Appendix J: Proposed Refinements Noise and Vibration Technical Report

Durham-Orange Light Rail Transit Project

GoTriangle

October 2018

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List of Acronyms and Abbreviations

Acronym/Abbreviation	Definition
dB	decibel
dBA	A-weighted decibel
DEIS	Draft Environmental Impact Statement
D-O LRT	Durham-Orange Light Rail Transit
EA	Environmental Assessment
EB	eastbound
FD	force density
FEIS	Final Environmental Impact Statement
ft	feet
FTA	Federal Transit Administration
GIS	Geographic Information Systems
Hz	hertz
In/sec	inches per second
Ldn	day-night sound level
Leq	equivalent sound level
Lmax	maximum sound level
LRT	Light Rail Transit
LSTM	Line Source Transfer Mobility
LT	long-term
Lv	vibration level
mph	miles per hour
NCCU	North Carolina Central University
NEPA	National Environmental Policy Act
PPV	peak particle velocity
RMS	root mean square
ROD	Record of Decision
ROMF	Rail Operations and Maintenance Facility
SEL	Sound Exposure Level
ST	short-term
TM	Transfer Mobility
TPSS	Traction Power Substation
UNC	University of North Carolina at Chapel Hill
VA	Veterans Affairs
VdB	vibration decibel
VP	Vibration Propagation
WB	westbound

1. Introduction and Summary

The previous National Environmental Policy Act (NEPA) documentation for the proposed Durham-Orange Light Rail Transit (D-O LRT) Project, including the Draft Environmental Impact Statement (DEIS) (2015), Final Environmental Impact Statement/Record of Decision (FEIS/ROD) (2016), Supplemental Environmental Assessment (EA) and Amended ROD (2016), evaluated the effects of the D-O LRT Project based on a preliminary engineering design referred to herein as the "Previous Design." Since the Amended ROD was issued, the engineering design has advanced, resulting in refinement proposals to modify certain physical and operational aspects of the proposed action. These Proposed Refinements to the Previous Design would modify the limits of disturbance of the D-O LRT Project and require additional effects evaluations.

A detailed noise and vibration impact assessment was conducted for the D-O LRT Project. The noise and vibration impact assessment and mitigation development was performed in accordance with the guidelines specified in the U.S. Federal Transit Administration (FTA) Transit Noise and Vibration Impact Assessment guidance manual (FTA, 2006), referred to hereafter as "the FTA guidance manual". The assessment was completed in support of a Supplemental Environmental Assessment for the D-O LRT Project. The objective of the assessment was to document the potential noise and vibration impacts at sensitive locations and identify appropriate mitigation measures, as necessary.

Based on Chapter 3 of the FTA guidance manual, the noise impact from transit operations was assessed by comparing the project noise with the existing noise and not the No Build Alternative. Based on the screening distances provided in Chapter 4 of the FTA guidance manual, the noise study area for the D-O LRT Project was within 350 feet of the alignment. Based on the screening distances provided in Chapter 9 of the FTA guidance manual, the vibration study area for the D-O LRT Project was limited to within 200 feet of the alignment, except for highly vibration-sensitive land uses where facilities within 600 feet of the alignment were considered.

Following a summary of the assessment results in **sections 1.1** and **1.2**, **section 2** provides a discussion of basic noise and vibration concepts, and **section 3** describes the impact criteria. **Section 4** discusses the affected environment, including a description of noise and vibration-sensitive land uses and the measurements conducted to determine the existing noise and vibration conditions. **Section 5** describes the methodology used for noise and vibration prediction, **section 6** includes the results of the noise and vibration impact assessment, and potential mitigation measures are described in **section 7**. Finally, **attachment J.1** includes photographs of the noise and vibration measurement sites, **attachment J.2** and **attachment J.3** provide noise and vibration data, respectively, and **attachment J.4** shows the noise impact locations.

1.1 Description of Proposed Refinements

The Proposed Refinements are a result of the following:

- Advancements in design since the Amended ROD, including refinements resulting from Value Engineering workshops and evaluation of additional measures to reduce project cost; and
- Responses to public comments and stakeholder feedback on the previous NEPA documentation and the Amended ROD.

The Proposed Refinements include the following changes:

- Modification to the station platform lengths;

- Adjustments to the location and configuration of the station platforms, as well as corresponding refinements to the track alignments;
- Modifications to the planned park-and-ride lots;
- Inclusion of bicycle and pedestrian facilities throughout the project;
- Changes in the locations and number of Traction Power Substations;
- Reconfiguration of the Rail Operations and Maintenance Facility (ROMF) and rail yard;
- Using single-track configuration for segment that includes New Hope Creek and Sandy Creek;
- Revision to the alignment to pass underneath the intersection of University Drive and Shannon Road, rather than cross through the intersection at grade;
- Elevation of the alignment on Erwin Road;
- Addition of a new station at Blackwell/Mangum Streets; and
- Inclusion of drainage, grading, and site preparation throughout the project.

1.2 Summary of Noise Impact Assessment

Results of the noise impact assessment for D-O LRT Project operations identified moderate impacts (as defined in **section 3**) at a total of 475 residential receptors at 24 buildings and one institutional receptor at one building, and severe impacts at a total of 34 residential receptors at two buildings without mitigation (**Table 1-1**). The majority of the noise impacts were at multifamily buildings located near the proposed alignment. In addition, a moderate noise impact was identified at one institutional receptor, the Duke Center for Documentary Studies, without mitigation. Without mitigation, the major sources of potential noise impacts associated with the D-O LRT Project are noise from at-grade crossings and operational noise for buildings located in close proximity to the tracks.

The assessment for the Rail Operations and Maintenance Facility (ROMF) also identified moderate noise impacts at an additional thirteen residential receptors without mitigation, all at single-family residences on the western and southern sides of the ROMF.

Table 1-1: Summary of Noise Impact Assessment

Project Component	Noise Impacts	
	Moderate	Severe
LRT Operations	476 (25)	34 (2)
ROMF	13 (13)	0 (0)

Note: The number in parentheses shows the number of buildings with impact. The number of units in multifamily buildings was estimated based on aerial photography and land use surveys.

1.3 Summary of Vibration Impact Assessment

No vibration impacts were identified along the D-O LRT Project Corridor, due to the vibration propagation characteristics of the soil along the proposed alignment. The vibration propagation testing described in **section 4.3** showed that vibration is not transmitted efficiently through the soil in the project area, thus the resulting vibration levels are projected to be well below the impact criteria. Along Erwin Road, where the tracks will be on an elevated structure, the vibration levels are projected to be below the most stringent thresholds for impacts to sensitive equipment.

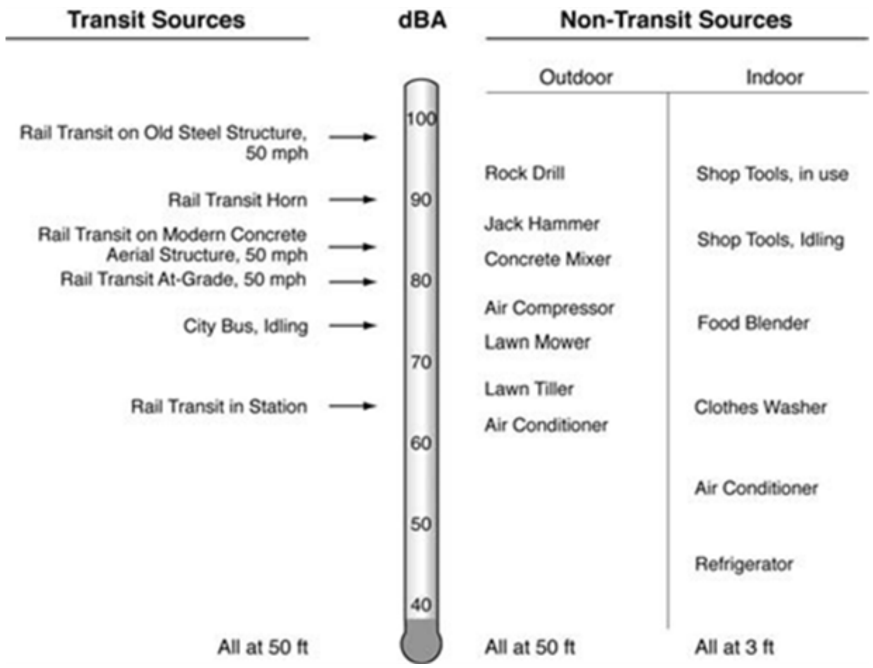
2. Noise and Vibration Concepts

2.1 Noise Fundamentals and Descriptors

Sound is defined as small changes in air pressure above and below the standard atmospheric pressure, and noise is considered to be unwanted sound. The three parameters that define noise include:

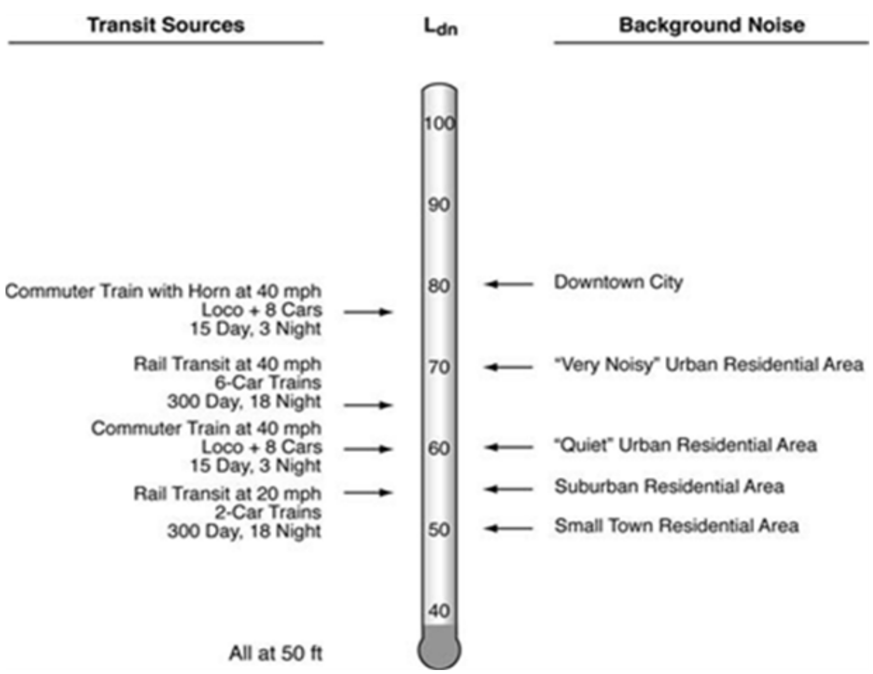
- **Level:** The level of sound is the magnitude of air pressure change above and below atmospheric pressure and is expressed in decibels (dB). Typical sounds fall within a range between 0 dB (the approximate lower limit of human hearing) and 120 dB (the highest sound level experienced in the environment). A 3 dB change in sound level is perceived as a barely noticeable change outdoors and a 10 dB change in sound level is perceived as a doubling (or halving) of loudness.
- **Frequency:** The frequency (pitch or tone) of sound is the rate of air pressure change and is expressed in cycles per second, or Hertz (Hz). Human ears can detect a wide range of frequencies from around 20 Hz to 20,000 Hz; however, human hearing is not as sensitive at high and low frequencies, and the A-weighting system, which measures what humans hear in a meaningful way by reducing the sound levels of higher and lower frequency sounds, is used to provide a measure in A-weighted decibels (dBA) that correlates with human response to noise. **Figure 2-1** shows typical maximum A-weighted sound levels for transit and non-transit sources. The A-weighted sound level has been widely adopted by acousticians as the most appropriate descriptor for environmental noise.
- **Time Pattern:** Because environmental noise is constantly changing, it is common to condense this information into a single number, called the “equivalent” sound level (L_{eq}). The L_{eq} represents the changing sound level over a period of time, 1 hour, or 24 hours, in transit noise assessments. For assessing the noise impact of rail projects at residential land use, the Day-Night Sound Level (L_{dn}) is the noise descriptor used; it has been adopted by many agencies as the best way to describe how people respond to noise in their environment. L_{dn} is a 24-hour cumulative A-weighted noise level that includes all noises that occur during a day, with a 10 dB penalty for nighttime noise (10 PM to 7 AM). This nighttime penalty means that any noise events at night are equivalent to 10 similar events during the day. Typical L_{dn} values for various transit operations and environments are shown on **Figure 2-2**.

In addition to the L_{eq} and L_{dn}, there is another descriptor used to describe noise. The loudest 1 second of noise over a measurement period, or maximum A-weighted sound pressure level (L_{max}), is used in many local and state ordinances for noise emitted from private land uses and for construction noise impact evaluations.



Source: FTA, 2006

Figure 2-1: Typical A-Weighted Sound Levels



Source: FTA, 2006

Figure 2-2: Typical L_{dn} Noise Exposure Levels

2.2 Vibration Fundamentals and Descriptors

Ground-borne vibration from trains refers to the fluctuating or oscillatory motion experienced by persons on the ground and in buildings near railroad tracks. Vibration can be described in terms of displacement, velocity, or acceleration. Displacement is the easiest descriptor to understand. For a vibrating floor, the displacement is simply the distance that a point on the floor moves away from its static position. Velocity represents the instantaneous speed of the floor movement, and acceleration is the rate of change of the speed. Although displacement is easier to understand, the response of humans, buildings, and equipment to vibration is accurately described using velocity or acceleration.

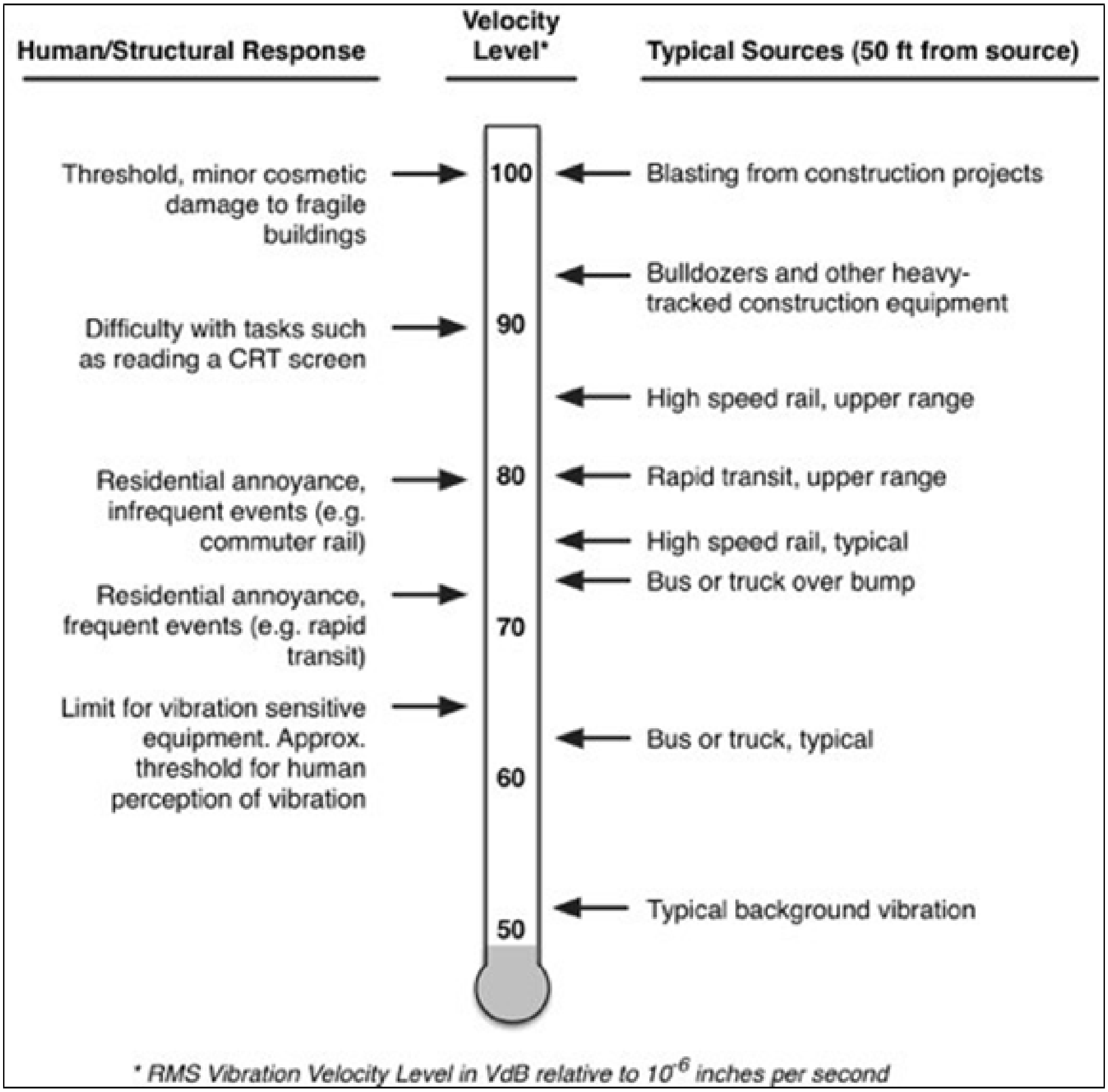
Two methods are used for quantifying vibration. The peak particle velocity (PPV) is defined as the maximum instantaneous positive or negative peak of the vibration signal. PPV often is used in monitoring blasting vibration, since it is related to the stresses experienced by buildings.

Although PPV is appropriate for evaluating the potential of building damage, it is not suitable for evaluating human response. It takes some time for the human body to respond to vibration impulses. In a sense, the human body responds to an average of the vibration amplitude. Because the net average of a vibration signal is zero, the root mean square (RMS) amplitude is used to describe the "smoothed" vibration amplitude.

PPV and RMS velocities are described in inches per second in the U.S. and in meters per second in the rest of the world. Although it is not universally accepted, decibel notation can be used for vibration as well and compresses the range of numbers required to describe vibration. Vibration levels in this report are referenced to 1 x 10^{-6} inches per second (in/sec). The abbreviation "VdB" is used in this document for vibration decibels to avoid confusion with sound decibels.

Common vibration sources and human and structural response to ground-borne vibration are illustrated in **Figure 2-3**. Typical vibration levels can range from below 50 VdB to 100 VdB (0.000316 in/sec to 0.1 in/sec). The human threshold of perception is approximately 65 VdB.

Ground-borne noise is a low-volume, low-frequency rumble inside buildings that occurs when ground vibration causes the flexible walls of the building to resonate and generate noise. Ground-borne noise is not a consideration when trains are elevated or at grade. In these situations, the airborne noise overwhelms ground-borne noise, so that airborne noise is the major factor. However, ground-borne noise becomes an important factor where there are sections of the corridor that are in an underpass or where sensitive interior spaces are well-isolated from the airborne noise. In these situations, the airborne path is not as important as the ground-borne path with regard to noise observed inside the building. In extremely unusual situations, ground-borne noise may also need to be considered in cases where the airborne noise from a project is mitigated by a sound wall. There is only one location with a proposed tunnel, but it is not located near any sensitive receptors.



Source: FTA, 2006

Figure 2-3: Typical Levels of Ground-Borne Vibration

3. Noise and Vibration Criteria

The noise and vibration impact criteria used for the D-O LRT Project are based on information contained in the FTA guidance manual (2006). The criteria used to assess noise and vibration impact from train operations are described in this section.

3.1 Transit Noise Impact Criteria

The FTA transit noise impact criteria are based on well-documented research on community response to noise and are based on both the existing level of noise and the change in noise exposure due to a project. The FTA noise criteria compare the project noise (2040) with the existing (2017) noise (not the no-build noise in the project build year of 2040). This is because the comparison is based on what people are experiencing now (existing noise), and the change in noise due to the project, rather than a comparison with a projection of noise at some future date.

The FTA noise criteria are based on the land use category of the sensitive receptor. The descriptors and criteria for assessing noise impacts vary according to the specific land use categories adjacent to the tracks. For Category 2 land uses where people live and sleep (e.g., residential neighborhoods, hospitals, and hotels), the day-night average sound level (L_{dn}) is the assessment parameter. For other land use types (Category 1 or 3) where there are noise-sensitive uses (e.g., outdoor concert areas, schools, and libraries), the equivalent noise level (L_{eq}) for an hour of noise sensitivity that coincides with train activity is the assessment parameter. **Table 3-1** summarizes the three land use categories.

Table 3-1: Land Use Categories and Metrics for Transit Noise Impact Criteria

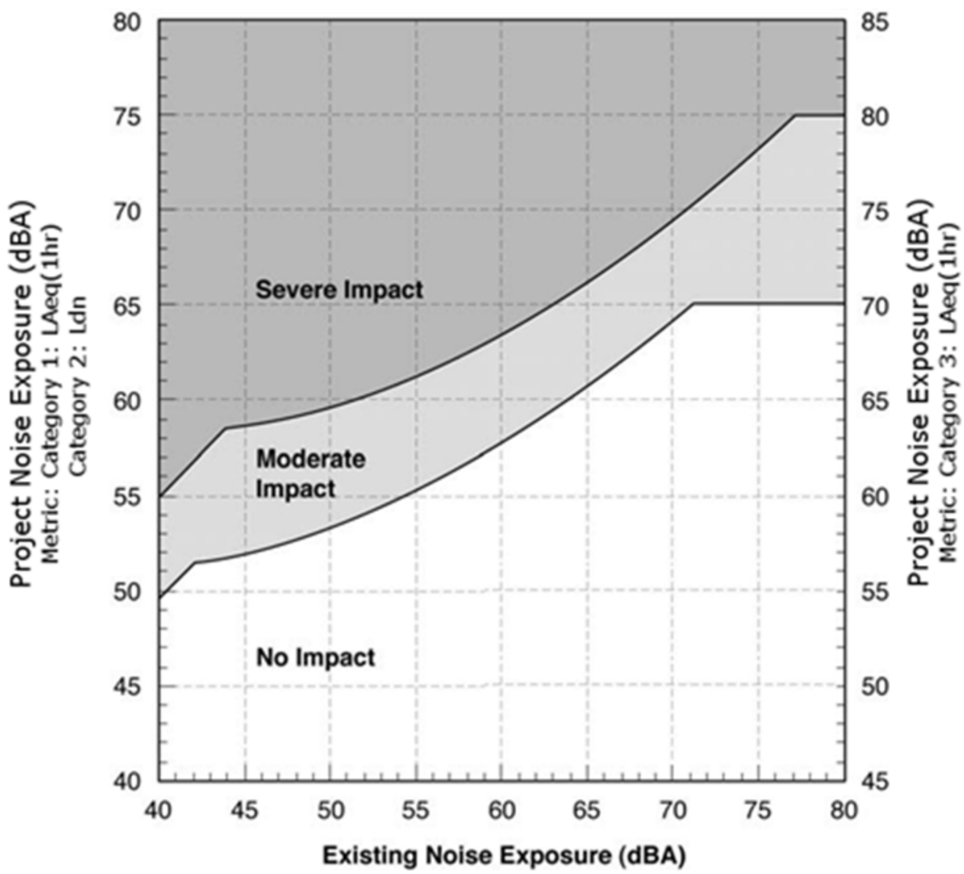
Land Use Category	Noise Metric (dBA)	Description of Land Use Category
1	Outdoor $L_{eq}(h)$ [a]	Tracts of land where quiet is an essential element in their intended purpose. This category includes lands set aside for serenity and quiet, and such land uses as outdoor amphitheaters and concert pavilions, as well as National Historic Landmarks with significant outdoor use. Also included are recording studios and concert halls.
2	Outdoor L_{dn}	Residences and buildings where people sleep. This category includes homes, hospitals, and hotels where a nighttime sensitivity to noise is assumed to be of utmost importance.
3	Outdoor $L_{eq}(h)$ [a]	Institutional land uses with 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.

Source: FTA, 2006

[a] L_{eq} for the noisiest hour of transit-related activity during hours of noise sensitivity.

The noise impact criteria are defined by the two curves shown on **Figure 3-1**, which allow increasing project noise as existing noise levels increase, up to a point at which impact is determined based on project noise alone. The FTA noise impact criteria include three levels of impact, as shown on **Figure 3-1**. The three levels of impact are:

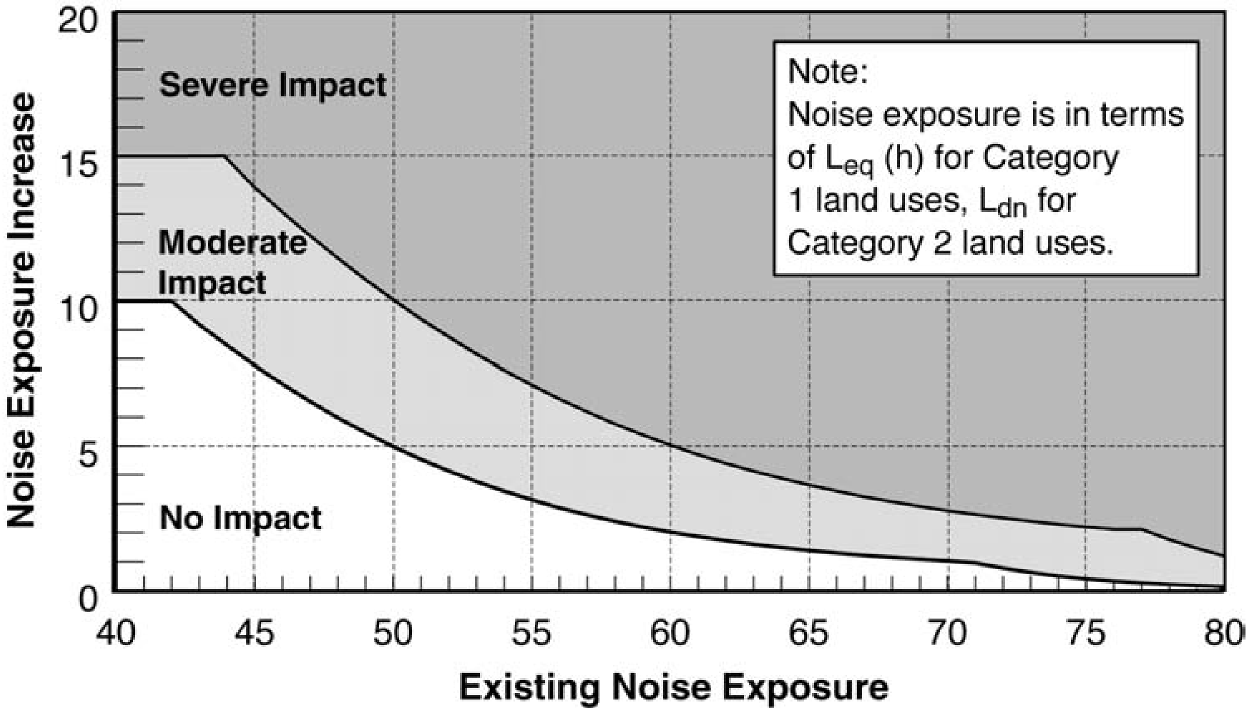
- **No Impact:** In this range, the D-O LRT Project is considered to have no impact because, on average, introduction of the D-O LRT Project will result in an insignificant increase in the number of people highly annoyed by the new project noise.
- **Moderate Impact:** At the moderate impact range, changes in cumulative noise levels are 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, such as the existing noise level, predicted level of increase over existing noise levels, and the types and numbers of noise-sensitive land uses affected.
- **Severe Impact:** At the severe impact range, a significant percentage of people would be highly annoyed by the new project noise. Severe noise impacts are considered to be "significant" under NEPA and should be avoided if possible. Noise mitigation should be applied for severe impacts where feasible.



Source: FTA, 2006

Figure 3-1: FTA Noise Impact Criteria

Although the curves shown on **Figure 3-1** are defined in terms of the project noise exposure and the existing noise exposure, the increase in the cumulative noise (i.e., when project-generated noise is added to existing noise levels) is the basis for the criteria. To illustrate this point, **Figure 3-2** shows the noise impact criteria for Category 1 and Category 2 land uses in terms of the allowable increase in the cumulative noise exposure. Because day-night sound level (L_{dn}) and equivalent sound level (L_{eq}) are measures of total acoustic energy, any new noise source in a community will cause an increase, even if the new source level is lower than the existing level. In **Figure 3-2,** the criterion for a moderate impact allows a noise exposure increase of 10 dB if the existing noise exposure is 42 dBA or less, but only a 1 dB increase when the existing noise exposure is 70 dBA.



Source: FTA, 2006

Figure 3-2: FTA Cumulative Noise Impact Criteria

As the existing level of ambient noise increases, the allowable level of transit noise increases, but the total amount that community noise exposure is allowed to increase is reduced. This accounts for the unexpected result that a project noise exposure that is lower than the existing noise exposure can still cause an effect.

3.2 Transit Vibration Impact Criteria

The transit vibration impact criteria used for the D-O LRT Project are based on the information contained in Chapter 8 of the FTA guidance manual. The criteria for a general vibration assessment are based on land use and train frequency, as shown in **Table 3-2**. Some buildings such as concert halls, recording studios, and theaters can have a higher sensitivity to vibration (or ground-borne noise), but do not fit into the three categories listed in **Table 3-2**. Because of the sensitivity of these buildings, special attention is paid during the environmental assessment of a project. **Table 3-3** shows the FTA criteria for acceptable levels of vibration for several types of special buildings.

Table 3-2: Ground-Borne Vibration and Noise Impact Criteria for General Assessment

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

Source: FTA, 2006

[a] "Frequent Events" is defined as more than 70 vibration events of the same source per day. Most rapid transit projects fall into this category.

[b] “Occasional Events” is defined as between 30 and 70 vibration events of the same source per day. Most commuter trunk lines have this many operations.

[c] "Infrequent Events" is defined as fewer than 30 vibration events of the same kind per day. This category includes most commuter rail branch lines.

[d] This criterion limit is based on levels that are acceptable for most moderately sensitive equipment such as optical microscopes. Vibration-sensitive manufacturing or research will require detailed evaluation to define the acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the HVAC systems and stiffened floors.

[e] Vibration-sensitive equipment is not sensitive to ground-borne noise.

Table 3-3: Ground-Borne Vibration and Noise Criteria for Special Buildings

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

Source: FTA, 2006

[a] "Frequent Events" is defined as more than 70 vibration events per day. Most rapid transit projects fall into this category.

