise exposure decreases. For example, in an area with an existing noise level of 55 dBA, the allowable increase in noise level is 3 dBA, resulting in a total future noise level of 58 dBA. For an area with an existing noise level of 60 dBA, the allowable increase in noise level is only 2 dBA, resulting in a total future noise level of 62 dBA.

FTA defines two levels of noise impact: moderate and severe. In accordance with the FTA Guidance Manual, mitigation to reduce noise levels must be considered for both degrees of impact. The manual also states that for severe impacts “… there is a presumption by FTA that mitigation is incorporated into the project unless there are truly extenuating circumstances which prevent it.” In considering mitigation for severe impacts in this study, the goal is to reduce noise levels to below the moderate impact threshold. FTA allows more discretion for mitigation of moderate impacts based on the consideration of factors including cost, number of sensitive receivers affected, community views, the amount by which the predicted levels exceed the impact threshold and the sensitivity of the affected receivers. For the Build Alternative,
mitigation is recommended for all moderate and severe noise impacts, except where moderate impacts are less than 1 dB or are close to 1 dB and due to safety measures like train bells.

The FTA noise impact criteria are given in tabular format in Table 2 with the thresholds rounded off to the nearest decibel. The criteria are shown graphically in Figure 2 for the different categories of land use along with an example of how the criteria are applied. The two graphs on the left are for nonresidential land uses where $\text{Leq}(h)$ represents the noise exposure metric, and the top right graph is for residential land uses where $\text{Ldn}$ represents the noise exposure metric. As shown in Figure 2, the impact threshold is a sliding scale and it typically increases with an increase in existing noise exposure. The existing noise appears on the horizontal axis, and the amount of new noise that the project can create is on the vertical axis. The lower curve (blue) defines the threshold for moderate impact and the upper curve (red) defines the threshold for severe impact.

**TABLE 2: FTA NOISE IMPACT CRITERIA**

<table>
<thead>
<tr>
<th>Existing Noise Exposure, $\text{Leq}$ or $\text{Ldn}$</th>
<th>Project Noise Exposure Impact Thresholds, $\text{Leq}$ or $\text{Ldn}$ (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1 or 2 Land Uses</td>
<td>Category 3 Land Uses</td>
</tr>
<tr>
<td>Moderate Impact</td>
<td>Moderate Impact</td>
</tr>
<tr>
<td>&lt;43</td>
<td>$\text{Ambient}+10$</td>
</tr>
<tr>
<td>43</td>
<td>52</td>
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<td>44</td>
<td>52</td>
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<td>61</td>
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</tbody>
</table>
TABLE 2: FTA NOISE IMPACT CRITERIA

<table>
<thead>
<tr>
<th>Existing Noise Exposure, Leq or Ldn</th>
<th>Project Noise Exposure Impact Thresholds, Leq or Ldn (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Category 1 or 2 Land Uses</td>
</tr>
<tr>
<td></td>
<td>Moderate Impact</td>
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<td>62</td>
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<td>75</td>
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<td>76</td>
<td>66</td>
</tr>
<tr>
<td>77</td>
<td>66</td>
</tr>
<tr>
<td>&gt;77</td>
<td>66</td>
</tr>
</tbody>
</table>

Source: Federal Transit Administration (2006)

Note: Ldn is used for land uses where nighttime sensitivity is a factor; maximum 1 hour Leq is used for land uses involving only daytime activities.

The sample graph located in the bottom right corner of Figure 2 may help clarify the concept of a sliding scale for noise impact. Assume that the existing noise has been measured at 60 dBA Ldn. This is the total noise from all existing noise sources over a 24-hour period: traffic, aircraft, lawnmowers, children playing, birds chirping, etc. Starting at 60 dBA on the horizontal axis, follow the vertical line up to where it intersects the moderate and severe impact curves. Then refer to the left axis to see the impact thresholds. An existing noise of 60 dBA Ldn gives thresholds of 57.8 dBA Ldn for moderate impact and 63.4 dBA Ldn for severe impact. Note that the values are measured in tenths of a decibel to avoid confusion from rounding off; in reality, one cannot perceive a tenth of a decibel change in sound level.

Note that the curves in Figure 2 are defined in terms of project-only noise (on the vertical axes) and the existing noise (on the horizontal axes). The project-only noise is the noise introduced into the environment by the project; it is not the future noise levels with the project. The project-only noise does not include noise from existing noise sources in the area that won't change as a result of the project such as automobile traffic and airplanes.
For TPSS units, an additional noise limit is applied that is more stringent than the FTA noise impact criteria to ensure no impacts are overlooked. A noise impact is indicated when the predicted TPSS nighttime Leq noise level exceeds the existing nighttime Leq minus 5 decibels at residential receivers. The criteria do not differentiate between moderate and severe impacts. Note that the FTA Guidance Manual does not include separate thresholds for TPSS noise. Noise level goals that are more stringent than the FTA guidance criteria are often applied. By setting the impact limit to 5 dB below the existing nighttime noise, this ensures that a TPSS unit will add less than 1 dB to the background noise during typical sleeping hours. U.S. Department of Transportation (U.S. DOT) publications state that a 3-dB change is barely perceptible, so a change of 1 dB is usually ignored. The criteria applied to the Northwest Phase II Light Rail Extension Project as described above have been used on other FTA-reviewed projects such as Tempe Streetcar and South Central Light Rail.
2.3 FTA IMPACT CRITERIA FOR GROUNDBORNE VIBRATION

The potential adverse effects of rail transit groundborne vibration include perceptible building vibration, rattle noises, reradiated noise (groundborne noise) and cosmetic or structural damage to buildings. The vibration caused by modern light rail operations is well below what is considered necessary to damage buildings. Therefore, the criteria for building vibration caused by transit operations are only concerned with potential annoyance of building occupants.

The FTA vibration impact criteria are based on the maximum indoor vibration level as a train passes. There are no impact criteria for outdoor spaces such as parks because outdoor groundborne vibration does not provoke the same adverse human reaction as indoor vibration. The FTA Guidance Manual (2006) provides two sets of criteria: one based on the overall vibration velocity level for use in General Vibration Impact Assessments, and one based on the maximum vibration level in any 1/3 octave band (the band maximum level) for use with a Detailed Vibration Assessment. A 1/3 octave band is a range of frequencies, and each 1/3 octave band is referred to by the center frequency in that band. Predicted vibration on a 1/3 octave band basis allows vibration mitigation to be designed for the frequency range in which it will be most effective. This study uses the Detailed Vibration Assessment criteria.

The criteria for use with Detailed Vibration Assessments are shown in Figure 3. The predicted vibration levels are compared to the criteria curves shown in Figure 3 to determine whether there is impact and the frequency range over which vibration mitigation is required. Impact is identified when the predicted vibration velocity in any 1/3 octave band exceeds the applicable curve. The VC-A through VC-E curves are used to specify acceptable vibration limits for sensitive equipment such as electron microscopes. The “Residential (Night)” curve is applied to residential land uses, similar to the Category 2 land use defined for the noise analysis. The “Residential (Day)” curve is applied to institutional land uses with primarily daytime use such as schools, libraries and churches, and is similar to the Category 3 land use defined for the noise analysis.

Table 3 provides a brief description of each of the curves shown in Figure 3. The use of the criteria is illustrated by the example vibration spectra (the dashed blue line) shown in Figure 3. The maximum example level exceeds the “Residential (Night)” curve in the 50 and 63 Hz 1/3 octave bands. For this example, impact would be predicted for residential land uses, and vibration mitigation would be evaluated. However, no impact would be predicted for institutional land uses, because the example spectra does not exceed the “Residential (Day)” curve in any 1/3 octave band.

Some buildings, such as concert halls, recording studios and theaters, can be very sensitive to vibration but are not associated with the curves in Figure 3. Given the sensitivity of these buildings, they usually warrant special attention during the environmental evaluation of a transit project. Table 4 gives the FTA criteria for acceptable levels of groundborne vibration and groundborne noise for various categories of special buildings. These criteria are for limits on the overall vibration or noise levels, not the 1/3 octave band spectra. No buildings along the main corridor alignment are considered a special land use.

The FTA vibration thresholds do not specifically account for existing vibration. Although there are substantial volumes of vehicular traffic including buses and trucks in the
project area, it is relatively rare that rubber-tired vehicles will generate perceptible ground vibration unless there are irregularities in the roadway surface such as potholes or wide expansion joints.

Note that historic structures that do not fall into the FTA land use categories are not included in the assessment for vibration impact from light rail operations. The vibration impact thresholds are based on annoyance, and the primary concern for historic structures is the risk of damage. The recommended limit in the FTA Guidance Manual for buildings extremely susceptible to damage is 90 VdB, which is 18 decibels higher than the limit for Category 2 (residential) land uses. Vibration from light rail operations will be well below the limit for buildings extremely susceptible to damage at all historic resources.

**FIGURE 3: FTA CRITERIA FOR DETAILED VIBRATION ANALYSIS**
### TABLE 3: INTERPRETATION OF VIBRATION CRITERIA FOR DETAILED ANALYSIS

<table>
<thead>
<tr>
<th>Criterion Curve</th>
<th>Max ( L_v )(^a) (VdB)</th>
<th>Description of Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workshop</td>
<td>90</td>
<td>Distinctly feelable vibration. Appropriate to workshops and nonsensitive areas.</td>
</tr>
<tr>
<td>Office</td>
<td>84</td>
<td>Feelable vibration. Appropriate to offices and nonsensitive areas.</td>
</tr>
<tr>
<td>Residential Day</td>
<td>78</td>
<td>Barely feelable vibration. Adequate for computer equipment and low-power optical microscopes (up to 20X).</td>
</tr>
<tr>
<td>Residential Night, Operating Rooms</td>
<td>72</td>
<td>Vibration not feelable, but groundborne noise may be audible inside quiet rooms. Suitable for medium-power optical microscopes (100X) and other equipment of low sensitivity.</td>
</tr>
<tr>
<td>VC-A</td>
<td>66</td>
<td>Adequate for medium- to high-power optical microscopes (400X), microbalances, optical balances and similar specialized equipment.</td>
</tr>
<tr>
<td>VC-B</td>
<td>60</td>
<td>Adequate for high-power optical microscopes (1000X), inspection and lithography equipment to 3 micron line widths.</td>
</tr>
<tr>
<td>VC-C</td>
<td>54</td>
<td>Appropriate for most lithography and inspection equipment to 1 micron detail size.</td>
</tr>
<tr>
<td>VC-D</td>
<td>48</td>
<td>Suitable in most instances for the most demanding equipment, including electron microscopes operating to the limits of their capability.</td>
</tr>
<tr>
<td>VC-E</td>
<td>42</td>
<td>The most demanding criterion for extremely vibration-sensitive equipment.</td>
</tr>
</tbody>
</table>

* Source: Federal Transit Administration (2006), Table 8-3

\(^a\) Maximum allowed vibration velocity in any 1/3 octave band over the range of 8 to 80 Hz.

### TABLE 4: GROUNDBORNE NOISE AND VIBRATION IMPACT CRITERIA FOR SPECIAL BUILDINGS

<table>
<thead>
<tr>
<th>Location</th>
<th>Groundborne Vibration Impact Levels (VdB re 1 micro-inch/second)</th>
<th>Groundborne Noise Impact Levels (dBA re 20 micro Pascals)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concert halls</td>
<td>65</td>
<td>25</td>
</tr>
<tr>
<td>TV studios</td>
<td>65</td>
<td>25</td>
</tr>
<tr>
<td>Recording studios</td>
<td>65</td>
<td>25</td>
</tr>
<tr>
<td>Auditoriums</td>
<td>72</td>
<td>30</td>
</tr>
<tr>
<td>Theaters</td>
<td>72</td>
<td>35</td>
</tr>
</tbody>
</table>

* Source: Federal Transit Administration (2006), Table 8-2

#### 2.4 FTA IMPACT CRITERIA FOR GROUNDBORNE NOISE

The FTA Guidance Manual also presents criteria for assessing groundborne noise impact for the sensitive land use categories other than the special buildings. Groundborne noise is caused by the vibration of room surfaces radiating sound waves. When audible groundborne noise occurs, it sounds like a low-frequency rumble. When the tracks are above ground, the groundborne noise is usually masked by the normal airborne noise radiated from the rails and it is not necessary to assess impact from
groundborne noise. However, for buildings that have no windows facing the rail, or have
interior spaces where airborne noise does not penetrate, groundborne noise may be a
factor. Measurements discussed in Section 3.4 indicate that there is efficient
propagation of vibration at 100 Hz as well as high force density level at 100 Hz. This is a
controlling frequency for LRV groundborne noise; therefore, a close analysis of
groundborne noise will be included in this analysis.

Table 5 shows the impact limits for groundborne noise for receivers. (Table 4, above,
shows the limits for special buildings.) The limits for groundborne noise are based on
overall A-weighted levels, in contrast to groundborne vibration, which has limits based
on 1/3 octave bands. Category 1 receivers have no defined limit; the limits for these
receivers are based on the specific needs such as specific equipment limits for
microscopes. Category 2 receivers have a limit of 35 dBA, and Category 3 receivers
have a limit of 40 dBA.

It is possible that airborne noise will dominate the noise at a receptor, in which case the
FTA limits may be more stringent than is necessary. Therefore, where FTA limits result
in groundborne noise impacts, it may be appropriate to compare the predicted
groundborne noise levels to either predicted indoor noise levels or to measured existing
noise to further assess whether or not there could be a potential impact.

There are two methods used here, to reflect differing ambient conditions throughout the
alignment. For receivers where the dominant source of noise is likely to be light rail
operations, it is best to compare groundborne noise to predicted airborne noise caused
by train operations. This method is used for receivers on 25th Avenue, where road
traffic is light. It is also used at locations along Dunlap Avenue where special trackwork,
crossing bells, and/or station bells contribute substantially to the predicted train
operational noise (potentially exceeding road traffic noise). For receivers where some
other source of noise dominates, such as highways or busy roads, it is best to compare
groundborne noise to existing measured noise. This method is used for receivers on
Dunlap Avenue and near I-17 Freeway, where traffic would be the dominant noise
source.

Since the groundborne noise is predicted for interior spaces only, the substitute criteria
must also represent interior noise levels. It is assumed that the attenuation from
outdoor-to-indoor is 25 dB. The substitute criteria are set 5 dB below the predicted
indoor level of the airborne noise. For example, if the measured Ldn at a receiver is
70 dBA, it is assumed that the interior Ldn is 45 dBA, and the groundborne noise limit
will be set at 40 dBA. This limit is compared to the Ldn indoors caused by groundborne
noise. The same process is used whether groundborne noise is compared to predicted
train Ldn, or to existing noise.
### TABLE 5: FTA IMPACT CRITERIA FOR GROUNDBORNE NOISE

<table>
<thead>
<tr>
<th>Land Use Category</th>
<th>Groundborne Noise Impact Levels (dBA re 20 micro Pascals)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequent Event&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Category 1: Buildings where vibration would interfere with interior operations. Typically land uses include vibration-sensitive research and manufacturing, hospitals with vibration-sensitive equipment and university research operations</td>
<td>N/A&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Category 2: Residences and buildings where people normally sleep</td>
<td>35</td>
</tr>
<tr>
<td>Category 3: Institutional land uses with primarily daytime use</td>
<td>40</td>
</tr>
</tbody>
</table>

Source: Federal Transit Administration (2006), Table 8-1

<sup>a</sup> “Frequent Events” is defined as more than 70 vibrations of the same source per day.

<sup>b</sup> “Occasional Events” is defined as between 30 and 70 vibration events of the same source per day.

<sup>c</sup> “Infrequent Events” is defined as fewer than 30 vibration events of the same source per day.

<sup>d</sup> Vibration-sensitive equipment is generally not sensitive to groundborne noise.

---

### 3.0 NOISE AND VIBRATION METHODOLOGY

#### 3.1 NOISE ASSESSMENT APPROACH

The detailed assessment for noise included the following steps:

1. Identify sensitive receivers. Noise-sensitive land uses along the corridor were identified first using aerial photography. Field visits were then conducted to confirm land uses and gather additional relevant information, such as the presence of second stories, land use in the first floor of mixed use buildings and the presence of any intervening structures. Sensitive receivers were grouped together in clusters, where appropriate, based on their location relative to the tracks and land use type. Predictions for each cluster are based on the distance from the proposed project to the closest sensitive receiver. Appendix F details the cluster locations used in the assessment.

