METRORapid Inner Katy Project – Harris County, Texas

Noise and Vibration Technical Report

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NOISE AND VIBRATION TECHNICAL REPORT

METRORapid Inner Katy Project

Harris County, Texas

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1. INTRODUCTION AND PROJECT DESCRIPTION

This technical memorandum summarizes a noise and vibration impact assessment for the METRORapid Inner Katy Project in Harris County, Texas. The investigation was conducted in support of the Categorical Exclusion (CE) for the Project as part of the National Environmental Policy Act (NEPA) process. A noise and vibration impact assessment has been performed in accordance with the Federal Transit Administration (FTA) methodology and criteria guidelines contained in the *Transit Noise and Vibration Impact Assessment Manual* (FTA Report No. 0123, September 2018).[1]

The Metropolitan Transit Authority of Harris County (METRO) is proposing the METRORapid Inner Katy Project in Harris County, Texas. The project would provide a vital east-west bus rapid transit (BRT) connection along the Houston region's busiest travel corridor, I-10 West (Inner Katy corridor) between I-610 and Downtown Houston and close a major gap in the regional transportation network through implementation of an exclusive busway. The exclusive busway would accommodate METRORapid bus rapid transit service, Regional Express Park & Ride bus service, and express bus service along the Inner Katy corridor.

The project would begin at Northwest Transit Center (NWTC) and continue east along the south of I-10 on an approximately four-mile elevated guideway to Downtown Houston. Once in Downtown, the project would continue along the street pairings of Capitol and Rusk Streets to St. Emanuel. The project is divided into two segments: the Inner Katy Segment and Downtown Segment. The Inner Katy Segment would be grade-separated on new and existing structures. The Downtown Segment would be street-running. The project would include five new stations – three in the Inner Katy corridor and two in Downtown. In addition to the new stations, the project would also utilize the existing NWTC and three existing METRORail Green and Purple Lines stations along Capitol and Rusk in Downtown. **Figure 1** depicts the project alignment and stations.

Figure 1. METRORapid Inner Katy Project

[1] https://www.transit.dot.gov/research-innovation/transit-noise-and-vibration-impact-assessment-manual-report-0123

1.1. INNER KATY SEGMENT

The Inner Katy Segment extends from NWTC to Downtown at I-45. It would be located in existing state-owned right-of-way (ROW), with the exception of several station locations that would require ROW acquisition. The Inner Katy Segment would use the existing high-occupancy vehicle (HOV) ramp from the NWTC, crossing over I-10 and then transition to the four-mile elevated guideway just along the south frontage road of I-10 in the vicinity of Washington Avenue and Westcott Street. The elevated structure would have one lane in each direction plus shoulders and bypass lanes at station areas. **Figure 2** shows a typical cross section of the elevated busway facing east.

Figure 2. Typical Cross Section of the Elevated Busway

East of Studemont Street, METRO is advancing two design options. Option 1 is the concept that was developed during the METRONext Long Range Plan and was the basis for the project's 2018 regional funding application. Option 1 consists of an exclusive busway on an elevated structure located along the south side of I-10 that ties back to the existing Katy Central Business District (CBD) ramp into downtown. Option 2 is similar to Option 1 and consists of an exclusive busway along the south side of I-10 but accounts for the Texas Department of Transportation's (TxDOT) North Houston Highway Improvement Project (NHHIP), the planned reconstruction of I-45 north between Downtown Houston and the North Sam Houston Tollway. The NHHIP calls for the partial removal of the Katy CBD ramp. Under Option 2, the exclusive busway would not transition to the Katy CBD ramp near Houston Avenue but would instead continue along the south side of I-10 toward Downtown and transition to the remaining segment of the Katy CBD ramp, just north of Franklin Street.

The NHHIP is currently on hold and being reviewed by the Federal Highway Administration (FHWA). While TxDOT has restarted design work on portions of the NHHIP, the area closest to the METRORapid Inner Katy Project remains on hold with timing of construction currently undetermined. **Figure 3** shows the difference between Options 1 and 2.

Within the Inner Katy Segment, the project would have three new stations from west to east in addition to the existing NWTC: Memorial Park Station at I-10 and Westcott Street, Shepherd/Durham Transit Center Station at I-10 between Durham and Shepherd Drives, and Studemont Station at I-10 and Studemont Street. The station locations would be located adjacent to the guideway to provide local access to the METRORapid service, connect with key destinations, and improve access to METRO's Bus Operations Optimized System Treatments (BOOST) and local bus transit services. Near station areas, the elevated guideway would also have bypass lanes to allow the Regional Express and express services to continue to and from Downtown without interim stops.

Figure 3. Options 1 and 2 East of Studemont Street

1.2. DOWNTOWN SEGMENT

For both options, the project would enter downtown via Preston, Franklin, and Bagby streets, and continue via the one-way street pairings of Capitol and Rusk Streets to St. Emanuel Street in the East Downtown (EaDo) neighborhood using the METRORail Green and Purple Lines rights-of-way and existing station locations. By interlining the light rail transit and BRT operations in the curb lanes along Capitol and Rusk, METRO is maximizing use of existing infrastructure and creating an east-west transit corridor. This alignment only applies to the METRORapid operations. There will be no change to the existing Regional Express and express service and alignments in Downtown.

In addition to retrofitting upgrades to the existing light rail stations along Capitol and Rusk streets, two new at-grade station platforms would be constructed: Franklin/Bagby Station and EaDo/St. Emanuel Station. The Franklin/Bagby Station would be located on a City of Houston owned property bordered by I-45 and Franklin, Bagby, and Preston streets. The EaDo/St. Emanuel Station would be located on St. Emanuel Street between Capitol and Rusk Streets. **Figure 4** is a map of the Downtown Segment and associated station locations.

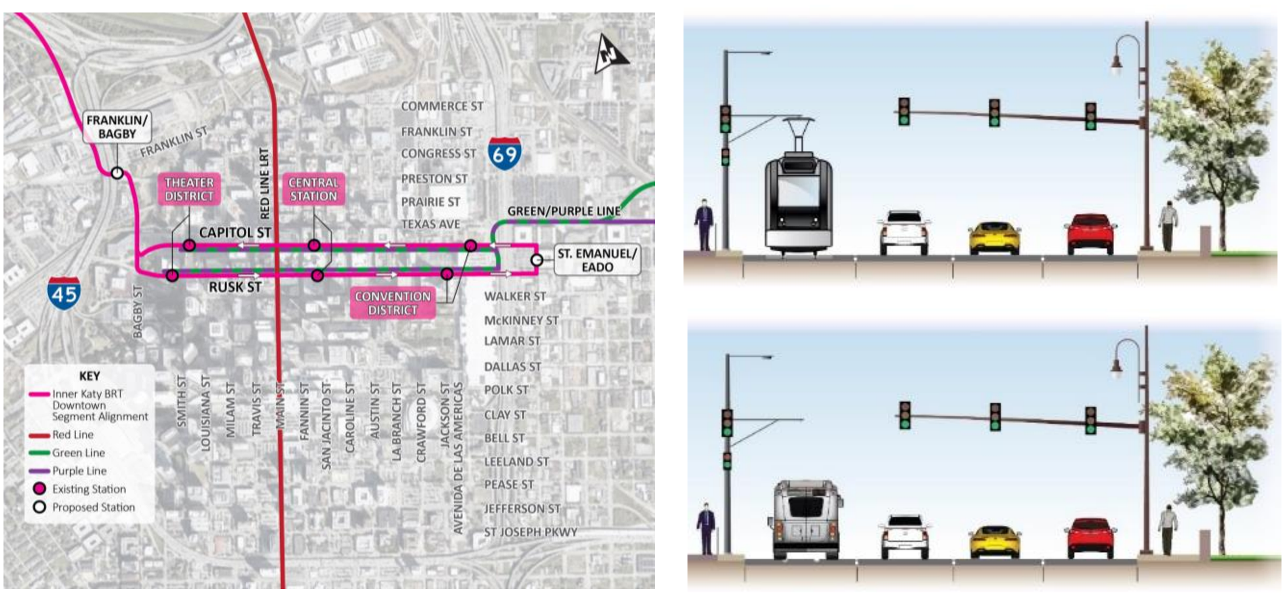


Figure 4. Downtown Segment and Associated Station Locations

2. METHODOLOGY

2.1. NOISE AND VIBRATION CONCEPTS

2.1.1. Noise Basics

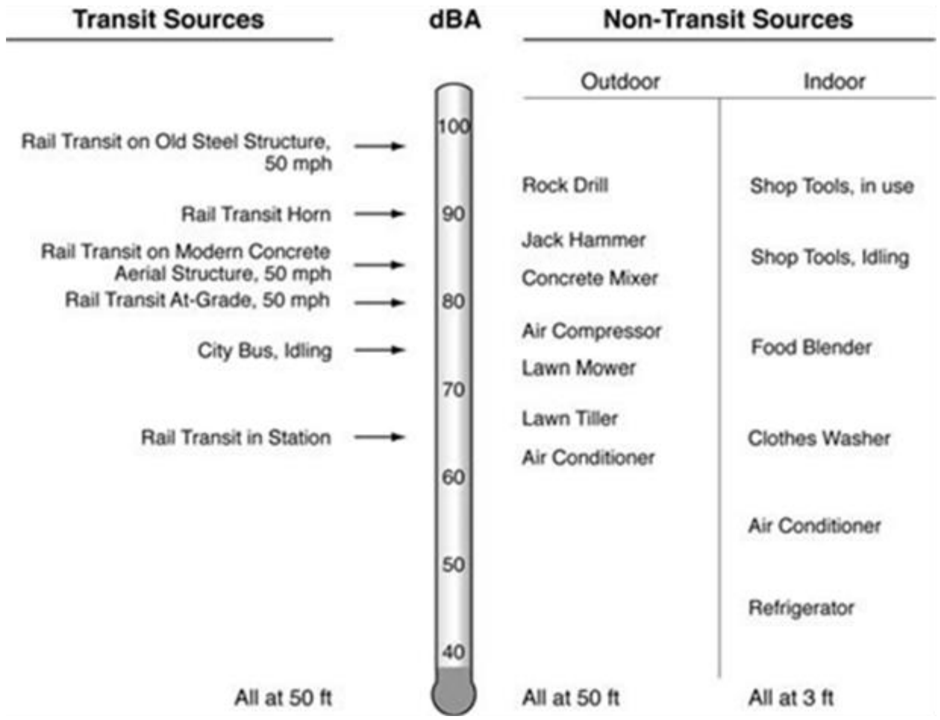
Sound is defined as small changes in air pressure above and below the standard atmospheric pressure and noise is usually considered to be unwanted sound. The three parameters that define noise include:

- **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 generally 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 typically perceived as a doubling (or halving) of loudness.

- **Frequency:** The frequency (pitch or tone) of sound is the rate of air pressure changes and is expressed in cycles per second, or Hertz (Hz). Human ears can detect a wide range of frequencies from about 20 Hz to 20,000 Hz; however, human hearing is less sensitive at high and low frequencies, and the A weighting system (dBA) is used to obtain a single-number descriptor that correlates with human response to noise. **Figure 5** 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.

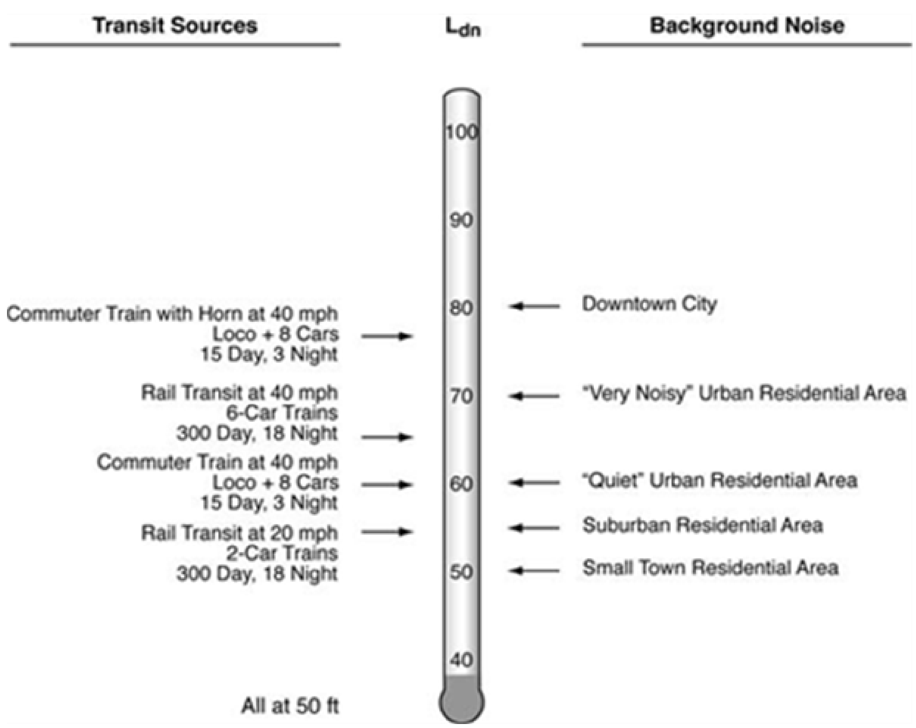
- **Time Pattern:** Because environmental noise is constantly changing, it is common to condense all of this information into a single number, called the "equivalent" sound level (Leq). The Leq represents the changing sound level over a period of time, typically 1 hour or 24-hours in transit noise applications. For assessing the noise impact of transit projects at residential land use, the Day-Night Sound Level (Ldn) is the noise descriptor commonly used, and it has been adopted by many agencies as the best way to describe how people respond to noise in their environment. Ldn 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 (10:00 PM to 7:00 AM). This nighttime penalty means that any noise event at night is equivalent to ten similar events during the daytime. Typical Ldn values for various transit operations and environments are shown on **Figure 6**.

  In addition to Leq and Ldn, there are other metrics used to describe transit and environmental noise. The loudest one second of noise over a measurement period, or maximum A-weighted sound level (Lmax), is used in many local and state ordinances for noise emitted from private land uses and for construction noise impact evaluations. Environmental noise can also be viewed on a statistical basis using percentile sound levels (Ln) which refer to the sound level exceeded “n” percent of the time. For example, the sound level exceeded 33 percent of the time, denoted as L33, is often found to approximate the Leq in the absence of loud intermittent noises (e.g., from trains or aircraft) and the sound level exceeded 90 percent of the time, denoted as L90, is often used to represent the “background” noise in a community.



Source: FTA, 2018

Figure 5. Typical A-Weighted Sound Levels



Source: FTA, 2018

Figure 6. Typical Ldn Noise Exposure Levels

2.1.2. Vibration Basics

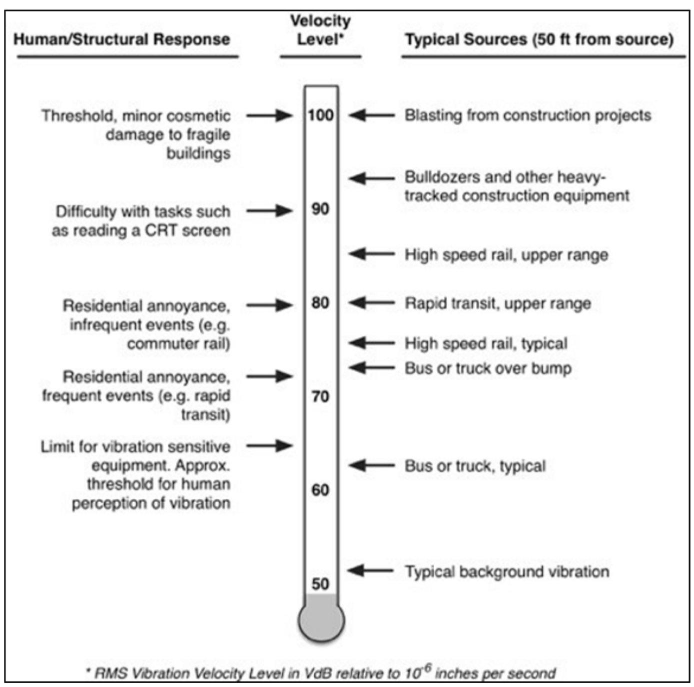
Ground-borne vibration refers to the fluctuating or oscillatory motion experienced by persons on the ground and in buildings. Vibration can be described in terms of displacement, velocity, or acceleration. Displacement is the easiest descriptor to understand. For a vibrating floor, the displacement is 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 more 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 of 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 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 normally 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 is in common use for vibration and is the notation specified by the FTA. Decibel notation 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). Although not a universally accepted notation, the abbreviation "VdB" is used in this document for vibration decibels as specified by the FTA to reduce the potential for confusion with sound decibels.

Figure 7 illustrates common vibration sources as well as human and structural response to ground-borne vibration. 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.



Source: FTA, 2018

Figure 7. Typical Levels of Ground-Borne Vibration

2.2. NOISE AND VIBRATION IMPACT CRITERIA

2.2.1. Operational Noise 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 with the existing noise (not the no-build noise). This is because comparison of a noise projection with an existing noise condition is more accurate than comparison of a projection with another noise projection. Because background noise may increase by the time the project is operational, this approach of using existing noise conditions is conservative.

