Technical Report
Noise and Vibration

1.0 Introduction

1.1 Purpose of Report

This *Noise and Vibration Technical Report* has been prepared in support of the Bottineau Transitway Project Draft Environmental Impact Statement (Draft EIS). The objective of this report is to evaluate the project's potential noise and vibration impacts within the study area. This includes the following:

- Discussion of environmental noise and vibration basics, federal impact criteria, and assessment methodology
- Description of the existing noise and vibration conditions and measurement results
- Assessment of the project's airborne noise levels and identification of project noise impacts
- Assessment of the project's ground-borne vibration levels and identification of project vibration impacts
- Recommendation of mitigation measures for noise and vibration impacts

2.0 Study Area

The for noise and vibration is based on the screening distances provided in Chapters 4 and 9 of the FTA guidance manual "Transit Noise and Vibration Impact Assessment" (May 2006). Screening distances provided in the FTA manual are based on typical project conditions and were adjusted based on the specific conditions of the Bottineau Transitway Project. All noise- and vibration-sensitive land uses within the relevant screening distances were reviewed to identify locations where impacts may possibly occur. Typical screening distances provided by the FTA for light rail transit projects are given in Table 1 and Table 2 for noise and vibration, respectively. In Table 1, the "unobstructed" screening distances apply to noise-sensitive receivers where no large buildings or rows of homes are located in the sound path between the receiver and the noise source to provide shielding from noise. The "intervening buildings" screening distances apply to noise-sensitive receivers where large buildings or rows of homes do exist in the sound path and provide shielding between the receiver and the noise source.

Table 1. FTA Screening Distances for Noise Assessments

Type of Project	Screening Distances[1] (ft)	
	Unobstructed	Intervening Buildings
Light Rail Transit	350	175
Commuter Rail-Highway Crossing with Horns and Bells	1,600	1,200
Yards and Shops	1,000	650
Parking Facilities	125	75
Power Substations	250	125

[1] Measured from the centerline of guideway for mobile sources; from center of noise-generating activity for stationary sources.
Source: Federal Transit Administration, 2006.

Table 2. FTA Screening Distances for Vibration Assessments

Type of Project	Critical Distance for Land Use Categories[1] Distance from Right-of-Way or Property Line (ft)		
	Cat. 1	Cat. 2	Cat. 3
Light Rail Transit	450	150	100

[1] The land-use categories are defined in Table 5. Other vibration-sensitive land uses are included in Table 6. For the screening procedure, vibration sensitive land uses such as TV and radio studios are evaluated as Category 1 receptors.
Source: Federal Transit Administration, 2006.

3.0 Noise Technical Analysis

3.1 Regulatory Context/Methodology

Noise has been assessed in accordance with guidelines specified in the U.S. Federal Transit Administration's (FTA) "Noise and Vibration Impact Assessment" guidance manual (FTA Report FTA-VA-90-1003-06, May, 2006). This manual describes the methodology for assessing potential impact from proposed transit projects such as the Bottineau Transitway Project.

The methodology for assessing potential long-term noise impact from transit operations essentially includes:

(1) identification of noise-sensitive land uses within the area of potential effect of the proposed project
(2) measurement and characterization of existing noise conditions at these sensitive receptors
(3) projections of future noise levels from transit operations for future build alternatives
(4) assessment of potential long-term noise impact
(5) recommendations for noise mitigation

The guidance manual also includes the methodology for predicting and assessing potential short-term noise impact from construction activities. The approach to assessing potential impact from construction activities is more general than for transit operations since specific construction equipment and methods depend on the contractor's approach and are not typically defined at this stage of project development. This report includes general recommendations for minimizing potential impact from construction activities.

3.1.1 Noise Fundamentals and Descriptors

Noise is typically defined as unwanted or undesirable sound, where sound is characterized by small air pressure fluctuations above and below the atmospheric pressure. The basic parameters of environmental noise that affect human subjective response are (1) intensity or level, (2) frequency content and (3) variation with time. Intensity or level is determined by how greatly the sound pressure fluctuates above and below the atmospheric pressure, and is expressed on a compressed scale in units of decibels. By using this scale, the range of normally encountered sound can be expressed by values between 0 and 120 decibels. On a relative basis, a 3-decibel change in sound level generally represents a barely noticeable change, whereas a 10-decibel change in sound level would typically be perceived as a doubling (or halving) in the loudness of a sound.

The frequency content of noise is related to the tone or pitch of the sound, and is expressed based on the rate of the air pressure fluctuation in terms of cycles per second (called hertz and abbreviated as Hz). The human ear can detect a wide range of frequencies from about 20 Hz to 17,000 Hz. However, because the sensitivity of human hearing varies with frequency, the "A-weighting system" is commonly used when measuring environmental noise to provide a single number descriptor that correlates with human subjective response. Sound levels measured using this weighting system are called "A-weighted" sound levels, and are expressed in decibel notation as "dBA." The A-weighted sound level is widely accepted by acousticians as a proper unit for describing environmental noise.

As stated in Chapter 2 of the FTA guidance manual, people's reaction to environmental noise depends on the number of noise events, how long they last, and whether they occur during the daytime or nighttime. While the maximum noise level (Lmax) provides information about the amplitude of noise generated by a source, it does not provide any information about how long the noise event lasted. The sound exposure level (SEL) is a noise metric that takes into account both how loud a noise source is and how long the event occurs. The SEL of a noise event is a building block used to determine cumulative noise exposure over a one-hour or 24-hour long period. Because environmental noise fluctuates from moment to moment, it is common practice to condense all of this information into a single number. Analysts use two primary noise measurement descriptors to assess noise impacts from traffic and transit projects. They are the equivalent sound level (Leq) and the day-night sound level (Ldn):

- The Leq represents a receiver's noise exposure including all noise events that occur in a specified period, such as 1 minute, 1 hour, 24 hours, etc. FTA noise impact criteria for non-residential land uses with daytime-only uses are based on the Leq in the peak hour of transit operations when noise could interfere with a sensitive activity, such as an hour when school is in session.

- The Ldn represents a receiver's noise exposure for all noise events that occur during a 24-hour period, with a penalty added for nighttime noise. The basic unit used in calculating Ldn is the hourly Leq for each one-hour period during day and night; the hourly Leq are then combined, after including a 10 dB penalty for nighttime noise (between 10 p.m. and 7 a.m.), to calculate the Ldn. FTA noise impact criteria for residential land use are based on Ldn.

Many surveys have shown that Ldn is well correlated with human annoyance, and therefore this descriptor is widely used for assessments of environmental noise impact. Figure 1 provides examples of typical noise environments and criteria in terms of Ldn. While the extremes of Ldn are shown to range from 35 dBA in a wilderness environment to 85 dBA in noisy urban environments, Ldn is generally found to range between 55 dBA and 75 dBA in most communities. As shown in Figure 1, this spans the range between an “ideal” residential environment and the threshold for an unacceptable residential environment, according to some U.S. federal agencies.

3.1.2 Noise Impact Criteria

Noise -Sensitive Land Use Categories

The FTA classifies noise-sensitive land uses into the following three categories:

- **Category 1**: Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, and such land uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included are recording studios and concert halls.

- **Category 2:** Residences and buildings where people normally sleep. This category includes homes, hospitals, and hotels where a nighttime sensitivity is assumed to be of utmost importance.

- **Category 3:** Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, theaters, 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, such as parks used for passive recreation like reading, conversation, meditation, etc. However, most parks used primarily for active recreation would not be considered noise sensitive.

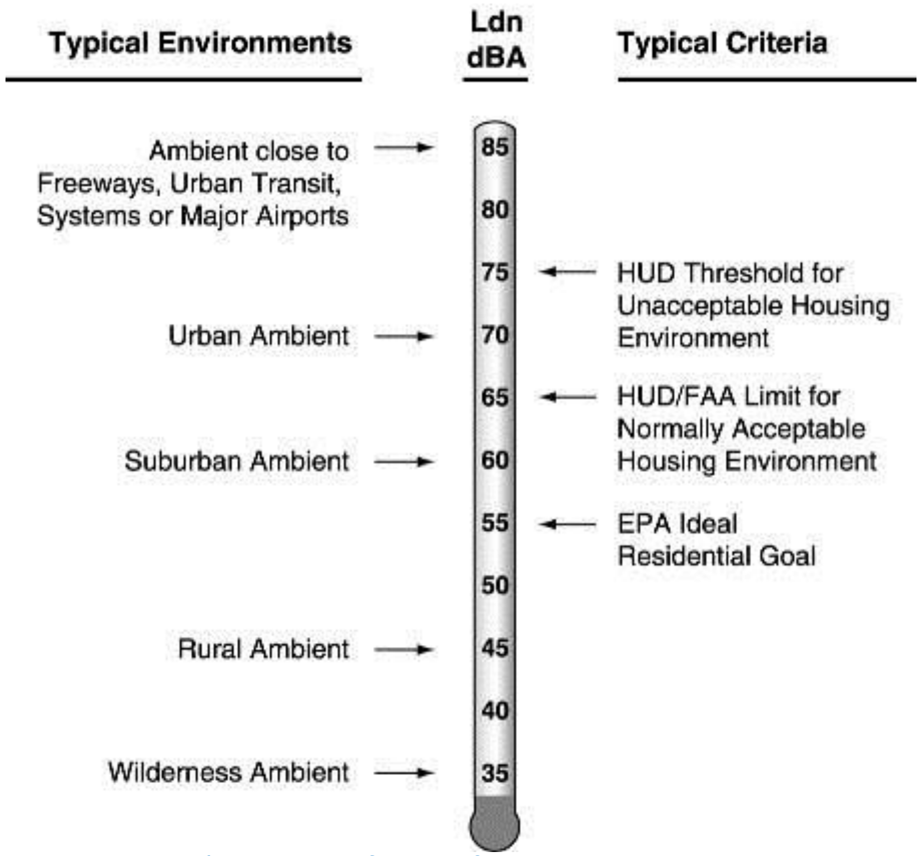


Figure 1. Examples of Typical Outdoor Ldn Noise Exposure
Source: Harris Miller Miller & Hanson Inc., 2012.

Noise Impact Criteria

The FTA airborne noise impact criteria are based on the future change in noise exposure using a sliding scale. At locations with higher levels of existing noise, smaller increases in total noise exposure will cause impact. The Ldn is used to characterize noise exposure for locations with nighttime sensitivity, or Category 2 uses. For institutional land uses with primarily daytime use, such as parks and school buildings (Categories 1 and 3), the one-hour Leq during the facility's operating period is used. Ldn and Leq are explained in Section 3.1.1.

There are two levels of impact used in the FTA criteria, as summarized below:

- **Severe Impact:** Project-generated noise in the severe impact range can be expected to cause a significant percentage of people to be highly annoyed by the new noise and represents the most compelling need for mitigation. Noise mitigation would normally be specified for severe impact areas unless there are truly extenuating circumstances that prevent it.

- **Moderate Impact:** In this range of noise impact, the change in the cumulative noise level is noticeable to most people but may not be sufficient to cause strong, adverse reactions from the community. In this transitional area, other project-specific factors must be considered to determine the magnitude of the impact and the need for mitigation. These factors include the existing noise level, the predicted level of increase over existing noise levels, the types and numbers of noise-sensitive land uses affected, the noise sensitivity of the properties, the effectiveness of the mitigation measures, community views and the cost of mitigating noise to more acceptable levels.

The noise impact criteria are summarized in graphical form in Figure 2. The figure shows existing noise exposure along the horizontal axis, noise from a new project source (alone) along the vertical axis and the resulting moderate and severe impact thresholds. In some instances, a proposed project may affect existing noise sources such as in the cases of relocation of streets or existing railroad tracks. In such cases, where existing noise sources would change as a direct result of the project, potential impact must be assessed based on the increase in overall noise exposure from existing to future conditions. While the two methods of assessing potential impact are equivalent, only the method based on the future increase in noise can be used to take into account changes to existing noise sources. Figure 3 expresses the same criteria in terms of the increase in total or cumulative noise that causes potential impact.

Because this project involves relocation of freight railroad tracks at some locations, this assessment uses the criteria in the form shown graphically in Figure 3. Along the horizontal axis of the graph is the range of existing noise exposure and the vertical axis shows the noise exposure increase due to the project that would cause either moderate or severe impact. The noise exposure increase is the difference between the existing noise level and the total future noise level, where the future level includes a combination of noise from existing and/or modified existing sources and from future project sources. Therefore, the future noise exposure increase would account for modifications to the existing environment such as shifting the freight railroad tracks.

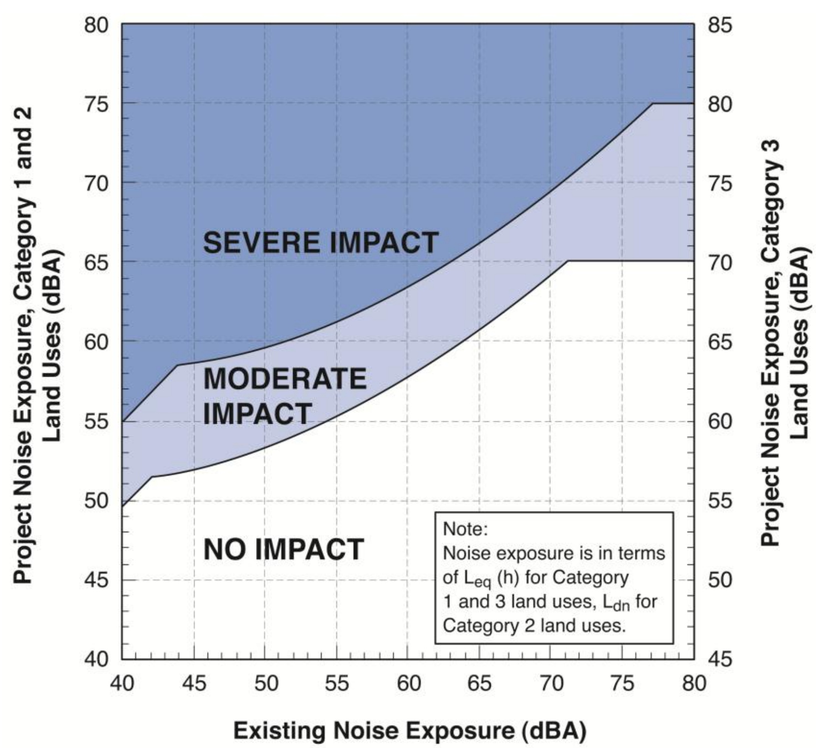


Figure 2. FTA Noise Impact Criteria Comparing Existing Noise to Project Noise
Source: Federal Transit Administration, 2006.

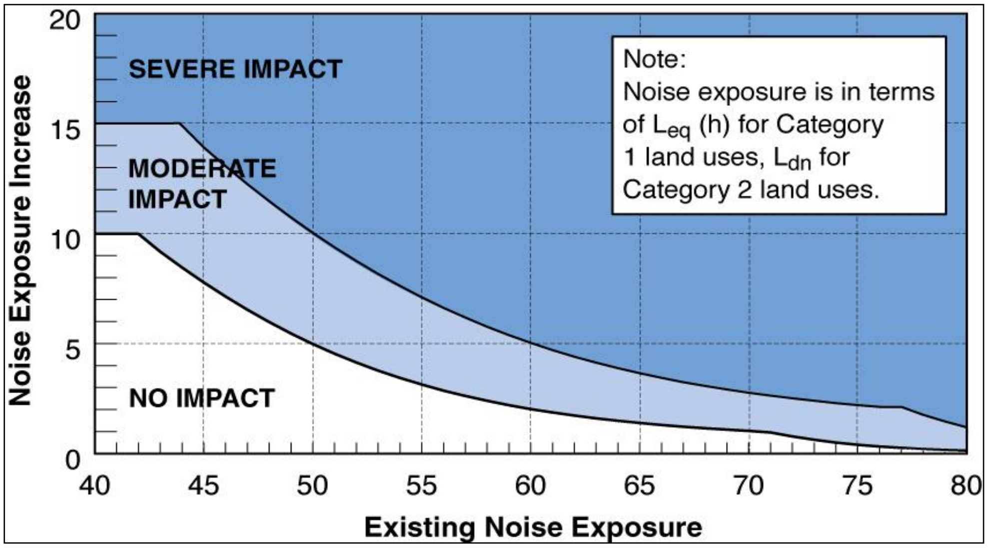


Figure 3: FTA Noise Impact Criteria Comparing Existing Noise to Increase in Future Noise
Source: Federal Transit Administration, 2006.

Construction Noise Impact Criteria

Construction noise criteria are based on the guidelines provided in the FTA guidance manual. These criteria, summarized in Table 3 below, are based on land use and time of day and are given in terms of noise exposure over an eight-hour work shift or 30-day period.

Table 3. Federal Transit Administration Construction Noise Assessment Criteria

Land Use	8-hour L_{eq}, dBA		Noise Exposure, dBA
	Day	Night	30-day Average
Residential	80	70	75[1]
Commercial	85	85	80[2]
Industrial	90	90	85[2]

[1] In urban areas with very high ambient noise levels (L_{dn} > 65 dB), L_{dn} from construction operations should not exceed existing ambient + 10 dB.
[2] Twenty-four-hour L_{eq}, not L_{dn}.
Source: Federal Transit Administration, 2006.

3.1.3 Noise Impact Assessment Methodology

The noise and vibration projections were carried out using the following methodological assumptions:

- All modeling projections are consistent with the methodology in the detailed assessment chapters of the U.S. Department of Transportation Federal Transit Administration's "Transit Noise and Vibration Impact Assessment" guidance manual (May 2006.)
- Noise-sensitive land use in the corridor was determined based on parcel data, aerial imagery,

and windshield surveys in the field.

- LRT speeds were provided by the project team at 100-foot increments along the corridor. Speeds range from 20 mph to 55 mph along the corridor, and the same speed profile was used for both directions of travel.
- LRT operations were assumed to use 3-car trains.
- The operating hours and service frequencies for LRT were assumed to be consistent with Metro Transit's Blue Line (Hiawatha). The service frequency assumed is as follows:
    - Early morning (4:00 to 6:00 a.m.): 20-30 minutes
    - Peak periods (6:00 to 9:00 a.m., 3:00 to 6:30 p.m.): 7.5 minutes
    - Midday (9:00 a.m. to 3:00 p.m.): 10 minutes
    - Evening (6:30 to 10:00 p.m.): 10 minutes
    - Late evening (10:00 p.m. to 2:00 a.m.): 30 minutes
- Existing noise levels were assigned to noise-sensitive receptors based on noise measurements conducted throughout the corridor and discussed in the next section of this report.
- The hours between 10:00 p.m. and 7:00 a.m. define nighttime events.
- Locations of aerial structures, crossovers, and embedded track were identified based on conceptual engineering plans available at the time of the assessment:
    - Noise level increases of up to 6 dB are assumed for receptors near crossover locations.
    - Noise level increases of 4 dB are assumed for receptors near aerial structures due to structure-radiated noise and reduced sound absorption for non-ballasted track.
    - Embedded track is assumed to be 1 dB quieter than ballast and tie track based on measured levels of the Blue Line (Hiawatha) LRT as reported in the Central Corridor LRT Final EIS.
    - Elevations of structures were based on profile information provided.
- Noise from audible warning devices was projected based on the following assumptions:
    - Trains will sound the bells when entering and exiting station platforms.
    - Train horns will begin to be sounded 20 seconds, but not more than ¼ mile, in advance of higher-speed grade crossings.
    - Wayside bells will be sounded before and after the passage of each train for a total duration of 30 seconds, based on field measurements of the Blue Line (Hiawatha).
    - Due to anticipated travel speeds in excess of 45 MPH the train high horn will be sounded at the following intersections:
        - 73rd Avenue (Alignment A Only)
        - 71st Avenue (Alignment B Only)
        - Corvallis Avenue
        - Broadway Avenue
        - 45 ½ Avenue
        - 42nd Avenue
        - 39 ½-40th Avenue
- Reference Levels:
    - The source reference levels for the Light Rail Vehicle (LRV) and wayside bells were based on the default values from the FTA guidance manual. The FTA manual assumes that a single rail car on ballast and tie track with continuous welded rail (CWR) generates a sound exposure level (SEL) of 82 dBA at a distance of 50 feet

from the track centerline, and that the wayside bells generate a maximum sound level (Lmax) of 73 dBA at a distance of 50 feet.
    - The source reference level for wayside bells at pedestrian crossings was determined based on field measurements of the Blue Line (Hiawatha). The pedestrian wayside crossing bells were found to generate a sound level of 68 dBA at a distance of 50 feet.
    - Reference levels for the vehicle horn and bell were provided by Metropolitan Council. It is assumed that LRV audible warning devices would generate sound levels of 95 dBA at 100 feet for the high horn and 79 dBA at 50 feet for the bell. Use of the high horn is assumed at all grade crossings where the speed exceeds 45 mph, and use of the bell is assumed at all other grade crossings. No low-horn usage was assumed.
    - Where LRVs operate on tight-radius curves (approximately 400-foot radius curves or less), there is the potential for increased noise due to wheel squeal. However, because wheel squeal is highly variable and difficult to predict, it has not been included in this assessment. It is assumed that mitigation for wheal squeal on curves, such as track lubrication devices, will be included in final design if curve squeal occurs on the Bottineau Corridor.
- Assumed property acquisitions were not counted as potential noise impacts.

Because the construction of the Bottineau Transitway in Alignments C and D1 would require the existing Burlington Northern Santa Fe (BNSF) rail line to be shifted to the west, the effect of moving freight operations relative to noise-sensitive receivers was included in the noise impact analysis. Freight train noise levels, including contributions from locomotives, rail cars and horns, were predicted using Federal Railroad Administration (FRA) methodology. Because freight trains tended not to contribute significantly to the measured existing noise levels, and to provide a consistent comparison of existing and future noise levels, the noise from current freight operations was first estimated and then combined with the background ambient noise levels described in Section 3.3.2 to determine the total existing noise levels in Alignments C and D1. The prediction of existing freight train noise was based on the following assumptions:

- Baseline freight train operations include one daily round trip during the daytime hours.
- All freight trains include 2 locomotives and 20 cars, and operate at a speed of 20 mph.
- All freight trains sound their horn 20 seconds, but not more than ¼ mile in advance of grade crossings in conformance with current FRA regulations.
- Locomotive horns are center mounted, generating a sound level of 104 dBA at a distance of 100 feet.
- The shifted BNSF railroad track will be updated from jointed rail to CWR.
- Wheel impacts at track joints cause noise level increases of 5 dB for rail cars.

The update of the BNSF rail line to CWR will result in a 5 dB decrease in noise level from the wheel rail interaction for rail cars, but no change to the noise level from locomotive engines. Properties west of the rail line will be closer to the relocated track and may experience an increase in noise level. The increase in noise level due to the shift of the BNSF rail line varies for these properties because their distance to the existing and future rail line varies. Noise levels may increase by up to 4 dB for properties within 50 feet of the shifted future freight line. Properties that are at least 100 feet or farther from the future freight line will experience little to no increase in noise level from freight operations.

Future freight train noise levels were estimated based on the information above, except that all operations were assumed to be on the relocated and upgraded track (from jointed rail to CWR). The future noise levels from the freight operations were then combined with both the existing baseline ambient noise levels and the predicted LRT noise levels to determine the total future noise exposure. Finally, noise impact was assessed based on the projected noise increase at each sensitive receptor area, according to the FTA criteria.

Additional noise from Operation and Maintenance Facility (OMF) and station park-and-ride activities has also been taken into account in the assessment. The prediction of noise from these facilities was based on the following assumptions:

- There will be 29 train movements for OMF locations on Alignment B.
- For the park-and-ride facility, the parking lot will fill to capacity in the morning (5 to 7 a.m. during nighttime hours) and empty completely in evening (5 to 7 p.m. during daytime hours)

Examples of the projected noise exposure from LRT operations at the maximum operating speed of 55 mph with and without vehicle horns and bells are shown in Figure 4 as a function of distance. The projections are based on the assumptions described above and are for community locations with an unobstructed view of the tracks. These results show that the highest noise levels occur when train horns are sounded.

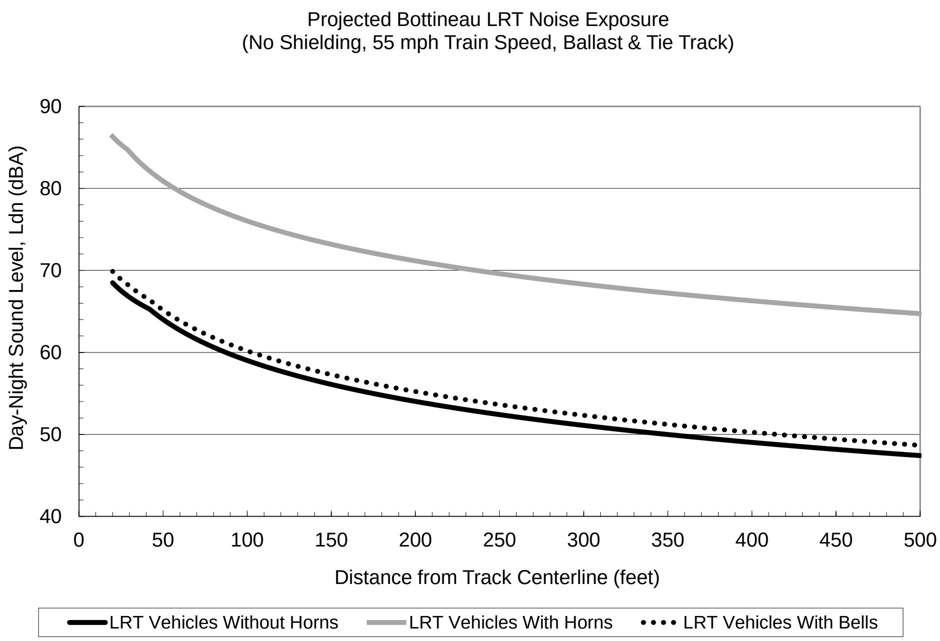


Figure 4. Projected 24-Hour Noise Exposure from LRT Operations
Source: Harris Miller Miller & Hanson Inc., 2012.

3.2 Affected Environment for Noise

The Bottineau Transitway Project build alternative alignments are located in suburban and urban areas in the greater Minneapolis metropolitan area. The existing noise environments and sensitive land uses vary among the alignments and are described below.

Alignment A

This alignment is located along County Road (CR) 130 and the predominant noise sources are CR 130 traffic, local roadway traffic, and commercial activity. Noise-sensitive land use includes Arbor

Lakes Senior Living, Hennepin Technical College, and several single- and multi-family residences near Boone Avenue North.

Alignment B

This alignment is located along CR 103 and CR 130 and the predominant noise sources are traffic on CR 103, CR 130, and local roadways. Activity from residential neighborhoods, schools, and commercial land uses also contribute to the existing noise environment. Noise-sensitive land use includes North Hennepin Community College, Step by Step Montessori School, and several single- and multi-family residences north and south of CR 109 (85th Avenue).

Alignment C

This alignment is located adjacent to the BNSF railroad tracks from 73rd Avenue North in Brooklyn Park to 36th Avenue North in Robbinsdale. The alignment is located along CR 81 starting from the north, and then shifts to run along West Broadway Avenue after crossing the Canadian Pacific (CP) railroad tracks. This alignment also passes by Crystal Airport. The predominant noise sources affecting the existing noise environment are traffic on CR 81 and West Broadway Avenue, BNSF train traffic, and airport activity. Noise-sensitive land use includes single- and multi-family residences, schools, churches, several hotels, parks identified for passive use, and Glen Haven Memorial Garden Cemetery, located about 450 feet west of the proposed alignment.

Alignment D1

This alignment is located along the BNSF railroad tracks and is adjacent to several park areas, including Theodore Wirth Regional Park. The alignment turns east along TH 55 until it reaches downtown Minneapolis. The predominant noise sources affecting the existing noise environment are train traffic on the BNSF railroad, as well as local roadway traffic, and community activity. Noise-sensitive land use includes single- and multi-family residences, schools, churches, hotels, Sumner Library, and parks identified for passive use.

Alignment D2

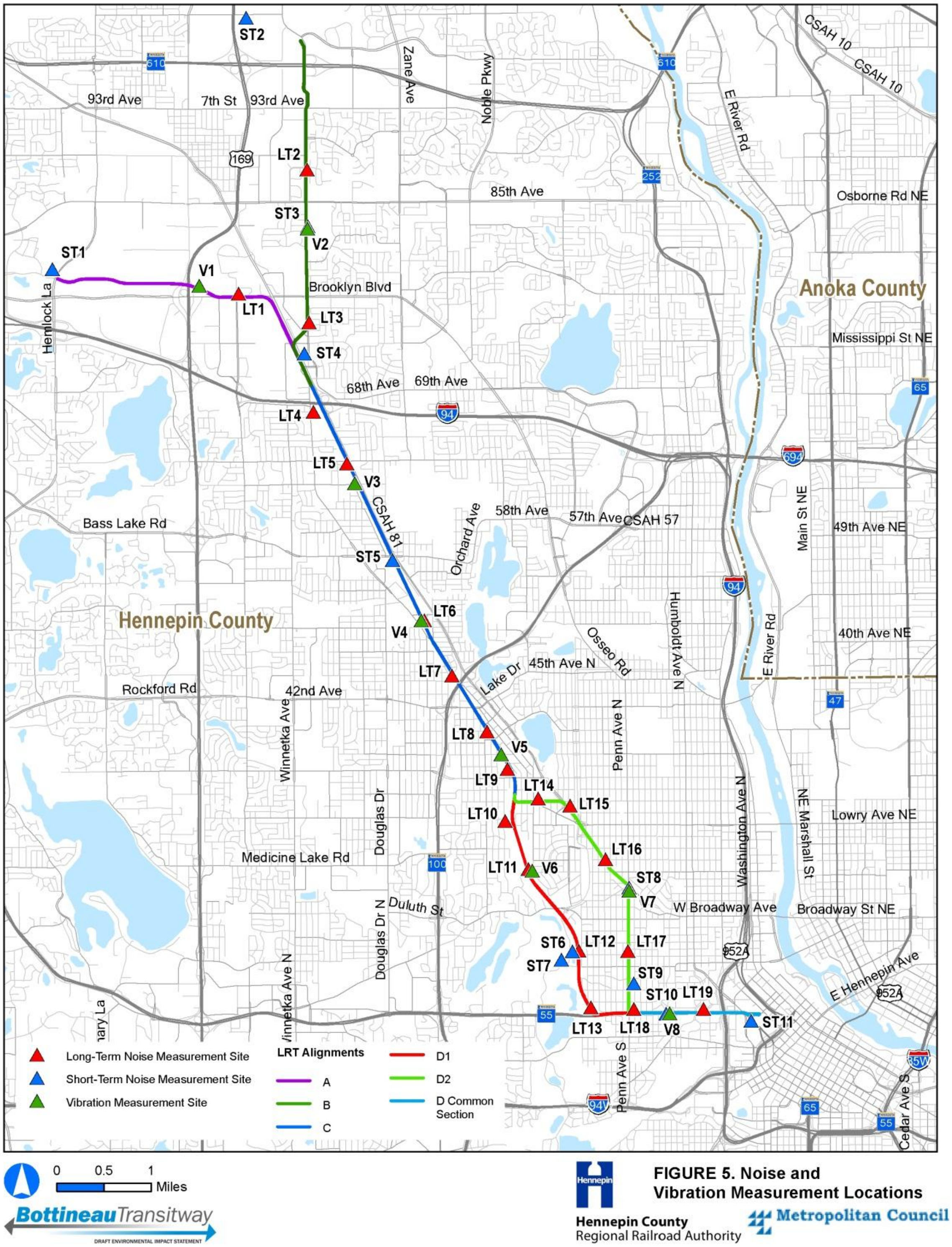
This alignment exits the rail corridor at 34th Avenue and proceeds east to CR 81. Along CR 81 and Penn Avenue and then turns east along TH 55 until it reaches downtown Minneapolis. The predominant noise sources affecting the existing noise environment are traffic on those roads, as well as local roadway traffic and community activity. North Memorial Medical Center, NorthPoint Health and Wellness Center, and KMOJ Radio Station are noise-sensitive land uses that are adjacent to this alignment. Other noise-sensitive land use includes single- and multi-family residences, schools, churches, hotels, Sumner Library, and parks identified for passive use.

3.2.1 Noise Measurement Locations and Procedures

Existing ambient noise levels in the project area were characterized through direct measurements at selected sites along the study corridor. The testing was performed during two time periods, first from July 13 through July 15, 2011 and subsequently from May 14 through May 18, 2012. The measurements consisted of long-term (24-hour) and short-term (1-hour) monitoring of the A-weighted sound level at representative noise-sensitive locations. Seven (7) long-term and two (2) short-term noise measurements were conducted in July of 2011, and twelve (12) long-term and nine (9) short-term noise measurements were conducted in May of 2012. The measurement locations, shown in Figure 5, were selected to be representative of the noise environment in general and specifically at locations most likely to be affected by transit noise. At each site, the measurement microphone was positioned to characterize the exposure of the site to the dominant noise sources in the area.

Bruel & Kjaer model 2250 noise monitors, conforming to ANSI Standard S1.4 for precision (Type 1) sound level meters, were used for gathering noise data. Calibrations, traceable to the U.S. National Institute of Standards and Technology (NIST) were carried out in the field using acoustic calibrators. Thunderstorms in the Minneapolis area on July 15, 2011 caused a measureable increase in ambient noise from approximately 11:00 a.m. to 1:00 p.m. To more accurately determine existing noise levels from noise monitoring conducted during the thunderstorms, noise levels from data in the hours prior to and following the affected hours were used to estimate the noise levels during the affected time period.

Figure 5. Noise and Vibration Measurement Locations



3.2.2 Noise Measurement Results

The results of the existing ambient noise measurements are summarized in Table 4. For each site, the table lists the adjacent alignment(s), site location, measurement details, and the measured noise levels. The results at each site are further described below. Photographs of the noise measurement sites are included in Appendix A, and detailed noise measurement results are included in Appendix B.