2. Determine existing conditions. As discussed in Section 4.0 and Appendix E, existing noise levels were measured along the project corridor at four long-term sites for 24 hours each, and at two short-term sites for 1 hour each. The measurements were used to estimate the existing $L_{dn}$ and daytime $Leq$ at all of the sensitive receiver clusters.

3. Develop prediction models. The noise prediction models are based on formulas provided in the FTA Guidance Manual and noise measurements of the Valley Metro Starter Line. The predictions of light rail noise are based on the forecasted future number of daily trains and the distribution of these trains throughout the day (early morning, daytime and nighttime); the distance from the tracks; addition of special trackwork; the train speed; the presence of walls, berms, or other structures that reduce noise levels and other site-specific conditions. The predictions also include
noise from train bells at stations and signaled intersections, crossing gate bells and TPSS units. A model was also developed to do separate predictions of noise from TPSS units for purposes of comparing noise levels to nighttime noise near residential receivers.

4. Estimate project noise levels at the representative receivers. The prediction models were used to predict noise levels from train operations at all clusters of sensitive receivers in the Northwest Light Rail Extension corridor. The predictions were compared to the applicable FTA impact thresholds to identify potential noise impacts.

5. Evaluate mitigation options. Mitigation options were evaluated for all locations where the predicted noise levels exceed the FTA impact thresholds.

3.2 NOISE PREDICTION MODEL

This section describes the models that were used to predict noise related to the light rail operations.

3.2.1 Noise from Train Operations

The noise prediction model follows the noise impact assessment methodology for detailed noise predictions presented in the FTA Guidance Manual and incorporates assumptions on operating conditions specific to the project, including speeds, vehicle type and train frequencies.

For well-maintained light rail systems, the wheel-rail noise dominates above 20 mph and the noise from propulsion motors, air conditioning and other auxiliary equipment on the vehicles dominate below 20 mph. The noise predictions for this analysis are based on reference noise level measurements from the embedded sections of the Valley Metro Light Rail Starter Line with operating speeds the same or similar to the proposed light rail alignment (refer to Appendix C for further discussion on the reference data used for the noise predictions). The reference levels used for this analysis are:

- Maximum sound level (Lmax) of a two-car train operating at 35 mph on embedded track at a distance of 50 feet: $77 \text{ dBA}$
- Train speed: 15 to 35 mph (varies by section)
- Train length: Two cars for all trains. Three-car trains are possible during high demand; these would be operated during daytime and evening hours, which would have minimal effect on noise predictions. Therefore, a two-car consist has been used as the normal train configuration for all noise modeling.
- Noise amplification from crossover frogs: $+10 \text{ dB}$ at a distance of 35 feet (adjusted by distance)
- Note that wheel squeal (noise amplification of $+10 \text{ dB}$ for any curve with radius less than 600 feet) was not included in any of the predictions. It is assumed that proper friction modification or lubrication would be applied such that wheel squeal is not an issue.
- Note that it is assumed that the rails and wheels would be maintained in a state of good repair such that noise from rail corrugations and wheels flats would be minimized, and additional noise for these elements is not included in the predictions.
These values were used with formulas included in the FTA Guidance Manual to predict the noise levels at each cluster of sensitive receivers. The FTA uses a descriptor known as the Sound Exposure Level (SEL), which normalizes the sound of an event to a 1-second duration. The principal formulas are:

**Relationship between \( L_{\text{max}} \) and the Sound Exposure Level (SEL):**

\[
SEL = L_{\text{max}} - 10 \times \log \left( \frac{\text{speed}}{\text{length}} \left( 2\alpha + \sin(2\alpha) \right) \right) + 3.3
\]

where:
- \( \text{speed} \) = Velocity in mph
- \( \text{length} \) = Length of vehicle (reference is two-car LRV = 190 feet)
- \( \alpha \) = \( \tan^{-1}(\text{length}/2\text{y}) \), where \( \text{y} \) is the distance from receiver to track centerline

**Change in sound level with speed:**

\[
\Delta SEL = 20 \log \left( \frac{\text{speed}_2}{\text{speed}_1} \right)
\]

where:
- \( \text{speed}_1 \) = Reference speed (35 mph)
- \( \text{speed}_2 \) = Predicted speed (25 to 35 mph, varies by section)
- \( \Delta SEL \) = Change in SEL for speed change from \( \text{speed}_1 \) to \( \text{speed}_2 \)

The above speed relationship is valid for train speeds higher than 20 mph.

**Calculation of \( L_{\text{dn}} \) and hourly \( L_{\text{eq}} \) from SEL:**

\[
L_{\text{dn}} = SEL_{\text{ref}} + 10 \log \left( N_{\text{Train\_DAY}} + N_{\text{Train\_NIGHT}} \times 10 \right) - 10 \log \left( \frac{\text{Dist}}{\text{Dist}_{\text{ref}}} \right) - 49.4
\]

\[
L_{\text{eq\_hour}} = SEL_{\text{ref}} + 10 \log \left( N_{\text{Train\_HOUR}} \right) - 10 \log \left( \frac{\text{Dist}}{\text{Dist}_{\text{ref}}} \right) - 35.6
\]

where:
- \( SEL_{\text{ref}} \) = SEL reference levels defined based on predicted \( L_{\text{max}} \)
- \( N_{\text{Train\_DAY}} \) = Number of trains during daytime hours (7 a.m. to 10 p.m.)
- \( N_{\text{Train\_NIGHT}} \) = Number of trains during nighttime hours (10 p.m. to 7 a.m.)
- \( N_{\text{Train\_HOUR}} \) = Number of trains during 1 hour
- \( \text{Dist} \) = Distance from train tracks to the sensitive receiver
- \( \text{Dist}_{\text{ref}} \) = Reference distance (50 feet)

The proposed operating schedule is shown in Table 6. The predicted noise levels in Section 5.0 include train operations between 5 a.m. and 3 a.m. to reflect worst-case noise conditions.

Also included in the noise prediction calculations are adjustments for ground type (for this project, hard ground is assumed) and shielding due to buildings (for receivers beyond the first row) as described in the FTA Guidance Manual.
### TABLE 6: PROPOSED TRAIN OPERATING SCHEDULE

<table>
<thead>
<tr>
<th>Hours</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 a.m.—6 a.m.</td>
<td>20 minutes</td>
</tr>
<tr>
<td>6 a.m.—7 p.m.</td>
<td>12 minutes</td>
</tr>
<tr>
<td>7 p.m.—12 a.m.</td>
<td>20 minutes</td>
</tr>
<tr>
<td>12 a.m.—3 a.m.</td>
<td>20 minutes (Friday and Saturday only)</td>
</tr>
</tbody>
</table>

#### 3.2.2 Prediction Model, Noise from Audible Warnings

Audible warnings include bells and horns mounted on vehicle, as well as bells mounted at grade crossings.

##### 3.2.2.1 Train Bells

Bells may be installed at both ends of the trains and may be activated at the front or both front and rear ends. The noise from bells is modeled based on the bell sound level for the Valley Metro light rail vehicles, and it is conservatively assumed that the bells are line sound sources (moving). The bell reference sound level is assumed to be a maximum sound level (Lmax) of 80 dBA at a distance of 50 feet from the bell. The train bells are included in the analysis for two reasons: (1) when stopping and starting from the train stations and (2) at stoplights when the train starts after stopping for the signals. A reasonable assumption is that approximately half of the trains would sound the bell at signaled intersections since the bells would only be sounded when the signal requires the train to stop at an intersection. The bell noise model also assumes that the bells would be sounded by all trains when stopping and starting from train stations.

The principal formulas used for this analysis are:

**Relationship between Lmax and SEL:**

\[
SEL = L_{max} + 10 \times \log(T)
\]

where:

- \( T = \) Duration of the bell noise (seconds/ring * # rings; \( T = 2 \) for this study)

**Calculation of Ldn and hourly Leq from SEL:**

\[
Ldn = SEL_{Bell} + 10 \log(N_{TrainDAY} + N_{TrainNIGHT} \times 10) - 10 \log \left( \frac{Dist}{Dist_{ref}} \right) - 49.4
\]

\[
Leq(hour) = SEL_{Bell} + 10 \log(N_{TrainHOUR}) - 10 \log \left( \frac{Dist}{Dist_{ref}} \right) - 35.6
\]
where:

\[ SEL_{Bell} = \text{SEL reference level defined based on bell Lmax and duration} \]
\[ N_{Train_{DAY}} = \text{Number of trains sounding bell during daytime hours} \]
\[ N_{Train_{NIGHT}} = \text{Number of trains sounding bell during nighttime hours} \]
\[ N_{Train_{HOUR}} = \text{Number of trains sounding bell during 1 hour} \]
\[ Dist = \text{Distance from the bell to the sensitive receiver} \]
\[ Dist_{ref} = \text{Reference distance (50 feet)} \]

### 3.2.2.2 Crossing Bells

Where crossing gates are installed, it is assumed that bells ring for 30 seconds, which includes only the time for warning, arms going down and arms going up (assumes bells are not sounded while down and the train is passing through). The assumed crossing bell reference level is 73 dBA maximum sound level (Lmax) at a distance of 50 feet from the bell (extracted from FTA Guidance Manual and equivalent to 87 dBA at 10 feet; note that the American Railway Engineering and Maintenance-of-Way Association (AREMA) C&S Manual, Part 3.2.61 [AREMA 2010] states that a soft tone bell should produce a sound level no more than 85 dBA and no less than 75 dBA at a distance of 10 feet). The same formulas apply as for train bells, with the exception of the distance correction. The crossing bells are assumed to be a point source rather than a line source, so the multiplier for the distance correction is 20 instead of 10 in the Ldn and Leq equations. So rather than a distance correction of \( -10\log(Dist/Dist_{ref}) \), the correction is \( -20\log(Dist/Dist_{ref}) \).

### 3.2.3 Ancillary Equipment

The only ancillary equipment expected to have the potential of causing noise impacts are the TPSS units. The primary noise sources from the TPSS units are the transformer hum and noise from cooling systems. On most modern TPSS units the transformer hum is minimal, so only the ventilation and cooling system has potential to cause noise impacts.

A recent noise measurement of a TPSS unit used in a residential area along the Los Angeles Metro Gold Line showed that the ventilation fan generated a sound level of 51 dBA at a distance of 40 feet from the fan, which is equivalent to an Leq of 49 dBA at a distance of 50 feet (the measurement was not done at 50 feet because of obstructions). The measured noise level is consistent with the limit of 50 dBA at 50 feet from any side of the TPSS that has been included in the purchase specifications for TPSS units on several recently completed light rail systems. It has been assumed that similar units would be used on the Northwest Light Rail Extension Project.

TPSS units are included two ways in the noise predictions: (1) added to the train noise for all sensitive receivers near the proposed TPSS sites and (2) examined separately for residential receivers for nighttime hours.

For both inclusions, a reference level of a constant 50 dBA at 50 feet has been assumed.

For inclusion in project noise, the TPSS noise is calculated using the reference and assuming continuous operation, then adjusting for distance and other sound propagation effects (ground type and shielding). Then the TPSS noise is combined with the train and bell noise.
For the separate nighttime analysis for residential receivers, the TPSS reference level is simply adjusted for distance.

### 3.2.4 Road Traffic Analysis

Road traffic noise is analyzed using the Federal Highway Administration Traffic Noise Model (FHWA TNM, 1998 and 2004 updates) Version 2.5. Several analyses are conducted and are described further in Section 5.1.3. For these analyses, each lane is modeled as a separate TNM roadway object for the most precise noise source placement possible. Since differences between the Build and No-Build traffic volumes are negligible, just Build traffic is used for the analysis on Dunlap Avenue; for the analysis on 25th Avenue, only existing traffic is used, since future traffic is unavailable. Posted speed limits are applied. The analyses focus on looking at the difference between sound levels predicted for the current roadway configuration to the modified roadway configuration where some traffic lanes would be shifted due to the light rail alignment.

These analyses were done separately from the operational light rail noise analysis, which is a typical first step to determine if noise from roadway changes needs to be included in the assessment of potential noise impact. Note that since the effects from these changes were determined to be minimal, it was not necessary to include them in the operational noise impact predictions.

### 3.2.5 Park and Ride Analysis

Noise from park-and-ride lots is analyzed using steps outlined in the FTA guidance. The following calculation is used:

\[
Leq(\text{hour}) = SEL_{\text{park-and-ride}} + C_N - 35.6
\]

where:

- \(SEL_{\text{park-and-ride}}\) = Reference level of 92 dBA at 50 feet (this is the FTA reference level for a parking garage, which considers automobiles only; the reference for FTA park-and-ride lots is intended for buses and assumes both automobiles and buses are present)
- \(C_N\) = \(10 \times \log(\# \text{ parking spaces / 1000})\).

The calculated lot noise is then compared to existing noise. If far below, no further consideration is warranted. If within about 10 dB of the existing noise, the predicted lot noise is combined with other project noise (train operations, TPSS units) to determine whether the combined level exceeds the FTA impact criteria. To convert the \(Leq\) values to \(Ldn\), it is assumed that a majority of the lot noise would be between the hours of 5 a.m. and 9 a.m. and between 3 p.m. and 7 p.m., the typical use for commuters. Note that effects from park-and-ride lots were not included in the operational noise impact predictions. The park-and-ride lots are beyond prescribed screening distances from sensitive receivers and would not contribute to the project noise levels.

### 3.3 VIBRATION ASSESSMENT APPROACH

The detailed assessments for vibration included the following steps:

1. **Identify sensitive receivers.** Vibration-sensitive land uses along the corridor were identified using the same procedure as the noise analysis. Sensitive receivers were grouped in clusters based on their location relative to the tracks and land use type. The
residential land use clusters were the same for both noise and vibration assessments. Predictions for each cluster are based on the distance from the proposed project to the closest sensitive receiver. Appendix F details the cluster locations used in the assessment. The noise-sensitive institutional land uses are also vibration-sensitive. The exception is open spaces such as parks, which are not considered vibration-sensitive land uses. The FTA Guidance Manual does identify vibration-sensitive land uses that are not noise sensitive, such as research laboratories with vibration-sensitive equipment. However, no such land uses exist within the project study area.

2. **Develop prediction models.** The vibration prediction models are based on the force density level (FDL) measurements made on the Valley Metro Starter Line by ATS Consulting in 2009, and by vibration propagation tests at representative sites along the Northwest Extension corridor spaced approximately 1/2 miles apart or less. The vibration prediction models are based on the FTA Guidance Manual's detailed vibration assessment methodology.

3. **Estimate future vibration levels at the representative receivers.** The prediction models were used to predict vibration levels from train operations at all sensitive receivers in the Northwest Light Rail Extension corridor. The predictions were compared to the applicable FTA impact thresholds to identify potential vibration impacts.

4. **Evaluate mitigation options.** Mitigation options were evaluated for all locations where the predicted vibration levels exceed the FTA impact thresholds.

3.4 **VIBRATION PREDICTION MODEL**

Localized geologic conditions such as soil stiffness, soil layering and depth to bedrock have a strong effect on groundborne vibration. However, it is difficult to obtain information on subsurface conditions in sufficient detail so that computer models can be used to accurately predict ground vibration. As a result, most detailed predictions of ground vibration are based largely on empirical methods that involve measuring vibration propagation in the soil.

The predictions of groundborne vibration for this study follow the Detailed Vibration Assessment procedure of the FTA Guidance Manual (2006). This is an entirely empirical method based on testing of the vibration propagation characteristics of the soil in the project corridor and measurements of the vibration characteristics of a similar train vehicle. The quantity derived from propagation tests is referred to as the Line Source Transfer Mobility (LSTM). The LSTM is used with the FDL—a measure of how much vibration energy trains generate—to predict the vibration energy received by the sensitive receivers.

The basic relationship used for the vibration predictions is:

\[ L_v = FDL + LSTM \]

where:

- \( L_v \) = Train vibration velocity measured at the ground surface
- \( LSTM \) = Measured line source transfer mobility
- \( FDL \) = Force density function that characterizes the vibration forces generated by the train and track

*(All quantities are expressed in decibels using a consistent set of decibel reference values)*
To predict impacts, this vibration level ($L_v$) is combined with receiver-specific adjustments—such as speed, special trackwork, coupling loss, floor amplification and other factors—and compared against the regulatory limits discussed in Section 2.0. These adjustments are discussed in a later section.

