TRAFFIC NOISE MANUAL

North Carolina Department of Transportation
Traffic Noise and Air Quality Group

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NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

TRAFFIC NOISE MANUAL

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1. INTRODUCTION

Some of the most pervasive sources of noise in our environment are those associated with transportation, and noise generated by vehicular traffic is a topic of public concern. The Federal-Aid Highway Act of 1970 mandated that the Federal Highway Administration (FHWA) develop noise standards for the abatement of highway traffic noise. FHWA prepared guidelines and standards for the abatement of highway traffic noise in the planning and design of federally funded highway projects. These standards comprise Title 23 of the United States Code of Federal Regulations Part 772 – *Procedures for Abatement of Highway Traffic Noise and Construction Noise* (23 CFR 772, July 2010) (USDOT-FHWA, 2010). The document "Highway Traffic Noise: Analysis and Abatement Guidance" (December 2011) (USDOT-FHWA, 2011) provides FHWA guidance for the analysis and abatement of highway traffic noise in accordance with 23 CFR 772. The 23 CFR 772 regulation required each state highway agency to develop their own set of guidelines that satisfy the requirements of 23 CFR 772.

In 2011, the North Carolina Department of Transportation (NCDOT) revised its *Traffic Noise Abatement Policy* and developed a *Traffic Noise Analysis and Abatement Manual* to comply with these federal requirements. The revised policy and manual became effective on July 13, 2011. The policy and manual were updated in 2016, with the 2016 NCDOT *Traffic Noise Policy* effective from October 6, 2016, to November 28, 2021. The most current updates are this 2022 manual and the 2021 NCDOT *Traffic Noise Policy* (effective date November 29, 2021). The current noise policy is included in **Appendix A**. Previous policies are included in **Appendix G**.

The purpose of this *Traffic Noise Manual* is to provide guidance and direction related to the performance of traffic noise analyses for NCDOT in order to assure conformance with the NCDOT *Traffic Noise Policy* and 23 CFR 772. Its intent is to provide such guidance and direction to NCDOT employees, consultants, local governments, and developers in their evaluation of traffic and construction noise and their development of appropriate noise reduction measures. The guidance contained in this manual is intended to supplement guidance contained in the FHWA's *Highway Traffic Noise: Analysis and Abatement Guidance*, and other FHWA guidance materials related to traffic noise analyses and the design of feasible and reasonable noise abatement measures.

2. DEFINITIONS

General definitions can be found in 23 CFR 772 (FHWA Website www.fhwa.dot.gov/environment/noise/regulations_and_guidance). The following definitions expand on those that are part of 23 CFR 772 and are particularly useful in areas for which direction and guidance are provided in this manual.

A-Weighted Sound Level: The weighting applied to measured sound pressure levels to account for frequencies to which human hearing is typically most sensitive (reference Decibel, below).

Acoustical Profile: The profile of the top of a noise barrier that is required to meet the acoustical performance requirements of the noise barrier. The top elevation of a constructed noise barrier at any point along the barrier must be equal to or higher than the acoustical profile's elevation at that point. Sometimes referred to as "minimum top of wall elevation."

Adjacent Receptor: A benefited receptor that 1) represents a property that abuts the highway right of way or 2) has no benefited receptor between it and the highway. Where multiple buildings containing benefited receptors are on the same property, such as an apartment or condominium complex, only the building closest to the highway is an adjacent receptor. Adjacent receptors will most often, but not always, be part of the front row of benefited receptors.

Ambient Noise: The combination of all noise sources that occur, typically described for a specific environment, location, and/or period of time.

Approach Criteria: One (1) dB(A) below the Federal Noise Abatement Criteria (NAC) for the land use activity categories A through E. A receptor is considered impacted if the predicted hourly equivalent traffic noise level meets or exceeds the approach criteria value. The Approach Criteria value is one of two criteria that define noise impacts, the other being a substantial increase in predicted noise levels over existing noise levels.

Benefited Receptor: All receptors, both impacted and non-impacted, that receive a noise level reduction of 5 dB(A) or more through placement of a noise abatement measure.

Categorical Exclusion (CE): A category of actions which do not individually or cumulatively have a significant effect on the human environment and for which neither an environmental assessment nor an Environmental Impact Statement is required. The term usually refers to the environmental document that supports this action.

Date of Public Knowledge: The date of approval of the final environmental document, determined by the approval of a Categorical Exclusion (CE) or the issuance of a State or Federal Finding of No Significant Impact (FONSI) or the issuance of a State or Federal Record of

Decision (ROD). If a noise study is prepared for a project processed under a Minimum Criteria Determination Checklist (MCDC), then the date of approval of the MCDC is the date of public knowledge.

Daytime Hours (Day): The hours of the day between 7:00 a.m. and 7:00 p.m.

Decibel (dB): The logarithmic unit for measuring sound pressure levels. For traffic noise measurements, decibels are most commonly reported in terms of the A- weighting frequency scale, which best includes the frequencies to which human hearing is typically most sensitive and is denoted by the abbreviation dB(A) (reference A-Weighted Sound Level, above).

Design Build Project: A project delivery system used in the construction industry. It is a method to deliver a project in which the design and construction services are contracted by a single entity known as the design-builder, design-build team, or design-build contractor.

Design Noise Report (DNR): A report that documents the methodology and findings of a final design noise analysis (reference Final Design Noise Analysis below). The Design Noise Report typically follows the recommendation of a Traffic Noise Report that traffic noise impacts exist, and that abatement measures are preliminarily deemed to meet feasibility and reasonableness criteria. A Design Noise Report may be prepared without a Traffic Noise Report if project criteria indicate a high likelihood that abatement measures will meet feasibility and reasonableness criteria.

Design Year: The future year used to estimate the probable traffic volume for which a highway is designed. Design year is typically 20 years beyond the completion year of project construction.

Environmental Assessment (EA): An Environmental Assessment is a public document that serves to briefly provide sufficient evidence and analysis for determining whether to prepare an Environmental Impact Statement (EIS) or a Finding of No Significant Impact (FONSI), to aid an agency's compliance with the National Environmental Policy Act when no EIS is necessary, and to facilitate preparation of an EIS when one is necessary.

Environmental Impact Statement (EIS): An Environmental Impact Statement is required for major actions that significantly affect the quality of the human and natural environment. An EIS is a full-disclosure document that details the process through which a transportation project was developed, includes consideration of a range of reasonable alternatives, analyzes the potential impacts resulting from these alternatives, and demonstrates compliance with other applicable environmental laws and executive orders.

Equivalent Receptor (ER): Receptors used to represent non-residential land uses. The number of equivalent receptors (or ER values) is determined by evaluating the person-hours-of-use-per-year associated with a non-residential land use and comparing it to the person-hours-of-use-per-year associated with a typical North Carolina single family residence. If the calculated total ER value mathematically is less than 1, a minimum total ER value of 1 should be used.

Evening Hours (Evening): The hours of the day between 7:00 p.m. and 10:00 p.m.

Final Design Noise Analysis: The analysis of noise that is usually conducted during the final design phase of project development. This analysis is usually initiated after the completion of a preliminary design noise analysis' preliminary determination that noise impacts exist, and that noise abatement is likely to be feasible and reasonable. A final design noise analysis may be prepared without a preliminary design noise analysis if sufficient design details are available and if there is a high likelihood that abatement measures will meet feasibility and reasonableness criteria. The final design noise analysis is documented in a Design Noise Report.

Finding of No Significant Impact (FONSI): When applicable, the conclusive determination after completion of the Environmental Assessment process that a highway project will not create any significant environmental impacts. The term usually refers to the environmental document that supports this action.

Holiday: Any weekend day or weekday recognized by the Federal and/or State Government as a non-working day.

Impacted Receptor: A receptor for which the predicted hourly equivalent traffic noise level 1) approaches (reaches one decibel less than), meets, or exceeds the Noise Abatement Criteria values found in Table 1 of the NCDOT *Traffic Noise Policy* (refer to **Appendix A**) or 2) exceeds the existing ambient noise level by 10 dB(A) or more.

Insertion Loss (IL): The reduction of traffic noise levels, in dB(A), that directly results from installation of a noise abatement measure. Insertion Loss only pertains to the reduction in traffic noise levels and is not synonymous with Noise Level Reduction (NLR), which also accounts for non-traffic noise sources.

L_{eq}: The equivalent steady-state sound level, which in a defined period of time, contains the same amount of acoustic energy as a time-varying sound level during the same period of time.

$L_{eq(h)}$: The equivalent sound level for a one-hour period of time.

NEPA (National Environmental Policy Act): Federal legislation that establishes environmental policy for the nation. It provides an interdisciplinary framework to ensure that decision-makers adequately take environmental factors into account.

Nighttime Hours (Night): The hours of the day between 10:00 p.m. and 7:00 a.m.

Noise: Any unwanted sound.

Noise Abatement Criteria (NAC)*:* Noise levels for various land uses that, if approached, met, or exceeded, require consideration of noise abatement (refer to **Table 8.1**). The NAC, along with Substantial Noise Increase, defined below, are used to determine if a proposed highway project creates noise impacts. The NAC are not intended to represent acceptable noise levels or noise abatement design goals. Compliance with the noise regulations is a prerequisite for the granting of Federal-aid highway funds for construction or reconstruction of a highway.

Noise Abatement Measure: Any method used to reduce traffic noise levels in response to predicted project-related noise impacts, such as noise walls and earthen berms.

Noise Barrier: A measure that provides noise abatement to impacted and non-impacted noise receptors. Such a measure can be either a single noise wall, a berm consisting of a variety of materials, a wall/berm system, or a system of more than one wall that acts as one unit. Noise barriers, or noise barrier systems functioning as a whole, must satisfy feasibility and reasonableness criteria to be recommended as abatement for a project.