The FTA noise criteria are based on the land use category of the sensitive receiver. The descriptors and criteria for assessing noise impact vary according to land use categories adjacent to the project alignment. For Category 2 land uses where people live and sleep (e.g., residential neighborhoods, hospitals, and hotels), the day-night sound level (Ldn) 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 sound level (Leq) for an hour of noise sensitivity that coincides with project activity is the assessment parameter. **Table 1** summarizes the three land use categories.

Table 1. Land Use Categories and Metrics for Transit Noise Impact Criteria

Land Use Category	Land Use Type	Noise Metric (dBA)	Description of Land Use Category
1	High Sensitivity	Outdoor Leq(1hr) *	Land where quiet is an essential element of its intended purpose. Example land uses include preserved land for serenity and quiet, outdoor amphitheaters and concert pavilions, and national historic landmarks with considerable outdoor use. Recording studios and concert halls are also included in this category.
2	Residential	Outdoor Ldn	This category is applicable to all residential land use and buildings where people normally sleep, such as hotels and hospitals.
3	Institutional	Outdoor Leq(1hr) *	This category is applicable to institutional land uses with primarily daytime and evening use. Example land uses include 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 are also included in this category.

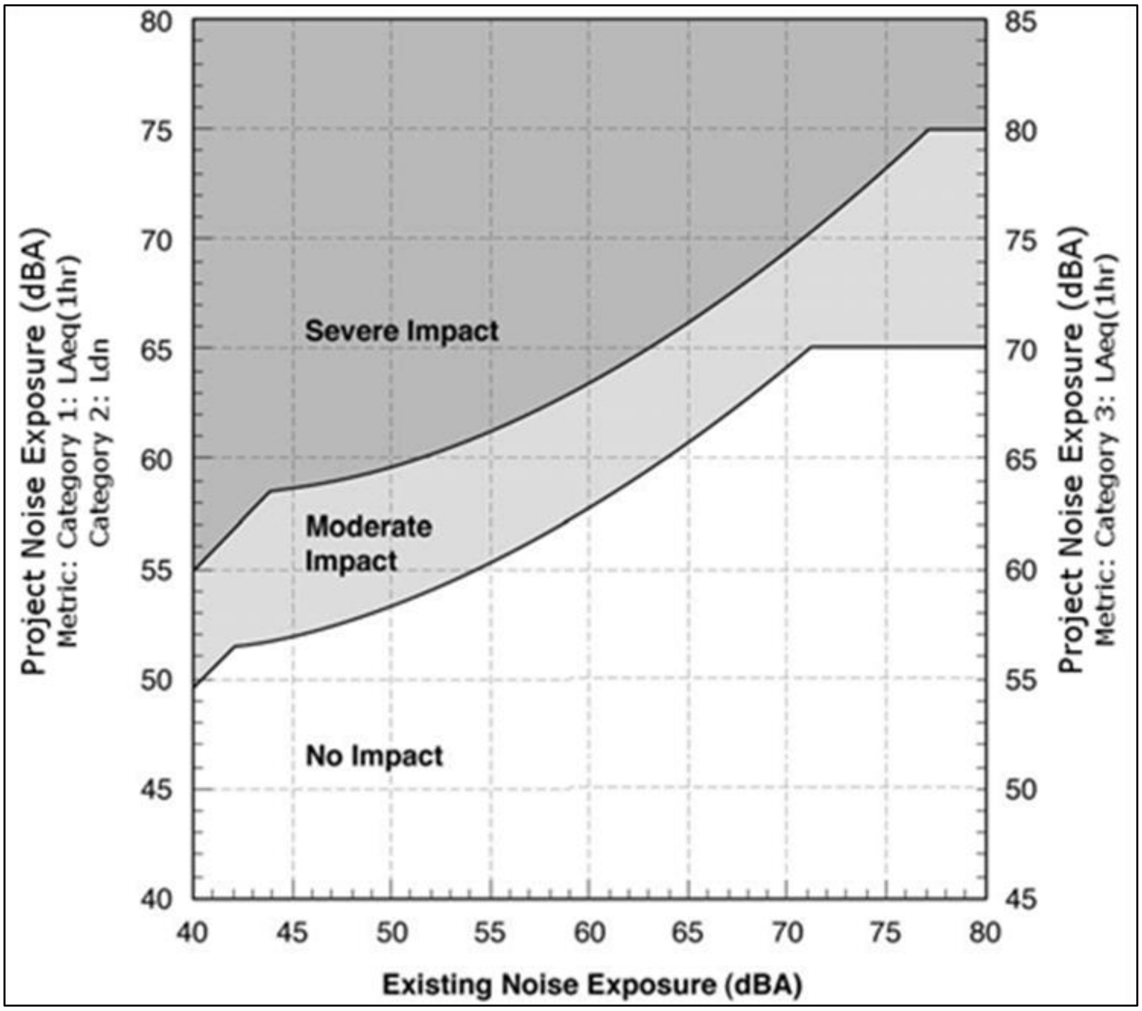
Source: FTA, 2018

* Leq(1hr) for the loudest hour of project-related activity during hours of noise sensitivity.

Figure 8 shows the two curves that are defined in the FTA noise impact criteria. These curves 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. The three levels of impact include:

- <u>No Impact</u>: Project-generated noise is not likely to cause community annoyance. Noise projections in this range are considered acceptable by FTA and mitigation is not required.

- Moderate Impact: Project-generated noise in this range is considered to cause impact at the threshold of measurable annoyance. Moderate impacts serve as an alert to project planners for potential adverse impacts and complaints from the community. Mitigation should be considered at this level of impact based on project specifics and details concerning the affected properties.
- Severe Impact: Project-generated noise in this range is likely to cause a high level of community annoyance. The project sponsor should first evaluate alternative locations/alignments to determine whether it is feasible to avoid severe impacts altogether. If it is not practical to avoid severe impacts by changing the location of the project, mitigation measures must be considered.



Source: FTA, 2018

Figure 8. FTA Noise Impact Criteria

The FTA noise impact criteria described above are based on levels of exterior noise and are designed to provide protection for both outdoor and indoor land uses. However, for locations where noise impact will be evaluated but there is no sensitive outdoor land use, such as apartment buildings, hotels or upper levels of multi-story buildings, indoor criteria can be used. In these cases, the criterion for indoor noise levels from project sources is a Ldn of 45 dBA. This criterion is consistent with Federal Aviation Administration (FAA) policy.

2.2.2. Operational Vibration Criteria

The FTA criteria for a general assessment of transit operations are based on land use and event frequency. For frequent events (e.g., more than 70 bus operations per day), the criteria for annoyance and activity interference depend on land use category as follows:

- 65 VdB for Category 1, including special buildings (e.g., concert halls) and buildings where vibration would interfere with interior operations (e.g., sensitive equipment)
- 72 VdB for Category 2, including residences and buildings where people normally sleep
- 75 VdB for Category 3, including institutional land uses with primarily daytime use

2.2.3. Construction Noise and Vibration Criteria

Table 2 shows the FTA construction noise criteria for a general assessment. The combined one-hour Leq for the two noisiest pieces of equipment for each phase of construction [Leq, equip(1hr)] is used to assess impact, based on construction noise calculations using the noise emission levels of the construction equipment, their location, and operating hours. The construction noise limits are based on land use and are normally assessed at the noise-sensitive receiver property line.

Table 2. General Assessment Construction Noise Criteria

Land Use	Leq, equip(1hr), dBA	
	Day	Night
Residential	90	80
Commercial	100	100
Industrial	100	100

Source: FTA, 2018

In addition to the vibration criteria for human annoyance and interference with equipment and spaces described in **Section 2.2.2**, there are also vibration criteria for damage from construction activities. Typical transit operations do not have the potential for damage, so only certain construction activities are assessed for damage.

Table 3 shows the FTA criteria for vibration damage to structures. These criteria are based on the structure and construction type (and not a designation as historic). **Table 3** also includes criteria in terms of both VdB and Peak Particle Velocity (PPV).

Table 3. FTA Construction Vibration Damage Criteria

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

Source: FTA, 2018

2.3. NOISE IMPACT ASSESSMENT METHODOLOGY

2.3.1. Operational Noise

The methodology for assessing noise impact from bus operations included the following steps:

- Identify noise-sensitive land uses in the corridor using aerial photography, GIS data and field surveys, typically within a distance of up to 500 feet from the alignments (based on the FTA noise impact screening distance for busways where the sound path is unobstructed).

- Measure or estimate existing noise levels in the corridor near sensitive receivers (see Section 3).

- Predict future project noise levels from transit operations, based on preliminary engineering plans and information on speeds, headways, and vehicle type using FTA Detailed Noise Analysis methodology. The project noise impact assessment includes noise from BRT, regional express and express bus operations, as well as idling noise from BRT buses at stations. Details regarding the information used to predict future project noise levels can be found below.

- Assess the impact of the project by comparing the predicted future project noise levels with the existing noise levels using the FTA noise impact criteria presented above in **Section 2.2.1**.

Project noise levels from transit operations are based on source reference levels in the FTA guidance manual and the current design of the proposed project. This information was used to predict noise levels at sensitive locations from the proposed alignments. Specific inputs used in the noise impact assessment include the following:

- Locations of the noise sensitive receivers in relation to the bus roadway, including the distances between the roadway and sensitive receivers and relative elevations

- A source reference noise level for diesel buses of 82 dBA SEL[2] at 50 feet and 50 mph

- Bus speeds of 50 mph along the elevated freeway portion of the busway, 30 mph on the connecting ramps to/from the NWTC and Downtown, and 30 mph along the Downtown route

- The weekday schedule for the buses operating on the Inner Katy Segment is as follows:

    - The BRT buses will operate with a headway of 6 minutes in each direction between 4:30 AM and 12:00 Midnight.
    - There will be a combined total of 411 inbound and 448 outbound regional express and express bus operations during the daytime hours (7:00 AM to 10:00 PM)
    - There will be a combined total of 113 inbound and 84 outbound regional express and express bus operations during the nighttime hours (10:00 PM to 7:00 AM)

- Along the Downtown Segment, BRT buses will operate with a headway of 6 minutes between 4:30 AM and 12:00 Midnight on weekdays

[2] The SEL is the cumulative noise exposure from a single noise event (e.g., a bus passage), normalized to an interval of one second. SEL contains the same overall sound energy as the actual varying sound energy during the event and is the primary metric for the measurement of transit vehicle noise emissions and an intermediate metric in the measurement and calculation of both Leq and Ldn. The SEL metric is A-weighted and is expressed in the unit dBA.

- A source reference noise level for idling diesel buses of 88 dBA SEL at 50 feet (corresponding to a noise level emission of 75 dBA at 50 feet for a period of 20 seconds)

The Project noise predictions represent exterior noise levels at all noise-sensitive receivers except for the Sawyer Heights Lofts Luxury Apartments, a four-story, multi-family building located between Studemont Street and Taylor Street along the Inner Katy Segment. At these apartments, which have no sensitive outdoor land use, interior noise was predicted. The façade of this building consists of brick or stucco walls with double-glazed, single-hung windows and is centrally air-conditioned such that the windows are typically kept closed. Federal Highway Administration (FHWA) guidance[3] suggests that, in the absence of detailed acoustical analyses or field measurements, the outdoor-to-indoor noise reduction for masonry buildings may be taken to be 35 dB with double-glazed windows. Thus, the interior Project noise level at the apartments was predicted by reducing the predicted exterior noise level by 35 dB, and the result was then compared with the FTA interior Ldn noise criterion of 45 dBA to assess noise impact.

2.3.2. Operational Vibration

Operational vibration impacts are assessed based on the FTA procedures for a general vibration assessment. **Figure 9** includes the generalized ground surface vibration curve from the FTA manual for rubber-tired vehicles operating at grade at a speed of 30 mph, which is applicable to the Downtown Segment. Also shown in **Figure 9** are the adjusted curves for bus operations on elevated structure at speeds of 30 mph and 50 mph, which are applicable to the Inner Katy Segment. Based on FTA methodology, the prediction curves for elevated structure operations assume a correction factor of -10 VdB with respect to at-grade operations and a +5 VdB adjustment to account for potential vibration increases due to expansion joints, as well as an adjustment of +4.4 VdB for operations at 50 mph.

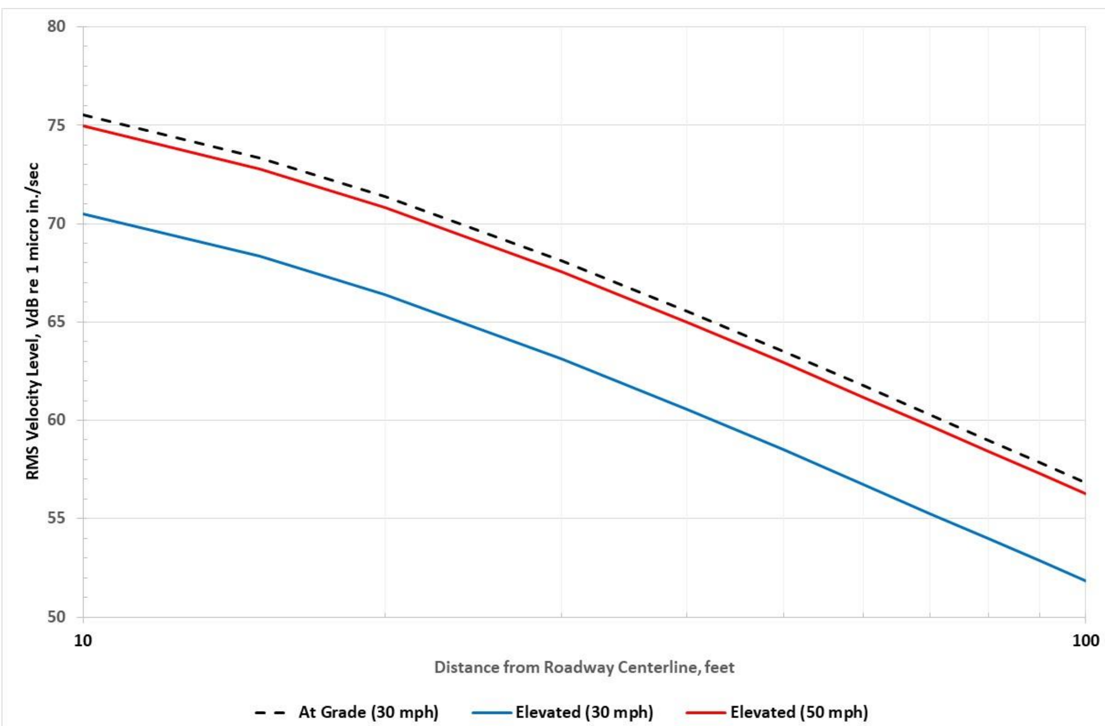


Figure 9. Generalized Ground Surface Vibration Curves for Rubber-Tired Vehicles

[3] U.S. Department of Transportation Federal Highway Administration, “Highway Traffic Noise Analysis and Abatement Policy and Guidance” (June 1995).

2.3.3. Construction Noise

Construction noise impacts are assessed using a combination of the methods and construction source data contained in the FTA guidance manual and the FHWA Roadway Construction Noise Model (RCNM) from the FHWA Construction Noise Handbook (Final Report FHWA-HEP-06-015, August 2006). **Table 4** lists typical noise levels generated by representative pieces of equipment.

The noise exposure at a receiver location may be calculated using decibel addition of all operating construction equipment using the following equation:

Leq(n) = Lmax + 10*log10(U.F.) – 20*log10(D/50) – A(shielding)

where:

Leq(n) = noise exposure at a receiver resulting from the operation of a single piece of equipment over n hours,

Lmax = noise emission level of the particular piece of equipment at the reference distance of 50 feet (taken from Table 10),

A(shielding) = shielding provided by barriers, building, or terrain,

D = distance from the receiver to the piece of equipment in feet, and

U.F. = usage factor that accounts for the fraction of time that the equipment is in use over the specified time period. For Leq(1-hr) the U.F. is assumed to be 100%, and for 8 hours or more the values in Table 10 are used.

For a general assessment, the Leq(1-hr) is calculated for the two noisiest pieces of equipment expected to be used in each phase of construction. Then, the levels for each phase of construction are combined using decibel addition.

2.3.4. Construction Vibration

Construction vibration is assessed for areas where there is potential for impact from construction activities. Such activities include blasting, pile driving, demolition, and drilling or excavation in close proximity to sensitive structures. **Table 5** lists typical vibration levels generated by representative pieces of equipment.

For damage assessment, the following equation is used:

PPVequip = PPVref * [(25/D)]^1.5

where:

PPVequip = the peak particle velocity in in/sec of the equipment adjusted for distance

PPVref = the reference vibration level in in/sec at 25 feet from **Table 5**, and

D = the distance from the equipment to the receiver in feet.

For annoyance assessment, the following equation is used:

Lv (D) = Lv (25 ft) – 30*log10(D/25)

where:

Lv(D) = RMS vibration level at distance D

Lv (25 ft) = RMS vibration level at 25 ft from **Table 5**, and

D = the distance from the equipment to the receiver in feet.