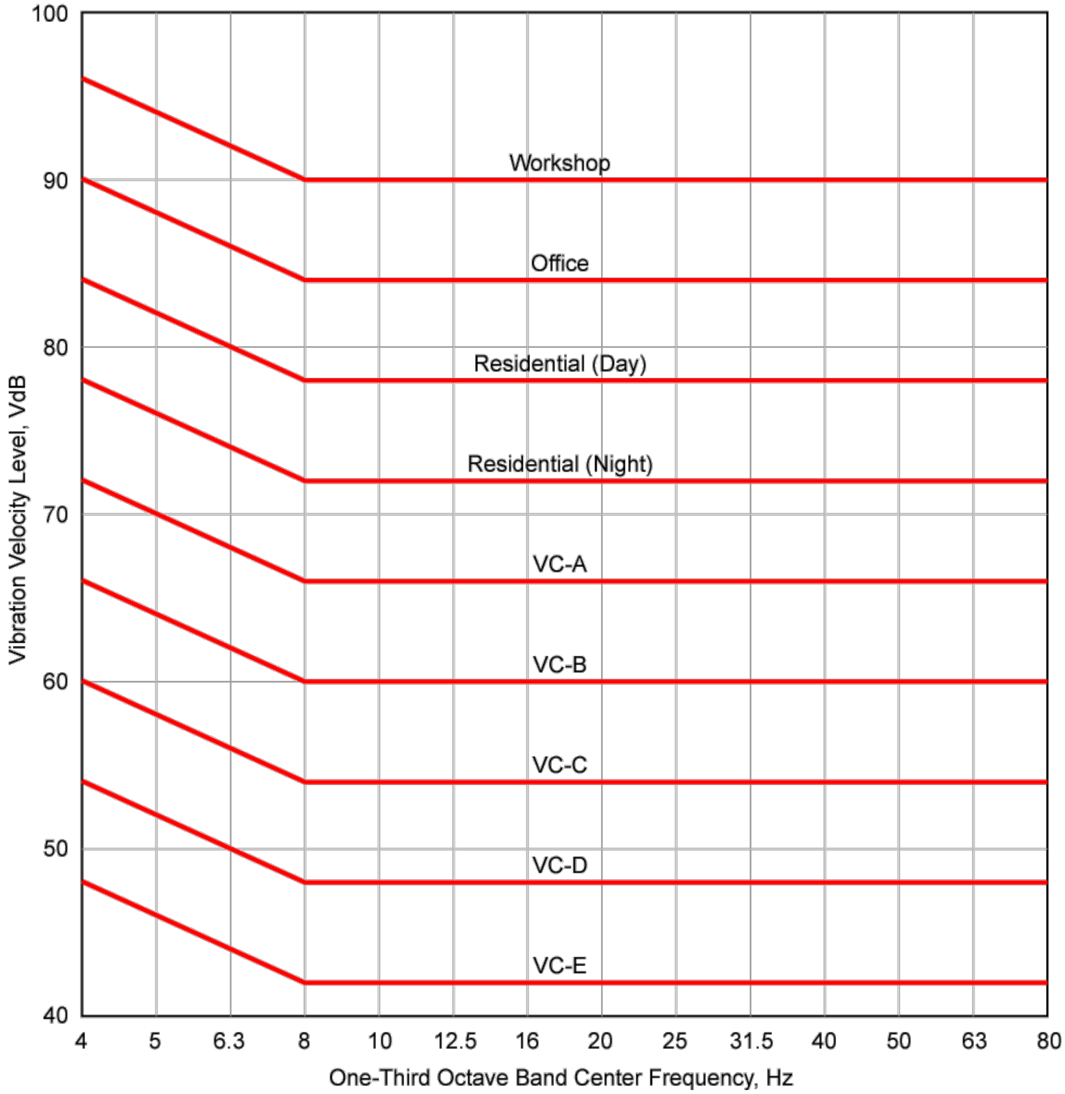
[b] "Occasional or Infrequent Events" is defined as fewer than 70 vibration events per day. This category includes most commuter rail systems.

Note: If the building will rarely be occupied when the trains are operating, there is no need to consider impact. As an example, consider locating a commuter rail line next to a concert hall. If no commuter trains will operate after 7:00 PM, it should be rare that the trains interfere with the use of the hall.

Table 3-2 and **Table 3-3** include additional criteria for ground-borne noise, which is a low-frequency noise that is radiated from the motion of room surfaces, such as walls and ceilings in buildings due to ground-borne vibration. Ground-borne noise is defined in terms of dBA, which emphasizes middle and high frequencies, which are audible to human ears. The criteria for ground-borne noise are much lower than for airborne noise to account for the low-frequency character of ground-borne noise; however, because airborne noise masks ground-borne noise for aboveground (at-grade or elevated) transit systems, ground-borne noise is only assessed for operations in tunnels, where airborne noise is not a factor, or at locations such as recording studios, which are well insulated from airborne noise.

The criteria for a detailed vibration assessment are shown on **Figure 3-3**, and descriptions of the curves are shown in **Table 3-4**. The curves shown on **Figure 3-3** are applied to the projected vibration spectrum for the D-O LRT Project. If the vibration level at any one frequency exceeds the criteria, there is an impact. Conversely, if the entire proposed vibration spectrum of the D-O LRT Project is below the curve, there is no impact.

For the D-O LRT Project, the detailed vibration assessment criteria will be used to assess operational ground-borne vibration, except at special buildings where the general vibration assessment criteria will be used.



Source: FTA, 2006

Figure 3-3: FTA Detailed Vibration Criteria

Table 3-4: Interpretation of Vibration Criteria for Detailed Analysis

Criterion Curve (See Figure 3-3)	Maximum Level (VdB)[a]	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.

4. Affected Environment

The affected noise and vibration environment along the D-O LRT Project Corridor was investigated based on a review of the Proposed Refinements and land use information and noise and vibration measurements conducted during December 2017. A summary of noise and vibration-sensitive land uses along the D-O LRT Project Corridor is provided in this section, followed by descriptions of the existing noise and vibration conditions in the study area.

4.1 Noise and Vibration-Sensitive Land Use

Land use in the study area includes a combination of residential, institutional, commercial, and industrial zones. Noise- and vibration-sensitive land uses in the study area were identified based on alignment drawings, aerial photographs, visual surveys, and land use information. Sensitive receptors located along the proposed alignment include single-family and multifamily residences, hotels, schools, places of worship, and medical facilities. Summary descriptions of noise and vibration-sensitive land use along the alignment, divided into three segments, are provided in **sections 4.1.1** through **4.1.3**.

4.1.1 Segment 1 – UNC Campus to Gateway Station

- **UNC Campus:** Land use along the alignment on the University of North Carolina at Chapel Hill (UNC) campus includes medical facilities and dormitories, including the following research facilities: Bioinformatics Building, Genetic Medicine Research Building, Radiological Research Laboratory, Lineberger Cancer Research Center, EPA Building, and Taylor, Isaac M. Hall.

- **East Chapel Hill**: Land use along the alignment in Chapel Hill, outside of the UNC campus, is residential. Between Manning Drive and Meadowmont Lane the alignment runs through a single-family neighborhood along Fordham Boulevard and a multifamily residential area along Raleigh Road, including UNC's Imaging and Outpatient Center, Glenwood Elementary School, Aldersgate Methodist Church (property now owned by St. Thomas More Church), and St. Thomas More Catholic Church. Between Meadowmont Lane and George King Road, the alignment runs through single- and multifamily residential neighborhoods along Raleigh Road, including the Courtyard by Marriott Chapel Hill hotel.
- **Leigh Village**: Land use along the first section of the alignment in Durham is undeveloped or residential. Between George King Road and Crescent Drive, the alignment runs through an undeveloped area and sparsely populated neighborhood. Between Crescent Drive and Farrington Road, the alignment runs through a sparsely populated neighborhood on the west side of Interstate 40. Between Farrington Road and Interstate 40, the alignment runs through a single-family neighborhood, including an apartment complex on the west side of Interstate 40.

4.1.2 Segment 2 – Gateway Station to Cameron Boulevard

- **US 15-501 Corridor**: Land use along the section of the alignment in Durham west of Duke University is residential and commercial. Between Interstate 40 and Garrett Road, the alignment runs through a commercial zone with three hotels, a small single-family neighborhood, and two apartment complexes. Between Garrett Road and Durham-Chapel Hill Boulevard, the alignment passes near two apartment complexes on the north side of University Drive. Between Durham-Chapel Hill Boulevard and Cameron Boulevard, the alignment runs through an area of mixed commercial and multifamily use and includes the Carter Community Charter School.

4.1.3 Segment 3 – Cameron Boulevard to NCCU

- **Erwin Road:** Land use along the section of the alignment along Erwin Road includes medical facilities, research buildings, and a mixture of single- and multifamily housing. The facilities in this area include the Kindred Transitional Care and Rehabilitation facility, Durham Veterans Affairs (VA) Medical Center, Duke University Hospital, the Clinical and Research Laboratory, the Edwin L. Jones Building, the Medical Sciences Research Building, Pavilion East at Lakeview, the Global Health Research building, the Snyderman Genome Science Research building, Lenox Baker Children's Hospital, and Pruitt Health.
- **Downtown Durham:** Land use along the alignment through downtown Durham includes a mixture of multifamily residences and commercial buildings, as well as a railroad corridor. This area includes three theaters and the Duke Center for Documentary Studies.
- **East Durham:** Land use along the alignment east of downtown Durham includes densely populated neighborhoods. Between Fayetteville Street and North Carolina Central University (NCCU), the alignment runs through a neighborhood south of the Durham Freeway. This area includes Russell Memorial CME Church.

4.2 Existing Noise Conditions

Noise-sensitive land use along the corridor was identified based on Geographic Information System (GIS) data, aerial photography, drawings, plans, and a field survey. Based on the information from these sources, a noise measurement program was developed and implemented as described in **sections 4.2.1** and **4.2.2**.

4.2.1 Noise Measurement Procedures and Equipment

To document the existing noise conditions for the D-O LRT Project, a series of noise measurements was conducted in December 2017 along the D-O LRT Project Corridor. Because the thresholds for impact in the FTA noise criteria are based on existing noise levels, measuring the existing noise and characterizing noise levels at sensitive locations is an important step in the impact assessment. The noise measurements included both long-term (24-hour) and short-term (1-hour) monitoring of the A-weighted sound level at noise-sensitive locations within the D-O LRT Project Corridor.

The noise measurements were performed with NTi Audio model XL2 noise monitors that conform to American National Standard Institute standards for Type 1 (precision) sound measurement equipment. Calibrations, traceable to the National Institute of Standards and Technology, were conducted before and after each measurement. The noise monitors were set to continuously monitor and record multiple noise level metrics, as well as to obtain audio recordings where appropriate.

4.2.2 Noise Measurement Locations and Results

Table 4-1 summarizes the results of the existing noise measurement program, and **Figure 4-1** through **Figure 4-3** show the locations, by segment, of the 16 long-term (LT) noise monitoring sites and 10 short-term (ST) noise monitoring sites for the D-O LRT Project. The results of the existing noise measurements were used to characterize the existing noise levels at all noise-sensitive locations within the study area. **Attachment J.1** includes photographs of the noise measurement sites and **attachment J.2** provides detailed noise measurement data. At each site, the measurement was conducted at the approximate setback of the building or buildings relative to the alignment. The measurement microphones were protected with windscreens and positioned approximately 5 feet above the ground and at least 10 feet away from any major reflecting surface. The noise measurement results at each site are described in Error! Reference source not found..

Table 4-1: Summary of Existing Ambient Noise Measurement Results

Site No.	Measurement Location	Measurement Start		Meas. Dur. (hr)	Noise Level (dBA)	
		Date	Time		L_{eq}	L_{dn}
LT-1	1207 Mason Farm Road, Chapel Hill	12/14/2017	11:00	24	50	56
LT-2	St. Thomas More Catholic Church – 940 Carmichael Street, Chapel Hill	12/14/2017	12:00	24	58	60
LT-3	100 Marriott Way, Chapel Hill	12/14/2017	10:00	24	58	61
LT-4	214 Celeste Circle, Chapel Hill	12/13/2017	16:00	24	51	52
LT-5	4315 Randall Road, Durham	12/13/2017	16:00	24	62	65
LT-6	3508 Mt. Moriah Road, Durham	12/12/2017	13:00	24	58	60
LT-7	100 North Creek Drive, Durham	12/11/2017	12:00	24	51	55
LT-8	Old Creek Village Apartments – 4230 Garrett Road, Durham	12/12/2017	14:00	24	66	68
LT-9	614 Snow Crest Trail, Durham	12/11/2017	13:00	24	46	52
LT-10	1920 Ivy Creek Boulevard, Durham	12/12/2017	14:00	24	59	59
LT-11	20 Morcroft Lane, Durham	12/11/2017	15:00	24	56	56
LT-12	2616 Erwin Road, Durham	12/11/2017	15:00	24	58	60
LT-13	921 Rome Avenue, Durham	12/13/2017	14:00	24	57	60
LT-14	West Village Apartments – 605 W Main Street, Durham	12/11/2017	17:00	24	60	66
LT-15	504 E Pettigrew Street, Durham	12/12/2017	18:00	24	63	70
LT-16	1009 Alston Avenue, Durham	12/12/2017	17:00	24	67	69
ST-1	UNC Campus – Mason Farm Road, Chapel Hill	12/15/2017	8:34	1	62	60
ST-2	Baity Hill at Mason Farm – 1503 Baity Hill Drive, Chapel Hill	12/15/2017	8:29	1	57	55
ST-3	Glenwood Elementary School – 2 Prestwick Road, Chapel Hill	12/14/2017	15:50	1	50	48
ST-4	Downing Creek Parkway and Kingswood Drive, Chapel Hill	12/15/2017	10:07	1	55	53
ST-5	Markham Memorial Gardens – 4826 Trenton Road, Chapel Hill	12/14/2017	14:26	1	67	65
ST-6	Chapel Tower Apartments – 1315 Morreene Road, Durham	12/13/2017	16:52	1	54	52
ST-7	Duke Children's Hospital – 2301 Erwin Road, Durham	12/13/2017	12:33	1	65	63
ST-8	St. Joseph's Episcopal Church – 1915 W Main Street, Durham	12/13/2017	9:43	1	64	62
ST-9	Durham Performing Arts Center – 123 Vivian Street, Durham	12/12/2017	17:35	1	62	60
ST-10	Lovett Square Apartments – 211 Stokes Street, Durham	12/13/2017	11:04	1	50	48

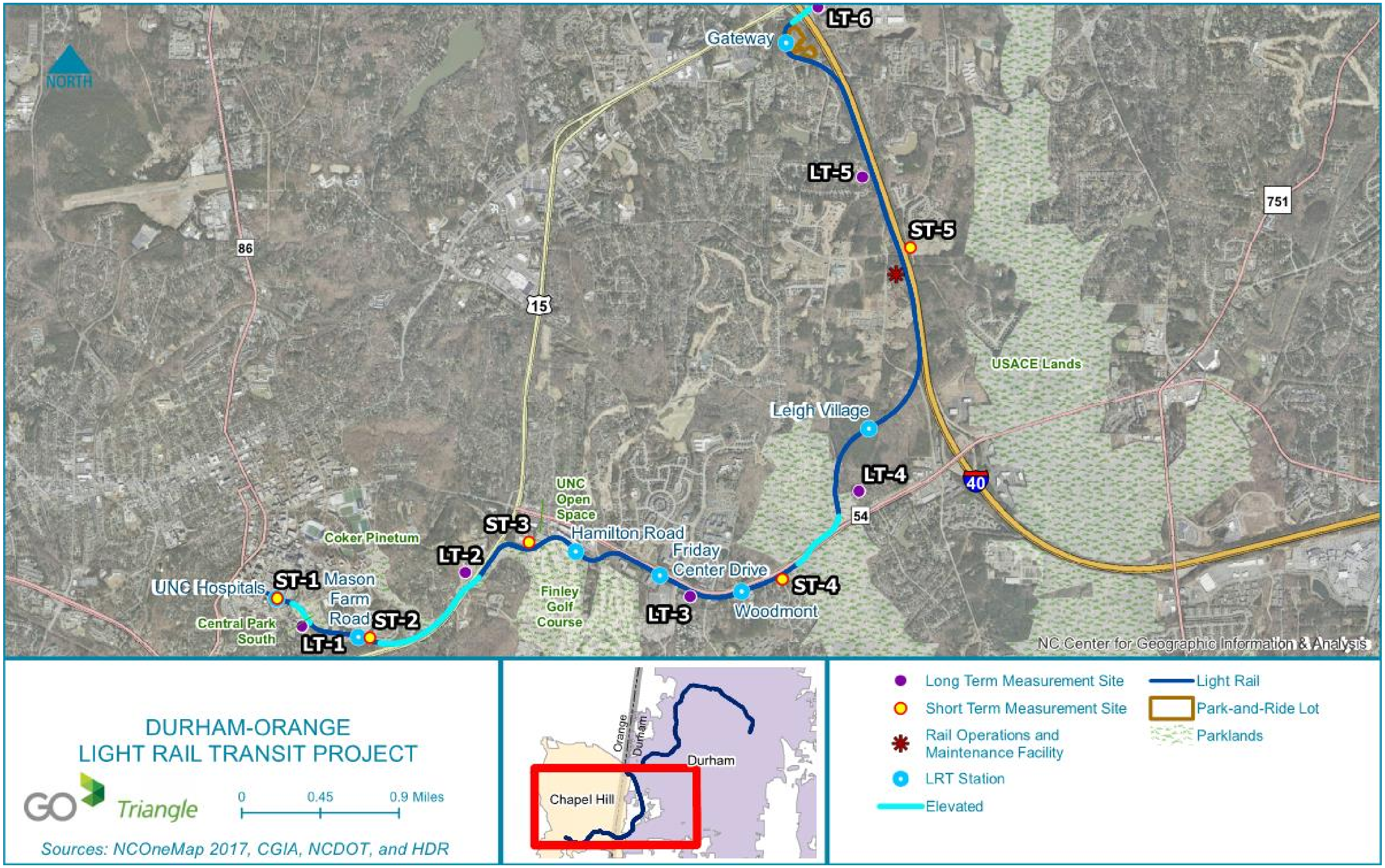


Figure 4-1: Existing Noise Measurement Locations - Segment 1

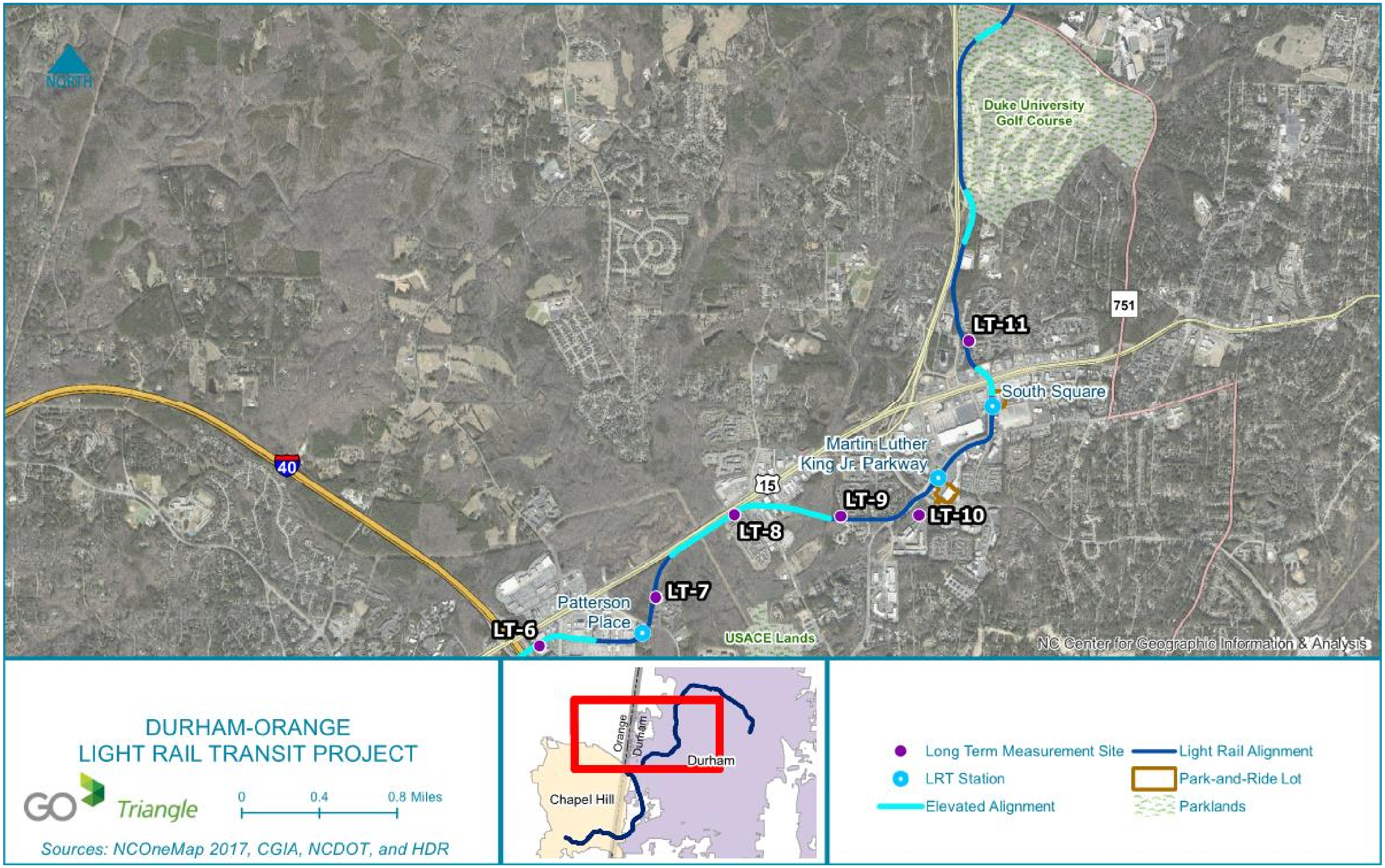


Figure 4-2: Existing Noise Measurement Locations - Segment 2

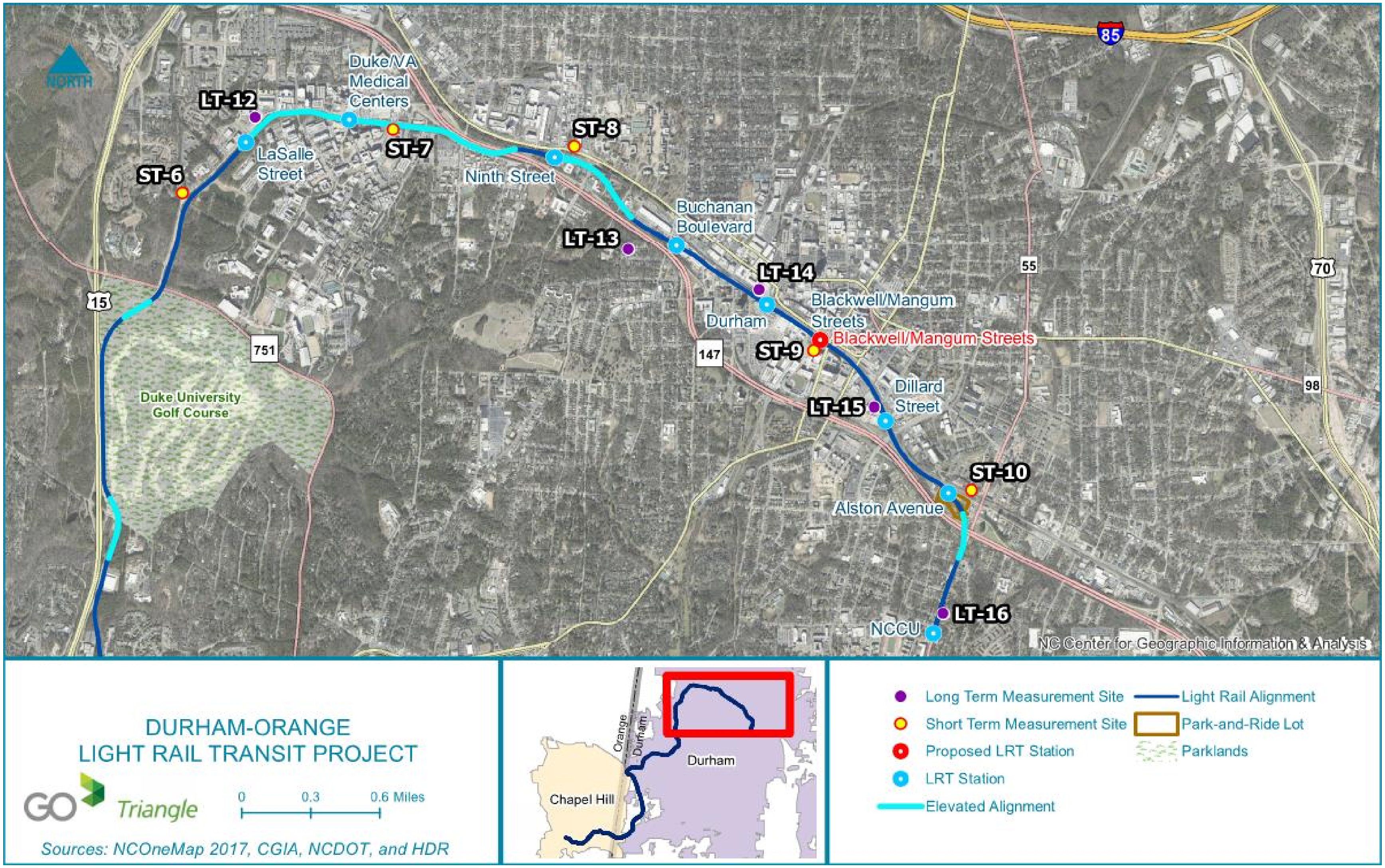


Figure 4-3: Existing Noise Measurement Locations - Segment 3

Table 4-2: Noise Measurement Results

Site No.	Location Description	Dominant Noise Source(s)	Noise Level (dBA)
Segment 1			
LT-1	1207 Mason Farm Road, Chapel Hill – yard on the west side of the **house**	Traffic on local roads and activity at nearby dorms	L_{dn}: 56
LT-2	St. Thomas More Catholic Church, 940 Carmichael Street, Chapel Hill – middle of the parking lot on the south side of the church	School noise and traffic on Fordham Boulevard (US 15-501)	L_{dn}: 60
LT-3	100 Marriott Way, Chapel Hill – edge of the parking lot on the east side of the building	Traffic on NC Highway 54 (NC 54)	L_{dn}: 61
LT-4	214 Celeste Circle, Chapel Hill – yard on the north side of the house	Traffic on NC 54, nearby construction on Macy Grove Drive, and utility work	L_{dn}: 52
LT-5	4315 Randall Road, Durham – yard on the south side of the house	Traffic on Interstate 40	L_{dn}: 65
LT-6	3508 Mt. Moriah Road, Durham – edge of the parking lot north of the Comfort Inn	Traffic on Interstate 40 and Durham-Chapel Hill Boulevard and parking lot activity	L_{dn}: 60
Segment 2			
LT-7	100 North Creek Drive, Durham – west edge of the property along the tree line	Local community activities and aircraft	L_{dn}: 55
LT-8	Old Creek Village Apartments – 4230 Garrett Road, Durham – west edge of the apartment complex	Traffic on Durham-Chapel Hill Drive	L_{dn}: 68
LT-9	614 Snow Crest Trail, Durham – southwest edge of the apartment complex	Local community activity	L_{dn}: 52
LT-10	1920 Ivy Creek Boulevard, Durham – edge of the parking lot east of the Extended Stay America	Traffic on University Drive and Martin Luther King Jr Parkway and parking lot activity	L_{dn}: 59
LT-11	20 Morcroft Lane, Durham – northwest corner of the apartment complex	Traffic on Pickett Road	L_{dn}: 56
Segment 3			
LT-12	2616 Erwin Road, Durham – patio at the southeast corner of the building	Traffic on Erwin Road	L_{dn}: 60
LT-13	921 Rome Avenue, Durham – yard on the north side of the house	Traffic on NC Highway 147 (NC 147)	L_{dn}: 60
LT-14	West Village Apartments – 605 W Main Street, Durham - near the fence on the east side of the apartment building	Traffic on W Chapel Hill Street and S Duke Street, trains along the existing track, and activity at the Amtrak station	L_{dn}: 66
LT-15	504 E Pettigrew Street, Durham – first-floor patio at the north side of the building	Traffic on Pettigrew Street and Dillard Street and trains on the nearby track	L_{dn}: 70
LT-16	1009 Alston Avenue, Durham – yard on the south side of the house	Traffic on Alston Avenue	L_{dn}: 69

Table 4-2 (Cont'd): Noise Measurement Results

Site No.	Location Description	Dominant Noise Source(s)	Noise Level (dBA)
Segment 1			
ST-1	UNC Campus – Mason Farm Road, Chapel Hill – open space on the southeast side of Mason Farm Road and Jackson Circle	Motor vehicle traffic on Mason Farm Road and pedestrian traffic	L_{eq}: 62
ST-2	Baity Hill at Mason Farm – 1503 Baity Hill Drive, Chapel Hill – near the side of Baity Hill Drive	Local traffic and neighborhood activity	L_{eq}: 57
ST-3	Glenwood Elementary School – 2 Prestwick Road, Chapel Hill – parking lot on the east side of the building	Traffic on US 15-501 and NC 54	L_{eq}: 50
ST-4	Downing Creek Parkway and Kingswood Drive, Chapel Hill – northwest corner of Kingswood Drive and Downing Creek Parkway	Local traffic	L_{eq}: 55
ST-5	Markham Memorial Gardens – 4826 Trenton Road, Chapel Hill – west side of the property next to Trenton Road	Traffic on Interstate 40 and Trenton Road	L_{eq}: 67
Segment 3			
ST-6	Chapel Tower Apartments – 1315 Morreene Road, Durham – southeast corner of the apartment complex	Traffic on Erwin Road	L_{eq}: 54
ST-7	Duke Children's Hospital – 2301 Erwin Road, Durham – southeast corner of Emergency Drive and Erwin Road	Traffic on Erwin Road and Emergency Drive	L_{eq}: 65
ST-8	St. Joseph's Episcopal Church – 1915 W Main Street, Durham – corner of W Main Street and Iredell Street	Traffic on W Main Street, Amtrak trains, and distant aircraft	L_{eq}: 64
ST-9	Durham Performing Arts Center – 123 Vivian Street, Durham – north side of the building	Traffic and pedestrians on the sidewalk	L_{eq}: 62
ST-10	Lovett Square Apartments – 211 Stokes Street, Durham – open space on the south side of the apartment complex	Traffic on NC 147 and train traffic	L_{eq}: 50

4.3 Existing Vibration Conditions

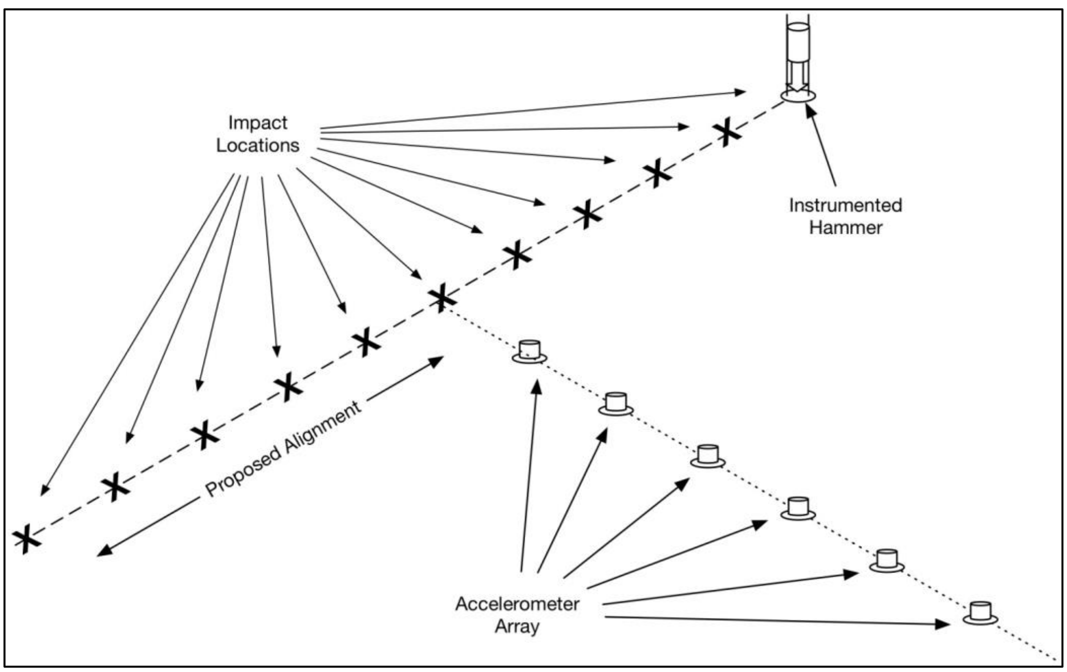
Vibration-sensitive land use along the project segments is the same as the noise-sensitive land use, except for parks and other outdoor sites that are not considered vibration sensitive. In addition, there are several vibration-sensitive medical and research facilities at the UNC and Duke Medical Campus areas.