Table 4. Summary of Existing Ambient Noise Measurement Results

Site No.	Alignment	Measurement Location	Start of Measurement		Meas. Duration (hrs)	Noise Exposure (dBA)	
			Date	Time		L_{dn}[1]	L_{eq}[2]
LT-1	A	7700 Boone Avenue North, Brooklyn Park	5-14-12	11:00	24	63	59
LT-2	B	8745 Oregon Avenue North, Brooklyn Park	7-14-11	10:00	24	66	62
LT-3	B	7428 75th Circle North, Brooklyn Park	5-14-12	13:00	24	60	55
LT-4	C	6648 West Broadway Avenue, Brooklyn Park	5-15-12	13:00	24	61	61
LT-5	C	6288 Louisiana Court N, Brooklyn Park (Waterford Manor)	5-14-12	12:00	24	63	57
LT-6	C	5001 Welcome Avenue North, Crystal	7-14-11	15:00	24	54	48
LT-7	C	4416 Toledo Avenue North, Robbinsdale	5-14-12	14:00	24	57	49
LT-8	C	3954 Noble Avenue North, Robbinsdale	7-14-11	14:00	24	66	49
LT-9	C	4400 36th Avenue North, Robbinsdale (Lee Square Co-Op)	5-15-12	15:00	24	54	48
LT-10	D1	3230 Kyle Avenue North, Golden Valley	5-15-12	14:00	24	51	45
LT-11	D1	3912 26th Avenue North, Robbinsdale	7-13-11	16:00	24	50	45
LT-12	D1	The Family Partnership – 1501 Xerxes Avenue North, Golden Valley	7-14-11	17:00	24	55	50
LT-13	D1	623 North Vincent Avenue, Minneapolis	5-16-12	17:00	24	56	50
LT-14	D2	3807 Van Demark Avenue, Robbinsdale	5-16-12	16:00	24	53	44
LT-15	D2	3334 Lakeland Avenue North, Robbinsdale	7-13-11	14:00	24	62	57
LT-16	D2	2519 North 27th Avenue, Minneapolis	5-16-12	18:00	24	65	61
LT-17	D2	1411 Penn Avenue North, Minneapolis	7-13-11	15:00	24	68	62

Site No.	Alignment	Measurement Location	Start of Measurement		Meas. Duration (hrs)	Noise Exposure (dBA)	
			Date	Time		L_{dn}[1]	L_{eq}[2]
LT-18	D common section	611 North Oliver Avenue, Minneapolis	5-17-12	12:00	24	62	59
LT-19	D common section	1000 TH 55, Minneapolis (Heritage Park)	5-15-12	18:00	24	65	61
ST-1	A	Arbor Lakes Retirement Community, Maple Grove	5-15-12	7:58	1	50	52
ST-2	B	Grace Fellowship Church, Brooklyn Park	5-14-12	17:00	1	54	56
ST-3	B	North Hennepin Community College, Brooklyn Park	5-14-12	15:33	1	58	60
ST-4	C	Prince of Peace Church, Brooklyn Park	5-16-12	13:11	1	57	59
ST-5	C	Becker Park, Crystal	5-17-12	13:51	1	54	56
ST-6	D1	Theodore Wirth Regional Park, Golden Valley	5-18-12	10:01	1	47	49
ST-7	D1	The Chalet at Theodore Wirth Regional Park, Golden Valley	5-18-12	11:20	1	53	55
ST-8	D2	KMOJ Radio Station – Penn Avenue and Broadway Avenue, Minneapolis	7-15-11	13:27	1	68	70
ST-9	D2	Lincoln Junior High – Oliver Street, Minneapolis	7-13-11	16:21	1	50	52
ST-10	D common section	Harrison Education Center, Minneapolis	5-15-12	16:07	1	60	62
ST-11	D common section	Mary My Hope Children's Center, Minneapolis	5-17-12	16:09	1	65	67

[1] For sites ST-1 through ST-11, the L_{eq} measurements were used to estimate the L_{dn} using FTA methodology for estimating noise exposure. This approach tends to be conservative and underestimate the existing noise levels, which can result in higher levels of noise impact for a project.
[2] For sites LT-1 through LT-19, the L_{eq} was taken from the quietest hour of the typical peak traffic hours: 6:00 a.m. to 9:00 a.m. and 4:00 p.m. to 7:00 p.m. The lowest peak traffic hour noise level is used to provide a conservative estimate of the noise.
Source: Harris Miller Miller & Hanson Inc., 2012

Site LT-1: 7700 Boone Avenue – Brooklyn Park, MN. The L_{dn} measured over a 24-hour period in the back yard of this single-family residence was 63 dBA. Sources contributing to the ambient noise environment at this location include traffic on Brooklyn Boulevard and other local roads.

Site LT-2: 8745 Oregon Avenue North – Brooklyn Park, MN. The L_{dn} measured over a 24-hour period in the back yard of this single-family residence was 66 dBA. Sources contributing to the ambient noise environment at this location include traffic on CR 103 and local roads as well as commercial and community activity.

Site LT-3: 7428 75th Circle North – Brooklyn Park, MN. The L_{dn} measured over a 24-hour period in the back yard of this duplex residence was 60 dBA. Sources contributing to the ambient noise environment at this location include traffic on CR 103 and local roads as well as commercial and community activity.

Site LT-4: 6648 West Broadway Avenue – Brooklyn Park, MN. The L_{dn} measured over a 24-hour period in the back yard of this single-family residence was 61 dBA. Sources contributing to the ambient noise environment at this location include traffic on CR 8 and CR 81, as well as other local roads.

Site LT-5: 6288 Louisiana Court N – Brooklyn Park, MN (Waterford Manor). The L_{dn} measured over a 24-hour period in the back yard of this multi-family retirement community was 63 dBA. Sources contributing to the ambient noise environment at this location include freight traffic on the BNSF railroad as well as traffic on CR 81 and other local roads.

Site LT-6: 5001 Welcome Avenue – Crystal, MN. The L_{dn} measured over a 24-hour period in the back yard of this single-family residence was 54 dBA. Sources contributing to the ambient noise environment at this location include freight traffic on the BNSF railroad and other nearby rail lines, traffic on local roads, and residential community activity.

Site LT-7: 4416 Toledo Avenue North – Robbinsdale, MN. The L_{dn} measured over a 24-hour period in the back yard of this single-family residence was 57 dBA. Sources contributing to the ambient noise environment at this location include freight traffic on the BNSF railroad as well as traffic on CR 8 and other local roads.

Site LT-8: 3854 Noble Avenue – Robbinsdale, MN. The L_{dn} measured over a 24-hour period in the back yard of this single-family residence was 66 dBA. Sources contributing to the ambient noise environment at this location include freight traffic on the BNSF railroad and traffic on local roads, as well as commercial and community activity.

Site LT-9: 4400 36th Ave N – Robbinsdale, MN (Lee Square Co-Op). The L_{dn} measured over a 24-hour period in the back yard of this multi-family retirement community was 54 dBA. Sources contributing to the ambient noise environment at this location include freight traffic on the BNSF railroad, pedestrian and bicycle path traffic, and traffic on 36th Avenue North and other local roads.

Site LT-10: 3230 Kyle Ave N – Golden Valley, MN. The L_{dn} measured over a 24-hour period in the back yard of this single-family residence was 51 dBA. Sources contributing to the ambient noise environment at this location include freight traffic on the BNSF railroad, local roadway traffic, and residential community activity.

Site LT-11: 3912 26th Avenue North – Robbinsdale, MN. The L_{dn} measured over a 24-hour period in the back yard of this single-family residence was 50 dBA. Sources contributing to the ambient noise environment at this location include freight traffic on the BNSF railroad as well as residential community activity.

Site LT-12: 1501 Xerxes Avenue North – Golden Valley, MN. The L_{dn} measured over a 24-hour period in the back yard of The Family Partnership was 55 dBA. Sources contributing to the ambient noise environment at this location include freight traffic on the BNSF railroad and traffic on local roads, as well as residential and school activity.

Site LT-13: 623 N Vincent Ave – Minneapolis, MN. The L_{dn} measured over a 24-hour period in the back yard of this duplex residence was 56 dBA. Sources contributing to the ambient noise environment at this location include freight traffic on the BNSF railroad and other nearby rail lines. Traffic on local roads also contributed to the existing noise environment.

Site LT-14: 3807 Van Demark Rd – Robbinsdale, MN. The L_{dn} measured over a 24-hour period in the side yard of this single-family residence was 53 dBA. Sources contributing to the ambient noise environment at this location include by traffic on CR 81 and local roads, as well as hospital activity at North Memorial Medical Center.

Site LT-15: 3334 Lakeland Avenue – Robbinsdale, MN. The L_{dn} measured over a 24-hour period in the side yard of this single-family residence was 62 dBA. Sources contributing to the ambient noise environment at this location include traffic on CR 81 and local roads, as well as hospital activity at North Memorial Medical Center.

Site LT-16: 2519 N 27th Ave – Minneapolis, MN. The L_{dn} measured over a 24-hour period in the side yard of this single-family residence was 65 dBA. Sources contributing to the ambient noise environment at this location include traffic on West Broadway Ave and local roads, as well as community activity.

Site LT-17: 1411 Penn Avenue – Minneapolis, MN. The L_{dn} measured over a 24-hour period in the back yard of this duplex residence was 68 dBA. Sources contributing to the ambient noise environment at this location include traffic on Penn Avenue and other local roads, as well as hospital activity at NorthPoint Health and Wellness Center.

Site LT-18: 611 N Oliver Ave – Minneapolis, MN. The L_{dn} measured over a 24-hour period in the back yard of this single-family residence was 62 dBA. Sources contributing to the ambient noise environment at this location include traffic on TH 55 and other local roads.

Site LT-19: 1000 TH 55 – Minneapolis, MN (Heritage Park). The L_{dn} measured over a 24-hour period in the back yard of this duplex residence was 65 dBA. Sources contributing to the ambient noise environment at this location include traffic on TH 55 and other local roads.

Site ST-1: Arbor Lakes Retirement Community – Maple Grove, MN. The L_{eq} measured over a 1-hour period on the property of this retirement community was 52 dBA. Sources contributing to the ambient noise environment at this location include traffic on Hemlock Lane and Arbor Lakes Parkway.

Site ST-2: Grace Fellowship Church – Brooklyn Park, MN. The L_{eq} measured over a 1-hour period at this church was 56 dBA. Sources contributing to the ambient noise environment at this location include traffic on US 169 and other nearby roads.

Site ST-3: North Hennepin Community College – Brooklyn Park, MN. The L_{eq} measured over a 1-hour period in the parking lot of this school was 60 dBA. Sources contributing to the ambient noise environment at this location include traffic on Broadway Avenue.

Site ST-4: Prince of Peace Church – Brooklyn Park, MN. The L_{eq} measured over a 1-hour period at this church was 59 dBA. Sources contributing to the ambient noise environment at this location include traffic on Broadway Avenue and CR 81.

Site ST-5: Becker Park – Crystal, MN. The L_{eq} measured over a 1-hour period in this park was 56 dBA. Sources contributing to the ambient noise environment at this location include traffic on CR 81, Bass Lake Road, and community activity.

Site ST-6: Theodore Wirth Regional Park – Golden Valley, MN. The L_{eq} measured over a 1-hour period in this park was 49 dBA. Sources contributing to the ambient noise environment at this location include traffic on Theodore Wirth Parkway.

Site ST-7: The Chalet at Theodore Wirth Regional Park – Golden Valley, MN. The L_{eq} measured over a 1-hour period in this park was 55 dBA. Sources contributing to the ambient noise environment at this location include traffic on Theodore Wirth Parkway.

Site ST-8: KMOJ Radio Station – Minneapolis, MN. The L_{eq} measured over a 1-hour period on the sidewalk next to this radio station was 70 dBA. Sources contributing to the ambient noise environment at this location include traffic on Broadway Avenue, Penn Avenue, and McNair Avenue, as well as commercial and community activity.

Site ST-9: Lincoln Junior High School – Minneapolis, MN. The L_{eq} measured over a 1-hour period in the parking lot of this school was 52 dBA. Sources contributing to the ambient noise environment at this location include traffic on Oliver Street as well as community activity.

Site ST-10: Harrison Education Center – Minneapolis, MN. The L_{eq} measured over a 1-hour period in this park was 62 dBA. Sources contributing to the ambient noise environment at this location include traffic on TH 55 and other local roads.

Site ST-11: Mary My Hope Children's Center – Minneapolis, MN. The L_{eq} measured over a 1-hour period on the sidewalk next to this children's center was 67 dBA. Sources contributing to the ambient noise environment at this location include traffic on 7th Avenue and community activity.

The noise measurement results indicate that most areas along the Bottineau project corridor within the study area have an existing noise environment typical of urban and suburban ambient levels, while some areas have ambient levels typical of quiet suburban environments. Noise monitoring sites in more densely populated areas such as downtown Robbinsdale, Penn Avenue, and TH 55 have ambient noise levels ranging from 62 to 68 dBA. This is because most of these sites are near major roadways and heavier commercial activity. Noise levels in Brooklyn Park range from 60 to 66 dBA due to the presence of major roadways and higher roadway speeds. Noise levels are lower for sites in the corridor where there is less roadway traffic and community and commercial activity. This includes sites near Theodore Wirth Regional Park on Alignment D1, with ambient noise levels ranging from 50 to 56 dBA. Some areas along alignment C that are further from major roadways and commercial activity also experience quieter suburban ambient noise levels. Due to the nature of the FTA noise criteria, areas with lower ambient noise levels are more likely to be affected by noise from the project, and therefore are more likely to have locations with noise impact.

3.3 Environmental Consequences for Noise

3.3.1 Operating Phase Impacts

No-Build Alternative

While there would be some changes in bus traffic on existing roadways due to future No-Build transit improvements, these would not significantly affect the existing noise levels. Thus, no noise impacts are anticipated within the Bottineau Transitway project area for the No-Build alternative.

Enhanced Bus/Transportation System Management Alternative

Similar to the No-Build alternative, no significant noise impacts would occur within the Bottineau Transitway project area for the Enhanced Bus/Transportation System Management alternative.

Build Alternatives

Table 5 below summarizes the results of the noise impact assessment by alignment option. Comparisons of the existing and future noise levels are presented in Table 5, which includes ranges of results for FTA Category 2 (residential) receptors with both daytime and nighttime sensitivity to noise and Category 3 receptors, consisting of institutional and recreational land uses with primarily daytime and evening use. In addition to the distances to the track and proposed train speeds, Table 5 includes the existing noise levels, the projected noise levels from rail operations, the future total noise levels, and the predicted noise increases due to the project within each segment along the corridor. The predicted noise level increase equals the future total noise level minus the existing noise level. Based on a comparison of the predicted noise level increase with the impact criteria, the table also includes an inventory of the number of moderate and severe noise impacts for each alignment option. The impacts for each alignment option are discussed below and Figures 12 through 40, located in the Figures Appendix in Section 6.0, show the locations of projected unmitigated noise impacts. This represents all of the potential impacts along the corridor if no mitigation measures were implemented. The application of mitigation measures would reduce the number of impacted locations and the severity of impacts. The noise impact figures show the entire Bottineau Corridor even though impacts are not projected to occur at all locations along the corridor.

Table 5. Summary of Unmitigated Noise Impacts by Alignment

Alignment	Receptor Type	Dist. to Track (ft)[1]	Train Speed (mph)	Existing Noise Level[1] (dBA)	Project Noise Level[1] (dBA)	Total Noise Level[1] (dBA)	Noise Level Increase[2] (dB)			Number of Receptors Impacted	
							Predicted[3]	Impact Criteria			
								Mod.	Sev.	Mod.	Sev.
A	Cat. 2	90 to 890	20 to 55	56 to 63	57 to 61	59 to 65	1.7 to 5.3	1.6 to 2.8	4.1 to 6.4	75	0
	Cat. 3	0		0	0	0	0	0	0	0	0
B	Cat. 2	65 to 890	20 to 50	56 to 66	57 to 74	59 to 75	1.5 to 11.4	1.3 to 3	3.5 to 6.9	150	8
	Cat. 3	450		56	63	64	7.4	5.8	10.7	1	0
C[4]	Cat. 2	30 to 770	20 to 55	54 to 68	55 to 83	58 to 83	1.7 to 26.5	1.1 to 3.6	3 to 7.8	689 to 708	481 to 484
	Cat. 3	90 to 610		48 to 49	59 to 75	59 to 75	10.1 to 26	9.4 to 10.2	15.3 to 16.3	4	2
D1[5]	Cat. 2	30 to 260	20 to 55	51 to 58	54 to 69	56 to 69	2.9 to 11.9	2.4 to 4.6	5.8 to 9.4	49 to 56	40
	Cat. 3	40 to 115		45 to 50	57 to 64	58 to 64	12.4 to 14.2	9.1 to 12.1	14.9 to 18.6	2	0
D2	Cat. 2	30 to 410	20 to 45	53 to 67	50 to 67	57 to 69	1.5 to 14.4	1.2 to 3.9	3.2 to 8.4	320	40
	Cat. 3	15 to 80		44 to 62	62 to 67	62 to 68	6.5 to 17.9	4.1 to 13	8.2 to 19.7	2	0
D Common Section	Cat. 2	100	20 to 35	64	61	66	1.8	1.5	4	18	0

[1] Distance to track is based on current alignment location data and has been rounded to the nearest 5 feet for this summary.

Alignment	Receptor Type	Dist. to Track (ft)[1]	Train Speed (mph)	Existing Noise Level[1] (dBA)	Project Noise Level[1] (dBA)	Total Noise Level[1] (dBA)	Noise Level Increase[2] (dB)			Number of Receptors Impacted	
							Predicted[3]	Impact Criteria			
								Mod.	Sev.	Mod.	Sev.

[2] Noise levels for land use category 2 are based on Ldn and noise levels for land use category 3 are based on one-hour Leq; both are measured in dBA.
[3] Predicted levels include LRV horn and bell noise and wayside crossing bells, where applicable.
[4] Impacts on C vary due to the use of horn at the 71st Avenue grade crossing with B and the bell with A. This assumption is based on speed.
[5] Impacts on D1 vary depending on use of the Golden Valley Road or Plymouth Avenue/Theodore Wirth Regional Park Station Options due to differences in speeds and noise sources at different locations on the corridor.
Source: Harris Miller Miller & Hanson Inc., 2012

Alignment A
For alignment A, no severe noise impact is predicted to occur and moderate noise impact is predicted to occur at 75 residences. There are generally a low number of impacts for this alignment option compared to other alignments due to a low number of noise-sensitive properties, although the presence of multi-family properties results in more residences affected. The impacts in this section are largely due to the use of the LRV high-horn audible warning device. Impacts are also caused by receiver proximity to both the track and to the wayside crossing signals.

Alignment B
For Alignment B, severe noise impact is predicted to occur at eight residences and moderate noise impact at 150 residences. Moderate noise impact is also predicted to occur at Prince of Peace Lutheran Church. The impacts in this section are largely due to receiver proximity to the track and wayside crossing signals, as well as proximity to crossovers.

Alignment C
For Alignment C, the total number of impacts differs depending on the north alignment option selected (A or B) as the assumed LRT speed at the 71st Avenue grade crossing is lower with Alignment A due to the proximity to the 71st Avenue station. The noise analysis assumes a bell will be sounded at the 71st Avenue grade crossing with Alignment A and a horn will be sounded with Alignment B. Severe noise impact is predicted to occur at 481 to 484 residences, Robin Hotel, Doug Stanton Ministries, and Triangle Park. Moderate noise impact is predicted to occur at 689 to 708 residences, Washburn McReavy Funeral Home, Sacred Heart Church and School, Welcome Park, and Lee Park. The impacts in this section are largely due to the use of the LRV high-horn audible warning device. Impacts are also caused by receiver proximity to the LRT track, the relocated BNSF rail line, and crossovers.

Alignment D1
For Alignment D1, the total number of impacts differs depending on which LRT station option is selected -- the Golden Valley Road Station Option or the Plymouth Avenue/Theodore Wirth Regional Park Station Option. This variation is due to changes in LRT speed depending on station location. Severe noise impact is predicted to occur at 40 residences and moderate noise impact is predicted to occur at 49 to 56 residences, South Halifax Park, and The Family Partnership School. The impacts in this section are largely due to receiver proximity to the track and crossovers. The residential noise impacts occur east of the alignment because the properties to the east are closer to the track and there are fewer residences to the west as the corridor is positioned along Walter Sochacki Park and Theodore Wirth Regional Park.

Alignment D2
For Alignment D2, severe noise impact is predicted to occur at 40 residences and moderate noise impact is predicted at 320 residences, North Memorial Medical Center and Outpatient Center, and NorthPoint Health and Wellness Center. The impacts in this section are largely due to receiver proximity to the track, crossovers, and track on aerial structure. No impact is predicted at KMOJ Radio Station. A greater number of moderate noise impacts is predicted on the west side of Penn Avenue (this includes homes that front on the east side of Queen Avenue with backyards adjacent to the transitway) than on the east due to the increase in future noise level predicted to result from the shift of Penn Avenue approximately 40 feet to the west. Impacts are due to both the removal of a row of homes facing Penn Avenue and the shift of Penn Avenue to the west.

Alignment D Common Section
For the Alignment D common section moderate noise impact is predicted to occur at 18 residences. The predicted impacts in this section are due to proximity to the track and crossovers. There are few

impacts in this section due to higher existing noise levels in this area as the corridor nears downtown Minneapolis and the placement of the alignment in the median of TH 55, which is a six-lane roadway along most of the alignment. There is also no predicted use of the high-horn in this section.

Summary of Impacts by Alternative

Table 6 below summarizes the predicted noise impact assessment results by Build Alternative.

Table 6. Summary of Unmitigated Noise Impacts by Alternative

Alternative	Total Number of Receptors with Moderate Noise Impact	Total Number of Receptors with Severe Noise Impact
No-Build Alternative	No noise impacts currently anticipated	
TSM Alternative	No noise impacts currently anticipated	
Alternative A-C-D1	844[1] 837[2]	523
Alternative A-C-D2	1,108	523
Alternative B-C-D1	939[1] 932[2]	534
Alternative B-C-D2	1,203	534

[1] With Golden Valley Road Station Option
[2] With Plymouth Avenue/Theodore Wirth Regional Park Station Option
Source: Harris Miller Miller & Hanson Inc., 2012

Roadway Changes

There would be modifications to existing roadways due to the proposed Bottineau Transitway project, which may affect future noise conditions. In particular, Penn Avenue on Alignment D2 would be shifted approximately 40 feet west, and the westbound lanes of TH 55 on Alignment D1 would be shifted approximately 60 feet north over a section approximately 800 feet in length. A noise analysis was conducted to determine the change in future noise levels for nearby sensitive receptors due to the roadway modifications. The noise analysis was based on measured noise levels from these roadways and future roadway alignments. The results indicate that roadway modifications would be expected to cause noise level increases of less than one dB, which would not substantially affect future noise conditions.

Stations

Noise projections near stations include speed adjustments and consideration of horn and bell noise at these locations. Additional noise from park-and-ride locations has also been included in the noise projections. However, the additional noise from park-and-ride activity does not significantly contribute to the total project noise level at any receptor.

Operation and Maintenance Facility (OMF)

The OMF option at the northernmost end of Alignment B at 101st Avenue is not predicted to cause noise impact at any noise-sensitive receptors. The closest receptor to this OMF option is Grace Fellowship church at approximately 1,300 feet from the center of OMF yard activity. The predicted Leq from yard noise is approximately 45 dBA at this receptor, which results in no increase above the measured existing Leq of 56 dBA at this location. For the OMF option on Alignment B at 93rd Avenue, the noise levels from yard activity is predicted to contribute to project noise levels at nearby receptors but is not predicted to cause impact.

Traction Power Substations

Traction power substations (TPSS) have the potential to cause noise impact when they are located in close proximity to noise-sensitive receptors. The primary noise sources associated with substations are magnetostriction of the transformer core, which causes low-frequency tonal noise (hum), and cooling fans, which typically generate broadband noise. At most, the potential for noise impacts from substations would be limited to noise-sensitive receptors located within 250 feet which is the FTA noise impact screening distance for this source; in reality, the extent of noise impact is generally much less. The potential for noise impact from substations will be evaluated in a later phase of the project when sufficient details relating to their design and specific locations become available. Noise impact can be avoided by selecting TPSS sites that are not near noise-sensitive receptors or, if necessary, by including noise limits in the procurement documents.

The Chalet at Theodore Wirth Regional Park

The Chalet at Theodore Wirth Regional Park is an active-use recreational building. Much of the use in Theodore Wirth Regional Park is active recreational activity, aside from an area of picnic tables that has been included in the noise assessment and is predicted to experience no noise impact due to the project. Facilities and parks meant for active-use are not considered noise-sensitive according to FTA criteria. However, the change in noise level that would be experienced at The Chalet at Theodore Wirth Regional Park due to the project has been considered. The existing noise level measured over a 1-hour period at The Chalet near the 10th Hole Tee was 55.4 dBA. According to FTA criteria, a noise level increase due to the project of 6.2 dBA would be the threshold for moderate impact at this location. The future noise level due to the project at this location would be 55.5 dBA with either the Golden Valley Road Station Option or the Plymouth Avenue/Theodore Wirth Regional Park Station Option. In either case, virtually no increase in noise level would be experienced at The Chalet due to the project.

3.3.2 Construction Phase Impacts

No-Build Alternative

No construction-related noise impacts of the Bottineau Transitway are anticipated to result from the No Build alternative.

Enhanced Bus/Transportation System Management Alternative

No construction-related noise impacts of the Bottineau Transitway are anticipated to result from the Enhanced Bus/Transportation System Management alternative.

Build Alternatives

Temporary noise impacts could result from activities associated with the construction of new tracks and stations, utility relocation, grading, excavation, track work, demolition, and installation of systems components. Such impacts may occur in residential areas and at other noise-sensitive land uses located within several hundred feet of the alignment. The potential for noise impact would be greatest at locations near pile-driving operations for bridges and other structures, pavement breaking, and at locations close to any nighttime construction work.

Construction noise varies greatly depending on the construction process, type and condition of equipment used, and layout of the construction site. Many of these factors are traditionally left to the contractor's discretion, which makes it difficult to accurately estimate levels of construction noise. Overall, construction noise levels are governed primarily by the noisiest pieces of equipment. For most construction equipment, the engine, which is usually diesel, is the dominant noise source. This is particularly true of engines without sufficient muffling. For activities such as impact pile driving and pavement breaking, the predominant noise is that generated by the actual process.

Table 7 summarizes some available data on noise emissions of construction equipment from the FTA guidance manual, in terms of averages of the Lmax values at a distance of 50 feet. Although the noise levels in the table represent typical values, there can be wide fluctuations in the noise emissions of similar equipment. Construction noise exposure at a given noise-sensitive location depends on the magnitude of noise during each construction phase, the duration of the noise, and the distance from the construction activities.

Table 7: Construction Equipment Noise Emission Levels

Equipment Type	Typical Sound Level at 50 ft. (dBA)
Backhoe	80
Bulldozer	85
Compactor	82
Compressor	81
Concrete Mixer	85
Concrete Pump	82
Crane, Derrick	88
Crane, Mobile	83
Loader	85
Pavement Breaker	88
Paver	89
Pile Driver, Impact	101
Pump	76
Roller	74
Truck	88
Source: Federal Transit Administration, 2006	

Projecting construction noise exposure requires an understanding of the equipment likely to be used, the duration of its use, and the way it may be used by an operator (e.g., the percentage of time during operating hours that the equipment operates under full power during each phase). Using typical sound emission characteristics, as given in Table 7, it is possible to estimate Leq or Ldn at various distances from the construction site.

The noise impact assessment for a construction site is based on:

- An estimate of the type of equipment that would be used during each phase of the construction and the average daily duty cycle for each category of equipment
- Typical noise emission levels for each category of equipment such as those in Table 7

- Estimates of noise attenuation as a function of distance from the construction site

Table 8 is an example of the noise projections for equipment that is often used during tie-and-ballast track construction. For the calculations, it is assumed that all the equipment is located at the geometric center of the construction work site. Based on this scenario, an 8-hour Leq of 88 dBA would be expected at a distance of 50 feet from the geometric center of the work site. This calculation in Table 8 does not assume any noise mitigation measures or any limits on the contractor about how much noise can be made. With at-grade track construction, the duration of the activities at a specific location along the alignment would be relatively limited, usually a matter of several weeks. As a result, even when there may be noise impacts, the limited duration of the construction can mean that mitigation is not cost effective.

Table 8: Typical Equipment List, At-Grade Track Construction

Equipment Item	Typical Maximum Sound Level at 50 ft. (dBA)	Equipment Utilization Factor (%)	Leq (dBA)
Air Compressor	83	50%	80
Backhoe	80	40%	76
Crane, Derrick	82	10%	72
Dozer	85	40%	81
Generator	81	80%	80
Loader	85	40%	81
Pavement Breaker	84	4%	70
Shovel	80	40%	76
Dump Truck	88	16%	80
Total Workday Leq at 50 feet (8-hour workday)			88
Source: Harris Miller Miller & Hanson Inc., 2012			

Based on the criteria in Section 3.1.3 and the noise projections in Table 8, and assuming that construction noise is reduced by 6 decibels for each doubling of distance from the center of the site, screening distances for potential track construction noise impact can be estimated. These estimates suggest that the potential for track construction noise impact would be minimal for commercial and industrial land use, with impact screening distances of 70 feet and 40 feet, respectively. Even for residential land use, the potential for temporary track construction noise impact would be limited to locations within about 125 feet of the corridor. However, the potential for noise impact from nighttime track construction could extend to residences as far as 400 feet.

3.3.3 Indirect/Secondary Impacts

No indirect/secondary noise impacts are anticipated for any of the project alternatives.

3.4 Avoidance, Minimization, and/or Mitigation Measures

3.4.1 Operational Noise Mitigation Measures

To mitigate noise impact from train operations, noise control can be considered at the source, along the sound path, or at the receiver. Potential mitigation measures for reducing noise impacts from the proposed project operations are described in Table 9.

Noise mitigation is considered depending on the need, feasibility, reasonableness, and effectiveness of potential options. The FTA states that in considering potential noise impact, severe impacts should be mitigated if at all practical and effective. At the moderate impact level, more discretion should be used, and other project-specific factors should be included in considering the need for mitigation. These factors include the existing noise level, predicted increase over the existing noise levels, the types and number of noise-sensitive land uses affected, the noise sensitivity of the properties, the acoustic effectiveness of mitigation options, and the cost-effectiveness of mitigating the noise.

Table 9. Potential Noise Mitigation Measures

Mitigation Location	Mitigation Option	Description
Source	Establishment of Quiet Zones	An effective option for mitigating noise impacts along the alignment would be to establish “quiet zones” near at-grade crossings. Quiet zones would need to be established in accordance with FRA regulations. In quiet zones, because of safety improvements at the at-grade crossings, train operators would sound horns only in emergency situations rather than as a standard operating procedure. Establishing quiet zones would require cooperative action among the municipalities along the corridor, Minnesota DOT, FRA, BNSF, and the transit agency. The municipalities are key participants in the process, as they must initiate the request to establish quiet zones through application to the FRA. To meet safety criteria, the municipalities may also be required to provide improvements at grade crossings such as modifications to the streets, raised medians, warning lights, and other devices. The FRA regulation also authorizes the use of automated wayside horns at crossings along with flashing lights and gates as a substitute for the train horn. While activated by the approach of trains, these devices are pole-mounted at the grade crossing, thereby limiting the horn noise exposure area to the immediate vicinity of the crossing.
	Modified Use of Audible Warning Devices	An approach for mitigating noise impacts due to LRV and wayside audible warning devices (e.g., horns and bells) would be to modify the design, settings or use of these devices.
	Special Trackwork	Turnouts are a major source of noise impact when they are located in sensitive areas. If turnouts cannot be relocated away from sensitive areas, other methods can be used to reduce noise impacts such as the use of spring-rail, flange-bearing, or moveable-point frogs in place of standard rigid frogs at turnouts. These devices allow the flangeway gap to remain closed in the main traffic direction for revenue service trains.
	Wheel/Rail Lubrication	There are several options to mitigate potential wheel squeal from small-radius curves, including on-board solid-stick rail lubrication and wayside rail lubrication. Automated wayside top-of-rail friction modifier systems put a small amount of lubricant onto the top of the rail, which maintains a constant coefficient of friction. This type of lubricant has been shown to reduce or eliminate the potential for wheel squeal.

Mitigation Location	Mitigation Option	Description
Path	Noise Barriers	This is a common approach to reducing noise impacts from surface transportation sources. The primary requirements for an effective noise barrier are that the barrier must be high enough and long enough to break the line-of-sight between the sound source and the receiver, be of an impervious material with a minimum surface density of four lb/sq. ft., and not have any gaps or holes between the panels or at the bottom. Because numerous materials meet these requirements, the selection of materials for noise barriers is usually dictated by aesthetics, durability, cost, and maintenance considerations. Noise barriers for transit projects typically range in height from eight feet to twelve feet.
Receiver	Building Sound Insulation	Sound insulation of residences and institutional buildings to improve the outdoor-to-indoor noise reduction has been widely applied around airports and in some situations for transit projects. Although this approach has no effect on noise in exterior areas, it may be the best choice for sites where noise barriers are not feasible or desirable, and for buildings where indoor sensitivity is of most concern. Substantial improvements in building sound insulation (of 5 to 10 dBA) can often be achieved by adding an extra layer of glazing to the windows, by sealing any holes in exterior surfaces that act as sound leaks, and by providing forced ventilation and air-conditioning so that windows do not need to be opened.
Source: Harris Miller Miller & Hanson Inc., 2012		

Potential noise mitigation measures associated with each alignment are summarized in Table 10. The table includes the number of impacted receptors that could be benefitted with the implementation of the primary potential mitigation measures listed, as well as the number of noise impacts that would remain. Additional potential mitigation measures that could be implemented to mitigate the remaining noise impacts are discussed in Table 10. These potential mitigation strategies will be further evaluated during preliminary engineering to determine their feasibility and reasonableness, considering factors such as safety impacts, cost effectiveness, and acceptability to the community.

Table 10. Potential Noise Mitigation Measures

Alignment	Primary Potential Mitigation Measure[1]	Receptors Benefitted with Primary Potential Mitigation Measure	Remaining Noise Impacts		Discussion
			Moderate	Severe	
A	Quiet Zones	65 to 70	5 to 10	0	Potential mitigation could include the implementation of quiet zones from 73rd Avenue to 40th Avenue, sound insulation, and modification to the design, settings or use of audible warning devices.
B	Quiet Zones	90 to 95	55 to 60	5 to 10	Potential mitigation could include the implementation of quiet zones from 73rd Avenue to 40th Avenue, sound insulation, and modification to the design, settings or use of audible warning devices.
C[2]	Quiet Zones, Noise Barriers, Crossover Mitigation	800 to 830	350 to 355	15 to 20	Potential mitigation could include the implementation of quiet zones from 73rd Avenue to 40th Avenue, modifying or relocating crossovers located between 39th Avenue North and 37th Avenue North, and the potential installation of two noise barriers on the east side of the alignment between Corvallis Avenue North and West Broadway Avenue and between 40th Avenue North and 34th Avenue North. Further potential mitigation includes modifications to the design, settings, and use of audible warning devices at grade crossings, additional noise barriers, or sound insulation.

Alignment	Primary Potential Mitigation Measure[1]	Receptors Benefitted with Primary Potential Mitigation Measure	Remaining Noise Impacts		Discussion
			Moderate	Severe	
D1[3]	Noise Barriers	70 to 75	25 to 35	0 to 5	Potential mitigation could include three noise barriers on the east side of the alignment between 34th Avenue North and 31 ½ Avenue North, 27th Avenue North and Golden Valley Road, and North Oak Park Avenue and TH 55. Further potential mitigation includes additional noise barriers, sound insulation or modifications to the design, settings or use of audible warning devices.
D2	Noise Barriers, Crossover Mitigation	45 to 50	305 to 310	5 to 10	Potential mitigation could include the installation of a noise barrier on the south side of the alignment between France Avenue North and Abbott Avenue North, as well as modification or relocation of crossovers between 30th Avenue North and 29th Avenue North. Further potential mitigation includes additional noise barriers, sound insulation or modifications to the design, settings or use of audible warning devices.
D Common Section	–	0	15 to 20	0	Potential mitigation could include sound insulation or relocating or modifying crossovers.

[1] Potential mitigation strategies will be further evaluated during preliminary engineering to determine their feasibility and reasonableness, considering factors such as safety impacts, cost effectiveness, and acceptability to the community.
[2] Properties on C vary depending on the north alignment selected (A or B).
[3] Properties on D1 vary depending on use of the Golden Valley Road or Plymouth Avenue/Wirth Park Station Options due to differences in speeds and noise sources at different locations on the corridor.
Source: Harris Miller Miller & Hanson Inc., 2012

3.4.2 Construction Noise Mitigation Measures

Construction activities would be carried out in compliance with all applicable local noise regulations. Noise control measures that could be applied during construction include the following:

- Avoiding nighttime construction in residential neighborhoods
- Using specially quieted equipment with enclosed engines and/or high-performance mufflers
- Locating stationary construction equipment as far as possible from noise-sensitive sites
- Constructing noise barriers, such as temporary walls or piles of excavated material, between noisy activities and noise-sensitive receivers
- Re-routing construction-related truck traffic along roadways that would cause the least disturbance to residents
- Avoiding impact pile driving near noise-sensitive areas, where possible. Drilled piles or the use of a sonic or vibratory pile driver are quieter alternatives where the geological conditions permit their use. If impact pile drivers must be used, their use would be limited to the periods between 8:00 a.m. and 5:00 p.m. on weekdays.
- Conducting noise monitoring during construction to verify compliance with the limits

4.0 Vibration Technical Analysis

4.1 Regulatory Context/Methodology

Vibration impact has been assessed according to guidelines specified in the U.S. Federal Transit Administration's (FTA) "Noise and Vibration Impact Assessment" guidance manual (FTA Report FTA-VA-90-1003-06, May, 2006). This manual describes the methodology for assessing potential impact from proposed transit projects such as the Bottineau Transitway Project.