Table 4. Construction Equipment Noise Emission Levels

Equipment	Typical Noise Level (Lmax) 50 ft from Source (dBA)	Usage Factor (U.F.), %
Air Compressor	80	40
Backhoe	80	40
Ballast Equalizer	82	50
Ballast Tamper	83	50
Compactor	82	20
Concrete Mixer	85	40
Concrete Pump	82	20
Crane, Derrick	88	16
Crane, Mobile	83	16
Dozer	85	16
Generator	82	50
Grader	85	40
Impact Wrench	85	50
Jack Hammer	88	20
Loader	80	40
Paver	85	50
Pile Driver (Impact)	101	20
Pile Driver (Vibratory)	95	20
Pneumatic Tool	85	50
Pump	77	50
Rail Saw	90	20
Rock Drill	85	20
Roller	85	20
Saw	76	20
Scarifier	83	20
Scraper	85	40
Shovel	82	40
Spike Driver	77	20
Tie Cutter	84	20
Tie Handler	80	20
Tie Inserter	85	20
Truck	84	40

Source: FTA, 2018 and FHWA, 2006

Table 5. Vibration Source Levels for Construction Equipment

Equipment		PPV at 25 feet (in/sec)	Approximate Lv* at 25 feet
Pile Driver (impact)	upper range	1.518	112
	typical	0.644	104
Pile Driver (vibratory)	upper range	0.734	105
	typical	0.170	93
Clam shovel drop (slurry wall)		0.202	94
Hydromill (slurry wall)	in soil	0.008	66
	in rock	0.017	75
Vibratory roller		0.210	94
Hoe ram		0.089	87
Large bulldozer		0.089	87
Caisson drilling		0.089	87
Loaded trucks		0.076	86
Jackhammer		0.035	79
Small bulldozer		0.003	58

Source: FTA, 2018

* RMS velocity in decibels (VdB) re 1 micro-inch/second

3. EXISTING NOISE CONDITIONS

3.1. INNER KATY SEGMENT

3.1.1. Noise-Sensitive Land Use

The areas adjacent to the proposed alignments for Inner Katy Options 1 and 2 include a mix of residential, institutional, commercial, and industrial land use. Noise-sensitive receivers located along the corridor primarily consist of single-family and multi-family residences, but also include a hotel, two churches, and parks as well as the Houston SPCA. In accordance with FTA procedures, noise measurements are not required at all sensitive receivers along the corridor but rather at locations that are representative of sensitive land use along the corridor.

Traffic on I-10 and adjacent service roads is the most significant source of existing noise along the Project corridor. However, I-10 is depressed in certain areas so that the freeway traffic noise is shielded from some nearby sensitive receivers. In addition, some receivers are shielded from freeway surface road traffic noise by intervening buildings or sound walls. Thus, sensitive receivers could have greater potential for noise impact from BRT operations in areas where the bus guideway is on an elevated platform where the shielding effects of intervening structures are reduced.

3.1.2. Noise Measurement Locations

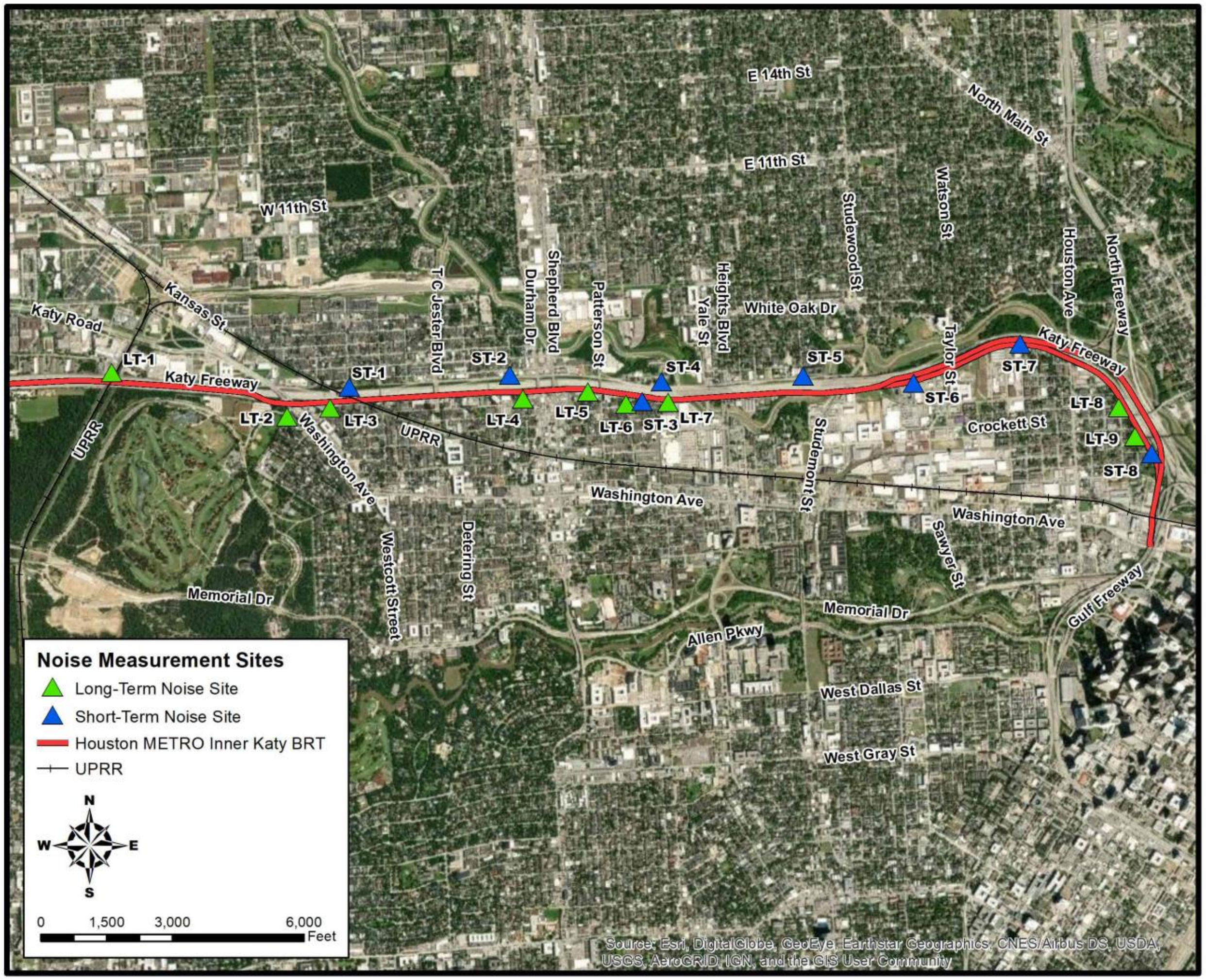
The noise measurement program consisted of both long-term (18 to 24-hour) and short-term (one-hour) monitoring of the A-weighted sound level at sites that were selected to represent a range of existing noise conditions at noise-sensitive areas along the Project corridor. Long-term noise measurements were made at nine (9) sites (designated as LT-1 through LT-9) and short-term noise measurements were made at eight (8) sites (designated as ST-1 through ST-8). The existing ambient noise measurement locations are shown on **Figure 10** for the overall alignment and in more detail on **Figures 11-15**. Photographs of these measurement sites are included in **Appendix A**.

3.1.3. Noise Measurement Procedures

The noise measurements were performed using NTi Audio model XL2 noise monitors that conform to American National Standards Institute (ANSI) Standard S1.4 for Class 1 (Precision) sound level meters. Calibrations, traceable to the U.S. National Institute of Standards and Technology (NIST), were carried out in the field before and after each set of measurements using an acoustical calibrator. In all cases, the measurement microphone was protected by a windscreen and supported on a tripod at a height of four to six feet above the ground surface and positioned to characterize the exposure of the site to the dominant noise sources in the area.

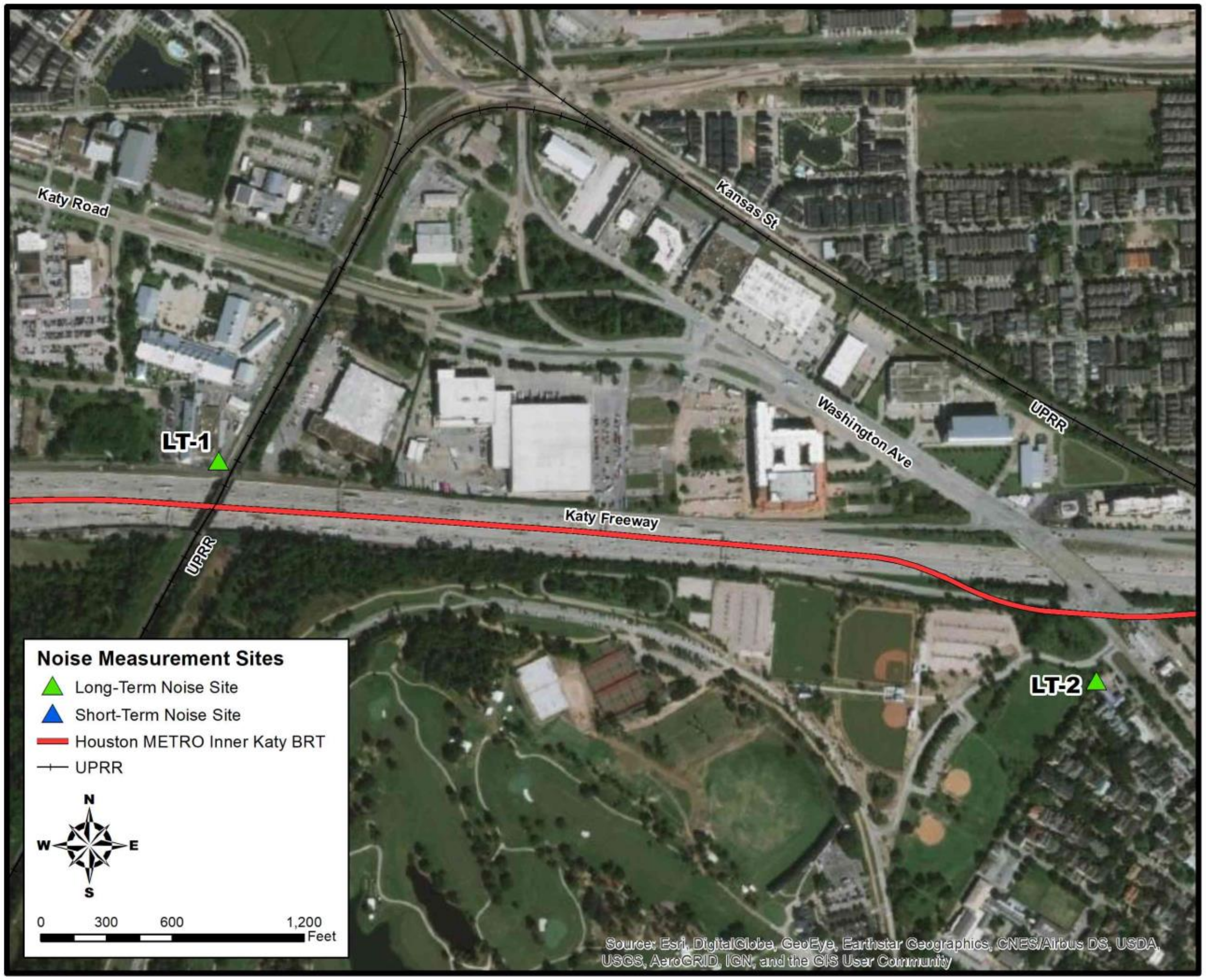
3.1.4. Noise Measurement Results

The results of the existing ambient noise measurements are summarized in **Table 6**, and hourly noise data for the long-term measurements are included in **Appendix B**. These results indicate Ldn values in the range of 64 dBA to 81 dBA and hourly Leq values in the range of 63 dBA to 80 dBA, depending on location, representative of the noise environment along a major highway corridor. Overall, the results in Table 1 serve as the basis for determining the existing noise conditions at all noise-sensitive receivers near the Project corridor as in **Section 3.1.5** below.



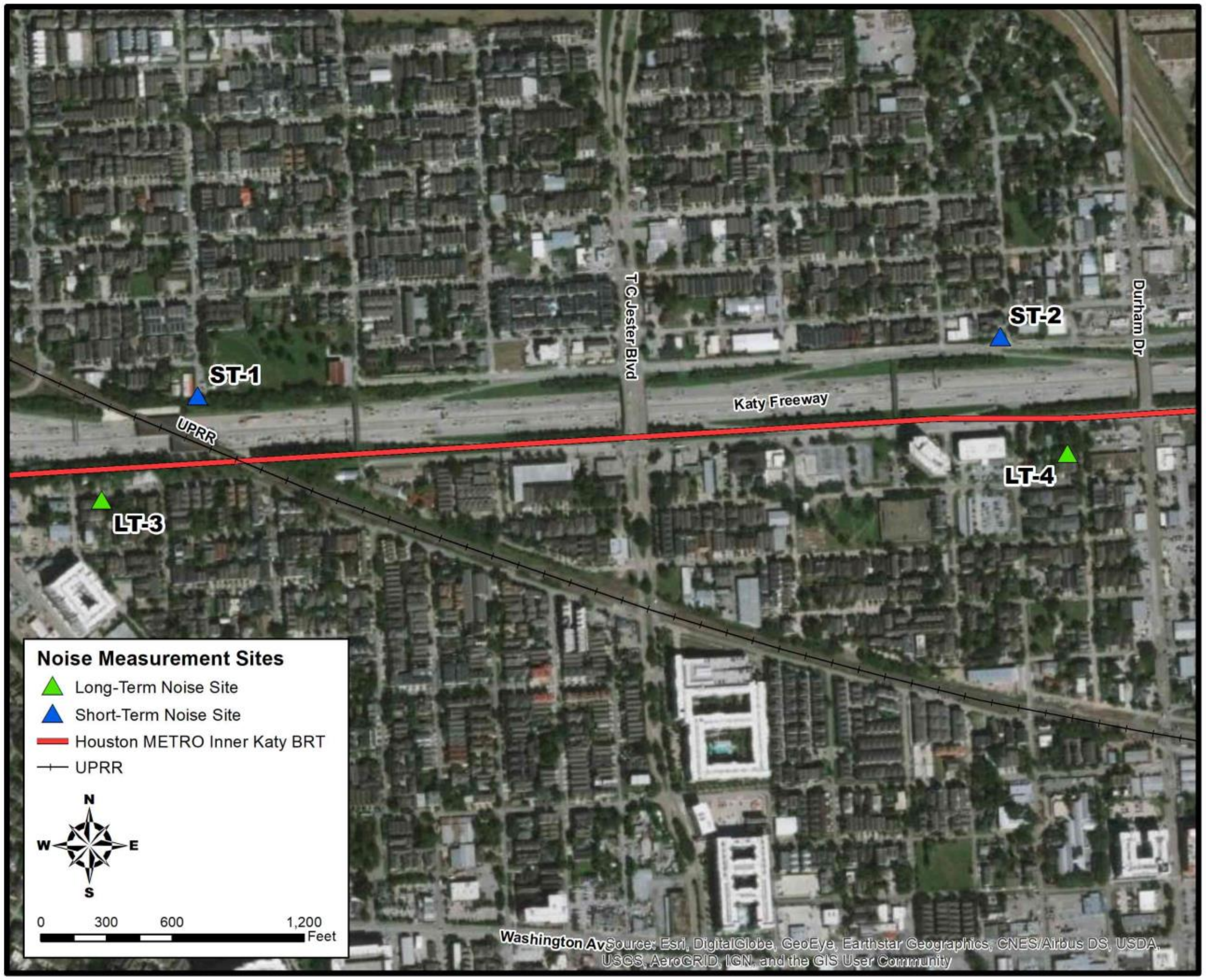
Source: Cross-Spectrum Acoustics, 2022

Figure 10. Existing Ambient Noise Measurement Locations (Overall Inner Katy Alignment)



Source: Cross-Spectrum Acoustics, 2022

Figure 11. Existing Ambient Noise Measurement Locations (Inner Katy Detail Map 1 of 5)