Existing vibration sources along the alignment include auto, bus, and truck traffic on local streets. However, vibration from street traffic is not perceptible unless streets have significant bumps, potholes, or other uneven surfaces. The only significant sources of existing ground vibration along the alignment are infrequent freight train movements and daily Amtrak trains over limited sections of the corridor. Furthermore, the FTA vibration impact criteria are not ambient-based; that is, future project vibrations are not compared with existing vibrations to assess impact. Therefore, the vibration measurements for the D-O LRT Project focused on characterizing the soil conditions along the proposed alignment rather than on characterizing the existing vibration levels as described in **section 4.3.1**.

4.3.1 Vibration Measurement Procedures and Equipment

Vibration propagation measurements were conducted in the study area during November-December 2017 to determine the vibration response characteristics of the ground near vibration-sensitive locations. A custom-built instrumented hammer was used to impart an impulsive force to the ground. The magnitude of the force was calculated based on the acceleration and mass of the falling hammer. The resulting vibration signals were measured using high-sensitivity accelerometers (PCB Model 393C and 393B05) mounted in a vertical orientation on pavement or on steel spikes driven into the ground. The signals from the hammer and accelerometers were recorded using Data Translation DT9837A digital acquisition hardware. Data Translation's QuickDAQ software, running on a laptop computer, was used to review the measurement data.

The vibration propagation test procedure is shown schematically on **Figure 4-4**. The instrumented hammer was used to generate impulses at specific locations spaced 15 feet apart along a line on or parallel to the proposed alignment. A line of accelerometers was placed perpendicular to the line of impacts as shown on **Figure 4-4**. The relationship between the input force and the resulting vibration measured by the accelerometers, known as the transfer mobility (TM), was calculated using proprietary software in the Cross-Spectrum Acoustics laboratory. The TM represents the vibration propagation characteristics of the ground at the measurement site and at other sites with similar geology.



Source: Cross-Spectrum Acoustics, 2018

Figure 4-4: Vibration Propagation Measurement Schematic

4.3.2 Vibration Measurement Locations

Ten representative vibration propagation test sites were selected for the 2017 measurements. The locations of the sites are shown on **Figure 4-5** through **Figure 4-7,** and site photographs are included in **attachment J.1**. The test sites are described in Error! Reference source not found..

Table 4-3: Summary of Vibration Propagation Locations

Site No.	Measurement Location/Description	Date of Measurement
VP-A	St. Thomas Moore Catholic Church – 940 Carmichael St, Chapel Hill Measured in the parking lot of St. Thomas More Catholic Church	11/28/2017
VP-B	1414 Raleigh Road, Chapel Hill Measured in the parking lot of the office building	11/30/2017
VP-C	Yardley Terrace and Randal Road, Durham Measured on the road surface at the northwest corner of Yardley Terrace and Randall Road	11/28/2017
VP-D	Homewood Suites – 3600 Mt. Moriah Road, Durham Measured in the parking lot on the south side of the hotel	11/28/2017
VP-E	1600 Snow Crest Trail, Durham Measured on the road surface and lawn of the Mission University Pines Apartments	12/01/2017
VP-F	Ashland Drive and Lindenshire Drive, Durham Measured on the road surfaces and sidewalks at the southwest corner of Ashland Drive and Lindenshire Drive	11/30/2017
VP-G	2816 Erwin Road, Durham Measured in the parking lot south of the commercial building and on the sidewalk along Erwin Road east of the parking lot	11/30/2017
VP-H	Crest Street Park – 2503 Crest Street, Durham Measured in the parking lot and yard east of the church, adjacent to Crest Street Park	11/29/2017
VP-I	309 Blackwell Street, Durham Measured on the lawn and sidewalk in front of the Aloft hotel, close to the Durham Performing Arts Center	11/29/2017
VP-J	Russel Memorial Church – 611 Alston Avenue, Durham Measured in the parking lot and adjacent playground of Russell Memorial Church	11/29/2017

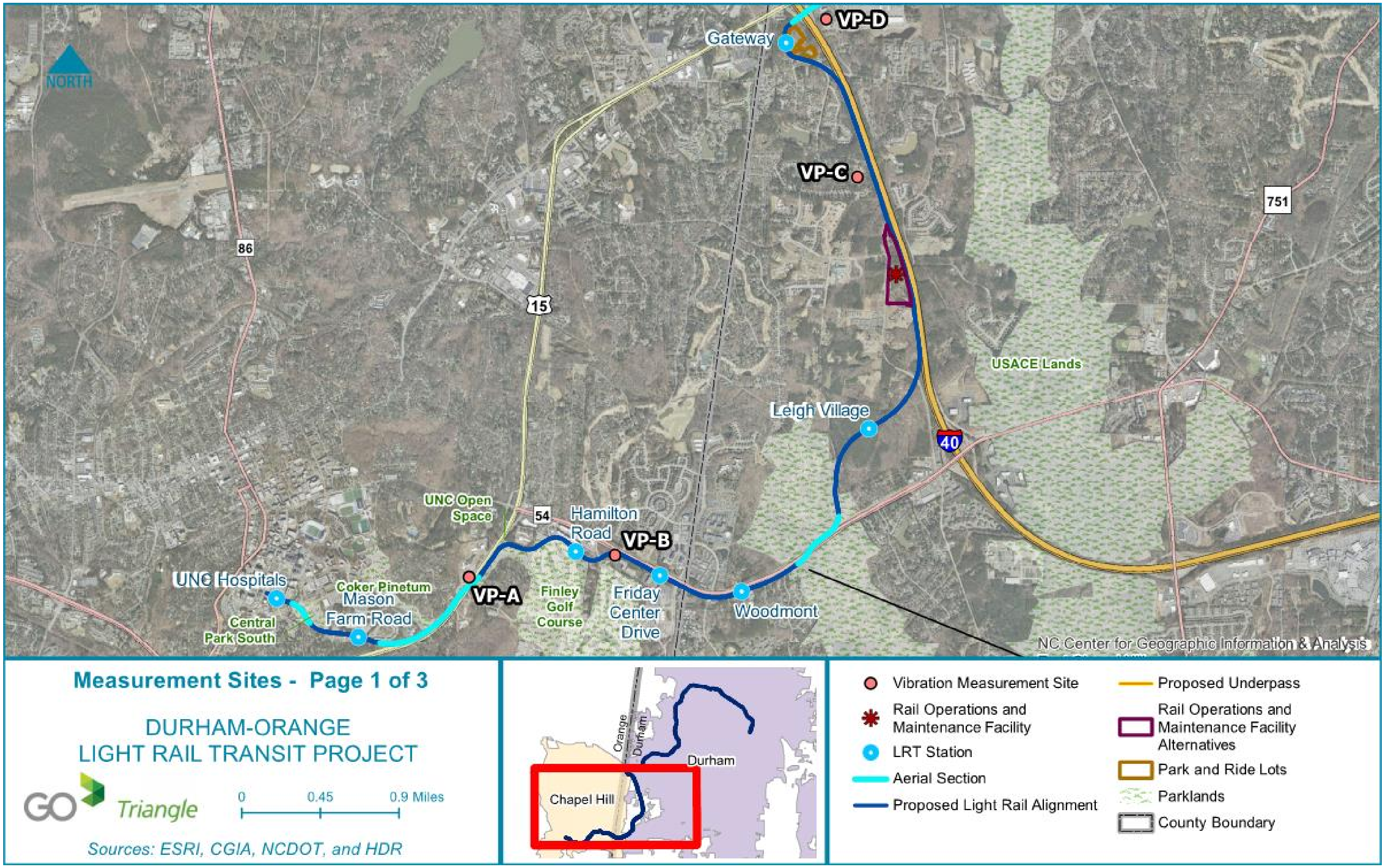


Figure 4-5: Vibration Propagation Measurement Locations - Segment 1

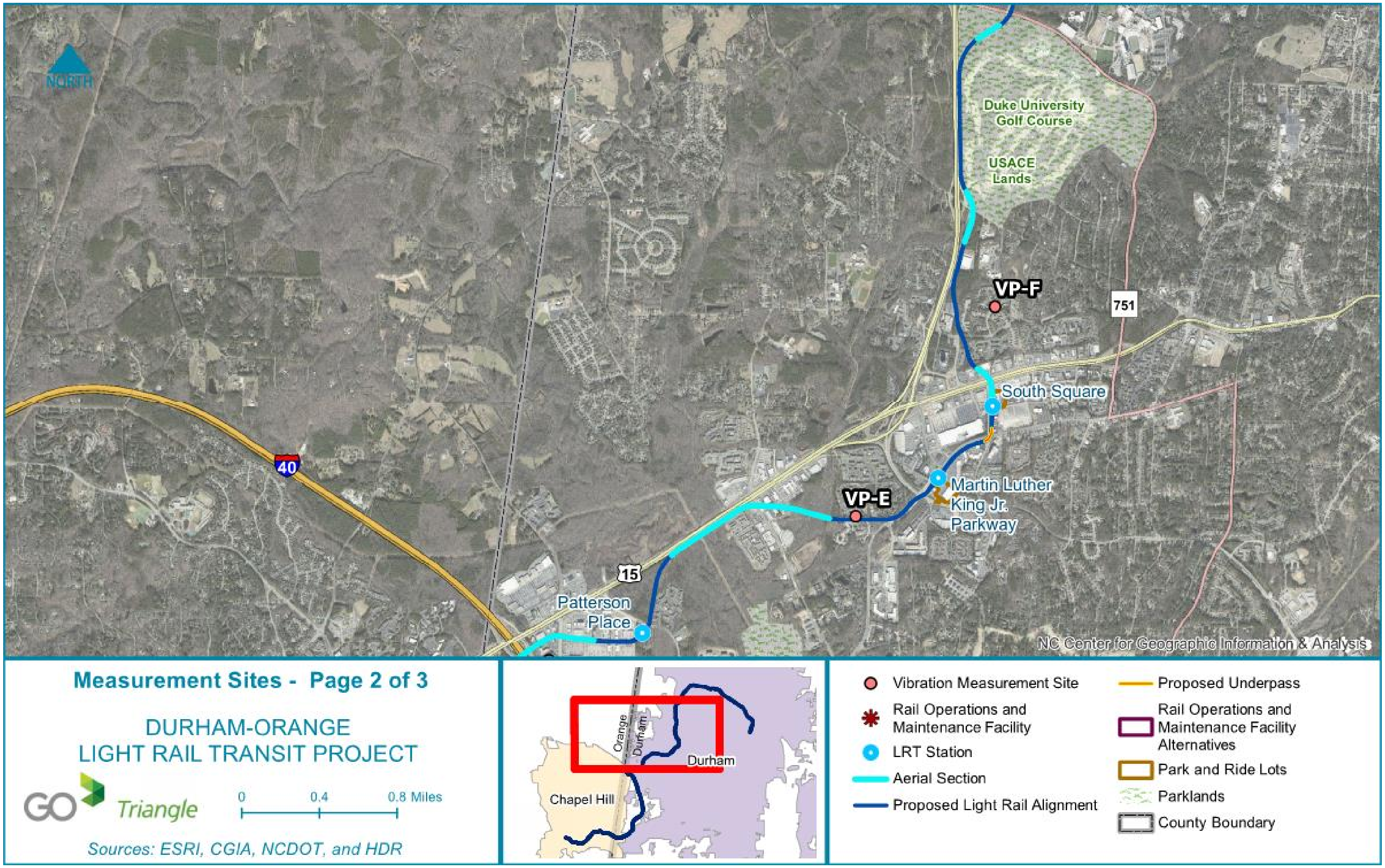


Figure 4-6: Vibration Propagation Measurement Locations - Segment 2

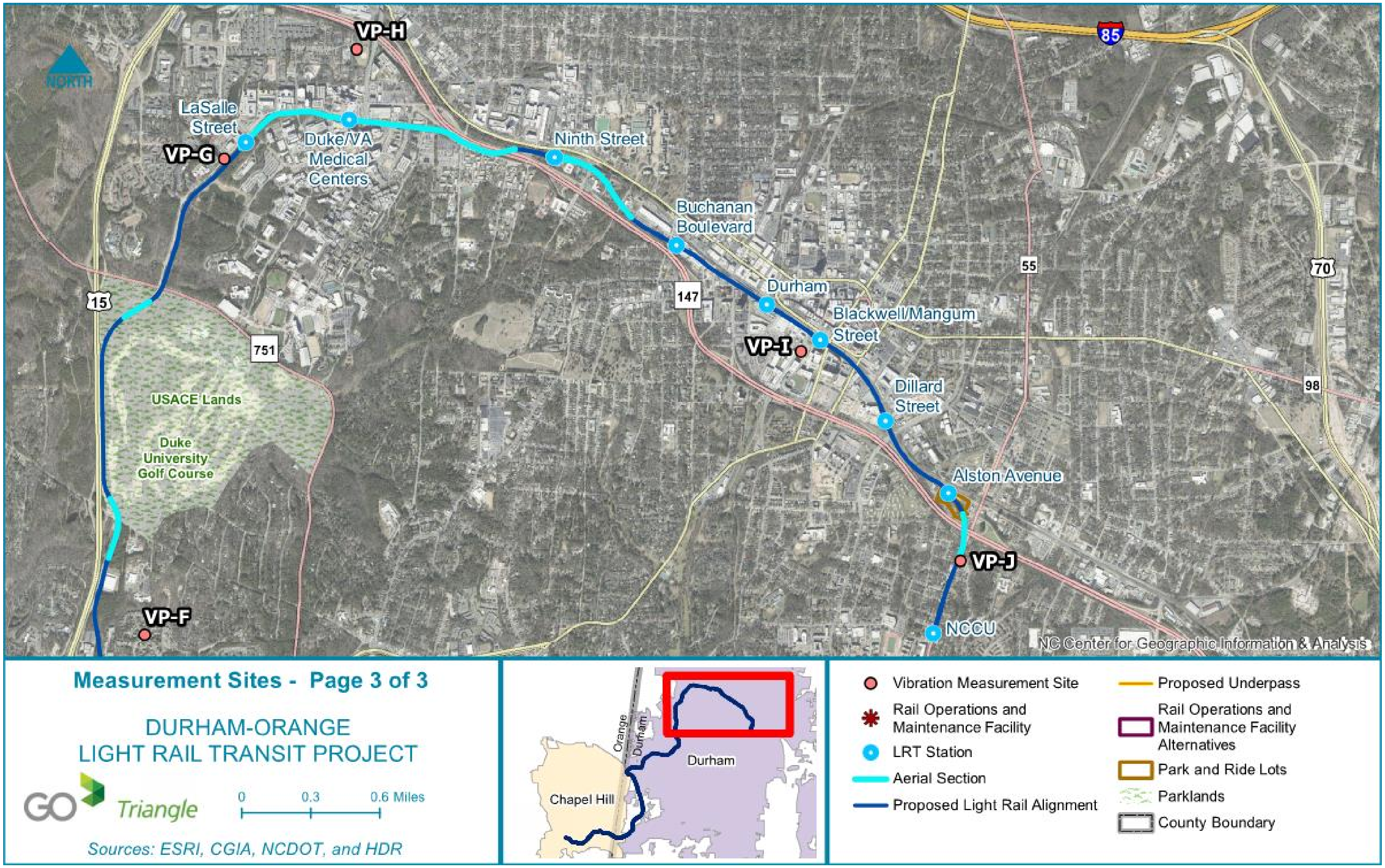
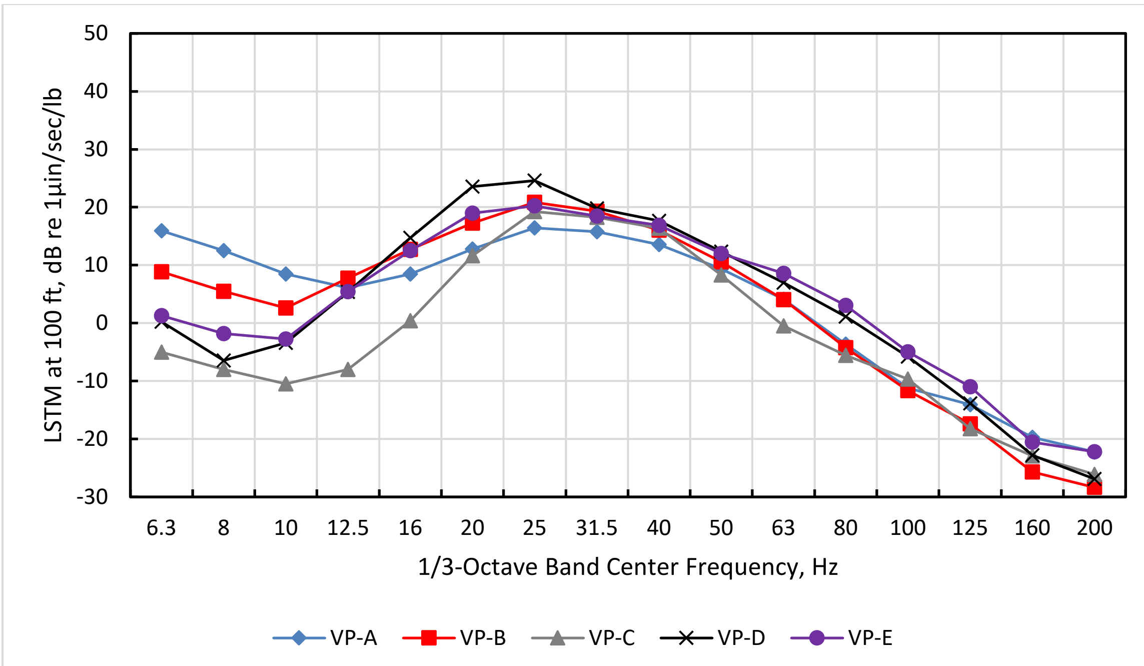


Figure 4-7: Vibration Propagation Measurement Locations - Segment 3

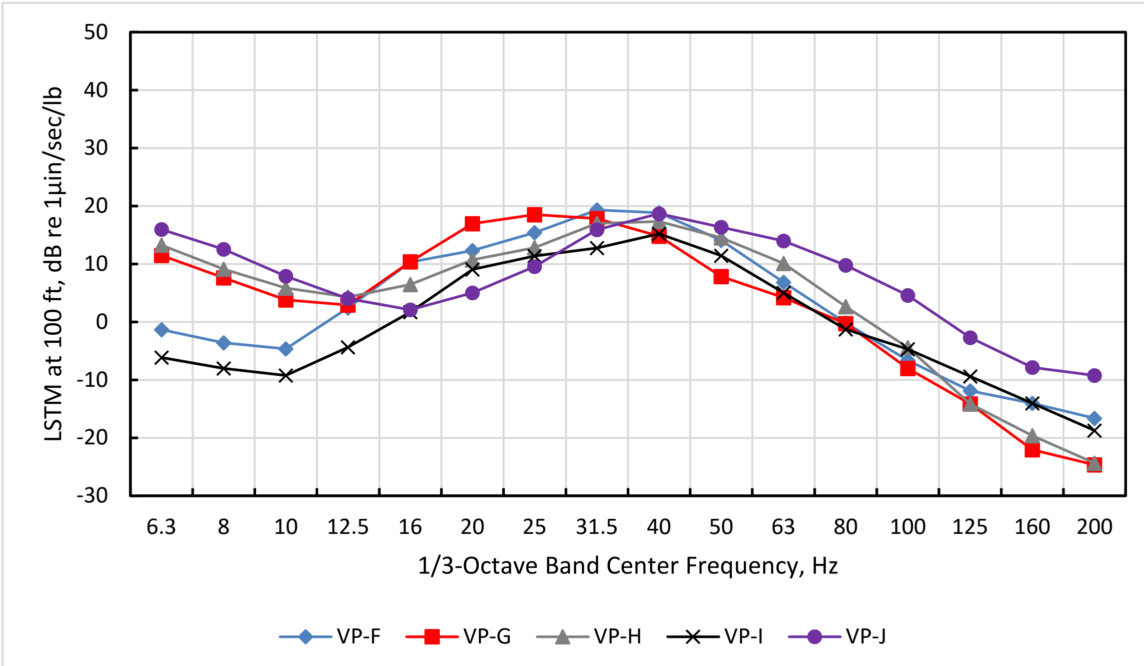
4.3.3 Vibration Measurement Results

Representative results of the vibration propagation tests are shown on **Figure 4-8** (for Sites VP-A, VP-B, VP-C, VP-D, and VP-E) and on **Figure 4-9** (for Sites VP-F, VP-G, VP-H, VP-I, and VP-J). The results in these figures are provided in terms of the measured Line Source Transfer Mobility (LSTM) at a distance of 100 feet. The results show less efficient propagation of vibration through the soil than has been seen in other locations around the country. Detailed vibration propagation data are provided in **attachment J.3**.



Source: Cross-Spectrum Acoustics, 2018

Figure 4-8: Vibration Propagation Test Data (Sites VP-A, VP-B, VP-C, VP-D, and VP-E)



Source: Cross-Spectrum Acoustics, 2018

Figure 4-9: Vibration Propagation Test Data (Sites VP-F, VP-G, VP-H, VP-I, and VP-J)

5. Prediction Methodology

5.1 Airborne Noise Prediction

5.1.1 LRT Noise Methodology

The primary components of wayside noise from LRT operations are the steel wheels rolling on steel rails and audible warning devices sounded by LRT vehicles approaching at-grade crossings. Secondary sources, such as the sounding of LRT bells while exiting passenger stations and stationary bells installed near at-grade crossings, will be audible in close proximity to the noise source but are not expected to be significant factors. The projection of wayside noise from LRT operations was determined using the model specified in the FTA guidance manual and current design of the D-O LRT Project with the following assumptions:

- LRT train speeds will range from 20 miles per hour (mph) to 55 mph for revenue operations, except for entry and exit from passenger station areas. LRT train speeds are based on modeled speed profiles in both directions (i.e., eastbound and westbound) that reflect train operating characteristics, track geometry, and passenger station locations.
- The LRT trains will consist of two LRT rail cars during hours of operation.
- The operating hours and headways will be as follows:
  - Morning peak operations (5:30 AM to 9:00 AM): 10-minute headways
  - Midday operations (9:00 AM to 3:30 PM): 20-minute headways

  - Evening peak operations (3:30 PM to 7:00 PM): 10-minute headways
  - Late night operations (7:00 PM to 12:00 AM): 20-minute headways
- The sound exposure level (SEL) at 50 feet for LRT trains with wheel skirts operating on ballast and tie track at 50 mph is assumed to be 80 dBA.
- The SEL at 50 feet for LRT trains with wheel skirts operating on embedded track at 50 mph is assumed to be 83 dBA.
- Stationary warning bells, generating a sound level of 75 dBA at 10 feet, will be sounded at all gated crossings before and after each LRT train for a total of 40 seconds. The corresponding SEL at 50 feet for crossing bells is assumed to be 77 dBA.
- LRT bells are assumed to generate a sound level of 80 dBA at 50 feet and sound for approximately 2 seconds prior to exiting a passenger station. The corresponding SEL at 50 feet for LRT bells is assumed to be 83 dBA.
- LRT bells are assumed to generate a sound level of 80 dBA at 50 feet and sound for 5 seconds prior to reaching an at-grade crossing. The corresponding SEL at 50 feet for LRT bells is assumed to be 87 dBA.
- Locations of elevated structures, crossovers, and embedded track were identified based on plan and profile maps provided.
- Wheel impacts at track crossovers and turnouts are assumed to cause localized noise increases of 6 dB up to a distance of 200 feet and no increase beyond 200 feet.
- Elevated structures increase the noise levels by 4 dB compared to ballast-and-tie track at nearby sensitive receptors due to the direct fixation track configuration and structure-borne noise.

5.1.2 ROMF Noise Methodology

The projection of noise from the proposed ROMF operations was determined using the model and reference values specified in the FTA guidance manual and current design and operational parameters for the ROMF with the following assumptions:

- The removal of up to 600 feet of intervening trees from the proposed ROMF site between Interstate 40 and sensitive receptors west of Farrington Road is assumed to increase existing highway noise from Interstate 40 by 10 dB.
- The reference SEL at 50 feet based on 20 LRT train movements within the ROMF is assumed to be 118 dBA.
- The schedule of LRT train movements within the ROMF is assumed to be as follows:
  - Daytime movements (7:00 AM to 10:00 PM): 32 total movements
  - Nighttime movements (10:00 PM to 7:00 AM): 48 total movements
- The tight radius curves within the proposed ROMF have the potential to cause wheel squeal as the radii of curvature are less than 100 times the width of the LRT trucks. The SEL at 50 feet for LRT wheel squeal is assumed to be 136 dBA and each train movement is assumed to generate five seconds of wheel squeal.

- The proposed substation within the ROMF is assumed to operate continuously, with an SEL at 50 feet of 99 dBA.
- The proposed ROMF buildings will provide up to 5 dB of shielding from proposed maintenance facility noise sources, as well as from the additional noise generated by existing vehicle traffic on Interstate 40.
- The proposed berm on the east side of Farrington Road was included in the assessment and provides shielding for some of the residences to the west.
- The existing berm on the west side of Farrington Road was included in the assessment and provides shielding for some of the residences to the west.

5.1.3 Traction Power Substation Noise Methodology

The projection of noise from proposed traction power substation (TPSS) locations was determined using the model and reference value (99 dBA SEL at 50 feet) specified in the FTA guidance manual.

5.2 Ground-Borne Vibration Prediction

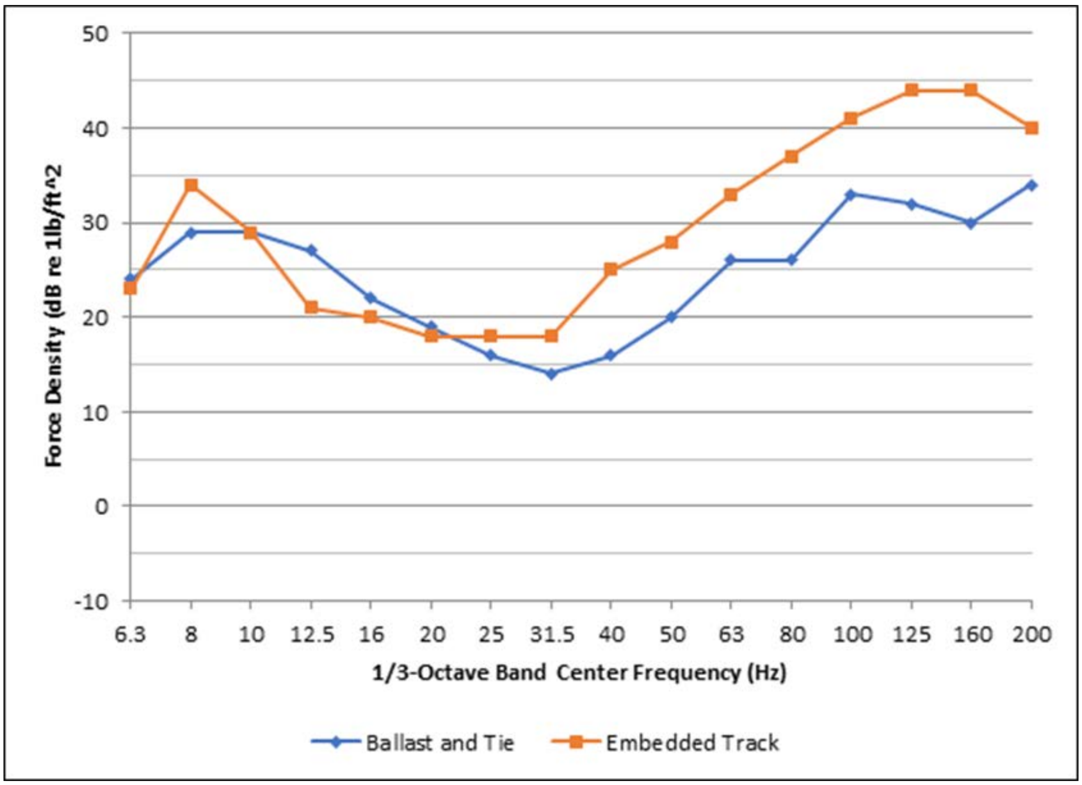
The projection of ground-borne vibration from LRT train operations was determined using the model specified in the FTA guidance manual with the following assumptions:

- LRT train speeds will range from 20 mph to 55 mph for revenue operations, except for entry and exit from passenger station areas. LRT train speeds are based on modeled speed profiles in both directions (i.e., eastbound and westbound) that reflect train operating characteristics, track geometry, and passenger station locations.
- The LRT trains will consist of two LRT rail cars during hours of operation.
- The operating hours and headways will be as follows, which will result in “frequent” events as defined in the vibration criteria section:
    - Morning peak operations (5:30 AM to 9:00 AM): 10-minute headways
    - Midday operations (9:00 AM to 3:30 PM): 20-minute headways
    - Evening peak operations (3:30 PM to 7:00 PM): 10-minute headways
    - Late night operations (7:00 PM to 12:00 AM): 20-minute headways
- Locations of elevated structures, crossovers, and embedded track were identified based on plan and profile maps.
- Wheel impacts at track crossovers and turnouts are assumed to cause localized vibration increases of up to 10 dB for nearby sensitive receptors due to the gap in the track.
- Elevated structures decrease the vibration levels by up to 10 dB for nearby sensitive receptors.
- The only tunnel section on the project is not located near any sensitive receptors, so ground-borne noise was not assessed.
- Future vibration levels from LRT operations were based on a combination of the force density (vehicle) and propagation (soil) data at sensitive locations. The procedure for projecting future vibration levels is to measure the vibration propagation characteristics of the soil and combine that information with the vehicle information independent of the soil (Force Density [FD]). The formula for calculating the future vibration levels is as follows:

Lv = FD + LSTM

Where: Lv is the projected train vibration level, FD is the vehicle force density, and LSTM is the line source transfer mobility at a given site.