The FDL used for this project was developed from measurements of trains running on the existing Valley Metro Starter Track. Train vibration and propagation measurements were conducted by ATS in 2009 at 5552 E Washington Street, as part of the Mesa Light Rail Environmental Analysis. Follow-up measurements were made at the same location for the Capitol I-10 Environmental Analysis. Appendix B is a summary of the results of the measurements made in both 2009 and 2013.

The LSTM was measured at three locations that were selected to represent the vibration sensitive receivers along the Northwest alignment. The sites were spaced by approximately 1/2 miles. Measurements were made at outdoor positions only. Figures in Appendix F show where the vibration sites are located along the alignment. The vibration is predicted for each receiver using data from the nearest vibration propagation measurement site.

The LSTM and FDL are both empirically derived quantities. The methodology used to derive these values for each receiver in the prediction model is discussed in the following subsections.

Groundborne noise is predicted following the FTA procedure that assumes that groundborne noise is directly to the vibration of room surfaces. Groundborne noise is derived by adding a radiation factor, $K_{rad}$, and applying A-weighting:

$$La = L_v + K_{rad} + K_{awt}$$

For this analysis $K_{rad}$ is set to $-5$ dB. This is the value recommended in the upcoming version of the FTA Guidance Manual (2016 est.).

### 3.4.1 Vibration Propagation Test Procedure

The vibration predictions for the Northwest Light Rail Extension Project are based on the Detailed Assessment approach recommended in the FTA Guidance Manual. The FTA Detailed Vibration Assessment uses state-of-the-art tools to characterize how localized soil conditions affect the levels of groundborne vibration. A vibration propagation test is conducted to measure how vibration is transmitted from the light rail tracks through the ground and into the foundations of nearby buildings (see Figure 4).

The test procedure consists of creating an impact force using a drop hammer and determining the transfer function relationship between the force generated by the drop hammer and the resulting vibration pulse. The ATS drop hammer drops a 40 lb weight from a height of 4 ft on to a load cell that measures the force of the decelerating weight. The impacts using the drop hammer are performed in a line located as close to the planned track centerline as possible, and vibration sensors are located at several distances from the impact line. Sensors may also be located inside nearby buildings to provide information on the propagation path from the track centerline into the building's occupied spaces. Vibration propagation tests were performed at three locations in the Northwest corridor, each using a line of 11 impact positions at intervals of 15 feet (marked as the line of impacts in Figure 4).
The relationship between the exciting force and the resulting vibration level is referred to as the “transfer mobility,” which indicates how easily vibration travels through the earth. Each of the 11 impact positions yields a point-source transfer mobility. Numerically integrating the 11 point-source transfer mobilities yields the LSTM. Each accelerometer yields its own LSTM at a different distance, which can be fit to LSTM-vs-log(distance) curves to predict LSTM as a function of distance for each 1/3 octave band.

3.4.2 Vibration Propagation Test Sites

The three locations for the vibration propagation tests were selected to represent the vibration-sensitive receivers along the Northwest Extension Phase II corridor. The sites were spaced by approximately 0.25 to 0.5 miles. The location of sensors and force-impacts at each measurement site is shown in figures in Appendix D.

The details of the vibration propagations sites are discussed below:

V-1 DeVry University: This measurement was performed at 2149 W Dunlap Avenue, in the parking lot of the DeVry University Campus. The line of impacts was placed on the sidewalk immediately south of Dunlap Avenue. Vibration sensors were placed in the parking lot at distances of 25, 37, 50, 75, 100 and 150 feet from the impact line. The 25 foot sensor was placed on an 8-inch stake in soil. The other sensors were mounted to metal plates and fixed to the ground using earthquake gel.

V-2 Atrium Court Apartment: This measurement was performed at 2323 W Dunlap Avenue, at the Atrium Court Apartment Homes. The line of impacts was on the sidewalk on the south of Dunlap Avenue. The vibration sensors were located on the west edge of the parking lot. All vibration sensors were mounted to 8-inch stakes and placed in soil. Sensors were located at distances of 25, 50, 75, 100 and 150 feet from the impact line.

V-3 Courtyard Marriott Phoenix North: This measurement was performed at 9631 N Black Canyon Highway, in the parking lot of the Courtyard Phoenix North Hotel. The line of impacts was conducted on the sidewalk immediately south of W Mountain View
Road, near the northeast corner of the parking lot. The vibration sensors were placed at
distances of 25, 37, 50, 75, 100 and 150 feet. All sensors were mounted to metal plates
and fixed to the ground using earthquake gel.

3.4.3 Applying Vibration Propagation Test Results to Prediction Model

The measured LSTMs and coherences for each vibration propagation test site are
shown in Appendix D. The LSTMs for each site were used to create best-fit curves of
LSTM versus log-distance. The best-fit coefficients are presented below in Table 7.

The equation used for the fit is as follows:

\[ LSTM(d) = A + B \times \log(d) + C \times \log(d)^2 \]

where:

- \( LSTM \) = Line Source Transfer Mobility in dB re 1 (µin/sec)/(lb/ft\(^{1/2}\))
- \( d \) = Distance in feet

As shown in Table 7, the \( C \) term described above is not used. The vibration propagation
data show that the quadratic term is not needed.

**TABLE 7: COEFFICIENTS USED FOR BEST-FIT CALCULATIONS**

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>V-1</th>
<th></th>
<th>V-2</th>
<th></th>
<th>V-3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>6.3</td>
<td>12.3</td>
<td>-2.2</td>
<td>24.89</td>
<td>-9.41</td>
<td>23.7</td>
<td>-8.9</td>
</tr>
<tr>
<td>8</td>
<td>24.6</td>
<td>-8.1</td>
<td>28.21</td>
<td>-9.39</td>
<td>25.6</td>
<td>-8.3</td>
</tr>
<tr>
<td>10</td>
<td>22.6</td>
<td>-4.1</td>
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<td>-13.11</td>
<td>29.6</td>
<td>-7.5</td>
</tr>
<tr>
<td>12.5</td>
<td>26.2</td>
<td>-1.9</td>
<td>50.29</td>
<td>-16.55</td>
<td>35.4</td>
<td>-8.1</td>
</tr>
<tr>
<td>16</td>
<td>36.5</td>
<td>-3.9</td>
<td>51.03</td>
<td>-13.23</td>
<td>39.3</td>
<td>-7.1</td>
</tr>
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<td>20</td>
<td>59.5</td>
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<td>-17.90</td>
<td>62.0</td>
<td>-16.4</td>
</tr>
<tr>
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</tr>
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<td>66.0</td>
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<td>101.70</td>
<td>-39.76</td>
<td>76.8</td>
<td>-28.3</td>
</tr>
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<td>80</td>
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<td>-25.2</td>
<td>89.22</td>
<td>-35.45</td>
<td>71.5</td>
<td>-27.7</td>
</tr>
<tr>
<td>100</td>
<td>84.3</td>
<td>-35.7</td>
<td>89.10</td>
<td>-40.65</td>
<td>80.8</td>
<td>-36.3</td>
</tr>
<tr>
<td>125</td>
<td>88.8</td>
<td>-41.6</td>
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<td>-45.75</td>
<td>90.1</td>
<td>-46.4</td>
</tr>
<tr>
<td>160</td>
<td>92.3</td>
<td>-49.5</td>
<td>76.21</td>
<td>-41.97</td>
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</tr>
<tr>
<td>200</td>
<td>80.8</td>
<td>-45.5</td>
<td>63.34</td>
<td>-38.17</td>
<td>68.3</td>
<td>-42.1</td>
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<td>-35.79</td>
<td>44.7</td>
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<tr>
<td>315</td>
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<td>-11.7</td>
<td>53.6</td>
<td>-37.2</td>
<td>20.5</td>
<td>-18.8</td>
</tr>
</tbody>
</table>
Figure 5 shows graphs of the best-fit LSTM at each measurement site and at varying distances. Coherence at all measurement sites is good between 16 and 200 Hz. Below is a summary of the key observations from Figure 5.

Site V-1 has peak propagation in the 31.5 Hz band. Site V-1 also has the highest propagation at distances farther than 25 feet.

- Site V-2 has peak propagation in the 40-50 Hz bands. Site V-2 has the highest propagation closer than 25 feet, but the lowest propagation at distances farther than 25 feet. This indicates that the attenuation with distance here is greater than at the other sites.
- Site V-3 has peak propagation in the 40-50 Hz bands. Site V-3 is generally between the other two sites.

Due to the variation in the propagation at the three sites the, predictions for each receiver will be made using the nearest propagation measurement. Generally, receivers east of 22nd Avenue will use Site V-1, receivers west of 22nd Avenue and south of the Canal will use Site V-2, and receivers north of the Canal will use Site V-3.

**FIGURE 5: BEST FIT LSTM AT EACH SITE**
3.4.4 Force Density Level

FDL is derived by measuring $L_v$ and $LSTM$ at a site where light rail is already in operation and calculating the FDL using the equation:

$$L_v = FDL + LSTM$$

Where all components are expressed in decibels. The project uses an FDL measurement from the Valley Metro Starter Line. The FDL of the Starter Line was measured in 2009 as part of the Mesa Project (Valley Metro 2010). The results of the FDL measurements at this site are shown in Figure 6 for LRV speeds of 30 mph. Details of the FDL tests and results are in Appendix B. The FDL has a peak at 80 Hz of about 40 dB. This is 10 dB higher than a typical light rail, as suggested by the FTA Guidance Manual. As discussed in Appendix B, a low FDL can be maintained in light rail systems through a program that manages optimal wheel-rail profile and proactively eliminates potential for wheel deformations.

![FIGURE 6: FORCE DENSITY LEVEL AT 30 MPH](image)

3.4.5 Adjustments of $L_v$ for Prediction Model

After determining the FDL and LSTM discussed in the previous sections, the following adjustments were incorporated into the prediction model to estimate vibration levels in occupied spaces of buildings:

- **Speed Adjustment**: The Washington Street FDL represents a train traveling at 30 mph. Adjustments to other speeds is made using $15\times\log(speed/30\text{mph})$.

- **Special Trackwork**: The additional vibration at special trackwork was accounted for by adding 10 dBs to the predicted vibration levels when the special trackwork frog
would be located less than 50 feet from a sensitive receiver. At distances greater than 50 feet, the additional vibration from crossovers is assumed to decay at a rate of $15 \times \log(\text{dist}/50 \text{ ft})$ (decay rate based on measured vibration propagation).

- **Theoretical Coupling Loss and Floor Amplification**: For lightweight wood-frame structures, the FTA Guidance Manual suggests +6 dB for floor amplification and −2 dB per floor for floor-to-floor attenuation up to five floors above grade, as well as a −5 dB adjustment for coupling loss. Combining the adjustment factors for a wood-frame structure such as a residence, there is −5 dB for the coupling loss, +6 dB for floor amplification and an additional −2 dB for each floor above the grade level. This leads to a net adjustment of between −1 to +1 dB for the vibration inside a typical residence. Therefore, no adjustment is applied to account for coupling loss and floor amplification in the prediction model for small single-story residences. For large masonry buildings, the FTA Guidance Manual suggests a −10 dB adjustment for coupling loss. This adjustment has been used at most multifamily residences and large office buildings.

- **Measured Building Amplification and Safety Factor**: It is not feasible to consider each receiver individually without a considerable amount of additional measurements. Therefore, to account for potential amplification effects from buildings and other possible sources of error in the predictions, a safety factor of +3 dB was added to each 1/3 octave band. This is a conservative approach, ensuring that in the majority of cases the predicted vibration levels are higher than what would occur after the proposed project is operational.

- **Radiation Factor, Krad**: The radiation factor is an adjustment to convert from groundborne vibration to sound pressure level. The 2006 FTA Guidance Manual suggests 0 dB for Krad. The upcoming revised FTA Guidance Manual will suggest −5 dB for Krad. In this analysis, −5 dB will be used. The final sound pressure levels will also have an A-weighting applied.

### 3.4.6 Converting Groundborne Noise to Ldn/Leq

In some cases, where groundborne noise exceeds FTA criteria, it is possible that the airborne noise will still be considerably greater than the groundborne noise. In these cases, the groundborne noise should be compared to either the measured existing noise, or to the predicted train operations Ldn.

In both cases a groundborne noise Ldn (or Leq) must be calculated. This follows the same procedure as for calculating the airborne Train Ldn, described in Section 3.2.1, except that the reference level is taken to be the predicted groundborne noise (Lmax).

Additionally, the airborne Ldn or existing noise must be adjusted to account for outdoor-to-indoor attenuation. As described in Section 2.4, this assumes 25 dB attenuation from outdoor-to-indoor. The criterion is set 5 dB below this indoor level.

### 3.4.7 Final Vibration Prediction Model

This section presents the predicted vibration level, Lv, with a +3 VdB safety factor at various distances. Figure 7 shows predictions made using Site V-1, Figure 8 shows predictions made using Site V-2, and Figure 9 shows predictions made using Site V-3.
Also plotted are two FTA criteria for impact for residential land uses. The figures show that residential receivers farther than 75 feet from the alignment would not exceed the FTA Residential (Night) criteria. Only a single 1/3 octave band L\textsubscript{v} needs to exceed 72 VdB for the residential receiver to be considered an impact. Note that the FTA criteria for a detailed vibration impact assessment uses the Residential (Night) criteria curve for land uses where people sleep including residences and hotels and the Residential (Day) criteria curve for institutional land uses such as schools and churches. These figures do not include adjustments made based on special trackwork or building attenuation. The complete inventory of vibration predictions at each receiver is given in Table 12 and Table 13, in Section 5.2.

**FIGURE 7: PREDICTED LRV VIBRATION SPECTRUM AT 25 MPH, SITE V-1**
4.0 AFFECTED ENVIRONMENT

Noise and vibration sensitive receivers were identified using the FTA Guidance Manual’s definitions of noise- and vibration-sensitive land uses. Existing noise-sensitive receivers in the Northwest Phase II Light Rail Extension corridor consist of single- and
multifamily residences, hotels, schools, and medical facilities. A full list of sensitive receivers can be found in Appendix F; some are individual properties and others are clusters or groups of properties. The list includes those potentially sensitive to train noise and vibration, as well as those potentially sensitive to the TPSS units. The indoor land uses consist of 540 existing dwelling units (includes high-rise building residences/hotel rooms that are exposed to the alignment) and 8 institutional land uses.

A noise and vibration test and measurement program was developed to characterize the ambient noise and vibration in the project area. The noise sites included long-term noise (24-hour) measurements, and short-term noise (1-hour) measurements throughout the alignment. The vibration test program included vibration propagation tests at three sites as well as ambient vibration measurements. At the vibration propagation test sites, the ambient vibration was measured to verify whether the background vibration was below the test signals. These tests were conducted by ATS between August 1 and 5, 2016. These vibration propagation measurements are documented in Appendix D, and the existing noise and vibration measurements are documented in Appendix E.

Maps of test/measurement locations in relation to sensitive receivers, are shown in Appendix F. Details of the measurements are discussed in the rest of this section.

4.1 EXISTING CONDITIONS – NOISE

The FTA noise impact analysis is based on the existing ambient noise in the project area. The project area has several transportation-related noise sources including vehicular traffic and light rail as listed below:

- The primary source of traffic noise is vehicles on Dunlap Avenue, 25th Avenue, Mountain View Road and I-17, including major intersections.

- Light rail is a noise source on the eastern boundary of the proposed alignment. It includes train bells when trains approach and leave the existing Dunlap station, crossing bells on 19th Ave, and vehicle noise from the existing park-and-ride lot.

The existing ambient noise levels along the project corridor were documented through a series of noise measurements performed at a number of representative sensitive receivers. In 2016, noise measurements were performed by ATS at four long-term sites for a period of 24 hours and at two short-term sites for a period of 1 hour. More detailed measurement information is in Appendix E.

There was heavy rain and thunder during the afternoon rush hours of two of the long term noise measurements. Thunderstorms increase the noise level and are not representative of normal conditions. Similarly, wet pavement can result in elevated noise levels. Additional short term measurements were taken the following day during the same time period to amend these long term measurements. The one-hour long measurements, taken during peak rush hour traffic, compensated for the thunderstorms and served as an upper noise limit for any wet pavement effects in the following hours.