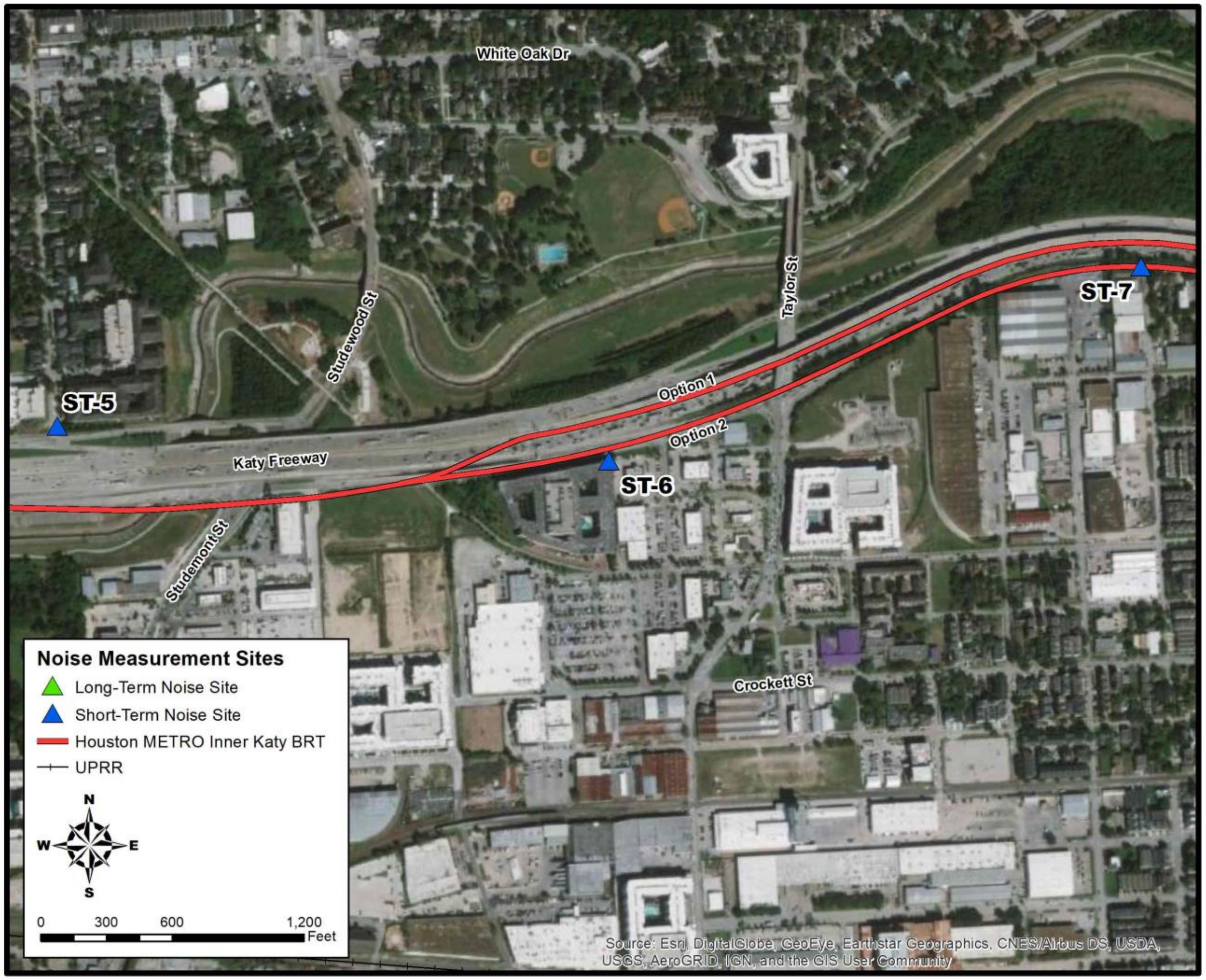


Source: Cross-Spectrum Acoustics, 2022

Figure 12. Existing Ambient Noise Measurement Locations (Inner Katy Detail Map 2 of 5)

Source: Cross-Spectrum Acoustics, 2022

Figure 13. Existing Ambient Noise Measurement Locations (Inner Katy Detail Map 3 of 5)



Source: Cross-Spectrum Acoustics, 2022

Figure 14. Existing Ambient Noise Measurement Locations (Inner Katy Detail Map 4 of 5)

Source: Cross-Spectrum Acoustics, 2022

Figure 15. Existing Ambient Noise Measurement Locations (Inner Katy Detail Map 5 of 5)

Table 6. Summary of Existing Ambient Noise Measurement Results along the Inner Katy Segment

Site No.	Side of Alignment	Measurement Location Description	Start of Measurement		Measurement Duration (hours)	Noise Exposure (dBA)	
			Date	Time		Ldn	Leq
LT-1	North	Houston SPCA	7/14/21	15:00	24	80	76[1]
LT-2	South	6677 Wescott Street (Scottish Inns Hotel)	7/14/21	13:00	24	67	63[1]
LT-3	South	6315 Stillman Street (SF Residence)	7/12/21	12:00	24	73	68[1]
LT-4	South	1801 Sandman Street (SF Residence)	7/13/21	09:00	18	68[2]	65[1,2]
LT-5	South	1814 Fowler Street (SF Residence)	7/14/21	11:00	24	81	76[1]
LT-6	South	1805 Thompson Street (SF Residence)	7/14/21	15:00	24	72	67[1]
LT-7	South	1612 Bonner Street (SF Residence)	7/13/21	11:00	24	76	70[1]
LT-8	West	1201 Shearn Street (SF Residence)	7/12/21	11:00	24	73	67[1]
LT-9	West	1619 Beachton Street (SF Residence)	7/12/21	10:00	24	75	67[1]
ST-1	North	2100 Arabelle Street (Cottage Grove Park)	7/12/21	11:25	1	73[3]	75
ST-2	North	2003 Roy Street (MF Residence)	7/13/21	09:00	1	72[3]	74
ST-3	South	4202 Marina Street (Residential area behind sound wall)	7/13/21	13:50	1	64[3]	66
ST-4	North	1814 Bonner Street (Residential area behind sound wall)	7/13/21	13:50	1	67[3]	69
ST-5	North	404 Oxford Street (Camden Heights Apts.)	7/14/21	08:40	1	78[3]	80
ST-6	South	2424 Katy Fwy. (Sawyer Heights Lofts Apts.)	7/14/21	08:40	1	72[3]	74
ST-7	South	2418 Sabine Street (SF Residence)	7/14/21	11:40	1	77[3]	79
ST-8	West	1400 Elder St. (American Statesmanship Park)	7/12/21	13:00	1	76[3]	78

Source: Cross-Spectrum Acoustics, 2022

[1] Represents the average Leq measured during the peak transit hours (6:00 am - 9:00 am and 3:00 pm - 6:00 pm)

[2] Estimated from available hourly data.

[3] The Leq measurement data were used to estimate the Ldn using FTA methodology. This approach tends to be conservative and underestimate the existing noise levels, which can result in the assessment of higher levels of noise impact for a project.

3.1.5. Characterization of the Existing Noise Conditions

The existing noise conditions were characterized at noise-sensitive receivers within the FTA noise impact screening distances (as measured from the centerline of the proposed busway). The applicable screening distances are 500 feet for receivers that will have an unobstructed view of the busway and 250 feet for receivers where intervening structures will obstruct the view of the busway. The existing noise exposure levels at these locations were characterized by generalizing the noise measurement results in **Table 6**.

The methodology used for assigning existing noise exposure levels at various locations along the Project corridor is summarized in **Table 7**, including the reference measurement sites that served as a basis for the assignments. Using FTA criteria, the potential for noise impact are assessed by comparing the predicted noise levels from the BRT Project with the existing noise levels determined according to the methodology described in **Table 7**.

Table 7. Characterization of Existing Noise Exposure Levels along the Inner Katy Segment

Noise-Sensitive Receiver Location (with respect to BRT Alignment)	Existing Noise Exposure Level (dBA)*	Reference Measurement Site(s)
Houston SPCA (North Side)	76 (Leq)	LT-1
Scottish Inns Hotel (South Side)	67 (Ldn)	LT-2
Washington Ave – TC Jester Blvd (North & South Sides)	73 (Ldn)	LT-3 & ST-1
TC Jester Blvd – Patterson St (North Side)	72 (Ldn)	ST-2
Patterson St – Yale St (North Side)	67 (Ldn)	ST-4
TC Jester Blvd – Yale St (South Side)	Unshielded Receivers: $Ldn = 81-10*\log_{10}(D/25)$ Receivers Shielded by Buildings: $Ldn = 81-10*\log_{10}(D/25) -5$ Receivers Shielded by Sound Wall: $Ldn = 81-10*\log_{10}(D/25) -10$ where D= distance from Service Road (feet)	LT-4 LT-5 LT-6 LT-7 ST-3
Yale St – Studemont St (North Side)	78 (Ldn)	ST-5
Sawyer Heights Lofts Luxury Apartments (South Side)	72 (Ldn)	ST-6
Sabine Street – Houston Ave (South Side)	77 (Ldn)	ST-7
Impact Houston Church of Christ (South Side)	79 (Leq)	ST-7
Houston Ave – Crockett St (West Side)	73 (Ldn)	LT-8
Crockett St – Dart St (West Side)	75 (Ldn)	LT-9
American Statesmanship Park (West Side)	78 (Leq)	ST-8
Ecclesia Houston Church– Downtown Campus (West Side)	78 (Leq)	ST-8

* See **Figure 6** to compare existing exposure noise levels with typical levels for various community environments.

Source: Cross-Spectrum Acoustics, 2022

3.2. DOWNTOWN SEGMENT

3.2.1. Noise-Sensitive Land Use

The areas adjacent to the proposed alignment for the Downtown Segment include a mix of residential, institutional, and commercial land use. Although the land use is primarily commercial, noise-sensitive receivers located along the proposed BRT route include residential apartment buildings, hotels, schools, and parks (Sesquicentennial Park, Little Tranquility Park, and Tranquility Park), as well as the Downtown Aquarium, Federal Courthouse and Jones Hall for the Performing Arts. The primary sources of existing noise at these locations include motor vehicle traffic on local streets and nearby freeways, as well as light rail train operations along portions of the proposed BRT route.

3.2.2. Noise Measurement Locations

The noise measurement program consisted of both long-term (three-hour) and short-term (one-hour) monitoring of the A-weighted sound level at sites that were selected to represent a range of existing noise conditions at noise-sensitive areas along the proposed BRT route. The long-term measurements were made at three (3) residential sites (designated as LT-10, LT-11, and LT-12) for one-hour periods during three typical hours of the day (during peak-hour roadway traffic, during the midday between the morning and afternoon roadway-traffic peak hours, and during the late night between midnight and 5:00 AM). Short-term noise measurements were made at each of eight (8) institutional sites (designated as ST-9 through ST-16) for periods of 40-60 minutes. The existing ambient noise measurement locations are shown in **Figure 16**, and photographs of these measurement sites are included in **Appendix A**.

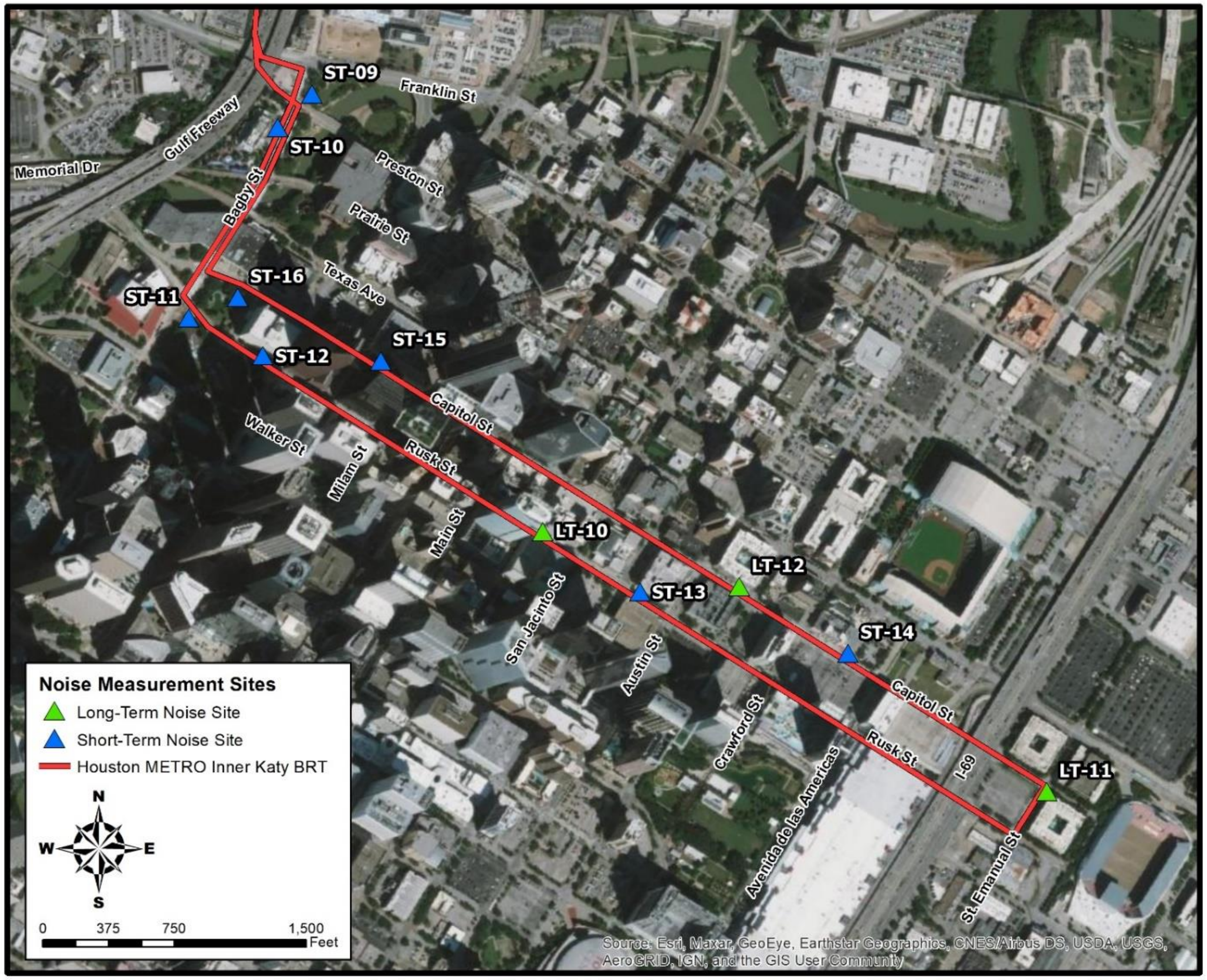
3.2.3. Noise Measurement Procedures

The noise measurements were performed using NTi Audio model XL2 noise monitors that conform to American National Standards Institute (ANSI) Standard S1.4 for Class 1 (Precision) sound level meters. Calibrations, traceable to the U.S. National Institute of Standards and Technology (NIST), were carried out in the field before and after each set of measurements using an acoustical calibrator. In all cases, the measurement microphone was protected by a windscreen and supported on a tripod at a height of four to six feet above the ground surface and positioned to characterize the exposure of the site to the dominant noise sources in the area. It should be noted that while the microphone location for the nighttime measurement at Site LT-12 was near the corner of this residential building, the location for the daytime measurements was relocated further from the intersection where traffic noise at the building is lower, thereby providing a more conservative basis for the noise impact assessment.

3.2.4. Noise Measurement Results

The results of the existing ambient noise measurements are summarized in **Table 8**. For the long-term measurement sites, the Ldn values were computed from three partial one-hour Leq measurements using FTA methodology for determining existing noise (Option 3 in Appendix E of the FTA Transit Noise and Vibration Impact Assessment Manual).

The results indicate Ldn values in the range of 68 dBA to 70 dBA and Leq values in the range of 61 dBA to 71 dBA, depending on location, representative of an urban noise environment. Overall, the results in **Table 8** serve as the basis for determining the existing noise conditions at all noise-sensitive receivers along the proposed BRT route.



Source: Cross-Spectrum Acoustics, 2022

Figure 16. Existing Ambient Noise Measurement Locations along the Downtown Segment

Table 8. Summary of Existing Ambient Noise Measurement Results along the Downtown Segment

Site No.	Measurement Location Description	Start of Measurement		Measurement Duration (minutes)	Noise Exposure (dBA)	
		Date	Time		Leq	Ldn
LT-10	The Star Apartments	1/18/22	03:28	60 (Night)	62	69[1]
		1/18/22	07:27	60 (Peak)	71	
		1/18/22	13:41	60 (Day)	70	
LT-11	2120 Capitol Street Apartments	1/18/22	01:12	60 (Night)	63	68[1]
		1/18/22	06:02	60 (Peak)	68	
		1/18/22	12:30	60 (Day)	67	
LT-12	1414 Texas Downtown Apartments	1/18/22	02:19	60 (Night)	63	70[1]
		1/18/22	07:11	60 (Peak)	71	
		1/18/22	13:38	60 (Day)	71	
ST-9	Sesquicentennial Park	1/19/22	09:16	60	65	--
ST-10	Downtown Aquarium – Houston	1/19/22	10:22	60	69	--
ST-11	Tranquility Park	1/19/22	11:45	60	61	--
ST-12	Federal Courthouse (515 Rusk St.)	1/19/22	12:48	60	66	--
ST-13	Kinder High School for the Performing and Visual Arts	1/19/22	11:35	40[2]	64	--
ST-14	Incarnate Word Academy (School)	1/19/22	12:44	60	65	--
ST-15	Jones Hall for the Performing Arts	1/19/22	10:16	60	67	--
ST-16	Little Tranquility Park	1/19/22	09:06	60	61	--

Source: Cross-Spectrum Acoustics, 2022

[1] The Leq measurement data were used to estimate the Ldn using FTA methodology. This approach tends to be conservative and underestimate the existing noise levels, which can result in the assessment of higher levels of noise impact for a project.