The methodology for assessing potential long-term vibration impact from transit operations includes

(1) identification of vibration-sensitive land uses within the area of potential effect of the proposed project
(2) measurement and characterization of existing vibration conditions at these receptors
(3) projections of future vibration levels from transit operations for future build alternatives
(4) assessment of potential long-term vibration impact
(5) recommendations for vibration mitigation

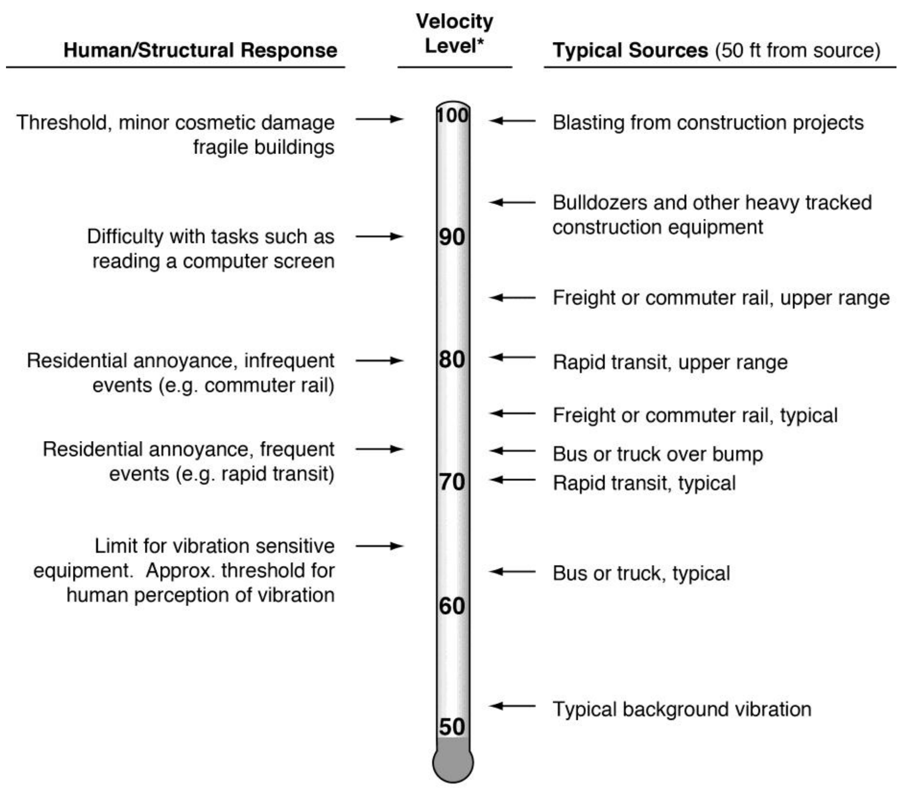
The guidance manual also includes the methodology for predicting and assessing potential short-term vibration impact from construction activities. The approach to assessing potential impact from construction activities is more general than for transit operations since specific construction equipment and methods depend on the contractor's approach and are not typically defined at this stage of the project. This report includes general recommendations for minimizing potential impact from construction activities.

4.1.1 Ground-Borne Noise and Vibration Fundamentals and Descriptors

Ground-borne vibration (GBV) is the oscillatory motion of the ground about some equilibrium position that can be described in terms of displacement, velocity, or acceleration. Because sensitivity to vibration typically corresponds to the amplitude of vibration velocity within the low-frequency range of most concern for environmental vibration (roughly four to 80 Hz), velocity is the preferred measure for evaluating GBV from transit projects.

Many metrics can be used to describe the amplitude of vibration velocity. A common metric used in monitoring blasting and other types of construction-generated vibration is the peak particle velocity (PPV), defined as the maximum instantaneous peak of the vibratory motion. This metric is commonly used to assess building response from vibration as it closely relates to the stresses experienced by building components. Although PPV is appropriate for evaluating building damage, it is less suitable for evaluating human response. Human and equipment sensitivity to vibration better relates to the average vibration amplitude. Thus, GBV from transit trains is characterized in terms of the "smoothed" root mean square (rms) vibration velocity level, reported in decibels (VdB), with a reference quantity of one micro-inch per second. VdB is used in place of dB to avoid confusing vibration decibels with sound decibels.

Figure 6 illustrates typical GBV levels for common sources as well as criteria for human and structural response. As shown, the range of concern is from approximately 50 to 100 VdB, representing an imperceptible background vibration to the threshold for structural damage. Although the approximate threshold of human perception to vibration is 65 VdB, annoyance is usually not significant unless the vibration exceeds 70 VdB.



** RMS Vibration Velocity Level in VdB relative to 10^{-6} inches/second*

Figure 6. Typical Ground-Borne Vibration Levels

Source: Federal Transit Administration, 2006.

Ground-borne noise (GBN) is perceived as a low frequency rumble and is produced when GBV propagates into a room and radiates noise from the motion of the surfaces. The room surfaces essentially act like a giant loudspeaker for the vibration. Airborne noise often masks GBN for at-grade and elevated rail systems, and GBN is usually a greater issue for subway operations where airborne noise is not a factor and for buildings that have highly sensitive interior spaces that are well insulated from exterior noise. Although airborne noise may not always mask GBN due to differences in the frequency content between the airborne and ground-borne noise, ground-borne noise criteria are applied only to buildings with sensitive interior spaces that are well insulated from exterior noise for the above ground Bottineau Corridor.

GBN is assessed based on the A-weighted sound level in dBA. While the potential annoyance of GBN can be evaluated using the A-weighted sound level, there are potential problems in using this metric to characterize low-frequency ground-borne noise as humans do not hear all sounds equally. Sounds with significant low-frequency content can seem louder than broadband sounds that have the same A-weighted level. This is accounted for by setting impact criteria limits lower for ground-borne noise than would be the case for broadband noise. As presented in the following section, there are separate noise criteria for potential impact from airborne noise and ground-borne noise.

4.1.2 Vibration Impact Criteria

Vibration-Sensitive Land Use Categories

The FTA Manual classifies vibration-sensitive land uses into the same three categories as noise. However, since vibration is only assessed inside buildings, outdoor land uses are not considered to be sensitive. In addition to the potential for human annoyance from vibration, vibration impact is also assessed to evaluate potential interference with the use of certain sensitive equipment and interior spaces and to evaluate the potential for damage to building structures.

- **Vibration Category 1:** High Sensitivity: Included in this category are buildings where vibration would interfere with operations. Vibration levels may be well below those associated with human annoyance. These buildings include vibration-sensitive research and manufacturing facilities, hospitals with sensitive equipment and university research operations. The sensitivity to vibration is dependent on the specific equipment present. Some examples of sensitive equipment include electron-scanning microscopes, magnetic resonance imaging scanners and lithographic equipment.

- **Vibration Category 2:** Residential: Residences and buildings where people normally sleep. This category includes homes, hospitals, and hotels.

- **Vibration Category 3:** Institutional: This category includes buildings with primarily daytime and evening use. This category includes schools, libraries and churches.

There are some buildings, such as concert halls, recording studios, and theaters, that can be very sensitive to noise and/or vibration but do not fit into any of the three categories. Due to the sensitivity of these buildings, they usually warrant special attention during the environmental assessment of a transit project.

Vibration Impact Criteria

The FTA vibration and GBN impact criteria are based on land use and train frequency, as shown in Table 11. Table 12 gives criteria for acceptable levels of GBV and GBN for various types of special buildings.

Table 11. Ground-Borne Noise and Vibration Impact Criteria

Land Use Category	Ground-Borne Vibration Impact Criteria (VdB re: 1 micro-inch per second)			Ground-Borne Noise Impact Criteria (dBA re: 20 micro-Pascal)		
	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]	Frequent Events[1]	Occasional Events[2]	Infrequent Events[3]
Category 1: Buildings where low ambient vibration is essential for interior operations.	65 VdB[4]	65 VdB[4]	65 VdB[4]	n/a[5]	n/a[5]	n/a[5]
Category 2: Residences and buildings where people normally sleep.	72 VdB	75 VdB	80 VdB	35 dBA	38 dBA	43 dBA
Category 3: Institutional land uses with primarily daytime use.	75 VdB	78 VdB	83 VdB	40 dBA	43 dBA	48 dBA

[1] "Frequent Events" is defined as more than 70 vibration events per day. Most rapid transit projects fall into this category.
[2] "Occasional Events" is defined as between 30 and 70 vibration events of the same kind per day. Most commuter rail trunk lines have this many operations.
[3] "Infrequent Events" is defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.
[4] This criterion limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. Vibration sensitive manufacturing or research would require detailed evaluation to define the acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the HVAC systems and stiffened floors.
[5] Vibration-sensitive equipment is generally not sensitive to ground-borne noise.
Source: Federal Transit Administration, 2006.

Table 12. Ground-Borne Noise and Vibration Impact Criteria for Special Buildings

Type of Building or Room	Ground-Borne Vibration Impact Criteria (VdB re: 1 micro-inch per second)		Ground-Borne Noise Impact Criteria (dBA re: 20 micro-Pascals)	
	Frequent Events	Occasional or Infrequent Events	Frequent Events	Occasional or Infrequent Events
Concert Halls	65 VdB	65 VdB	25 dBA	25 dBA
TV Studios	65 VdB	65 VdB	25 dBA	25 dBA
Recording Studios	65 VdB	65 VdB	25 dBA	25 dBA
Auditoriums	72 VdB	80 VdB	30 dBA	38 dBA
Theatres	72 VdB	80 VdB	35 dBA	43 dBA

Source: Federal Transit Administration, 2006.

In addition to the criteria provided in Table 11 and Table 12 for general assessment purposes, FTA has established criteria in terms of one-third octave band frequency spectra for use in detailed analyses. Table 13 and Figure 7 show the more detailed vibration criteria and the description of their use.

Table 13. FTA Criteria for Detailed Vibration Analysis

Criterion Curve	Maximum Vibration Level (VdB re: 1 micro-inch per second)	Description of Use
Workshop	90	Distinctly feelable vibration. Appropriate to workshops and non-sensitive areas
Office	84	Feelable vibration. Appropriate to offices and non-sensitive areas
Residential Day	78	Barely feelable vibration. Adequate for computer equipment and low-power optical microscopes (up to 20X)
Residential Night, Operating Rooms	72	Vibration not feelable, but ground-borne noise may be audible inside quiet rooms. Suitable for medium-power optical microscopes (100X) and other equipment of low sensitivity
VC-A	66	Adequate for medium- to high-power optical microscopes (400X), microbalances, optical balances, and similar specialized equipment
VC-B	60	Adequate for high-power optical microscopes (1000X), inspection and lithography equipment to 3 micron line widths
VC-C	54	Appropriate for most lithography and inspection equipment to 1 micron detail size
VC-D	48	Suitable in most instances for the most demanding equipment, including electron microscopes operating to the limits of their capability
VC-E	42	The most demanding criterion for extremely vibration-sensitive equipment
Source: Federal Transit Administration, 2006.		

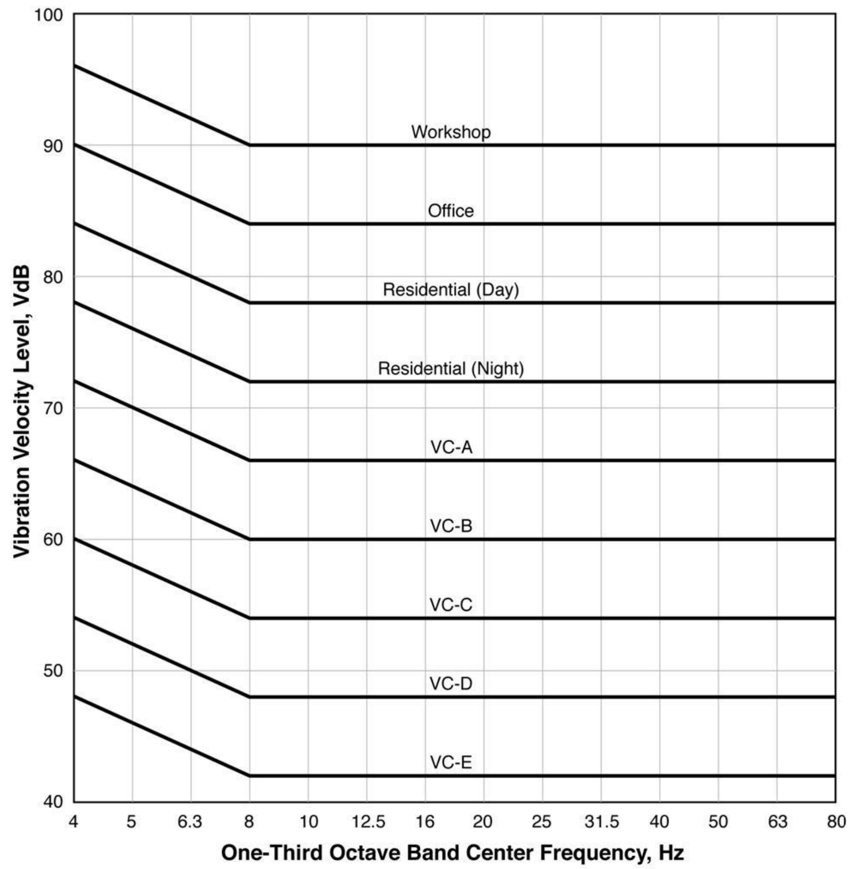


Figure 7. FTA Criteria for Detailed Vibration Analysis
Source: Federal Transit Administration, 2006.

In accordance with FTA guidance, the existing vibration conditions in the corridor have been used to determine the assessment approach for sensitive receptors within an existing rail corridor. Because the BNSF railroad in the project area is an infrequently-used rail corridor (fewer than 5 trains per day), the same approach is used to assess vibration impact for light rail operations as would be used for an alignment not within an existing rail corridor, and the FTA criteria for a detailed vibration analysis are applied. However, potential vibration impact due to the future shift of the BNSF railroad freight operations is assessed separately. For this scenario, the FTA criteria for a general vibration assessment are applied to both the existing and predicted future vibration levels from the freight activity and impact is identified based on the following guidelines:

- If the existing freight vibration levels exceed the general assessment criteria, impact is only identified if the future freight vibration levels are more than 3 VdB greater than the existing levels.
- If the existing freight vibration levels do not exceed the general criteria, impact is identified if the future freight vibration levels exceed the general assessment criteria.

Construction Vibration Impact Criteria

In addition to GBV criteria for humans in residential, institutional and special buildings and for vibration-sensitive equipment, there are GBV criteria for potential damage to structures. The limits of vibration that structures can withstand are substantially higher than those that affect humans and sensitive equipment. Table 14 presents the FTA criteria for assessing the potential for vibration damage to structures based on the type of building construction. This table includes criteria in terms of rms vibration levels in VdB referenced to 1 micro-inch per second as well as in terms of peak-particle velocity levels in inches per second. A crest factor of four, representing a difference of 12 decibels between peak and rms values is assumed in this table. It should be noted that these criteria are more conservative than other standards, such as the U.S. Bureau of Mines frequency-dependent vibration criterion which is equivalent to approximately 114 VdB at 40 Hz and above.

Table 14. FTA Vibration Criteria for Potential Structural Damage

Building Category	PPV (in/sec)	Approximate L_v[1]
I. Reinforced-concrete, steel or timber (no plaster)	0.5	102
II. Engineered concrete and masonry (no plaster)	0.3	98
III. Non-engineered timber and masonry buildings	0.2	94
IV. Buildings extremely susceptible to vibration damage	0.12	90

[1] RMS velocity in VdB re: 1 micro-inch/second.
Source: Federal Transit Administration, 2006.

4.1.3 Vibration Impact Assessment Methodology

The assessment of vibration impact resulting from the Bottineau Transitway project was based on the following assumptions:

- All modeling projections are consistent with the methodology in the detailed assessment chapters of the U.S. Department of Transportation Federal Transit Administration's "Transit Noise and Vibration Impact Assessment" guidance manual (May 2006.)
- Vibration-sensitive land use in the corridor was determined based on parcel data, aerial imagery, and windshield surveys in the field.
- LRT speeds were provided by the project team at 100-foot increments along the corridor. Speeds range from 20 mph to 55 mph along the corridor, and the same speed profile was used for both directions of travel.
- LRT operations were assumed to use 3-car trains.
- The operating hours and service frequencies for LRT mode were assumed to be consistent with Metro Transit's Blue Line (Hiawatha). For the vibration impact assessment, this assumed schedule corresponds to the criteria for "Frequent Events."
- Locations of aerial structures, crossovers, and embedded track were identified based on conceptual engineering plans available at the time of the assessment:
    - Vibration level increases of up to 10 VdB are assumed for receptors near crossover locations.
    - A vibration level reduction of 10 VdB are assumed for receptors near aerial structures.
    - Structure elevations were based on profile information provided.
- Reference Levels:
    - Vehicle vibration force density levels measured on the Blue Line (Hiawatha) and reported in *Vibration Measurements and Predictions for Central Corridor LRT Project* (ATS Consulting, 2008) were used in this assessment.

  - A safety factor of three vibration decibels (VdB) was included in the projected vibration levels.
- Assumed property acquisitions were not counted as potential vibration impacts.
- Vibration levels from BNSF freight trains were modeled using the FTA General Vibration Assessment methodology. Maximum vibration levels from diesel locomotive-hauled trains were assumed to follow the Locomotive Powered Passenger or Freight curve in Figure 10-1 of the FTA guidance manual.

Because construction of the Bottineau Transitway in Alignments C and D1 would require the existing BNSF rail line to be shifted to the west, the effect of moving freight operations relative to vibration-sensitive receivers was included in the vibration impact analysis. The prediction of freight train vibration was based on the following assumptions:

- Baseline freight train operations include one daily round trip during the daytime hours.
- All freight trains include two locomotives and 20 cars, and operate at a speed of 20 mph.
- The shifted BNSF railroad track will be updated from jointed rail to CWR.
- Wheel impacts at track joints cause vibration level increases of 5 VdB.

Future vibration levels from LRV operations are projected based on reference vibration levels of the trains (force density), the vibration propagation conditions of the soil (line source transfer mobility) and the presence of any special trackwork (i.e. turnouts or crossovers). By measuring the line source transfer mobility (TMline) at a given site and knowing the reference force of an LRV (LF, force density) the projected vibration generated by the LRV can be calculated as follows:

$$Lv = LF + TMline,$$

where LF is the vehicle force density, Lv is the measured train GBV and TMline is the line source transfer mobility at the reference site. Once a vehicle force density is calculated, it is then used to project future vibration levels by combining it with line source transfer mobility measurements at sites along the project corridor.

The vehicle force density depends on several factors including the speed and length of the trains. Sample force densities of the LRVs currently operating on the Blue Line (Hiawatha) on both ballast and tie track and embedded track at 40 mph are shown in Figure 8. The force density spectra for numerous vehicle speeds used in the vibration impact assessment are included in Appendix D.

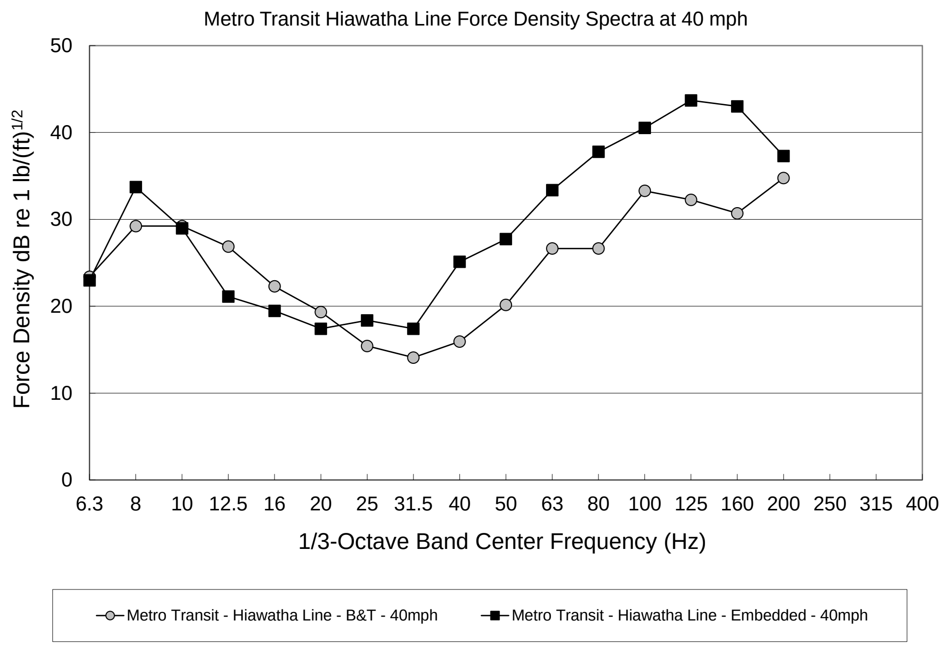


Figure 8. Metro Transit Vehicle Force Density Spectra
Source: Harris Miller Miller & Hanson Inc., 2012.

4.2 Affected Environment for Vibration

The Bottineau Transitway build alternative alignments are located in suburban and urban areas in the greater Minneapolis metropolitan area. The existing vibration environment and sensitive land uses vary among the alignments and are described below by alignment option.

Alignment A

This alignment is located along County Road (CR) 130. Existing sources of vibration are limited to vehicular traffic on local roadways. Vibration-sensitive land use includes Arbor Lakes Senior Living, Hennepin Technical College, and several single- and multi-family residences near Boone Avenue North.

Alignment B

This alignment is located along CR 103 and CR 130. Existing sources of vibration are limited to vehicular traffic on local roadways. Vibration-sensitive land use includes North Hennepin Community College, Step by Step Montessori School, and several single- and multi-family residences north and south of CR 109 (85th Avenue). Vibration-sensitive equipment exists at two commercial properties on this alignment, Northwest EMC and Genmab.

Alignment C

This alignment is located adjacent to the BNSF railroad tracks from 73rd Avenue North in Brooklyn Park to 36th Avenue North in Robbinsdale. The alignment is located along CR 81 starting from the north, and then shifts to run along West Broadway Avenue after crossing the Canadian Pacific (CP) railroad tracks. This alignment also passes by Crystal Airport. Existing sources of vibration are limited to vehicular traffic on local roadways and freight train operations on the BNSF railroad. Vibration-sensitive land use includes single-and multi-family residences, schools, churches, and several hotels.

Alignment D1

This alignment is located along the BNSF railroad tracks. The alignment turns east along TH 55 until it reaches downtown Minneapolis. Existing sources of vibration are limited to vehicular traffic on local roadways and freight train operations on the BNSF railroad. Vibration-sensitive land use includes single- and multi-family residences, schools, churches, hotels, and Sumner Library.

Alignment D2

This alignment runs along CR 81 and Penn Avenue and then turns east along TH 55 until it reaches downtown Minneapolis. Existing sources of vibration are limited to vehicular traffic on local roadways. North Memorial Medical Center, NorthPoint Health and Wellness Center, and KMOJ Radio Station are vibration-sensitive land uses that are adjacent to this alignment. Other vibration-sensitive land use includes single- and multi-family residences, schools, churches, hotels, and Sumner Library.

4.2.1 Vibration Measurement Locations and Procedures

Vibration propagation measurements were conducted in the project area from May 14 through May 18, 2012. The testing method is shown schematically in Figure 9. As shown in the cross-section view at the top, the test consists of dropping a 60-pound weight from a height of about three feet onto the ground. A Sensotec load cell was used to measure the force of the impact, and PCB 393 A/C accelerometers, mounted in a vertical orientation on either paved surfaces or metal stakes driven into the soil, were used to measure the resulting vibration pulses on the ground at various distances (10 to 200 feet). The impact force and acceleration signals were recorded using a multi-channel TEAC LX-110 digital recorder and subsequently analyzed using digital signal processing software. The relationship between the input force and the ground surface vibration, called the transfer mobility, characterizes vibration propagation at each location. It is then possible to estimate the ground vibration caused by another source, such as a train, by substituting the train force for the impact force.

The bottom sketch in Figure 9 shows how impact tests are made at regularly spaced locations along a proposed rail alignment to simulate the vibration generated by a line source such as a train. For these tests, impacts were made at eleven points, spaced 15 feet apart. Accelerometers were positioned perpendicular to the proposed rail alignment at various distances. The measurement sites were selected to be open and free of buildings so as not to affect the vibration propagation conditions. The integration of the transfer mobility measured at each position along the entire train length is termed the line source transfer mobility (TMline). More details on the propagation test and analysis procedures are given in the FTA manual.

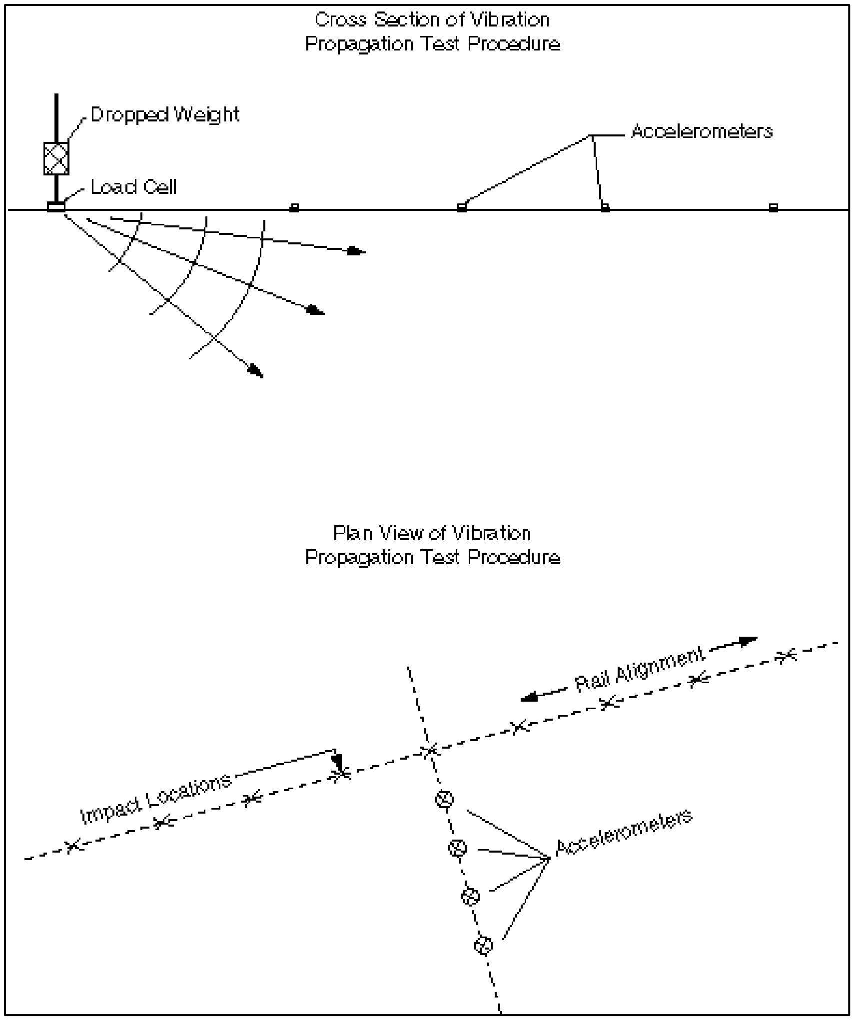


Figure 9. Vibration Propagation Test Procedure
Source: Harris Miller Miller & Hanson Inc., 2012.

Vibration propagation testing was performed at eight locations along the Bottineau Transitway project area. Measurement sites were selected to be representative of the different areas with vibration-sensitive receptors in close proximity of the proposed project. The measurement site locations are shown in Figure 5. Table 15 describes the locations of the vibration propagation test sites.

Table 15. Ground-Borne Vibration Propagation Measurement Locations

Measurement Site No.	Alignment	Measurement Location Description
V-1	A	Hennepin Technical College, Brooklyn Park
V-2	B	North Hennepin Community College, Brooklyn Park
V-3	C	6801 62nd Avenue North, Crystal
V-4	C	Doyle's Lanes, Crystal
V-5	C	Lee Park, Robbinsdale
V-6	D1	26th Avenue North and Kewanee Way, Golden Valley
V-7	D2	KMOJ Radio Station, Minneapolis
V-8	D common section	Harrison Park, Minneapolis
Source: Harris Miller Miller & Hanson Inc., 2012		

Site V-1: Hennepin Technical College – Brooklyn Park, MN. Vibration propagation testing was conducted in the parking lot of this school. This measurement site represents the soil vibration propagation characteristics of the Maple Grove and Brooklyn Park area on Alignment A.

Site V-2: North Hennepin Community College – Brooklyn Park, MN. Vibration propagation testing was conducted in the parking lot of this school. This measurement site represents the soil vibration propagation characteristics of the Brooklyn Park area on Alignment B.

Site V-3: 6801 62nd Avenue North – Crystal, MN. Vibration propagation testing was conducted in the roadway near this single-family residence. This measurement site represents the soil vibration propagation characteristics on Alignment C in Crystal between Interstate 94/694 and 56th Avenue North.

Site V-4: Doyle's Lanes – Crystal, MN. Vibration propagation testing was conducted in the parking lot of this commercial property. This measurement site represents the soil vibration propagation characteristics on Alignment C in Crystal between 56th Avenue North and MN-100 North.

Site V-5: Lee Park – Robbinsdale, MN. Vibration propagation testing was conducted in a field at this park. This measurement site represents the soil vibration propagation characteristics on Alignment C in Robbinsdale between MN-100 North and 34th Avenue North.

Site V-6: 26th Avenue North and Kewanee Way – Golden Valley, MN. Vibration propagation testing was conducted at the intersection of these roadways. This measurement site represents the soil vibration propagation characteristics on Alignment D1 in Golden Valley between 34th Avenue North and TH 55.

Site V-7: KMOJ Radio Station – Minneapolis, MN. Vibration propagation testing was conducted in the parking lot adjacent to this commercial property. This measurement site represents the soil vibration propagation characteristics on Alignment D2 in Minneapolis between 34th Avenue North and TH 55.

Site V-8: Harrison Park – Minneapolis, MN. Vibration propagation testing was conducted in the roadway adjacent to this park. This measurement site represents the soil vibration propagation characteristics on the Alignment D common section in Minneapolis along TH 55.

4.2.2 Vibration Measurement Results

To summarize the results of the vibration propagation tests, line source transfer mobilities at a distance of 100 feet are shown for all measurement sites in Figure 10. This figure illustrates the variability in vibration propagation efficiency across all sites. Depending on the site location, vibrations from the proposed LRV operations may range 20 to 30 VdB. Detailed vibration propagation measurement data are included in Appendix C of this report.

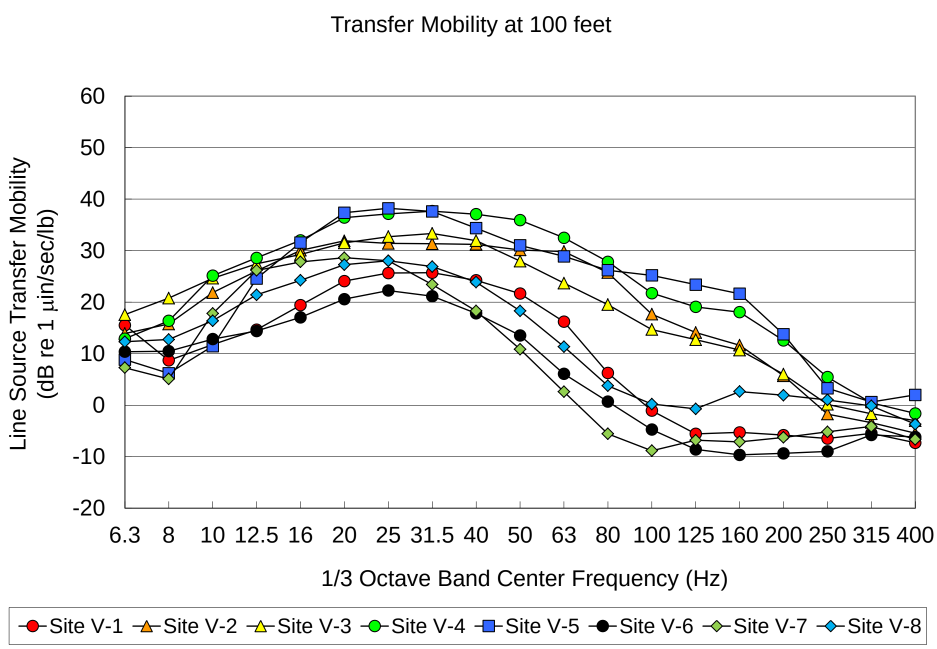


Figure 10. Line Source Transfer Mobilities at Measurement Sites
Source: Harris Miller Miller & Hanson Inc., 2012.

As described in Section 3.1.3, maximum ground vibration levels from LRV operations were projected by combining the reference vehicle force density and measured line source transfer mobility. Figure 11 shows the maximum ground-borne vibration levels projected at each of the eight test sites for trains operating at 55 mph (maximum speed along the corridor) on ballast and tie track, without special trackwork and without any adjustment for vibration coupling between the ground and the building foundation. Each of the curves has a different level versus distance characteristic, which determines the impact distances in each of the regions. The results show that beyond approximately 100 feet from the track, the projected maximum vibration levels at the maximum speed are all below the FTA residential impact criterion. Detailed vibration projections at each measurement site are included in Appendix E.

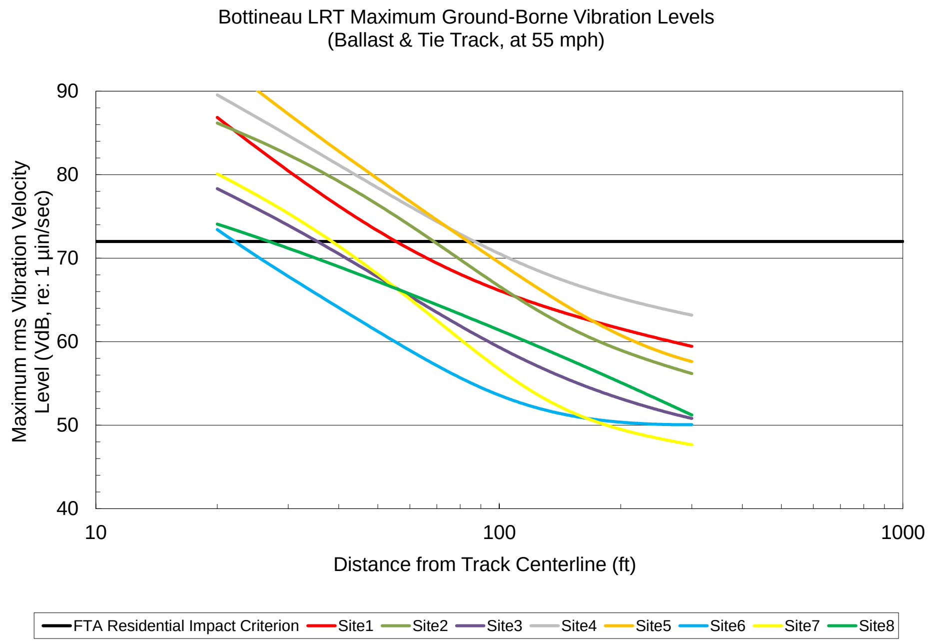


Figure 11. Projected Maximum LRT Vibration Levels on B&T Track at 55 mph
Source: Harris Miller Miller & Hanson Inc., 2012.

4.3 Environmental Consequences for Vibration

4.3.1 Operating Phase Impacts

No-Build Alternative

While there would be some changes in bus traffic on existing roadways due to other future No-Build transit improvements, these would not significantly affect the existing vibration levels. Thus, no vibration impacts are anticipated within the Bottineau Transitway project area for the No-Build alternative.