Noise Barrier System: A noise barrier system is a combination of two or more overlapping barrier segments to provide benefits in the same Noise Study Area, where all segments are required to function as a whole to satisfy feasibility and reasonableness criteria. The overlapping segments may be needed to allow access for maintenance, to accommodate utilities, or for other reasons. A noise barrier system may also include a barrier that is broken into two segments to allow neighborhood access where both barrier segments are acoustically dependent on each other to provide abatement for the same Noise Study Area.

Noise Contour: A linear representation of equal noise levels, similar to elevation contour lines on a topographic map.

Noise Level Reduction (NLR): The reduction in $L_{eq(h)}$ noise levels accounting for all known noise sources and attenuating measures. For traffic noise analyses, NLR is the assessment of barrier insertion loss, IL, screened against measured or otherwise quantified noise sources. For example, if a barrier adjacent to a proposed highway on new alignment was predicted to reduce worst noise hour traffic noise levels at an impacted receptor from 66 dB(A) to 54 dB(A), the Insertion Loss would be 12 dB(A). However, if the measured existing ambient noise level in the area that includes the receptor was 57 dB(A), then the *actual* reduction in worst noise hour noise levels would be 66 dB(A) – 57 dB(A), or 9 dB(A). Because barriers can only reduce traffic noise levels, NLR is the actual reduction in worst hour noise levels as described in the example and is the appropriate metric by which to quantify predicted barrier effectiveness.

Noise Reduction Coefficient (NRC): A single number rating of the sound-absorptive properties of a material. NCDOT has an NRC criterion of 0.70 or greater when an absorptive treatment is required.

Noise Reduction Design Goal (NRDG): The minimum-required predicted noise level reduction resulting from design of a traffic noise abatement measure. A noise reduction design goal of 7 dB(A) must be achieved for at least one benefited receptor, whether impacted or not. If it can be achieved for one benefited receptor, then the barrier shall be optimized to achieve 7 dB(A) NLR at as many impacted receptors as possible. The initial evaluation of at least one NRDG is focused on all benefits. The subsequent assessment of achieving NRDG at additional receptors is focused only on meeting a 7 dB(A) reduction at impacted receptors.

Noise Study Area (NSA): A group or grouping of receptors into an area that is influenced by similar noise sources.

Optimized Barrier: A noise barrier design with a horizontal alignment and vertical (top) profile based upon an appropriate TNM model, that is designed to find a balanced approach that provides noise level reduction benefits to as many predicted impacted receptors as possible, meets the Noise Reduction Design Goal, meets applicable feasibility and reasonableness criteria, and addresses all other pertinent considerations such as, but not limited to, costs, lines-of-sight, visual impacts, environmental impacts, safety, drainage, utility conflicts, maintenance of the barrier, and with-barrier noise levels.

Peak Hour Traffic: Highest hourly traffic volume in a 24-hour period, not to be confused with the worst noise hour traffic (refer below to Worst Noise Hour).

Permitted: The approval of a building permit for an individual lot or site. Approval of a development plat or any other development plan does not by itself meet the definition of "permitted".

Practicable: Available and capable of being done after taking into consideration cost, existing technology, and logistics in light of overall project purposes. This determination only applies to state funded projects that do not utilize federal-aid highway funds and do not require FHWA approval.

Preliminary Design Noise Analysis: The analysis of noise conducted during the preliminary design phase of project development. The results of this analysis are usually provided in a Traffic Noise Report (TNR), which is summarized or incorporated into the appropriate NEPA/SEPA document prepared for the environmental clearance of a proposed project.

Property Owner: An entity that holds legal ownership of land or other real property.

Public Hearing: A forum which is open to the general public to present information related to a project and to obtain formal input from the public.

Public Meeting: A forum which is open to the general public or specific portions of the public to present and discuss information related to a project with attendees, to answer questions from attendees, and to obtain input from attendees. Public meetings are generally less formal than public hearings and may only deal with specific topics, such as traffic noise.

Receptor: A discrete or representative location of a noise sensitive area(s), for any of the land uses listed in Table 1 of 23 CFR 772. A receptor is interchangeable with the term “receiver” in TNM. However, NCDOT prefers the term receptor be used in TNR and DNR documentation.

Record of Decision (ROD): The final step in the Environmental Impact Statement process, whereby the Federal and/or State Government issues final approval of the environmental documentation.

Sound Level Meter (SLM): An instrument used to measure sound levels, as specified by ANSI S1.4-1983. A Type-I or Type II sound level meter must be used to obtain all sound level data for NCDOT preliminary design noise analyses, final design noise analyses, and construction noise analyses pertaining to NCDOT projects.

Sound Transmission Class (STC): A single number rating used to compare sound insulation properties of barriers. NCDOT has an STC criterion of 30 or greater based upon ASTM E90.

Substantial Noise Increase: Along with the NAC, defined above, one of two criteria to determine noise impacts created by a proposed highway project. A receptor is considered impacted if the predicted future hourly equivalent noise level exceeds the existing ambient noise level by 10 dB(A) or more.

TNM Receiver: A location where traffic noise levels are modeled using the FHWA Traffic Noise Model (TNM). It is interchangeable with the term "receptor"; NCDOT prefers “receptor” in its documentation. Although a TNM Receiver may represent one or more receptors in the input field in TNM, NCDOT requires the use of one receptor for each dwelling unit, including apartments and other multi-family development. A TNM Receiver is also used to represent a measurement site when validating the TNM.

Traffic Noise Impacts: Noise levels that are predicted to approach or exceed the NAC and/or represent a substantial noise increase at noise-sensitive receptors in the project area.

Traffic Noise Model (TNM): The computer modeling program created by FHWA used to predict hourly equivalent traffic noise levels. The TNM version required for use by FHWA, or another model determined by FHWA to be consistent with the methodology of TNM, shall be used on all federal- and state-funded highway projects in North Carolina for which traffic noise analysis is required.

Traffic Noise Report (TNR): A report that documents the methodology and findings of a preliminary design noise analysis.

Type I Project: Type I Projects are defined in the 2021 NCDOT Traffic Noise Policy as:

(a) The construction of a highway on new location; or,

(b) The physical alteration of an existing highway where there is either:

(i) Substantial Horizontal Alteration. A project that halves the distance between the traffic noise source and the closest receptor between the existing condition to the future build condition (Note: NCDOT measures the distance from the edge of the nearest travel lane to the closest receptor); or,

(ii) Substantial Vertical Alteration. A project that removes shielding, exposing the line of sight between the receptor and the traffic noise source. This occurs when either the highway vertical alignment is altered, or when the intervening topography between the highway traffic noise source and receptor is altered; or,

(c) The addition of a through-traffic lane(s). This includes the addition of a through-traffic lane that functions as a HOV lane, High-Occupancy Toll (HOT) lane, bus lane, or truck climbing lane; or,

(d) The addition of an auxiliary lane 2,500 feet long or longer; or,

(e) The addition or relocation of interchange lanes or ramps added to a quadrant to complete an existing partial interchange; or,

(f) Restriping existing pavement for the purpose of adding a through-traffic lane or an auxiliary lane; or,

(g) The addition of a new or substantial alteration of a weigh station, rest stop, ride- share lot or toll plaza.

(h) If a project is determined to be a Type I project under this definition, then the entire project area as defined in the environmental document is a Type I project.

(i) NOTE 1: If any improvement or element of a project is defined as a Type I project, then the entire project as defined in the NEPA or SEPA document is a Type I project. See **Section 5.1** for more information.

NOTE 2: During project scoping, if it is discovered there are no noise sensitive receptors in the noise study area, only noise contour information is required even if the project is a Type I project. See **Section 5.1** for more information.

Type II Project: A Federal or Federal-aid highway project that provides noise abatement on an existing highway without any other roadway improvements. For a Type II project to be eligible for Federal-aid funding, the highway agency must develop and implement a Type II program in accordance with 23 CFR 772.7(e).

Type III Project: A Federal or Federal-aid highway project that does not meet the classifications of a Type I or Type II project. Type III projects do not require a noise analysis.

Weekday: Excluding holidays, the days of the week between Monday and Friday, inclusive.

Weekend: Excluding holidays, the days of the week including Saturday and Sunday.

Worst Noise Hour: The hour within a day in which the highest magnitude hourly equivalent sound level occurs. The worst traffic noise hour typically occurs when traffic is flowing freely at a high volume relative to the peak traffic hour volume, with a high percentage of trucks.

3. TRAFFIC NOISE FUNDAMENTALS

Sound is created when an object moves – the rustling of leaves as the wind blows, the air passing through our vocal cords, the almost invisible movement of stereo speakers. The movements cause the vibrations of the molecules in the air to move in waves like ripples on water. When the vibrations reach our ears, we hear them.

Noise is unwanted or irritating sound. It is emitted from many sources, including airplanes, factories, railroads, commercial businesses, and highway vehicles. Highway traffic noise is predominantly a composite of noises from the vehicles' engine exhaust, drive train, and tire-roadway interaction.

The magnitude of sound (and noise) is typically described by the logarithm of the ratio of the sound pressure to a reference sound pressure, which is usually twenty micro-Pascals (20 μPa). Since the range of sound pressure ratios varies greatly – over many orders of magnitude, a base-10 logarithmic scale is used to express sound levels in dimensionless units of decibels (dB). The commonly accepted limits of human hearing to detect magnitudes of sound are between the threshold of hearing at 0 decibels and the threshold of pain at 140 decibels.