[2] The measurement duration at this site was limited due to noise from a student soccer game that began 40 minutes after the measurement start time near the microphone location.

4. ENVIRONMENTAL IMPACTS

4.1. INNER KATY SEGMENT

4.1.1. Operational Noise Impacts

The potential for noise impact from bus operations along the Inner Katy Segment of the Project was assessed at a total of 437 noise-sensitive receiver locations within the FTA screening distance for busways. Of these, 426 are FTA Category 2 (residential) locations and 11 are FTA Category 3 (institutional) locations.

Comparisons of the existing and future noise levels are presented in **Table 9** and **Table 10** for Option 1 and in **Table 11** and **Table 12** for Option 2. **Table 9** and **Table 11** include ranges of results for FTA Category 2 (residential) receivers with both daytime and nighttime sensitivity to noise, whereas **Table 10** and **Table 12** include ranges of results for FTA Category 3 (institutional) receivers with primarily daytime and evening use. In addition to the distances to the near bus lane and anticipated bus speeds, the tables include the existing noise levels and the projected noise levels from bus operations for each section or noise-sensitive receiver along the Inner Katy Segment. Based on a comparison of the predicted Project noise levels with the impact criteria, the tables also include an inventory of the number of moderate and severe noise impacts without mitigation for each section or noise-sensitive receiver. At locations where impacts are predicted, the data provided in the table represent a range for the impacted receivers. In sections where no impacts are predicted, the data are for the receiver with the highest predicted Project noise level.

For Option 1, the results in **Table 9** identify moderate noise impacts without mitigation at a total of 60 residences, all on the eastbound (south) side of the busway. Most (46) of these predicted impacts are in the neighborhood between Patterson Street and Yale Street where many of the closest residences are shielded from existing traffic noise by a sound wall that results in lower existing noise levels. No severe impacts are predicted at any residences. Furthermore, no moderate or severe impacts are predicted at any noise-sensitive institutional land use as indicated by the results in **Table 10**. The locations of the predicted residential noise impacts without mitigation for Option 1 are shown on **Figure 17**, **Figure 18**, and **Figure 19**.

For Option 2, the noise impacts are predicted to be the same as for Option 1, with one additional impact predicted between Spring Street and Crockett Street. As indicated in **Table 11**, moderate noise impacts without mitigation are identified at a total of 61 residences, all on the eastbound (south) side of the busway. No severe impacts are predicted at any residences. Furthermore, no moderate or severe impacts are predicted at any noise-sensitive institutional land use as indicated by the results in **Table 12**. The locations of the predicted residential noise impacts without mitigation for Option 2 are shown on **Figure 17 through Figure 20**.

Based on the results of the noise impact assessment, similar impacts are predicted for Option 1 and Option 2 and therefore it is concluded that both options are essentially the same from a noise perspective.

Table 9. Summary of FTA Category 2 (Residential) Noise Impacts Without Mitigation (Inner Katy Option 1)

Corridor Segment Description	Side of Busway[1]	Number of Receivers	Distance from Near Lane (feet)	Bus Speed (mph)	Existing Noise Level (dBA)[2]	Project Noise Level (dBA)[2]			Number of Residential Impacts	
						Predicted[3]	Impact Criteria[4]		Moderate	Severe
							Moderate	Severe		
NWTC to Washington – South	EB	1	321	15	67	57	62	67	0	0
Washington to TC Jester – North	WB	27	359	50	73	60	65	72	0	0
Washington to TC Jester – South	EB	115	57 to 104	50	73	65 to 68	65	72	9	0
TC Jester to Patterson – North	WB	51	316	50	72	60	65	71	0	0
TC Jester to Patterson – South	EB	21	69 to 99	50	77 to 80	65 to 67	65	74 to 75	5	0
Patterson to Yale – North	WB	9	324	50	67	60	62	67	0	0
Patterson to Yale – South	EB	102	59 to 270	50	61 to 77	59 to 68	58 to 65	64 to 75	46	0
Yale to Studemont – North	WB	7	318	50	78	61	65	75	0	0
Yale to Studemont – South	EB	3	270	50	78	61	65	75	0	0
Studemont to Sabine – South	EB	1	188	50	72	63	65	71	0	0
Sabine to Houston – South	EB	26	145	30	77	58	65	75	0	0
Houston to Crockett – West	EB	27	299	30	73	55	65	72	0	0
Crockett to Dart – West	EB	36	235	30	75	56	65	73	0	0
TOTAL NUMBER OF NOISE IMPACTS:									60	0

Source: Cross-Spectrum Acoustics, 2022

[1] Eastbound (EB) or Westbound (WB)
[2] Noise levels are based on Ldn and measured in dBA (rounded to the nearest decibel).
[3] Predicted levels include bus idling noise, where applicable (rounded to the nearest decibel) and are compared with the impact criteria to assess noise impact.
[4] The noise impact thresholds vary, depending on the land use category and the existing noise levels.

Table 10. Summary of FTA Category 3 (Institutional) Noise Impacts Without Mitigation (Inner Katy Option 1)

Noise-Sensitive Receiver Description	Side of Busway[1]	Distance from Near Lane (feet)	Bus Speed (mph)	Existing Noise Level (dBA)[2]	Project Noise Level (dBA)[2]			Number of Institutional Impacts	
					Predicted[3]	Impact Criteria[4] Moderate	Impact Criteria[4] Severe	Moderate	Severe
Houston SPCA	WB	553	50	76	58	70	79	0	0
Santana Funeral Directors	WB	329	50	74	60	70	77	0	0
Medical Offices at 5225 Katy Fwy	EB	105	50	67	65	67	72	0	0
Medical Offices at 5151 Katy Fwy	EB	115	50	67	64	67	72	0	0
Michael A. Wong, DDS General Dentistry	EB	97	50	67	65	67	72	0	0
Zora Diaa DDS	WB	343	50	74	60	70	77	0	0
Open Door Deliverance Apostolic Church	EB	176	50	67	63	67	72	0	0
Pearl Dentistry	EB	413	50	74	59	70	77	0	0
Impact Houston Church of Christ	EB	137	30	77	60	70	80	0	0
American Statesmanship Park	EB	218	30	78	59	70	80	0	0
Ecclesia Houston - Downtown Campus	EB	78	30	78	63	70	80	0	0
TOTAL NUMBER OF NOISE IMPACTS:								0	0

Source: Cross-Spectrum Acoustics, 2022

[1] Eastbound (EB) or Westbound (WB)
[2] Noise levels are based on 1-hour Leq and measured in dBA (rounded to the nearest decibel).
[3] Predicted levels include bus idling noise, where applicable (rounded to the nearest decibel) and are compared with the impact criteria to assess noise impact.
[4] The noise impact thresholds vary, depending on the land use category and the existing noise levels.

Table 11. Summary of FTA Category 2 (Residential) Noise Impacts Without Mitigation (Inner Katy Option 2)

Corridor Segment Description	Side of Busway[1]	Number of Receivers	Distance from Near Lane (feet)	Bus Speed (mph)	Existing Noise Level (dBA)[2]	Project Noise Level (dBA)[2]			Number of Residential Impacts	
						Predicted[3]	Impact Criteria[4] Moderate	Impact Criteria[4] Severe	Moderate	Severe
NWTC to Washington - South	EB	1	321	15	67	57	62	67	0	0
Washington to TC Jester - North	WB	27	359	50	73	60	65	72	0	0
Washington to TC Jester – South	EB	115	57 to 104	50	73	65 to 68	65	72	9	0
TC Jester to Patterson - North	WB	51	316	50	72	60	65	71	0	0
TC Jester to Patterson – South	EB	21	69 to 99	50	77 to 80	65 to 67	65	74 to 75	5	0
Patterson to Yale - North	WB	9	324	50	67	60	62	67	0	0
Patterson to Yale – South	EB	102	59 to 270	50	61 to 77	59 to 68	58 to 65	64 to 75	46	0
Yale to Studemont - North	WB	7	318	50	78	61	65	75	0	0
Yale to Studemont - South	EB	3	270	50	78	61	65	75	0	0
Studemont to Sabine – South	EB	1	69	50	72	32[5]	45[5]	45[5]	0	0
Sabine to Houston - South	EB	26	39	30	77	64	65	75	0	0
Houston to Crockett - West	EB	27	22	30	73	66	65	72	1	0
Crockett to Dart - West	EB	36	49	30	75	63	65	73	0	0
TOTAL NUMBER OF NOISE IMPACTS:									61	0

Source: Cross-Spectrum Acoustics, 2022

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

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

[3] Predicted levels include bus idling noise, where applicable (rounded to the nearest decibel) and are compared with the impact criteria to assess noise impact.

[4] The noise impact thresholds vary, depending on the land use category and the existing noise levels.

[5] Noise levels represent interior noise at the Sawyer Heights Lofts Luxury Apartments where there is no sensitive outdoor land use.

Table 12. Summary of FTA Category 3 (Institutional) Noise Impacts Without Mitigation (Inner Katy Option 2)

Noise-Sensitive Receiver Description	Side of Busway[1]	Distance from Near Lane (feet)	Bus Speed (mph)	Existing Noise Level (dBA)[2]	Project Noise Level (dBA)[2]			Number of Institutional Impacts	
					Predicted[3]	Impact Criteria[4]		Moderate	Severe
						Moderate	Severe		
Houston SPCA	WB	553	50	76	58	70	79	0	0
Santana Funeral Directors	WB	329	50	74	60	70	77	0	0
Medical Offices at 5225 Katy Fwy	EB	105	50	67	65	67	72	0	0
Medical Offices at 5151 Katy Fwy	EB	115	50	67	64	67	72	0	0
Michael A. Wong, DDS General Dentistry	EB	97	50	67	65	67	72	0	0
Zora Diaa DDS	WB	343	50	74	60	70	77	0	0
Open Door Deliverance Apostolic Church	EB	176	50	67	63	67	72	0	0
Pearl Dentistry	EB	292	50	74	61	70	77	0	0
Impact Houston Church of Christ	EB	30	30	77	67	70	80	0	0
American Statesmanship Park	EB	37	30	78	66	70	80	0	0
Ecclesia Houston - Downtown Campus	EB	79	30	78	63	70	80	0	0
TOTAL NUMBER OF NOISE IMPACTS:								0	0

Source: Cross-Spectrum Acoustics, 2022

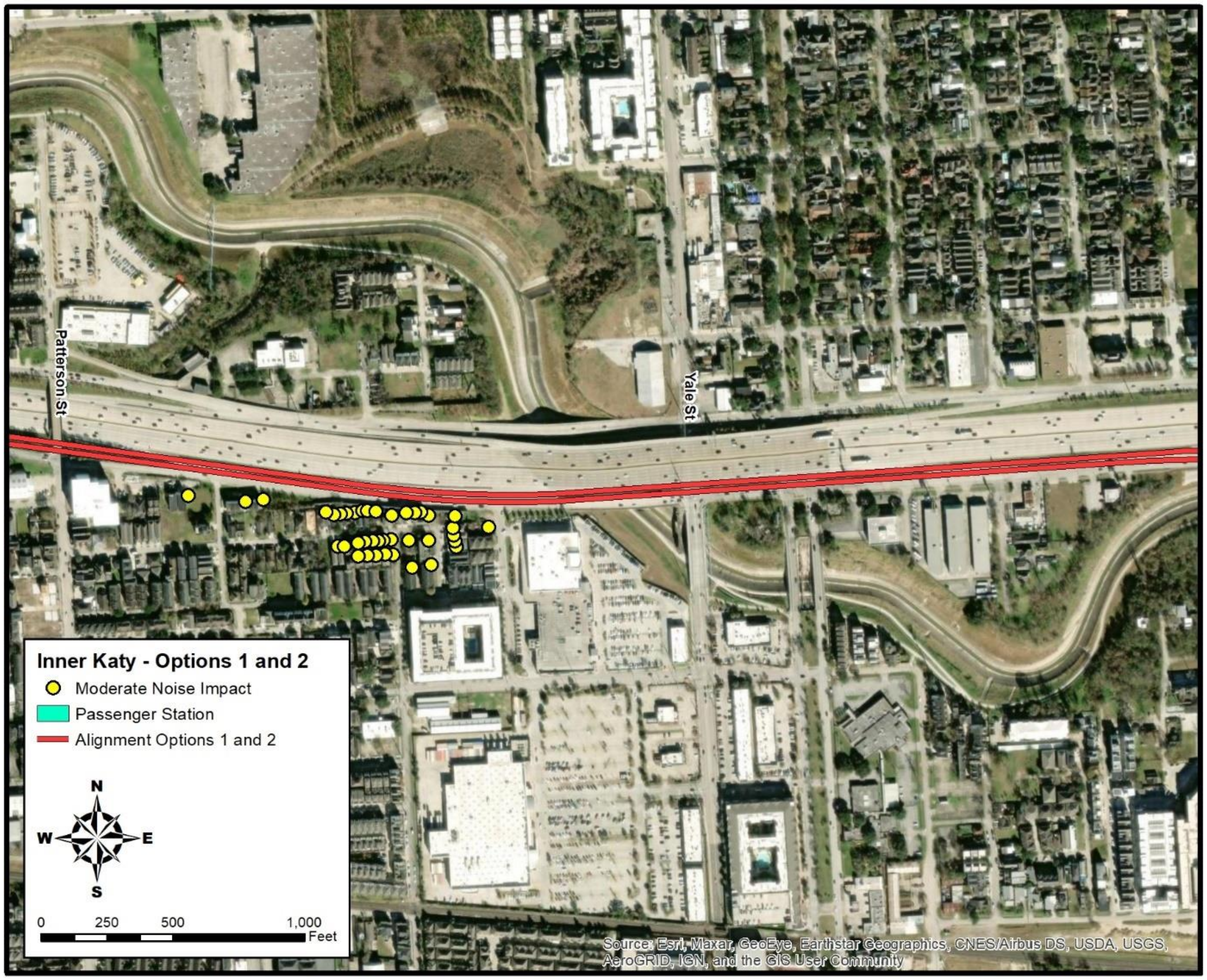
[1] Eastbound (EB) or Westbound (WB)
[2] Noise levels are based on 1-hour Leq and measured in dBA (rounded to the nearest decibel).
[3] Predicted levels include bus idling noise, where applicable (rounded to the nearest decibel) and are compared with the impact criteria to assess noise impact.
[4] The noise impact thresholds vary, depending on the land use category and the existing noise levels.

Source: Cross-Spectrum Acoustics, 2022

Figure 17. Noise Impact Locations for Inner Katy Options 1 and 2 (Washington Avenue to TC Jester Boulevard)

Source: Cross-Spectrum Acoustics, 2022

Figure 18. Noise Impact Locations for Inner Katy Options 1 and 2 (TC Jester Boulevard to Patterson Street)



Source: Cross-Spectrum Acoustics, 2022

Figure 19. Noise Impact Locations for Inner Katy Options 1 and 2 (Patterson Street to Yale Street)

Source: Cross-Spectrum Acoustics, 2022

Figure 20. Noise Impact Locations for Inner Katy Option 2 (Spring Street to Crockett Street)

4.1.2. Operational Vibration Impacts

Land use along the Inner Katy Segment includes FTA Category 2 (residential) receivers and FTA Category 3 (institutional) receivers; there are no FTA Category 1 (high-sensitivity) receivers. Based on the ground surface vibration curves in **Figure 9**, vibration levels from bus operations on the elevated guideway are predicted to exceed the FTA vibration criterion for Category 2 land use (72 VdB) within 20 feet of the guideway centerline where the bus speeds are 50 mph and within 10 feet of the guideway centerline where the bus speeds are 30 mph. For Category 3 land use, vibration levels from bus operations are predicted to exceed the FTA vibration criterion (75 VdB) within 10 feet of the guideway centerline where the bus speeds are 50 mph. Because there are no vibration-sensitive receivers within these distances, no vibration impacts are anticipated from bus operations along the Inner Katy Segment.

4.1.3. Construction Noise and Vibration Impacts

Construction of the aerial BRT guideway, stations, transit center and other BRT-related facilities will result in the generation of noise from construction equipment. Temporary noise during construction in and along I-10, primarily from site preparation and construction of the aerial BRT guideway, has the potential of being intrusive to residents near the construction sites.

Construction activities that could cause intrusive vibration include vibratory compaction, jack hammering and the use of tracked vehicles, such as bulldozers. The most substantial sources of construction vibration are blasting and pile driving. However, it is anticipated that no blasting will be required for this project and that pile driving will be limited.

Construction noise and vibration will vary greatly depending on the construction process, type and condition of equipment used, and layout of the construction site. Many of these factors are traditionally left to the contractor's discretion, which makes construction noise difficult to accurately estimate during the planning phase of a project. Therefore, a quantitative assessment of construction noise and vibration impacts will be conducted during the design phase of the Project when detailed construction scenarios are available.

4.2. DOWNTOWN SEGMENT

4.2.1. Operational Noise Impacts

The potential for noise impact from BRT operations along the Downtown Segment of the Project was assessed at a total of 26 noise-sensitive receiver locations adjacent to the proposed bus route. Of these, 2 are FTA Category 1 (sensitive) locations, 16 are FTA Category 2 (residential) locations and 8 are FTA Category 3 (institutional) locations.