Enhanced Bus/Transportation System Management Alternative

Similar to the No-Build alternative, no significant vibration impacts would occur within the Bottineau Transitway project area for the Enhanced Bus/Transportation System Management alternative.

Build Alternatives

Table 16 below summarizes the results of the GBV impact assessment by alignment option. The estimated root mean square (RMS) velocity levels (VdB re 1 micro-in./sec.) for sensitive receptors at representative distances are provided for FTA Category 2 (residential) receptors. No Category 3 receptors are impacted by GBV. The table also lists the locations, the civil station, the distance to the near track, and the projected LRT speed at each location. In addition, the predicted project GBV level and the impact criterion level are indicated along with the number of impacts projected for each receptor or receptor group.

Table 16. Summary of Ground-Borne Vibration Impacts by Alignment

Alignment	Receptor Type	Distance to Track (ft)[1]	Train Speed (mph)	Maximum Vibration Velocity Level (VdB) in any 1/3-Octave Band from 4 Hz to 200 Hz[2]		Number of Receptors with GBV Impact
				Projected Vibration Velocity Level	Vibration Impact Criterion	
A[3]	Cat. 2	90	20 to 55	52	72	0
B[3]	Cat. 2	80	20 to 50	69	72	0
C	Cat. 2	30 to 80	20 to 55	72 to 90	72	51
D1[3]	Cat. 2	60	20 to 55	68	72	0
D2[3]	Cat. 2	50	20 to 45	71	72	0
D Common Section[3]	Cat. 2	100	20 to 35	59	72	0

[1] Distance to track is based on current alignment location data and has been rounded to the nearest 5 feet for this summary.
[2] GBV levels are measured in VdB referenced to 1 μ-in/sec.
[3] Data are for the closest non-impacted residential receptor. There are no vibration impacts in this section.
Source: Harris Miller Miller & Hanson Inc., 2012

The GBV impacts for each alignment are discussed below and Figures 12 through 40, located in the Figures Appendix in Section 6.0, show the locations of projected vibration impacts. The vibration impact figures only show locations of the Bottineau Corridor where impact is projected to occur.

Alignment A
Vibration-sensitive receptors adjacent to this alignment are generally no closer than about 85 feet from the near track centerline. No GBV impacts are predicted to occur with this alignment. The maximum vibration velocity level (in any 1/3 octave-band from 4 to 200 Hz) predicted from LRV passbys at the closest receptor is 52 VdB.

Alignment B
Vibration-sensitive receptors adjacent to this alignment are generally no closer than about 65 feet from the near track centerline. No GBV impacts are predicted to occur with this alignment. The maximum vibration velocity level (in any 1/3 octave-band from 4 to 200 Hz) predicted from LRV passbys at the closest receptor is 69 VdB. In addition, GBV and GBN levels were assessed at Northwest EMC, Genmab, and the Science Building of North Hennepin Community College based on the FTA criteria. No GBV or GBN impact is predicted at any of these receptors.

Alignment C
Vibration-sensitive receptors adjacent to this alignment are generally no closer than about 30 feet from the near track centerline. GBV impacts are predicted to occur at 51 residences with this

alignment option. Predicted GBV levels from LRV passbys range from 72 to 90 VdB (in any 1/3 octave-band from 4 to 200 Hz) at impacted receptors.

No vibration impact would occur from the shift of the BNSF freight operations. The shifted freight tracks would not result in an increase of more than 3 VdB at any sensitive receptors.

Alignment D1
Vibration-sensitive receptors adjacent to this alignment are generally no closer than about 45 feet from the near track centerline. No GBV impacts are predicted to occur with this alignment option. The maximum vibration velocity level (in any 1/3 octave-band from 4 to 200 Hz) predicted from LRV passbys at the closest receptor is 68 VdB.

No vibration impact would occur from the shift of the BNSF freight operations. The shifted freight tracks would not result in an increase of more than 3 VdB at any sensitive receptors.

Alignment D2
Vibration-sensitive receptors adjacent to this alignment are generally no closer than about 30 feet from the near track centerline. No GBV impacts are predicted to occur with this alignment option. The maximum vibration velocity level (in any 1/3 octave-band from 4 to 200 Hz) predicted from LRV passbys at the closest receptor is 71 VdB. In addition, GBV and GBN levels were assessed at KMOJ Radio Station based on the FTA criteria, and the results indicate that no GBV or GBN impact is predicted at this location.

Alignment D Common Section
Vibration-sensitive receptors adjacent to this alignment are generally no closer than about 95 feet from the near track centerline. No GBV impacts are predicted to occur in for this alignment option. The maximum vibration velocity level (in any 1/3 octave-band from 4 to 200 Hz) predicted from LRV passbys at the closest receptor is 59 VdB.

Summary of Impacts by Alternative

Table 17 below summarizes the predicted vibration impact assessment results by Alternative.

Table 17. Summary of Vibration Impacts By Alternative

Alternative	Total GBV Impacted Receptors
No-Build Alternative	No vibration impacts currently anticipated
TSM Alternative	No vibration impacts currently anticipated
Alternative A-C-D1	51
Alternative A-C-D2	51
Alternative B-C-D1	51
Alternative B-C-D2	51
Source: Harris Miller Miller & Hanson Inc., 2012	

4.3.2 Construction Phase Impacts

No-Build Alternative

No construction vibration impacts currently anticipated within the Bottineau Transitway project area for the No-Build alternative.

Enhanced Bus/Transportation System Management Alternative

No construction vibration impacts are anticipated within the Bottineau Transitway project area for the Enhanced Bus/Transportation System Management alternative.

Build Alternatives

Temporary vibration impacts could result from activities associated with the construction of new tracks and stations, utility relocation, grading, excavation, track work, demolition, and installation of systems components. Such impacts may occur in residential areas and at other vibration-sensitive land uses located within several hundred feet of the alignment. The potential for vibration impact would be greatest at locations near pile-driving for bridges and other structures, pavement breaking, and at locations close to vibratory compactor operations.

4.3.3 Indirect/Secondary Impacts

No indirect/secondary vibration impacts are anticipated for any of the project alternatives.

4.4 Avoidance, Minimization, and/or Mitigation Measures

4.4.1 Operational Vibration Mitigation Measures

The vibration assessment assumes that the vehicle wheels and track are maintained in good condition with regular wheel truing and rail grinding. Beyond this, there are several approaches to mitigate predicted vibration impact from LRT operation, as described below in Table 18.

Table 18. Potential Vibration Mitigation Measures

Mitigation Option	Description
Ballast Mats	A ballast mat consists of a pad made of rubber or rubber-like material placed on an asphalt or concrete base with the normal ballast, ties, and rail on top. The reduction in GBV provided by a ballast mat is strongly dependent on the vibration frequency content and the design and support of the mat.
Tire Derived Aggregate (TDA)	Also known as shredded tires, a typical TDA installation consists of an underlayment of 12 inches of nominally 3-inch size tire shreds or chips wrapped with filter fabric, covered with 12 inches of sub-ballast and 12 inches of ballast above that to the base of the ties. Tests suggest that the vibration attenuation properties of this treatment are midway between that of ballast mats and floating slab track. This low-cost option has been installed on two U.S. light rail transit systems (San Jose and Denver) for a number of years and test results have shown this treatment to be very effective at frequencies above about 25 Hz.
Floating Slabs	Floating slabs consist of thick concrete slabs supported by resilient pads on a concrete foundation; the tracks are mounted on top of the floating slab. Most successful floating slab installations are in subways, and their use for at-grade track is less common. Although floating slabs are designed to provide vibration reduction at lower frequencies than ballast mats, they are extremely expensive.
Resiliently Supported Concrete Ties (Under-Tie Pads)	This treatment involves a special soft rubber pad embedded in the base of a concrete tie. The pad serves two purposes: (1) provides a pliable surface to help anchor the ties on ballast; and (2) provides vibration isolation between the tie and the ballast. This relatively simple treatment has been used extensively in Europe. Test results have shown this treatment to be very effective at frequencies above about 25 Hz and its cost is about 1.2 times the cost of a standard concrete tie.
Resilient Rail Fasteners	Resilient fasteners can be used to provide vibration isolation between rails and ties, as well as on concrete slabs for direct fixation track on aerial structures or in tunnels. These fasteners include a soft, resilient element to provide greater vibration isolation than standard rail fasteners in the vertical direction. There are resilient fasteners available that can be used on high axle load transit systems such as locomotive hauled passenger trains. Resilient rail fasteners are effective at frequencies above about 40 Hz.
Special Trackwork	Because the impacts of vehicle wheels over rail gaps at track turnout locations increases GBV by about 10 VdB close to the track, turnouts are a major source of vibration impact when they are located in sensitive areas. If turnouts cannot be relocated away from sensitive areas, another approach is to use spring-rail, flange-bearing or moveable-point frogs in place of standard rigid frogs at turnouts. These devices allow the flangeway gap to remain closed in the main traffic direction for revenue service trains.
Source: Harris Miller Miller & Hanson Inc., 2012	

Potential vibration mitigation measures associated with each alignment are summarized in Table 19. The table includes the number of receptors that could be benefitted with the implementation of the potential mitigation measure listed. These potential mitigation strategies will be further evaluated during preliminary engineering to determine their feasibility and reasonableness, considering factors such as safety impacts, cost effectiveness, and acceptability to the community.

Table 19. Potential Vibration Mitigation Measures

Alignment Option	Potential Mitigation Measure[1]	Receptors Benefitted with Potential Mitigation Measure	Discussion
A	No Mitigation Required		No GBV impacts are predicted to occur, and therefore no vibration mitigation is required.
B	No Mitigation Required		No GBV impacts are predicted to occur, and therefore no vibration mitigation is required.
C	Crossover Mitigation / Track Vibration Isolation Treatment	51	Potential mitigation could include modification or relocation of crossovers between Corvallis Avenue North and West Broadway Ave and 40th Avenue and 36th Avenue North, as well as installation of track vibration isolation treatment.
D1	No Mitigation Required		No GBV impacts are predicted to occur, and therefore no vibration mitigation is required.
D2	No Mitigation Required		No GBV impacts are predicted to occur, and therefore no vibration mitigation is required.
D Common Section	No Mitigation Required		No GBV impacts are predicted to occur, and therefore no vibration mitigation is required.

[1] Potential mitigation strategies will be further evaluated during preliminary engineering to determine their feasibility and reasonableness, considering factors such as safety impacts, cost effectiveness, and acceptability to the community.
Source: Harris Miller Miller & Hanson Inc., 2012

4.4.2 Construction Vibration Mitigation Measures

Construction activities would be carried out in compliance with all applicable local regulations. Measures to limit vibration during construction could be developed including, but not limited to, the following:

- Re-routing construction-related truck traffic along roadways that would cause the least disturbance to residents
- Avoiding impact pile driving near vibration-sensitive areas, where possible. Drilled piles or the use of a sonic or vibratory pile driver are alternatives where the geological conditions permit their use.

- Conducting vibration monitoring during construction to verify compliance with the limits.
- Implementing a complaint resolution procedure to rapidly address any problems that may develop during construction

With the incorporation of appropriate mitigation measures, impacts from construction-generated vibration would be minimized.