- Vehicle force density levels were based on measurements conducted for the Minneapolis Central Corridor LRT Project (ATS Consulting, 2008) for a typical modern LRT vehicle (Bombardier Flexity) operating on both ballast-and-tie and embedded track. Representative force density spectra for both ballast-and-tie and embedded track conditions are shown on **Figure 5-1**.
- Vibration propagation tests were conducted at representative sites along the corridor near sensitive receptors, as described in **section 4.3**. The results of these tests were combined with the LRT vehicle vibration source level measurement data to provide projections of vibration levels from the D-O LRT Project.



Source: ATS, 2008

Figure 5-1: LRT Vehicle Force Density

6. Environmental Consequences

Detailed noise and vibration impact assessments were performed based on the criteria discussed in **section 3** and the prediction methodology described in **section 5**. The assessment results are presented in this section.

6.1 Noise Impact Assessment

The FTA guidance manual (FTA, 2006) is the primary source for the noise methodology. Noise impact has been evaluated using the Detailed Noise Assessment methodology contained in Chapter 6 of the FTA guidance manual (FTA, 2006). The noise assessment included the following steps:

- Noise-sensitive land uses along the corridor were identified using aerial photography, GIS data, and field surveys within 350 feet of the alignment.
- Existing noise levels along the corridor were measured at sensitive receptors (**section 4.2**).
- Project noise levels from transit operations were predicted using project drawings and information on speeds, headways, track type, vehicle type, and at-grade-crossing operations.
- The impact from transit operations was assessed by comparing the project noise with the existing noise (and not the No Build Alternative noise) using the FTA noise impact criteria in Chapter 3 of the FTA guidance manual (FTA, 2006). See **Figure 3-1.**
- The impact from ROMF operations was assessed by comparing the projected cumulative noise exposure increase with the existing noise level. See **Figure 3-2.**
- Mitigation was recommended at locations where project noise levels exceed the impact criteria.

6.1.1 LRT Operations

Comparisons of the existing and future noise levels are presented in **Table 6-1** and **Table 6-2**. **Table 6-1** includes the results for FTA Category 2 (residential) receptors with both daytime and nighttime sensitivity to noise; **Table 6-2** includes the results for FTA Category 3 (institutional) receptors with daytime and evening use. In addition to the distances to the track and proposed train speeds, **Table 6-1** and **Table 6-2** include the existing noise levels, the projected noise levels from LRT operations, the predicted total noise levels, and projected noise increases due to the project for each location along the D-O LRT Project Corridor. Based on a comparison of the predicted project noise levels with the impact criteria, the table also includes an inventory of the moderate and severe noise impacts in each section.

As shown in **Table 6-1** and **Table 6-2**, the D-O LRT Project will result in 475 moderate noise impacts at 24 buildings and 34 severe noise impacts at 2 buildings for residential land uses and moderate impact at one institutional site. The majority of the noise impacts are at multifamily buildings and are related to the sounding of LRT bells as the trains approach at-grade crossings along the corridor and locations where residences are located in close proximity to the proposed tracks. The number of units in multifamily buildings was estimated based on aerial photography and land use surveys. The noise impact locations are shown graphically in **attachment J.4** and the projected noise impacts are described in **sections 6.1.1.1** through **6.1.1.3**.

Table 6-1: Summary of FTA Category 2 (Residential) Noise Impacts Without Mitigation

Location[a]	Side of Track[b]	Near Track Dist. (ft)	Max. Train Speed (mph)	Existing Noise Level[c] (Ldn, dBA)	Project Noise Levels – Ldn[c] (dBA)			Type and # of Impacts[d]	
					LRT	FTA Criteria			
						Mod.	Sev.	Mod.	Sev.
UNC Campus to Manning Drive (See Figure on page J.4-1)	EB	46	45	56	59	56	62	89 (2)	0
UNC Campus to Manning Drive (See Figure on page J.4-1)	WB	109	45	60	57	58	64	0	0
Manning Drive to Meadowmont Lane	EB	244	40	61	49	58	64	0	0
Manning Drive to Meadowmont Lane	WB	100	45	61	57	58	64	0	0
Meadowmont Lane to George King Road	EB	88	45	61	57	58	64	0	0
Meadowmont Lane to George King Road	WB	250	45	61	49	58	64	0	0
George King Road to Crescent Drive (See Figure on page J.4-2)	EB	82	55	52	55	54	60	9 (9)	0
George King Road to Crescent Drive (See Figure on page J.4-2)	WB	146	55	52	55	54	60	1 (1)	0
Crescent Drive to Farrington Road	EB	No noise-sensitive receivers							
Crescent Drive to Farrington Road	WB	116	55	65	54	61	66	0	0
Farrington Road to Interstate 40	EB	No noise-sensitive receivers							
Farrington Road to Interstate 40	WB	129	55	65	52	61	66	0	0
Interstate 40 to Garrett Road (See Figure on page J.4-4)	EB	89	55	55	62	55	61	24 (2)	18 (1)
Interstate 40 to Garrett Road	WB	235	35	60	50	58	63	0	0
Garrett Road to Durham-Chapel Hill Boulevard (See Figure on page J.4-4)	EB	70	45	52	62	54	60	60 (3)	16 (1)
Garrett Road to Durham-Chapel Hill Boulevard (See Figure on page J.4-4)	WB	53	45	52	59	54	60	138 (3)	0

Table 6-1 (Cont'd): Summary of FTA Category 2 (Residential) Noise Impacts Without Mitigation

Location[a]	Side of Track[b]	Near Track Dist. (ft)	Max. Train Speed (mph)	Existing Noise Level[c](Ldn, dBA)	Project Noise Levels – Ldn[c] (dBA) LRT	FTA Criteria Mod.	FTA Criteria Sev.	Type and # of Impacts[d] Mod.	Type and # of Impacts[d] Sev.
Durham-Chapel Hill Boulevard to Cameron Boulevard (See Figure on page J.4-5)	EB	32	45	56	57	56	62	90 (3)	0
Durham-Chapel Hill Boulevard to Cameron Boulevard	WB	92	45	56	56	56	62	0	0
Cameron Boulevard to Swift Avenue	EB	60	35	63	57	59	65	0	0
Cameron Boulevard to Swift Avenue (See Figure on page J.4-6)	WB	67	35	52	58	54	60	64 (1)	0
Swift Avenue to Fayetteville Street	EB	118	45	70	57	64	69	0	0
Swift Avenue to Fayetteville Street	WB	198	45	66	51	61	67	0	0
Fayetteville Street to NCCU	EB	45	35	69	60	63	69	0	0
Fayetteville Street to NCCU	WB	60	35	69	60	63	69	0	0
Total								**475 (24)**	**34 (2)**

Source: Cross-Spectrum Acoustics, 2018

[a] The location of impacts is shown in the figures noted in **attachment J.4**.

[b] Eastbound (EB) or Westbound (WB)

[c] Noise levels are based on Ldn and measured in dBA (rounded to the nearest decibel).

[d] The numbers in parenthesis show the number of buildings with impact. The number of units in multifamily buildings was estimated based on aerial photography and land use surveys.

Table 6-2: Summary of FTA Category 3 (Institutional) Noise Impacts Without Mitigation

Location[a]	Name	Side of Track[b]	Near Track Dist. (ft.)	Max. Train Speed (mph)	Existing Noise Level[c] (Leq, dBA)	Noise Levels[c] – Leq (dBA) LRT	FTA Criteria Mod.	FTA Criteria Sev.	Type and # of Impacts[d] Mod.	Type and # of Impacts[d] Sev.
Manning Drive to Meadowmont Lane	North Carolina Botanical Garden[e]	EB	222	45	58	51	57	62	0	0
Manning Drive to Meadowmont Lane	Alders Gate United Methodist Church	WB	110	45	58	55	62	67	0	0
Manning Drive to Meadowmont Lane	St. Thomas More Catholic Church	WB	445	40	58	40	62	67	0	0
Durham-Chapel Hill Boulevard to Cameron Boulevard	Carter Community Charter School	EB	392	45	56	47	61	67	0	0
Manning Drive to Meadowmont Lane	Glenwood Elementary School	WB	246	30	50	42	58	64	0	0
Cameron Boulevard to Swift Avenue	St. Joseph's Episcopal Church	WB	317	45	64	46	65	70	0	0
Swift Avenue to Fayetteville Street (See Figure on page **J.4**-7)	Duke – Center for Documentary Studies[e]	WB	52	45	64	60	60	65	1	0
Swift Avenue to Fayetteville Street	Duke Memorial United Methodist Church	EB	154	40	65	48	62	68	0	0
Swift Avenue to Fayetteville Street	The Pinhook	WB	293	25	62	42	64	70	0	0
Swift Avenue to Fayetteville Street	Durham Performing Arts Center	EB	242	25	62	47	64	70	0	0
Fayetteville Street to NCCU	Russell Memorial CME Church	WB	98	35	50	49	58	65	0	0
Total									**1 (1)**	**0**

Source: Cross-Spectrum Acoustics, 2018
[a] The location of impacts is shown in the figures noted in **attachment J.4**.
[b] Eastbound (EB) or Westbound (WB)
[c] Noise levels are based on Leq and measured in dBA (rounded to the nearest decibel).
[d] The numbers in parenthesis show the number of buildings with impact.
[e] This location is a Category 1 receptor, with increased sensitivity to noise.

6.1.1.1 Line Section 1

- **UNC Campus to Manning Drive (EB):** There are two multifamily buildings with 89 receivers projected to have moderate noise impact along the eastbound side of the proposed alignment between the UNC campus and Manning Drive. The noise impacts at this location are due to the proximity of the tracks, the nearby grade crossing, and station noise.
- **George King Road to Crescent Drive (EB):** There are nine single-family receivers along the eastbound side of the proposed alignment between George King Road and Crescent Drive projected to have moderate noise impact. The noise impacts at this location are due to the proximity of the tracks, nearby grade crossing, and low existing noise levels.
- **George King Road to Crescent Drive (WB):** There is one single-family receiver along the westbound side of the proposed alignment between George King Road and Crescent Drive projected to have moderate noise impact. The noise impact at this location are due to the proximity of the tracks and the nearby grade crossings.

6.1.1.2 Line Section 2

- **Interstate 40 to Garrett Road (EB):** There are three multifamily buildings with 42 receivers projected to have moderate or severe noise impact along the eastbound side of the proposed alignment between Interstate 40 and Garrett Road. The only building projected to have a severe noise impact in this area is primarily due to a track switch that allows trains to transition from a two track alignment to a single track alignment. The noise impacts at this location are due to the proximity of the tracks and the nearby grade crossing.
- **Garrett Road to Durham-Chapel Hill Boulevard (EB):** There are four multifamily buildings with 76 receivers projected to have moderate or severe noise impact along the eastbound side of the proposed alignment between Garrett Road and Durham-Chapel Hill Boulevard. The only building projected to have a severe noise impact in this area is primarily due to a track switch that allows trains to transition from a two track alignment to a single track alignment. The noise impacts at this location are due to the proximity of the tracks and the nearby grade crossings.
- **Garrett Road to Durham-Chapel Hill Boulevard (WB):** There are three multifamily buildings with 138 receivers projected to have moderate noise impact along the westbound side of the proposed alignment between Garrett Road and Durham-Chapel Hill Boulevard. The noise impacts at this location are due to the proximity of the tracks and the nearby grade crossings.
- **Durham-Chapel Hill Boulevard to Cameron Boulevard (EB):** There are three multifamily buildings with 90 receivers projected to have moderate noise impact along the eastbound side of the proposed alignment between Durham-Chapel Hill Boulevard and Cameron Boulevard. The noise impacts at this location are due to the proximity of the tracks and the nearby grade crossings.

6.1.1.3 Line Section 3

- **Cameron Boulevard to Swift Avenue (WB):** There is one multifamily building with 64 receivers along the westbound side of the proposed alignment between Cameron Boulevard and Swift Avenue projected to have moderate noise impacts. The noise impacts at this location are due to the proximity of the tracks.

- There is only one projected institutional noise impact. The Duke University Center for Documentary Studies is projected to have moderate noise impact. This noise impact is due to the proximity of the tracks and the sensitivity of the receiver.

6.1.2 Stations

The major noise source at stations, other than LRT operations, is the sounding of the LRT bells as the trains enter and exit the stations. The noise from the LRT bells has been accounted for in the LRT operational noise assessment detailed in **section 6.1.1**.

6.1.3 Park and Rides

No noise-sensitive receptors were located within the FTA screening distance of 225 feet. Therefore, there are no impacts projected for park and ride locations.

6.1.4 Traction Power Substations

There is only one location where noise sensitive receptors are located within the FTA screening distance of 250 feet for a TPSS; however, based on the noise assessment of TPSS operations, there would be no noise impact at that location.

6.1.5 Rail Operations and Maintenance Facility

A summary of the noise impact assessment for the ROMF is presented in **Table 6-3** for FTA Category 2 (residential) receptors with both daytime and nighttime sensitivity to noise. There are no FTA Category 3 (institutional) receptors that will be affected by maintenance facility noise. In addition to the distances to the proposed maintenance facility, **Table 6-3** includes the existing noise levels, the projected noise levels from maintenance facility operations, the predicted total noise levels and projected noise increases due to the proposed maintenance facility.

The projected noise levels from the maintenance facility include noise from LRT train movements, potential wheel squeal and the substation, and increased noise from traffic on Interstate 40 due to the removal intervening trees. Shielding of noise from the ROMF is achieved by the presence of the existing berm on the west side of Farrington Road, the proposed berm on the east side of Farrington Road, and the ROMF buildings. Based on a comparison of the predicted cumulative noise exposure increase with the impact criteria, the table also includes an inventory of the moderate and severe noise impacts.

Table 6-3: Summary of Maintenance Facility Noise Impacts Without Mitigation

Location[a]	Side of Track[2]	Maintenance Facility Dist. (ft)	Existing Noise Level[c] (Ldn, dBA)	Cumulative Maintenance Facility Noise Level (Ldn, dBA)	Cumulative Noise Level Increases – Ldn[c] (dB)			Type and # of Impacts[d]	
					Increase	FTA Criteria Mod.	FTA Criteria Sev.	Mod.	Sev.
Culp Hill Drive to Ephesus Church Road (See Figure on page J.4-3)	WB	360	61	64	2.2	1.9	4.8	12	0
Ephesus Church Road to Interstate 40 (See Figure on page J.4-3)	WB	500	64	68	4.7	1.9	4.8	1	0
Total								**13 (13)**	**0**

Source: Cross-Spectrum Acoustics, 2018

[a] The location of impacts is shown in the figures noted in **attachment J.4**.

[b] Eastbound (EB) or Westbound (WB)

[c] Noise levels are based on Ldn and measured in dBA (rounded to the nearest decibel).

[d] The numbers in parenthesis show the number of buildings with impact.

As shown in **Table 6-3**, the ROMF will result in moderate noise impacts at 13 single-family residences. The majority of the noise impacts are related to increased noise from Interstate 40 traffic due to the removal of intervening trees. The noise impact locations are shown graphically in **attachment J.4** and the projected noise impacts are described as follows.

Culp Hill Drive to Ephesus Church Road (WB): There are 12 single-family receivers projected to have moderate noise impact to the west of the proposed ROMF between Culp Hill Drive and Ephesus Church Road. The noise impacts at this location are due to the proximity of the proposed ROMF and the increase in highway traffic noise caused by the removal of existing intervening trees.

Ephesus Church Road to Interstate 40 (WB): There is one single-family receiver projected to have moderate noise impact to the west of the proposed ROMF between Ephesus Church Road and Interstate 40. The noise impact at this location is due to the increase in highway traffic noise caused by the removal of existing intervening trees.

6.2 Vibration Impact Assessment

The FTA guidance manual (2006) is the primary source for the vibration methodology. The FEIS uses a Detailed Vibration Assessment methodology, as described in Chapter 11 of the FTA guidance manual (2006).

The vibration assessment included the following steps:

- Vibration-sensitive land uses along the corridor were identified using aerial photography, GIS data, and field surveys, within 200 feet of the alignment for residences and 600 feet for highly sensitive receptors.
- Vibration-propagation characteristics of the soil along the corridor were measured at representative sensitive receptors (**section 4.3**).
- Project vibration levels from transit operations were predicted using current D-O LRT Project drawings, and information on speeds, headways, track type, and vehicle vibration characteristics.
- The impact from transit operations was assessed by comparing the project vibration with the FTA vibration impact criteria in Chapter 8 of the FTA guidance manual (2006).
- Mitigation was recommended at locations where project vibration levels exceed the impact criteria.

This section describes the vibration impacts for the D-O LRT Project. The D-O LRT Project team conducted a detailed vibration analysis. Summaries of the analysis results are presented in **Table 6-4** and **Table 6-5** for residential and institutional (e.g., churches and schools) land uses, respectively.

The results include a tabulation of location information for each sensitive receptor group, the projections of future vibration levels, the impact criteria, and whether there will be vibration impacts. The tables also show the total number of vibration impacts for each location. As shown in **Table 6-4** and **Table 6-5**, there will be no vibration impacts due to the D-O LRT Project. Because there are no vibration impacts identified, there are no figures for vibration impact locations included in the report.

The low projected vibration levels and lack of vibration impacts along the corridor are due to the vibration propagation characteristics of the soil. The vibration propagation testing described in **section 4.3** showed that vibration is not transmitted efficiently through the soil in the project area, and thus the resulting vibration levels are well below the impact criteria. In the area along Erwin Road, the vibration levels are projected to be below the most stringent thresholds for sensitive equipment due to the effects of the elevated structure (which reduces vibration relative to at-grade operations).

Table 6-4: Summary of FTA Category 2 Vibration Impact Assessment without Mitigation

Location	Side of Track[a]	Near Track Dist. (ft)	Max. Train Speed (mph)	DOLRT Vibration Level[a] (VdB)		# of Impacts
				Project	FTA Criteria	
UNC Campus to Manning Drive	EB	46	45	51	72	0
UNC Campus to Manning Drive	WB	49	45	47	72	0
Manning Drive to Meadowmont Lane	EB	244	40	40	72	0
Manning Drive to Meadowmont Lane	WB	100	45	40	72	0
Meadowmont Lane to George King Road	EB	88	45	41	72	0
Meadowmont Lane to George King Road	WB	250	45	29	72	0
George King Road to Crescent Drive	EB	282	55	26	72	0
George King Road to Crescent Drive	WB	146	55	34	72	0
Crescent Drive to Farrington Road	EB	No vibration-sensitive receivers				
Crescent Drive to Farrington Road	WB	116	55	37	72	0
Farrington Road to Interstate 40	EB	No vibration-sensitive receivers				
Farrington Road to Interstate 40	WB	129	55	33	72	0
Interstate 40 to Garrett Road	EB	48	55	47	72	0
Interstate 40 to Garrett Road	WB	235	35	27	72	0
Garrett Road to Durham-Chapel Hill Boulevard	EB	28	45	68	72	0
Garrett Road to Durham-Chapel Hill Boulevard	WB	53	45	51	72	0
Durham-Chapel Hill Boulevard to Cameron Boulevard	EB	32	45	63	72	0
Durham-Chapel Hill Boulevard to Cameron Boulevard	WB	92	45	37	72	0
Cameron Boulevard to Swift Avenue	EB	117	35	26	72	0
Cameron Boulevard to Swift Avenue	WB	67	35	34	72	0
Swift Avenue to Fayetteville Street	EB	118	45	23	72	0
Swift Avenue to Fayetteville Street	WB	198	45	25	72	0
Fayetteville Street to NCCU	EB	45	35	56	72	0
Fayetteville Street to NCCU	WB	60	35	54	72	0

Source: Cross-Spectrum Acoustics, 2018

[a] Eastbound (EB) or Westbound (WB)

[b] Maximum one-third octave frequency band ground-borne vibration velocity level, measured in VdB referenced to 1 µin/sec (rounded to the nearest decibel)

Table 6-5: Summary of FTA Category 3 Vibration Impact Assessment without Mitigation

Location	Name	Side of Track[a]	Near Track Dist. (ft)	Max. Train Speed (mph)	DOLRT Vibration Level[b] (VdB)		# of Impacts
					Project	FTA Criteria	
Manning Drive to Meadowmont Lane	Alders Gate United Methodist Church	WB	110	45	30	75	0
Manning Drive to Meadowmont Lane	St. Thomas More Catholic Church	WB	445	40	39	75	0
Durham-Chapel Hill Boulevard to Cameron Boulevard	Carter Community Charter School	EB	378	45	12	75	0
UNC Campus to Manning Drive	UNC – Taylor, Isaac Hall	WB	625	25	34	65	0
UNC Campus to Manning Drive	UNC – EPA Building	EB	640	25	34	65	0
UNC Campus to Manning Drive	UNC – Lineberger Cancer Research Center	WB	323	25	35	65	0
UNC Campus to Manning Drive	UNC – Radiological Research Laboratory	WB	269	25	35	65	0
UNC Campus to Manning Drive	UNC – Genetic Medicine Research Building	EB	364	25	35	65	0
UNC Campus to Manning Drive	UNC – Bioinformatics Building	EB	82	25	37	65	0
Manning Drive to Meadowmont Lane	Glenwood Elementary School	WB	246	30	26	75	0
Manning Drive to Meadowmont Lane	UNC – Imaging and Outpatient Center	WB	469	30	22	65	0
Cameron Boulevard to Swift Avenue	PruittHealth	WB	156	35	34	65	0
Cameron Boulevard to Swift Avenue	Lenox Baker Children's Hospital	WB	155	35	34	65	0
Cameron Boulevard to Swift Avenue	Duke – Snyderman Genome Science Research Building	EB	212	35	24	65	0
Cameron Boulevard to Swift Avenue	Duke – Global Health Research Laboratory	EB	258	35	24	65	0

Table 6-5 (Cont'd): Summary of FTA Category 3 Vibration Impact Assessment without Mitigation

Location	Name	Side of Track[a]	Near Track Dist. (ft)	Max. Train Speed (mph)	DOLRT Vibration Level[b] (VdB)		# of Impacts
					Project	FTA Criteria	
Cameron Boulevard to Swift Avenue	Duke – Pavilion East at Lakeview	WB	193	35	24	65	0
Cameron Boulevard to Swift Avenue	Duke – Medical Sciences Research Building	EB	352	35	24	65	0
Cameron Boulevard to Swift Avenue	Duke – Edwin L. Jones Building	EB	533	35	24	65	0
Cameron Boulevard to Swift Avenue	Duke – Clinical and Research Laboratory	EB	470	35	24	65	0
Cameron Boulevard to Swift Avenue	Duke University Hospital	EB	117	35	26	65	0
Cameron Boulevard to Swift Avenue	Durham VA Medical Center	WB	86	35	27	65	0
Cameron Boulevard to Swift Avenue	St. Joseph's Episcopal Church	WB	317	45	13	75	0
Cameron Boulevard to Swift Avenue	Kindred Transitional Care and Rehabilitation	EB	60	45	29	75	0
Swift Avenue to Fayetteville Street	Hillcrest Convalescent Center	EB	118	45	20	75	0
Swift Avenue to Fayetteville Street	Duke – Center for Documentary Studies	WB	52	45	37	65	0
Swift Avenue to Fayetteville Street	Duke Memorial United Methodist Church	EB	145	40	26	72	0
Swift Avenue to Fayetteville Street	The Carolina Theater	WB	748	25	25	72	0
Swift Avenue to Fayetteville Street	The Pinhook	WB	293	25	25	72	0
Swift Avenue to Fayetteville Street	Durham Performing Arts Center	EB	228	25	26	72	0
Fayetteville Street to NCCU	Russell Memorial CME Church	WB	98	35	40	75	0

Source: Cross-Spectrum Acoustics, 2018

[a] Eastbound (EB) or Westbound (WB)

[b] Maximum one-third octave frequency band ground-borne vibration velocity level, measured in VdB referenced to 1 μin/sec (rounded to the nearest decibel)

7. Mitigation

7.1 Noise Impact Mitigation

FTA guidance states that severe noise impacts should be mitigated unless there are no feasible or practical means to do so (FTA, 2006). For moderate impacts, discretion should be used, and project-specific factors should be included in the consideration of mitigation. The project-specific factors can include both the existing noise levels and the projected increase in noise levels, the types and number of noise-sensitive land uses with impacts, existing sound insulation of buildings, and the cost-effectiveness of providing noise mitigation.

GoTriangle is developing a noise mitigation policy to address mitigation for transit noise impacts, including those at the moderate level, based on the FTA's guidance on mitigation. Once this policy is enacted, specific mitigation measures will be determined for those locations that qualify for mitigation.

7.1.1 Noise Mitigation Methods

Several options exist for providing noise mitigation at the source, path, or receiver. The most common noise mitigation measures are described in **sections 7.1.1.1** through **7.1.1.3**.

7.1.1.1 Source

- **Resilient or Damped Wheels:** Using either resilient or damped wheels can achieve approximately a 2 dB reduction in wheel/rail noise from transit vehicles on typical track sections.
- **Track Dampers:** Using damping materials on tracks can achieve an approximately 1 to 3 dB reduction in noise radiated from the tracks on typical track sections.
- **Vehicle Design:** Certain design features of transit vehicles can provide some shielding and/or absorption of the noise generated by the vehicle. Acoustical absorption under the car can provide up to a 5 dB reduction in wheel/rail noise and propulsion-system noise on rapid transit trains. Similarly, vehicle skirts (which are already specified) over the wheels can provide up to 5 dB of reduction in noise.
- **Special Trackwork:** The rail gaps in the frogs located in turnouts and crossovers can cause noise increases of about 6 dB at locations close to the track. If turnouts are located in sensitive areas and cannot be moved, one approach is to utilize special components such as spring rail frogs, moveable point frogs, or flange bearing frogs to manage the rail gap as the vehicle moves through the turnouts.
- **Quiet Zones:** Quiet Zones are locations, as least one-half mile in length, where the routine sounding of horns is not required based on safety improvements at at-grade crossings, including modifications to the streets, raised median barriers, four quadrant gates, and other improvements. Horns will only be sounded in emergency situations at these locations.
- **Wayside Horns:** Wayside horns are mounted at the at-grade-crossing, directed down the roadway, instead of mounted on the train. The wayside horns are directive and provide warning to motorists and pedestrians at the at-grade crossing while limiting the noise exposure to areas located down the tracks from the crossing.
- **Modified Grade Crossing Procedures:** The noise from the sounding of bells at grade crossings is dependent on both the length of time the bell is sounded and the noise level of the bell. Limiting

the duration of bell sounding prior to a grade crossing, reducing the noise level of the bell, or both can significantly reduce the noise exposure to areas near grade crossings. However, such modifications would need to meet appropriate safety standards and regulatory requirements.

7.1.1.2 Path

- **Noise Barriers:** This is the most common approach to reducing noise impacts from transit and rail projects. For noise barriers to be effective, they must break the line-of-sight between the source of the noise and the receiver. Additionally, the barrier must be made of a material that has a minimum surface density of four pounds/square foot and not have any gaps or holes that could degrade the performance of the barrier. Noise barriers can be made of virtually any material that meets these requirements and can provide between 5 and 10 dB of reduction, depending on the design of the barrier. Project features, such as retaining walls or crash walls, can act as effective noise barriers.
- **Berms:** Berms are another approach to mitigating noise along the path. Berms work in much the same way as barriers and need to block the line of sight between the source and the receiver to be effective. Berms can also provide between 5 and 10 dB of reduction but are not used in transit applications due to the space requirements (a berm must be twice as wide as it is tall).

7.1.1.3 Receiver

- **Sound Insulation:** At locations where noise barriers are not feasible or practical, for multistory buildings, or at locations where there is no exterior use, sound insulation of buildings can be an effective approach to noise mitigation. While this treatment does not provide mitigation for exterior use, it can be very effective for indoor uses and provide between 5 and 10 dB of noise reduction. Sound insulation focuses on improvements to windows and doors, sealing any gaps or holes and providing central ventilation and air conditioning so that windows can remain closed. The criterion for indoor noise levels is 45 dBA Ldn.