Sound frequencies are represented in units of Hertz (Hz), which correspond to the number of vibrations per second of a given tone. A cumulative sound level is equivalent to ten times the base-10 logarithm of the ratio of the sum of the sound pressures of all frequencies to the reference sound pressure. To simplify the mathematical process of determining sound levels, sound frequencies are grouped into ranges, or bands, each typically representing either one octave or 1/3 octave of the sound frequency spectrum. Since the cumulative sound level is a representation of the total sound pressure (energy), cumulative sound levels are then calculated by adding all the sound pressure levels of each band and multiplying the logarithm of the ratio of the result and the reference sound pressure level (e.g., 20 μPa) by ten.

The commonly accepted limits of human hearing to detect sound frequencies are between 20 Hz and 20,000 Hz, and human hearing is most sensitive to the frequencies between 1,000 Hz and 6,000 Hz. Although people are generally not as sensitive to lower-frequency sounds as they are to higher frequencies, most people's ability to hear high-frequency sounds is reduced as they age. To accommodate varying receptor sensitivities, frequency sound levels are commonly adjusted, or filtered, before being logarithmically added and reported as a single sound level magnitude of that filtering scale.

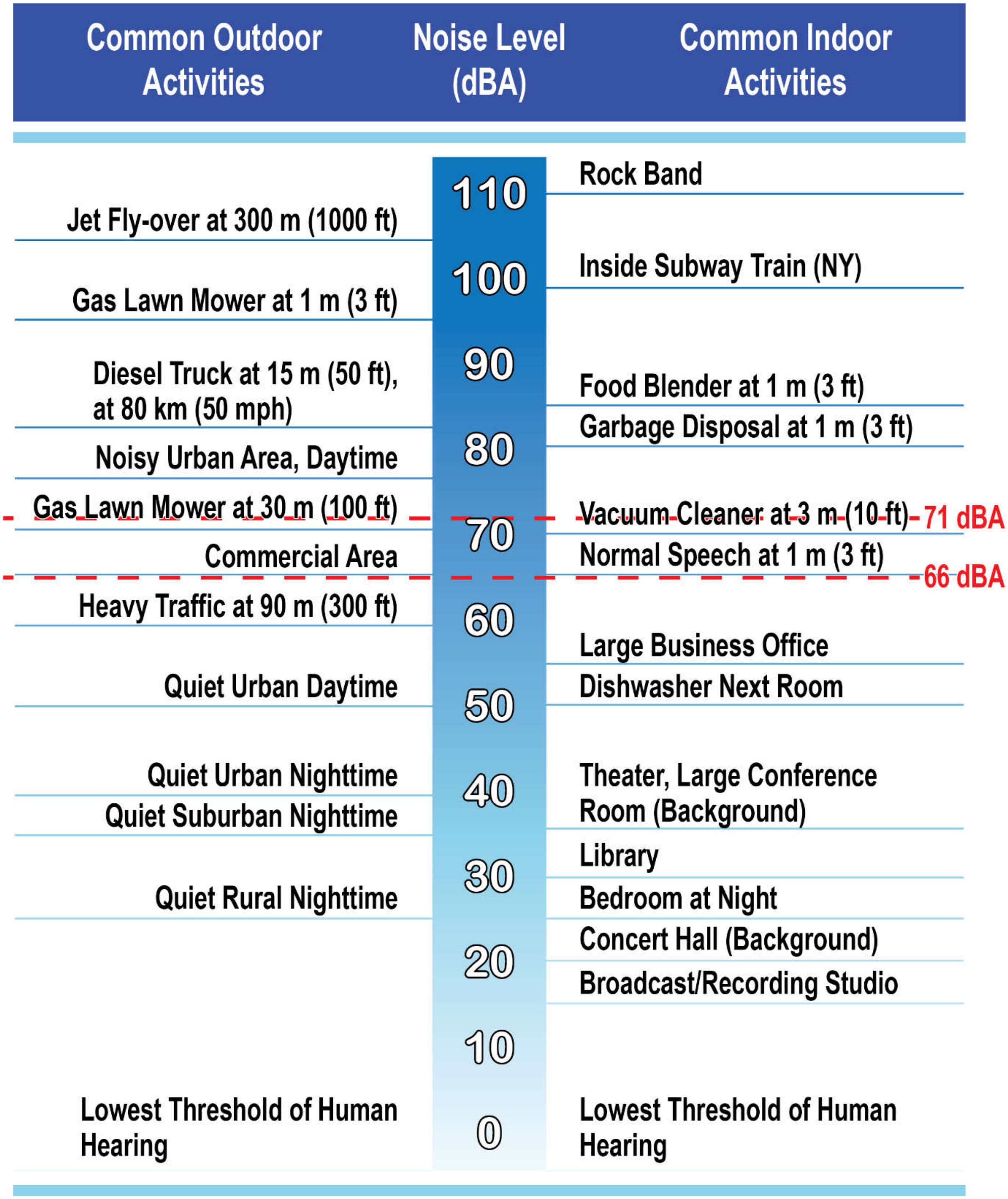
Table 3.1. Comparison of Unweighted vs. A-Weighted Sound Levels for a Truck

	A	B	C=A+B
Octave-Band Center Frequency (Hz)	Unweighted Sound Level from a Truck (dB)	Adjustment of Unweighted Sound to Reflect What Human Ears Hear (dB)	Sound Level that Human Ear Perceives = A-Weighted Sound Level or dB(A)
31	75	-39	36
63	78	-26	52
125	83	-16	67
250	84	-9	75
500	81	-3	78
1000	75	0	75
2000	71	1	72
4000	63	1	64
8000	54	-1	53
	89		82
	Total Unweighted Sound Level in dB		Total A-Weighted Sound Level in dB(A)

The A-weighted decibel filtering scale applies numerical adjustments to sound frequencies to emphasize the frequencies at which human hearing is sensitive, and to minimize the frequencies to which human hearing is not as sensitive. In essence, the A-weighting approximates the sound that a person with average hearing perceives. This concept of A-weighting is illustrated in **Table** 3.1 above for a single truck. The actual (unweighted) sound produced by the truck is comprised of various frequencies (left column of the table) and produces a sound level for each frequency (Column A) resulting in a total noise level of 89 decibels (dB). However, the human ear perceives (hears) each frequency differently. The adjustments that reflect how the human ear perceives or filters each frequency's sound level are listed in Column B of the table. Column C contains each frequency's adjusted (or A-weighted) sound levels, resulting in a total A-weighted sound level of 82 dB, expressed as 82 dB(A). Thus, while the truck's unweighted sound level is 89 dB, it is perceived by the human ear to be 82 dB(A).

Several examples of noise levels, expressed in dB(A), are listed in **Table** 3.2. A review of **Table** 3.2 indicates that most individuals are exposed to fairly high noise levels from many sources on a regular basis.

Table 3.2. Common Indoor and Outdoor Noise Levels



Adapted from exhibit on FHWA website accessed 5/4/22:
https://www.fhwa.dot.gov/environment/noise/resources/reviewing_tnm_model/#toc493601036 (USDOT-FHWA, 2018)

The degree of disturbance or annoyance from exposure to unwanted sound depends upon three factors:

1. The amount, nature, and duration of the intruding sound
2. The relationship between the intruding sound and the existing (ambient) sound environment; and
3. The situation in which the disturbing sound is heard

In considering the first of these factors, it is important to note that individuals have varying sensitivity to sound. Loud sounds bother some people more than other people, and some individuals become increasingly upset if an unwanted sound persists. The time patterns of sound also enter into perception as to whether or not a sound is offensive. For example, sounds that occur during nighttime (sleeping) hours are usually considered to be more offensive than the same sounds in the daytime.

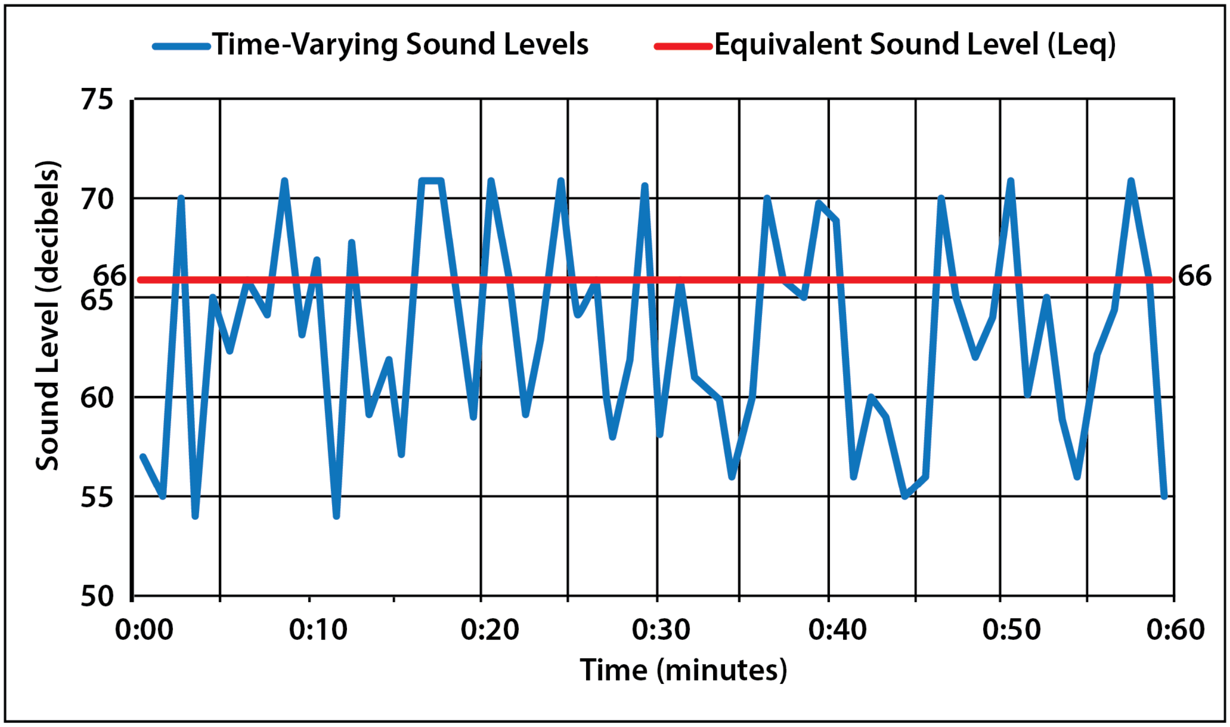
With regard to the second factor, individuals tend to judge the annoyance of an unwanted sound in terms of its relationship to sounds from other sources, or background sound levels. A car horn blowing at night when background sound levels are low would generally be more objectionable than one blowing in the afternoon when background sound levels are typically higher. The response to sound stimulus is analogous to the response to turning on an interior light. During the daytime an illuminated bulb simply adds to the ambient light, but when eyes are conditioned to the dark of night, a suddenly illuminated bulb can be temporarily blinding.