5.0 Appendices

FIGURES

FIGURE 12: ALIGNMENT A NOISE IMPACT LOCATIONS

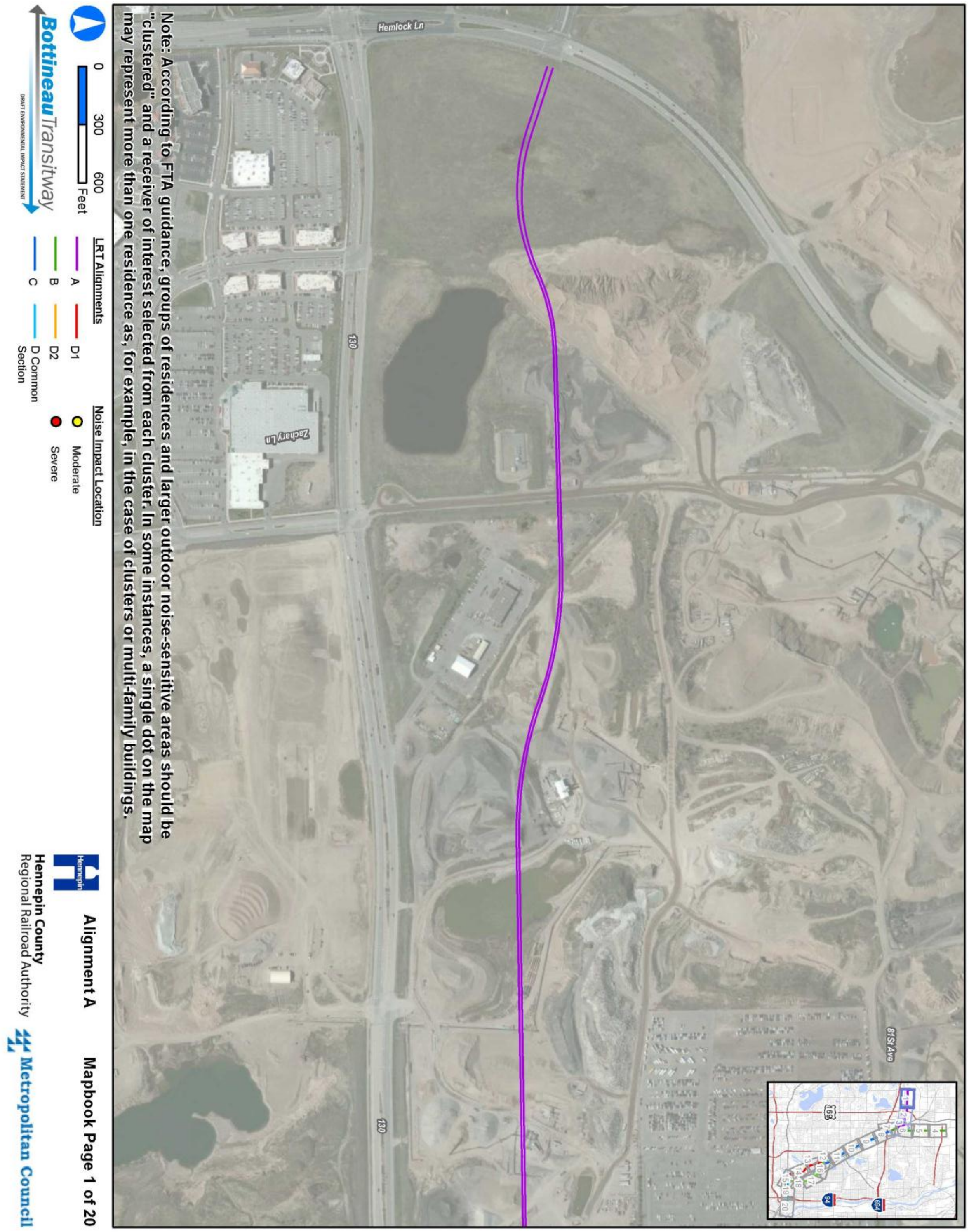


FIGURE 13: ALIGNMENT A NOISE IMPACT LOCATIONS

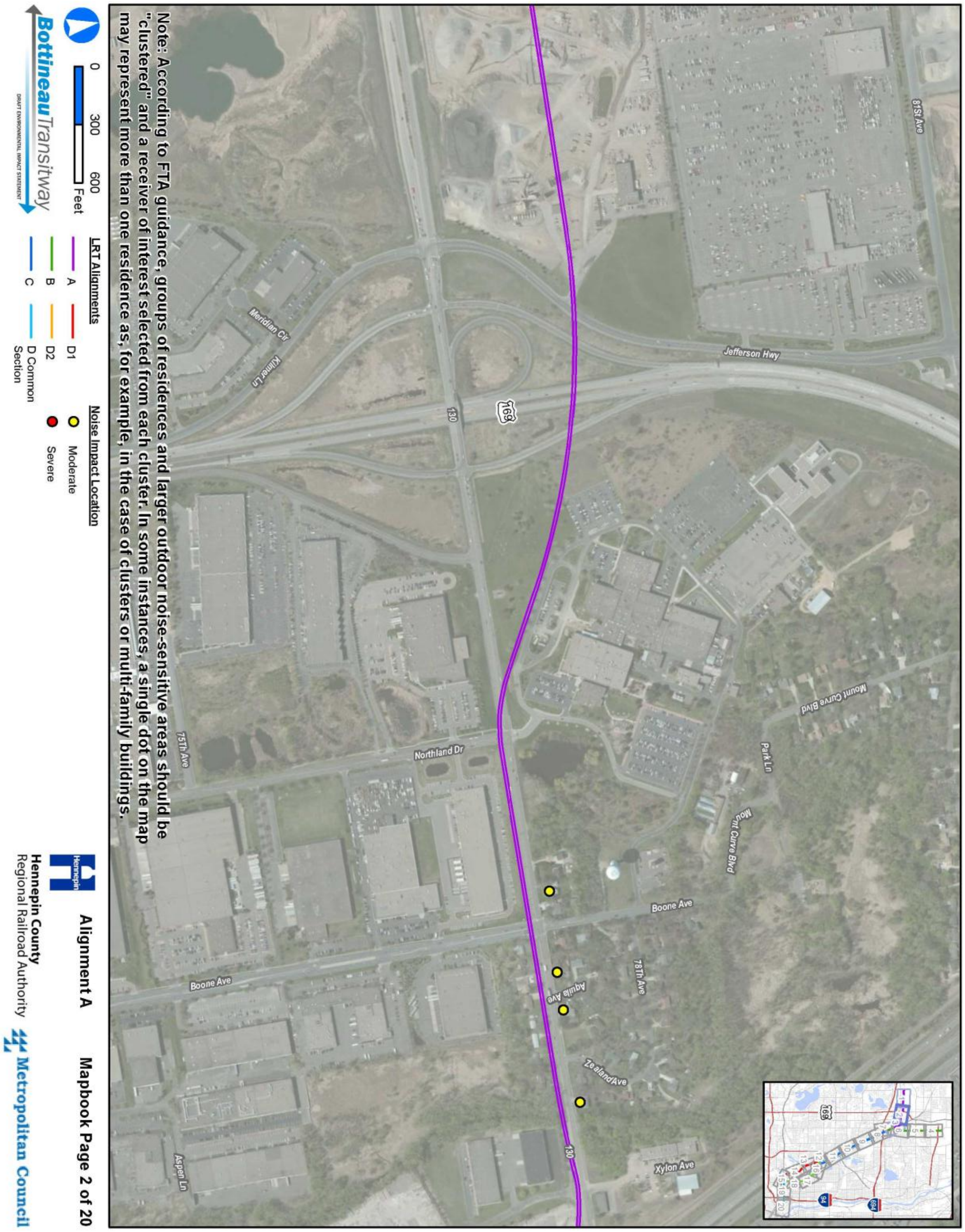


FIGURE 14: ALIGNMENT A NOISE IMPACT LOCATIONS

FIGURE 15: ALIGNMENT B NOISE IMPACT LOCATIONS

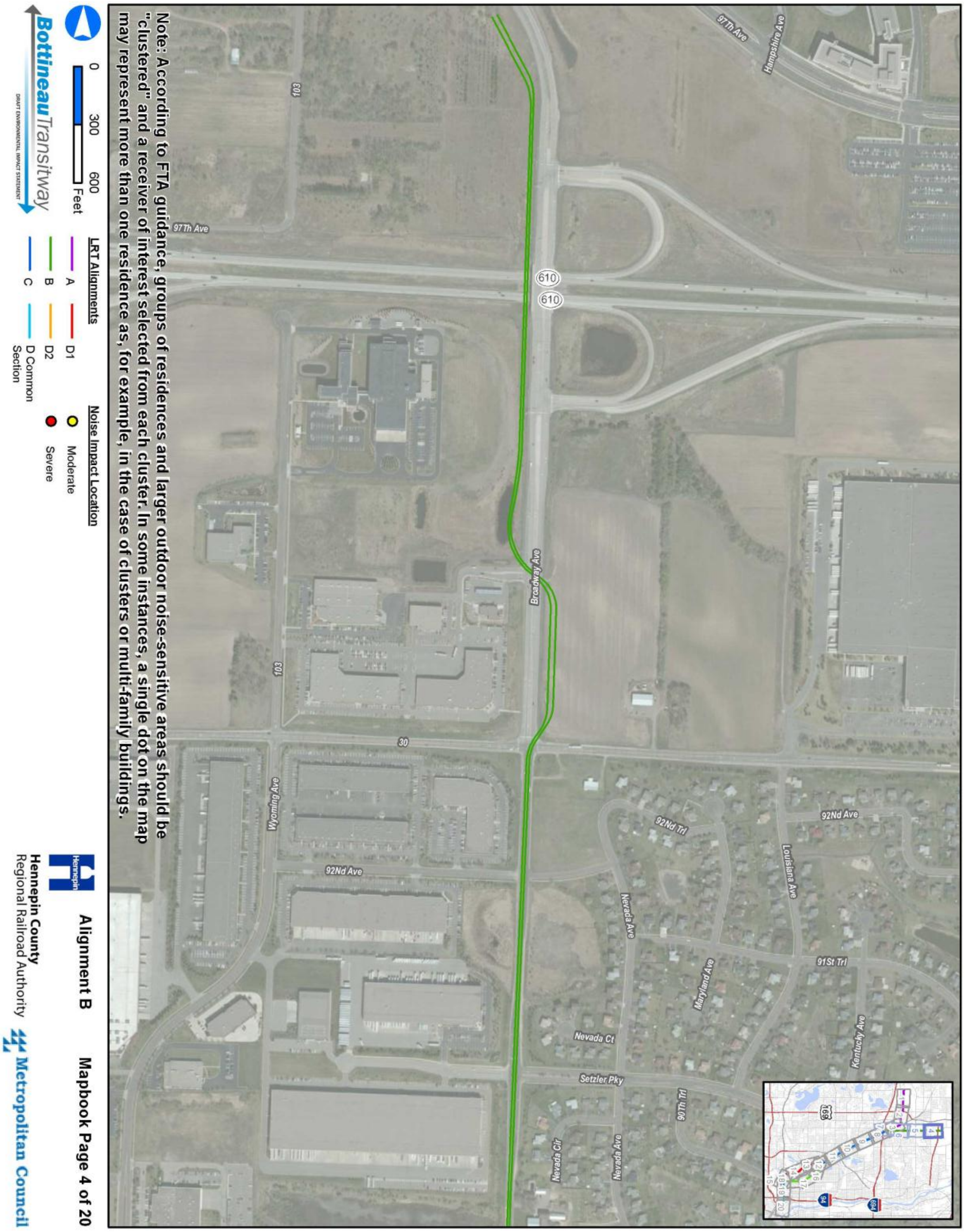


FIGURE 16: ALIGNMENT B NOISE IMPACT LOCATIONS

FIGURE 17: ALIGNMENT B NOISE IMPACT LOCATIONS

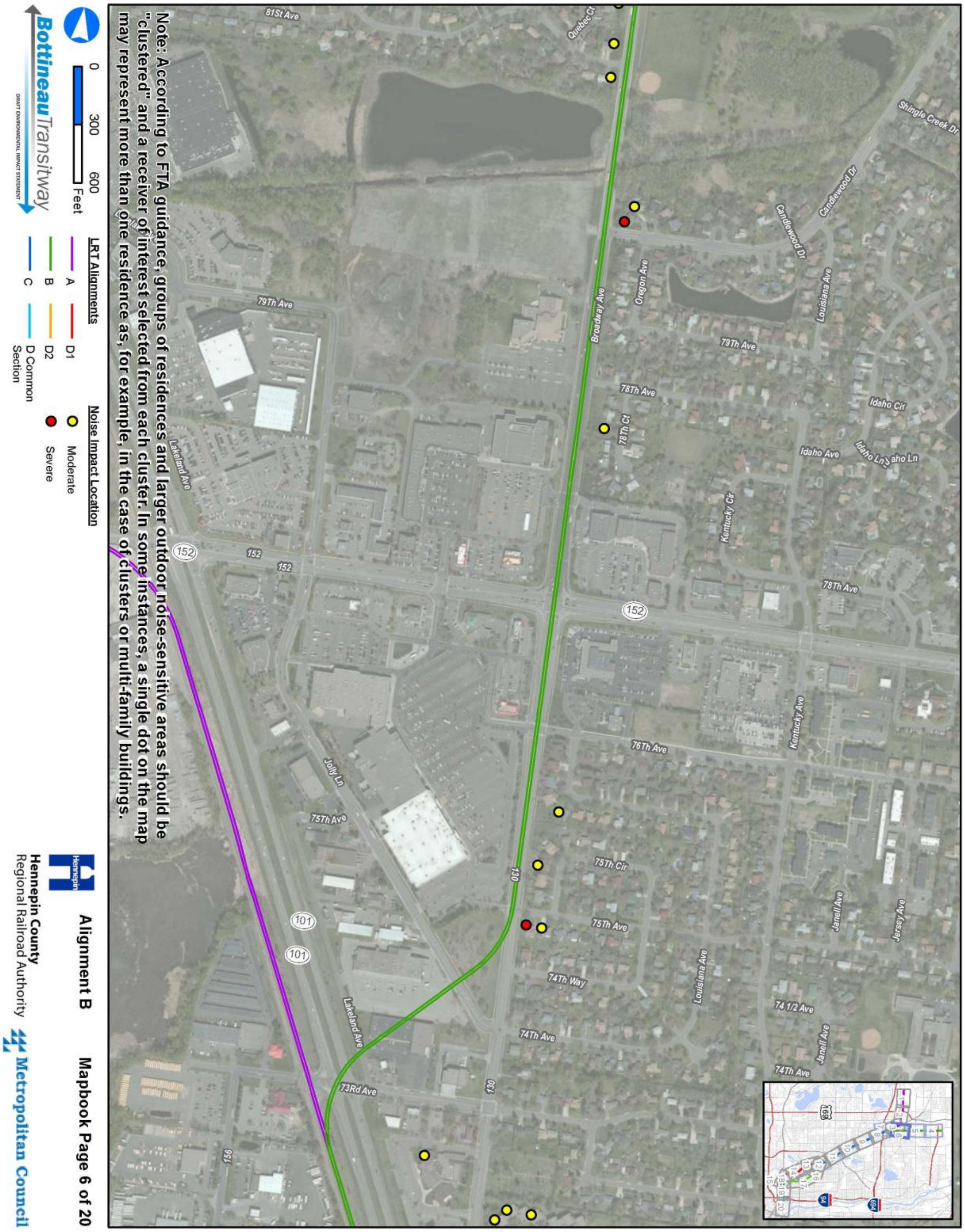


FIGURE 18: ALIGNMENT B NOISE IMPACT LOCATIONS

FIGURE 19: ALIGNMENT C NOISE IMPACT LOCATIONS

FIGURE 20: ALIGNMENT C NOISE IMPACT LOCATIONS

FIGURE 21: ALIGNMENT C NOISE IMPACT LOCATIONS

FIGURE 22: ALIGNMENT C NOISE IMPACT LOCATIONS

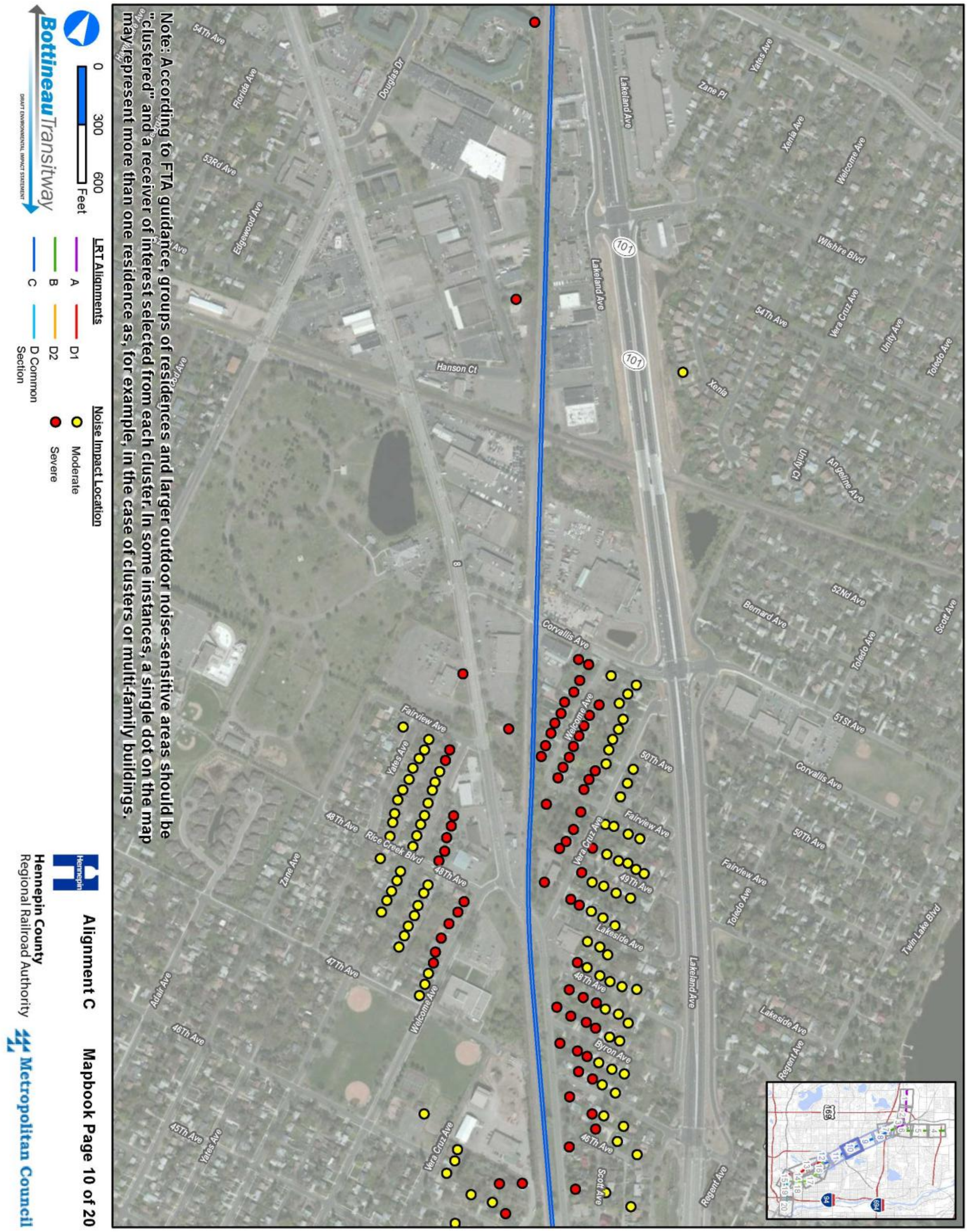


FIGURE 23: ALIGNMENT C NOISE IMPACT LOCATIONS

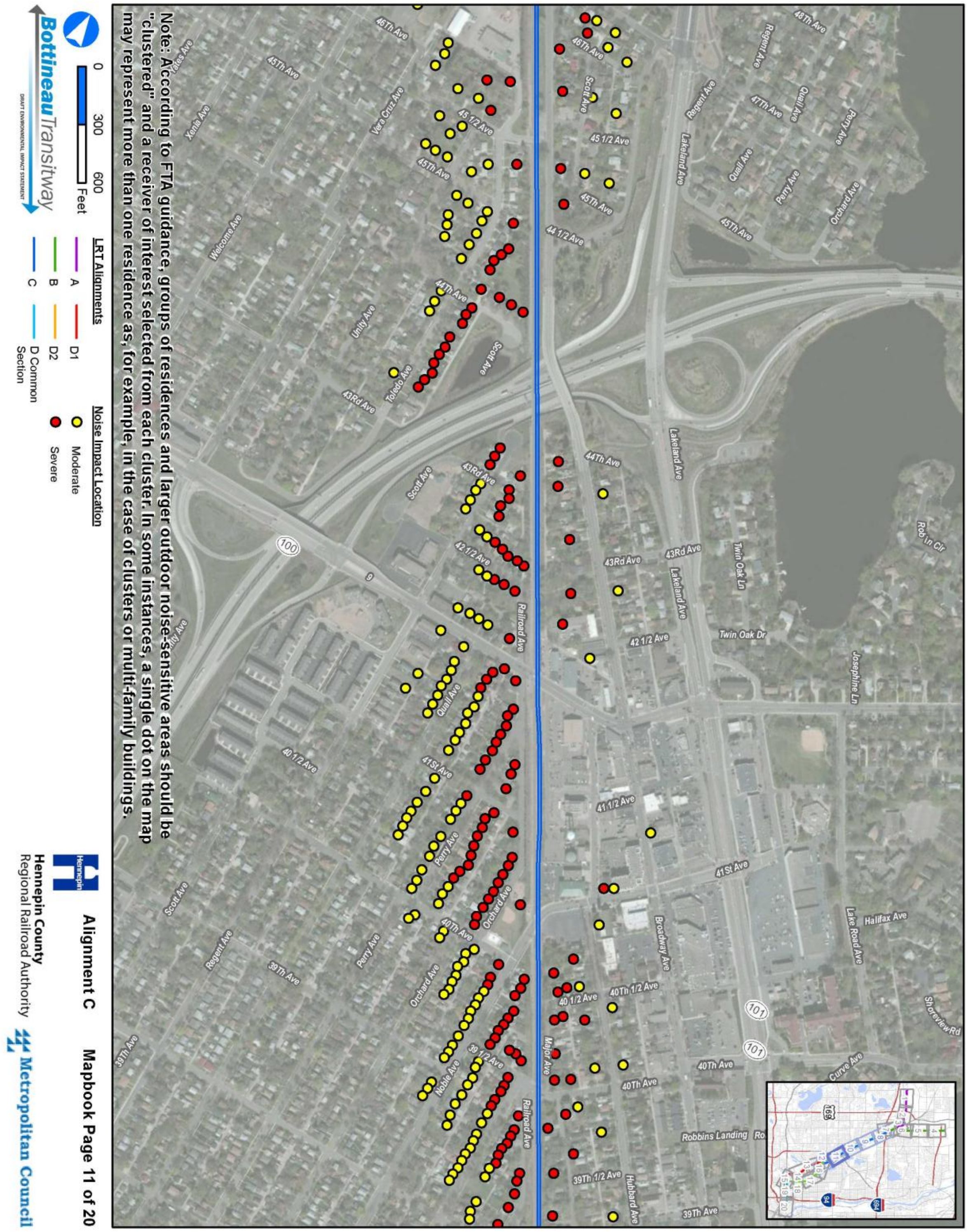


FIGURE 24: ALIGNMENT C NOISE IMPACT LOCATIONS

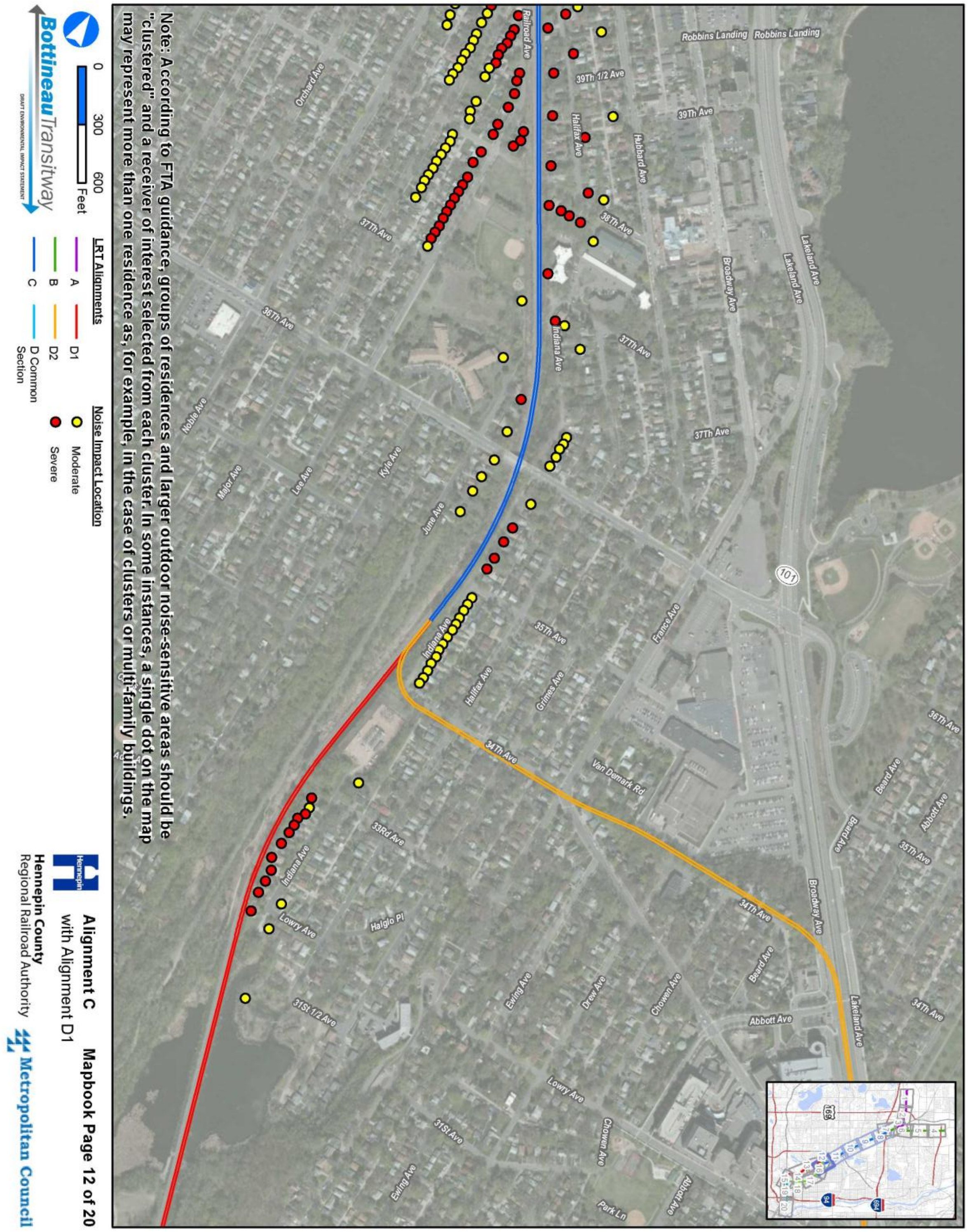


FIGURE 25: ALIGNMENT C NOISE IMPACT LOCATIONS

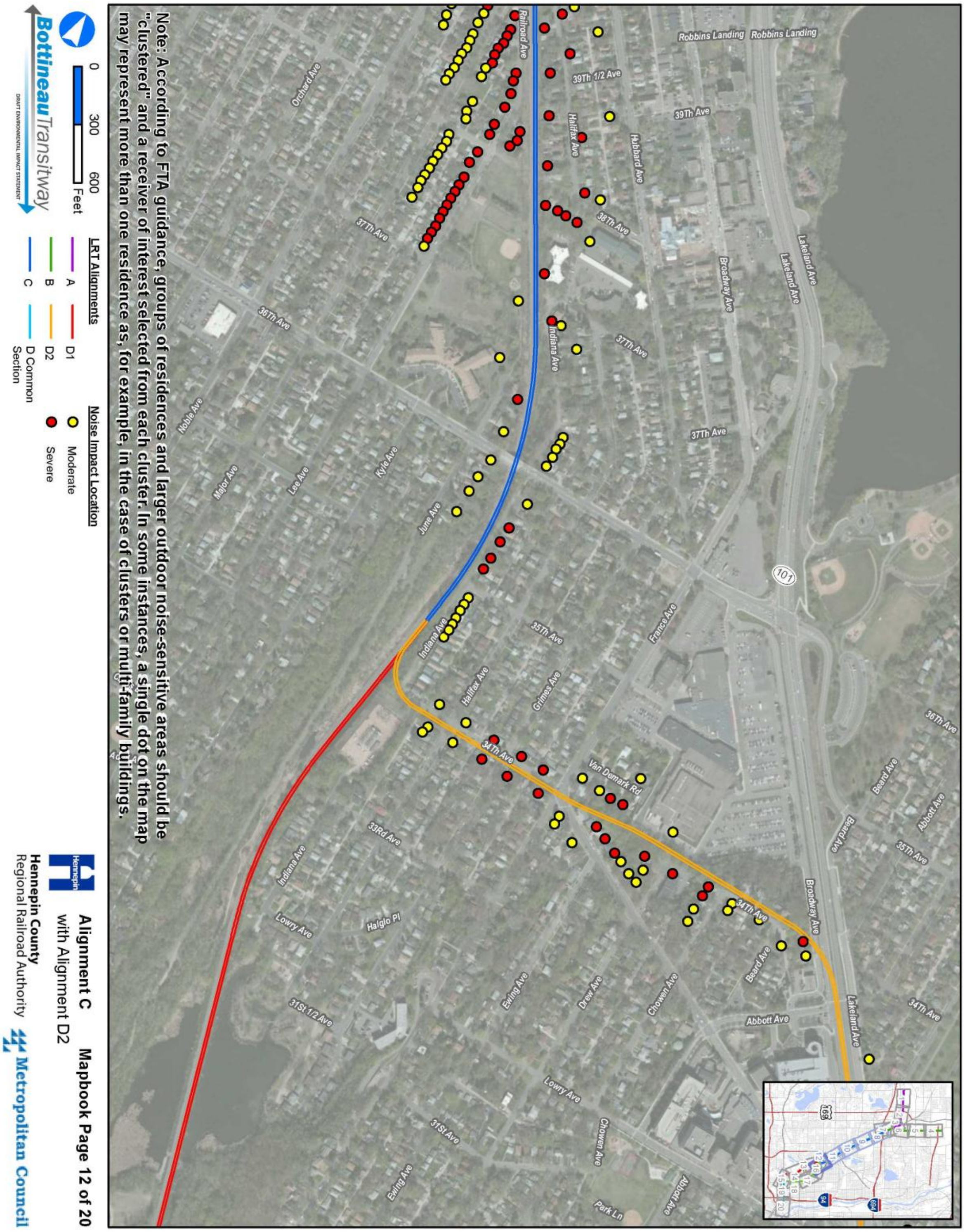


FIGURE 26: ALIGNMENT D1 NOISE IMPACT LOCATIONS

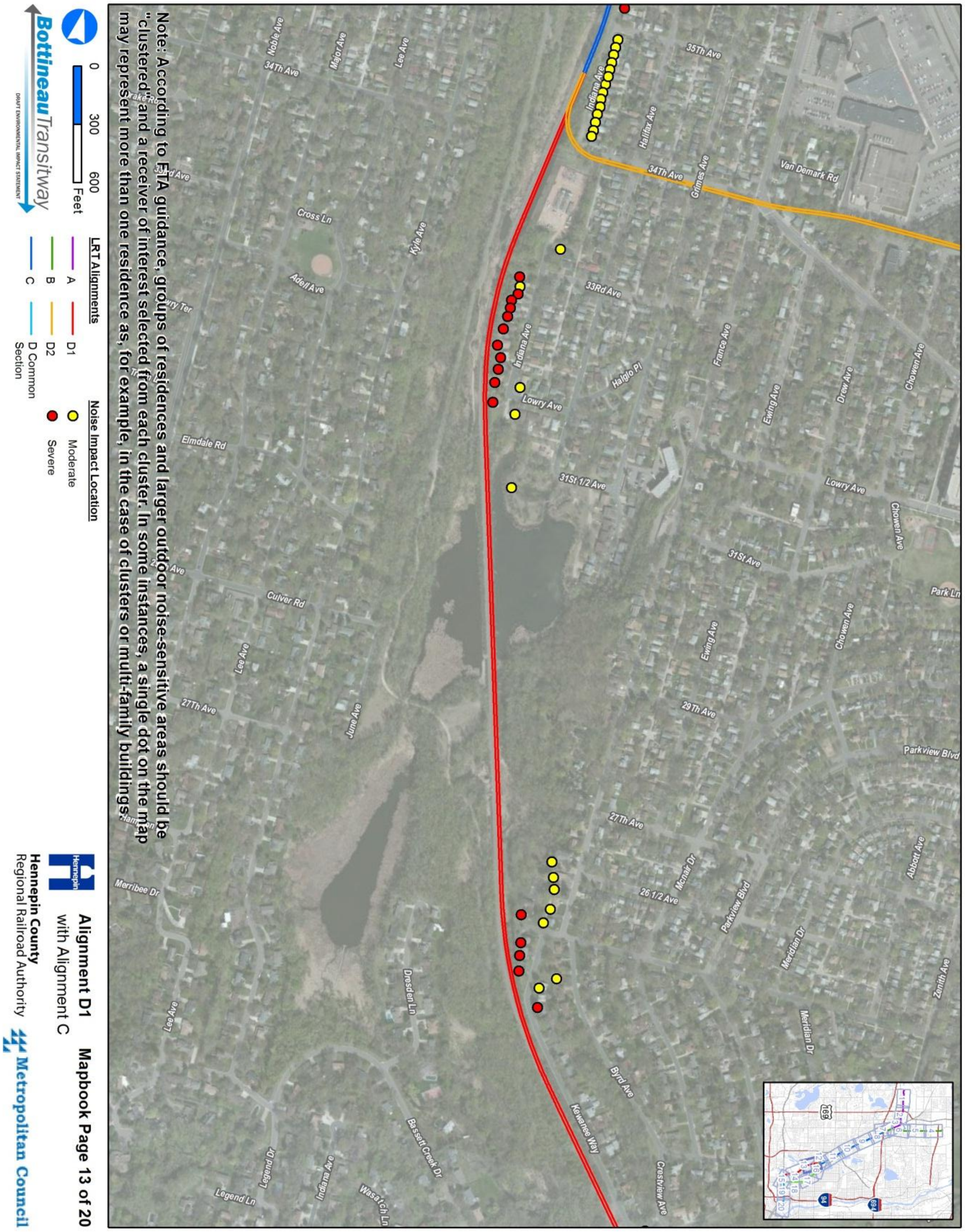


FIGURE 27: ALIGNMENT D1 NOISE IMPACT LOCATIONS

FIGURE 28: ALIGNMENT D1 NOISE IMPACT LOCATIONS

FIGURE 29: ALIGNMENT D1 NOISE IMPACT LOCATIONS

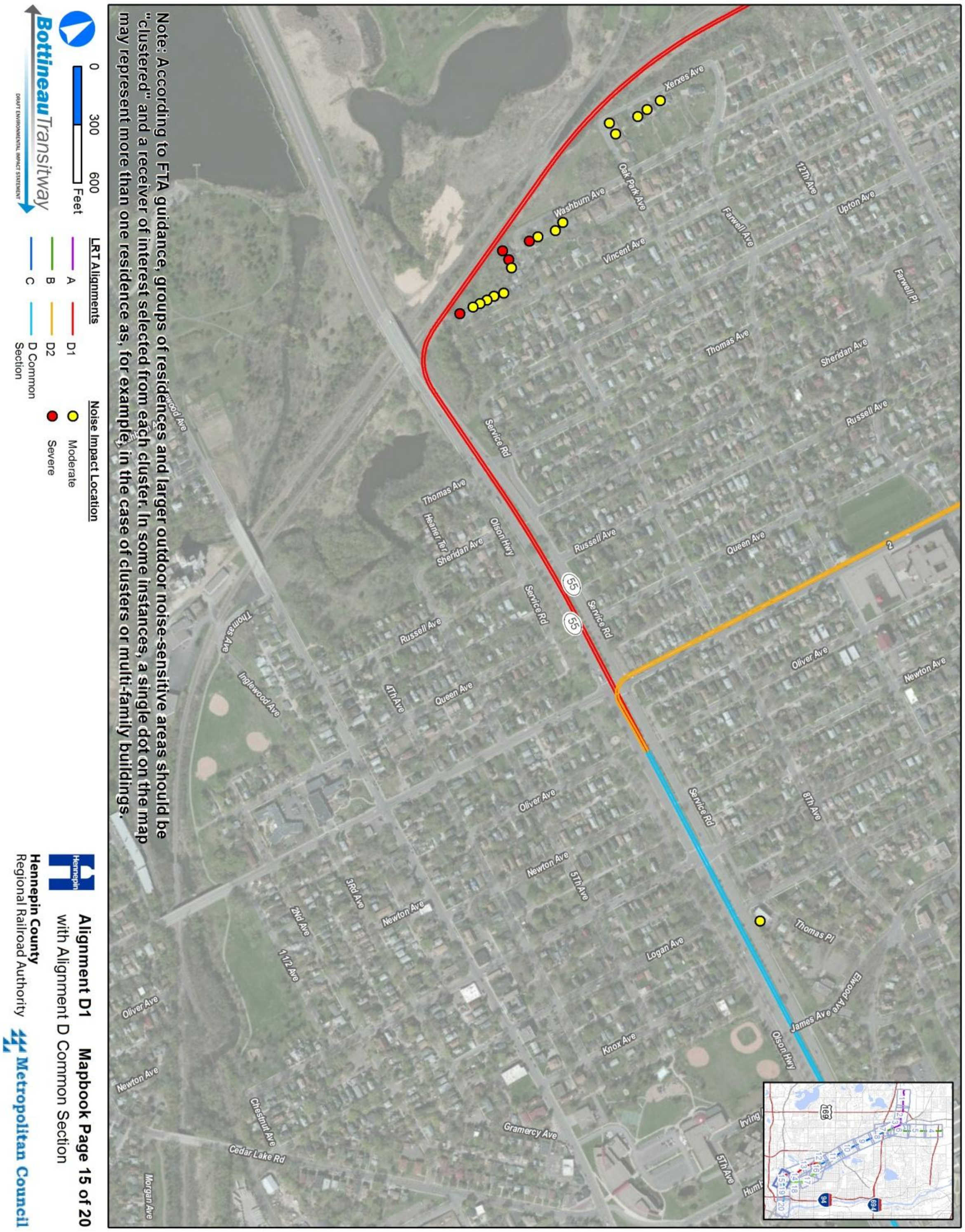


FIGURE 30: ALIGNMENT D2 NOISE IMPACT LOCATIONS

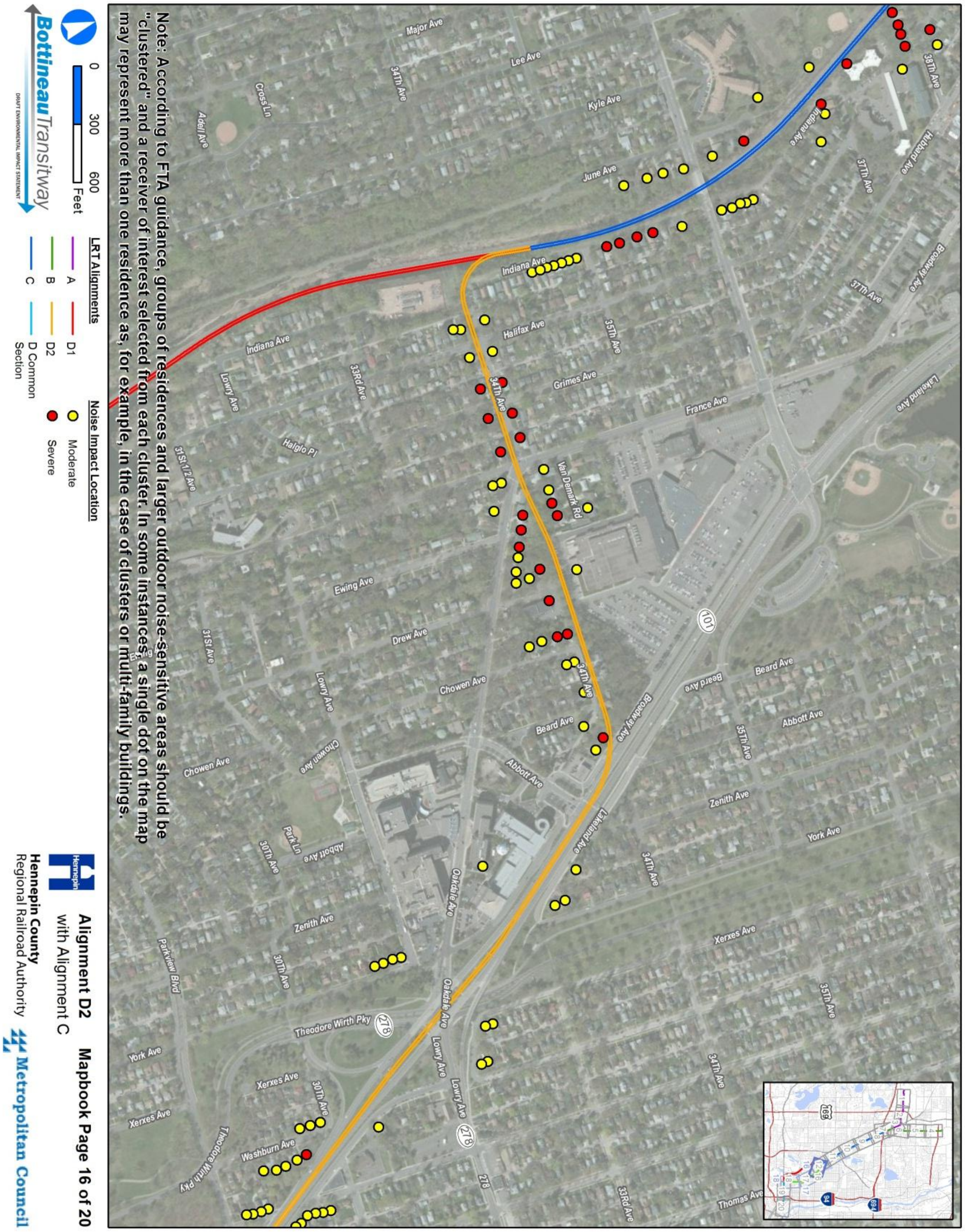


FIGURE 31: ALIGNMENT D2 NOISE IMPACT LOCATIONS

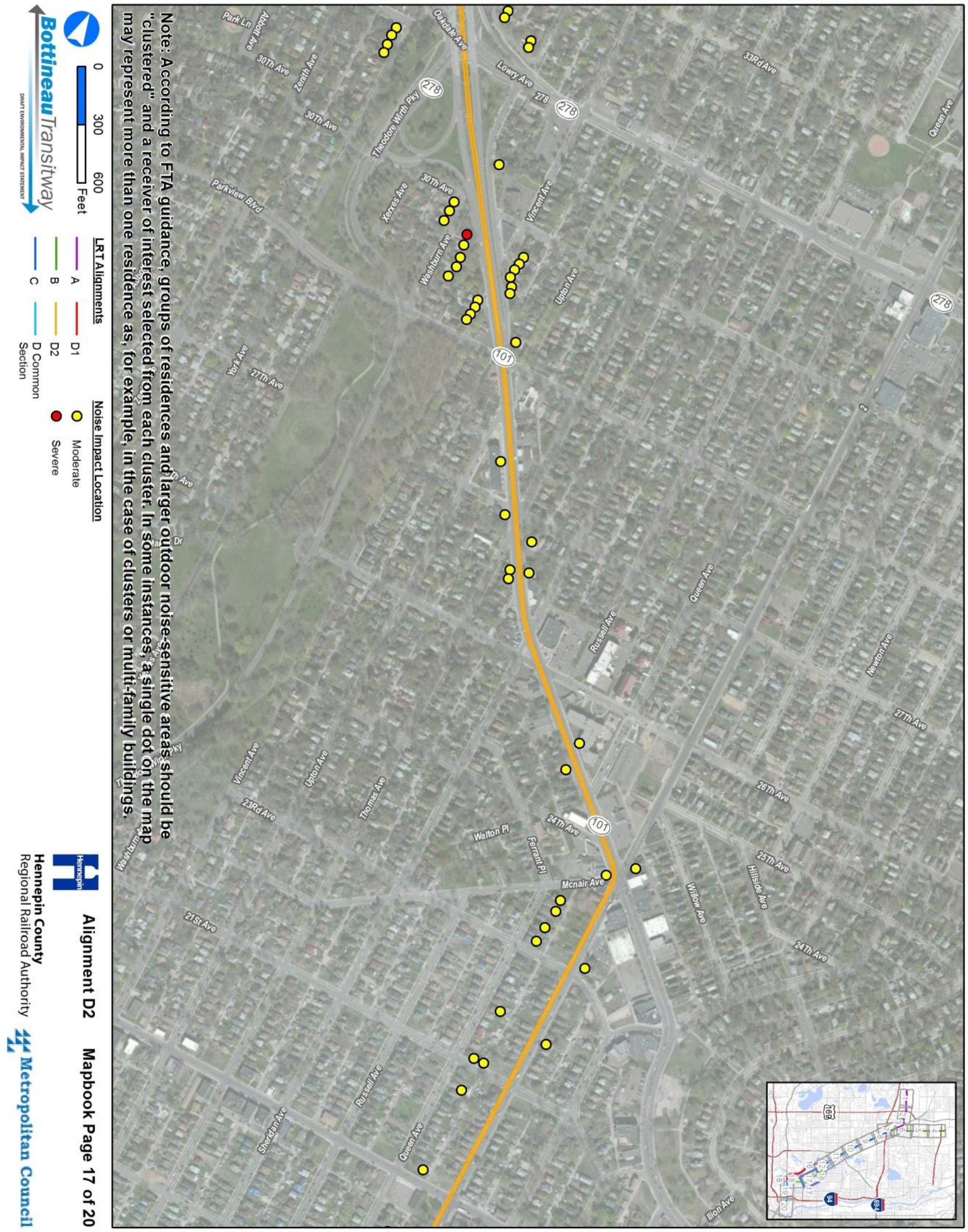


FIGURE 32: ALIGNMENT D2 NOISE IMPACT LOCATIONS

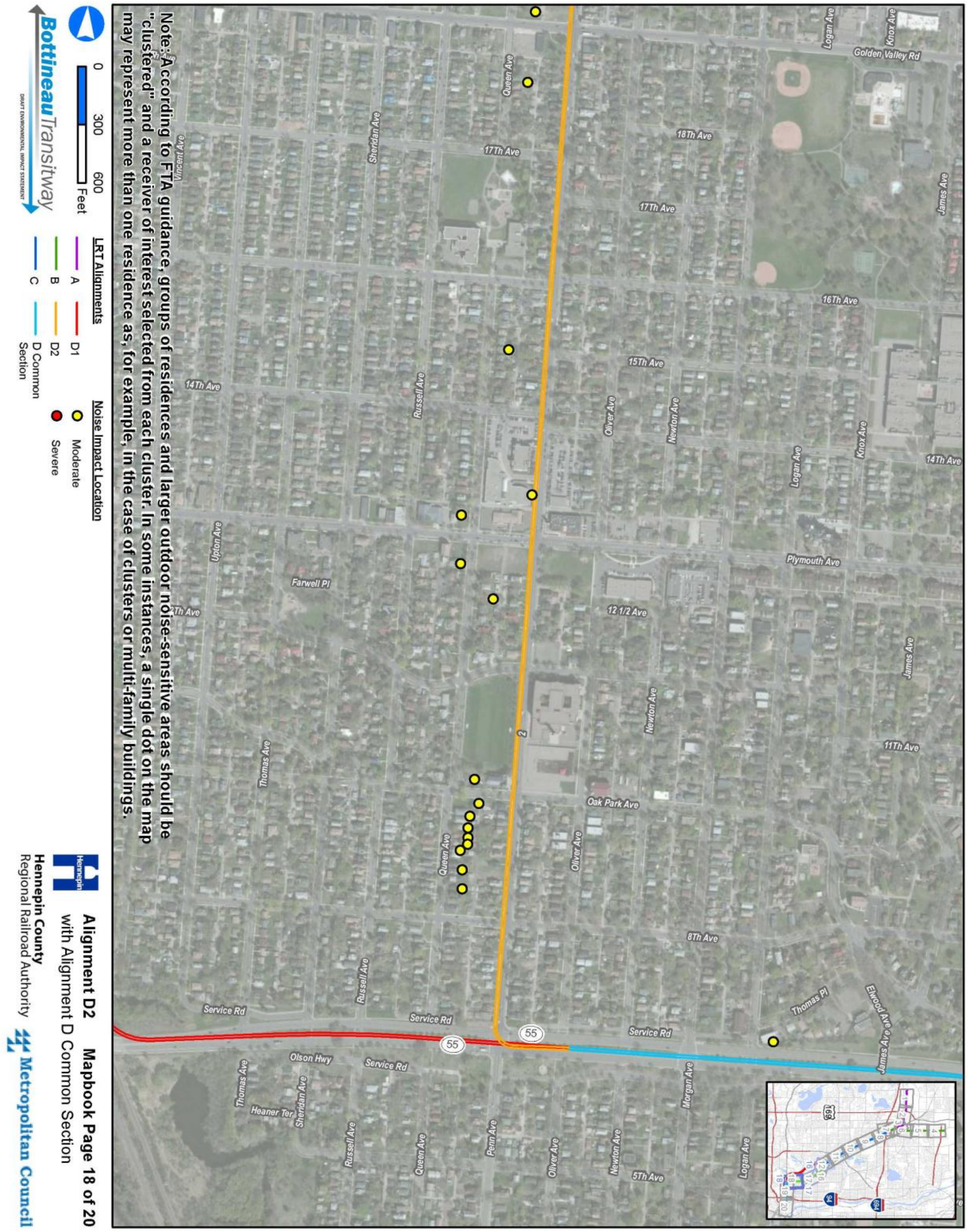


FIGURE 33: ALIGNMENT D COMMON SECTION NOISE IMPACT LOCATIONS

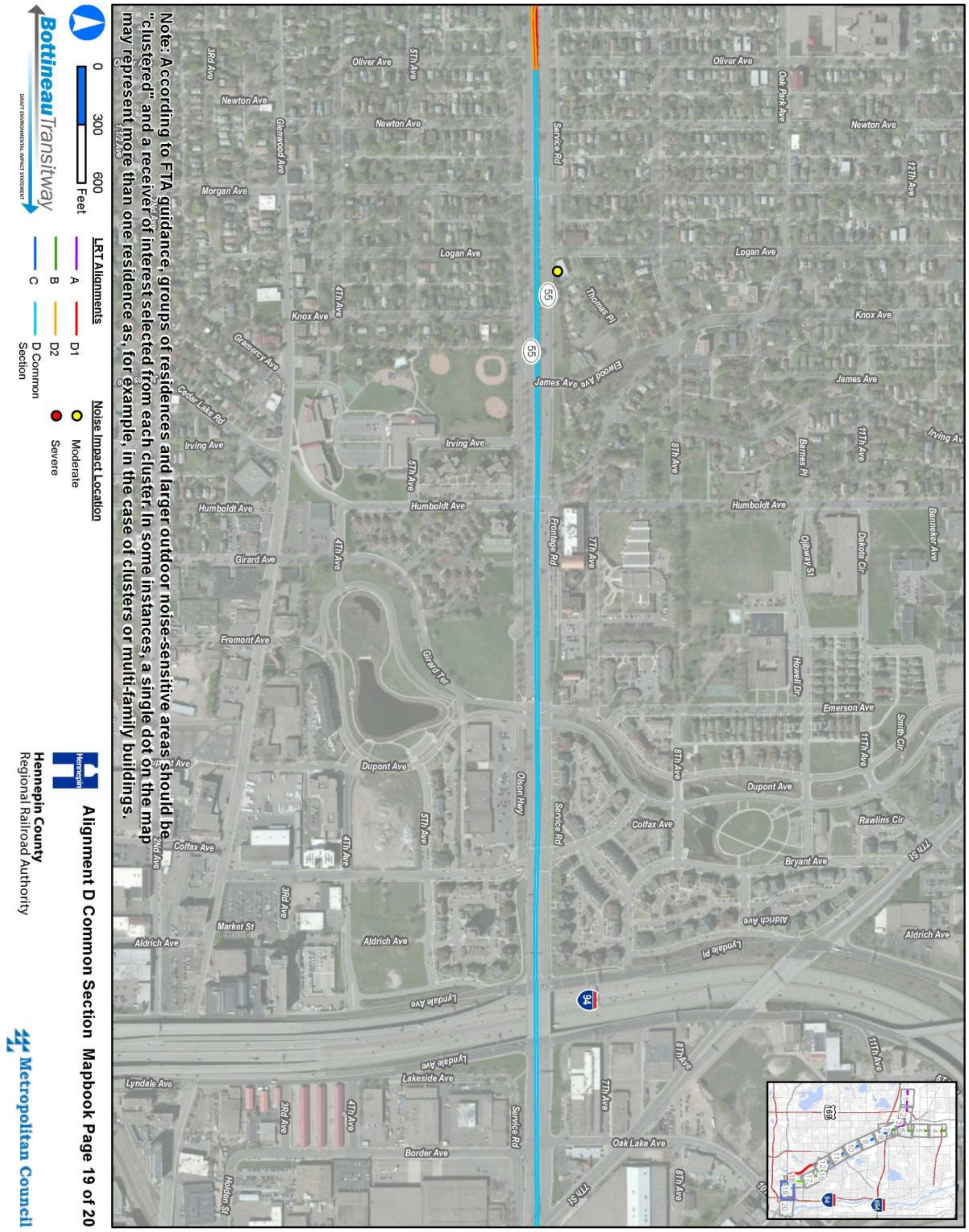


FIGURE 34: ALIGNMENT D COMMON SECTION NOISE IMPACT LOCATIONS

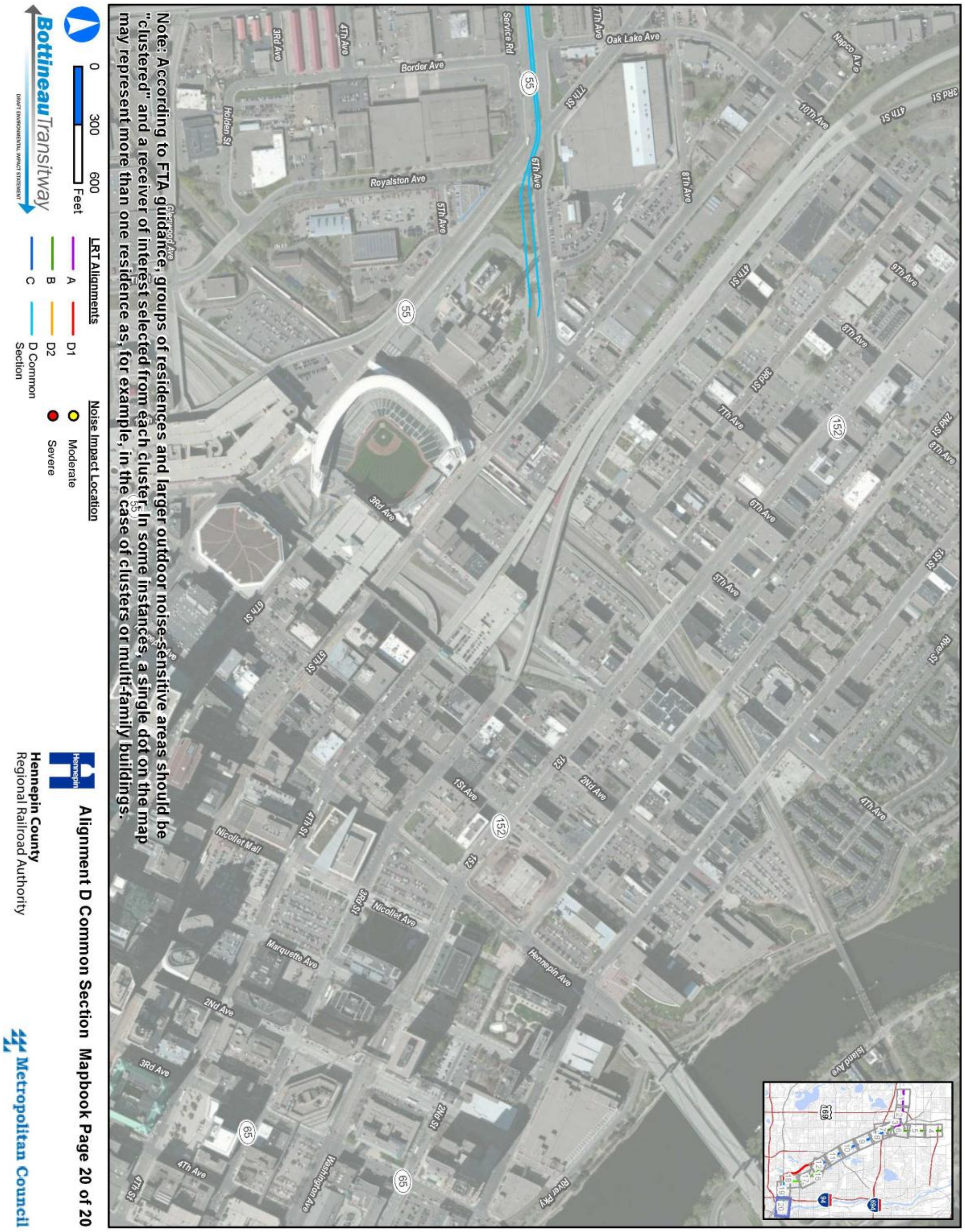
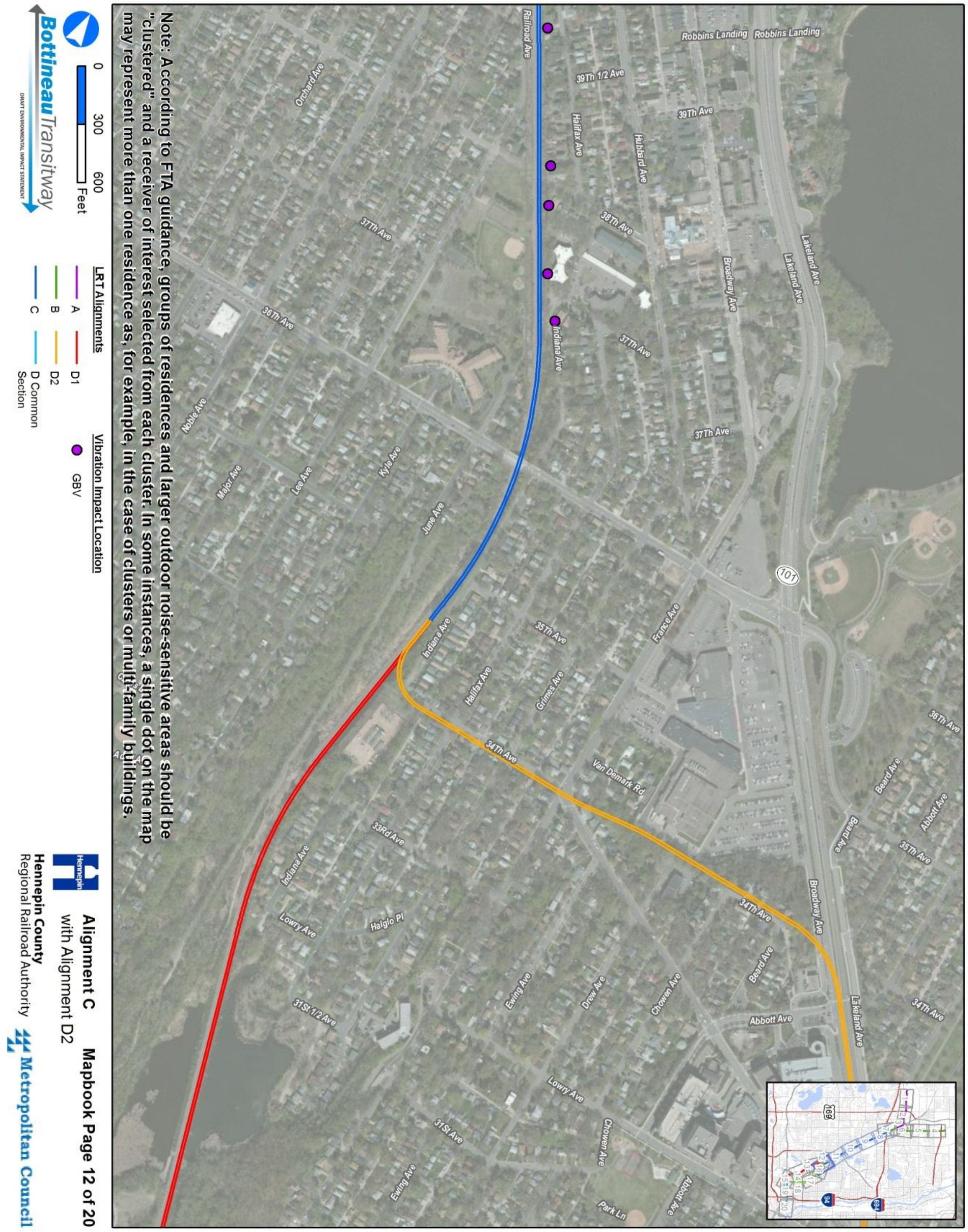