7.1.2 Project Noise Mitigation

7.1.2.1 LRT Operations

Once the GoTriangle noise mitigation policy is enacted, specific mitigation measures for LRT operations will be determined. Based on the location of the majority of impacts near grade crossings, the use of noise barriers, in most cases, would not be practical or feasible. Since the majority of the impacts are at multifamily buildings with no outdoor use, sound insulation testing could be conducted to determine compliance with the interior noise criterion. Sound insulation of residences that do not meet the interior noise criterion of 45 dBA would likely be recommended.

7.1.2.2 Traction Power Substations

There are no impacts due to TPSS operations, so no mitigation is required.

7.1.2.3 Maintenance Facility

Once the GoTriangle noise mitigation policy is enacted, specific mitigation measures for ROMF operations will be determined. A combination of noise barriers, or improvements to proposed fencing along the edges of the ROMF, or sound insulation of residences that do not meet the interior noise criterion of 45 dBA would likely be recommended.

7.1.2.4 Vibration Impact Mitigation

Because no vibration impacts have been identified, no vibration mitigation is required for the D-O LRT Project.

8. References

ATS Consulting. 2008. Vibration Measurements and Predictions for Central Corridor LRT Project.

Federal Transit Administration (FTA). 2006. Transit Noise and Vibration Impact Assessment guidance manual.

Attachments

Attachment J.1: Measurement Site Photographs

Figure J.1-1
Noise Measurement Site LT-1. 1207 Mason Farm Road, Chapel Hill

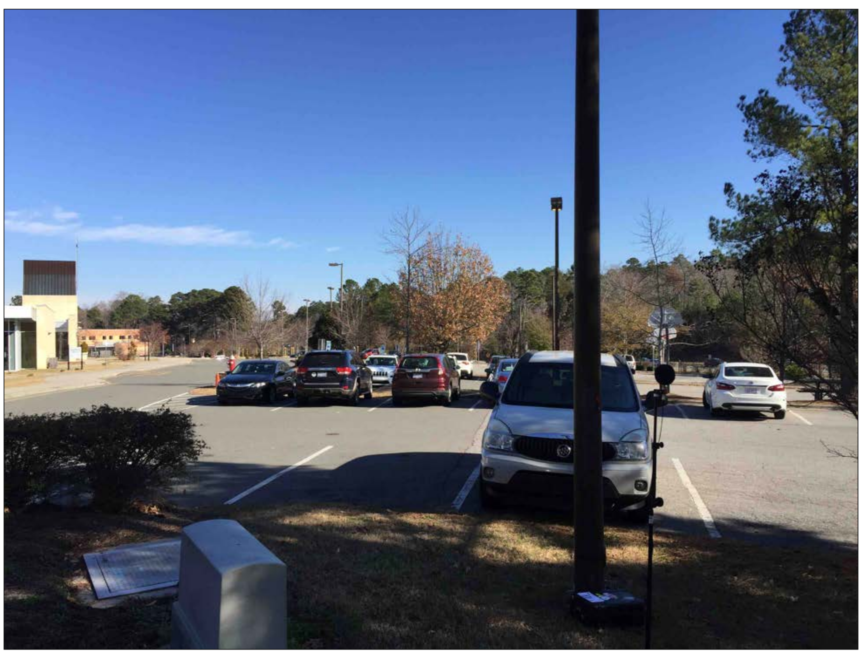


Figure J.1-2
Noise Measurement Site LT-2. St Thomas More Catholic Church – 940 Carmichael Street, Chapel Hill

Figure J.1-3
Noise Measurement Site LT-3. 100 Marriott Way, Chapel Hill

Figure J.1-4
Noise Measurement Site LT-4. 214 Celeste Circle, Chapel Hill

Figure J.1-5
Noise Measurement Site LT-5. 4315 Randall Road, Durham

Figure J.1-6
Noise Measurement Site LT-6. 3508 Mt. Moriah Road, Durham

Figure J.1-7
Noise Measurement Site LT-7. 100 North Creek Drive, Durham

Figure J.1-8
Noise Measurement Site LT-8. Old Creek Village Apartments – 4230 Garret Road, Durham

Figure J.1-9
Noise Measurement Site LT-9. 614 Snow Crest Trail, Durham

Figure J.1-10
Noise Measurement Site LT-10. 1920 Ivy Creek Boulevard, Durham

Figure J.1-11
Noise Measurement Site LT-11. 20 Morcroft Lane, Durham

Figure J.1-12
Noise Measurement Site LT-12. 2616 Erwin Road, Durham

Figure J.1-13
Noise Measurement Site LT-13. 921 Rome Avenue, Durham

Figure J.1-14
Noise Measurement Site LT-14. West Village Apartments – 605 W Main Street, Durham

Figure J.1-15
Noise Measurement Site LT-15. 504 E Pettigrew Street, Durham

Figure J.1-16
Noise Measurement Site LT-16. 1009 Alston Avenue, Durham

Figure J.1-17
Noise Measurement Site ST-1. UNC Campus – Mason Farm Road, Chapel Hill

Figure J.1-18
Noise Measurement Site ST-2. Baity Hill at Mason Farm – 1503 Baity Hill Drive, Chapel Hill

Figure J.1-19
Noise Measurement Site ST-3. Glenwood Elementary School – 2 Prestwick Road, Chapel Hill

Figure J.1-20
Noise Measurement Site ST-4. Downing Creek Parkway and Kingswood Drive, Chapel Hill

Figure J.1-21
Noise Measurement Site ST-5. Markham Memorial Gardens – 4826 Trenton Road, Chapel Hill

Figure J.1-22
Noise Measurement Site ST-6. Chapel Tower Apartments – 1315 Morreene Road, Durham

Figure J.1-23
Noise Measurement Site ST-7. Duke Children's Hospital – 2301 Erwin Road, Durham

Figure J.1-24
Noise Measurement Site ST-8. St Joseph's Episcopal Church – 1915 W Main Street, Durham

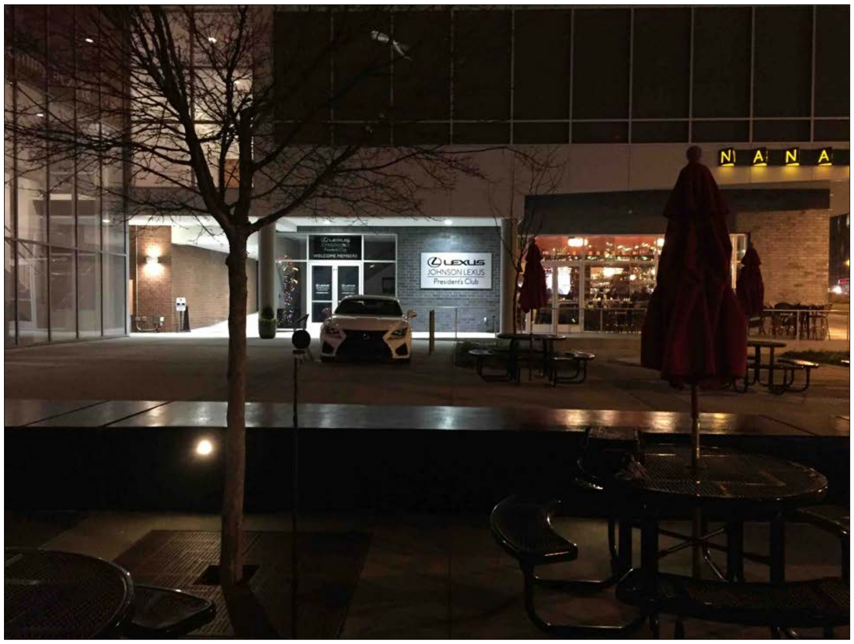


Figure J.1-25
Noise Measurement Site ST-9. Durham Performing Arts Center – 123 Vivian Street, Durham

Figure J.1-26
Noise Measurement Site ST-10. Lovett Square Apartments – 211 Stokes Street, Durham

Figure J.1-27
Vibration Measurement Site VP-A. St Thomas More Catholic School. 940 Carmichael Street Chapel Hill

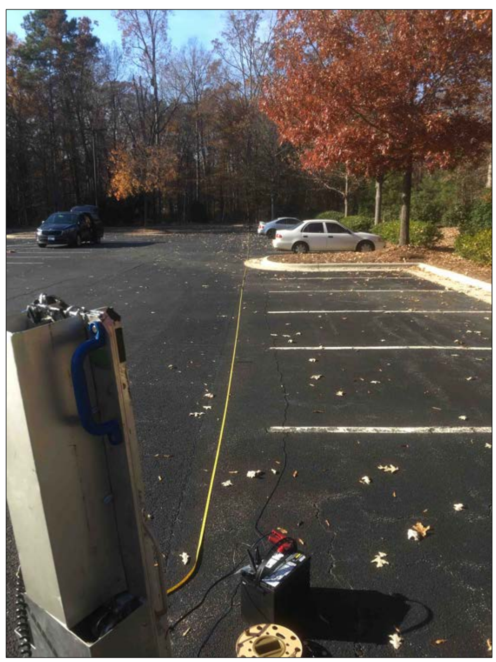


Figure J.1-28
Vibration Measurement Site VP-B. 1414 Raleigh Road, Chapel Hill

Figure J.1-29
Vibration Measurement Site VP-C. 4405 Randall Road, Durham

Figure J.1-30
Vibration Measurement Site VP-D. 3600 Mt Moriah Road, Durham

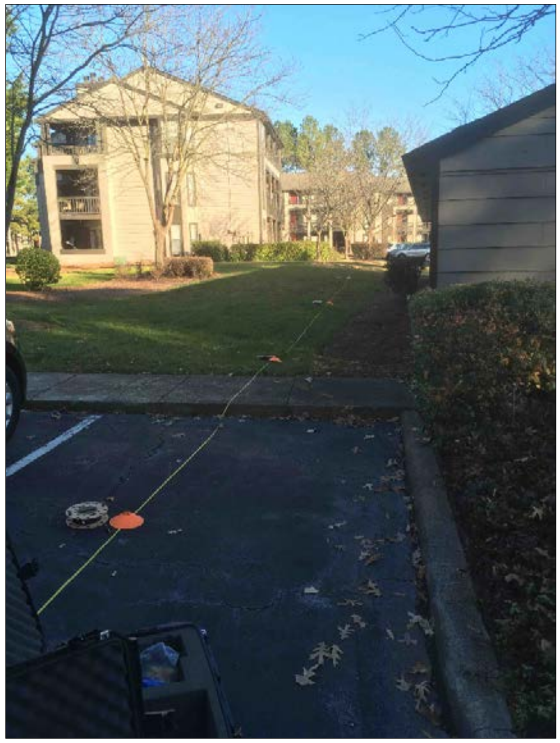


Figure J.1-31
Vibration Measurement Site VP-E. 1600 Snow Crest Trail, Durham

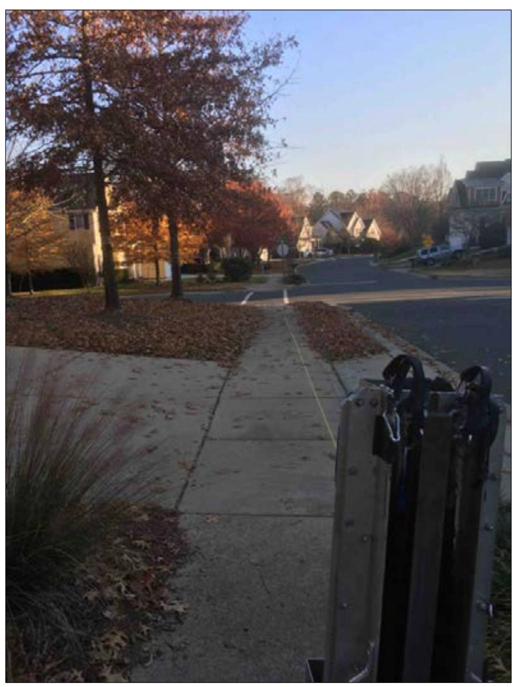


Figure J.1-32
Vibration Measurement Site VP-F. Ashland Drive and Lindenshire Drive, Durham