The third factor – situational sound – is related to the interference of sound levels with activities of individuals. In a 55 dB(A) environment such as is commonly found in a large business office, normal conversation would be possible, while sleep might be difficult. Loud sounds may easily interrupt activities that require a quiet setting for greater mental concentration or rest; however, the same loud sounds may not interrupt activities requiring less mental focus or tranquility.

Over time, individuals tend to acclimate to the sounds that intrude into their lives, e.g., regularly scheduled trains or subways in a city, particularly if the sounds occur at predicted intervals and are expected. Attempts have been made to regulate many types of unwanted sounds (or noise) including airplane noise, factory noise, railroad noise, and highway noise.

In addition to sound varying in frequency, sound intensity fluctuates with time. The L_{eq}, or equivalent sound level, is the equivalent steady-state sound level which in a stated period of time contains the same acoustic energy as a time-varying sound level during the same period. This sound descriptor has gained wide acceptance as a good representation of the aforementioned three factors. With regard to traffic noise, fluctuating sound levels associated with traffic are represented in terms of L_{eq}, the steady, or equivalent, sound level with the same energy. **Figure** 3-1 illustrates an example of the variation in noise levels over an hour that equate to a 66 dB(A) L_{eq} level.

Figure 3-1. Time-Varying Sound Levels vs. Equivalent Sound Level (Leq)



Because decibels are logarithmic representations of large ratios, they cannot be added arithmetically. A chart for approximate decibel addition is shown in **Table 3.3**. A doubling of the sound source produces a 3 dB(A) increase. For example, two trucks producing 90 dB(A) each will combine to produce 93 dB(A), not 180 dB(A). Also, assuming the same distribution of vehicle types, doubling the traffic volume from 400 vehicles per hour (vph) to 800 vph would create a 3 dB(A) noise level increase if the traffic speed remained constant.

Table 3.3. Rules for Combining Sound Levels by Decibel Addition

For sound levels known or desired to an accuracy of +/- 1 decibel:

When two decibel values differ by	Add the following amount to the higher value
0 or 1 dB(A)	3 dB(A)
2 or 3 dB(A)	2 dB(A)
4 or 9 dB(A)	1 dB(A)
10 dB(A) or more	0 dB(A)

As referenced in **Table 3.4**, variations of three dB(A) or less are commonly considered barely perceptible to normal human hearing. A five decibel (5 dB(A)) change is more readily noticeable. An increase or decrease of 10 dB(A) in the sound pressure level is typically perceived as a doubling or halving of the sound level intensity. For example, a sound at 70 dB(A) will sound twice as loud as a sound at 60 dB(A).

Generally, sound intensity decreases in proportion to distance from the source. Sound levels from a point source will generally decrease by 6 dB(A) or more for each doubling of distance away from the point of origin because the sound energy dissipates from the source in a spherical pattern. Sound levels from a line source such as steady vehicle traffic on a highway will generally decrease by 3 dB(A) or more for each doubling of distance away from the line of origin because the sound energy dissipates from the source in a cylindrical pattern. Empirical evidence has shown that noise levels produced by steady vehicle traffic on a highway decrease at varying rates, converging at approximately a 4.5 dB(A) reduction per doubling of distance from the highway, depending upon several attenuating factors including distance, intervening ground hardness/softness, structures, forestation, ground elevations, source-to-receptor spatial relationships, weather, and other factors.

Table 3.4. Relationships Between Changes in Sound Levels and Loudness

Sound Level Change	Relative Change in Loudness Perceived by Humans
+30 dB(A)	Eight Times as Loud
+20 dB(A)	Four Times as Loud
+10 dB(A)	Twice as Loud
+5 dB(A)	Readily Perceptible
+3 dB(A)	Barely Perceptible
0 dB(A)	No Change
-3 dB(A)	Barely Perceptible
-5 dB(A)	Readily Perceptible
-10 dB(A)	Half as Loud
-20 dB(A)	1/4 as Loud
-30 dB(A)	1/8 as Loud

Since the sound levels associated with vehicles traveling on highways are almost always considered to be either intruding, annoying, unwanted, or disturbing to nearby receptors of such sounds, the term noise is usually used in describing the levels, impacts, and abatement associated with vehicles traveling on highways.

For the purpose of highway traffic noise analyses, motor vehicles fall into one of five categories:

- Automobiles - vehicles with two axles and four wheels,
- Medium Trucks - vehicles with two axles and six wheels,
- Heavy Trucks - vehicles with three or more axles,
- Buses – vehicles suited for transport of nine or more passengers, and
- Motorcycles – open-cockpit vehicles with two or three wheels.

The emission levels of all of these vehicle types increase as a function of the logarithm of their speed.

The level of highway traffic noise is primarily dependent upon:

- the volume of the traffic,
- the percentages of the different types of vehicles in the volume of traffic,
- the speed of the traffic,
- pavement condition, and
- distance between the receptor and the roadway.

Generally, the loudness of traffic noise is increased by heavier traffic volumes, a higher percentage of trucks, and/or higher speeds. Vehicle noise is predominantly a combination of noise emissions from engines, exhausts, and tire/pavement interaction. Traffic noise is also dependent upon other factors such as roadway geometry (e.g., inclines and/or declines), defective equipment, and vehicle operation. Assuming constant vehicle mix and speed, a tenfold increase in traffic volumes (200 vehicles per hour increases to 2000 vehicles per hour) sounds twice as loud. Traffic at 65 miles per hour sounds twice as loud as traffic at 30 miles per hour. One truck at 55 miles per hour sounds as loud as ten cars at 55 miles per hour (https://acousticstoday.org/wp-content/uploads/2018/08/Highway-Traffic-Noise-Judith-L.-Rochat.pdf (Rochat, 2016)).

4. LEGISLATION, REGULATIONS, AND ORDINANCES

Mitigating the undesirable effects of highway traffic noise requires that land use near highways be controlled, quieter vehicles be manufactured, and consideration of traffic noise impacts and abatement occur on qualifying highway projects.

The first component of effective highway traffic noise control is for local governments to develop and implement noise-sensitive land use planning regulations. The second component is source control. The final component is the responsibility of Federal, State, and local governments to identify and, when feasible and reasonable, abate traffic noise impacts as part of individual highway projects.

4.1. Land Use Planning and Control

The FHWA and NCDOT have no authority to regulate land use planning or the land development process. The FHWA and other Federal agencies encourage State and local governments to practice land use planning and control in the vicinity of highways. The FHWA advocates that local governments use their power to regulate land development in such a way that noise-sensitive land uses are either prohibited from being located adjacent to a highway, or that the developments are planned, designed, and constructed in such a way that traffic noise impacts are minimized.

In accordance with 23 CFR 772.17, NCDOT will provide "information to local officials on estimated future design year noise levels at various distances from the edge of the nearest travel lane of the highway improvement where the future noise levels meet the highway agency's definition of "approach" for undeveloped lands or properties within the project limits." This information is typically provided in a letter to local governments. The future design year noise levels are obtained from a TNR or DNR, as applicable. If requested, NCDOT also will assist local officials with information on noise-compatible planning concepts.

4.2. Source Control

The Environmental Protection Agency (EPA) historically coordinated all federal noise control activities through its Office of Noise Abatement and Control. However, in 1981, the EPA concluded that noise issues were best handled at the State or local government level. As a result, the EPA phased out the office's funding in 1982 as part of a shift in federal noise control policy to transfer the primary responsibility of regulating noise to state and local governments. The Noise Control Act of 1972 and the Quiet Communities Act of 1978 were not rescinded by

Congress and remain in effect today, although essentially unfunded. (EPA website: www.epa.gov/history/epa-history-noise-and-noise-control-act, accessed 6/8/22 (USEPA, 2021)).

The Federal Motor Carrier Safety Administration has adopted regulations under Chapter 49 Code of Federal Regulations Section 325 – *Compliance with Interstate Motor Carrier Noise Emission Standards 49 (CFR 325)* (USDOT-FHWA, 2013). Section 325.7 defines allowable noise levels for motor carriers governed by the regulations.

4.3. Highway Project Noise Impact Determination and Abatement

The National Environmental Policy Act (NEPA) of 1969 provides broad authority and responsibility for evaluating and abating adverse environmental effects including highway traffic noise. NEPA directs the Federal government to use all practical means and measures to promote the general welfare and foster a healthy environment.

The Federal-Aid Highway Act of 1970 mandated that FHWA develop noise standards for abating highway traffic noise. The FHWA regulations for abatement of highway traffic noise in the planning and design of federally aided highways are contained in 23 CFR 772 – *Procedures for Abatement of Highway Traffic Noise and Construction Noise*. The entire 23 CFR 772 constitutes the FHWA noise standards.