Comparisons of the existing and future noise levels are presented in **Table 13** for FTA Category 2 receivers including residences and hotels with both daytime and nighttime sensitivity to noise, and in **Table 14** for FTA Category 1 and 3 (institutional) receivers with primarily daytime and evening use. In addition to the distances to the near bus lane and anticipated bus speeds, the tables include the existing noise levels and the predicted noise levels from bus operations at each noise-sensitive receiver. Based on a comparison of the predicted Project noise levels with the impact criteria, the tables also include an inventory of the number of moderate and severe noise impacts without mitigation at each location. The results in **Table 13** and **Table 14** indicate that no moderate or severe noise impacts are predicted for BRT operations along the Downtown Segment.

Table 13. Summary of FTA Category 2 (Residential) Noise Impacts Without Mitigation (Downtown Segment)

Noise-Sensitive Receiver Description	Street Location	Distance from Near Lane (feet)	Bus Speed (mph)	Existing Noise Level (dBA)[1]	Project Noise Level (dBA)[1]			Number of Residential Impacts	
					Predicted[2]	Impact Criteria[3]		Moderate	Severe
						Moderate	Severe		
Tennison Lofts	Franklin	166	30	67	52	62	67	0	0
JW Marriott Houston Downtown	Rusk	27	30	69	58	64	69	0	0
AC by Marriott Houston Downtown	Rusk	47	30	69	56	64	69	0	0
Houston Quarters Hotel	Rusk	50	30	69	56	64	69	0	0
The Star	Rusk	53	30	69	56	64	69	0	0
Le Meridien Houston Downtown	Rusk	163	30	69	51	64	69	0	0
Homewood Suites and Hampton Inn	Rusk	48	30	69	56	64	69	0	0
Marriott Marquis Houston	Rusk	28	30	69	58	64	69	0	0
2120 Capitol Street Apartments	St. Emanuel	52	30	68	56	63	68	0	0
Lofts at the Ballpark Apartments	Capitol	80	30	68	54	63	68	0	0
Lofts at the Ballpark Apartments	Capitol	55	30	68	56	63	68	0	0
Westin Houston Downtown	Capitol	152	30	70	51	64	69	0	0
1414 Texas Downtown	Capitol	50	30	70	55	64	69	0	0
Cambria Hotel Houston Downtown	Capitol	188	30	70	50	64	69	0	0
Hyatt Place Houston	Capitol	191	30	70	50	64	69	0	0
Magnolia Hotel Houston	Capitol	177	30	70	51	64	69	0	0
TOTAL NUMBER OF NOISE IMPACTS:								0	0

Source: Cross-Spectrum Acoustics, 2022

[1] Noise levels are based on Ldn and measured in dBA (rounded to the nearest decibel).
[2] Predicted levels include bus idling noise, where applicable (rounded to the nearest decibel) and are compared with the impact criteria to assess noise impact.
[3] The noise impact thresholds vary, depending on the land use category and the existing noise level.

Table 14. Summary of FTA Category 1 and 3 (Institutional) Noise Impacts Without Mitigation (Downtown Segment)

Noise-Sensitive Receiver Description	Street Location	Distance from Near Lane (feet)	Bus Speed (mph)	Existing Noise Level (dBA)[1]	Project Noise Level (dBA)[1]			Number of Institutional Impacts	
					Predicted[2]	Impact Criteria[3] Moderate	Impact Criteria[3] Severe	Moderate	Severe
Sesquicentennial Park	Bagby	117	30	65	52	66	71	0	0
Downtown Aquarium Houston	Bagby	74	30	69	54	69	74	0	0
Little Tranquility Park	Rusk/ Capitol	90	30	61	53	63	69	0	0
The Hobby Center for the Performing Arts	Bagby/ Rusk	166	30	61	50	58	64	0	0
Tranquility Park	Rusk	84	30	61	52	63	69	0	0
Federal Courthouse - 515 Rusk St	Rusk	53	30	66	54	66	72	0	0
Incarnate Word Academy	Capitol	48	30	65	54	66	71	0	0
Annunciation Catholic Church	Capitol	189	30	65	49	66	71	0	0
Kinder High School for the Performing Arts	Rusk/ Capitol	49	30	64	54	65	71	0	0
Jones Hall for the Performing Arts	Capitol	64	30	67	53	62	67	0	0
TOTAL NUMBER OF NOISE IMPACTS:								0	0

Source: Cross-Spectrum Acoustics, 2022

[1] Noise levels are based on 1-hour Leq and measured in dBA (rounded to the nearest decibel).
[2] Predicted levels include bus idling noise, where applicable (rounded to the nearest decibel) and are compared with the impact criteria to assess noise impact.
[3] The noise impact thresholds vary, depending on the land use category and the existing noise level.

Regarding **Table 13** and **Table 14**, it is important to note that the existing noise levels include highway noise and that the FTA criteria assess noise impact based on a comparison of the predicted noise from the proposed improvements with the existing noise rather than on the existing noise levels alone. The criteria are designed to limit the increase in cumulative noise when project-generated noise is added to existing noise levels. Because the cumulative noise increase due to the predicted project-generated noise did not exceed limits that are the basis of the FTA criteria, no moderate or severe noise impacts were identified along the Downtown Segment of the Inner Katy BRT Project, despite the existing noise conditions.

4.2.2. Operational Vibration Impacts

Land use along the Downtown Segment includes FTA Category 1 (high-sensitivity) receivers (the Hobby Center and Jones Hall), FTA Category 2 (residential) receivers and FTA Category 3 (institutional) receivers. Based on the ground surface vibration curves in **Figure 9**, vibration levels from bus operations at 30 mph on the downtown roadways are predicted to exceed the FTA vibration criterion for Category 1 land use (65 VdB) within 45 feet of the roadway centerline, the FTA vibration criterion for Category 2 land use (72 VdB) within 20 feet of the roadway centerline, and the FTA vibration criterion for Category 3 land use (75 VdB) within 10 feet of the roadway centerline. Because there are no vibration-sensitive receivers within these distances, no vibration impacts are anticipated from bus operations along the Downtown Segment. Furthermore, the proposed BRT vehicles would generate ground-borne vibrations that are comparable to vibrations generated by existing buses and lower than vibrations generated by light rail vehicles already in service along the planned BRT route.

4.2.3. Construction Noise and Vibration Impacts

Construction of BRT-related facilities will result in the generation of noise and vibration from construction equipment. Temporary noise and vibration during construction in the Downtown area, especially from construction of the new stations, has the potential of being intrusive to residents near the construction sites.

Construction noise and vibration will vary greatly depending on the construction process, type and condition of equipment used, and layout of the construction site. Many of these factors are traditionally left to the contractor's discretion, which makes construction noise difficult to accurately estimate during the planning phase of a project. Therefore, a quantitative assessment of construction noise and vibration impacts will be conducted during the design phase of the Project when detailed construction scenarios are available.

5. MITIGATION MEASURES

5.1. OPERATIONAL NOISE

Measures are being considered to mitigate the predicted moderate noise impacts from bus operations on the Inner Katy Segment of the Project. For the Downtown Segment, no operational noise impacts are predicted and therefore no mitigation measures are required.

Approaches that can be taken to mitigate the moderate noise impacts identified for bus operations along the Inner Katy Segment include noise control at the source (e.g., low noise pavements), noise control along the sound path (e.g., sound walls), and noise control at the receiver (e.g., residential noise insulation). Factors considered in identifying potential mitigation options include the following:

- Noise reduction effectiveness
- Feasibility (e.g., safety)
- Construction cost
- Operation and maintenance cost
- Agency (e.g., TxDOT) approval
- Visual Impact

Noise barriers are the most common mitigation measure for highway and transit projects. As such, METRO has considered various noise wall options along the elevated guideway, including transparent walls to minimize the visual impact. However, due to the high cost and safety considerations on the guideway, METRO has determined not to move forward with the noise wall options and has evaluated various low noise pavement options instead. Based on the above factors, the following three low noise pavement options (in combination with a solid 36-inch-high bridge parapet) have been determined to be feasible and to warrant consideration for mitigating noise impacts from bus operations along the Inner Katy Segment:

- **Longitudinal Saw Grooving.** Saw grooving is done to a concrete surface without smoothing or dressing the surface first (i.e., for a new deck). Grooves are cut with a diamond tipped saw so the blades last longer while cutting concrete. In combination with a solid 36-inch-high bridge parapet, this option is predicted to reduce project noise by 2 to 8 dBA.
- **Portland Cement Concrete (PCC) with Diamond Ground Surface.** Diamond grinding smooths the surface with closely spaced diamond tipped saw blades, producing a flat surface to reduce noise. In combination with a solid 36-inch-high bridge parapet, this option is predicted to reduce project noise by 3 to 9 dBA.
- **Next Generation Concrete Surface (NGCS).** Next Generation Concrete Surface (NGCS) combines saw grooving with diamond grinding to produce an even quieter surface, channel storm water, and increase skid resistance. In combination with a solid 36-inch-high bridge parapet, this option is predicted to reduce project noise by 3 to 10 dBA.

The noise reductions for the above options were predicted using a special research version of the FHWA Traffic Noise Model (TNM) v2.5. Detailed noise mitigation analysis will be conducted during design/ construction phase.

5.2. OPERATIONAL VIBRATION

No vibration impacts have been identified for bus operations along the Inner Katy Segment or Downtown Segment of the Project, and therefore no operational vibration mitigation measures are required.

5.3. CONSTRUCTION NOISE AND VIBRATION

All construction activities will be carried out in compliance with Houston METRO specifications and the applicable noise limits of the City of Houston Code of Ordinances. In addition, the following mitigation measures will be applied to the extent practical as needed to minimize temporary construction noise and vibration impacts:

- Avoid nighttime construction near residential neighborhoods;
- Construct noise barriers, such as temporary walls or piles of excavated material, between noisy activities and noise-sensitive receivers;
- Locate stationary equipment on the construction site as far away from noise sensitive sites as possible;
- Attach noise-deadening material to the inside of hoppers, conveyor transfer points or chutes;
- Limit the number and duration of equipment idling on the site, the use of annunciators of public address systems and the use of air or gasoline-driven hand tools;
- Minimize noise from the use of back-up alarms using measures that meet OSHA regulations (e.g., by using self-adjusting ambient-sensitive back-up alarms, using manually adjustable alarms on low setting, using observers, and configuring construction sites or scheduling activities to minimize alarm use);
- Use alternative construction methods to minimize the use of impact equipment (e.g., the use of drilled piles in place of impact pile driving); and
- Avoid the use of vibratory rollers and packers near sensitive areas.

A. APPENDIX – NOISE MEASUREMENT SITE PHOTOGRAPHS

Figure A-1. Site LT-1 (Houston SPCA)

Figure A-2. Site LT-2 (Scottish Inns Hotel)

Figure A-3. Site LT-3 (6315 Stillman Street)

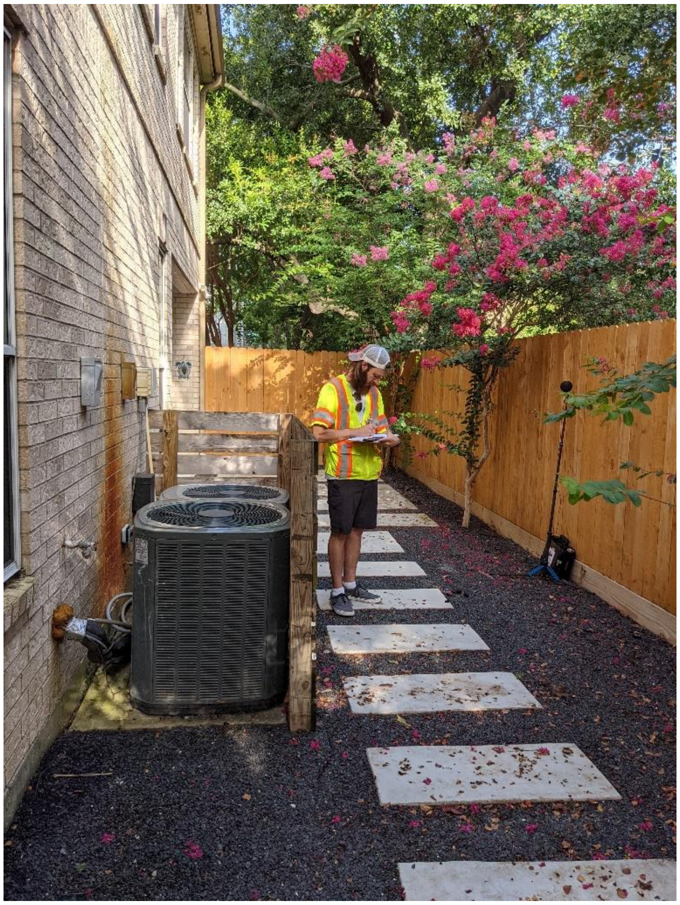


Figure A-4. Site LT-4 (1801 Sandman Street)

Figure A-5. Site LT-5 (1814 Fowler Street)

Figure A-6. Site LT-6 (1805 Thompson Street)

Figure A-7. Site LT-7 (1612 Bonner Street)

Figure A-8. Site LT-8 (1201 Shearn Street)

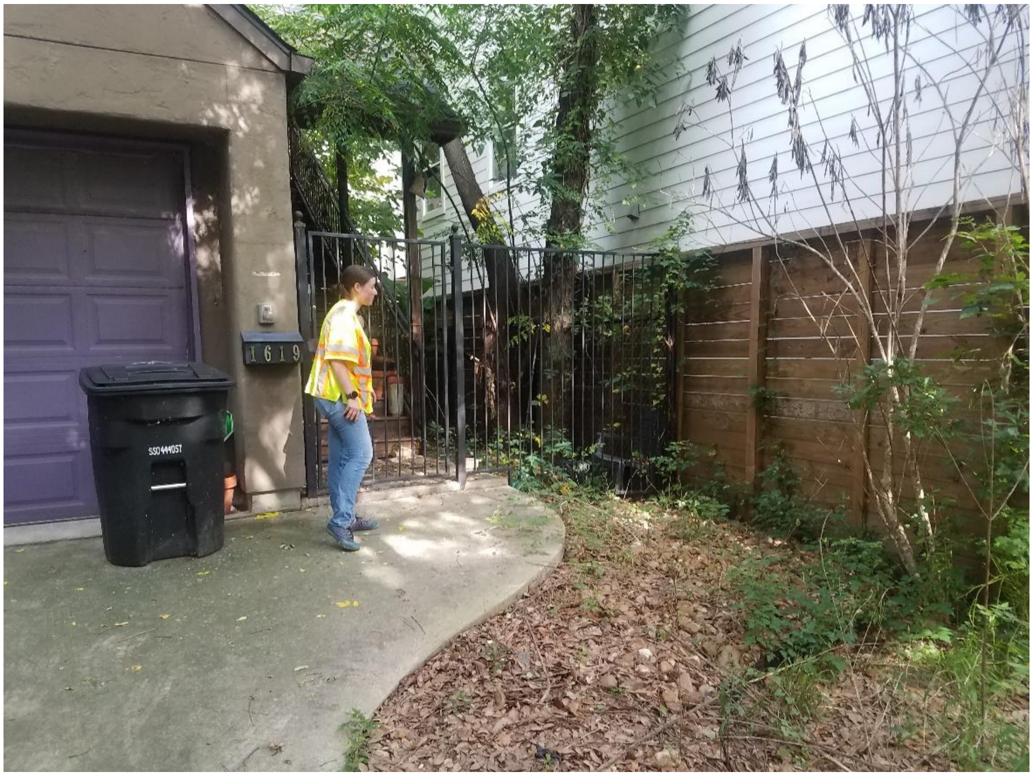


Figure A-9. Site LT-9 (1619 Beachton Street)

Figure A-10. Site LT-10 (The Star Apartments)

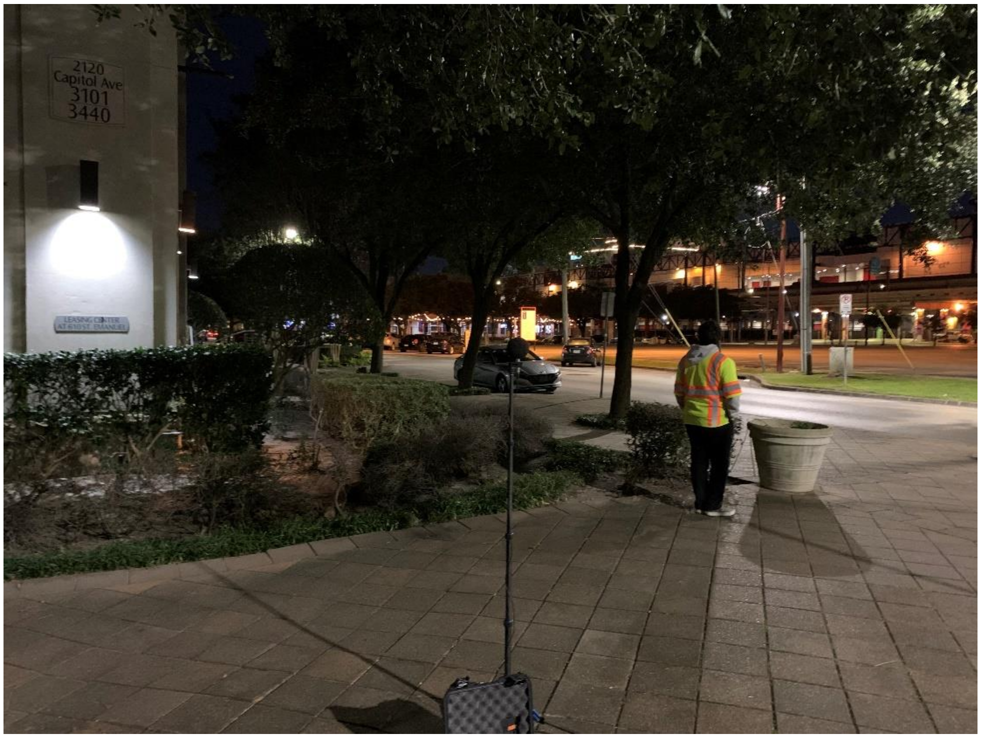


Figure A-11. Site LT-11 (2120 Capitol Street Apartments)