FIGURE 39: ALIGNMENT C VIBRATION IMPACT LOCATIONS

FIGURE 40: ALIGNMENT C VIBRATION IMPACT



APPENDIX A

Measurement Site Photographs

Figure A-1. Site LT-1: 7700 Boone Avenue - Brooklyn Park, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-2. Site LT-2: 8745 Oregon Avenue North - Brooklyn Park, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-3. Site LT-3: 7428 75th Circle North - Brooklyn Park, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-4. Site LT-4: 6648 W Broadway Avenue - Brooklyn Park, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-5. Site LT-5: 6288 Louisiana Court North - Brooklyn Park, MN (Waterford Manor)

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-6. Site LT-6: 5001 Welcome Avenue North - Crystal, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-7. Site LT-7: 4416 Toledo Avenue North - Robbinsdale, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-8. Site LT-8: 3954 Noble Avenue North - Robbinsdale, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-9. Site LT-9: 4400 36th Avenue North - Robbinsdale, MN
(Lee Square Co-Op)

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-10. Site LT-10: 3230 Kyle Avenue North - Golden Valley, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-11. Site LT-11: 3912 26th Avenue North - Robbinsdale, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-12. Site LT-12: 1501 Xerxes Avenue North - Golden Valley, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-13. Site LT-13: 623 North Vincent Avenue - Minneapolis, MN
Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-14. Site LT-14: 3807 Van Demark Road - Robbinsdale, MN
Source: Harris Miller Miller & Hanson Inc., 2012

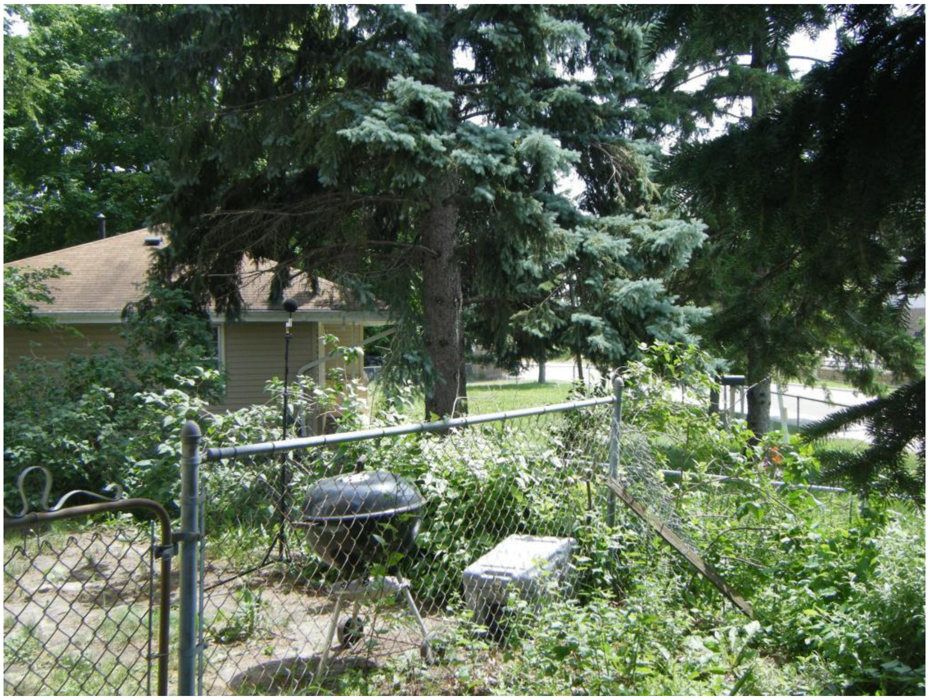


Figure A-15. Site LT-15: 3334 Lakeland Avenue North - Robbinsdale, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-16. Site LT-16: 2519 North 27th Avenue - Minneapolis, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-17. Site LT-17: 1411 Penn Avenue North - Minneapolis, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-18. Site LT-18: 611 North Oliver Avenue - Minneapolis, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-19. Site LT-19: 1000 Olson Memorial Highway - Minneapolis, MN (Heritage Park)

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-20. Site ST-1: Arbor Lakes Retirement Community, Maple Grove, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-21. Site ST-2: Grace Fellowship Church, Brooklyn Park, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-22. Site ST-3: North Hennepin Community College, Brooklyn Park, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-24. Site ST-4: Prince of Peace Church, Brooklyn Park, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-24. Site ST-5: Becker Park, Crystal, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-25. Site ST-6: Theodore Wirth Park, Golden Valley, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-26. Site ST-7: The Chalet at Theodore Wirth Park, Golden Valley, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-27. Site ST-8: KMOJ Radio Station – Penn Avenue and Broadway Avenue, Minneapolis, MN
Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-28. Site ST-9: Lincoln Junior High – Oliver Street, Minneapolis, MN
Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-29. Site ST-10: Harrison Education Center, Minneapolis, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-30. Site ST-11: Mary My Hope Children's Center, Minneapolis, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-31. Site V-1: Hennepin Technical College, Brooklyn Park, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-32. Site V-2: North Hennepin Community College, Brooklyn Park, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-33. Site V-3: 6801 62nd Avenue North, Crystal, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-34. Site V-4: Doyle's Lanes, Crystal, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-35. Site V-5: Lee Park, Robbinsdale, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-36. Site V-6: 26th Avenue North and Kewanee Way, Golden Valley, MN

Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-37. Site V-7: KMOJ Radio Station, Minneapolis, MN
Source: Harris Miller Miller & Hanson Inc., 2012

Figure A-38. Site V-8: Harrison Park, Minneapolis, MN
Source: Harris Miller Miller & Hanson Inc., 2012

APPENDIX B

Noise Measurement Data

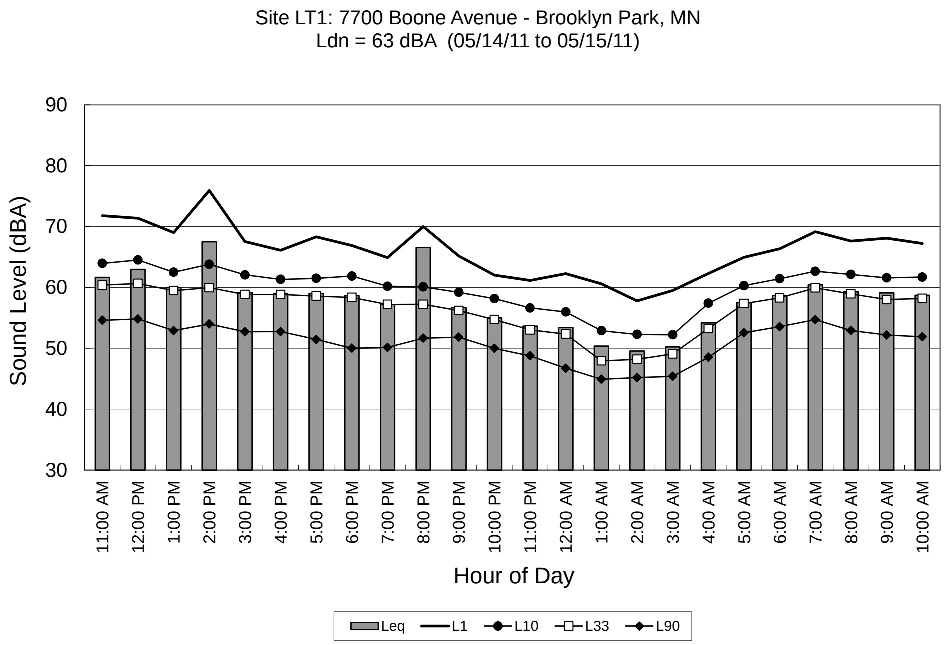


Figure B-1. Site LT-1 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

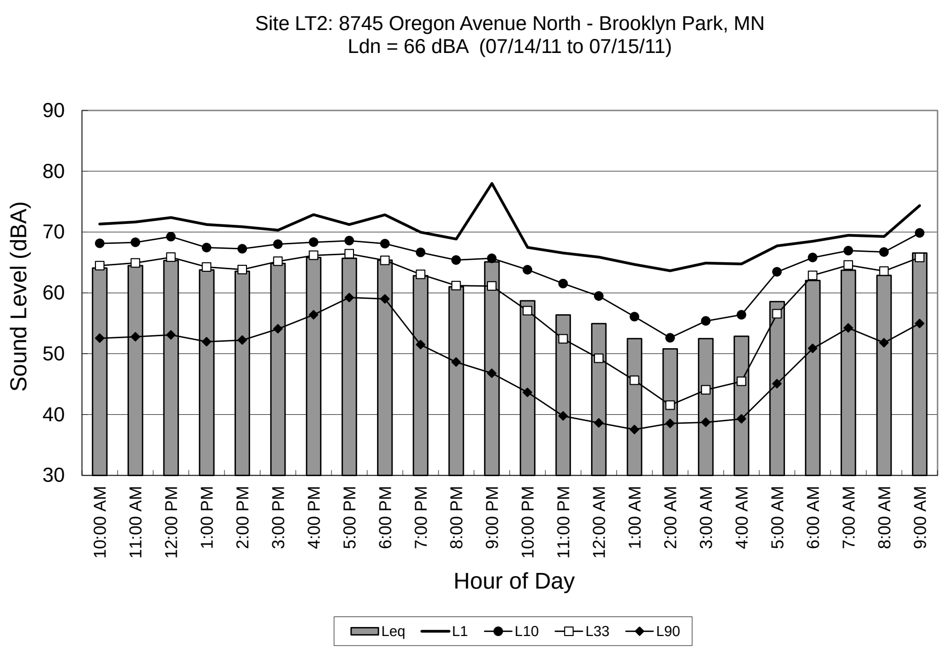


Figure B-2. Site LT-2 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

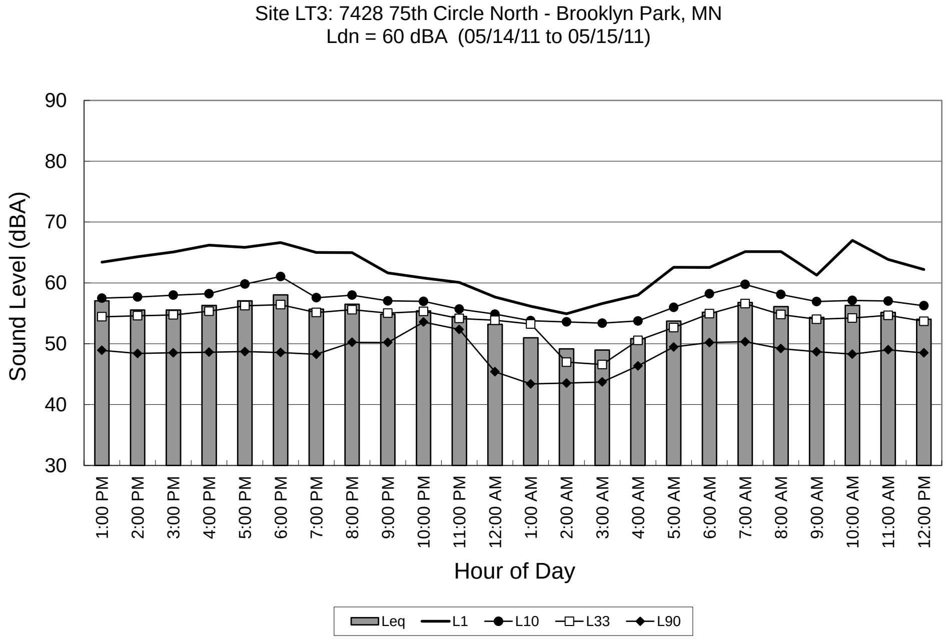


Figure B-3. Site LT-3 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

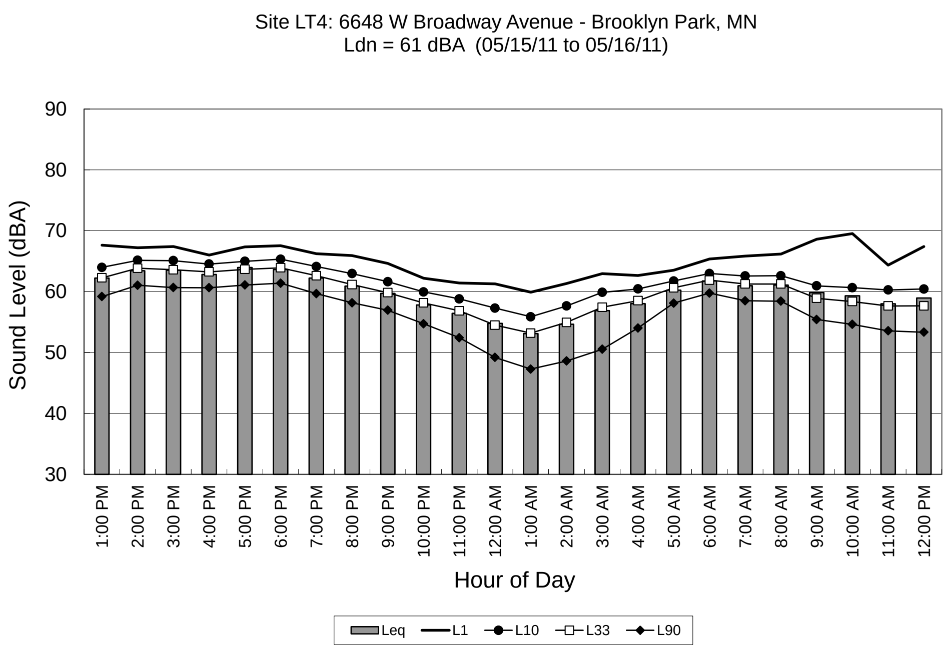


Figure B-4. Site LT-4 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

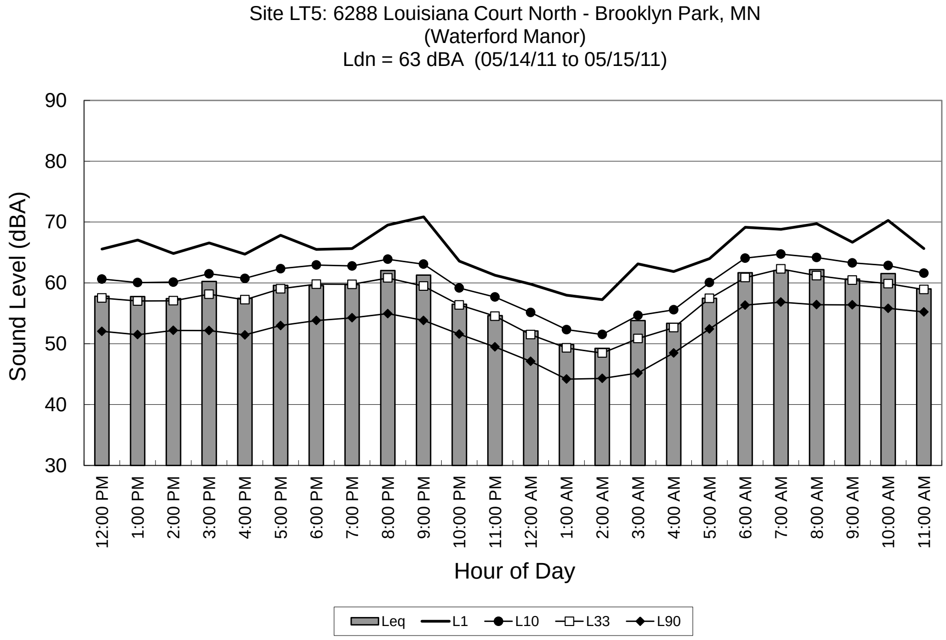


Figure B-5. Site LT-5 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

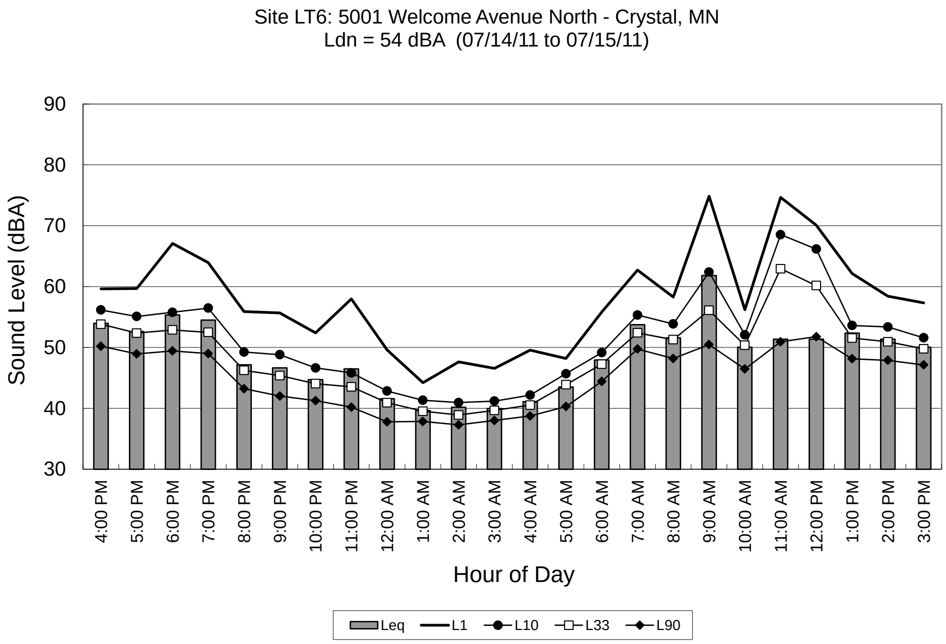


Figure B-6. Site LT-6 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

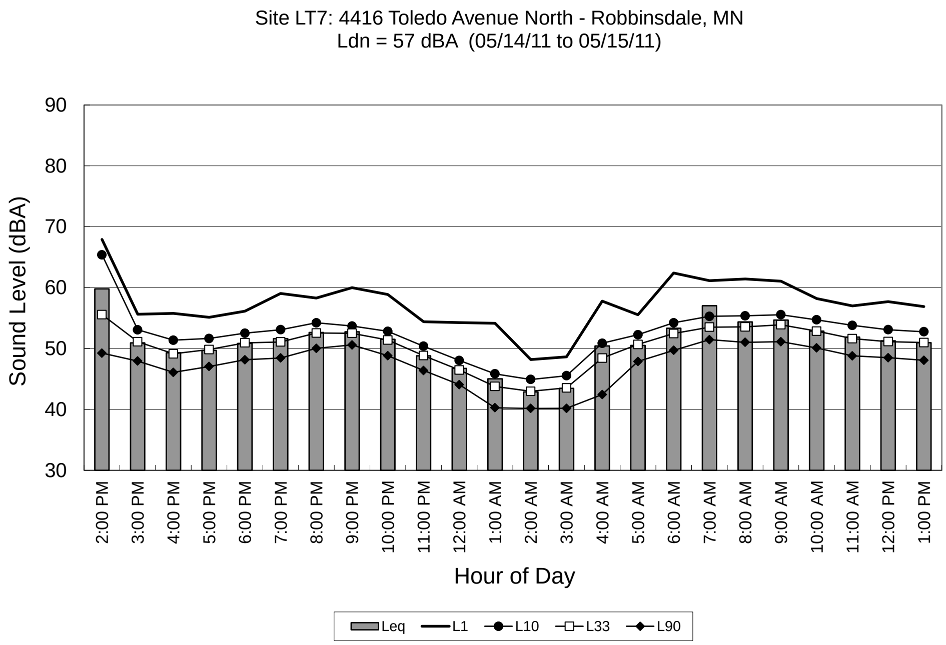


Figure B-7. Site LT-7 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

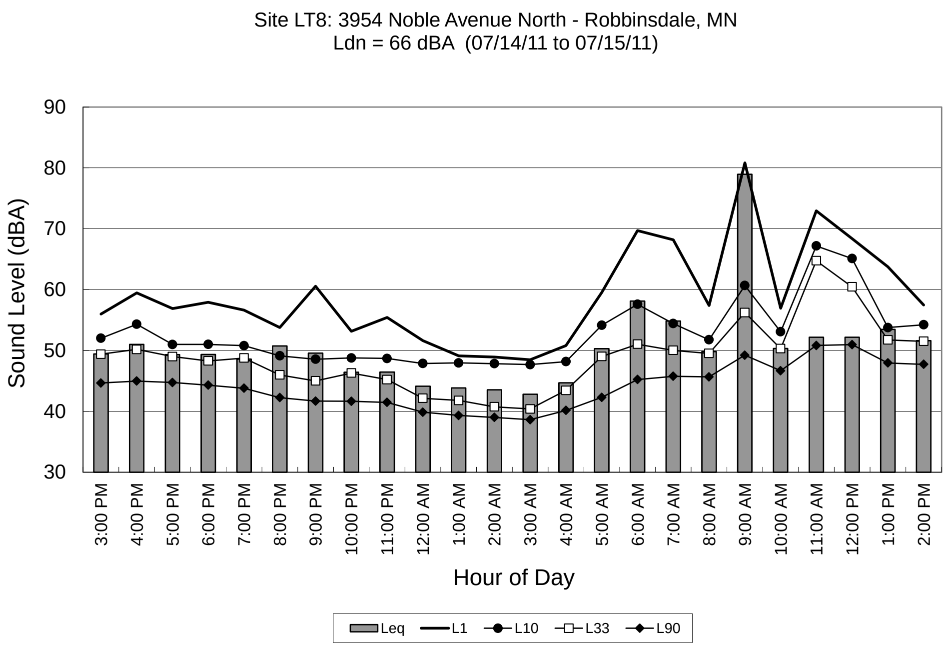


Figure B-8. Site LT-8 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

Site LT9: 4400 36th Avenue North - Robbinsdale, MN
(Lee Square Co-Op)
Ldn = 54 dBA (05/15/11 to 05/16/11)

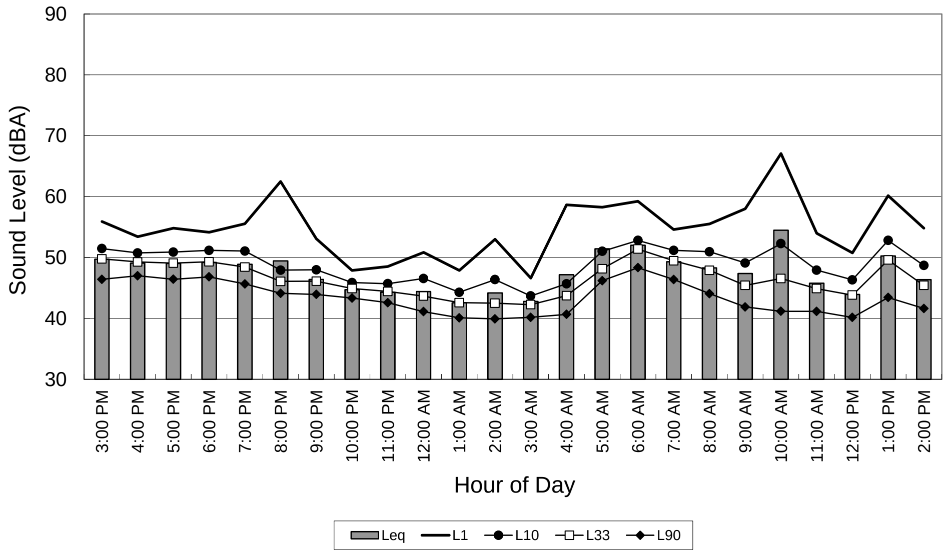


Figure B-9. Site LT-9 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

Site LT10: 3230 Kyle Avenue North - Golden Valley, MN
Ldn = 51 dBA (05/15/11 to 05/16/11)