A part of the FHWA noise standards is the Noise Abatement Criteria (NAC), which define noise levels for various land use activity categories that, when approached or exceeded, require the consideration of noise abatement (see **Table 8.1**). In developing the NAC, FHWA considered several factors, such as hearing impairment; annoyance, sleep, task interference; and interference with speech communication. The FHWA ultimately determined that the NAC should represent noise levels that are predominantly associated with interference of speech communication and represent a compromise between noise levels that are desirable and those that are achievable.

The 23 CFR 772 regulations require specific actions by transportation agencies during the planning and design of highway projects, including:

- Defining acceptable criteria for determination of traffic noise impacts for different types of land uses and human activities,
- Identifying traffic noise impacts,
- Evaluating the feasibility of alternative abatement measures, considering such factors as safety, barrier height, topography, drainage, utilities, and maintenance of the abatement measures,

- Evaluating the reasonableness of feasible noise abatement measures (including noise reduction design goal, cost-reasonableness, and the viewpoints of benefited property owners and tenants),
- Incorporating feasible and reasonable noise abatement measures into the highway project plans, and
- Coordinating with local officials by providing helpful information on noise-compatible land use planning and control.

Compliance with the noise regulations is a prerequisite for the granting of Federal-aid highway funds for construction or reconstruction of a highway.

5. APPLICABILITY

Projects utilizing federal-aid highway funds or that require FWHA approval

This manual applies to all Type I federal or federal-aid highway projects in the State of North Carolina, including federal projects that are administered by local public agencies. The definitions of Type I, Type II, and Type III can be found in the NCDOT *Traffic Noise Policy* (see **Appendix A** of this document). The NCDOT *Traffic Noise Policy* and this manual were developed in accordance with 23 CFR 772.

Any highway project that utilizes federal-aid highway funds or that requires FHWA approval, regardless of funding source, must comply with 23 CFR 772.

Projects that are State funded

Projects that are State funded do not use the federal type of designation (Types I, II, and III) for applicability.

For State-funded projects the NCDOT *Traffic Noise Policy* and this manual will apply if the project is located on a US or Interstate route that has full control of access and where the project involves adding a through-traffic lane or an auxiliary lane that is at least 2,500 feet long.

All other State-funded projects for which an Environmental Assessment (EA) or Environmental Impact Statement (EIS) is prepared will comply with the North Carolina (or state) Environmental Policy Act (SEPA) and the North Carolina Administrative Code. For these projects, a traffic noise analysis is required to identify traffic noise impacts. Noise barriers will be considered where practicable as determined by the Division Engineer.

Projects that are classified as State Minimum Criteria do not require a noise analysis provided the following conditions are met: 1) no federal-aid highway funds are utilized 2) no FHWA approval is needed and 3) the project does not involve adding a through-traffic lane or auxiliary lane at least 2,500 feet long to a US or Interstate route that has full control of access. However, the Division Engineer has the option of completing a noise analysis anyway and determining the practicability of noise abatement. In this case, the approval date of the Minimum Criteria Determination Checklist (MCDC) will determine the Date of Public Knowledge.

5.1. Type I Projects

The NCDOT *Traffic Noise Policy* and this manual will be utilized for all Type I federal or federal-aid highway projects and include:

a) The construction of a highway on new location; or,

b) The physical alteration of an existing highway where there is either:

   i. Substantial Horizontal Alteration. A project that halves the distance between the traffic noise source and the closest receptor between the existing condition to the future build condition (Note: NCDOT measures the distance from the edge of the nearest travel lane to the closest receptor); or,

   ii. Substantial Vertical Alteration. A project that removes shielding, therefore exposing the line of sight between the receptor and the traffic noise source. This is done by either altering the vertical alignment of the highway or by altering the topography between the highway traffic noise source and the receptor; or,

c) The addition of a through-traffic lane(s). This includes the addition of a through-traffic lane that functions as High Occupancy Vehicle (HOV) lane, High-Occupancy Toll (HOT) lane, bus lane, or truck climbing lane; or,

d) The addition of an auxiliary lane 2,500 feet long or longer; or,

e) The addition or relocation of interchange lanes or ramps added to a quadrant to complete an existing partial interchange; or,

f) Restriping existing pavement for the purpose of adding a through-traffic lane or an auxiliary lane; or,

g) The addition of a new or substantial alteration of a weigh station, rest stop, ride-share lot or toll plaza.

If a project is determined to be a Type I project under this definition, then the entire project area as defined by the limits of improvements in the environmental document is a Type I project and should be analyzed in a TNR and DNR (as applicable).

If a proposed project in the planning phase includes multiple design alternatives that are a mix of Type I and Type III design alternatives, only the Type I design alternatives must be evaluated in detail in the TNR. The TNR must document that the Type III design alternatives do not contain any design features that may cause the alternative to become a Type I design alternative.

If a project is a Type I project, but there are no existing noise sensitive receptors in the project noise study area, then only design year build condition traffic noise contour information is required to be prepared for local governments, as described below.

- Identify the typical section and projected design year build condition traffic volumes for each major section of roadway (between interchanges, between major intersections, etc.).

- For each typical section/traffic volume combination identified, create a TNM model that includes the following:

  - A 3,000-foot-long set of roadway elements (use up to 200-foot-long segments) that reflect the proposed typical section. Input the roadway elements as straight and at an elevation of zero. Include the projected traffic volume/mix for each roadway element and design speed.

  - Input a set of receptors in the center of the roadway length at varying distances perpendicular from the roadway elements. Adjust the array of receptors until there are receptor results at 71 dB(A) and at 66 dB(A).

- Prepare a memorandum documenting the project and analysis methodology and results. Report the distances to the design year build condition 71 dB(A) and 66 dB(A) traffic noise contour lines as measured from the edge of the nearest travel lane for each typical section/traffic combination.

5.2. Type II Projects

NCDOT does not participate in Type II projects for noise abatement constructed on an existing highway.

5.3. Type III Projects

Type III projects do not meet the classification of either a Type I or Type II project. Type III projects do not require a noise analysis.

Generally, the list of projects described in 23 CFR 771.117(c) and (d) are Type III projects (CFR website: http://www.ecfr.gov/current/title-23/chapter-I/subchapter-H/part-771/section-771.117, accessed 6/7/22) (USDOT-FHWA, 2022), with some exceptions as noted below, for which FHWA has determined the project clearly meets the definition of a Type I or Type II project. The following projects, if Type I, also require a noise analysis.

- 771.117(c)(6) The installation of noise barriers or alterations to existing publicly owned buildings to provide for noise reduction (Type II project).

- 771.117(c)(12) Improvements to existing rest areas and truck weigh stations. Improvements to existing rest areas and truck weigh stations that involve increased capacity for overnight parking, relocation of parking facilities closer to noise sensitive land uses or other changes in the configuration of the facility would meet the description of a Type I project.

- 771.117(c)(13) Ridesharing activities. Construction or expansion of an existing ride-share lot and access roads to a ride-share lot are a Type I project.

- 771.117 (c)(26) Modernization of a highway by resurfacing, restoration, rehabilitation, reconstruction, adding shoulders, or adding auxiliary lanes (e.g., parking, weaving, turning, climbing). Construction of auxiliary lanes other than turn lanes are a Type I project per the definition of a Type I project provided in 772.5.

- 771.117 (c)(28) Bridge rehabilitation, reconstruction or replacement or the construction of grade separation to replace existing at-grade railroad crossings if the actions meet the constraints in Section 771.117 (e).

  - Construction of a grade separation to replace existing at-grade railroad crossings may result in a substantial vertical alteration of an existing roadway. In some cases, the grade separation project results in an overall benefit to the noise environment due to reduced requirements to sound train horns at grade separated crossings and/or from shielding of traffic noise by bridge structures when the roadway is elevated. Highway agencies may consider the benefit of noise level reduction resulting from reduced train horn usage by evaluation of transportation noise from multimodal sources per guidance in FHWA Noise Measurement Handbook (FHWA-HEP-18-065, June 2018).

- 771.117 (d)(5) Construction of new truck weigh stations or rest areas (Type I project).

6. DATE OF PUBLIC KNOWLEDGE

The Date of Public Knowledge is when the public is notified of a proposed highway project's location and potential noise impacts, designated as the approval date of the final environmental decision document, whether Categorical Exclusion (CE), the NCDOT or FHWA Finding of No Significant Impact (FONSI) for an (EA, or the NCDOT or FHWA Record of Decision (ROD) for an EIS.

NCDOT is not responsible for evaluating traffic noise impacts or implementing noise abatement measures to protect developed or undeveloped lands that were not permitted before a project's Date of Public Knowledge. NCDOT advocates use of local government authority to regulate land development, planning, design and construction in such a way that noise impacts are minimized.

The criteria for determining when undeveloped land is permitted for development is the approval date of a building permit for an individual lot or site. **Approval of a development plat or any other development plan does not meet the permitted criteria.** For undeveloped lands where no permits for construction have been issued, noise level information shall be developed for use by local officials and others in future planning efforts. This information may be provided by developing noise contours or by providing information in tabular form. See **Section 11.16** for more detail.

NCDOT treats any abandoned property as undeveloped land. An abandoned property is any property that requires substantial reconstruction and/or a new permit to resume active use. This applies only to those structures that are condemned or otherwise not useable in the current condition as evidenced by missing windows/doors, missing roof(s), etc. As needed, the analyst should check the status of such properties with local officials to verify the need for an occupancy permit or building permit for redevelopment prior to treating these locations as undeveloped lands (NAC Activity Category G). The analyst will include lands determined as undeveloped in the Information for Local Officials section of the noise analysis report (TNR or DNR as applicable).