The results of the noise measurements are summarized in Table 8. Details on noise metrics used in this section and Appendix E can be found in Appendix A. Site labels for noise include a prefix that varies based on the duration of the measurement (LT = long term, ST = short term). Sites with a 24-hour measurement show sound levels for both the
Ldn and Leq peak hour metrics, since these sites can represent both residential and institutional sensitive receivers in the area. The details of each measurement site follow. Note that the levels shown in the table have been normalized to a distance of 25 feet from the center of the near traffic lane except where noted; the levels shown in the site descriptions below have not been normalized and are the actual measured sound levels.

**LT-1: Royal Palm Mobile Homes**

This long-term measurement was performed at the southwest corner of the Royal Palm Mobile Home community at 2050 W Dunlap Avenue, west of C Street. The primary noise source was vehicular traffic on Dunlap Avenue. Secondary noise sources include the crossing gate on 19th Avenue. The microphone was 35 feet from the near lane of Dunlap Avenue. The measured 24-hour Ldn was 72.5 dBA and the peak hour Leq was 74.2 dBA.

An additional measurement was taken at this site due to a thunderstorm during the 24-hour measurement. The thunderstorm occurred during the afternoon rush hour when we would expect high levels of traffic noise. The measured 1-hour Leq was 70.1 dBA. Due to this, the weather adjusted 24-hour Ldn was 72.3 dBA, a reduction of 0.2 dBA. The weather adjusted peak hour Leq was 70.1 dBA, a reduction of 4.1 dBA.

**LT-2: Crossland Economy Studios**

This long-term measurement was performed at the southwest corner of Crossland Economy Studios west on 2102 W Dunlap Avenue. The primary noise source was vehicular traffic on Dunlap Avenue. The microphone was 45 feet from the near lane of Dunlap Avenue. The measured 24-hour Ldn was 71.9 dBA and the peak hour Leq was 69.3 dBA.

An additional measurement was taken at this site due to a thunderstorm. The bad weather occurred during the afternoon rush hour when we would expect high levels of traffic noise. The measured 1-hour Leq was 68.3 dBA. The weather adjusted 24-hour Ldn was 71.7 dBA, a reduction of 0.2 dBA. The weather adjusted peak hour Leq remained 69.3 dBA.

**LT-3: Acclaim Apartments**

This long-term measurement was performed on the east side of the Acclaim Apartment complex on 2506 W Dunlap Avenue. The primary noise source was vehicular traffic on 25th Avenue. Secondary noise sources include vehicular traffic on Dunlap Avenue. The microphone was 35 feet from the near lane of Dunlap Avenue. The measured 24-hour Ldn was 65.7 dBA and the peak hour Leq was 66.5 dBA.

**LT-4: Courtyard Marriott – Phoenix North**

This long-term measurement was performed at the northwest corner of the Courtyard Marriott on 9631 N Black Canyon Hwy. The primary noise source was vehicular traffic on I-17. Secondary noise sources include vehicular traffic on the Black Canyon Hwy frontage road. The microphone was 70 feet from the near lane of I-17. The measured 24-hour Ldn was 75.0 dBA and the peak hour Leq was 73.3 dBA.

**ST-1: Argosy University**

This short-term measurement was performed on the north side of Argosy University, 2233 W Dunlap Avenue. The primary noise source was vehicular traffic on Dunlap
Avenue. Secondary noise sources include vehicular traffic on 23rd Avenue. The microphone was 80 feet from the near lane of Dunlap Avenue. The measured 1-hour Leq was 66.7 dBA.

**ST-2: Ottawa University**

This short-term measurement was performed on the east side of Ottawa University, 9414 North 25th Avenue. The primary noise source was vehicular traffic on 25th Avenue. Secondary noise sources include dogs at the dog park across 25th Avenue. The microphone was 50 feet from the near lane of 25th Avenue. The measured 1-hour Leq was 63.7 dBA.

### TABLE 8: SUMMARY OF EXISTING NOISE MEASUREMENTS

<table>
<thead>
<tr>
<th>Site</th>
<th>Location</th>
<th>Date</th>
<th>Dur.</th>
<th>Start Time</th>
<th>Dist. from Near Lane of Adjacent Street, ft&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Peak Hour Leq at 25 ft&lt;sup&gt;c&lt;/sup&gt;, dBA</th>
<th>Ldn at 25 ft&lt;sup&gt;c&lt;/sup&gt;, dBA</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT-1</td>
<td>Royal Palms Mobile Homes</td>
<td>8/2/16</td>
<td>24-hr</td>
<td>9:00 a.m.</td>
<td>35</td>
<td>75.7</td>
<td>73.9</td>
</tr>
<tr>
<td>LT-1&lt;sup&gt;d&lt;/sup&gt;</td>
<td></td>
<td>8/3/16</td>
<td>1-hr</td>
<td>5:00 p.m.</td>
<td>35</td>
<td>71.6</td>
<td>—</td>
</tr>
<tr>
<td>LT-1&lt;sup&gt;e&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>35</td>
<td>71.6</td>
<td>73.7</td>
</tr>
<tr>
<td>LT-2</td>
<td>Crossland Economy Studios</td>
<td>8/2/16</td>
<td>24-hr</td>
<td>9:00 a.m.</td>
<td>45</td>
<td>71.8</td>
<td>74.4</td>
</tr>
<tr>
<td>LT-2&lt;sup&gt;de&lt;/sup&gt;</td>
<td></td>
<td>8/3/16</td>
<td>1-hr</td>
<td>5:00 p.m.</td>
<td>45</td>
<td>70.9</td>
<td>—</td>
</tr>
<tr>
<td>LT-2&lt;sup&gt;e&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>45</td>
<td>71.8</td>
<td>74.3</td>
</tr>
<tr>
<td>LT-3</td>
<td>Acclaim Apartments</td>
<td>8/3/16</td>
<td>24-hr</td>
<td>11:00 a.m.</td>
<td>35</td>
<td>68.0</td>
<td>67.2</td>
</tr>
<tr>
<td>LT-4</td>
<td>Courtyard Marriott</td>
<td>8/3/16</td>
<td>24-hr</td>
<td>10:00 a.m.</td>
<td>70</td>
<td>77.8</td>
<td>79.5</td>
</tr>
<tr>
<td>ST-1</td>
<td>Argosy University</td>
<td>8/2/16</td>
<td>1-hr</td>
<td>7:03 a.m.</td>
<td>80</td>
<td>71.8</td>
<td>—</td>
</tr>
<tr>
<td>ST-2</td>
<td>Ottawa University</td>
<td>8/3/16</td>
<td>1-hr</td>
<td>7:00 a.m.</td>
<td>50</td>
<td>69.8</td>
<td>—</td>
</tr>
</tbody>
</table>

Source: ATS Consulting, 2016 data

<sup>a</sup> Duration of measurement.

<sup>b</sup> The distance of the microphone from the centerline of nearest lane of Dunlap Avenue, 25th Avenue or I-17.

<sup>c</sup> Leq and Ldn levels obtained from noise measurements have been normalized to 25 feet, using the correction factor: +10*LOG10(Dist_from_Near_Lane/25).

<sup>d</sup> An additional short term measurement was taken at this site to correct for bad weather.

<sup>e</sup> This is the weather adjusted noise levels for this site. For more information on the weather adjustment, see Appendix E.

### 4.2 EXISTING CONDITIONS – VIBRATION

The potential adverse effects of light rail groundborne vibration include perceptible building vibration, rattle noises, reradiated noise (groundborne noise) and cosmetic or structural damage to buildings. Existing vibration sources in the project corridor primarily consist of vehicular traffic. Secondary sources on the eastern end of the alignment include light rail operations. When vehicular traffic causes perceptible vibration, the source is usually traced to potholes, wide expansion joints or other “bumps” in the roadway surface.

The FTA assessment procedures for vibration from rail transit projects do not require measurements of existing vibration levels. The criteria for vibration impact are independent of existing vibration levels.
The project area primary source of traffic vibration is vehicles (including buses) on Dunlap Avenue, 25th Avenue, Mountain View Road, and I-17, including major intersections.

The test locations are described below and can be seen graphically in relation to sensitive receivers in Appendix F. Short-term vibration measurements were taken at the short-term noise measurement sites (see Appendix D). Short-term vibration measurements were also taken at the vibration propagation sites (see Appendix D). The results of the existing vibration measurements are summarized in Table 9, showing the energy-average vibration levels for each site at the sensor locations. The details of each measurement site are below:

**ST-1: Argosy University**

This short-term measurement was performed on the north side of Argosy University. The primary vibration source was vehicular traffic on Dunlap Avenue. Secondary vibration sources include vehicular traffic on 23rd Avenue. The accelerometer was 80 feet from the near lane of Dunlap Avenue. The measured 1-hour Leq was 56.6 VdB.

### TABLE 9: SUMMARY OF EXISTING VIBRATION MEASUREMENTS

<table>
<thead>
<tr>
<th>Site</th>
<th>Location</th>
<th>Date</th>
<th>Dur.(^a)</th>
<th>Start Time, hh:mm</th>
<th>Dist. from Near Lane of Adjacent Street, (ft^b)</th>
<th>Vibration at Sensor, VdB</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST-1</td>
<td>Argosy University</td>
<td>8/2/16</td>
<td>1 hour</td>
<td>7:03 am</td>
<td>80</td>
<td>56.6</td>
</tr>
<tr>
<td>ST-2</td>
<td>Ottawa University</td>
<td>8/3/16</td>
<td>1 hour</td>
<td>7:00 am</td>
<td>50</td>
<td>52.5</td>
</tr>
<tr>
<td>V-1</td>
<td>DeVry University</td>
<td>8/1/16</td>
<td>10 min</td>
<td>7:19 pm</td>
<td>35</td>
<td>52.3</td>
</tr>
<tr>
<td>V-1</td>
<td>DeVry University</td>
<td>8/1/16</td>
<td>10 min</td>
<td>7:19 pm</td>
<td>47.5</td>
<td>53.7</td>
</tr>
<tr>
<td>V-1</td>
<td>DeVry University</td>
<td>8/1/16</td>
<td>10 min</td>
<td>7:19 pm</td>
<td>63</td>
<td>53.2</td>
</tr>
<tr>
<td>V-1</td>
<td>DeVry University</td>
<td>8/1/16</td>
<td>10 min</td>
<td>7:19 pm</td>
<td>85</td>
<td>52.9</td>
</tr>
<tr>
<td>V-1</td>
<td>DeVry University</td>
<td>8/1/16</td>
<td>10 min</td>
<td>7:19 pm</td>
<td>120</td>
<td>50.7</td>
</tr>
<tr>
<td>V-1</td>
<td>DeVry University</td>
<td>8/1/16</td>
<td>10 min</td>
<td>7:19 pm</td>
<td>160</td>
<td>49.3</td>
</tr>
<tr>
<td>V-2</td>
<td>Atrium Court Apartments</td>
<td>8/3/16</td>
<td>10 min</td>
<td>7:09 pm</td>
<td>32</td>
<td>55.9</td>
</tr>
<tr>
<td>V-2</td>
<td>Atrium Court Apartments</td>
<td>8/3/16</td>
<td>10 min</td>
<td>7:09 pm</td>
<td>57</td>
<td>53.1</td>
</tr>
<tr>
<td>V-2</td>
<td>Atrium Court Apartments</td>
<td>8/3/16</td>
<td>10 min</td>
<td>7:09 pm</td>
<td>82</td>
<td>49.1</td>
</tr>
<tr>
<td>V-2</td>
<td>Atrium Court Apartments</td>
<td>8/3/16</td>
<td>10 min</td>
<td>7:09 pm</td>
<td>107</td>
<td>48.9</td>
</tr>
<tr>
<td>V-2</td>
<td>Atrium Court Apartments</td>
<td>8/3/16</td>
<td>10 min</td>
<td>7:09 pm</td>
<td>157</td>
<td>47.7</td>
</tr>
<tr>
<td>V-3</td>
<td>Courtyard Marriott</td>
<td>8/4/16</td>
<td>10 min</td>
<td>7:05 pm</td>
<td>37</td>
<td>46.9</td>
</tr>
<tr>
<td>V-3</td>
<td>Courtyard Marriott</td>
<td>8/4/16</td>
<td>10 min</td>
<td>7:05 am</td>
<td>49.5</td>
<td>46.2</td>
</tr>
<tr>
<td>V-3</td>
<td>Courtyard Marriott</td>
<td>8/4/16</td>
<td>10 min</td>
<td>7:05 am</td>
<td>62</td>
<td>44.9</td>
</tr>
<tr>
<td>V-3</td>
<td>Courtyard Marriott</td>
<td>8/4/16</td>
<td>10 min</td>
<td>7:05 am</td>
<td>87</td>
<td>43.6</td>
</tr>
<tr>
<td>V-3</td>
<td>Courtyard Marriott</td>
<td>8/4/16</td>
<td>10 min</td>
<td>7:05 am</td>
<td>112</td>
<td>42.9</td>
</tr>
<tr>
<td>V-3</td>
<td>Courtyard Marriott</td>
<td>8/4/16</td>
<td>10 min</td>
<td>7:05 am</td>
<td>152</td>
<td>41.1</td>
</tr>
</tbody>
</table>

Source: ATS Consulting, 2016 data

\(^a\) Duration of measurement.

\(^b\) The distance of the accelerometer from the centerline of nearest lane of Dunlap Avenue and Mountain View Road.
ST-2: Ottawa University
This short-term measurement was performed on the east side of Ottawa University. The primary vibration source was vehicular traffic on 25th Avenue. Secondary vibration sources include dogs at the dog park across 25th Avenue. The accelerometer was 50 feet from the near lane of 25th Avenue. The measured 1-hour Leq was 52.5 VdB.

V-1: DeVry University
This site was also used for vibration propagation testing. See Section 3.4.2 for a detailed site description. Existing vibration levels ranged from 49 to 54 VdB, depending on distance from the road.

V-2: Atrium Court Apartments
This site, at 2323 W Dunlap Avenue, was also used for vibration propagation testing. See Section 3.4.2 for a detailed site description. Existing vibration levels ranged from 47 to 56 VdB, depending on distance from the road.

V-3: Courtyard Marriott Phoenix North
This site was also used for vibration propagation testing. See Section 3.4.2 for a detailed site description. Existing vibration levels ranged from 41 to 47 VdB, depending on distance from the road.

5.0 POTENTIAL OPERATIONAL NOISE AND VIBRATION IMPACTS AND MITIGATION

This section describes the components of light rail operations that contribute to noise and vibration. Noise and vibration predictions for each receiver are given and impacts are identified. Suggestions for mitigating noise and vibration impacts are also given.

5.1 LIGHT RAIL RELATED NOISE

Noise from light rail operations may be caused by several parts of the rail infrastructure. This includes noise from the vehicles themselves, as well as noise from crossing gate bells and from support equipment, such as TPSS units. Noise may also be caused by changes in behavior to traffic or bus patterns.

5.1.1 Operational Noise
The noise-sensitive land uses for FTA Categories 2 and 3 along the Build Alternative alignment have been separated into clusters (note there are no Category 1 land uses). Each cluster includes similar land uses that are about the same distance from the tracks and have similar train speeds and other operational parameters past each receiver in the cluster. Individual properties may have multiple clusters on them, for example, receivers at Royal Palm Mobile Home Park are broken into five clusters by row and proximity to existing station. Additionally, not every receiver within the mobile home park is included in one of these clusters, only the receivers within the screening distance. The locations of the clusters and buildings included in each cluster are shown in Figure 10, and also in Appendix F. The noise predictions are based on the sensitive receiver within each cluster that is closest to the tracks.
Table 10 presents the predicted noise levels from train operations for Category 2 land use clusters, and Table 11 presents the predictions for Category 3 land use clusters. Category 2 land uses include residences and hotels. Category 3 land uses include schools, medical facilities, and a conference center.