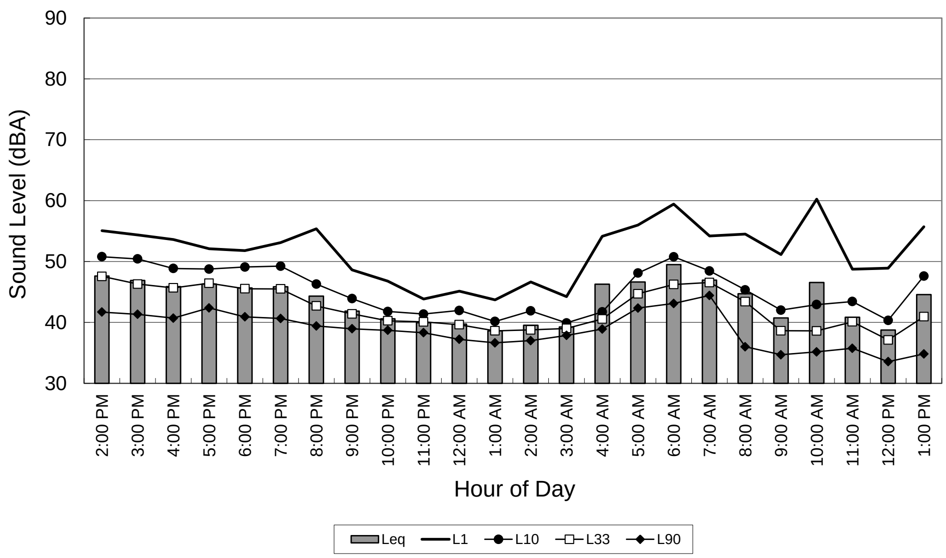


Figure B-10. Site LT-10 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

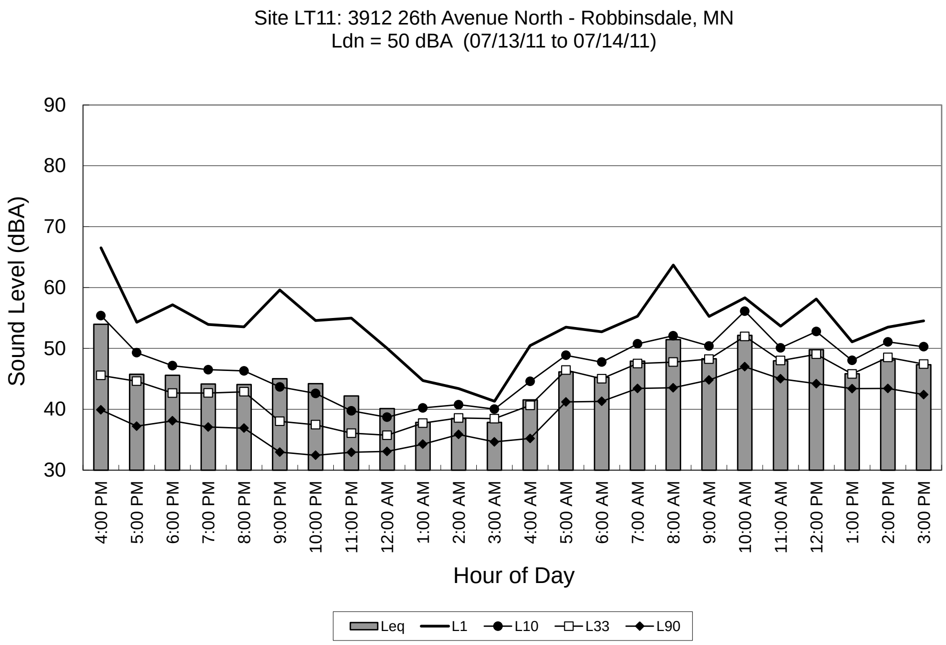


Figure B-11. Site LT-11 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

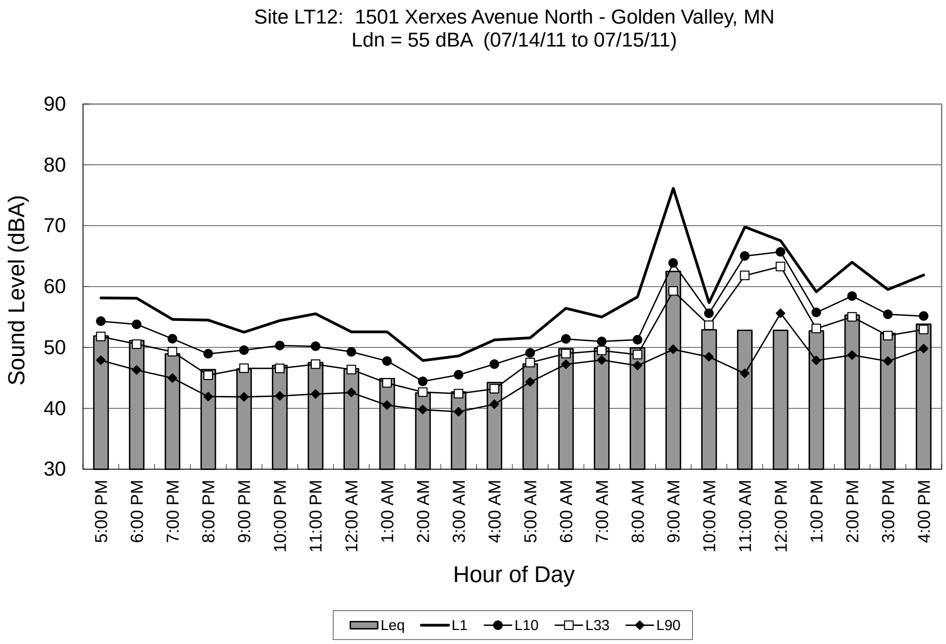


Figure B-12. Site LT-12 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

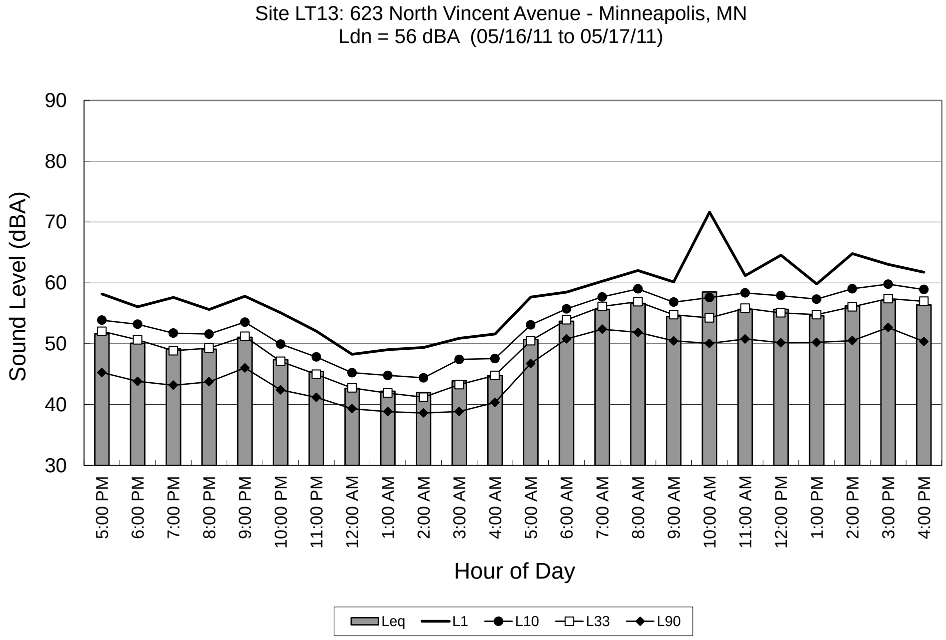


Figure B-13. Site LT-13 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

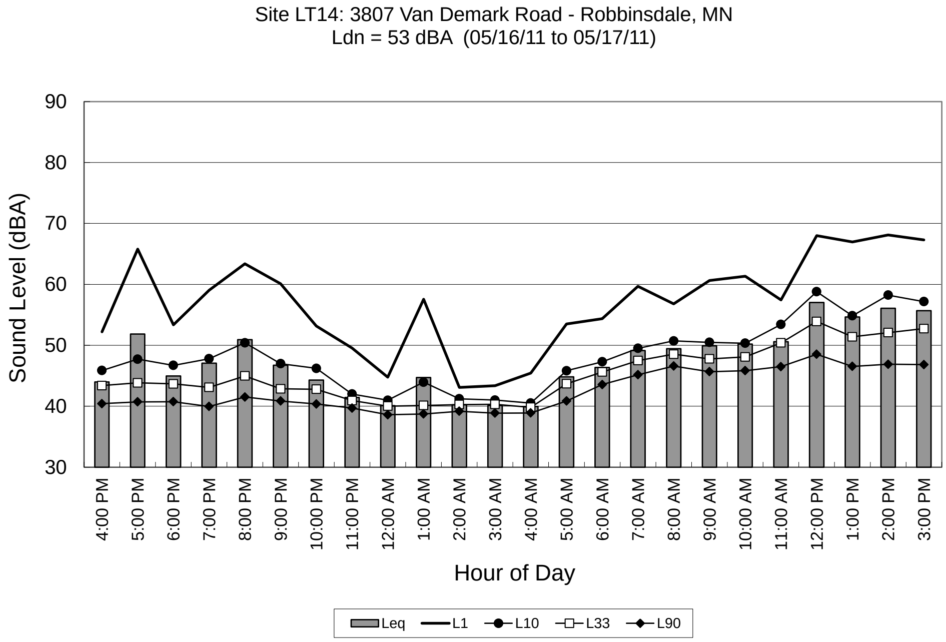


Figure B-14. Site LT-14 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

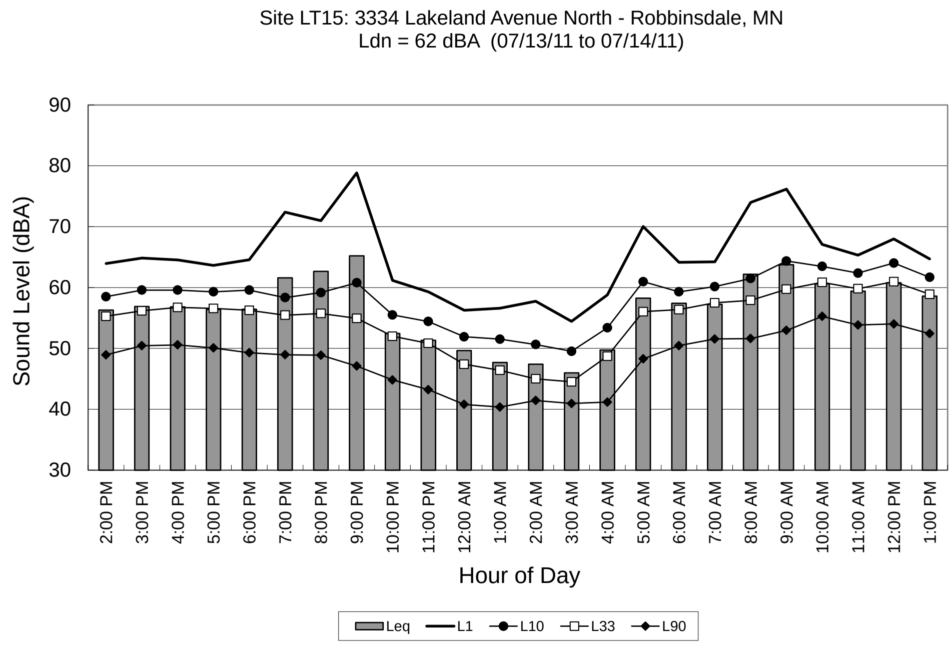


Figure B-15. Site LT-15 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

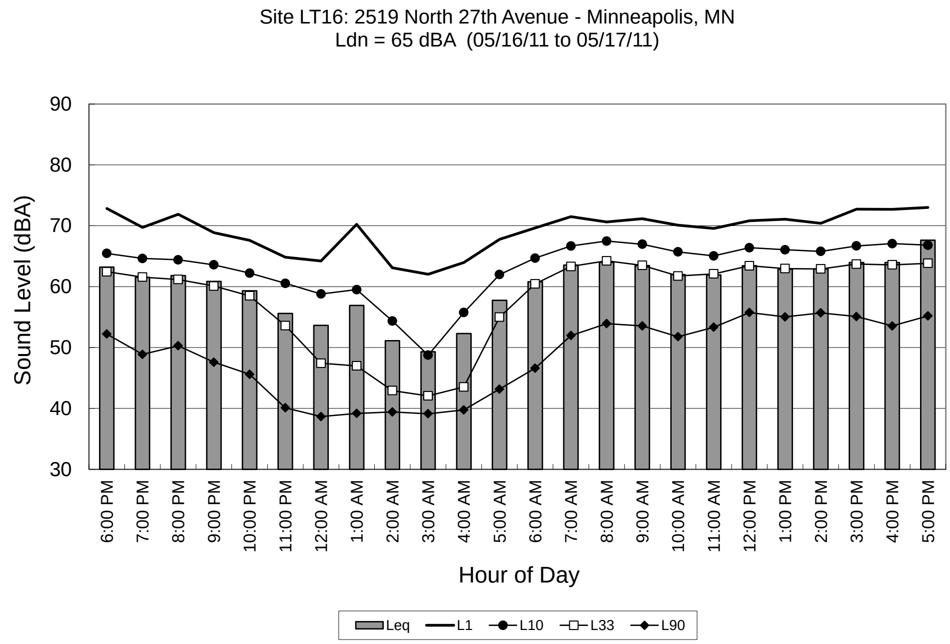


Figure B-16. Site LT-16 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

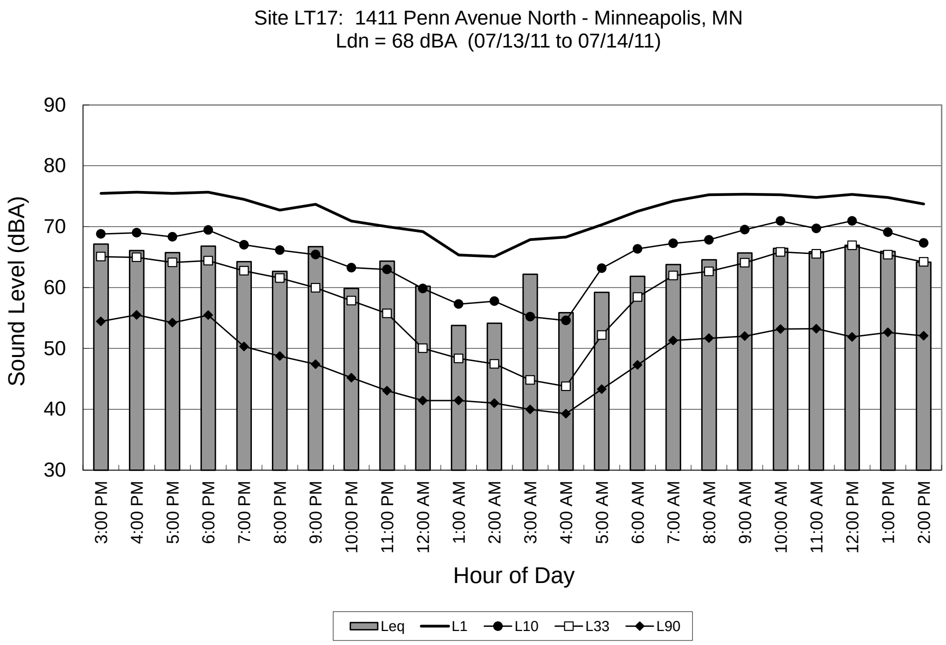


Figure B-17. Site LT-17 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

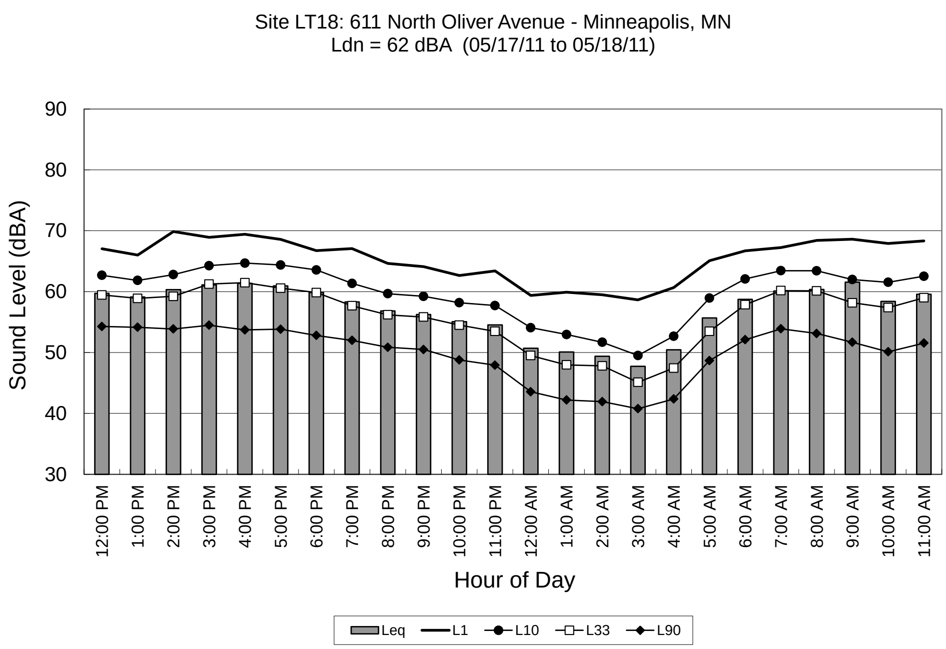


Figure B-18. Site LT-18 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

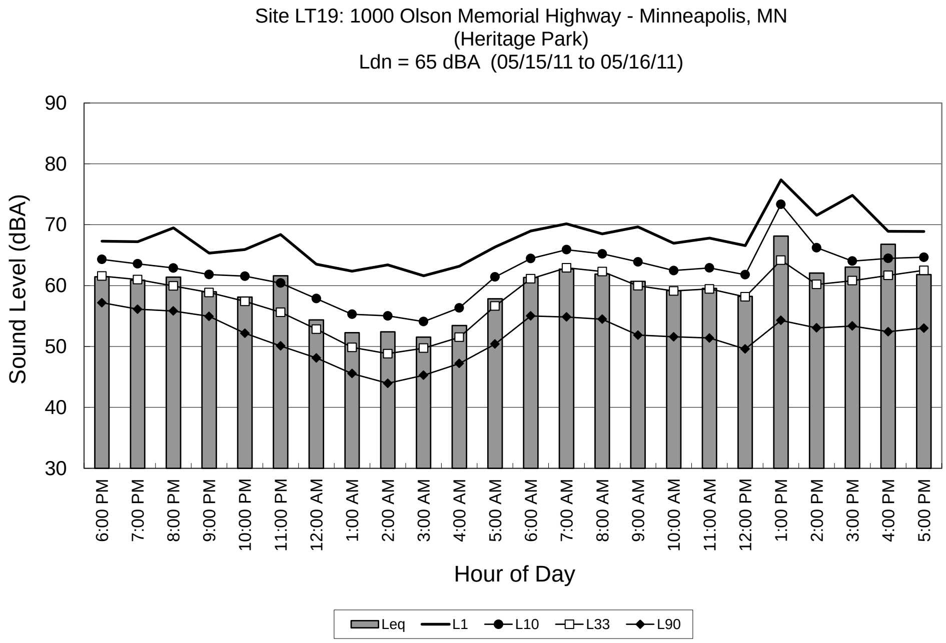


Figure B-19. Site LT-19 Measured Sound Levels

Source: Harris Miller Miller & Hanson Inc., 2012

APPENDIX C

Vibration Propagation Measurement Data

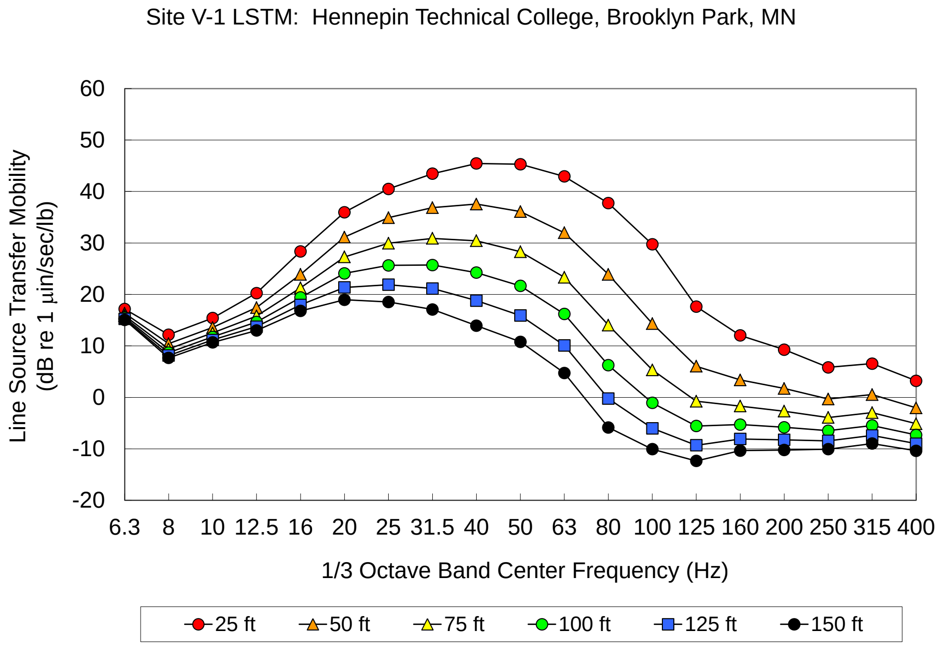


Figure C-1. Site V-1 Representative Transfer Mobility Functions

Source: Harris Miller Miller & Hanson Inc., 2012

Table C-1. Site V-1 Line Source Transfer Mobility Coefficients

Frequency (Hz)	A[1]	B[1]	C[1]
6.3	21.0	-2.8	0.0
8	20.3	-5.8	0.0
10	23.9	-6.1	0.0
12.5	33.3	-9.3	0.0
16	49.1	-14.8	0.0
20	29.6	21.5	-12.1
25	18.2	44.4	-20.3
31.5	14.7	55.6	-25.1
40	11.1	66.4	-29.9
50	19.5	58.8	-28.9
63	30.6	46.0	-26.6
80	52.2	19.0	-21.0
100	101.2	-51.1	0.0
125	71.5	-38.5	0.0
160	52.3	-28.8	0.0
200	44.3	-25.1	0.0
250	34.4	-20.4	0.0
315	34.4	-19.9	0.0
400	27.7	-17.5	0.0

[1] Line Source Transfer Mobility (TMline) is calculated as follows:

TMline = A + B*log(d) + C*(log(d))^2, where:

TM = Transfer Mobility in dB re: µin/sec/lb/(ft)^(1/2)

D = Distance in feet

Source: Harris Miller Miller & Hanson Inc., 2012

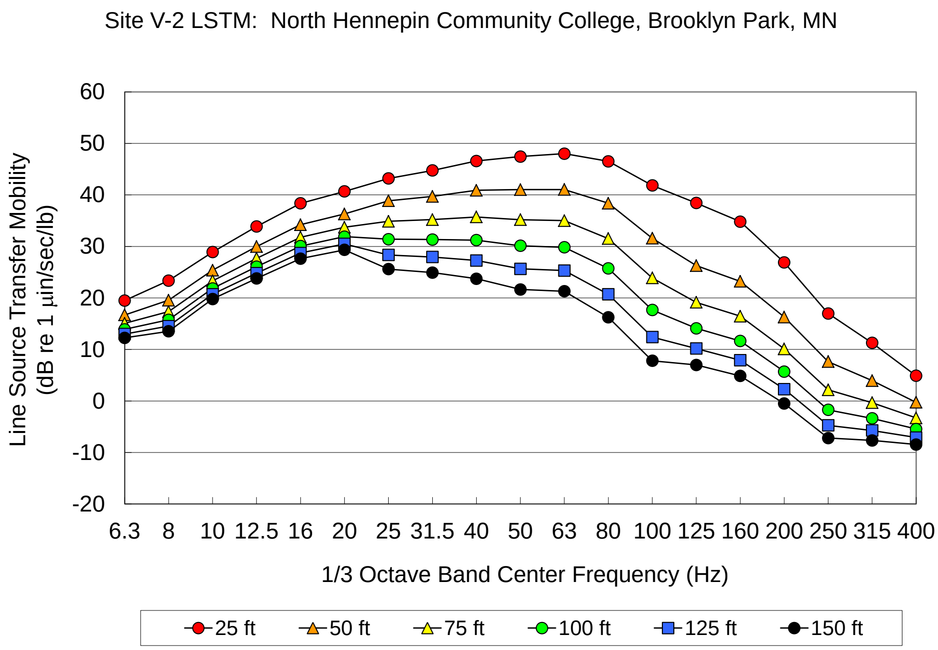


Figure C-2. Site V-2 Representative Transfer Mobility Functions

Source: Harris Miller Miller & Hanson Inc., 2012

Table C-2. Site V-2 Line Source Transfer Mobility Coefficients

Frequency (Hz)	A[1]	B[1]	C[1]
6.3	32.5	-9.3	0.0
8	41.0	-12.6	0.0
10	45.3	-11.7	0.0
12.5	52.0	-13.0	0.0
16	57.7	-13.8	0.0
20	61.1	-14.6	0.0
25	22.6	38.8	-17.2
31.5	24.8	39.7	-18.2
40	20.9	49.0	-21.9
50	18.1	55.7	-24.9
63	24.5	49.7	-23.5
80	25.2	50.0	-24.9
100	41.2	28.8	-20.3
125	94.9	-40.4	0.0
160	88.6	-38.5	0.0
200	76.1	-35.2	0.0
250	60.4	-31.1	0.0
315	45.3	-24.3	0.0
400	28.9	-17.1	0.0

[1] Line Source Transfer Mobility (TMline) is calculated as follows:
TMline = A + B*log(d) + C*(log(d))^2, where:
TM = Transfer Mobility in dB re: µin/sec/lb/(ft)^(1/2)
D = Distance in feet
Source: Harris Miller Miller & Hanson Inc., 2012

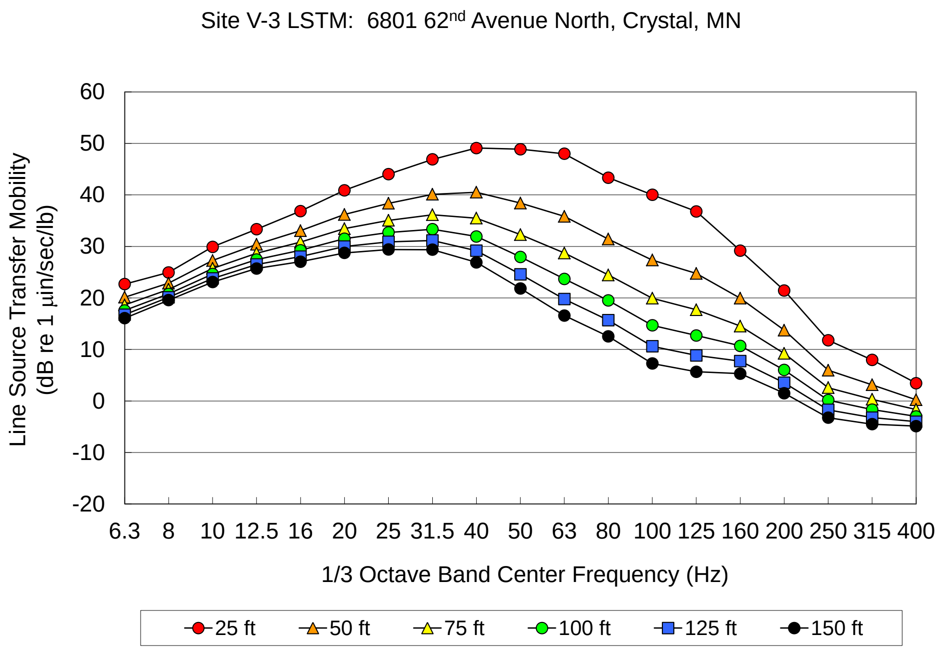


Figure C-3. Site V-3 Representative Transfer Mobility Functions

Source: Harris Miller Miller & Hanson Inc., 2012

Table C-3. Site V-3 Line Source Transfer Mobility Coefficients

Frequency (Hz)	A[1]	B[1]	C[1]
6.3	34.6	-8.5	0.0
8	34.6	-6.9	0.0
10	42.2	-8.8	0.0
12.5	47.0	-9.8	0.0
16	54.5	-12.6	0.0
20	62.7	-15.6	0.0
25	70.3	-18.8	0.0
31.5	78.4	-22.5	0.0
40	89.0	-28.5	0.0
50	97.4	-34.7	0.0
63	104.4	-40.4	0.0
80	98.7	-39.6	0.0
100	98.8	-42.1	0.0
125	92.7	-40.0	0.0
160	72.1	-30.7	0.0
200	57.3	-25.6	0.0
250	38.8	-19.3	0.0
315	30.3	-16.0	0.0
400	18.4	-10.7	0.0

[1] Line Source Transfer Mobility (TMline) is calculated as follows:
TMline = A + B*log(d) + C*(log(d))^2, where:
TM = Transfer Mobility in dB re: µin/sec/lb/(ft)^(1/2)
D = Distance in feet
Source: Harris Miller Miller & Hanson Inc., 2012

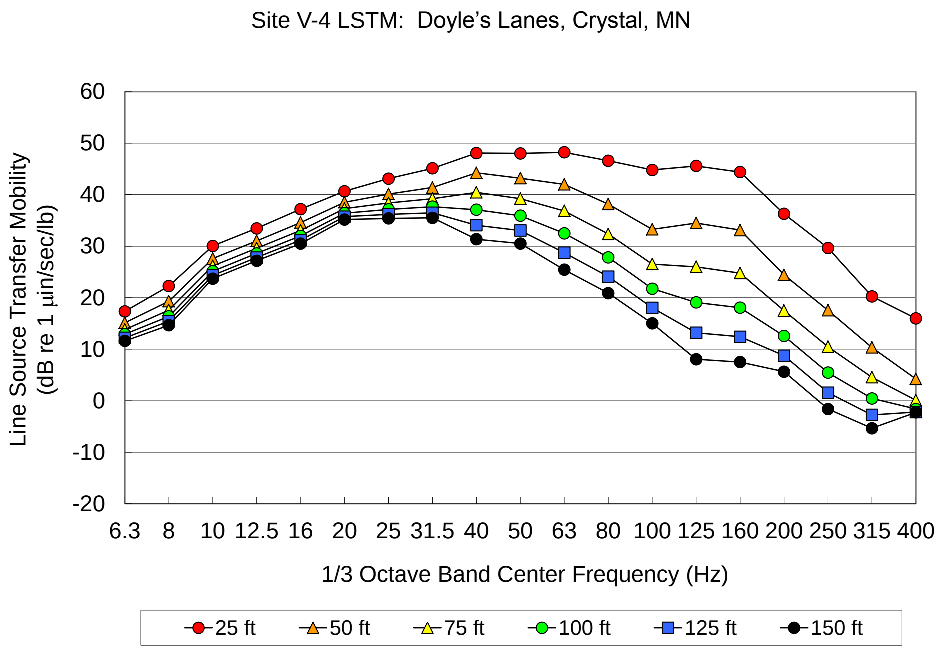


Figure C-4. Site V-4 Representative Transfer Mobility Functions

Source: Harris Miller Miller & Hanson Inc., 2012

Table C-4. Site V-4 Line Source Transfer Mobility Coefficients

Frequency (Hz)	A[1]	B[1]	C[1]
6.3	27.6	-7.4	0.0
8	35.9	-9.8	0.0
10	41.4	-8.2	0.0
12.5	44.7	-8.1	0.0
16	49.2	-8.6	0.0
20	50.5	-7.0	0.0
25	57.0	-9.9	0.0
31.5	62.4	-12.3	0.0
40	22.5	43.9	-18.3
50	38.1	26.1	-13.6
63	34.2	35.3	-18.1
80	60.2	5.1	-10.7
100	98.3	-38.3	0.0
125	40.4	37.0	-23.8
160	47.1	27.3	-20.9
200	91.3	-39.4	0.0
250	85.8	-40.2	0.0
315	66.2	-32.9	0.0
400	148.5	-140.7	32.8

[1] Line Source Transfer Mobility (TMline) is calculated as follows:

TMline = A + B*log(d) + C*(log(d))^2, where:

TM = Transfer Mobility in dB re: µin/sec/lb/(ft)^(1/2)

D = Distance in feet

Source: Harris Miller Miller & Hanson Inc., 2012

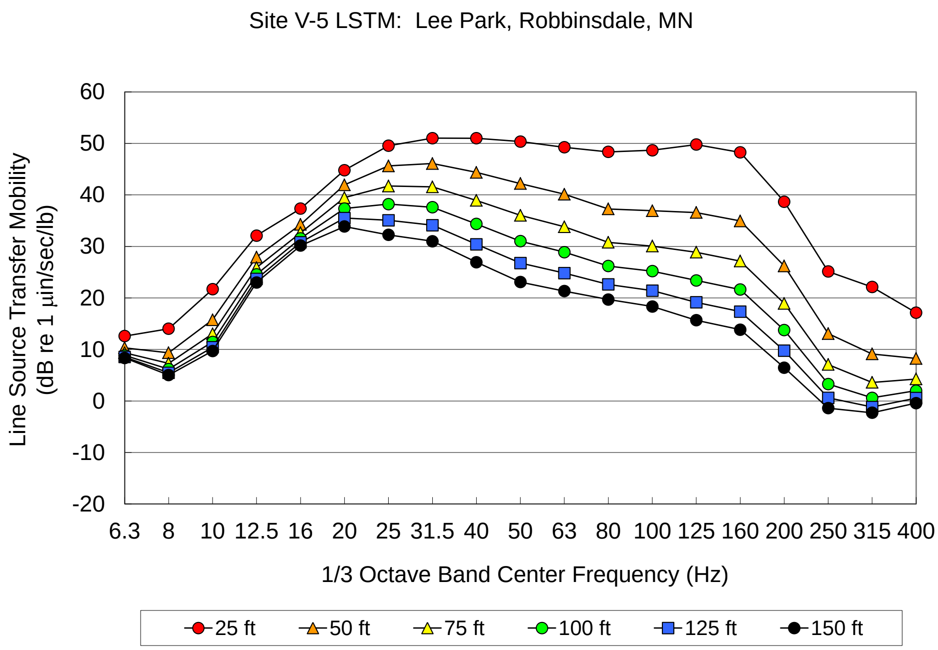


Figure C-5. Site V-5 Representative Transfer Mobility Functions

Source: Harris Miller Miller & Hanson Inc., 2012

Table C-5. Site V-5 Line Source Transfer Mobility Coefficients

Frequency (Hz)	A[1]	B[1]	C[1]
6.3	33.8	-21.4	4.4
8	55.3	-41.1	8.3
10	70.8	-47.8	9.1
12.5	62.2	-27.8	4.5
16	56.5	-16.6	2.1
20	35.2	20.3	-9.6
25	21.9	46.8	-19.3
31.5	27.3	44.3	-19.6
40	37.3	35.9	-18.7
50	48.5	24.7	-16.7
63	63.5	6.3	-11.8
80	99.8	-36.8	0.0
100	103.1	-39.0	0.0
125	111.0	-43.8	0.0
160	110.1	-44.2	0.0
200	96.5	-41.4	0.0
250	110.8	-78.8	12.5
315	141.3	-119.8	24.7
400	93.2	-74.9	14.6

[1] Line Source Transfer Mobility (TMline) is calculated as follows:
TMline = A + B*log(d) + C*(log(d))^2, where:
TM = Transfer Mobility in dB re: µin/sec/lb/(ft)^(1/2)
D = Distance in feet

Source: Harris Miller Miller & Hanson Inc., 2012

Site V-6 LSTM: 26th Avenue North and Kewanee Way, Golden Valley, MN

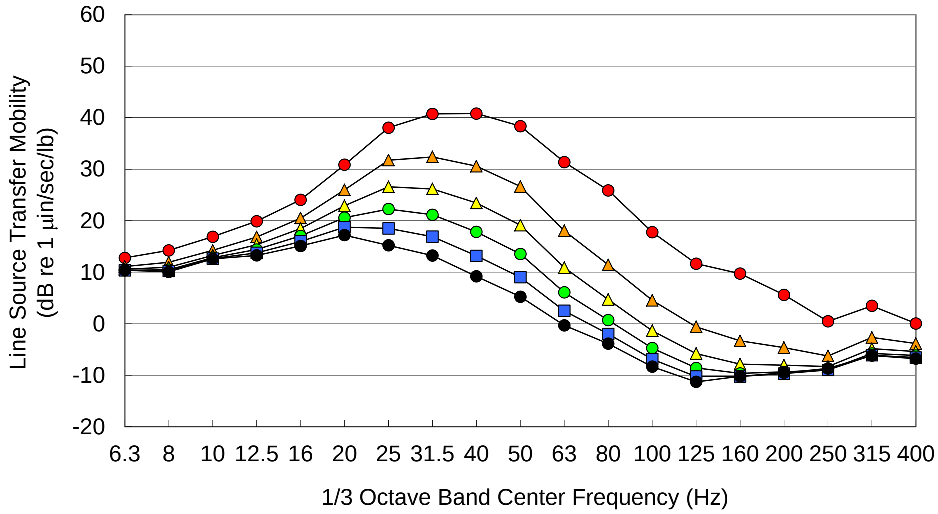


Figure C-6. Site V-6 Representative Transfer Mobility Functions

Source: Harris Miller Miller & Hanson Inc., 2012

Table C-6. Site V-6 Line Source Transfer Mobility Coefficients

Frequency (Hz)	A[1]	B[1]	C[1]
6.3	33.0	-21.8	5.2
8	36.6	-22.9	4.9
10	45.4	-30.0	6.8
12.5	42.3	-20.8	3.4
16	42.2	-13.9	0.7
20	46.6	-7.2	-2.9
25	25.4	33.7	-17.6
31.5	41.4	21.9	-16.0
40	54.8	9.6	-14.0
50	74.7	-15.4	-7.6
63	110.5	-66.8	7.3
80	141.6	-111.4	20.5
100	131.0	-111.5	21.8
125	124.4	-113.6	23.5
160	158.7	-158.6	37.2
200	125.6	-128.5	30.5
250	84.4	-91.0	22.2
315	72.0	-72.5	16.8
400	39.0	-40.1	8.8

[1] Line Source Transfer Mobility (TMline) is calculated as follows:
TMline = A + B*log(d) + C*(log(d))^2, where:
TM = Transfer Mobility in dB re: µin/sec/lb/(ft)^(1/2)
D = Distance in feet
Source: Harris Miller Miller & Hanson Inc., 2012

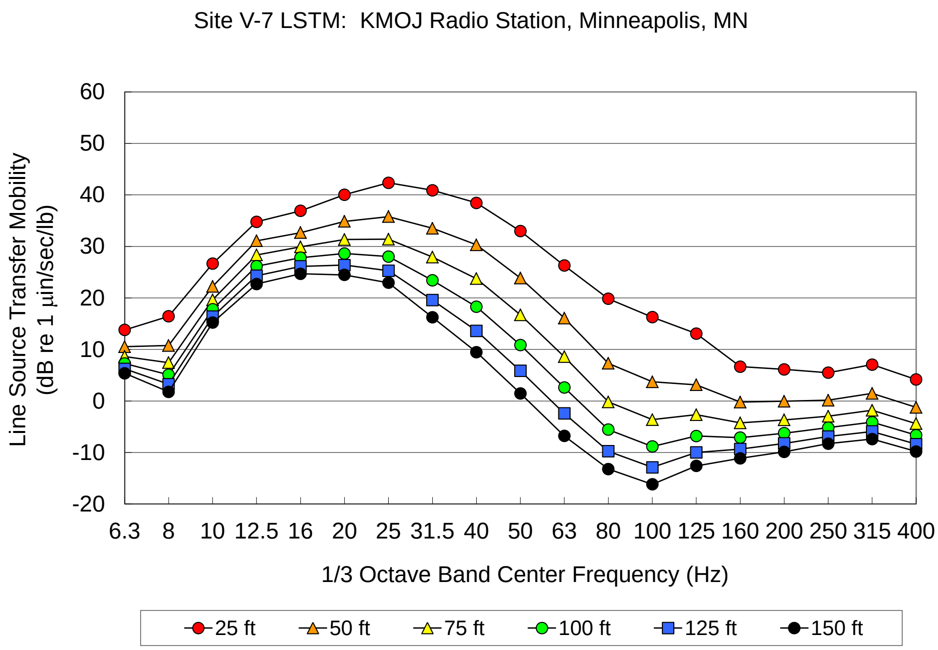


Figure C-7. Site V-7 Representative Transfer Mobility Functions

Source: Harris Miller Miller & Hanson Inc., 2012

Table C-7. Site V-7 Line Source Transfer Mobility Coefficients

Frequency (Hz)	A[1]	B[1]	C[1]
6.3	28.9	-10.8	0.0
8	42.8	-18.9	0.0
10	47.2	-14.7	0.0
12.5	35.9	8.6	-6.7
16	48.5	-3.5	-3.4
20	50.0	1.1	-5.9
25	57.2	-1.5	-6.6
31.5	39.4	22.1	-15.0
40	25.5	39.2	-21.4
50	24.7	35.8	-21.3
63	30.8	22.0	-18.0
80	73.9	-36.2	-1.8
100	74.6	-41.7	0.0
125	59.2	-33.0	0.0
160	38.6	-22.9	0.0
200	34.9	-20.6	0.0
250	30.2	-17.7	0.0
315	33.0	-18.6	0.0
400	29.3	-18.0	0.0

[1] Line Source Transfer Mobility (TMline) is calculated as follows:
TMline = A + B*log(d) + C*(log(d))^2, where:
TM = Transfer Mobility in dB re: µin/sec/lb/(ft)^(1/2)
D = Distance in feet
Source: Harris Miller Miller & Hanson Inc., 2012

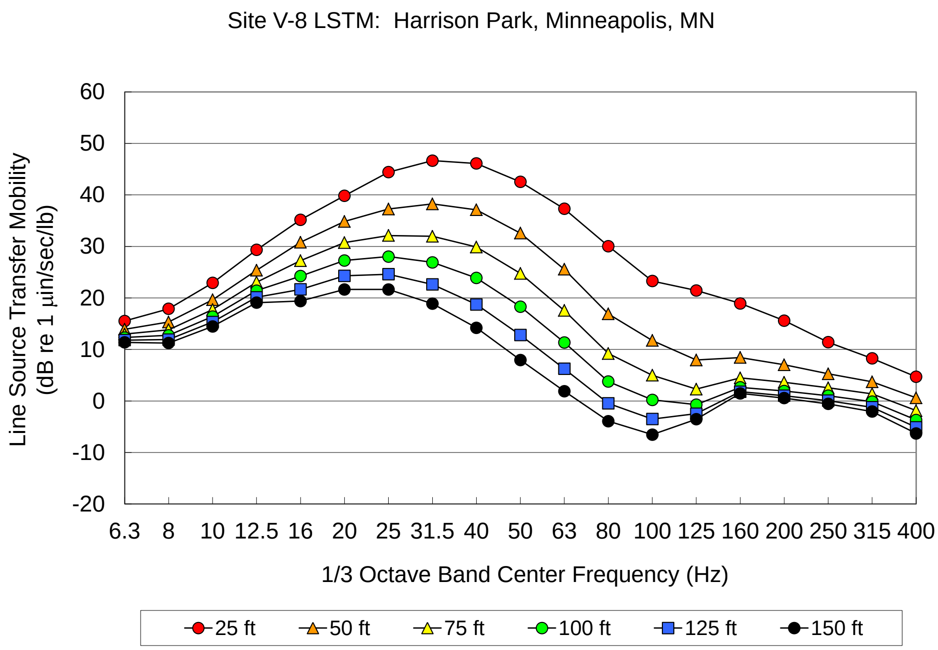


Figure C-8. Site V-8 Representative Transfer Mobility Functions

Source: Harris Miller Miller & Hanson Inc., 2012

Table C-8. Site V-8 Line Source Transfer Mobility Coefficients

Frequency (Hz)	A[1]	B[1]	C[1]
6.3	23.0	-5.3	0.0
8	29.8	-8.5	0.0
10	38.1	-10.9	0.0
12.5	47.8	-13.2	0.0
16	26.7	23.0	-12.1
20	29.0	27.7	-14.3
25	50.4	11.8	-11.5
31.5	46.9	22.6	-16.3
40	32.7	42.1	-23.2
50	32.2	40.7	-23.8
63	59.4	3.2	-13.6
80	91.1	-43.6	0.0
100	76.9	-38.3	0.0
125	147.7	-127.7	26.7
160	129.7	-115.7	26.1
200	100.9	-87.9	19.2
250	64.9	-53.0	10.5
315	38.7	-27.2	3.9
400	20.7	-9.7	-1.2

[1] Line Source Transfer Mobility (TMline) is calculated as follows:
TMline = A + B*log(d) + C*(log(d))^2, where:
TM = Transfer Mobility in dB re: µin/sec/lb/(ft)^(1/2)
D = Distance in feet
Source: Harris Miller Miller & Hanson Inc., 2012