How the Date of Public Knowledge is Used to Determine Applicable NCDOT Noise Policy and Manual Versions

Projects with a Date of Public Knowledge on or after the effective date of the 2021 NCDOT Traffic Noise Policy shall comply with the 2021 policy. Projects subject to the 2021 policy without an accepted TNR as of the effective date of this manual shall comply with this manual. DNRs subject to the 2021 Policy shall comply with this manual. A reevaluation of an environmental document does not typically establish or change the Date of Public Knowledge.

The Date of Public Knowledge and its relationship to NEPA documents and, as applicable, SEPA documents is as follows:

- A noise analysis conforming to the 2021 policy and this manual (except as noted in the paragraph above) is required for all NEPA/SEPA documents (CEs, FONSIs, and RODs) signed on or after November 29, 2021.
- A revised noise analysis conforming to the 2021 policy and manual is not required for Programmatic CEs (Types I, II(A) & II(B)) signed before November 29, 2021, since consultations are not required.
- A revised noise analysis conforming to the 2021 policy and manual is not required for full CEs (Type III(C)) signed before November 29, 2021, or for which consultation occurs on or after November 29, 2021, when the consultation confirms the CE classification is still valid. A revised noise analysis conforming to the new policy and manual is required when the consultation results in a decision to prepare either an EA or EIS.
- A revised noise analysis conforming to the 2021 policy and this manual is not required for FONSIs and RODs signed before November 29, 2021, or for which consultation (or re-evaluation) occurs on or after November 29, 2021, as long as the consultation (or re-evaluation) confirms the FONSI or ROD finding is valid.
- Projects with a Date of Public Knowledge prior to the expiration date of the 2011 Traffic Noise Abatement Policy and still to be let to construction, will be reviewed under the criteria of the 2011 NCDOT Traffic Noise Abatement Policy.
- Except as otherwise noted, projects with a Date of Public Knowledge before the effective date of the 2021 NCDOT Traffic Noise Policy shall comply with the criteria of the 2016 Traffic Noise Manual.

All other situations will be determined on a case-by-case basis in coordination with NCDOT and FHWA.

7. ANALYSIS OF HIGHWAY TRAFFIC NOISE

The following represents the sequential process for traffic noise analysis and abatement evaluation:

- Establish that there is a Type I highway project
- Identify noise sensitive receptors
- Identify which receptors are impacted based on modeling
- Consider abatement for all impacted receptors.
    - Assess abatement for feasibility
        - Unless there are clear engineering feasibility conflicts that would prevent the need to do so, model barrier to see if it can achieve 5 dB(A) at least 2 impacted receptors.
        - If at least 2 impacted receptors can be benefited by the wall, extend/modify the wall as necessary to try to achieve benefits at as many impacts as possible. If the wall can achieve benefits at all impacts, this is the acoustically feasible wall. If benefits cannot be achieved at all impacts, the acoustically feasible wall is the one that achieves benefits at as many impacts as possible while meeting other feasibility and reasonableness criteria.
    - Assess abatement for reasonableness
        - Evaluate those benefited to determine if a reduction of 7 dB(A) can be achieved for at least one. This one NRDG receptor can be impacted or not impacted.
        - Once a 7 dB(A) reduction is achieved at one benefit (impacted or not impacted), then optimize the wall to achieve 7 dB(A) at as many impacted receptors as possible. This may require modeling a taller or longer wall or at a better location. This level of optimization is focused only on the impacted receptors.

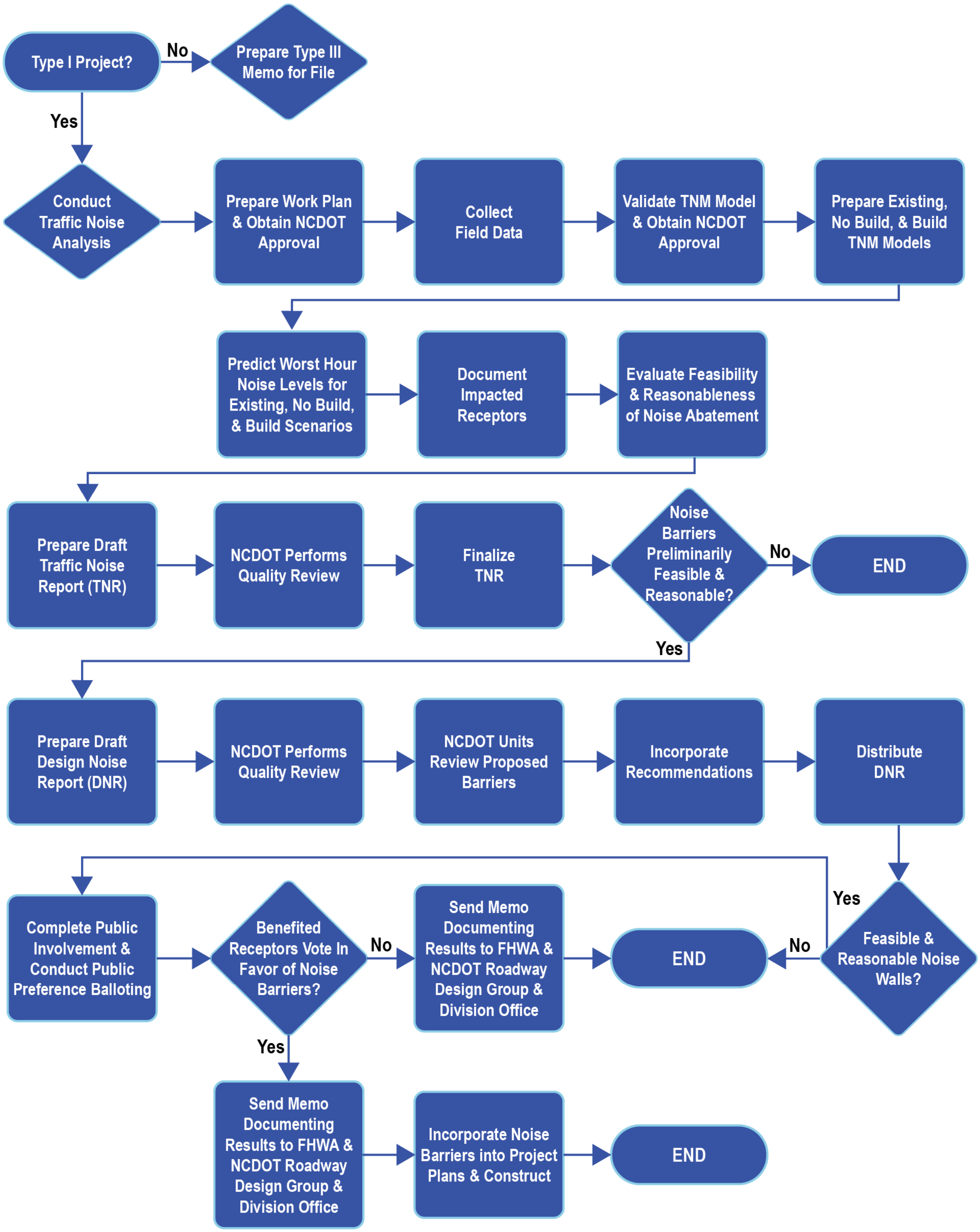
To document the process NCDOT performs and contracts two main types of traffic noise analyses – traffic noise reports (TNRs) and design noise reports (DNRs). **Figure 7-1** details the traffic noise analysis, reporting, and public balloting processes.

TNRs are usually conducted during the early phases of project design, when detailed study alternatives are known, and preliminary plans have been developed to the degree that enables such noise analyses to be performed. These analyses usually occur concurrently with, and in support of, the environmental clearance document that is being prepared during this project development phase. The TNR addresses existing conditions, future no-build conditions, and future build conditions.

The results of the TNR may require that a DNR be prepared during the final design phase of project development, when more detailed engineering plans are available. DNRs are usually more detailed, building upon analyses and determinations made during the preliminary design noise analyses from the TNR. Traffic noise analyses performed during this phase are also typically focused on the preferred alternative or selected alternative as identified in the environmental document. Future no-build conditions do not need to be reanalyzed in a DNR if already included in the previous TNR. Final design noise analyses may be performed by NCDOT, by its consultants, or through a design-build process by a design-build team. For design build projects, NCDOT provides a TNR during the procurement process prior to project letting.

Regardless of the project phase, the type of traffic noise analysis required will depend upon project specifics and previously completed efforts. Communication is the key to producing accurate and comprehensive final results. The NCDOT Traffic Noise and Air Quality Group encourages collaboration and supports traffic noise analysis efforts not only at project initiation and after project completion, but also throughout the duration of each project.

Figure 7-1. Traffic Noise Analysis Process



7.1. NCDOT Traffic Noise Analyst Required Qualifications

Only qualified personnel shall perform highway traffic noise analyses for NCDOT. NCDOT pre-qualification requirements are found online at https://connect.ncdot.gov/business/Prequal/Pages/Private-Consulting-Firm.aspx (NCDOT, 2022).

Qualified personnel must have successfully completed formal training in the area of Highway Noise Analysis and the use of the FHWA-approved Traffic Noise Model (TNM) software. Qualified personnel also must have demonstrated experience in conducting noise analysis studies for highway transportation projects and must have a working knowledge of procedures outlined in FHWA's *Measurement of Highway-Related Noise* (Report Number FHWA-PD-96-046) (USDOT-FHWA, 2018), and 23 CFR 772. All persons in charge of the performance of noise analyses must also be proficient in the use of the most currently approved version of FHWA Traffic Noise Model (TNM) software and be able to support their analyses with expert testimony if required.