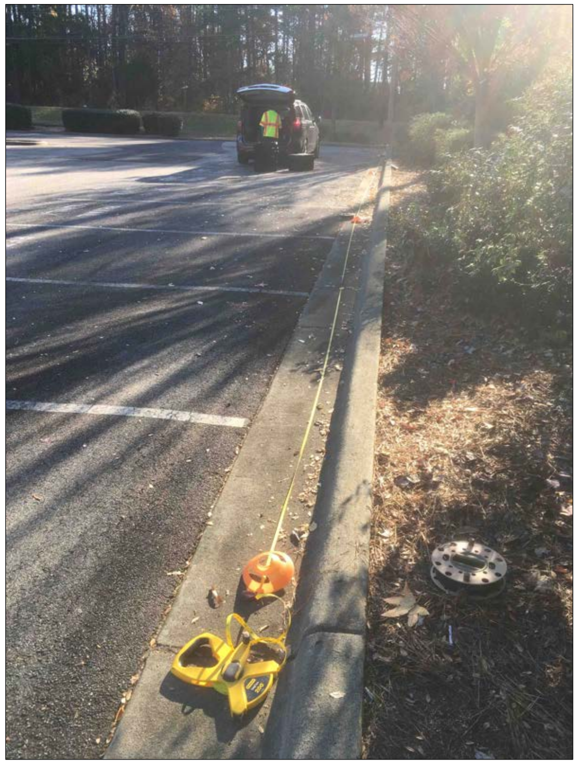


Figure J.1-33
Vibration Measurement Site VP-G. 2816 Erwin Road, Durham

Figure J.1-34
Vibration Measurement Site VP-H. Crest Street Park

Figure J.1-35
Vibration Measurement Site VP-I. 309 Blackwell Street, Durham

Figure J.1-36
Vibration Measurement Site VP-J. 611 Alston Avenue, Durham

Attachment J.2: Noise Measurement Data

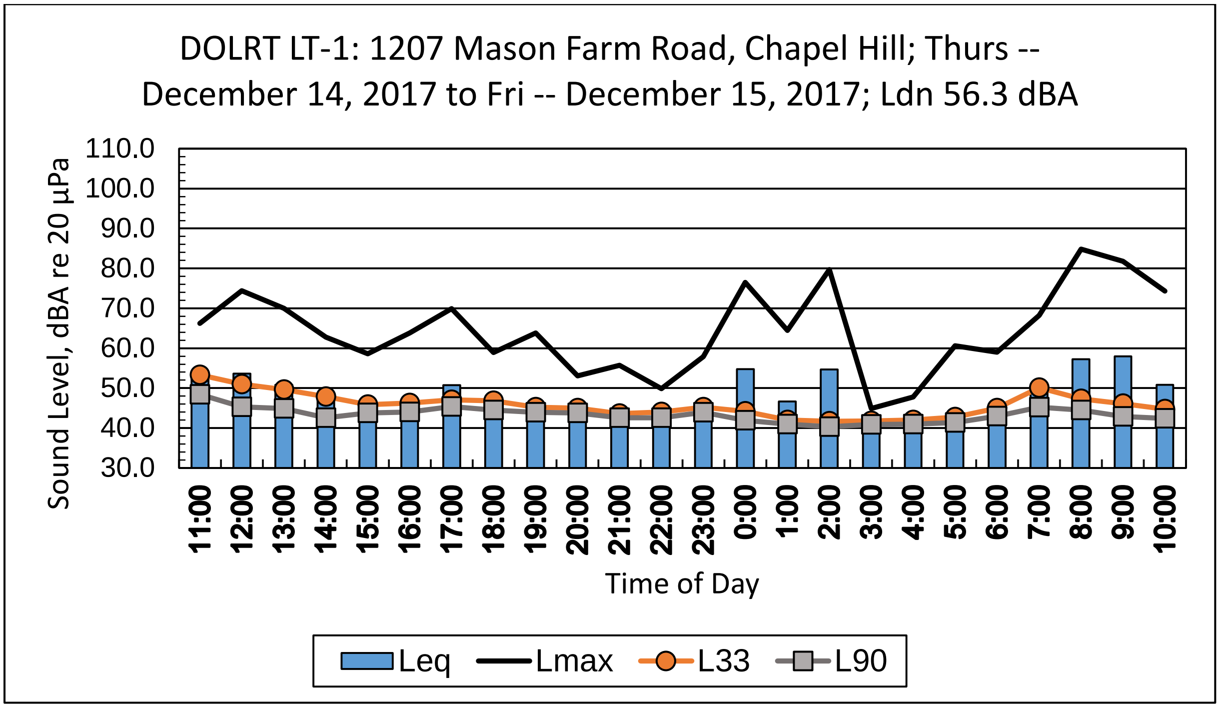


Figure J.2-1
Long-Term Noise Measurement Site Data – Site LT-1

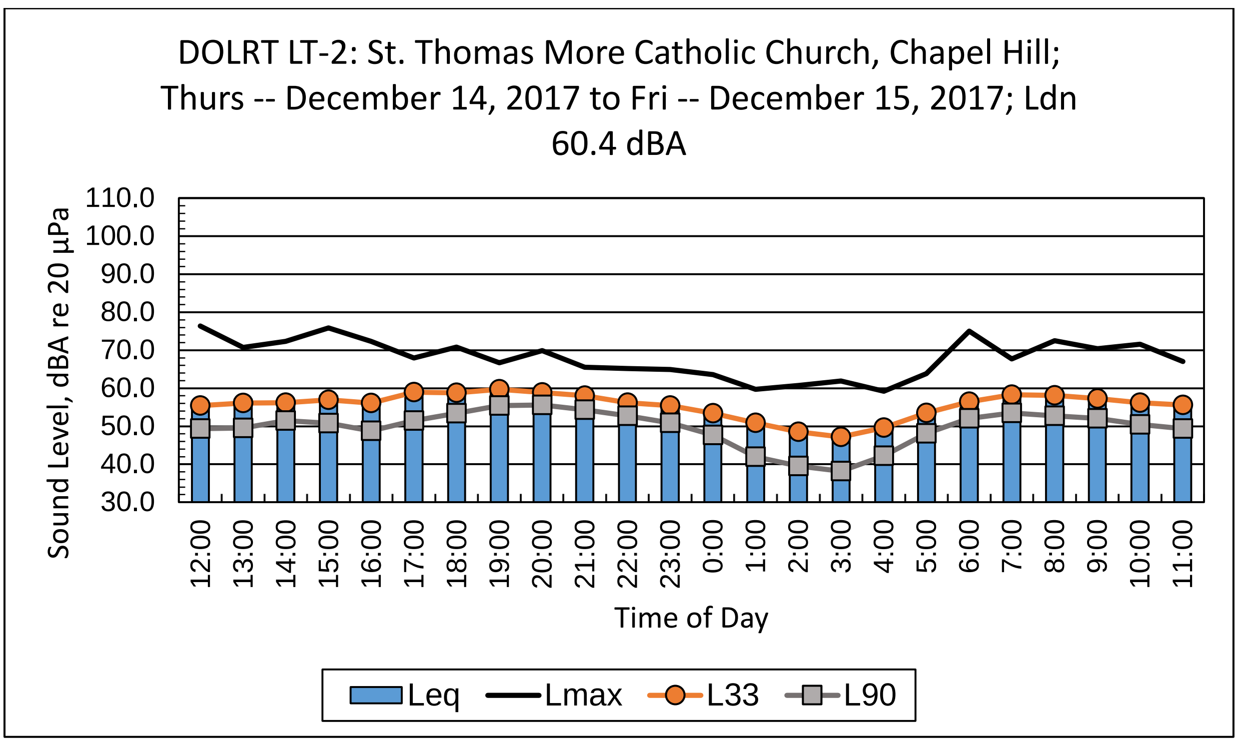


Figure J.2-2
Long-Term Noise Measurement Site Data – Site LT-2

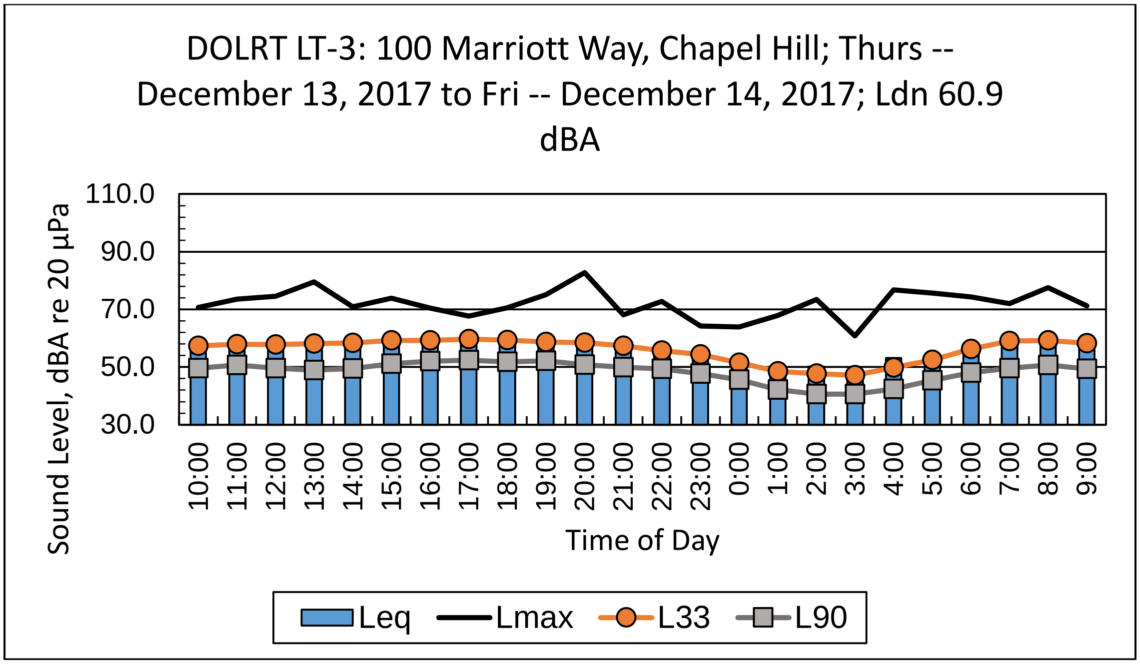


Figure J.2-3
Long-Term Noise Measurement Site Data – Site LT-3

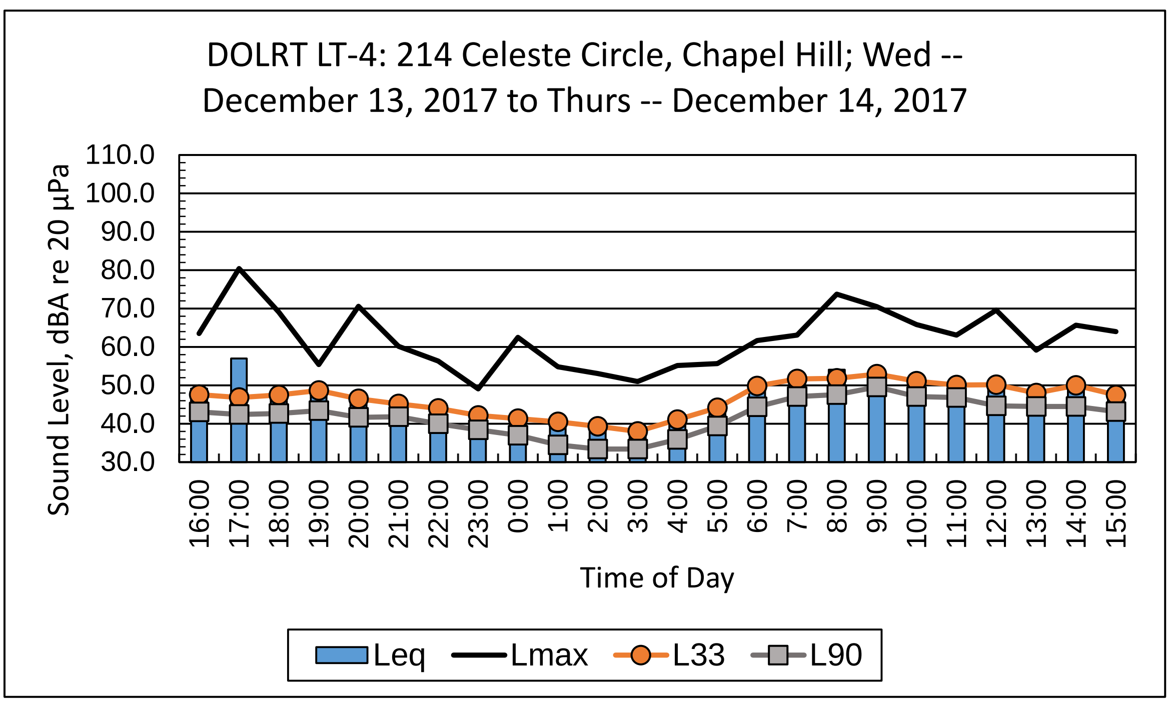


Figure J.2-4
Long-Term Noise Measurement Site Data – Site LT-4

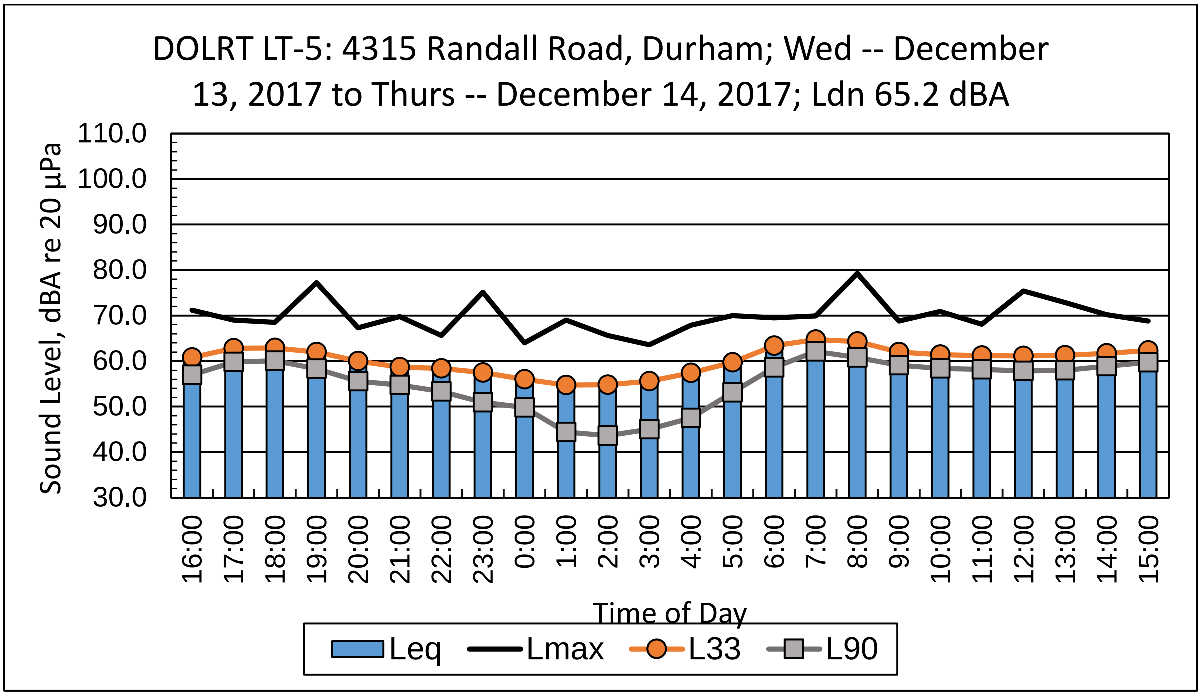


Figure J.2-5
Long-Term Noise Measurement Site Data – Site LT-5

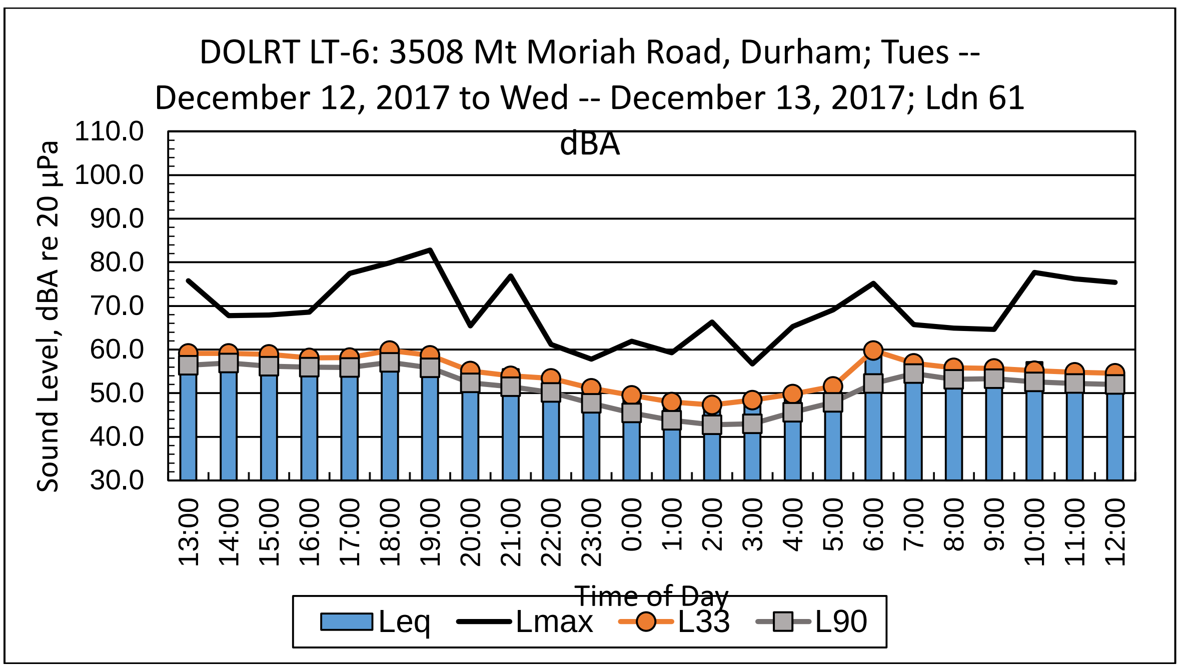


Figure J.2-6
Long-Term Noise Measurement Site Data – Site LT-6

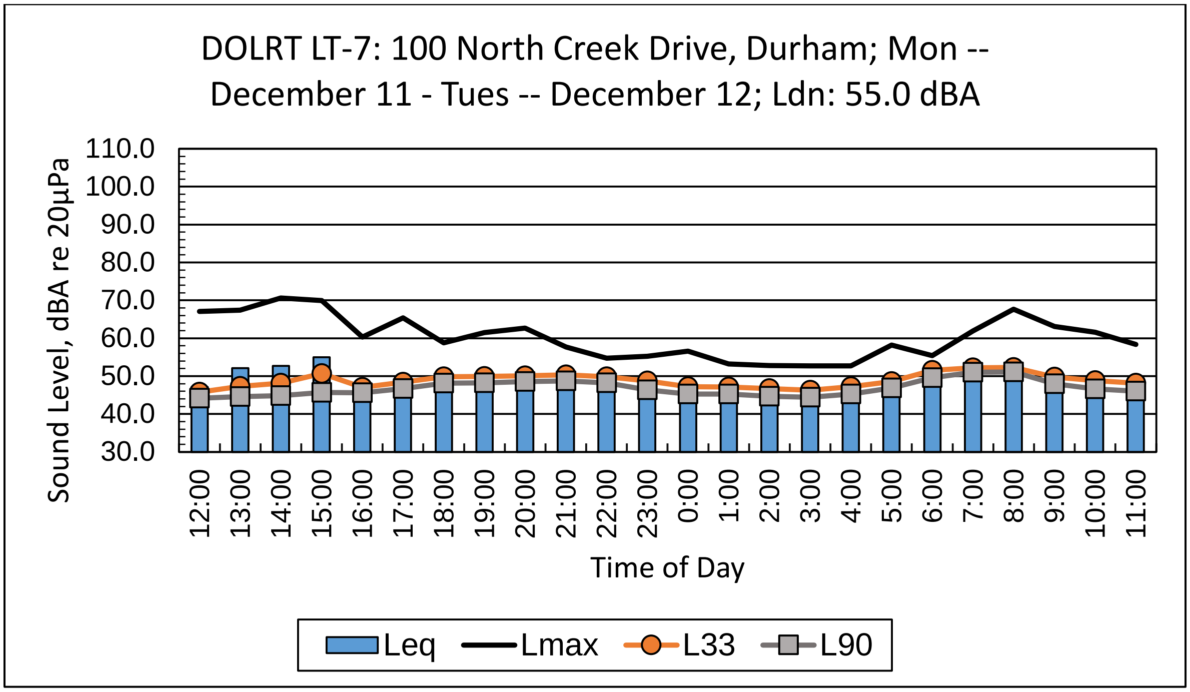


Figure J.2-7
Long-Term Noise Measurement Site Data – Site LT-7

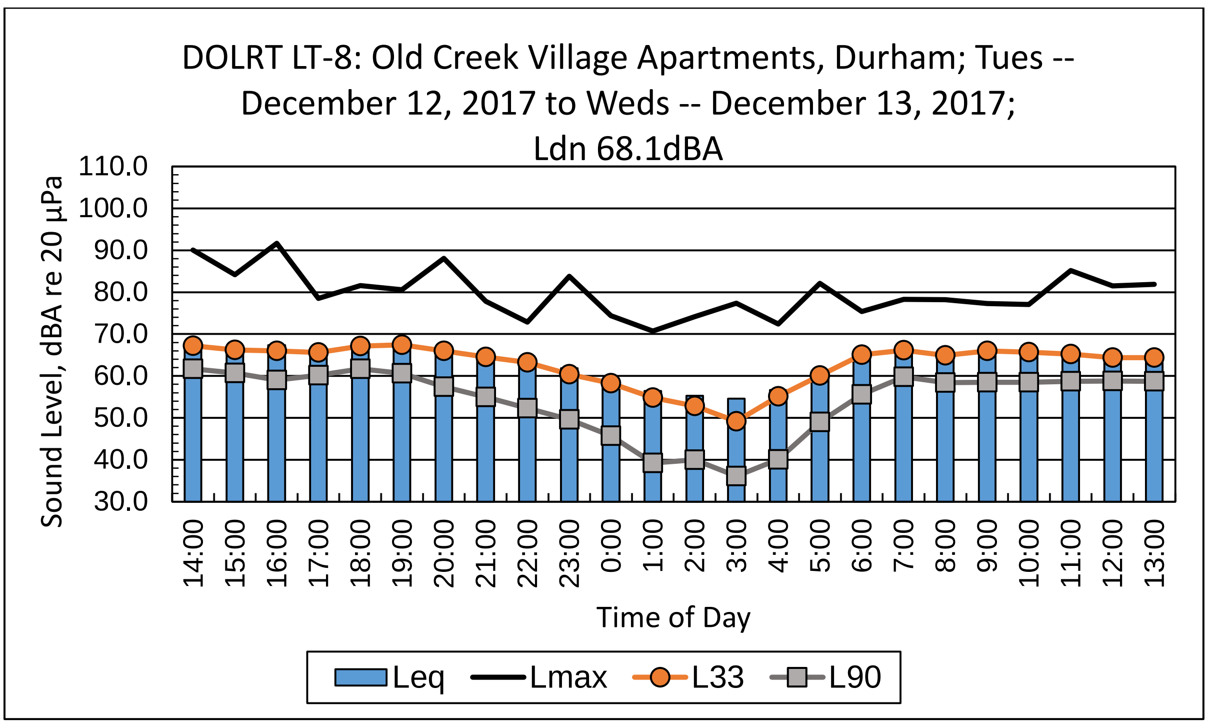


Figure J.2-8
Long-Term Noise Measurement Site Data – Site LT-8

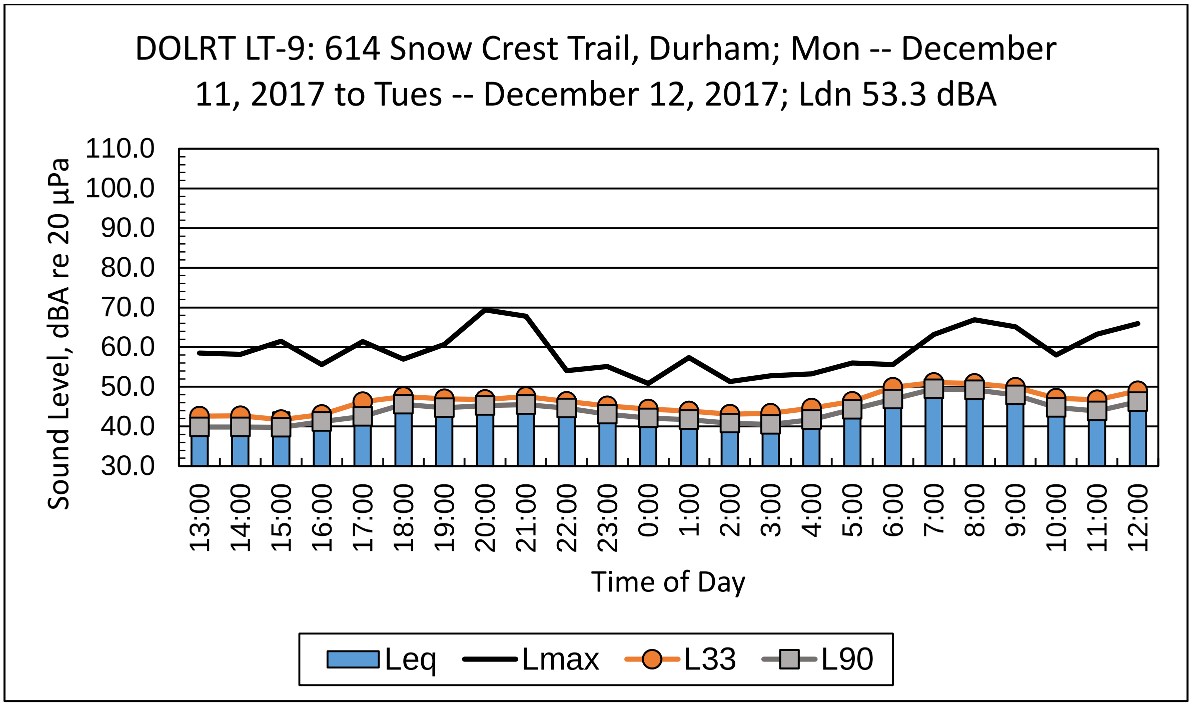


Figure J.2-9
Long-Term Noise Measurement Site Data – Site LT-9

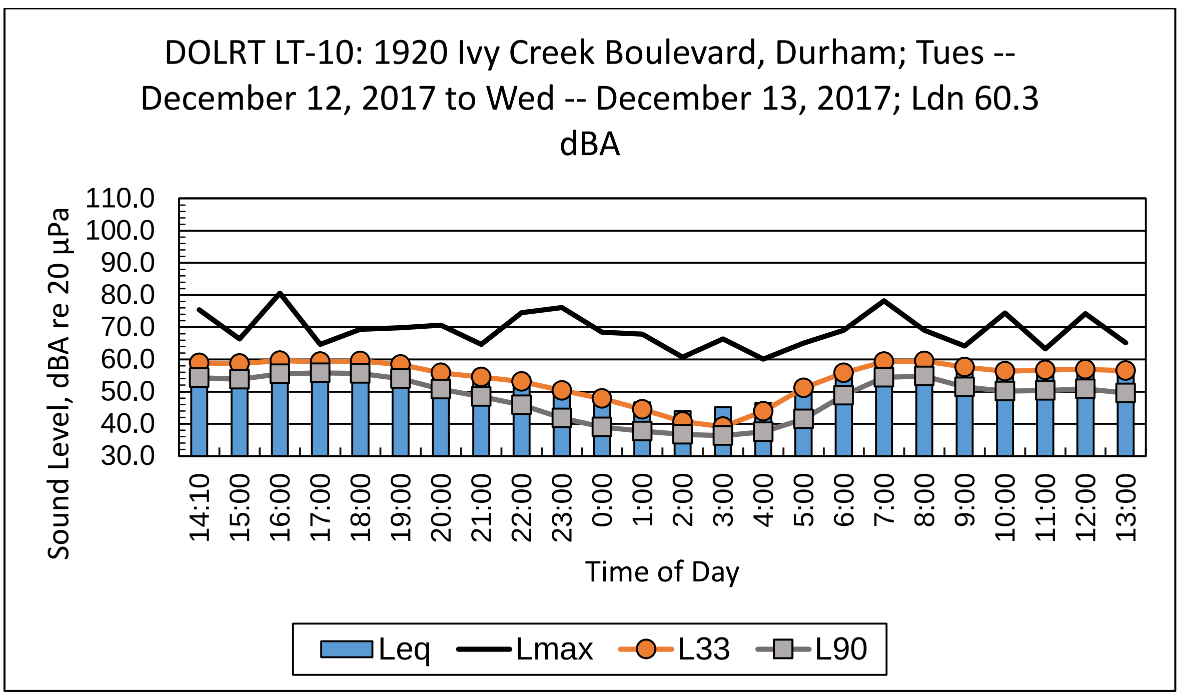


Figure J.2-10
Long-Term Noise Measurement Site Data – Site LT-10

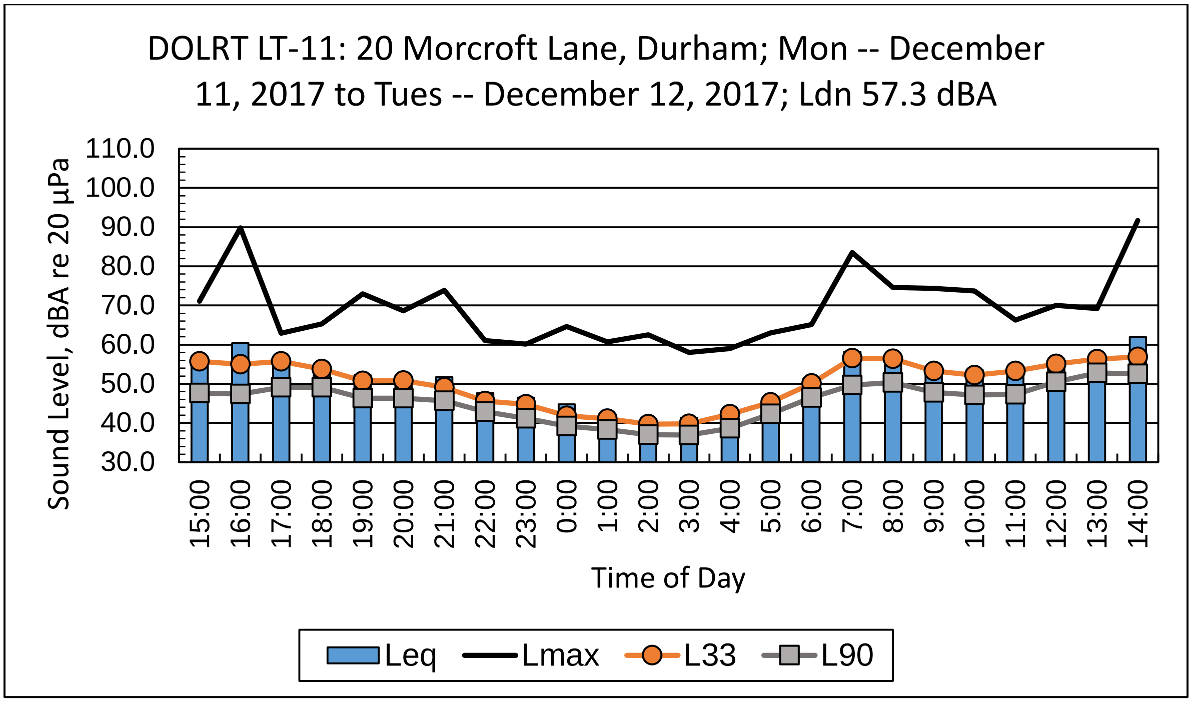


Figure J.2-11
Long-Term Noise Measurement Site Data – Site LT-11

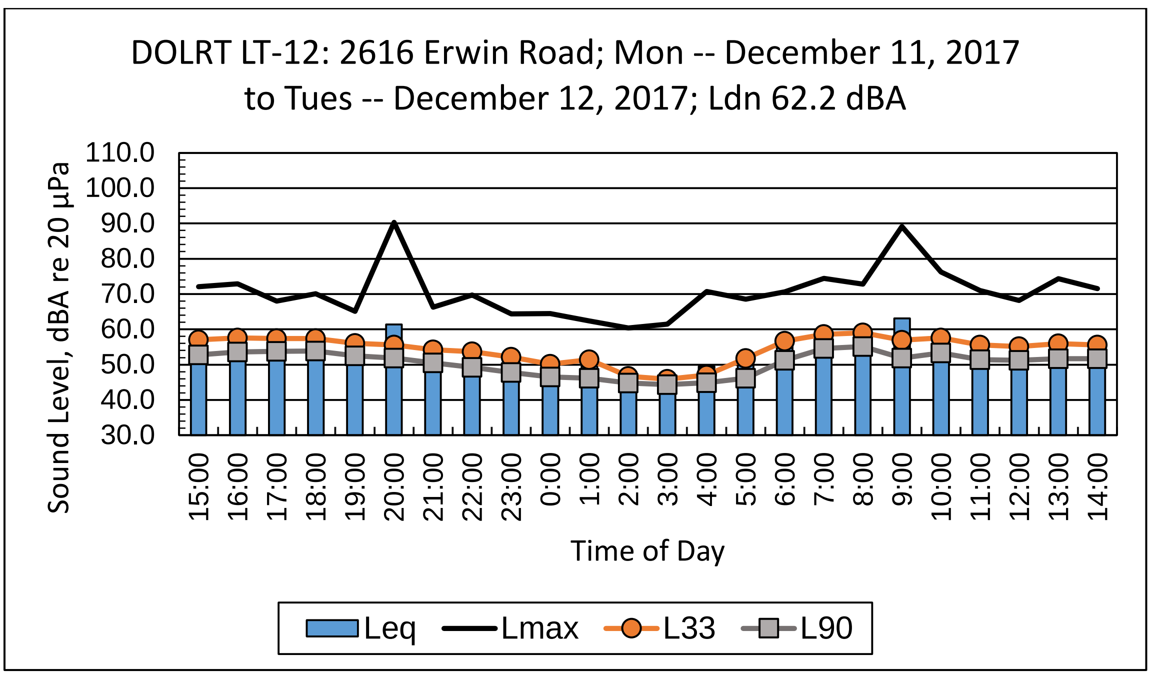


Figure J.2-12
Long-Term Noise Measurement Site Data – Site LT-12

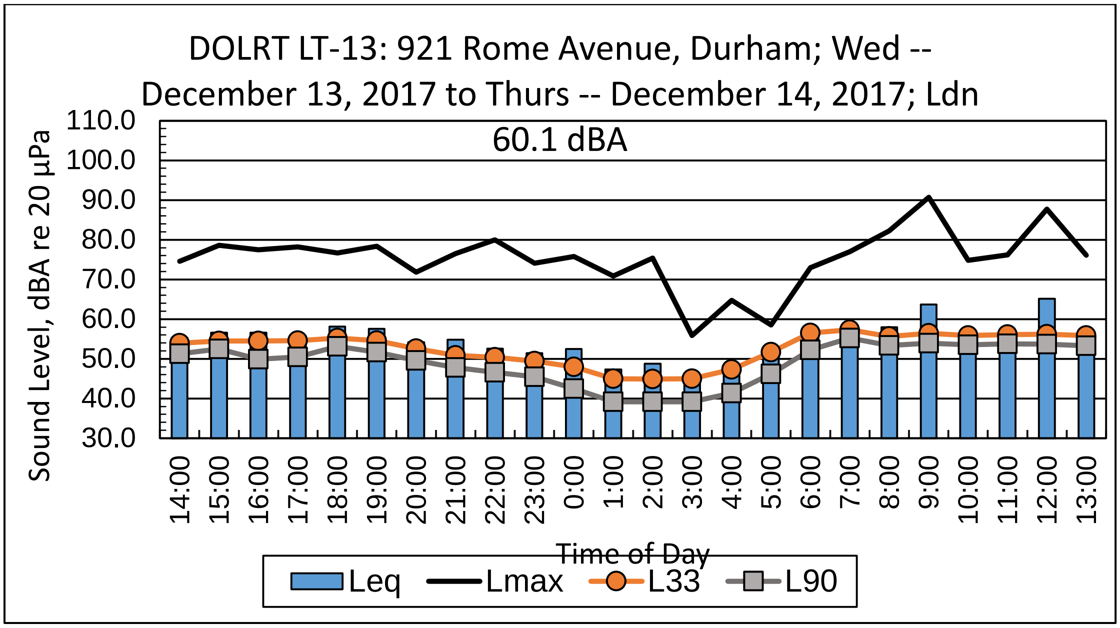


Figure J.2-13
Long-Term Noise Measurement Site D3ata – Site LT-13

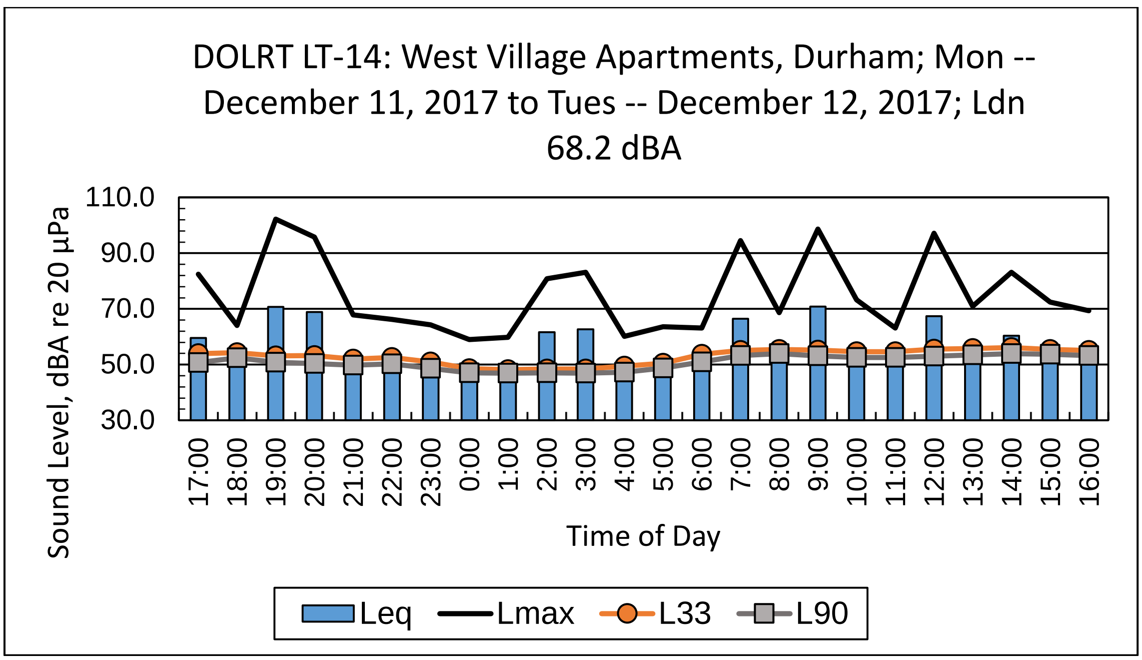


Figure J.2-14
Long-Term Noise Measurement Site Data – Site LT-14

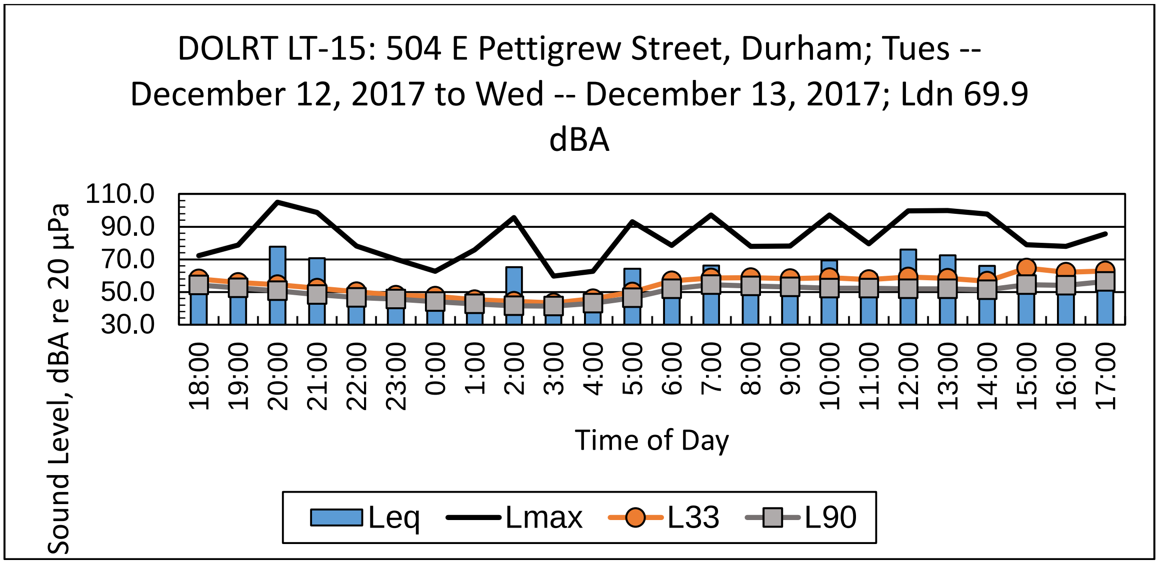


Figure J.2-15
Long-Term Noise Measurement Site Data – Site LT-15

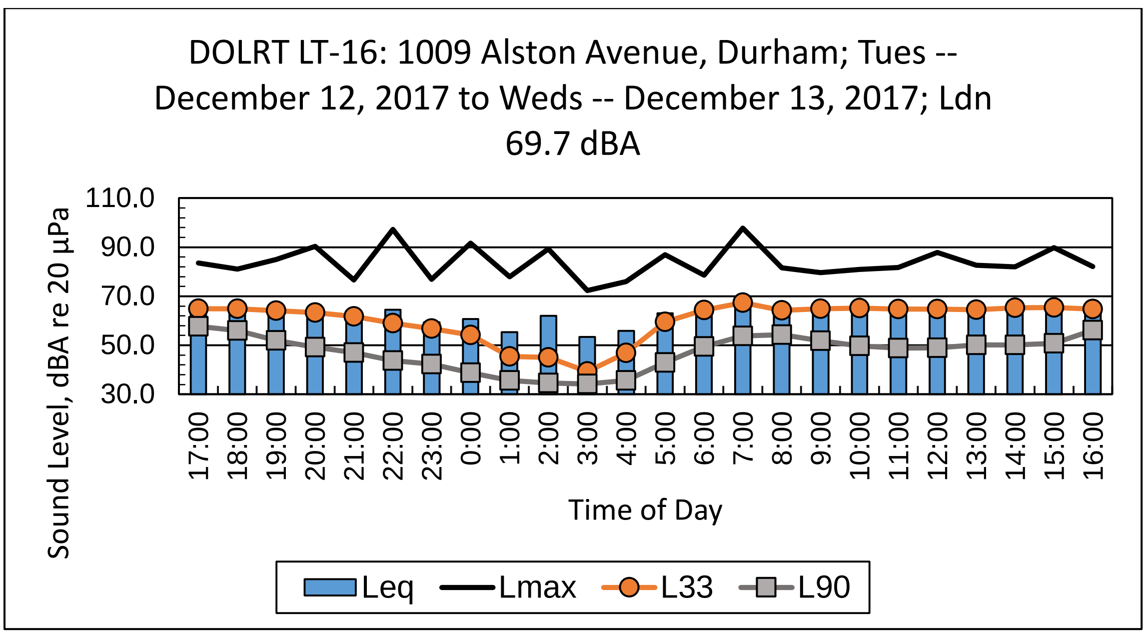


Figure J.2-16
Long-Term Noise Measurement Site Data – Site LT-16

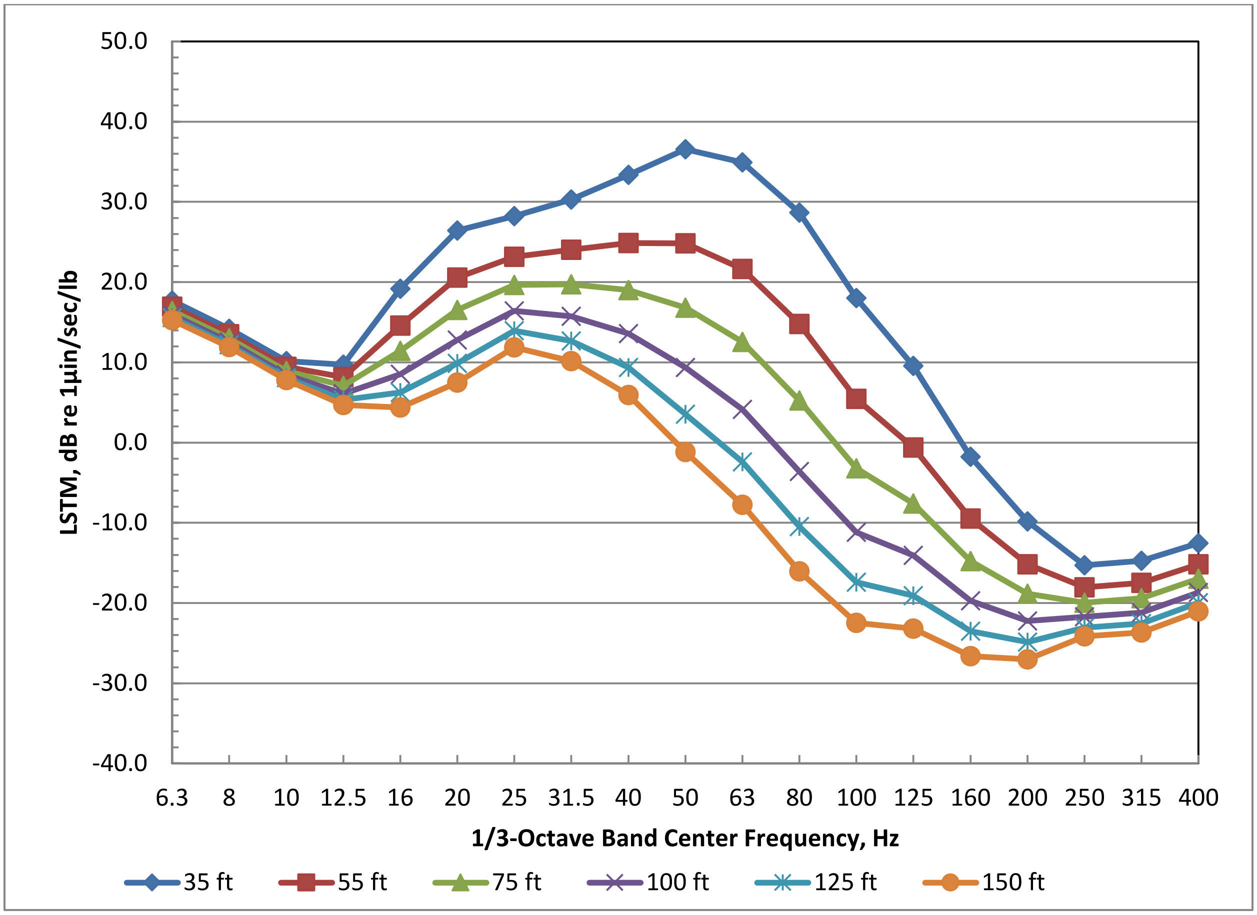
Attachment J.3: Vibration Measurement Data

Vibration Site VP-A

1/3-Octave Band Transfer Mobility Coefficients – Site VP-A: St. Thomas More Catholic Church, Chapel Hill