Figure A-12. Site LT-12 (1414 Texas Downtown Apartments - Day)

Figure A-13. Site LT-12 (1414 Texas Downtown Apartments - Night)

Figure A-14. Site ST-1 (2100 Arabelle Street)

Figure A-15. Site ST-2 (2003 Roy Street)

Figure A-16. Site ST-3 (4202 Marina Street)

Figure A-17. Site ST-4 (1814 Bonner Street)

Figure A-18. Site ST-5 (Camden Heights Apartments)

Figure A-19. Site ST-6 (Sawyer Heights Lofts Apartments)

Figure A-20. Site ST-7 (2418 Sabine Street)

Figure A-21. Site ST-8 (American Statesmanship Park)

Figure A-22. Site ST-9 (Sesquicentennial Park)

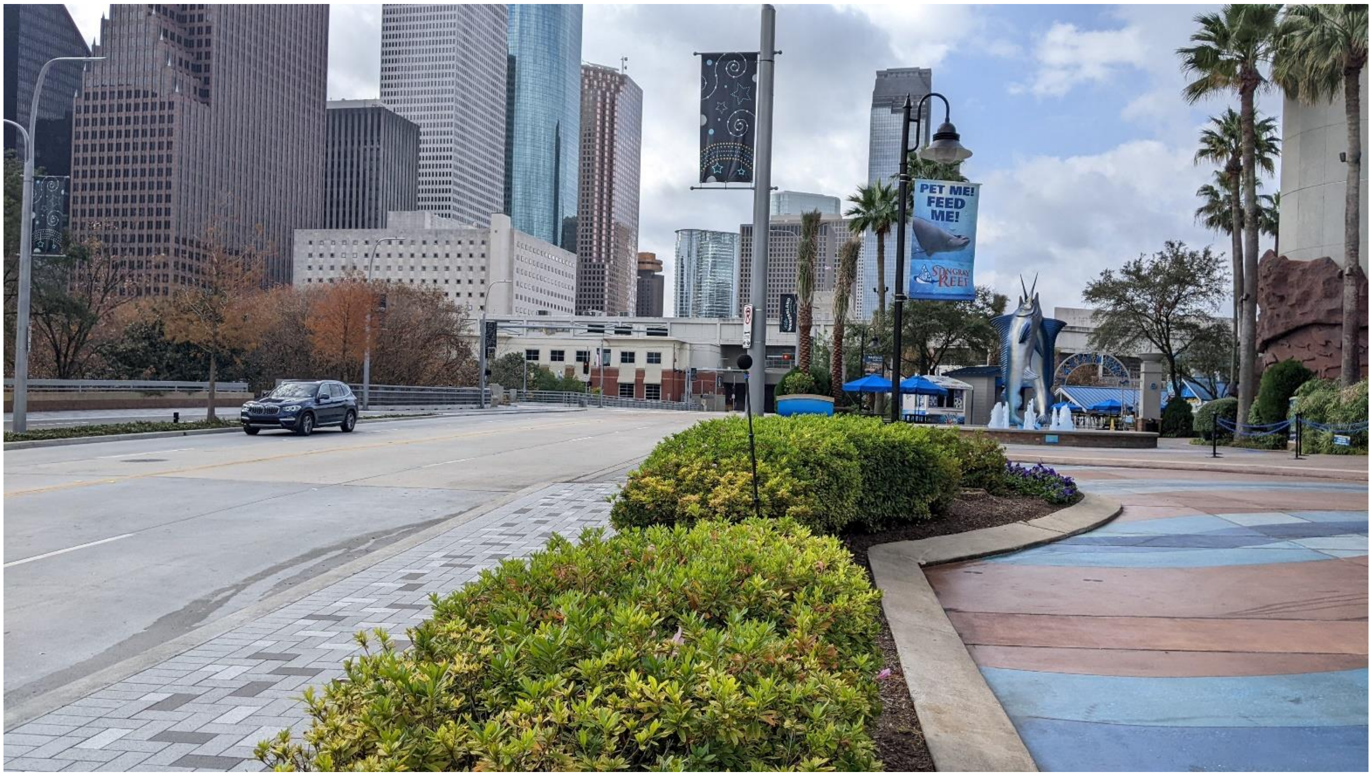


Figure A-23. Site ST-10 (Downtown Aquarium - Houston)

Figure A-24. Site ST-11 (Tranquility Park)

Figure A-25. Site ST-12 (Federal Courthouse)

Figure A-26. Site ST-13 (Kinder High School for the Performing and Visual Arts)

Figure A-27. Site ST-14 (Incarnate Word Academy)

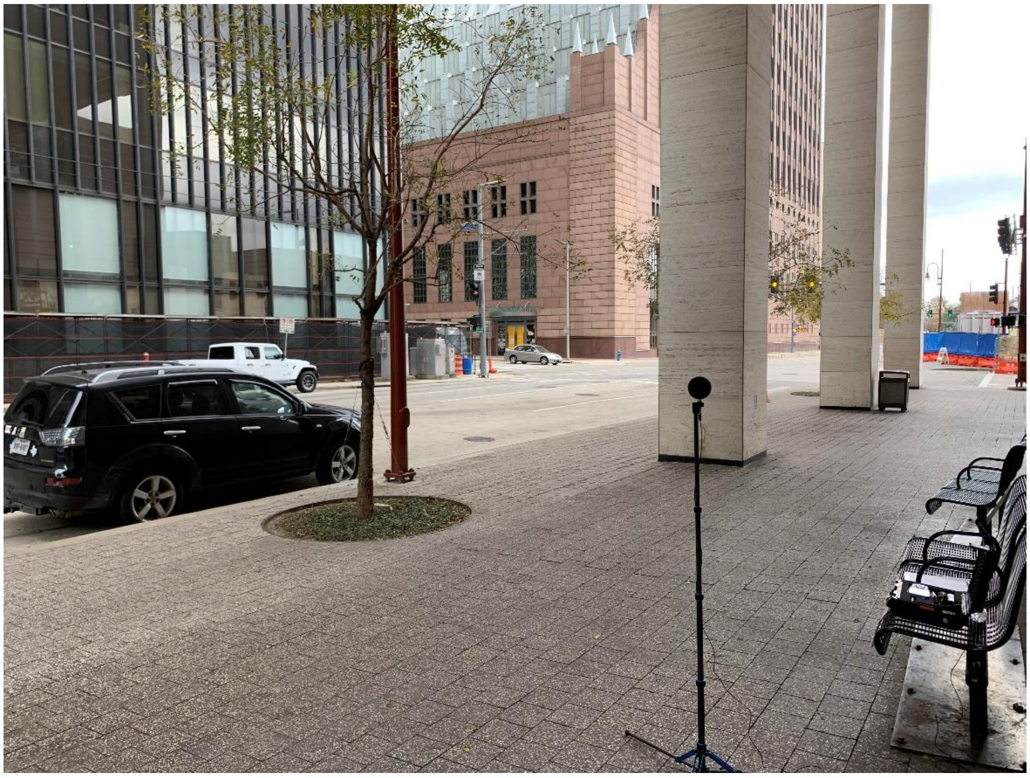


Figure A-28. Site ST-15 (Jones Hall for the Performing Arts)

Figure A-29. Site ST-16 (Little Tranquility Park)

B. APPENDIX – HOURLY NOISE MEASUREMENT DATA

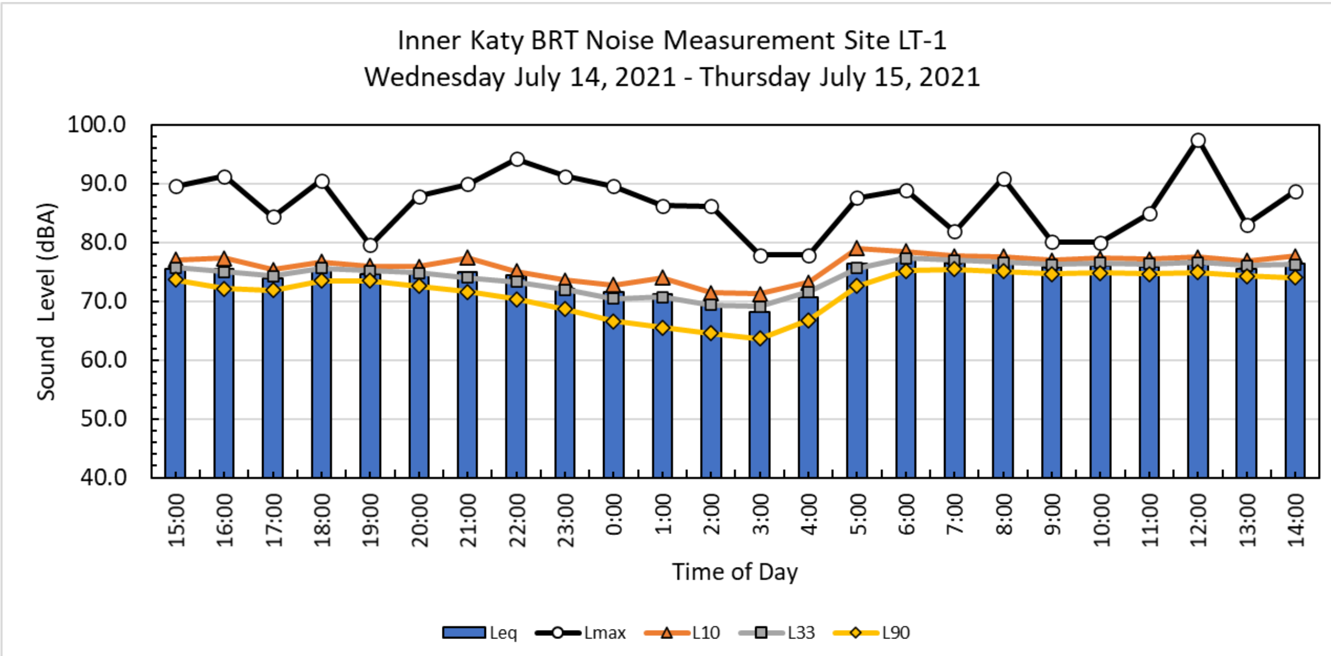


Figure B-1. Hourly Noise Levels at Site LT-1 (Houston SPCA)

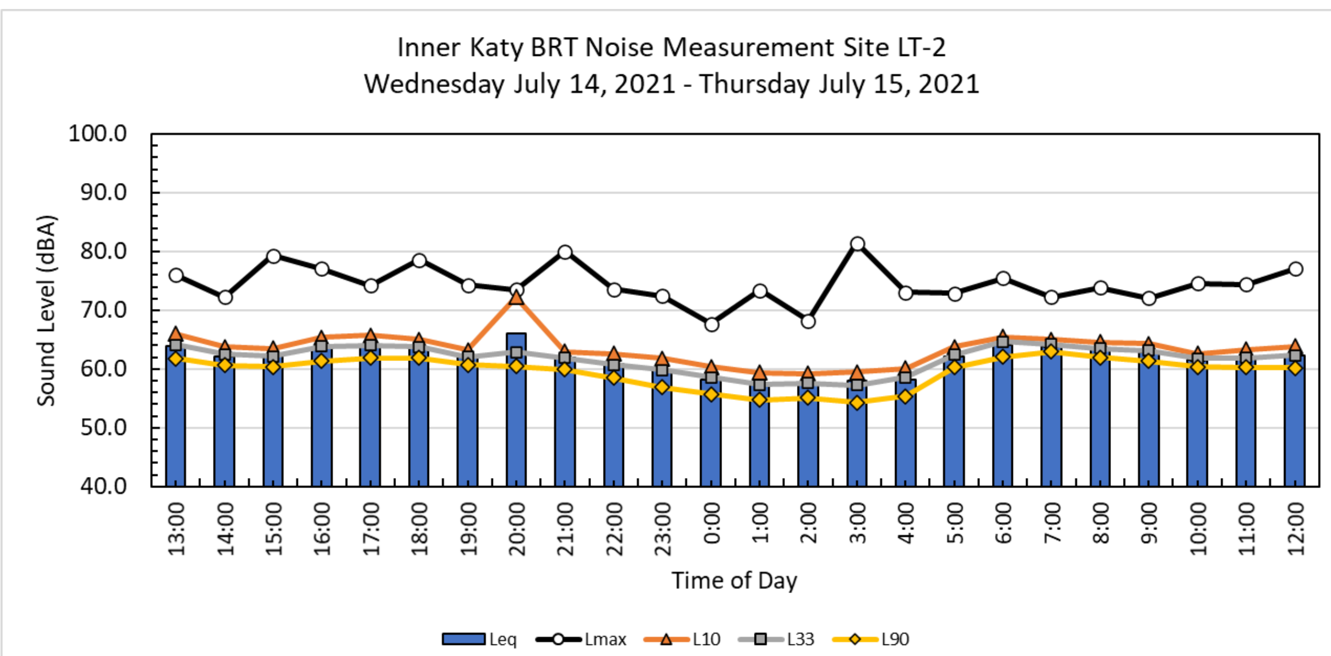


Figure B-2. Hourly Noise Levels at Site LT-2 (Scottish Inns Hotel)

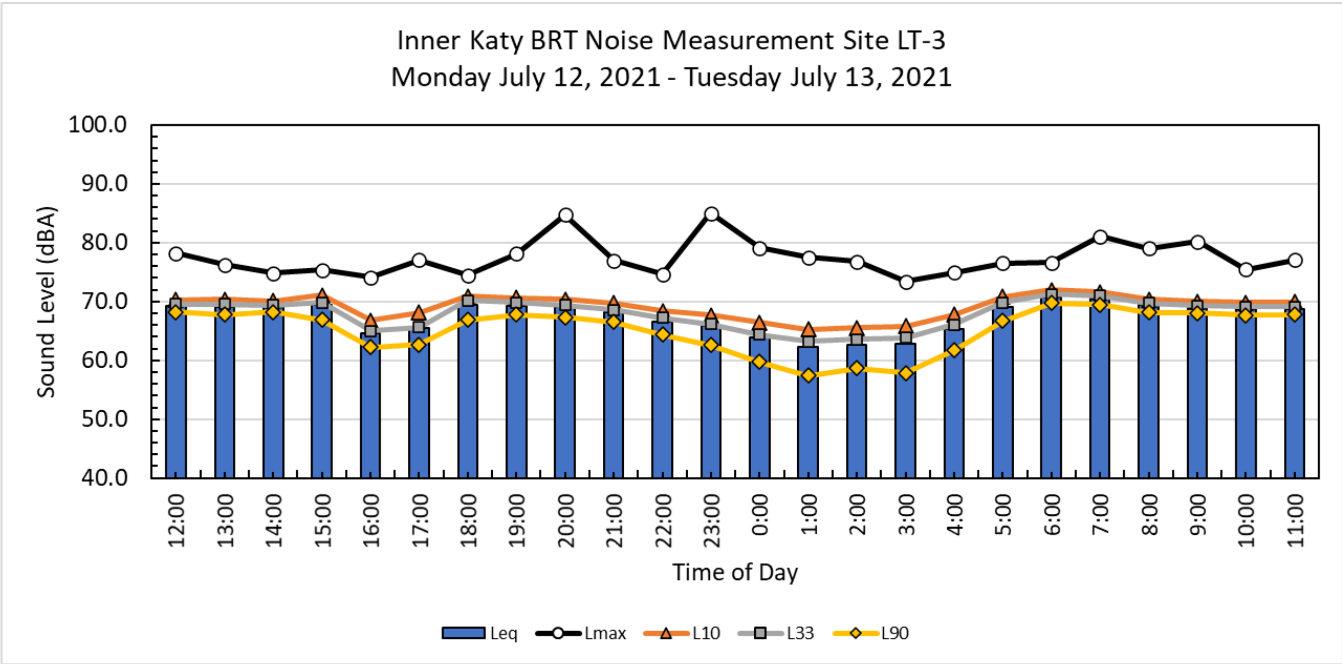


Figure B-3. Hourly Noise Levels at Site LT-3 (6315 Stillman Street)