The columns in the tables provide the following information:

- **ID**: Identification for sensitive receiver cluster. The location of each sensitive receiver cluster is presented in the maps in Appendix F.
- **Desc.**: Describes the type of land use or name of the receiver.
- **Near Track Dist.**: Distance in feet from the near track centerline to the closest part of the noise-sensitive building or group of buildings.
- **Speed**: Maximum expected train speed on the track closest to the sensitive receiver. The speeds were based on the maximum projected speed for each section of the alignment. The actual train speeds would often be lower near train stations and signal stops.
- **Exist. Noise Site**: Indicates which noise measurement site was used to represent the existing noise.
- **Existing**: Estimated existing noise level (Ldn for Category 2, Leq for Category 3) at each sensitive receiver cluster based on the existing noise measurement results.
- **Project**: Predicted future Ldn or Leq or from train noise, including special trackwork and TPSS units. The noise predictions include bell noise from the trains at stations and stoplights and crossing gate bell noise. For each noise source, receivers out to a distance of 350 feet were evaluated; if there was an obstruction in the sound path from the noise source to the receiver (for example, a row of homes), the screening distance for bell noise was 175 feet.
- **Impact Threshold**: The FTA impact thresholds for moderate and severe impact are based on the existing noise levels.
- **Number of Impacts**: The number of dwelling units within each cluster of sensitive receivers where the predicted levels of light rail noise meet or exceed the Moderate (Mod.) and Severe impact thresholds. Note that the number of units are those estimated to be facing, or exposed to, the noise from train operations.

As indicated in Sections 1.2 and 3.2, LRVs have the potential to generate wheel squeal on the curves. There are revenue service train movements through low-radius curves at the Dunlap Ave/25th Avenue intersection, the Mountain View Rd/25th Avenue intersection, and on the aerial structure south of the Metrocenter station. This noise element is not included in the noise impact analysis since all existing vehicles are equipped and all new vehicles would be equipped with friction control devices that would be used near sensitive receivers.

Following is a summary of the noise impact assessment of the proposed Build Alternative (the causes of impacts and recommended mitigation are described for each receiver in Section 5.3):
Several moderate impacts are predicted from light rail operations at Category 2 land uses (residential or other sensitive receivers with both daytime and nighttime use, for example, residences, hotels, motels) as shown in Table 10. The moderate impacts occur at two sensitive receiver clusters that consist of 74 residential units. Cluster NB-08 includes 24 units at the San Valiente Apartments. A total of 50 units would be impacted at the Acclaim Apartments, Cluster SB-09. Receivers are shown in Figure 10 and also in Appendix F.

- NB-08, San Valiente Apartments, is located near special trackwork and crossing gate bells. The impact is less than 1 dB above the moderate impact threshold.
- SB-09, Acclaim Apartments has an impact of less than 1 dB above the moderate impact threshold. The noise at this cluster is influenced by train bells sounded at the nearby station.
- No noise impacts are predicted from light rail operations at Category 3 land uses (institutional with primarily daytime use), as shown in Table 11.
### TABLE 10: SUMMARY OF NOISE IMPACT ASSESSMENT FOR CATEGORY 2

<table>
<thead>
<tr>
<th>ID*</th>
<th>Desc. b</th>
<th>Near Track Dist. (ft)</th>
<th>Sensitive Receiver Location</th>
<th>Speed (mph)</th>
<th>Exist. Noise Site</th>
<th>Ldn(^c) (dBA)</th>
<th>Impact Threshold</th>
<th># of Impacts(^d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB-01</td>
<td>SFR</td>
<td>153</td>
<td>Royal Palm Mobile Home Park</td>
<td>35</td>
<td>LT-1</td>
<td>71</td>
<td>61(^{TB})</td>
<td>—</td>
</tr>
<tr>
<td>NB-02</td>
<td>SFR</td>
<td>250</td>
<td>Royal Palm Mobile Home Park</td>
<td>35</td>
<td>LT-1</td>
<td>63</td>
<td>51</td>
<td>60</td>
</tr>
<tr>
<td>NB-03</td>
<td>SFR</td>
<td>162</td>
<td>Royal Palm Mobile Home Park</td>
<td>35</td>
<td>LT-1</td>
<td>67</td>
<td>60(^{CB, TB})</td>
<td>62</td>
</tr>
<tr>
<td>NB-04</td>
<td>SFR</td>
<td>262</td>
<td>Royal Palm Mobile Home Park</td>
<td>35</td>
<td>LT-1</td>
<td>59</td>
<td>49</td>
<td>57</td>
</tr>
<tr>
<td>NB-05</td>
<td>SFR</td>
<td>374</td>
<td>Royal Palm Mobile Home Park</td>
<td>35</td>
<td>LT-1</td>
<td>56</td>
<td>46</td>
<td>56</td>
</tr>
<tr>
<td>NB-06</td>
<td>HT</td>
<td>113</td>
<td>Crossland Economy Studios</td>
<td>35</td>
<td>LT-1</td>
<td>69</td>
<td>63(^{X, CB, TB})</td>
<td>63</td>
</tr>
<tr>
<td>NB-07</td>
<td>HT</td>
<td>341</td>
<td>Crossland Economy Studios</td>
<td>35</td>
<td>LT-2</td>
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<td>NB-08</td>
<td>MFR</td>
<td>77</td>
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<td>35</td>
<td>LT-2</td>
<td>71</td>
<td>66(^{X, CB})</td>
<td>65</td>
</tr>
<tr>
<td>NB-09</td>
<td>MFR</td>
<td>228</td>
<td>San Valiente Apartments</td>
<td>35</td>
<td>LT-2</td>
<td>60</td>
<td>52(^{X})</td>
<td>58</td>
</tr>
<tr>
<td>SB-01</td>
<td>MFR</td>
<td>285</td>
<td>8902 N 19th Avenue</td>
<td>35</td>
<td>LT-1</td>
<td>57</td>
<td>49</td>
<td>56</td>
</tr>
<tr>
<td>SB-02</td>
<td>MFR</td>
<td>127</td>
<td>Atrium Courts Apartments</td>
<td>35</td>
<td>ST-1</td>
<td>68</td>
<td>60(^{TB})</td>
<td>63</td>
</tr>
<tr>
<td>SB-03</td>
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<td>ST-1</td>
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<td>62(^{TB})</td>
<td>63</td>
</tr>
<tr>
<td>SB-04</td>
<td>MFR</td>
<td>275</td>
<td>Atrium Courts Apartments</td>
<td>35</td>
<td>ST-1</td>
<td>63</td>
<td>51</td>
<td>60</td>
</tr>
<tr>
<td>SB-05</td>
<td>MFR</td>
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<td>MFR</td>
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<td>60</td>
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<td>147</td>
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<td>LT-3</td>
<td>61</td>
<td>59(^{TB})</td>
<td>58</td>
</tr>
</tbody>
</table>

\(^{a}\) ID: Identification number for each location.

\(^{b}\) Desc.: Description of sensitive receiver location.

\(^{c}\) Ldn: Lane-averaged daily noise level.

\(^{d}\) # of Impacts: Number of impacts exceeding the threshold.
<table>
<thead>
<tr>
<th>ID</th>
<th>Desc.</th>
<th>Near Track Dist. (ft)</th>
<th>Sensitive Receiver Location</th>
<th>Speed (mph)</th>
<th>Existing Noise Site</th>
<th>Ldn&lt;sup&gt;c&lt;/sup&gt; (dBA)</th>
<th>Impact Threshold</th>
<th># of Impacts&lt;sup&gt;d&lt;/sup&gt;</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SB-10</td>
<td>MFR</td>
<td>85</td>
<td>Acclaim Apartments</td>
<td>35</td>
<td>LT-3</td>
<td>64</td>
<td>61&lt;sup&gt;TB&lt;/sup&gt;</td>
<td>60</td>
<td>66</td>
</tr>
<tr>
<td>SB-11</td>
<td>HT</td>
<td>222</td>
<td>Courtyard Phoenix North</td>
<td>15</td>
<td>LT-4</td>
<td>71</td>
<td>60&lt;sup&gt;X&lt;/sup&gt;</td>
<td>65</td>
<td>70</td>
</tr>
</tbody>
</table>

<sup>a</sup> ID identifies sensitive receivers as shown in the maps in Figure 10 and Appendix F. NB = northbound side, SB = southbound side.

<sup>b</sup> SFR = single-family residence, MFR = multifamily residence, HT=hotel.

<sup>c</sup> Rounded to nearest whole number in accordance with FTA guidance.

<sup>X</sup>: Includes special trackwork (standard crossover) noise.

CB: Includes crossing gate bell noise.  TB: Includes train bell noise at stoplights or train stations.  TPSS: Includes TPSS unit noise.

<sup>d</sup> Number of Impacts. This is a count of the number of properties/units represented for each potentially impacted sensitive receiver cluster.
TABLE 11: SUMMARY OF NOISE IMPACT ASSESSMENT FOR CATEGORY 3

<table>
<thead>
<tr>
<th>ID</th>
<th>Desc.</th>
<th>Near Track Dist. (ft)</th>
<th>Sensitive Receiver Location</th>
<th>Speed (mph)</th>
<th>Exist. Noise Site</th>
<th>Leq&lt;sup&gt;c&lt;/sup&gt; (dBA)</th>
<th>Impact Threshold</th>
<th># of Impacts&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Existing</td>
<td>Project</td>
<td>Mod.</td>
</tr>
<tr>
<td>SB-A</td>
<td>SC</td>
<td>405</td>
<td>DeVry University</td>
<td>35</td>
<td>LT-1</td>
<td>60</td>
<td>48</td>
<td>63</td>
</tr>
<tr>
<td>SB-B</td>
<td>SC</td>
<td>115</td>
<td>Argosy University / Art Institute</td>
<td>35</td>
<td>ST-1</td>
<td>66</td>
<td>55&lt;sup&gt;TB&lt;/sup&gt;</td>
<td>66</td>
</tr>
<tr>
<td>SB-C</td>
<td>MD</td>
<td>71</td>
<td>NHW Community Health Center</td>
<td>25</td>
<td>ST-1</td>
<td>69</td>
<td>56&lt;sup&gt;TB&lt;/sup&gt;</td>
<td>69</td>
</tr>
<tr>
<td>SB-D</td>
<td>SC</td>
<td>139</td>
<td>Ottawa University</td>
<td>35</td>
<td>ST-2</td>
<td>64</td>
<td>57&lt;sup&gt;TB&lt;/sup&gt;</td>
<td>65</td>
</tr>
<tr>
<td>SB-E</td>
<td>MD</td>
<td>199</td>
<td>VA Health Clinic</td>
<td>35</td>
<td>ST-2</td>
<td>61</td>
<td>56&lt;sup&gt;TB&lt;/sup&gt;</td>
<td>64</td>
</tr>
<tr>
<td>SB-F</td>
<td>Conf Ctr</td>
<td>197</td>
<td>Black Canyon Conference Center</td>
<td>30</td>
<td>ST-2</td>
<td>62</td>
<td>56&lt;sup&gt;TB&lt;/sup&gt;</td>
<td>64</td>
</tr>
<tr>
<td>SB-G</td>
<td>SC</td>
<td>64</td>
<td>Sanford Brown College</td>
<td>25</td>
<td>ST-2</td>
<td>67</td>
<td>55&lt;sup&gt;TB,TPSS&lt;/sup&gt;</td>
<td>67</td>
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<td>SB-H</td>
<td>SC</td>
<td>84</td>
<td>College America</td>
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<td>LT-4</td>
<td>71</td>
<td>59&lt;sup&gt;X&lt;/sup&gt;</td>
<td>70</td>
</tr>
</tbody>
</table>

<sup>a</sup> ID identifies sensitive receivers as shown in the maps in Figure 10 and Appendix F. NB = northbound side, SB = southbound side.

<sup>b</sup> SC = school, MD = medical, Conf. Ctr = Conference Center

<sup>c</sup> Maximum 1-hour Leq during daytime when facility is in use. Rounded to nearest whole number in accordance with FTA guidance.

<sup>x</sup> Includes special trackwork (standard crossover) noise.

TB: Includes train bell noise at stoplights or train stations. TPSS: Includes TPSS unit noise.

<sup>d</sup> Number of Impacts. This is a count of the number of properties/units represented for each potentially impacted sensitive receiver cluster.
FIGURE 10: OVERVIEW OF CLUSTERS
5.1.2 Ancillary Equipment

TPSS units are the only ancillary equipment associated with the proposed project with the potential to cause noise impacts. Three locations are being evaluated, and two will be selected. The locations of the TPSS units are shown in the receiver drawings in Appendix F. One of the selected sites is adjacent to at least one sensitive receiver being evaluated.

It is common to include noise limits in the purchase specifications for TPSS units to minimize the potential for noise impacts from TPSS noise. The specifications generally include maximum noise limits for potential noise generators, such as the transformer hum and any cooling systems. The cooling fans are the major noise source on many modern TPSS units, and the transformer hum is usually inaudible except when very close to the receiver.

The first step in controlling TPSS noise is to include a noise limit in the purchase specifications for TPSS units. The recommended limit is that the maximum noise level not exceed 50 dBA at a distance of 50 feet from any part of a TPSS unit. In addition, the cooling fans should be oriented away from the nearest receiver to minimize the noise at the receiver.

In addition to evaluating the TPSS units as part of the project noise, they are also examined separately for nighttime noise at residential receivers. The typically adopted design goal for noise from TPSS units is at least 5 decibels lower than the nighttime ambient level. However, no residential receivers are within the screening distance (125 feet shielded, 250 feet unshielded) of any proposed TPSS unit. For this reason, nighttime TPSS noise is not an issue and this analysis is not needed.

5.1.3 Traffic Noise Due to Roadway and Traffic Changes

The Build Alternative involves some physical roadway changes, as described in Section 1.1. Note that there are no changes in bus service. Traffic volume differences between the Build and No-Build Alternatives are minor. The following roadway design modifications have the potential to change the noise environment and were, therefore, evaluated using FHWA’s TNM. The evaluation concluded that traffic noise is not an issue for this project, as discussed below:

- On Dunlap Avenue, there are three different modifications to the road as a result of the project: 1) between 25th Avenue and 24th Avenue, all lanes will shift south one half of a lane width; 2) from 24th Avenue to the existing Dunlap Station, all eastbound lanes will shift south one lane width and 3) from 24th Avenue to 22nd Avenue, westbound lanes shift north one lane width. Applying 2035 future traffic volumes and comparing the existing road geometry to a geometry with lane shifts applied, the analysis showed that there would be less than 0.5-dB influence, with some increases and some decreases in sound level. Given the minimal effect, the road changes are not included in project noise predictions.

- On 25th Avenue north of the canal, the southbound lane will shift west one lane width as a result of the project. Future traffic volumes were unavailable and, as with Dunlap Avenue, the differences between the Build and No-Build cases are expected
to be minor. The analysis was done with existing traffic volumes, comparing the existing road geometry to a geometry with the lane shift applied. The analysis showed that there would be negligible influence on the noise levels. Given the negligible effect, the road changes are not included in project noise predictions.

The other modifications would not result in a potential noise increase or are not near any sensitive receivers, so evaluations are not warranted.

5.1.4 Park-and-Ride Facilities

The park-and-ride lots to be used for the project consist of one proposed in the Dillard’s parking lot (near the Metrocenter station) and one proposed along 25th Avenue (near the proposed Mountain View Rd/25th Avenue station).

Parking spaces in the existing Metrocenter lot across North Metro Parkway from the Metrocenter station would be allocated for LRT and bus users. There are no sensitive receivers within the screening distance of 125 feet from the parking structure. Therefore, no further consideration is warranted.

Approximately 146 spaces will be added to the existing parking lot along 25th Avenue at Rose Mofford Sports Complex. Recreational users would be able to use all the existing and additional spaces. A parking area within the lot will be designated for both light rail and recreational users. There are no sensitive receivers within the screening distance of 125 feet from the parking lot. Therefore, no further consideration is warranted.

An additional 33 spaces will be added to the south end of the existing parking lot along 25th Avenue at Rose Mofford Dog Park. Recreational users would be able to use all the existing and additional spaces. A parking area within the lot will be designated for both light rail and recreational users. There are no sensitive receivers within the screening distance of 125 feet from the parking lot. Therefore, no further consideration is warranted.

5.2 LIGHT RAIL OPERATIONAL VIBRATION

As discussed in Section 2.3, the FTA Guidance Manual provides two criteria for assessing vibration impacts. The first criterion is based on the overall vibration velocity level and is intended for use with a General Assessment. The second FTA criterion is based on the maximum 1/3 octave band spectrum of the predicted vibration. FTA indicates that the second criterion is intended for use with a Detailed Assessment when vibration propagation testing has been performed and the predictions include the vibration spectrum. All groundborne vibration and groundborne noise impacts are defined in the interior of occupied spaces. There are no criteria defined for exterior spaces, such as parks and residential yards. Criteria are defined based on human response and are not used to assess potential building damage, which is discussed in Section 6.3.