Coefficients	6.3 Hz	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
A	23.6	19.8	15.9	22.0	55.3	72.7	68.1	79.5	100.4	128.8	139.2	137.9	116.9	89.6	59.0	32.1
B	-3.9	-3.6	-3.7	-7.9	-23.4	-30.0	-25.8	-31.9	-43.4	-59.7	-67.5	-70.8	-64.0	-51.8	-39.3	-27.1
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

$$TM = A + B * \log(dist) + C * \log(dist)^2$$

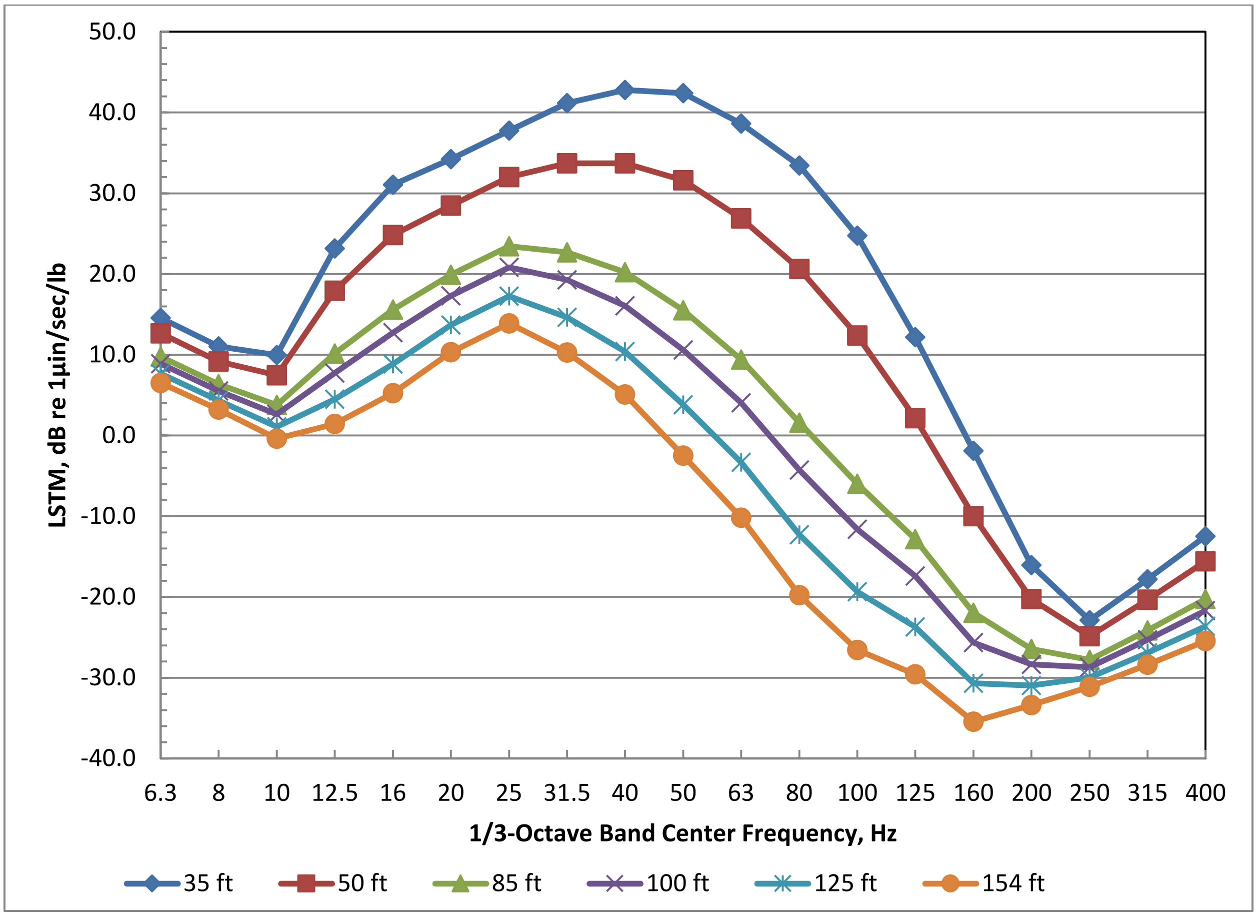


Vibration Site VP-B

1/3-Octave Band Transfer Mobility Coefficients – Site VP-B: 1414 Raleigh Road, Chapel Hill

Coefficients	6.3 Hz	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
A	33.9	29.7	34.8	75.3	93.0	91.5	95.0	115.2	133.3	150.2	155.8	161.1	147.9	112.4	78.5	32.1
B	-12.5	-12.1	-16.1	-33.8	-40.1	-37.1	-37.1	-48.0	-58.6	-69.8	-75.9	-82.7	-79.7	-64.9	-52.1	-27.1
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

$$TM = A + B * \log(dist) + C * \log(dist)^2$$

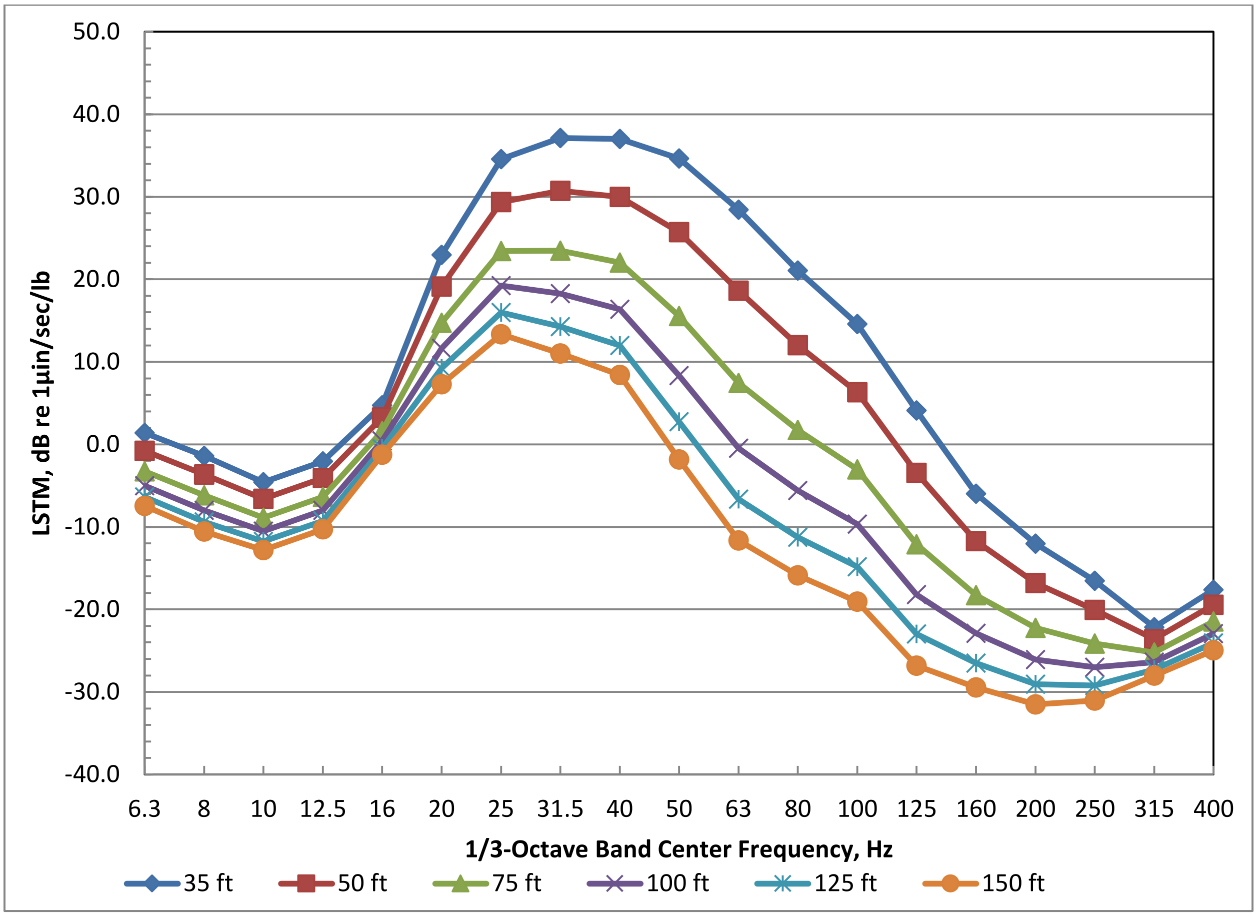


Vibration Site VP-C

1/3-Octave Band Transfer Mobility Coefficients – Site VP-C: Yardley Terrace and Randall Road, Durham

Coefficients	6.3 Hz	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
A	23.0	21.0	15.5	18.0	19.4	61.3	86.4	101.0	106.8	123.7	126.4	111.3	96.7	79.7	51.3	35.5
B	-14.0	-14.5	-13.0	-13.0	-9.5	-24.8	-33.6	-41.3	-45.2	-57.7	-63.4	-58.5	-53.2	-49.0	-37.1	-30.8
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

$$TM = A + B * \log(dist) + C * \log(dist)^2$$

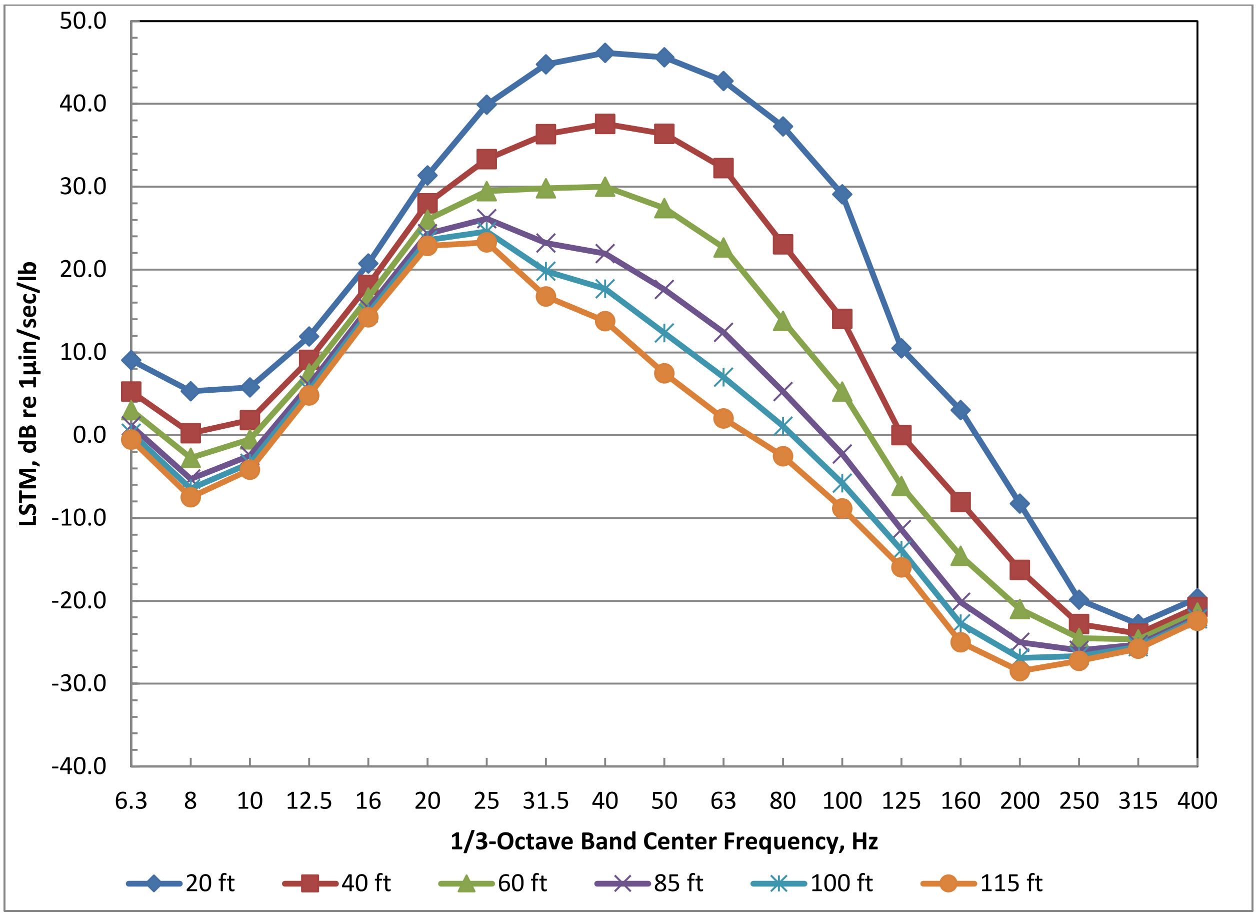


Vibration Site VP-D

1/3-Octave Band Transfer Mobility Coefficients – Site VP-D: 3600 Mt. Moriah Road, Durham

Coefficients	6.3 Hz	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
A	25.4	27.2	22.8	24.1	31.8	46.0	68.4	40.2	18.6	-3.8	3.1	74.9	94.0	55.8	51.1	26.4
B	-12.6	-16.8	-13.1	-9.4	-8.5	-11.2	-21.9	29.0	61.5	93.6	83.6	-14.1	-49.9	-34.8	-36.9	-26.7
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-19.6	-31.0	-42.8	-40.8	-11.4	0.0	0.0	0.0	0.0

$$TM = A + B * \log(dist) + C * \log(dist)^2$$

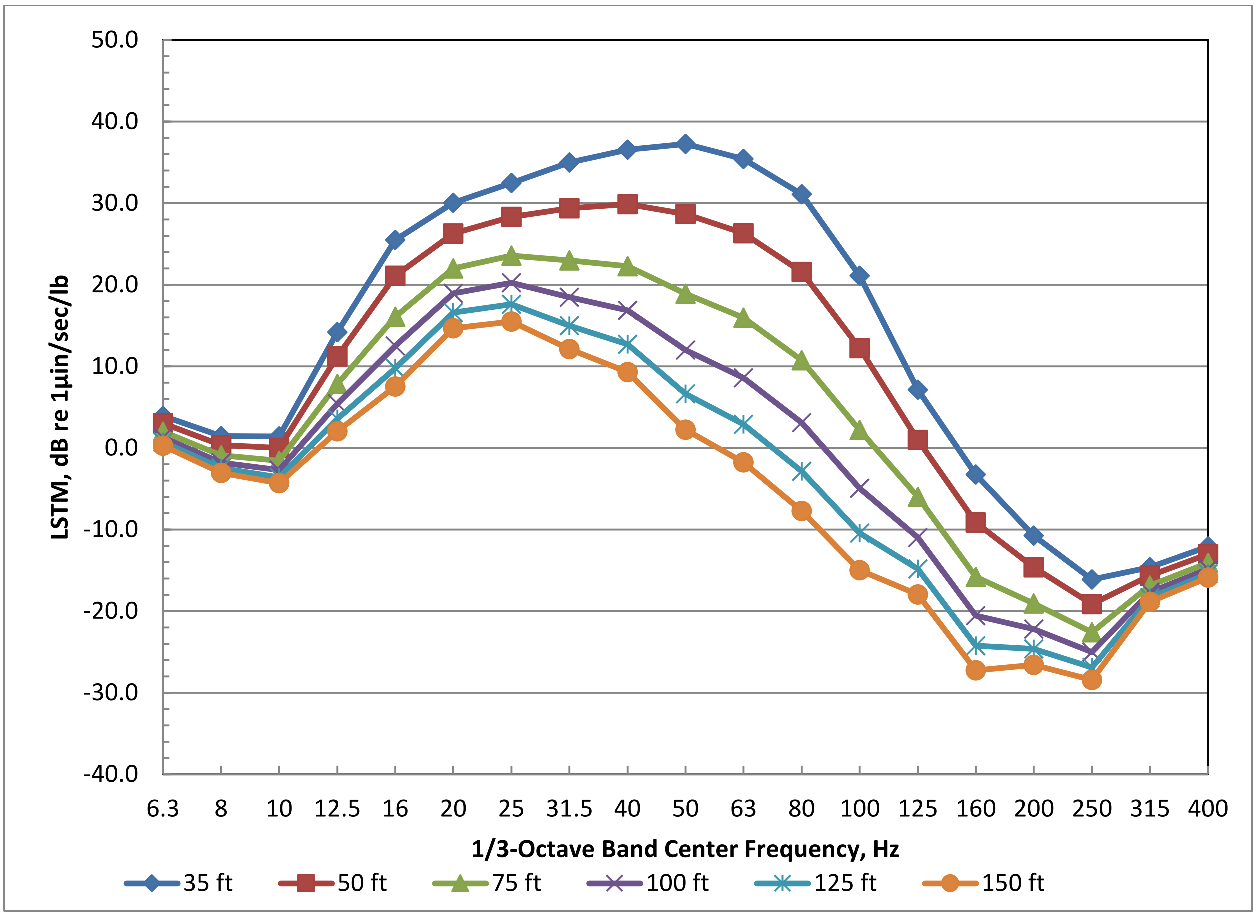


Vibration Site VP-E

1/3-Octave Band Transfer Mobility Coefficients – Site VP-E: 1600 Snow Creek Trail, Durham

Coefficients	6.3 Hz	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
A	12.7	12.4	15.4	43.8	69.3	67.6	74.0	90.8	103.1	122.8	126.2	126.0	109.2	68.5	55.3	27.9
B	-5.7	-7.1	-9.1	-19.2	-28.4	-24.3	-26.9	-36.2	-43.1	-55.4	-58.8	-61.4	-57.1	-39.8	-37.9	-25.1
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

$$TM = A + B * \log(dist) + C * \log(dist)^2$$

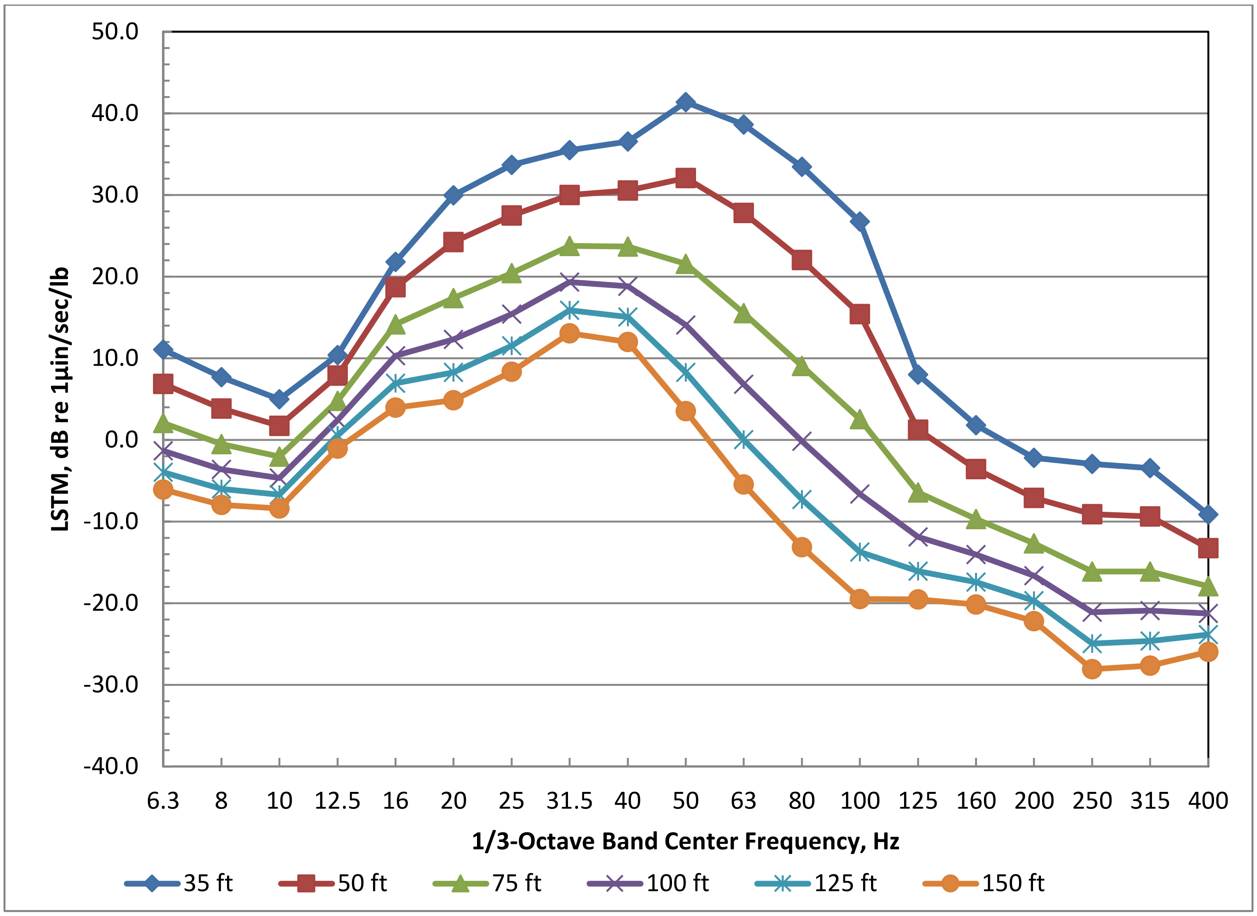


Vibration Site VP-F

1/3-Octave Band Transfer Mobility Coefficients – Site VP-F: Ashland Drive and Lindenshire Drive, Durham

Coefficients	6.3 Hz	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
A	52.9	45.9	37.7	26.1	7.8	73.0	95.6	90.2	96.6	133.8	146.4	147.2	139.8	75.3	55.5	46.7
B	-27.1	-24.8	-21.2	-4.5	35.6	-19.5	-40.1	-35.5	-38.9	-59.9	-69.8	-73.7	-73.2	-43.6	-34.8	-31.7
C	0.0	0.0	0.0	-3.6	-17.1	-5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

$$TM = A + B * \log(dist) + C * \log(dist)^2$$

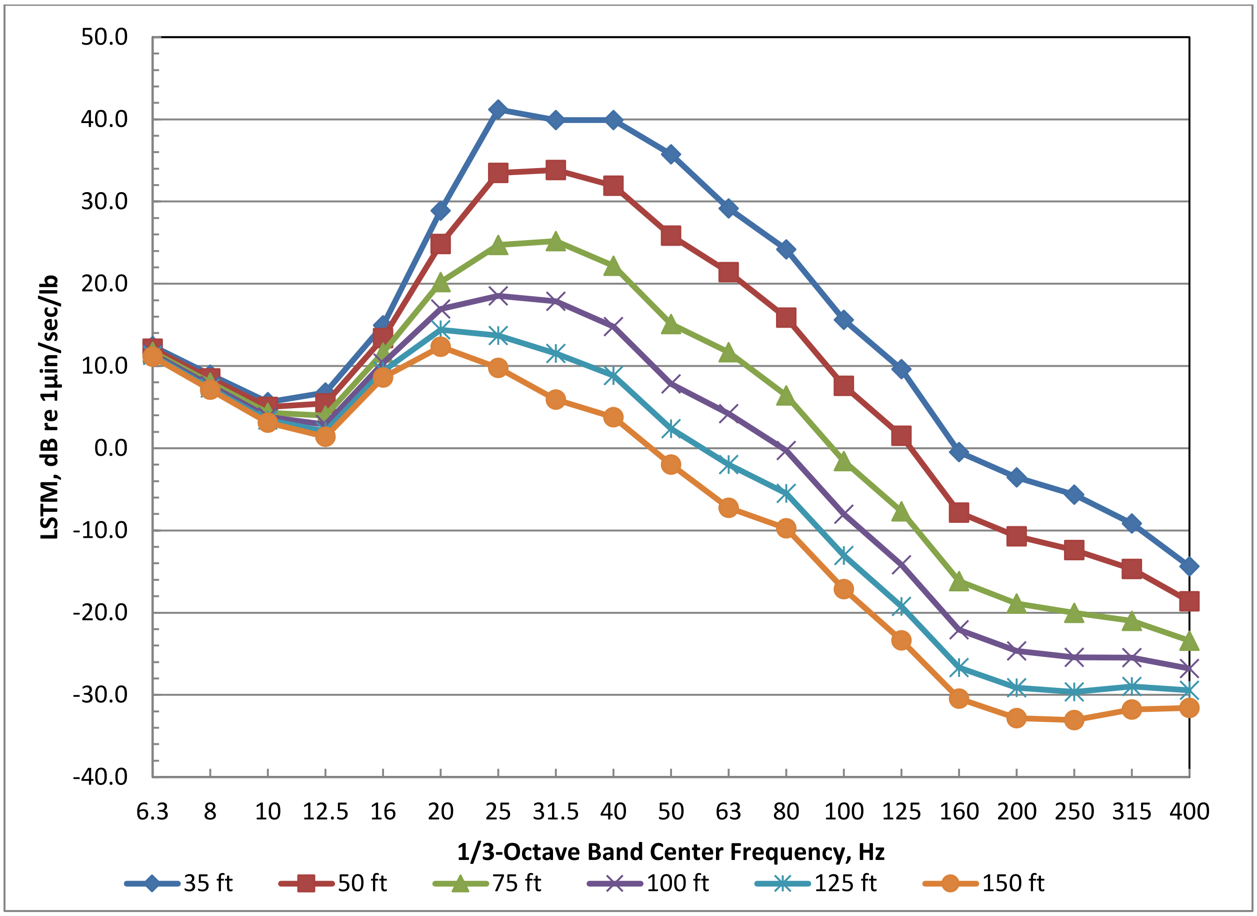


Vibration Site VP-G

1/3-Octave Band Transfer Mobility Coefficients – Site VP-G: 2816 Erwin Road, Durham

Coefficients	6.3 Hz	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
A	15.5	13.5	11.7	19.9	30.5	69.4	118.0	19.2	88.4	158.3	64.4	107.1	95.6	90.2	72.7	67.9
B	-2.0	-2.9	-4.0	-8.5	-10.1	-26.2	-49.7	61.0	-13.1	-93.3	1.9	-53.7	-51.8	-52.2	-47.4	-46.3
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-30.9	-11.9	9.0	-16.0	0.0	0.0	0.0	0.0	0.0

$$TM = A + B * \log(dist) + C * \log(dist)^2$$

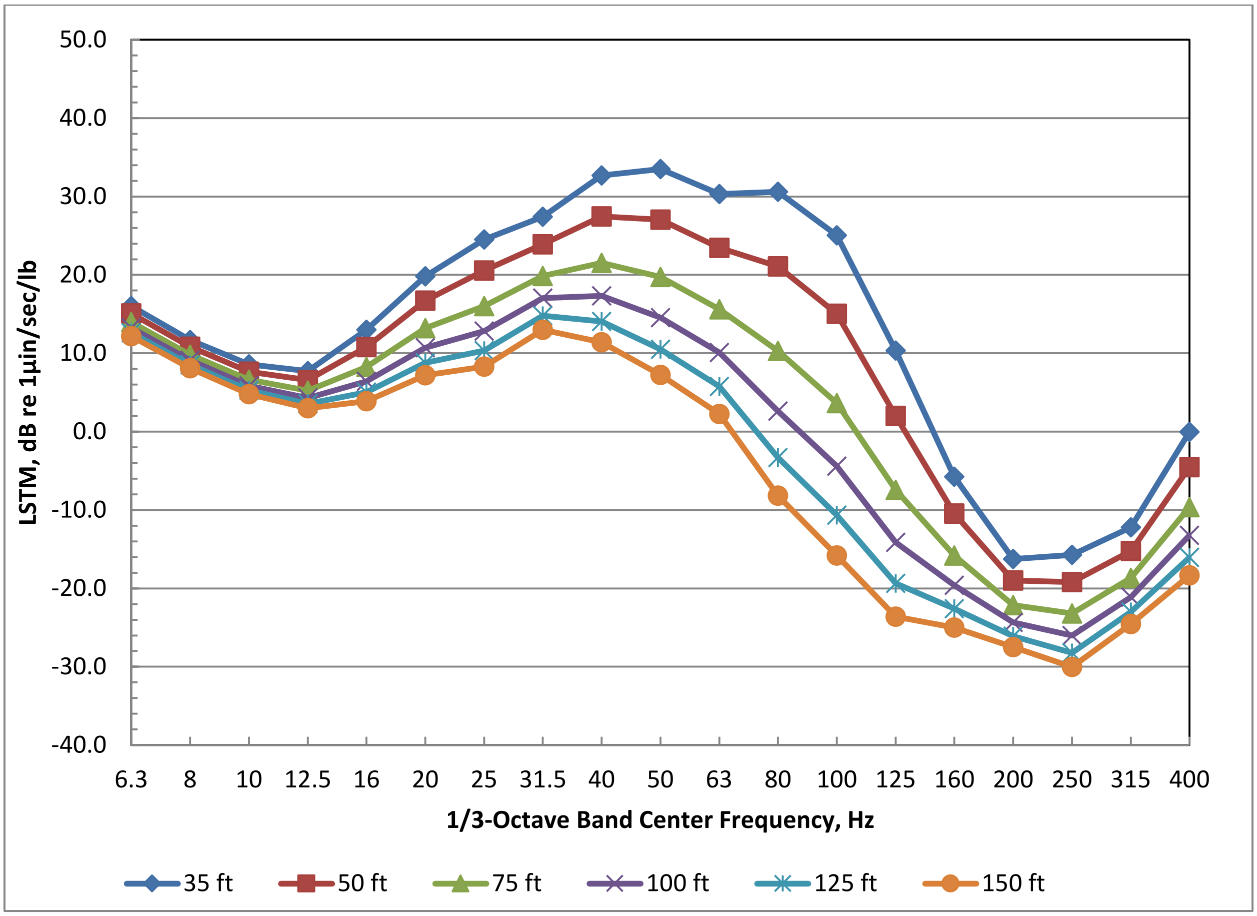


Vibration Site VP-H

1/3-Octave Band Transfer Mobility Coefficients – Site VP-H: Crest Street Park, Durham