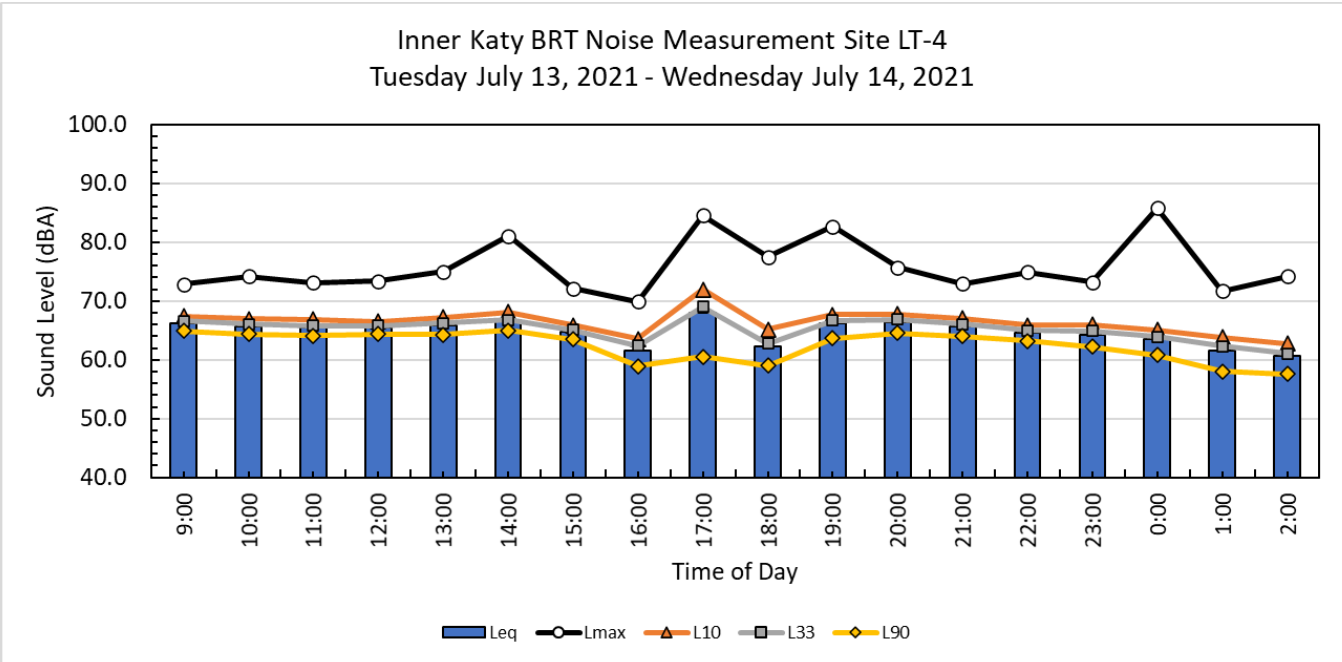


Figure B-4. Hourly Noise Levels at Site LT-4 (1801 Sandman Street)

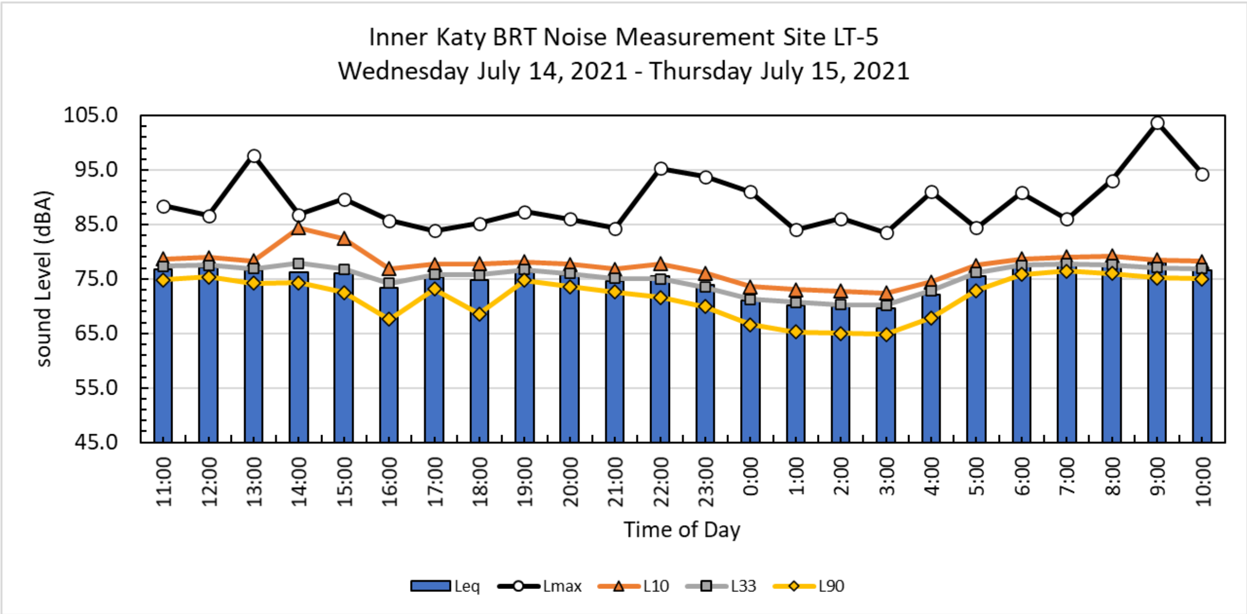


Figure B-5. Hourly Noise Levels at Site LT-5 (1814 Fowler Street)

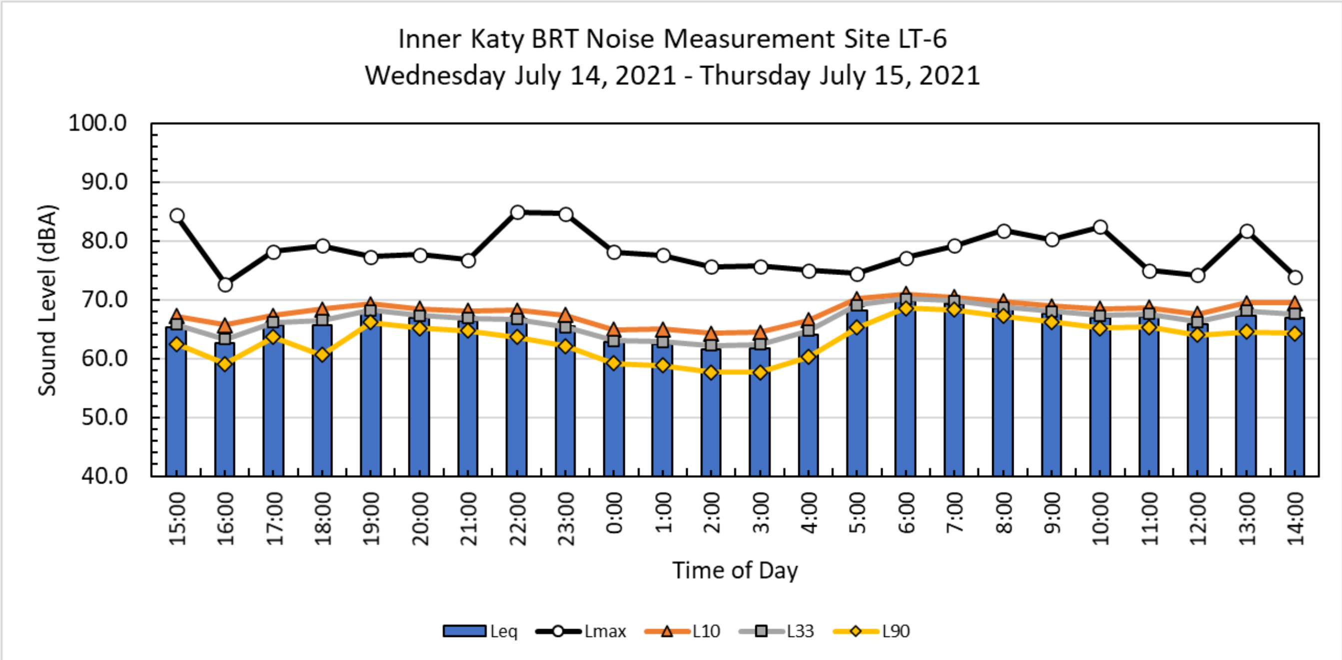


Figure B-6. Hourly Noise Levels at Site LT-6 (1805 Thompson Street)

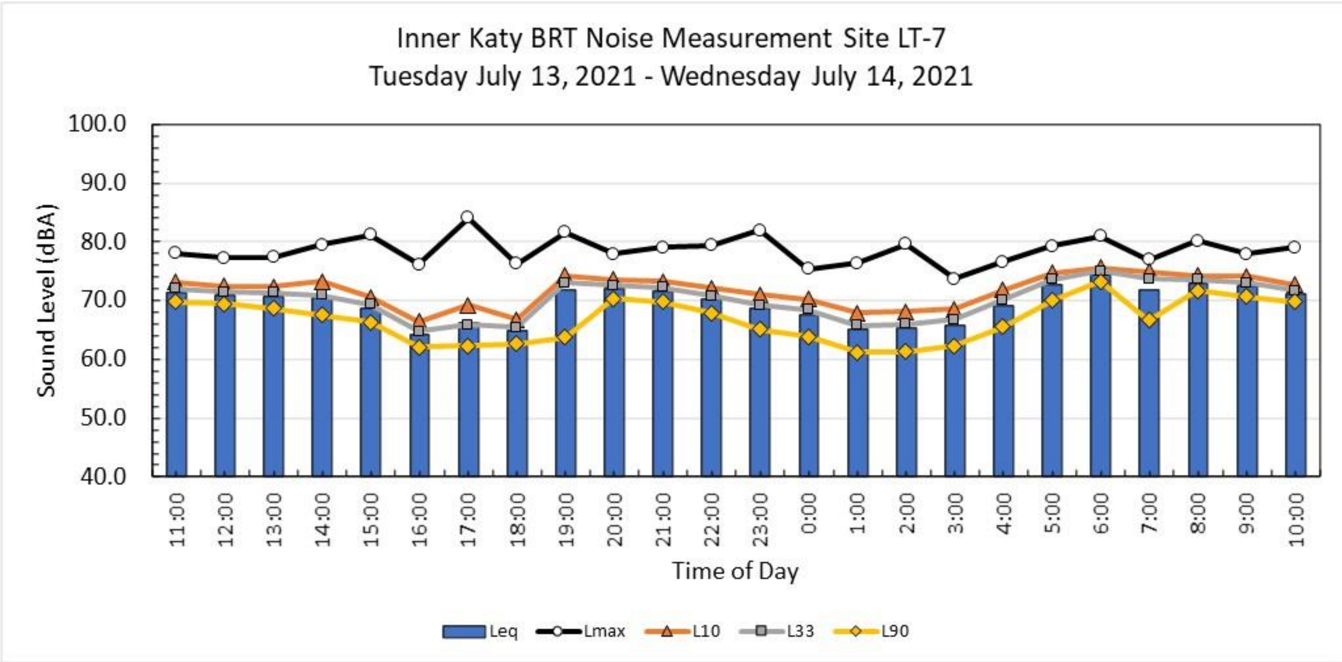


Figure B-7. Hourly Noise Levels at Site LT-7 (1612 Bonner Street)

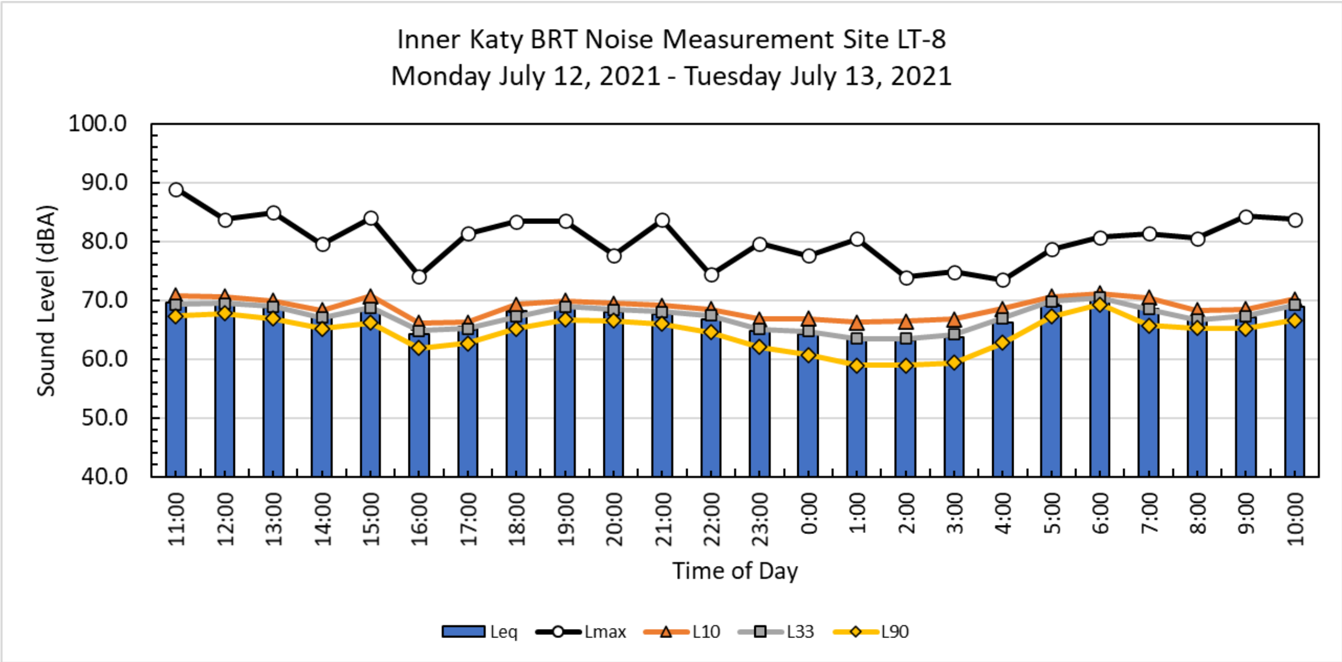


Figure B-8. Hourly Noise Levels at Site LT-8 (1201 Shearn Street)

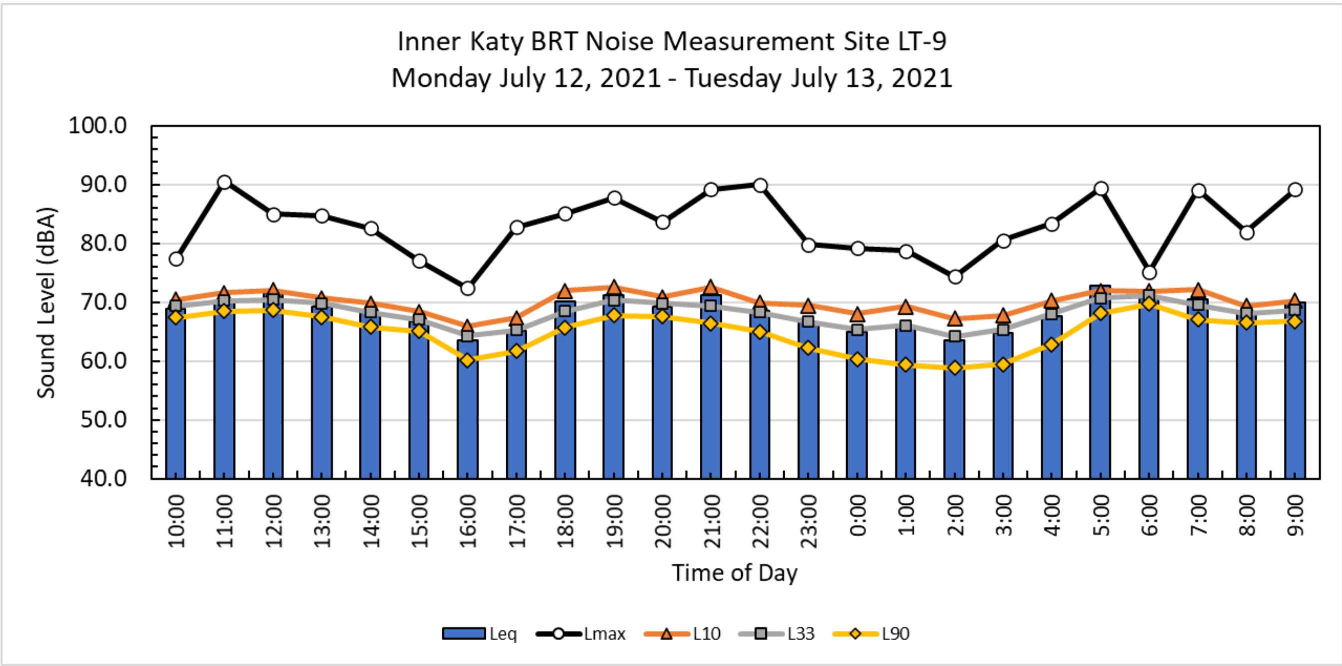


Figure B-9. Hourly Noise Levels at Site LT-9 (1619 Beachton Street)