As discussed in Section 3.4.2, vibration propagation tests were performed at three locations in the project corridor and were used as the basis for the vibration prediction model. Therefore, it is appropriate to apply the Detailed Assessment criteria to more accurately identify potential vibration impacts.
The key thresholds applicable to the Northwest Extension Phase II Light Rail Project are a maximum vibration level of 72 VdB for Category 2 (residential) land uses and 78 VdB for Category 3 (institutional) land uses. The thresholds apply to 1/3 octave frequencies in the range of 8 to 80 Hz. This means that for residential land uses, an impact would occur if any 1/3 octave band level between 8 and 80 Hz is predicted to exceed 72 VdB. (Note that no vibration Category 1 properties exist along the corridor, which would include vibration-sensitive research and manufacturing, hospitals with vibration-sensitive equipment and university research operations.)

Limits are also set by FTA for maximum groundborne noise: 35 dBA for Category 2 and 40 dBA for Category 3. Groundborne noise radiates off the structure and is caused directly by groundborne vibration. However, in most cases, the airborne noise from at-grade LRV traffic dominates the noise source. In these cases, the groundborne noise is best compared to predicted airborne noise or existing noise.

The vibration predictions are presented in Table 12 and Table 13 for Category 2 and Category 3 land uses, respectively. The data presented in the tables include:

- **ID**: Identification number. The location of each sensitive receiver cluster is presented in the maps in Appendix F.
- **Desc.**: Describes the type of land use or name of the receiver.
- **Near Track Dist.**: Distance in feet from the near track centerline to the facade of the closest vibration-sensitive building.
- **Groundborne Vibration**: The predicted level of light rail vibration in VdB. These predictions are a single value representing the maximum level in a single 1/3 octave band. This value is compared to the FTA Detailed Assessment criteria to determine impact.
- **Groundborne Noise**: Predicted groundborne noise in dBA based on overall vibration level.
- **GBN Limit**: Receiver-specific limit for groundborne noise, in dBA. This limit is based on the FTA limits except where noted. Where noted, the limit is based on the predicted indoor noise level from train operations or the existing noise level, as indicated. Groundborne noise impact is defined if the groundborne noise exceeds the airborne noise indoors.
- **GBV Impact**: Indicates “Y” for yes as to whether the predicted levels exceed the applicable Detailed Assessment criterion curve, based on maximum vibration levels compared to 72 VdB (Category 2) or 78 VdB (Category 3) limits.
- **GBN Impact**: Indicates “Y” for yes as to whether the predicted levels exceed the applicable limit set for each receiver. The limit for each receiver is given in column “GBN Limit.”
As shown in Table 12, vibration impact is predicted at a single Category 2 (residential) sensitive receiver. This receiver is within 80 ft of a crossover:

- NB-09 San Valiente Apartments

As shown in Table 13, no groundborne vibration and noise impacts are predicted at Category 3 (institutional) sensitive receivers.
### TABLE 12: SUMMARY OF VIBRATION IMPACT ASSESSMENT FOR CATEGORY 2

<table>
<thead>
<tr>
<th>ID</th>
<th>Desc.</th>
<th>Near Track Dist. (ft)</th>
<th>Sensitive Receiver Location</th>
<th>Speed (mph)</th>
<th>Groundborne Vibration(^{c,d}) (VdB)</th>
<th>Groundborne Noise(^d) (dBA)</th>
<th>GBN Criteria(^d) (dBA)</th>
<th>GBV Impact(^i)</th>
<th>GBN Impact(^i)</th>
</tr>
</thead>
<tbody>
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<td>NB-01</td>
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</tr>
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<td>69</td>
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<td>33(^h)</td>
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<td>MFR</td>
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<td>MFR</td>
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### TABLE 12: SUMMARY OF VIBRATION IMPACT ASSESSMENT FOR CATEGORY 2

<table>
<thead>
<tr>
<th>ID</th>
<th>Desc.</th>
<th>Near Track Dist. (ft)</th>
<th>Sensitive Receiver Location</th>
<th>Speed (mph)</th>
<th>Groundborne Vibration&lt;sup&gt;c,d&lt;/sup&gt; (VdB)</th>
<th>Groundborne Noise&lt;sup&gt;d&lt;/sup&gt; (dBA)</th>
<th>GBN Criteria&lt;sup&gt;d&lt;/sup&gt; (dBA)</th>
<th>GBV Impact&lt;sup&gt;i&lt;/sup&gt;</th>
<th>GBN Impact&lt;sup&gt;i&lt;/sup&gt;</th>
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<tbody>
<tr>
<td>SB-10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>MFR</td>
<td>85</td>
<td>Acclaim Apartments</td>
<td>35</td>
<td>56</td>
<td>30</td>
<td>35</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>SB-11</td>
<td>HT</td>
<td>222</td>
<td>Courtyard Phoenix North</td>
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<td>1</td>
<td>35</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Note: Refer to Table F-1 in Appendix F for indications of special trackwork for each receiver; the special trackwork increases vibration levels.

<sup>a</sup>ID identifies sensitive receivers as shown in the maps in Appendix F. NB = northbound side, SB = southbound side.

<sup>b</sup>Desc. = Type of land use, SFR = single-family residence, MFR = multifamily residence, HT = hotel.

<sup>c</sup>Groundborne vibration is level in VdB of maximum 1/3 octave band, compared to 72 VdB. Groundborne vibration levels cannot exceed FTA impact thresholds of 72 vibration decibels (VdB) for residential and 78 VdB for institutional uses.

<sup>d</sup>Predictions and limits are shown to the nearest decibel.

<sup>e</sup>Dedicated lane 25th Avenue.

<sup>f</sup>Groundborne noise predictions and criteria for this receiver based on indoor noise levels using the Ldn metric; criteria based on existing noise.

<sup>g</sup>Groundborne noise predictions and criteria for this receiver based on indoor noise levels using the Ldn metric; criteria based on predicted noise from train operations.

<sup>i</sup>“Yes” indicates potential impact is identified, “—” means no potential impact is identified.
TABLE 13: SUMMARY OF VIBRATION IMPACT ASSESSMENT FOR CATEGORY 3

<table>
<thead>
<tr>
<th>ID</th>
<th>Desc.</th>
<th>Near Track Dist. (ft)</th>
<th>Sensitive Receiver Location</th>
<th>Speed (mph)</th>
<th>Groundborne Vibration(^c,d) (VdB)</th>
<th>Groundborne Noise(^d) (dBA)</th>
<th>GBN Criteria(^d) (dBA)</th>
<th>GBV Impact</th>
<th>GBN Impact</th>
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</tr>
<tr>
<td>SB-B</td>
<td>SC</td>
<td>115</td>
<td>Argosy University / Art Institute</td>
<td>35</td>
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<td>26</td>
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<td>—</td>
</tr>
<tr>
<td>SB-C</td>
<td>MD</td>
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<td>67</td>
<td>19(^a)</td>
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<td>—</td>
<td>—</td>
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</tr>
<tr>
<td>SB-E</td>
<td>MD</td>
<td>199</td>
<td>VA Health Clinic</td>
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<td>61</td>
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<td>—</td>
</tr>
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<td>SB-F</td>
<td>Conf Ctr</td>
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<td>Black Canyon Conference Center</td>
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<td>28</td>
<td>40</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>SB-G</td>
<td>SC</td>
<td>64</td>
<td>Sanford Brown College</td>
<td>25</td>
<td>59</td>
<td>29</td>
<td>40</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>SB-H</td>
<td>SC</td>
<td>84</td>
<td>College America</td>
<td>15</td>
<td>59</td>
<td>28</td>
<td>40</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Note: Refer to Table F-1 in Appendix F for indications of special trackwork for each receiver; the special trackwork increases vibration levels.

\(^a\) ID identifies sensitive receivers as shown in the maps in Appendix F. NB = northbound side, SB = southbound side.

\(^b\) Desc. = Type of land use, SC = school, MD = medical, Conf. Ctr = conference center.

\(^c\) Groundborne vibration is level in VdB of maximum 1/3 octave band, compared to 78 VdB. Groundborne vibration levels cannot exceed FTA impact thresholds of 72 vibration decibels (VdB) for residential and 78 VdB for institutional uses.

\(^d\) Predictions and limits are shown to the nearest decibel.

\(^a\) Groundborne noise predictions and criteria for this receiver based on indoor noise levels using the Leq metric; criteria based on existing noise.
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5.3 OPERATIONAL NOISE MITIGATION

Table 14 summarizes predicted noise limit exceedances and mitigation recommendations for each potentially impacted sensitive receiver. Predicted impact exceedance is shown as the amount above a moderate impact level. There were no exceedances of the FTA severe impact level threshold. Also shown in the table is the cause of the impact. For the Northwest Phase II Light Rail Extension Project, no mitigation is recommended for noise impacts.

Mitigation is not recommended for exceedances less than 1 dB. The reasonableness of providing mitigation is a factor when considering mitigation. A less than 1 dB change in noise level with the project is negligible given that 3 dB is considered the threshold at which an average listener can detect change. This assumption is reasonable. In the case of train bells at stations causing the <1 dB exceedance, the primary purpose of the train bells is safety-related to warn people on or near the station platform that the train is either approaching or departing the station and to stay clear of the tracks and/or edge of the platform. The train bells are set at the lowest volume possible without compromising safety, so no mitigation is recommended. For all predictions and mitigation recommendations, it is assumed that the track and wheels would be maintained in a state of good repair (that is, rail corrugations and wheel flats would be minimized through maintenance procedures—rail grinding and wheel truing).

All noise levels are either below the moderate impact threshold or up to 1 dBA above it. Those 1 dBA impacts are due to train bells which are safety-related so no mitigation is recommended.

### TABLE 14: SUMMARY OF RECOMMENDED NOISE MITIGATION

<table>
<thead>
<tr>
<th>ID</th>
<th>Desc.</th>
<th>Sensitive Receiver Location</th>
<th>Impact Exceedance (dB)</th>
<th>Cause</th>
<th>Recommended Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB-08</td>
<td>MFR</td>
<td>San Valiente Apartments</td>
<td>&lt;1</td>
<td>Special trackwork</td>
<td>Low-impact frog recommended for vibration impact would fully mitigate this impact (for special trackwork by 22nd Ave); see Table 15</td>
</tr>
<tr>
<td>SB-09</td>
<td>MFR</td>
<td>Acclaim Apartments</td>
<td>&lt;1</td>
<td>Train bells at station</td>
<td>Mitigation not recommended. Ensure train bells are at lowest safe level</td>
</tr>
</tbody>
</table>

*a ID identifies sensitive receivers as shown in the maps in Appendix F. NB = northbound side, SB = southbound side.  
b MFR = Multi-family residence; HT=Hotel.  
c Moderate limit exceedance.

5.4 OPERATIONAL VIBRATION MITIGATION

A single impact due to groundborne vibration is predicted at cluster NB-08, San Valiente Apartments. Table 15 shows the predicted impacts to the Category 2 receiver and the recommended mitigation. No groundborne noise impacts are predicted.

At cluster NB-08, installation of low-impact frogs and low-vibration rail boot at the nearby track crossover is the recommended measure to mitigate vibration. The gaps in the rail associated with standard frogs can cause vibration levels to increase by up to 10 dBS. Low-impact frogs can reduce vibration levels by creating a smoother transition
through the gap in the rails at the special trackwork. Examples of low-impact frogs include monoblock frogs, flange-bearing frogs, moveable point frogs or spring rail frogs. Where possible, special trackwork may also be relocated farther away from the receiver. More information on low-impact frogs is included in Appendix G.

With implementation of only low-impact frogs, cluster NB-08 exceeds the vibration criteria by less than 1 dB. Use of a vibration isolating rail boot design would lower the predicted levels by at least 1-2 dB, below the threshold of 72 VdB. A vibration isolating rail boot uses thicker rubber than standard to provide vibration attenuation.

**TABLE 15: SUMMARY OF VIBRATION MITIGATION FOR SENSITIVE RECEIVER**

<table>
<thead>
<tr>
<th>ID</th>
<th>Desc.</th>
<th>Sensitive Receiver Location</th>
<th>GBV (VdB)</th>
<th>GBN (dBA)</th>
<th># of Units</th>
<th>Recommended Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB-08</td>
<td>MFR</td>
<td>San Valiente Apartments</td>
<td>72</td>
<td>76</td>
<td>&lt;72</td>
<td>36</td>
</tr>
</tbody>
</table>

---

6.0 POTENTIAL CONSTRUCTION NOISE AND VIBRATION

6.1 CONSTRUCTION NOISE

The use of heavy equipment during project construction has the potential to result in substantial, yet temporary, increases in local noise levels along the corridor. The FTA Guidance Manual recommends using local construction noise limits, if possible. For the City of Phoenix, the municipal code is interpreted as having no specific noise limits that apply. As a result, the construction noise for this project should be examined in terms of the FTA guidance (shown in Table 16) for evaluating the potential community response to construction noise. The guidelines are based on an average Leq over a typical 8-hour workday. The FTA recommended limit of 80 dBA for the daytime Leq has been used in this assessment as the threshold for impact for residential areas.
TABLE 16: CONSTRUCTION NOISE GUIDELINES

<table>
<thead>
<tr>
<th>Land Use</th>
<th>Noise Limit, 8-hour Leq (dBA)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daytime</td>
<td>Nighttime</td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>80</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Commercial</td>
<td>85</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>90</td>
<td>90</td>
<td></td>
</tr>
</tbody>
</table>

Source: Federal Transit Administration (2006)

Construction noise levels depend on the number of pieces and type of equipment, their general condition, the amount of time each piece operates per day, the presence or lack of noise-attenuating features such as walls and berms and the location of the construction activities relative to the sensitive receivers. The majority of these variables are left to the discretion of the construction contractor selected by Valley Metro as the project approaches the construction phase. Therefore, it is not possible to accurately estimate construction noise levels at this conceptual design stage of the project.

For a rough estimate of construction noise, the following describes a typical construction scenario. The construction of light rail track requires use of heavy earth-moving equipment, pneumatic tools, generators, concrete pumps and similar equipment. Table 17 shows the equipment likely to be used during the noisiest periods of track construction, the typical noise generated by this equipment, the usage factors and the estimated work-shift Leq. The combined work-shift Leq for the construction scenario shown in Table 17 is 84 dBA at a distance of 50 feet. Given that some residences along the corridor are close to 50 feet of the alignment, there is a possibility that the contractor would exceed the impact threshold of 80 dBA for the work-shift Leq, considering construction equipment will likely be closer than the alignment. This analysis shows that impacts are likely unless the contractor is required to implement noise control measures when working near residences.

TABLE 17: PREDICTED CONSTRUCTION NOISE AT 50 FEET

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Sound Level at 50 feet Under Load</th>
<th>Source Usage Factor (% Time Under Full Load)</th>
<th>Leq (8-hour Work Shift)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earthmover (bulldozer, front-end loader, etc.)</td>
<td>82 dBA</td>
<td>40%</td>
<td>78 dBA</td>
</tr>
<tr>
<td>Mobile crane</td>
<td>81 dBA</td>
<td>20%</td>
<td>74 dBA</td>
</tr>
<tr>
<td>Dump truck</td>
<td>76 dBA</td>
<td>40%</td>
<td>72 dBA</td>
</tr>
<tr>
<td>Pneumatic tools</td>
<td>85 dBA</td>
<td>30%</td>
<td>80 dBA</td>
</tr>
<tr>
<td>Generator</td>
<td>78 dBA</td>
<td>40%</td>
<td>74 dBA</td>
</tr>
<tr>
<td>Compressor</td>
<td>81 dBA</td>
<td>40%</td>
<td>77 dBA</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>84 dBA</strong></td>
</tr>
</tbody>
</table>
6.2 CONSTRUCTION NOISE MITIGATION

Listed below are some typical approaches to reducing noise levels associated with the construction phase of major projects. Requiring the contractor to employ these methods should leave the contractor with enough flexibility to perform the work without undue financial or logistical burdens while protecting adjacent noise-sensitive receivers from excessive construction noise levels.