Coefficients	6.3 Hz	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
A	25.4	20.5	17.8	19.4	35.3	50.7	64.1	62.7	84.6	97.7	98.9	125.4	124.8	93.2	41.2	11.2
B	-6.1	-5.7	-6.0	-7.5	-14.4	-20.0	-25.7	-22.8	-33.6	-41.6	-44.4	-61.4	-64.6	-53.7	-30.4	-17.8
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

$$TM = A + B * \log(dist) + C * \log(dist)^2$$

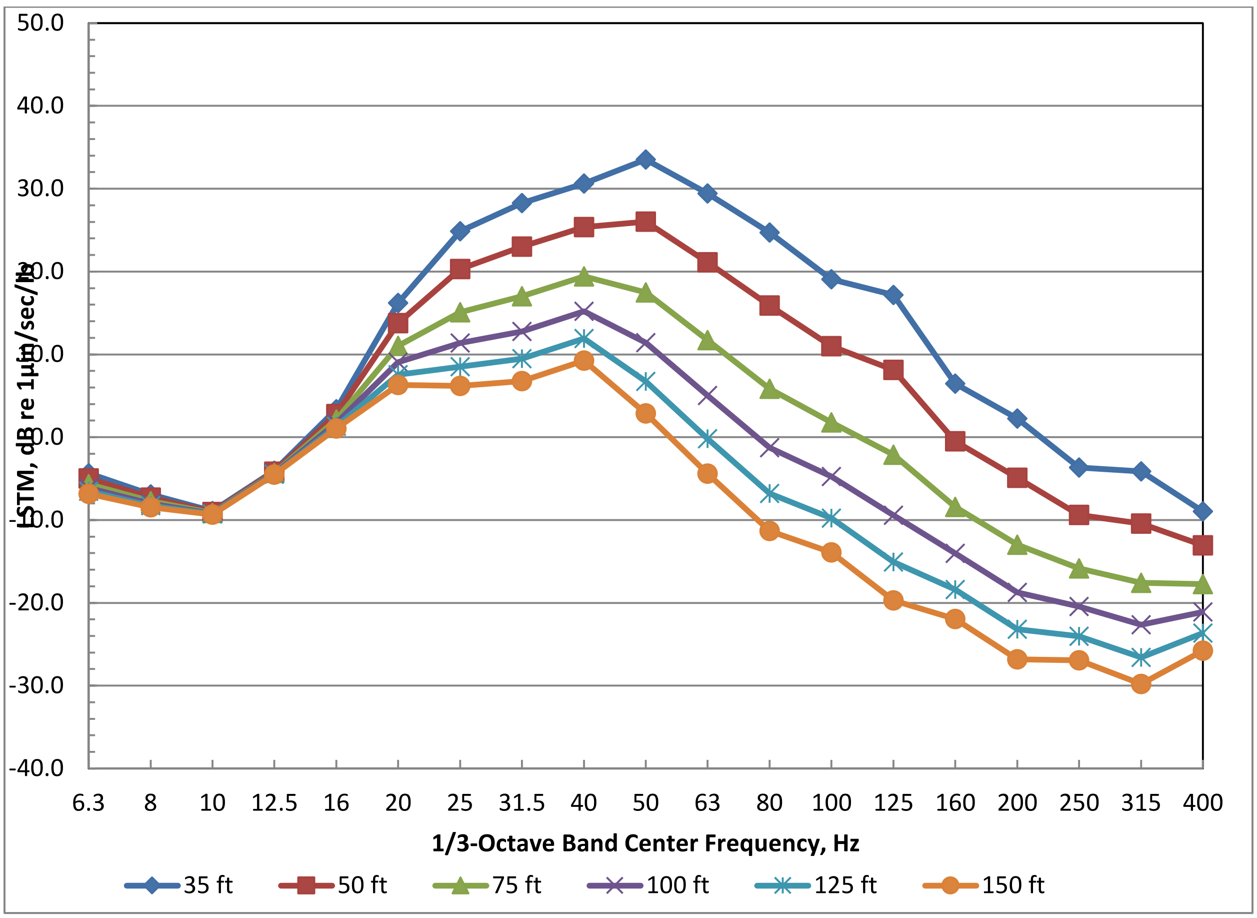


Vibration Site VP-I

1/3-Octave Band Transfer Mobility Coefficients – Site VP-I: 309 Blackwell Street, Durham

Coefficients	6.3 Hz	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
A	1.7	-3.1	-7.9	-2.9	9.0	40.4	70.6	80.8	82.8	108.4	112.0	112.7	99.6	107.3	75.8	73.3
B	-3.9	-2.5	-0.6	-0.7	-3.7	-15.7	-29.6	-34.0	-33.8	-48.5	-53.5	-57.0	-52.2	-58.3	-44.9	-46.0
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

$$TM = A + B * \log(dist) + C * \log(dist)^2$$

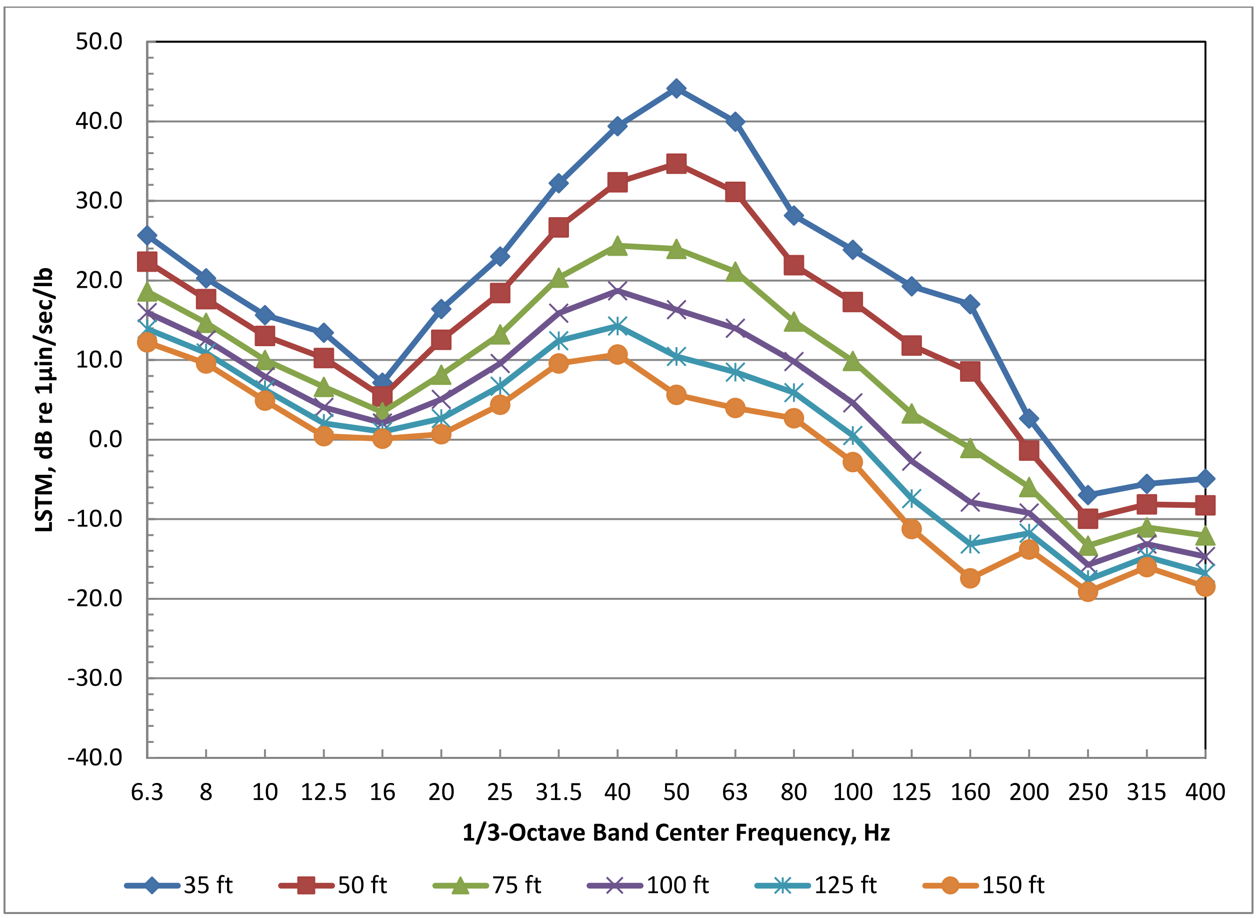


Vibration Site VP-J

1/3-Octave Band Transfer Mobility Coefficients – Site VP-J: 611 Alston Avenue, Durham

Coefficients	6.3 Hz	8 Hz	10 Hz	12.5 Hz	16 Hz	20 Hz	25 Hz	31.5 Hz	40 Hz	50 Hz	63 Hz	80 Hz	100 Hz	125 Hz	160 Hz	200 Hz
A	58.5	46.4	41.9	45.2	24.3	54.8	68.5	87.6	109.5	138.2	127.9	90.3	88.9	93.8	101.2	42.8
B	-21.3	-16.9	-17.0	-20.6	-11.1	-24.9	-29.5	-35.9	-45.4	-60.9	-56.9	-40.3	-42.2	-48.3	-54.5	-26.0
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

$$TM = A + B * \log(dist) + C * \log(dist)^2$$



Attachment J.4: Noise Impact Locations

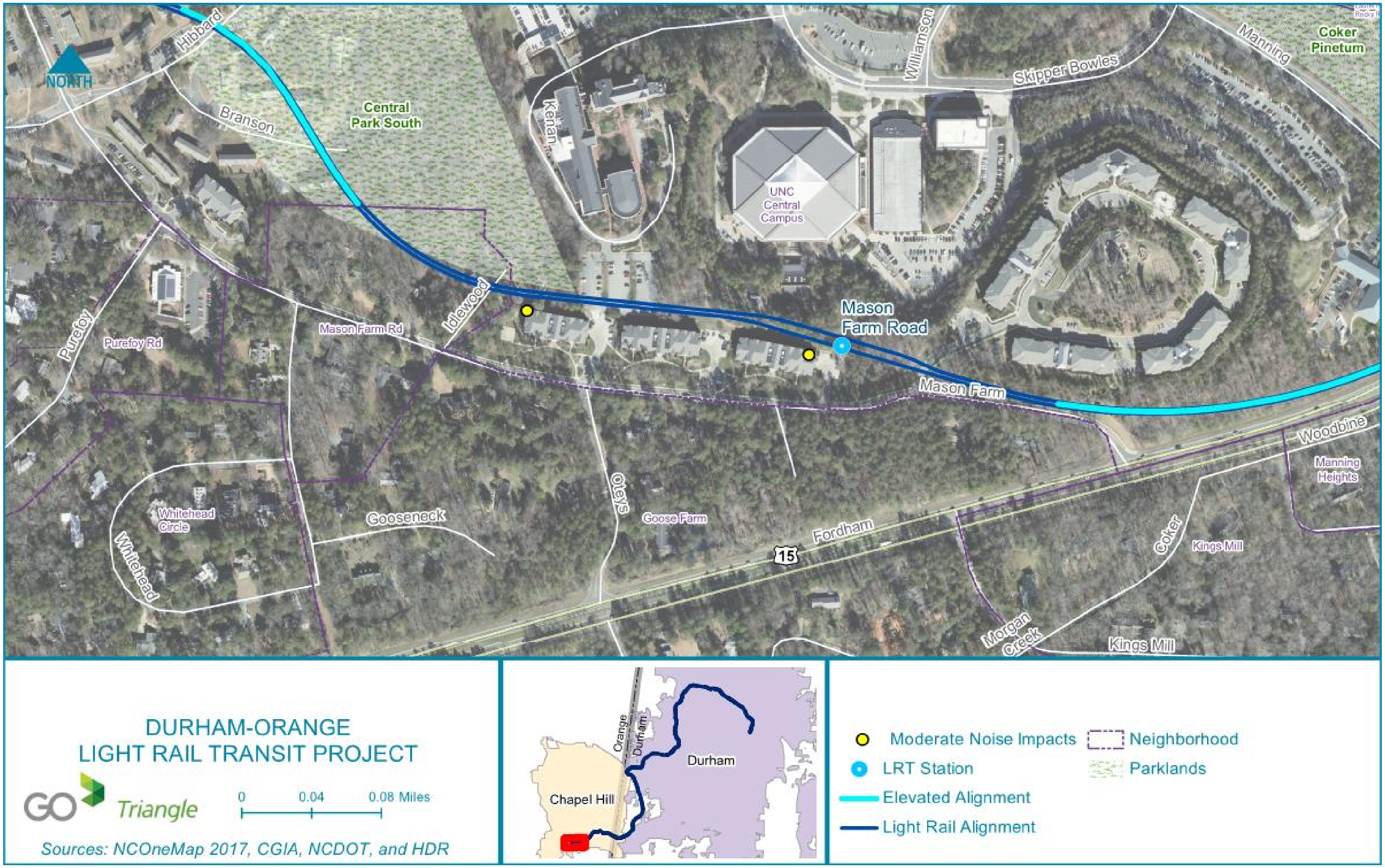


Figure J.4-1: Noise Impact Locations

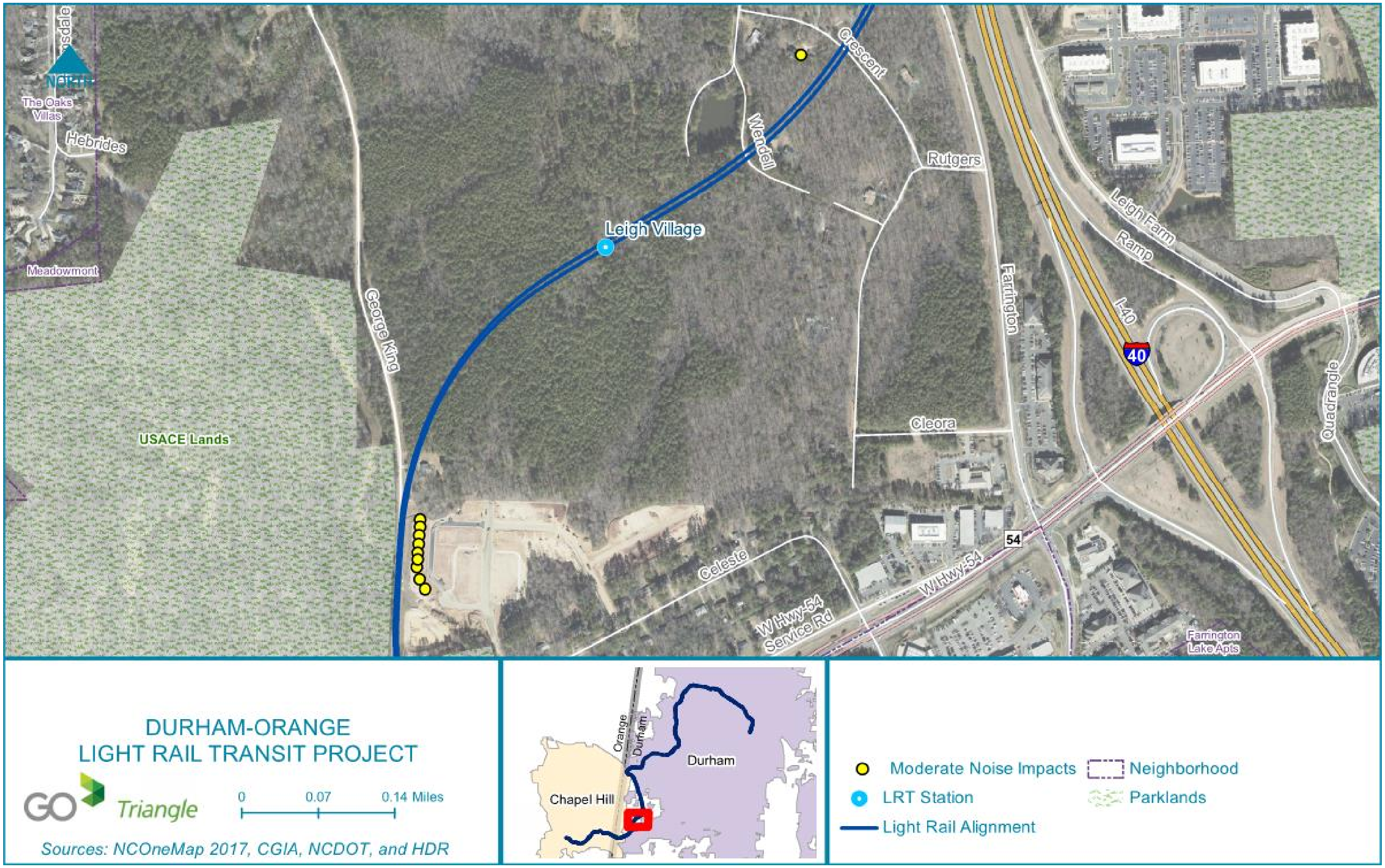


Figure J.4-2: Noise Impact Locations

Figure J.4-3: Noise Impact Locations

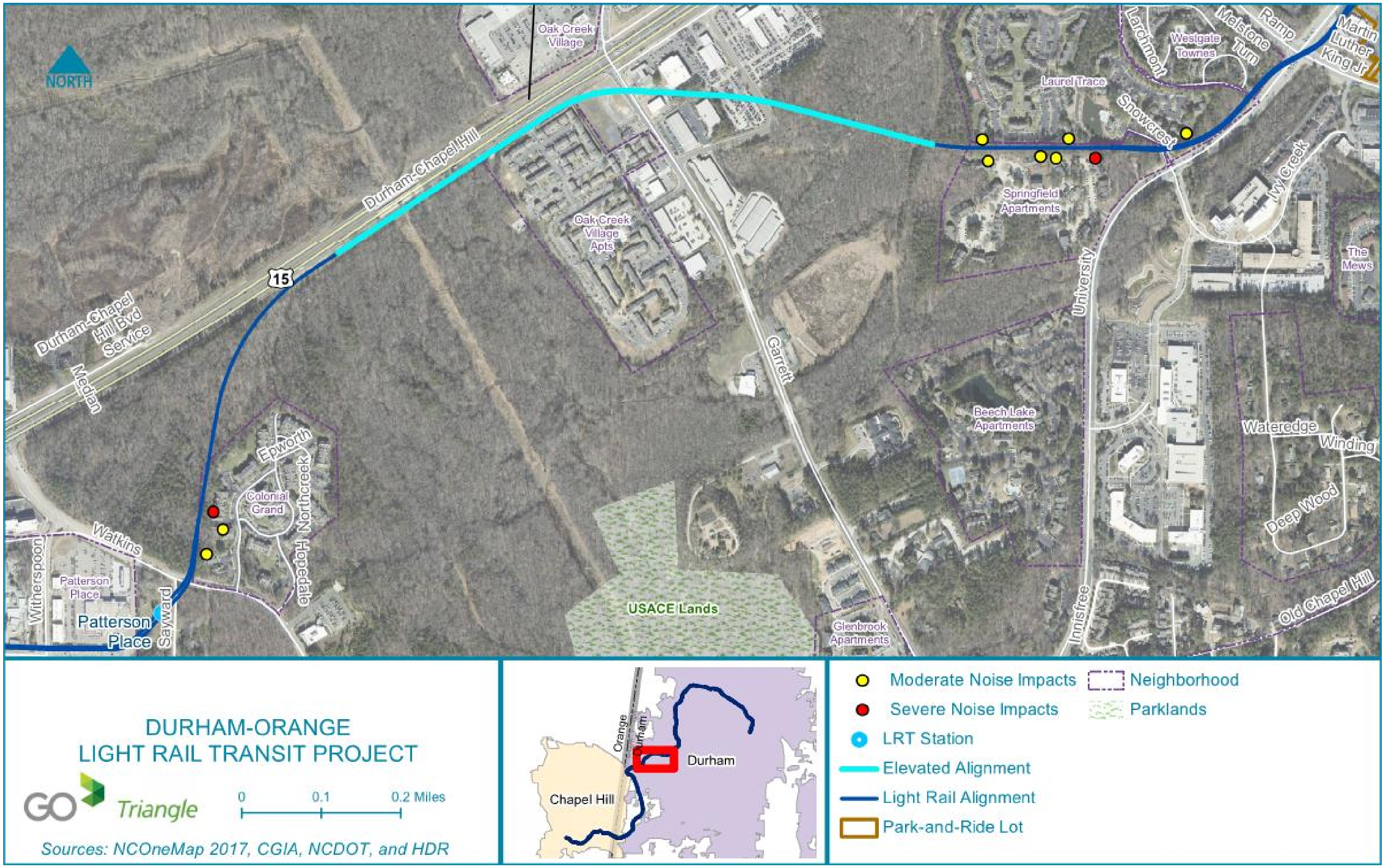


Figure J.4-4: Noise Impact Locations

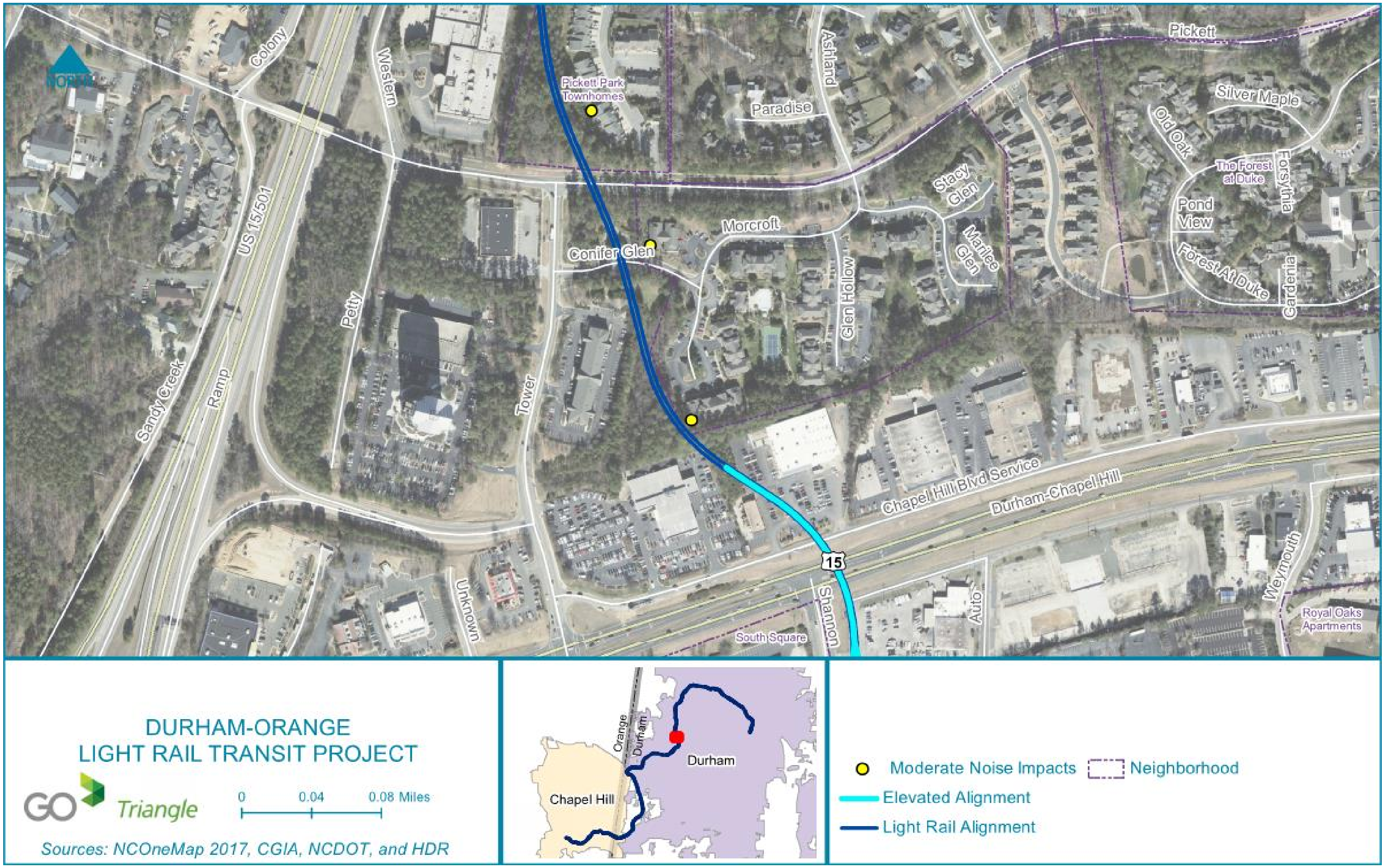


Figure J.4-5: Noise Impact Locations

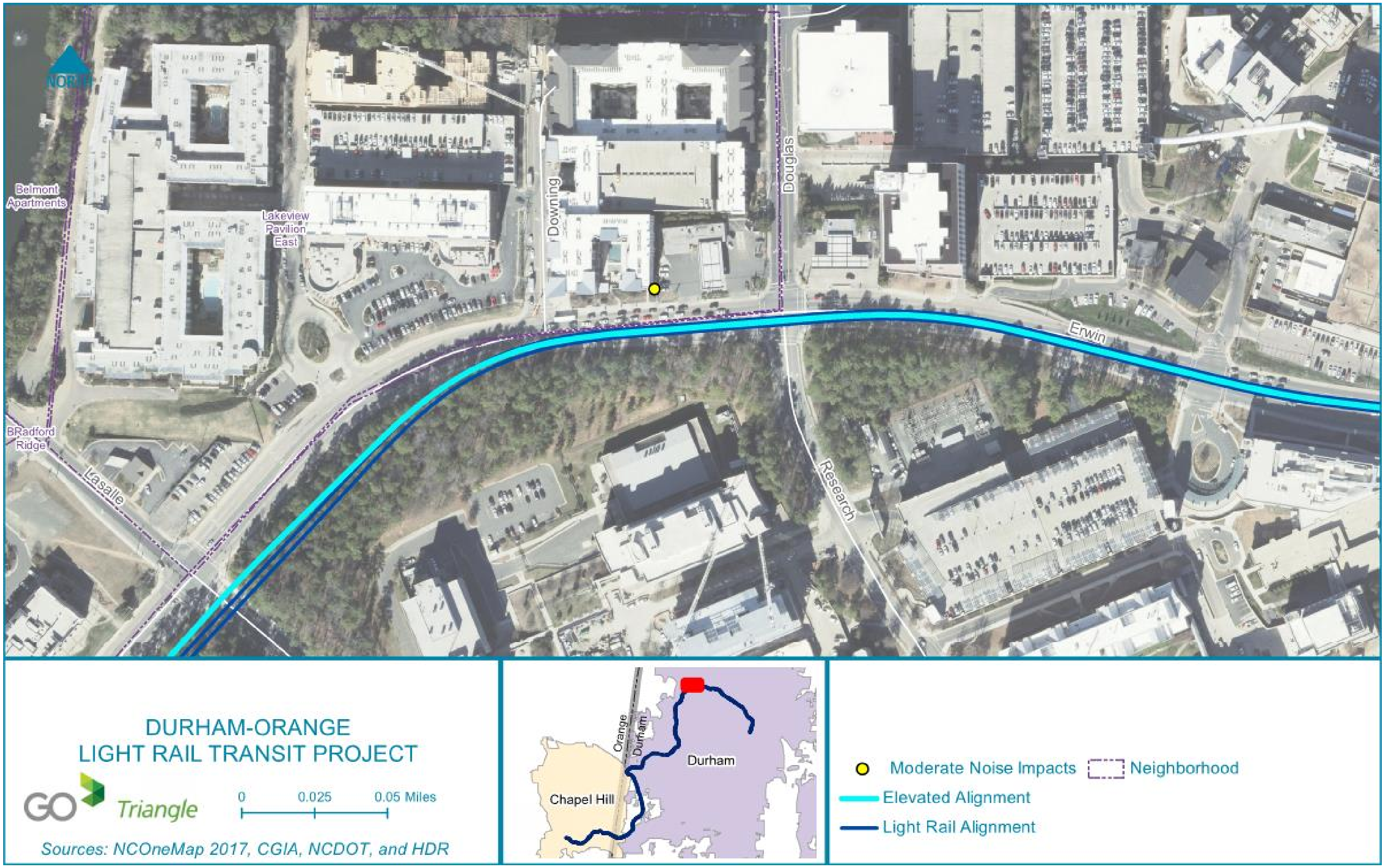


Figure J.4-6: Noise Impact Locations

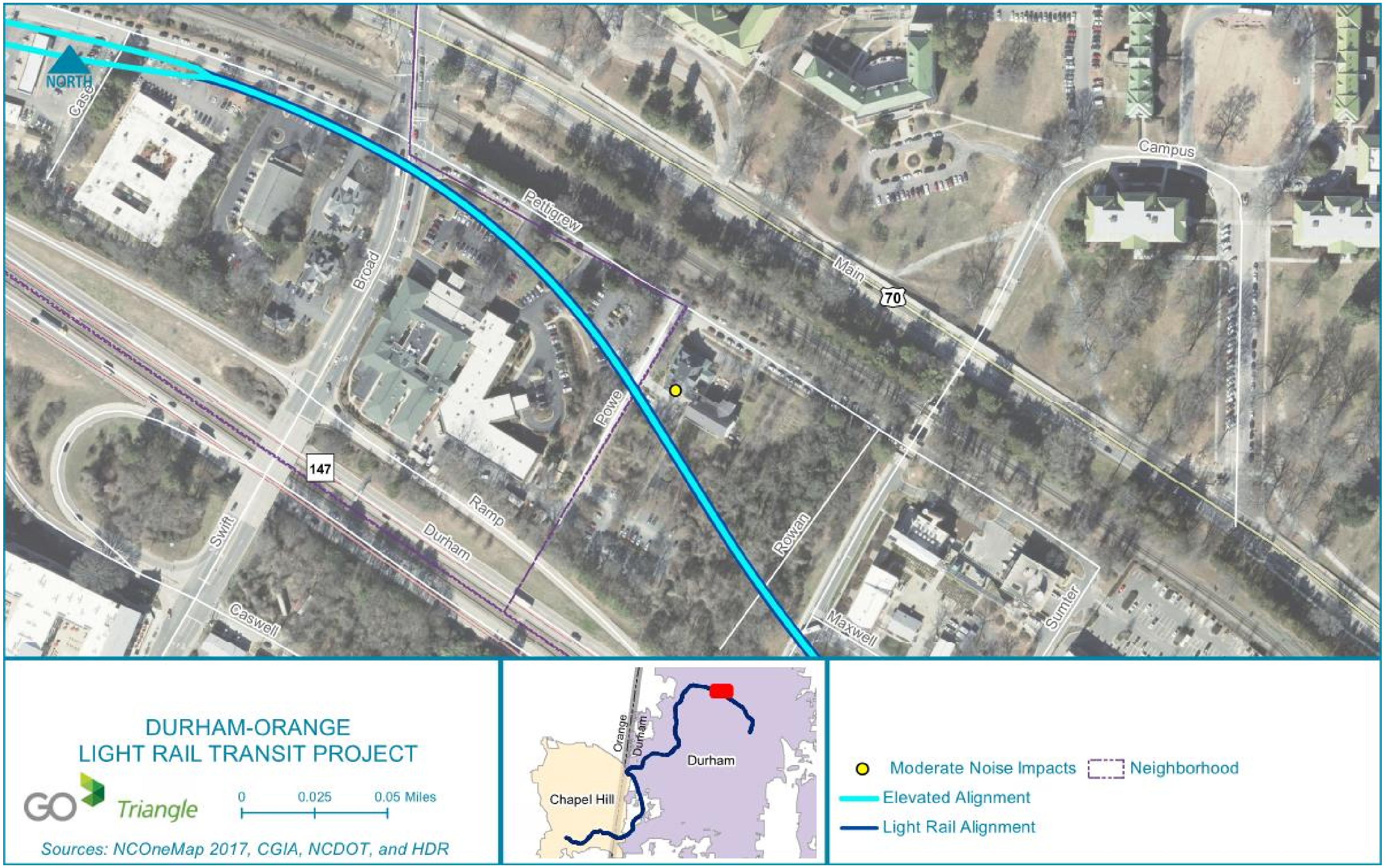


Figure J.4-7: Noise Impact Locations