Alternatively, NCDOT shall reserve the right to qualify personnel based upon involvement in the development and/or instruction of noise models and/or training courses, or other relevant experience.

The above qualifications must be met by all persons providing quality assurance functions for NCDOT traffic noise analyses.

Persons who perform a traffic noise analysis may not also provide quality assurance for the same project. Traffic Noise Reports and Design Noise Reports must be signed by the analyst and quality assurance reviewer of the report.

7.2. Noise Level Rounding Convention

With the exception of TNM model validation (refer to **Section 7.9**), all noise levels shall be rounded to the nearest whole decibel prior to conducting traffic noise impact assessment and insertion loss/noise level reduction calculations. Noise levels shall be stated in units of whole decibels in NCDOT traffic noise reports and design noise reports, and normal rounding conventions that round x.5 up to the next whole number shall be used. For example, a value in TNM at 68.5 is rounded up to 69 in the report.

The exception to using whole number decibel values is when reporting noise level measurements and noise validation model results. These should be reported to the tenths of a decibel.

7.3. Traffic Noise Analysis Process

Commencement of any traffic noise analysis by a non-NCDOT party should be preceded by a project initiation meeting between NCDOT Traffic Noise and Air Quality Group staff and the traffic noise analyst (consultant, municipality, etc.) performing the work. This meeting will identify and define the specific tasks required.

7.3.1. Preliminary Design Traffic Noise Analysis

Critical information necessary to initiate a preliminary design traffic noise report (TNR) for a proposed highway project includes the proposed project description, preliminary project design plans for the alternatives under detailed study, appropriate scalable mapping, existing and future traffic data (no-build and build conditions), anticipated posted and design speeds, right-of-way width, and the scope of the project (widening, improvement, new location, etc.). The planned roadway access (uncontrolled, partially controlled, limited controlled, fully controlled access) must also be known to appropriately determine feasibility of potential abatement options.

To adequately address traffic noise propagation, other design information is normally required, such as the proposed typical section, shoulder types, lane configurations, median barrier type and location, safety barriers, etc. The existing and future traffic forecast diagrams with traffic information (percentages and types of trucks, design hour volumes, and directional distribution) are essential in creating noise models and in determining existing and future noise levels. Project mapping must be dated, scaled, and clearly display a north arrow and show all detailed study alternatives required to be evaluated. Mapping shall be at an appropriate scale to identify all noise sensitive land uses within the area of noise impacts and clearly show all project elements needed to document traffic noise levels, impacts, and abatement.

Other useful information includes properties included in project relocation reports, names and locations of lands protected under Section 4(f) of the DOT Act of 1966, and names and locations of historic properties protected under Section 106 of the National Historic Preservation Act. **Section 11** provides more information on reporting requirements.

7.3.2. Final Design Traffic Noise Analysis

Critical information necessary to initiate a final design traffic noise analysis and DNR for a proposed highway project includes essentially the same information as that required for a preliminary design traffic noise analysis plus the following additional information. Also, see **Section 11** for more information on reporting requirements.

- Reasonably complete design plans, or data included in Stage 3 Plan-In-Hand of the NCDOT Project Delivery Network diagram (NCDOT, 2021).

- A copy of the Traffic Noise Report (TNR), including all TNM modeling files.
- Any updated traffic forecasts for the build alternative.
- Any updated information pertaining to changed land uses (particularly new building permits or construction) that may have occurred since approval of the TNR and prior to the Date of Public Knowledge.

7.4. Traffic Data Requirements

Traffic forecasts are essential in initiating traffic noise analysis during any project phase. These forecasts ideally include the Annual Average Daily Traffic (AADT), Design Hour Volume (DHV), average daily truck volume percentages for Tandem Tractor & Semi-Trailer (TTST), average daily truck volume percentages for Duals (trucks with more than 4 wheels but not a TTST), and directional percentage split in the peak hour volume.

In some instances, such as with complex system interchanges, the information provided in the traffic forecast is not sufficient to readily determine individual ramp volumes, collector-distributor road volumes, etc. In these situations, the hourly volumes generated in the project's traffic operations technical memo may be used.

In most cases, using a 50/50 directional split in the total traffic is adequate for the analysis. If there are extreme directional splits (65/35 or more), then consult with the NCDOT Traffic Noise and Air Quality Group as part of the Noise Analysis Work Plan. Additional traffic data may be required to determine the worst noise hour used in all traffic noise analyses.

The traffic characteristics that yield the worst noise hour predicted traffic noise levels shall be used for the assessment of existing, design-year no-build, and design-year build conditions. The worst hour traffic noise conditions shall be evaluated as the lesser of the DHV percentage of the AADT or the maximum roadway vehicle capacity Level of Service C (LOS C) operating at the design speed. TTST and dual truck volumes shall be assessed using the predicted average daily volume percentages. The LOS C traffic volumes appropriate for various types of roadways and traffic mixes can be found in *Level of Service C Volumes for Traffic Noise Modeling* (ITRE, September 2018).

Example: TNM Traffic Volume Calculation – Directional Split w/LOS C Cap:

AADT = 100,000, DHV = 9%

Classified Vehicle Distribution = 4% Duals, 5% TTST (91% Automobiles)

Roadway = Interstate, 3-Lane Directional Segment

Directional Split = 65% (Peak Direction) / 35% (Non-Peak Direction)

Peak Direction DHV = (100,000 VPD) x (9% DHV) x (65% Directional Volume) = 5,850 VPH

Non-Peak Direction DHV = (100,000 VPD) x (9% DHV) x (35% Directional Volume) = 3,150 VPH

LOS C Cap = (1,450 VPH/lane) x (3 lanes) = 4,350 VPH

Peak Directional DHV = 4,350 VPH (*lesser* of 5,850 or 4,350)

Non-Peak Directional DHV = 3,150 VPH (*lesser* of 3,150 or 4,350)

Peak Direction Autos = 4,350 VPH x 91% = **3,959** VPH

Peak Direction Medium Trucks = 4,350 VPH x 4% = **174** VPH;

Peak Direction Heavy Trucks = 4,350 VPH x 5% = **218** VPH

Non-Peak Direction Autos = 3,150 VPH x 91% = **2,867** VPH

Non-Peak Direction Medium Trucks = 3,150 VPH x 4% = **126** VPH;

Non-Peak Direction Heavy Trucks = 3,150 VPH x 5% = **158** VPH

Example: TNM Traffic Volume Calculation – 50% / 50% Directional Split w/LOS C Cap:

AADT = 100,000, DHV = 9%

Classified Vehicle Distribution = 4% Duals, 5% TTST (91% Automobiles) Roadway = Interstate, 3-Lane Directional Segment

Directional Split = 50%/50%

Directional DHV = (100,000 VPD) x (9% DHV) x (50% Directional Volume) = 4,500 VPH

LOS C Cap = (1,450 VPH / lane) x (3 lanes) = 4,350

VPH Directional DHV = 4,350 VPH (*lesser* of 4,500 or 4,350)

Directional Autos = 4,350 VPH x 91% = **3,959** VPH;

Directional Medium Trucks = 4,350 VPH x 4% = **174** VPH;

Directional Heavy Trucks = 4,500 VPH x 5% = **218** VPH

(Note Applicable to Both Examples Above: Calculated classified vehicle volumes must be distributed appropriately throughout the modeled TNM roadway elements. For example, if truck travel is prohibited on the inside (fast) lanes of a section of an 8-lane interstate (4 lanes in each direction), then the number of trucks should be distributed only on the TNM roadway elements representing the three outer (slower) lanes in each direction.)

7.5. Project Area Reconnaissance

Prior to initiating any noise measurements or modeling activities, a project area reconnaissance may need to be conducted unless most or all of the bulleted data requirements listed below can be obtained without a reconnaissance. While it may be possible to conduct the field review concurrently with the initiation meeting with NCDOT, sufficient time must be allocated to obtain the following information. The need for a project area reconnaissance will be determined on a case-by-case basis.

- Define Noise Study Areas (NSAs) and establish relationship of NSAs located near the limits of the project study area and determine the extent of receptors within these NSAs to be included in the noise analysis. (See **Section 7.7** below for further discussion.)
- If it is discovered there are no noise sensitive receptors in the study area, only noise contour information is required even if the project is a Type I project. See **Section 5.1** for more information.
- Confirm and define topography and acoustically pertinent features of the study area, such as terrain features or privacy walls that may need to be considered in the model validation process or in the modeling of existing noise levels.
- Identify existing noise walls in the study area and document their horizontal alignment, height, and vertical profiles. Information on barrier locations and heights may also be contained in the NCDOT inventory of noise barriers prepared for FHWA, as well as in survey or topographical data found on local agency GIS websites and aerial imagery from online sources.
- Observe traffic flow conditions.
- Identify any supplementary and/or non-highway noise sources in the study area.
- Determine short-term and long-term measurement locations.
- Determine where and how to model large parcels and non-residential land use activities for which equivalent receptor (ER) values may need to be calculated.
- Obtain usage data required to calculate ER values. Recommended methods to obtain this data are included in the forms and guidance in **Appendix C** spreadsheets.
- Determine locations where upper story receptors need to be analyzed.
- Identify Activity Category D land uses where measurement and/or analysis of interior noise levels is anticipated. The type of structure, window type, and evidence of air conditioning should be noted.

- Establish appropriate heights to assign to building barriers.
- Make determinations of where tree zones and ground zones may need to be included in the models used for determining existing and future traffic noise levels (see **Sections 7.10.5** and **7.10.6**).
- For final design noise analyses, identify any changes that have occurred since the completion of the Traffic Noise Report. Examples might include design changes, updated traffic forecasts, new building permits and changes to NCDOT policy.