- Avoid nighttime construction when possible. If nighttime construction is necessary, develop nighttime noise limits.
- Use specialty equipment with enclosed engines and/or high-performance mufflers.
- Locate equipment and staging areas as far from noise-sensitive receivers as possible.
- Limit unnecessary idling of equipment.
- Install temporary noise barriers. This approach can be particularly effective for stationary noise sources such as compressors and generators.
- Reroute construction-related truck traffic away from local residential streets.
- Avoid impact pile driving where possible. Where geological conditions permit, the use of drilled piles or a vibratory pile driver is generally quieter.

Specific measures to be employed to mitigate construction noise impacts should be developed by the contractor and presented in the form of a Noise Control Plan.

6.3 CONSTRUCTION VIBRATION

The primary concern regarding construction vibration is potential damage to structures. The thresholds for potential damage are much higher than the thresholds for evaluating potential annoyance used to assess impact from operational vibration. The FTA Guidance Manual limits for construction vibration for the various building categories, as defined in this table, are shown in Table 18. It is important to note that the vibration limits in Table 18 are the levels at which there is a risk for damage for each building category, not the level at which damage would occur. These limits should be viewed as criteria that should be used during the impact assessment phase to identify potential problem locations.

Predicted vibration levels for different pieces of construction equipment are shown in Table 19. At a distance of 50 feet from buildings, the predicted vibration level for all pieces of equipment is below the damage risk criteria for even those buildings most susceptible to damage. At a distance of 25 feet, the vibration level from a vibratory roller is predicted to exceed the damage criteria for Building Categories III and IV. As mentioned, the criteria levels indicate where there is a risk for damage—not that actual damage would occur.

Vibration generated from the vibratory roller could result in an adverse effect if it is operated within 25 feet of nonengineered timber or masonry buildings. In the event that other vibration-generating equipment must be used for a sustained period of time closer
than 25 feet to sensitive receivers, the Construction Management Plan should also include measures to minimize those potential vibration impacts during construction.

An examination was done to determine if there were any historic structures along the project area that may be susceptible to damage. A structure eligible for historic listing is the Souper Salad building in Metrocenter. This building was constructed in the 1970s and is unlikely to be considered a fragile structure. The property of the Royal Palm Mobile Home Park is also eligible to be listed as historic; there are no buildings that would likely be considered fragile on this property. There are no other properties along the alignment where buildings are expected to be considered to be fragile.

**TABLE 18: CONSTRUCTION VIBRATION DAMAGE RISK CRITERIA**

<table>
<thead>
<tr>
<th>Building Category</th>
<th>Peak Particle Velocity (inches/second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Reinforced-concrete, steel or timber (no plaster)</td>
<td>0.5</td>
</tr>
<tr>
<td>II. Engineered concrete and masonry (no plaster)</td>
<td>0.3</td>
</tr>
<tr>
<td>III. Nonengineered timber and masonry buildings</td>
<td>0.2</td>
</tr>
<tr>
<td>IV. Buildings extremely susceptible to vibration damage</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Source: Federal Transit Administration (2006)

**TABLE 19: CONSTRUCTION VIBRATION PREDICTIONS**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Peak Particle Velocity at 25 feet (inches/second)</th>
<th>Peak Particle Velocity at 50 feet (inches/second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibratory roller</td>
<td>0.21</td>
<td>0.07</td>
</tr>
<tr>
<td>Hoe ram</td>
<td>0.09</td>
<td>0.03</td>
</tr>
<tr>
<td>Large bulldozer</td>
<td>0.09</td>
<td>0.03</td>
</tr>
<tr>
<td>Caisson drilling</td>
<td>0.09</td>
<td>0.03</td>
</tr>
<tr>
<td>Loaded trucks</td>
<td>0.08</td>
<td>0.03</td>
</tr>
<tr>
<td>Jackhammer</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>Small bulldozer</td>
<td>0.003</td>
<td>0.001</td>
</tr>
</tbody>
</table>

6.4 CONSTRUCTION VIBRATION MITIGATION

The primary concern regarding construction vibration is potential damage to structures. Construction-related vibration activities are unlikely to exceed the impact thresholds shown in Table 19. However, the construction contract specifications should provide vibration level limits based on accepted industry standards and practices. These limits can be based on FTA guidance for potential damage as listed in Table 18 and considering the types of structures along the alignment.

It is unlikely that high-vibration-generating equipment, such as a vibratory roller, would be operated closer than 25 feet of the nearest buildings. However, the following
precautionary vibration mitigation strategies should be implemented to minimize the potential for damage to any structures in the corridor:

1. **Preconstruction Survey:** The survey should include inspecting building foundations and taking photographs of preexisting conditions. The survey can be limited to buildings within 25 feet of high-vibration-generating construction activities. The only exception is if an important and potentially fragile historic resource is located within approximately 200 feet of construction, in which case it should be included in the survey. As previously stated, no fragile buildings are likely to be located anywhere along the project alignment.

2. **Vibration Limits:** The FTA Guidance Manual suggests vibration limits in terms of peak particle velocity ranging from 0.12 inches/second for “buildings extremely susceptible to vibration damage” to 0.5 inches/second for “Reinforced-concrete, steel or timber” buildings. The contract specifications should limit construction vibration to a maximum of 0.5 inches/second for all buildings in the corridor. Should the preconstruction survey identify any buildings that are particularly sensitive to vibration, these structures should be assessed by an architect to determine appropriate vibration limits.

3. **Vibration Monitoring:** In locations within 25 feet of buildings (the distance where there is a potential risk for damage) and at locations where the building owners or occupants have complained about high vibration levels, vibration monitoring should be conducted when high-vibration construction generating equipment is used.

4. **Alternative Construction Procedures:** If construction vibration levels exceed limits specified in the contract, then alternative procedures may be needed. Examples of such procedures include use of nonvibratory compaction in limited areas or use of a concrete saw instead of a hoe ram to break up pavement.
7.0 SOURCES AND REFERENCES CITED


APPENDIX A. FUNDAMENTALS OF NOISE AND VIBRATION

NOISE FUNDAMENTALS

Sound is mechanical energy transmitted by pressure waves in a compressible medium such as air. Typically, noise is defined as unwanted or excessive sound. Sound can vary in intensity by over one million times within the range of human hearing. Therefore, a logarithmic scale, known as the decibel scale (dB), is used to quantify sound intensity and compress the scale to a more convenient range.

Sound is characterized by both its amplitude and frequency (or pitch). The human ear does not hear all frequencies equally. In particular, the ear deemphasizes low and very high frequencies. The A-weighted decibel scale (dBA) better approximates the sensitivity of human hearing. On this scale, the human range of hearing extends from approximately 3 dBA to around 140 dBA. As a point of reference, Figure A-1 includes examples of A-weighted sound levels from common indoor and outdoor sounds.

Using the decibel scale, sound levels from two or more sources cannot be directly added together to determine the overall sound level. Rather, the combination of two sounds at the same level yields an increase of 3 dB. The smallest recognizable change in sound level is approximately 1 dB. A 3 dB increase in the A-weighted sound level is considered generally perceptible, whereas a 5 dB increase is readily perceptible. A 10 dB increase is judged by most people as an approximate doubling of the perceived loudness.

The two primary factors that reduce levels of environmental sounds are (1) increasing the distance between the sound source and the receiver and (2) having intervening obstacles such as walls, buildings or terrain features that block the direct path between the sound source and the receiver. Factors that act to make environmental sounds louder include moving the sound source closer to the receiver, sound enhancements caused by reflections and focusing caused by various meteorological conditions.

The following are brief definitions of the measures of environmental noise used in this report:

Maximum Sound Level (Lmax): Lmax is the maximum sound level that occurs during an event such as a light rail passing. For this analysis, Lmax is defined as the maximum sound level using the slow setting on a standard sound level meter.

Equivalent Sound Level (Leq): Environment sound fluctuates constantly. The equivalent sound level (Leq) is the most common means of characterizing community noise. Leq represents a constant sound that, over a specified period of time, has the same sound energy as the time-varying sound. Leq is used by FTA to evaluate noise impacts at institutional land uses, such as schools, churches and libraries, from proposed transit projects.

Day-Night Sound Level (Ldn): Ldn is a 24-hour Leq with an adjustment to reflect the greater sensitivity of most people to nighttime noise. The adjustment is a 10 dB penalty for all sound that occurs between the hours of 10 p.m. to 7 a.m. The effect of the penalty is that, when calculating Ldn, any event that occurs during the nighttime is equivalent to ten occurrences of the same event during the daytime. Ldn is the most
common measure of total community noise over a 24-hour period and is used by FTA to evaluate residential noise impacts from proposed transit projects.

**Lxx:** This is the percentage of time a sound level is exceeded during the measurement period. For example, the L99 is the sound level exceeded 99 percent of the measurement period. For a 1-hour period, L99 is the sound level exceeded for all except 36 seconds of the hour. L1 represents typical maximum sound levels, L33 is approximately equal to Leq when free-flowing traffic is the dominant noise source, L50 is the median sound level and L99 is close to the minimum sound level.

**Sound Exposure Level (SEL):** SEL is a measure of the acoustic energy of an event such as a train passing. In essence, the acoustic energy of the event is compressed into a 1-second period. SEL increases as the sound level of the event increases and as the duration of the event increases. It is often used as an intermediate value in calculating overall metrics such as Leq and Ldn.

**Sound Transmission Class (STC):** STC ratings are used to compare the sound insulating effectiveness of different types of noise barriers, including windows, walls, etc. Although the amount of attenuation varies with frequency, the STC rating provides a rough estimate of the transmission loss from a particular window or wall.
VIBRATION FUNDAMENTALS

One potential community impact from the proposed project is vibration that is transmitted from the tracks through the ground to adjacent houses. This is referred to as groundborne vibration. When evaluating human response, groundborne vibration is expressed in terms of decibels using the root mean square (RMS) vibration velocity. RMS is defined as the average of the squared amplitude of the vibration signal. To avoid confusion with sound decibels, the abbreviation VdB is used for vibration decibels. All vibration decibels in this report use a decibel reference of 1 micro-inch/second (µin/sec).\(^1\)

The potential adverse impacts of rail transit groundborne vibration are as follows:

**Perceptible Building Vibration:** The vibration of the floor or other building surfaces that the occupants feel. Experience shows that the threshold of human perception is around 65 VdB and that vibration that exceeds 75 to 80 VdB is perceived as intrusive and annoying to occupants.

**Rattle:** The building vibration can cause rattling of items on shelves and hangings on walls, and various rattle and buzzing noises from windows and doors.

**Reradiated Noise:** The vibration of room surfaces radiates sound waves that are audible to humans (groundborne noise). Groundborne noise sounds like a low-frequency rumble. Usually, for a surface rail system such as the proposed light rail, the groundborne noise is masked by the normal airborne noise radiated from the transit vehicle and the rails.

**Damage to Building Structures:** Although it is conceivable that vibration from a light rail system can damage fragile buildings, the vibration from rail transit systems is one to two orders of magnitude below the most restrictive thresholds for preventing building damage. Hence the vibration impact criteria focus on human annoyance, which occurs at much lower amplitudes than does building damage.

Vibration is an oscillatory motion that is described in terms of the displacement, velocity or acceleration of the motion. The response of humans to vibration is very complex. However, the general consensus is that for the vibration frequencies generated by light rail, human response is best approximated by the vibration velocity level. Therefore, this study uses vibration velocity to describe light rail-generated vibration levels.

Figure A-2 shows typical vibration levels from rail and nonrail sources as well as the human and structure response to such levels.

Although there is relatively little research into human and building response to groundborne vibration, there is substantial experience with vibration from rail systems. In general, the collective experience indicates that:

It is rare that groundborne vibration from transit systems results in building damage (even minor cosmetic damage). Therefore, the primary consideration is whether or not the vibration is intrusive to building occupants or interferes with interior activities or machinery.

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\(^1\) One µin/sec = 10\(^{-6}\) in/sec
The threshold for human perception is approximately 65 VdB. Vibration levels in the range of 70 to 75 VdB often are noticeable but acceptable. Beyond 80 VdB, vibration levels are considered unacceptable.

For human annoyance, there is a relationship between the number of daily events and the degree of annoyance caused by groundborne vibration. The FTA Guidance Manual includes an 8 VdB higher impact threshold if there are fewer than 30 events per day and a 3 VdB higher threshold if there are fewer than 70 events per day.

**FIGURE A-2: VIBRATION LEVELS FROM COMMON SOURCES**

<table>
<thead>
<tr>
<th>Human/Structural Response</th>
<th>Velocity Level*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold, minor cosmetic damage</td>
<td>100</td>
</tr>
<tr>
<td>Difficulty with tasks such as reading a computer screen</td>
<td>90</td>
</tr>
<tr>
<td>Residential annoyance, infrequent events (e.g., commuter trains)</td>
<td>80</td>
</tr>
<tr>
<td>Residential annoyance, occasional events</td>
<td>70</td>
</tr>
<tr>
<td>Residential annoyance, frequent events (e.g., light rail transit)</td>
<td>60</td>
</tr>
<tr>
<td>Approximate threshold of human perception; Limit for vibration sensitive equipment</td>
<td>50</td>
</tr>
</tbody>
</table>

Typical Sources (50 ft) from source

- Blasting from construction projects
- Bulldozers and other heavy tracked vehicles
- Freight trains, upper range
- Light rail transit near a crossover
- Bus or truck over pothole
- Streetcar at 50 ft, normal track
- Bus or truck, smooth roadway
- Typical background level

RMS Vibration Velocity Level in VdB using a decibel reference of 10^-6 inches/second

Often it is necessary to determine the contribution at different frequencies when evaluating vibration or noise signals. The 1/3-octave band spectrum is the most common procedure used to evaluate frequency components of acoustic signals. The term *octave* is borrowed from music, where it refers to a span of eight notes. The ratio of the highest frequency to the lowest frequency in an octave is 2:1. For a 1/3-octave band spectrum, each octave is divided into three bands, where the ratio of the lowest frequency to the highest frequency in each 1/3-octave band is $2^{1/3}:1$ ($1.26:1$). An octave consists of three 1/3 octaves.

The 1/3-octave band spectrum of a signal is obtained by passing the signal through a bank of filters. Each filter excludes all components except those that are between the upper and lower range of one 1/3-octave band.
APPENDIX B. FORCE DENSITY LEVEL MEASUREMENTS

FORCE DENSITY MEASUREMENT RESULTS

This appendix provides the results of the light rail vibration testing that was performed at the Valley Metro Starter Line. The equipment (vehicles and track design) that is used for the Starter Line is similar to the equipment that would be used on the Northwest Extension.

FDL measurements were performed in Phoenix along the Light Rail Starter Line as a part of the Valley Metro Rail Mesa Extension Noise and Vibration Technical Report (2010). The test was performed at 5552 E Washington Street at a section along tangent track (Figure B-1). A single train was operated on the near track (NT) at controlled speeds.

Following is a summary of the tests performed to derive a force density for the Valley Metro Starter Line:

1. Light rail vibration was measured at five distances from the track. The accelerometers were placed at distances ranging from 50 to 200 feet north of the westbound track, which was the NT. The eastbound track was 12 feet south of the westbound track.

2. The root mean square (rms) light rail vibration at each measurement position was determined on a 1/3 octave band basis over the frequency range of 5 to 315 Hz. The measured 1/3 octave band rms vibration levels were adjusted to obtain the maximum 1-second rms value for the light rail vibration.

3. Transfer mobility was measured using a line of impacts. The impact line consisted of 11 locations separated by 15 feet for a total length of 150 feet. The same accelerometer positions used for the train vibration were used for the transfer mobility tests. The impact line was located in the center of the NT. The point source transfer mobilities at the 11 impact points were combined to obtain the line source transfer mobility (LSTM) at each accelerometer position.

4. The FDL from each train passby was calculated as the difference between the measured train vibration level and the LSTM. The vibration data from frequency bands where the light rail vibration did not exceed the background vibration was not used in the FDL calculation.