APPENDIX D

Reference Vehicle Vibration Data

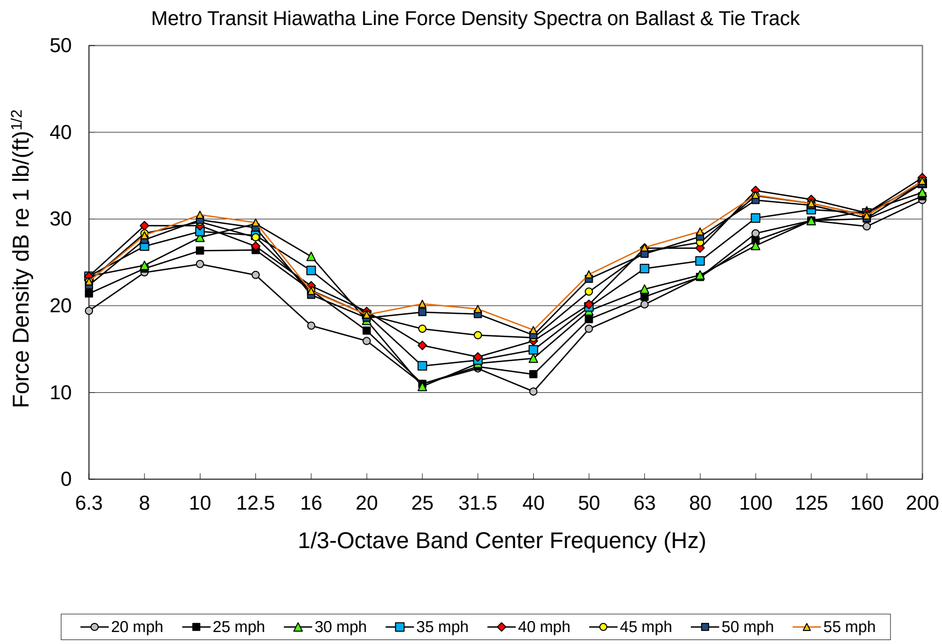


Figure D-1. Metro Transit Reference LRV Force Density Levels on B&T Track

Source: ATS Consulting, 2008

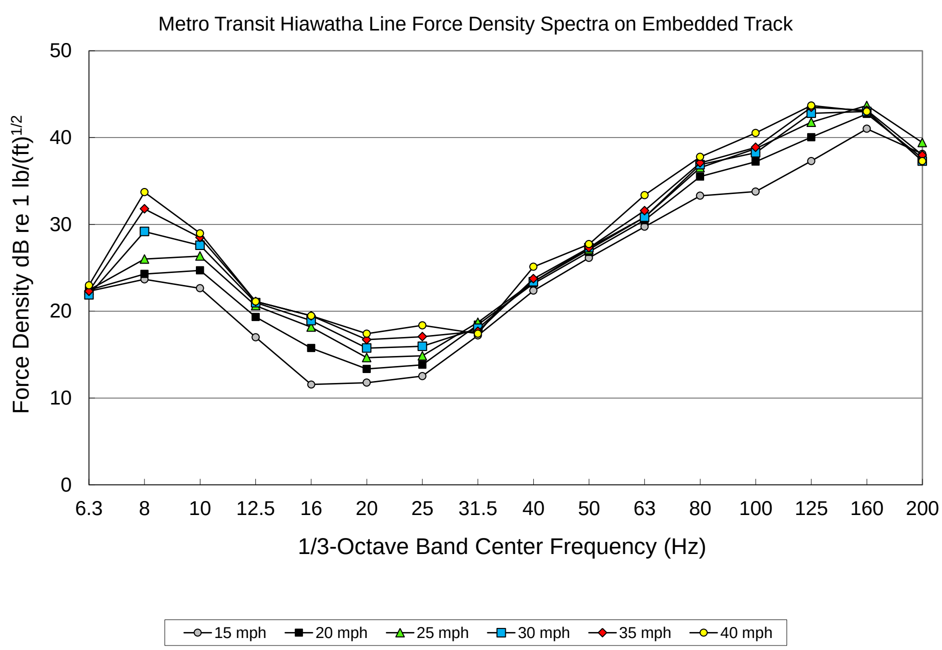


Figure D-2. Metro Transit Reference LRV Force Density Levels on Embedded Track

Source: ATS Consulting, 2008

APPENDIX E

Detailed Vibration Projections

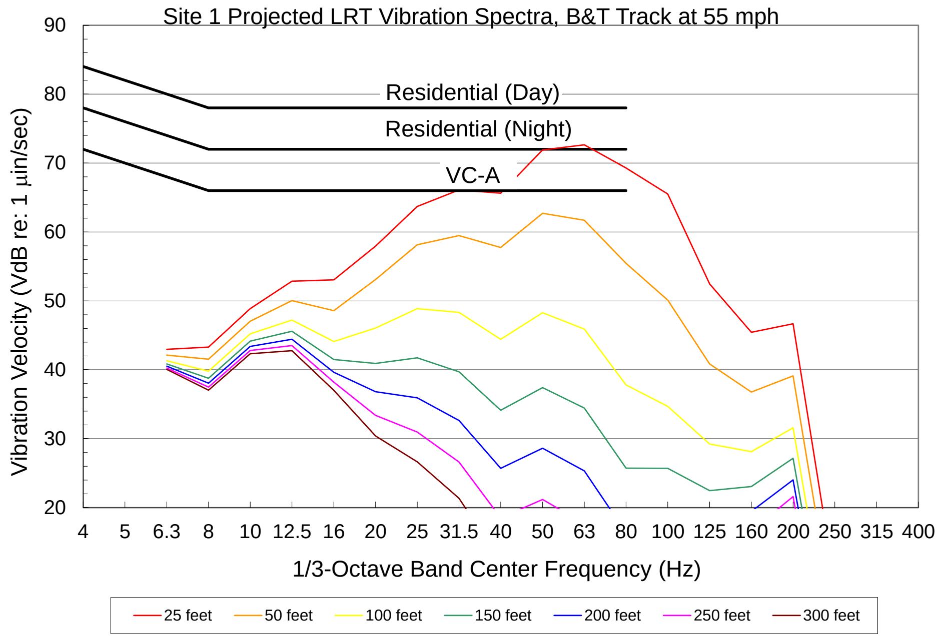


Figure E-1. Site 1 Projected LRT Vibration Spectra on B&T Track at 55 mph

Source: Harris Miller Miller & Hanson Inc., 2012

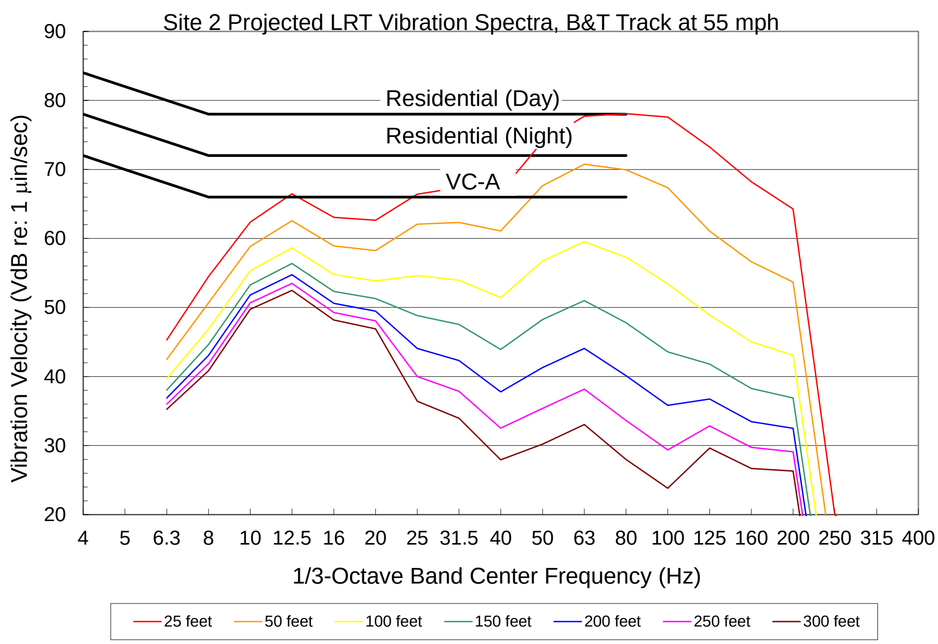


Figure E-2. Site 2 Projected LRT Vibration Spectra on B&T Track at 55 mph

Source: Harris Miller Miller & Hanson Inc., 2012

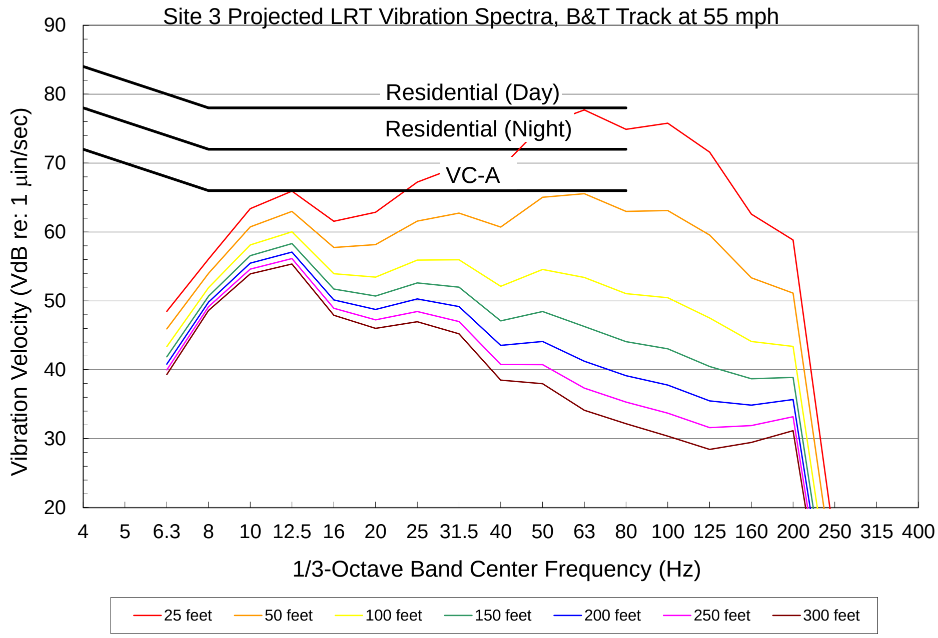


Figure E-3. Site 3 Projected LRT Vibration Spectra on B&T Track at 55 mph

Source: Harris Miller Miller & Hanson Inc., 2012

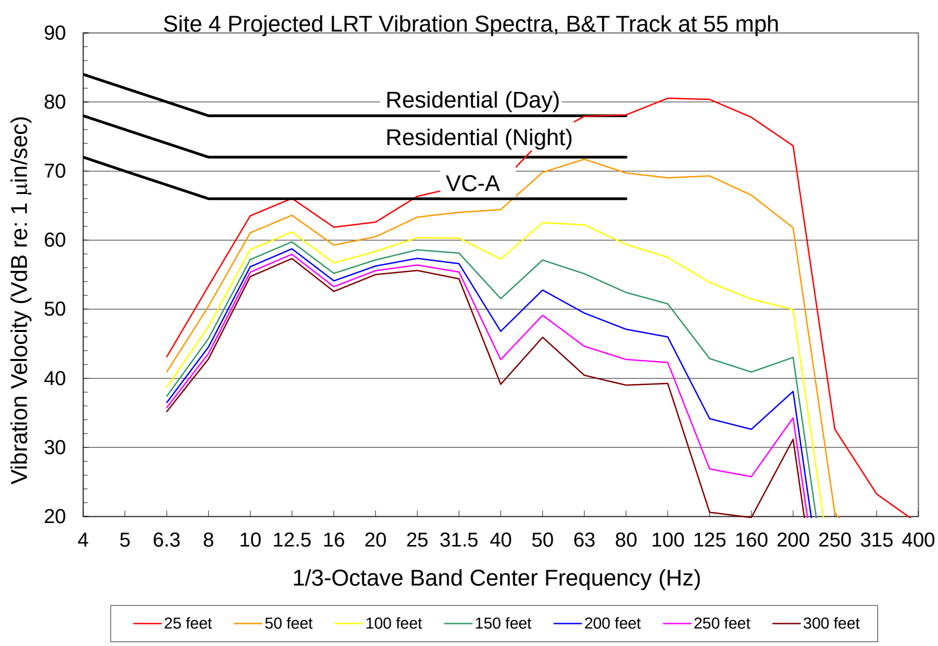


Figure E-4. Site 4 Projected LRT Vibration Spectra on B&T Track at 55 mph

Source: Harris Miller Miller & Hanson Inc., 2012

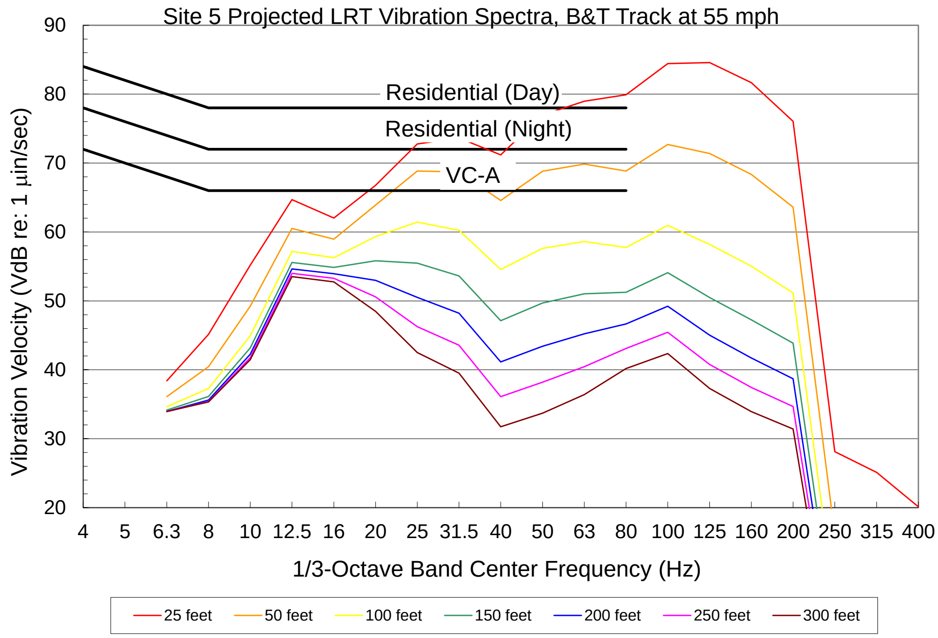


Figure E-5. Site 5 Projected LRT Vibration Spectra on B&T Track at 55 mph

Source: Harris Miller Miller & Hanson Inc., 2012

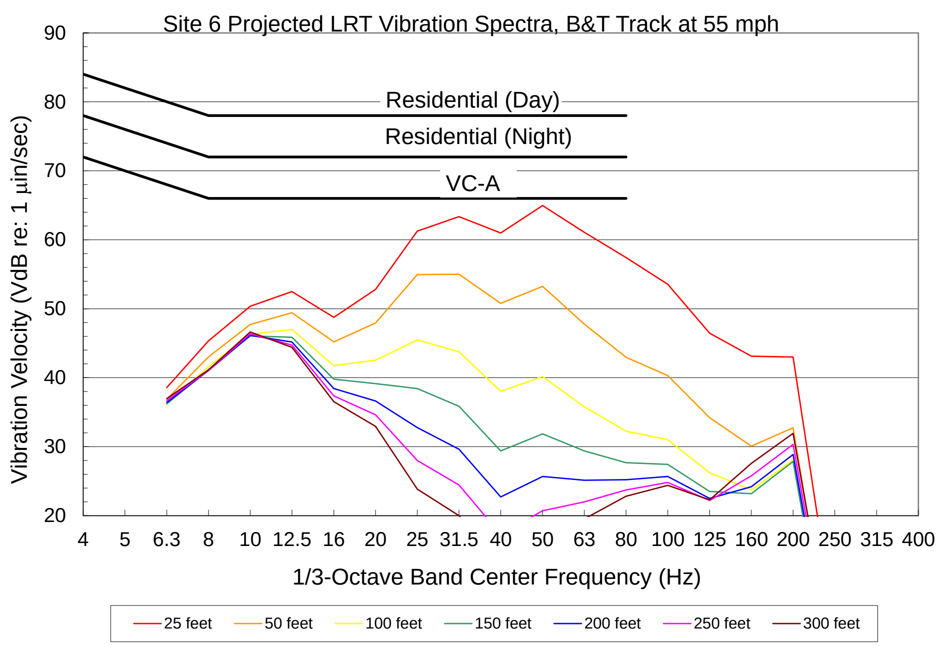


Figure E-6. Site 6 Projected LRT Vibration Spectra on B&T Track at 55 mph

Source: Harris Miller Miller & Hanson Inc., 2012

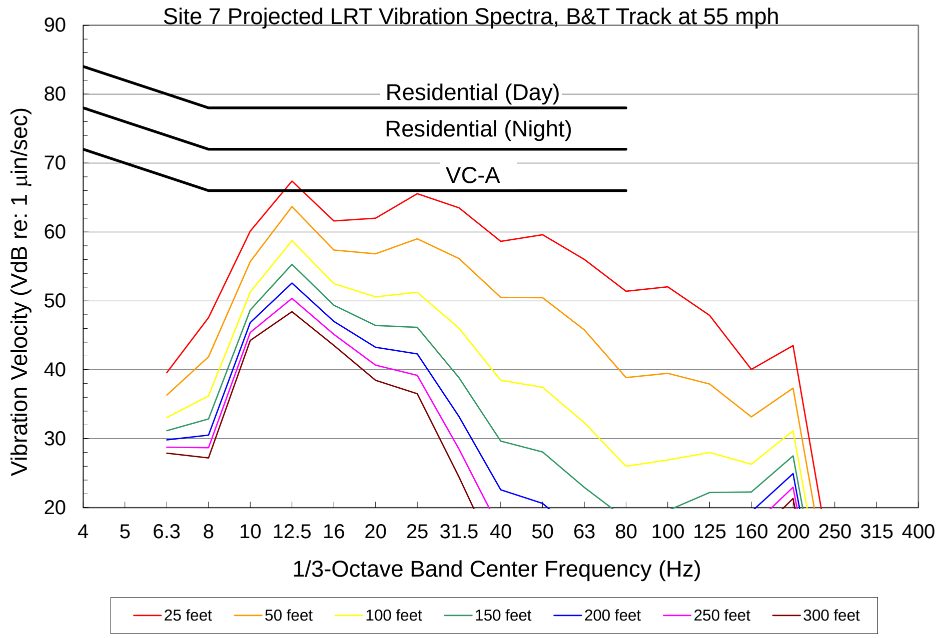


Figure E-7. Site 7 Projected LRT Vibration Spectra on B&T Track at 55 mph

Source: Harris Miller Miller & Hanson Inc., 2012

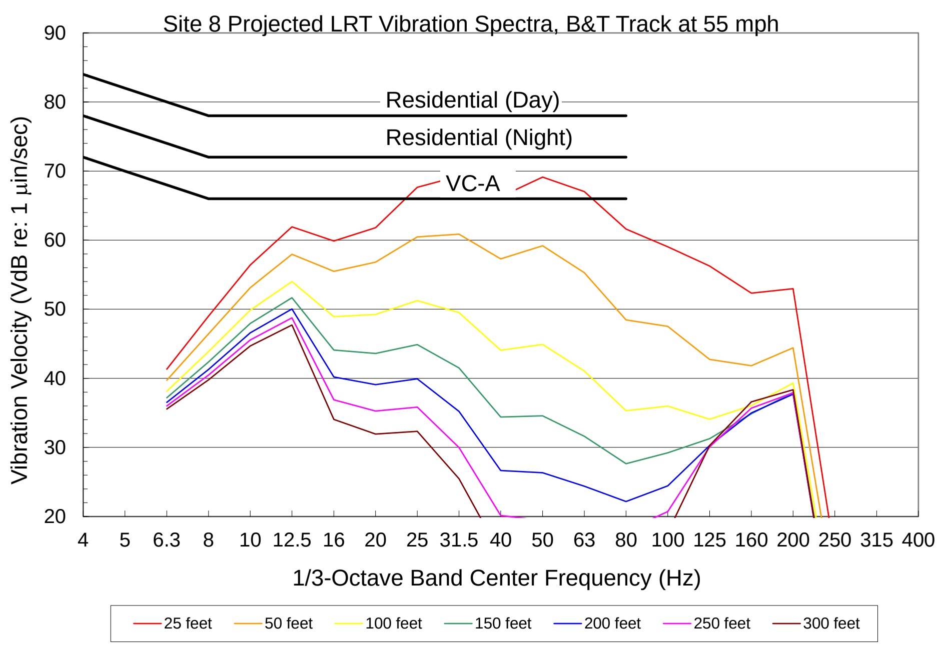


Figure E-8. Site 8 Projected LRT Vibration Spectra on B&T Track at 55 mph

Source: Harris Miller Miller & Hanson Inc., 2012

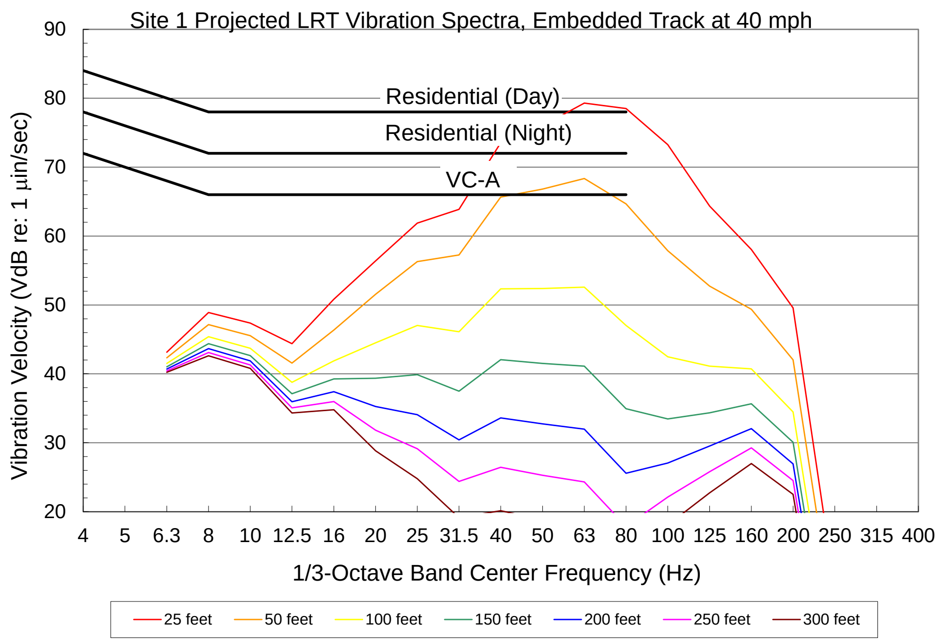


Figure E-9. Site 1 Projected LRT Vibration Spectra on Embedded Track at 40 mph

Source: Harris Miller Miller & Hanson Inc., 2012

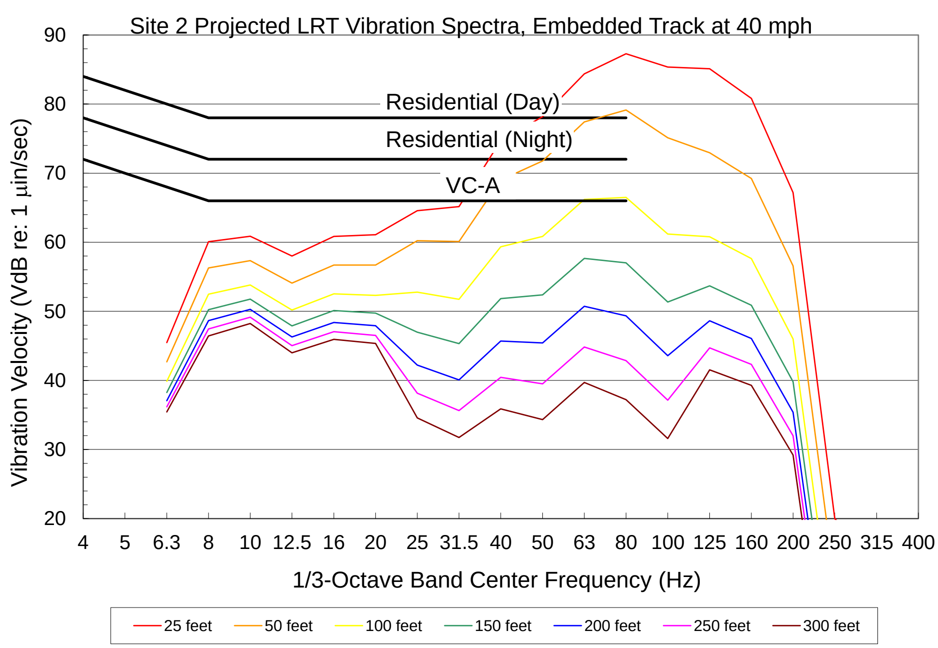


Figure E-10. Site 2 Projected LRT Vibration Spectra on Embedded Track at 40 mph

Source: Harris Miller Miller & Hanson Inc., 2012

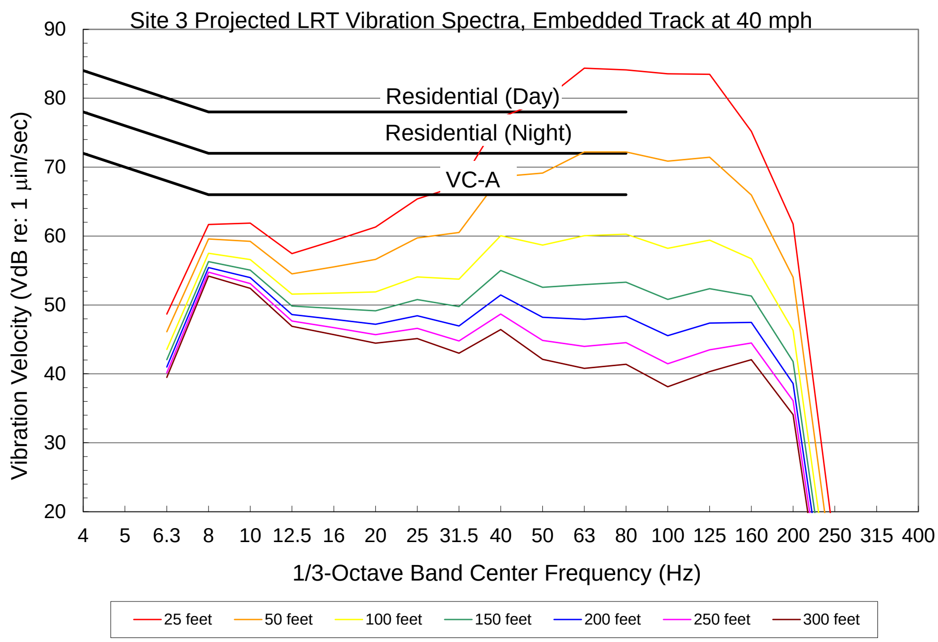


Figure E-11. Site 3 Projected LRT Vibration Spectra on Embedded Track at 40 mph

Source: Harris Miller Miller & Hanson Inc., 2012

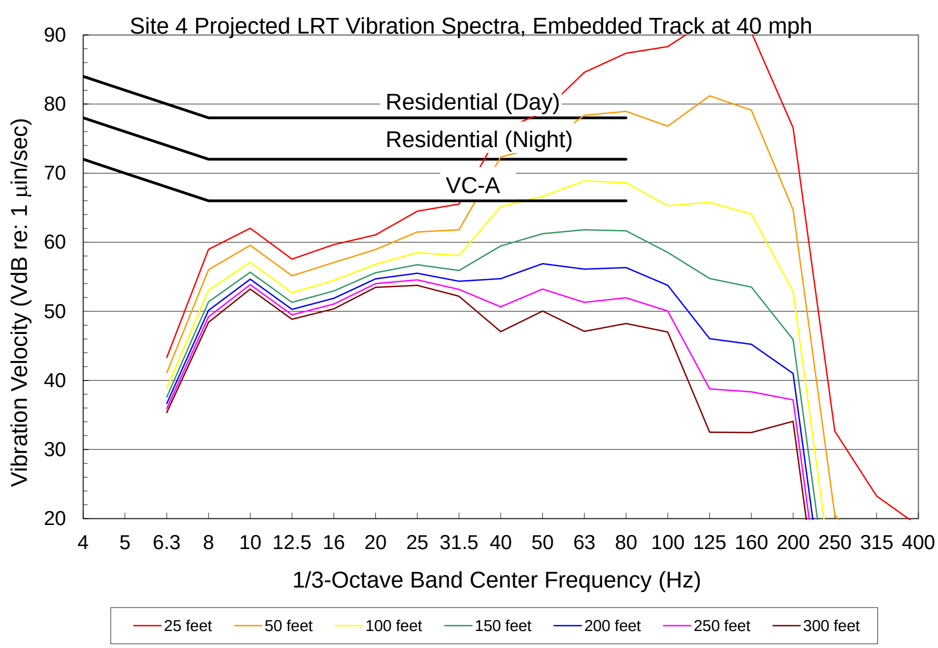


Figure E-12. Site 4 Projected LRT Vibration Spectra on Embedded Track at 40 mph

Source: Harris Miller Miller & Hanson Inc., 2012

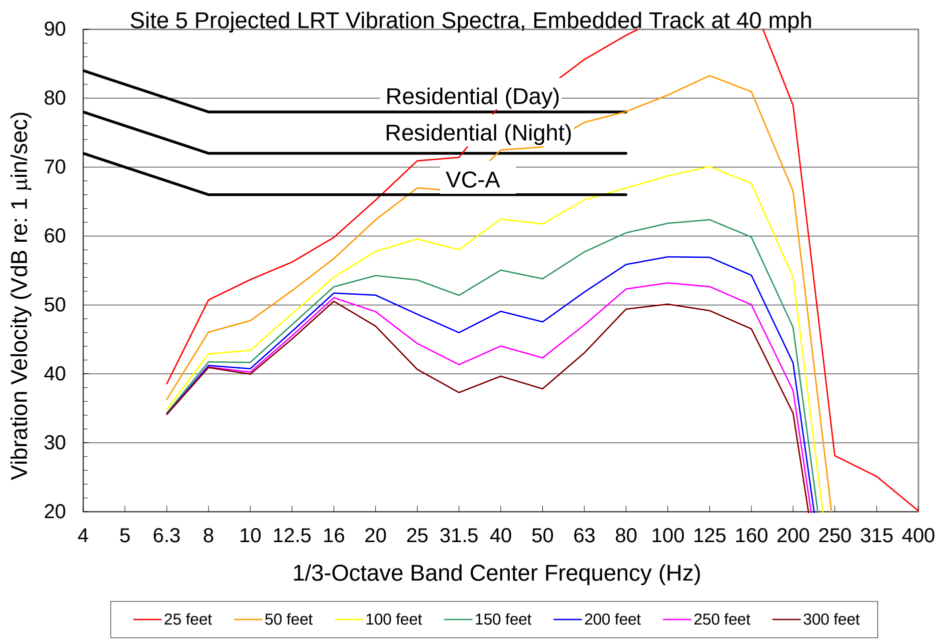


Figure E-13. Site 5 Projected LRT Vibration Spectra on Embedded Track at 40 mph

Source: Harris Miller Miller & Hanson Inc., 2012

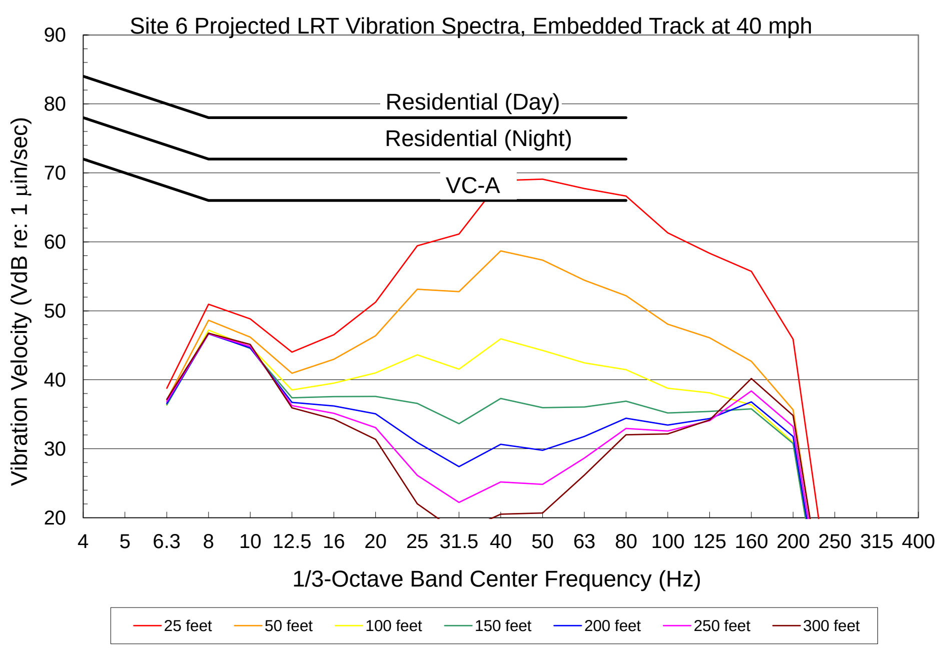


Figure E-14. Site 6 Projected LRT Vibration Spectra on Embedded Track at 40 mph

Source: Harris Miller Miller & Hanson Inc., 2012

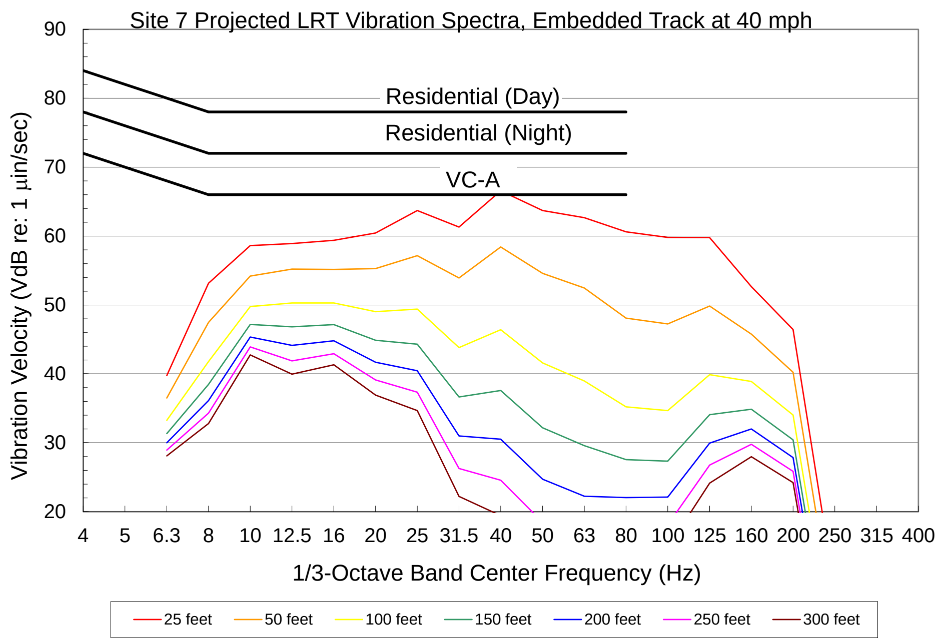


Figure E-15. Site 7 Projected LRT Vibration Spectra on Embedded Track at 40 mph

Source: Harris Miller Miller & Hanson Inc., 2012

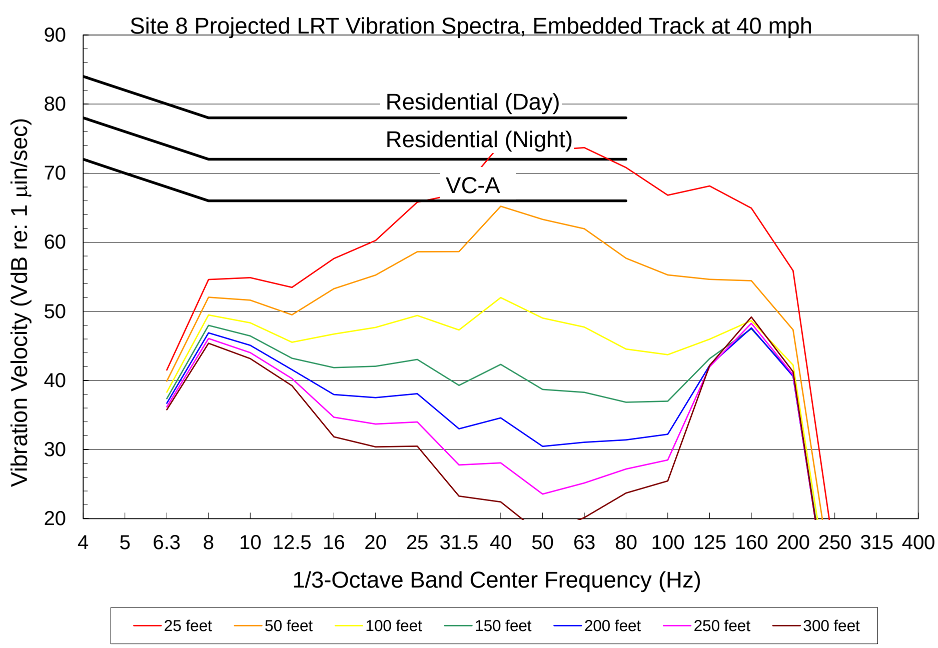


Figure E-16. Site 8 Projected LRT Vibration Spectra on Embedded Track at 40 mph

Source: Harris Miller Miller & Hanson Inc., 2012