5. At each accelerometer position, the FDL estimates for each vehicle and track were energy averaged.

6. The final FDLs for the two vehicles were estimated by using the maximum of the energy-averaged force densities of all sensor positions. This approach was taken to ensure that the final FDLs would be an upper bound of the true FDL and would tend to over predict light rail vibration levels rather than under predict vibration levels.
TRANSFER MOBILITY TESTS

The measured transfer mobility and coherence functions from the propagation tests are given Figure B-2. The transfer mobilities were measured using accelerometers mounted at distances of 50, 75, 100, 150 and 200 feet from the westbound track centerline. The impact line was located on the track centerline. As expected, the transfer mobilities decreased with distance from the impact line. There was good coherence over the 16 to 250 Hz range at all except the 125-foot measurement position. The transfer mobility at 125 feet had poor coherence above 80 Hz.
LIGHT RAIL VEHICLE VIBRATION

Light rail vibration was measured at the same locations as the transfer mobility measurements. Two tracks were at the measurement location. The westbound track was the NT and the eastbound track centerline was 12 feet from the westbound track centerline. As discussed earlier, the vibration sensors were located at 50, 75, 100, 150 and 200 feet from the westbound track centerline and were identified as Channels 2, 3, 4, 5 and 6, respectively.

During the measurement period, 16 total passbys were measured, two passbys at speeds of 5, 10, 15, 20, 25, 30, 35 and 40 mph each. The light rail speeds were verified with a radar gun. The measurement results are shown in Figure B-3. Observations from the light rail vibration results are:

Train vibrations at various speeds are reasonably well-grouped; however, there is as much as a 10-dB difference between the maximum and minimum events.
FIGURE B-3: MEASURED TRAIN VIBRATION AT VARYING SPEEDS

Train Vibration, 50 ft

Train Vibration, 75 ft

Train Vibration, 100 ft

Train Vibration, 150 ft
FORCE DENSITY

Figure B-4 shows the average FDL at each speed from the Washington Street measurements. The FDL at each speed are reasonably grouped within a 5-dB range. The exception is at the 50-foot position, which has high levels below 31.5 Hz. These levels are not included in the average FDL for these speeds. The final FDL for each train speed is shown in Figure B-5.
FIGURE B-5: METRO LRV FORCE DENSITY LEVELS VERSUS SPEED

Phoenix METRO LRT Force Density Levels

- Avg FDL, 5 mph
- Avg FDL, 10 mph
- Avg FDL, 15 mph
- Avg FDL, 20 mph
- Avg FDL, 25 mph
- Avg FDL, 30 mph
- Avg FDL, 35 mph
- Avg FDL, 40 mph
COMPARISON TO FDL USED IN CAPITOL I-10 PROJECT

Additional measurements of the Valley Metro LRV FDL were made as a part of the Capitol/I-10 West Light Rail Extension. These measurements were conducted by consulting firm Harris, Miller, Miller, and Hanson Inc. (HMMH), during 2013. The results of these FDL tests were reported in the Capitol/I-10 West Light Rail Extension Noise and Vibration Technical Report, issued June 2015 (Valley Metro 2015).

The 2013 FDL measurements (Valley Metro 2015) were conducted at the same Washington Street site as in 2009. The results from both the 2009 and 2013 FDL measurements are shown in Figure B-6. This shows that above 25 Hz there is good agreement, with less than a 3-dB difference in any of the high frequency 1/3 octave bands. There is also a similar peak of 40 dB at 80 Hz. There is a discrepancy of about 5 dB at frequencies lower than 25 Hz. The groundborne vibration propagation along the Northwest Light Rail Extension is most efficient at frequencies between 25 Hz and 80 Hz; therefore, this moderate discrepancy would not play a significant role in predicting impacts.

FIGURE B-6: COMPARISON OF WASHINGTON STREET FDL MEASURED IN 2009 AND 2013
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APPENDIX C. NOISE SOURCE LEVEL

NOISE SOURCE LEVEL

For the Northwest Light Rail Extension noise analysis, the Lmax measurements performed on the Valley Metro Starter Line (light rail embedded track) were used as the reference noise. The noise measurements from the Valley Metro Starter Line are documented in the Noise and Vibration Appendix of the Final Environmental Assessment for the Central Mesa LRT Extension, May 2011.

Noise measurements of train passbys were performed at controlled speeds after revenue hours on the Valley Metro Starter Line. Measurements were made at distances of 50, 100 and 200 feet from the near track and at speeds of 5 to 40 mph in increments of 5 mph. The reference level of 77 dBA at 50 feet for train speeds of 35 mph was derived from these tests.
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APPENDIX D. VIBRATION PROPAGATION TEST RESULTS

This appendix provides photographs of the vibration propagation test sites, measured Line Source Transfer Mobility (LSTM) and coherence at each site and the best-fit coefficients derived from the measured LSTM at each site. Maps of test locations in relation to sensitive receivers are shown in Appendix F. This appendix is organized by test site. Each site includes the following:

- Photographs of the vibration propagation sites
- Aerial diagrams of the vibration propagation sites
- Measured LSTM and coherence
- Table of coefficients for the best-fit curves

V-1: DEVRY UNIVERSITY

FIGURE D-1: PHOTOS OF MEASUREMENT SITE V-1
FIGURE D-2: AERIAL VIEW OF VIBRATION PROPAGATION SITE V-1

FIGURE D-3: MEASURED LSTM AT SITE V-1
FIGURE D-4: MEASURED COHERENCE AT SITE V-1

![Graph showing measured coherence at Site V-1 with data points and lines representing different distances.]

TABLE D-1: BEST-FIT COEFFICIENTS SITE V-1

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<tr>
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FIGURE D-5: SITE V-1 BEST-FIT LINE SOURCE TRANSFER MOBILITY

V-2: ATRIUM APARTMENTS

FIGURE D-6: PHOTOS OF VIBRATION PROPAGATION SITE V-2
FIGURE D-7: AERIAL VIEW OF VIBRATION PROPAGATION SITE V-2

FIGURE D-8: MEASURED LSTM AT SITE V-2
FIGURE D-9: MEASURED COHERENCE AT SITE V-2

TABLE D-2: BEST FIT COEFFICIENTS SITE V-2

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FIGURE D-10: SITE V-2 BEST-FIT LINE SOURCE TRANSFER MOBILITY

Site V-2 Best Fit LSTM

V-3: COURTYARD MARRIOTT PHOENIX NORTH

FIGURE D-11: PHOTO OF VIBRATION PROPAGATION SITE V-3

P.C.: Google Earth
FIGURE D-12: AERIAL VIEW OF VIBRATION PROPAGATION SITE V-3

FIGURE D-13: MEASURED LSTM AT SITE V-3
FIGURE D-14: MEASURED COHERENCE AT SITE V-3

TABLE D-3: BEST FIT COEFFICIENTS SITE V-3

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FIGURE D-15: SITE V-3 BEST-FIT LINE SOURCE TRANSFER MOBILITY

Site V-3 Best Fit LSTM

Line Transfer Mobility, dB re 1 (μm/μs)/ft²

1/3 Octave Band Center Frequency, Hz

BF 25'
BF 37'
BF 50'
BF 75'
BF 100'
BF 150'
APPENDIX E. AMBIENT NOISE AND VIBRATION MEASUREMENT SITES

This section provides the detailed ambient noise and vibration data for the sites discussed in Section 4.0. All data shown here were collected in August 2016. Maps of measurement locations in relation to sensitive receivers are shown in Appendix F.

LT-1: ROYAL PALMS MOBILE HOMES

This long-term measurement was performed at the southwest corner of the Royal Palm Mobile Home community west of C Street. The primary noise source was vehicular traffic on Dunlap Avenue. Secondary noise sources include the crossing gate on 19th Avenue. The microphone was 35 feet from the near lane of Dunlap Avenue. The measured 24-hour Ln was 72.5 dBA and the peak hour L eq was 74.2 dBA.

An additional measurement was taken at this site due to bad weather. The bad weather occurred during the afternoon rush hour when we would expect high levels of traffic noise. The measured 1-hour L eq was 70.1 dBA. Due to this, the weather adjusted 24-hour Ln was 72.3 dBA. The weather adjusted peak hour L eq was 70.1 dBA.

FIGURE E-1: PHOTO OF NOISE MEASUREMENT SITE LT-1
FIGURE E-2: LT-1, 24-HOUR AMBIENT NOISE TIME HISTORY

FIGURE E-3: LT-1, 1-HOUR AMBIENT NOISE TIME HISTORY
LT-2: CROSSLAND ECONOMY STUDIOS

This long term measurement was performed at the southwest corner of Crossland Economy Studios west on 2102 W Dunlap Ave. The primary noise source was vehicular traffic on Dunlap Avenue. The microphone was 45 feet from the near lane of Dunlap Avenue. The measured 24-hour Ldn was 71.9 dBA and the peak hour Leq was 69.3 dBA.

An additional measurement was taken at this site due to bad weather. The bad weather occurred during the afternoon rush hour when we would expect high levels of traffic noise. The measured 1-hour Leq was 68.3 dBA. The weather adjusted 24-hour Ldn was 71.7 dBA. The weather adjusted peak hour Leq remained 69.3 dBA.

FIGURE E-4: PHOTOS OF NOISE MEASUREMENT SITE LT-2
FIGURE E-5: LT-2, 24-HOUR AMBIENT NOISE TIME HISTORY

FIGURE E-6: LT-2, 1-HOUR AMBIENT NOISE TIME HISTORY
LT-3: ACCLAIM APARTMENTS

This long term measurement was performed on the east side of the Acclaim Apartment complex on 2506 W Dunlap Ave. The primary noise source was vehicular traffic on 25th Avenue. Secondary noise sources include vehicular traffic on Dunlap Avenue. The microphone was 35 feet from the near lane of Dunlap Avenue. The measured 24-hour Ldn was 65.7 dBA and the peak hour Leq was 66.5 dBA.

**FIGURE E-7: PHOTOS OF NOISE MEASUREMENT SITE LT-3**

**FIGURE E-8: LT-3, 24-HOUR AMBIENT NOISE TIME HISTORY**
LT-4: COURTYARD MARRIOTT PHOENIX NORTH

This long term measurement was performed at the northwest corner of the Courtyard Marriott on 9631 N Black Canyon Hwy. The primary noise source was vehicular traffic on I-17. Secondary noise sources include vehicular traffic on the Black Canyon Hwy frontage road. The microphone was 70 feet from the near lane of I-17. The measured 24-hour Ldn was 75.0 dBA and the peak hour Leq was 73.3 dBA.
ST-1: ARGOSY UNIVERSITY

This short-term measurement was performed on the north side of Argosy University. The primary noise source was vehicular traffic on Dunlap Avenue. Secondary noise sources include vehicular traffic on 23rd Avenue. The microphone and accelerometer were 80 feet from the near lane of Dunlap Avenue. The measured 1-hour noise Leq was 66.7 dBA. The measured 1-hour vibration Leq was 56.6 VdB.

FIGURE E-11: PHOTOS OF NOISE MEASUREMENT SITE ST-2

FIGURE E-12: ST-1, 1-HOUR AMBIENT NOISE TIME HISTORY
FIGURE E-13: ST-1, 1-HOUR AMBIENT VIBRATION TIME HISTORY
ST-2: OTTAWA UNIVERSITY

This short-term measurement was performed on the east side of Ottawa University. The primary noise source was vehicular traffic on 25th Avenue. Secondary noise sources include dogs at the dog park across 25th Avenue. The microphone and accelerometer were 50 feet from the near lane of 25th Avenue. The measured 1-hour noise Leq was 63.7 dBA. The measured 1-hour vibration Leq was 52.5 VdB.

FIGURE E-14: PHOTOS OF NOISE MEASUREMENT SITE ST-2

FIGURE E-15: ST-2, 1-HOUR AMBIENT NOISE TIME HISTORY
FIGURE E-16: ST-2, 1-HOUR AMBIENT VIBRATION TIME HISTORY
APPENDIX F. SENSITIVE RECEIVER INVENTORY

Table F-1 lists the sensitive receivers potentially affected by the light rail operations/construction and also the TPSS units. Figure F-1 shows the overall project area, including the receiver clusters, sensitive land uses, measurement sites, and receivers where impacts are predicted. Figures F-2 through Figure F-6 show the sensitive receivers along the proposed alignment by region of the alignment.
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<th>No. of Units</th>
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### TABLE F-1: SENSITIVE RECEIVER INVENTORY

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</tbody>
</table>

<sup>a</sup> SFR = single-family, MFR = multifamily, HT = hotel, SC = school, MD = medical, Conf. Ctr = Conference Center.

<sup>b</sup> Extra elements are included in the analysis, indicated with the following letter codes: X = crossover, CB = crossing bells, TB = train bells (at intersections or stations), TPSS = traction power substation unit.

<sup>c</sup> Number of rooms/units estimated to be potentially exposed to noise.
FIGURE F-1: OVERVIEW OF NOISE AND VIBRATION MEASUREMENT SITES AND SENSITIVE LAND USES
FIGURE F-2: NOISE- AND VIBRATION-SENSITIVE LAND USES AND IMPACT LOCATIONS, 19TH AVENUE TO 22ND AVE
FIGURE F-3: NOISE- AND VIBRATION-SENSITIVE LAND USES AND IMPACT LOCATIONS, 22ND AVENUE TO 25TH AVE

Proposed Track
Existing Track
Station
Transit Center

Park and Ride
TPSS
* Noise Impact
** Noise and Vibration Impact

MFR-Multifamily Residences
SFR-Mobile Home, Single Family Residences
HT-Hotel
Institutional

Measurement
- Long Term Noise (LT-x)
- Short Term Noise (ST-x)
- Vibration (V-x)

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community
FIGURE F-5: NOISE- AND VIBRATION-SENSITIVE LAND USES AND IMPACT LOCATIONS, 25TH AVENUE TO METROCENTER
FIGURE F-6: NOISE- AND VIBRATION-SENSITIVE LAND USES AND IMPACT LOCATIONS, AT METROCENTER
APPENDIX G. VIBRATION MITIGATION FOR SWITCHES

VIBRATION MITIGATION FOR SWITCHES

The banging that occurs when transit car wheels pass through switches is generally found to increase groundborne vibration levels at locations less than about 15 m from the switch by 10 decibels. Almost all of the increase in groundborne vibration and airborne noise occurs as the wheels pass through frogs. There are several alternatives to typical rail-bound manganese (RBM) frogs that will result in lower vibration and noise levels:

RBM frogs: The common rail-bound manganese (RBM) frog is designed for main line freight track but is often used on transit systems. Wheel impacts as wheels cross the gap in the rail and when wheels hit the frog point typically increase noise levels by approximately 6 dBA and vibration levels by approximately 10 VdB. The actual increase will depend on the condition of the frog, how smoothly the wheel load is transferred from one side of the rail gap to the other, whether the movement over the frog is a straight-through or diverting move and the distance from the frog. Conceptually, higher number frogs have a smaller angle between the rails and the transition over the gap is distributed over a greater distance, so the additional noise and vibration levels should be lower. We are not aware of any measurement results that confirm that higher number frogs generate less noise and vibration than lower number frogs.

Monoblock frogs: Monoblock frogs are basically milled out of a single block of steel. Because they are machined rather than cast, the tolerances can be tighter. Monoblock frogs are generally thought to create less noise and vibration than RBM frogs. Based on informal measurement that ATS performed at the PATH commuter rail system in New Jersey, it appears that the increase in noise and vibration levels with a good-condition monoblock frog is about half of that with a standard RBM frog.

Flange-bearing frogs: Well-designed and maintained, flange-bearing frogs can generate much less noise and vibration than standard RBM frogs. If the ramps are too short and/or the frogs are not properly maintained, the noise and vibration benefits may be marginal. The recommended length of the ramp in the frog is a minimum of 2 feet. AREMA standards suggest a speed limit of 24 km/h for flange-bearing frogs on transit systems, so special approval may be necessary to operate at higher speeds if a flange-bearing frog is used.

One-way low-speed (OWL) frogs: OWL frogs are designed for use when traffic in the diverting direction is infrequent and low speed. Most OWL designs are flange bearing in the diverting direction and have no break in the rail in the main line direction. These are often referred to as "jump frogs" because in the diverting direction the wheels are lifted up and over the rail with some form of flange-bearing ramps. A Vossloh representative said that the cost of their OWL is about $3,000 more than a standard RBM frog and about the same as a monoblock frog. Because the rail is solid in the main line direction, there would be little or no increase in noise and vibration. Vossloh, Progress Rail and Nortrak all have variants of OWL jump frogs.
Spring rail and moveable point frogs: These frogs can be substantially more expensive in terms of parts, installation and maintenance. When properly designed, installed and maintained, there can be only a marginal increase in noise and vibration levels with spring rail and moveable point frogs.