If a field reconnaissance is conducted, taking spot measurements with hand-held sound level meters might help define the noise measurement sites and limits of noise measurements. These spot measurements can aid in determining the extent and limits of noise measurements necessary to define the existing noise environment from all sources in the noise study area(s) and to help determine the limits of potential traffic noise impacts. The duration of spot measurements depends on achieving a stable Leq, but in general should last at least five (5) minutes.

7.6. Noise Analysis Work Plan

Pertinent project data, including information obtained from the project area reconnaissance (as applicable), shall be included in a Noise Analysis Work Plan, which must be submitted to NCDOT for approval prior to initiation of any noise measurements or modeling. All proposed measurement and analysis locations shall be included in a graphic (photo or plan base), with the noise abatement criteria (NAC) activity category associated with each receptor identified in the work plan.

23 CFR 772.11(d)(4) stipulates that the limits of the noise study area shall be set so that all traffic noise impacts are identified, and therefore it follows that no spatial limits exist for which traffic noise analysis must be completed. Since all traffic noise impacts must be determined in the noise analysis process, the modeling of additional receptors may be necessary following initial noise modeling efforts if the initially identified receptors do not define the outer limits or distances from roadway(s) for which traffic noise impacts are predicted to occur.

The measurement plan is intended for the analyst to use as a guide to measurement locations. NCDOT recognizes that there may be instances where measurement locations must be adjusted due to unforeseen circumstances encountered in the field.

The duration of noise measurements shall be stated and the process by which large parcels and non-residential receptors (including those requiring calculation of equivalent receptors) are to be modeled shall be identified in the work plan. The work plan shall also include a schedule for completing the traffic noise analysis.

The work plan shall discuss whether there is a need for model validation for projects that include new location alternatives (see **Section 7.9**). The work plan shall also include justification for including tree zones, if proposed, when predicting existing and future noise levels (see **Section 7.10.5**). It is rare for tree zones to be included in TNM models when predicting existing and future noise levels.

For projects where a noise analysis was prepared under the 2016 policy/manual and is being updated for compliance with the 2021 NCDOT Traffic Noise Policy and 2022 NCDOT Traffic Noise Manual, a work plan may not be necessary where ambient noise measurements have already been obtained and no additional field work is anticipated.

For final design noise analyses, the noise measurement and modeling data contained in the Traffic Noise Report shall be reviewed with NCDOT Traffic Noise and Air Quality Group to determine its appropriateness for use or reference in the final design noise analysis. Additional measurements and modeling inputs may be required to complete the final design noise analysis.

7.7. Defining Noise Study Areas (NSAs) and Modeling Limits

7.7.1. Noise Study Areas

All modeled receptors must be placed in a Noise Study Area. This makes it easier to track each modeled receptor and the TNM models the receptors are located in. There is no set way to define NSAs, but good practices include:

- Group receptors into an NSA that may all be affected by a potential noise barrier.
- Group receptors into an NSA that are between interchanges or major roadways or are otherwise separate from other groups of receptors.

An NSA can contain only receptors within a certain Activity Category (such as residences) or it can contain receptors that represent several types of activity land uses (such as residences, schools, daycare facilities, places of worship, etc.).

7.7.2. Defining Modeling Limits

The noise analyses in a TNR and DNR must identify all noise impacts caused by the proposed project. This means the modeled area must extend a sufficient distance in all directions to include all receptors impacted by the proposed project. At a minimum, this typically means the project design limits plus a certain distance away from the limits to capture all project-related noise impacts. For DNRs, another factor to consider is whether the modeled area is sufficient to identify the outmost limits of benefits provided by a project's proposed abatement measures. Temporary features such as detour routes are not included in this area.

Table 7.1 provides guidance on typical distances needed for different roadway functional classifications in order to capture all project-related noise impacts. These distances are for limits extending outward (laterally) from a proposed project's design limits, and also extending parallel to the ends of a project, like a halo around the entire project.

Table 7.1. Typical Noise Study Area Limits

Functional Class	Distance
Freeway/Expressway	800 feet
Arterial/Major Collector	500 feet
Minor Collector/Local	200 feet

These distances can be used to guide the initial determination of the noise study area limits extending outward (or laterally) from the sides of a project and extending parallel to the ends of a project. The key consideration is that the NSAs must be adequately sized to ensure that all impacts due to the project have been identified.

The analyst shall extend the modeling limits at a minimum distance based on the roadway functional classification (see **Table 7.1**) or to a logical terminus point greater than the minimum distance from the end of physical construction. This logical terminus point for the noise analysis might be a roadway crossing or change in land use that is beyond the minimum distance from the end of physical construction. Next, the analyst shall determine if the project's noise impacts extend beyond this point. If impacts do exist, the analyst shall extend the modeling farther away from the project terminus to a point where the project physical improvements do not create a substantial noise increase (10 dB(A)) over existing noise levels or cause receptors to approach or exceed the applicable NAC as a result of the project.

The mapped receptors and associated narrative should clearly indicate that the analysis has gone far enough to demonstrate that receptors are neither experiencing a 10 dB(A) or greater increase over existing noise levels nor are they approaching or exceeding applicable NAC for the future build condition(s) as a result of the project.

For receptors beyond a project's physical design limits (e.g., down the road from the end of the project), these receptors are not considered impacted by the project if the no-build and build noise levels are within 2 dB(A) or less of each other, even if they exceed the NAC. The 2 dB(A) threshold was chosen because standard practice shows that a 3 dB(A) increase is barely perceptible for most people; changes at or under this threshold can be assumed to not be project-related impacts. For example, a project to widen an interstate ends at Station 1200+00. A receptor 400 feet beyond the final station location has a no-build noise level of 73 dB(A) Leq and a build noise level of 74 dB(A) Leq; this receptor would not be counted as a project impact.

It would be counted as a project impact if the build noise level was 76 dB(A) Leq. For receptors within the project design limits (e.g., receptors within the area where a line is drawn perpendicular to the ends of the project), this example does not apply. Receptors within the project design limits that approach or exceed the NAC in the build condition or have substantial increases in noise levels are impacts, regardless of the difference between the build and no-build noise levels.

Based upon the results of feasibility and reasonableness evaluations for noise abatement measures, it may be necessary to ultimately extend the noise model limits to incorporate required noise abatement for any impacted receptors in the areas beyond the ends of a project. The focus in these areas beyond the project design limits must strictly be on incorporating any abatement for the receptors impacted by the project and not on increasing the number of benefited receptors.

7.8. Ambient Noise Measurements

Ambient noise measurements should be conducted following NCDOT approval of the Noise Analysis Work Plan. Ambient noise measurements conducted before approval of the Noise Analysis Work Plan may need to be repeated. Field personnel shall obtain an NCDOT right-of-entry letter prior to entering private property for the purposes of data collection. For projects on new alignment, the purpose of the measurement program is to determine existing ambient noise levels. For roadway improvement projects, the primary purposes of the measurement program (along with the collection of concurrent traffic data) is to serve as the foundation for the creation of a validated TNM model for modeling existing and future noise levels. Measurements over a 24-hour period may be required to help determine the worst noise hour(s) if there is not enough traffic data for TNM to calculate worst noise hour equivalent sound levels, or where other noise sources such as railroads or airports are in proximity.

Field work is the foundation of traffic noise analyses and ultimately for traffic noise impact prediction and noise abatement. NCDOT recommends that analysts employ a methodical, deliberate, and scientific approach to obtaining field sound level data, observed traffic data, weather data, and ambient environment observations. Field staff should be sufficient in number to observe and document noise events at each noise monitoring location – at each sound level meter. NCDOT recommends taking and retaining thorough field notes, sketches, pictures, etc., to maximize the accuracy of ambient noise environment analysis and documentation. NCDOT requires that analysts conducting field work shall adhere to industry best practices, NCDOT Traffic Noise Manual, and FHWA guidance (e.g., FHWA-HEP-18-065) for field data and ambient noise environment analysis acceptance.

Noise measurements may also be required during the construction phase of the project to address complaints or to validate any prescribed construction noise abatement.

- Ambient noise measurement locations shall be selected to provide a suitable foundation for accurately predicting existing and design-year traffic noise levels at identified receptor locations.

- For projects on new alignment, ambient noise measurement locations shall be selected at areas of noise-sensitive land uses that will be near the proposed new alignment and also near an existing roadway (if present in the project area) that can be used in a validation model. Additional locations should be selected to be representative of groups of noise-sensitive land uses (such as subdivisions) in areas near where the proposed new alignments will be located but are away from major traffic noise sources and other noise sources to establish existing ambient noise levels, for use in determining substantial increase impacts for these locations.

- While the collection of existing noise measurement data for receptors located at distances beyond the probable limits of traffic noise impact occurrence is encouraged, such measurements are not required if no sensitive receptors exist or are permitted, since impacts are only defined for receptors that existed or were permitted prior to the Date of Public Knowledge. In addition, measurement of noise at a receptor where there is clearly no exterior area of frequent human use is not required unless the site is an Activity Category D land use and an assessment of interior noise impacts is necessary.

- Collection of existing noise measurement data for the purposes of evaluating traffic noise levels, and for the formation of a validated TNM model, will require sufficient measurement sites to represent sound level attenuation at exterior areas of frequent human use associated with receptors located at increasing distance(s) from the roadway. If no noise sensitive receptors exist beyond a front row measurement site, then no other sites farther away need to be measured. If receptors exist beyond the front row, additional sites will be required. Focus shall be placed upon locating noise meters for ambient noise measurement data collection at locations that are representative of discernible noise sensitive sites, rather than at nominal distances from the subject roadway.

- To reemphasize the point made in the previous bullet, noise measurement data shall not be obtained at locations that are not, or will not in the future, be representative of actual noise sensitive receptors (e.g., collection of ambient noise measurement data within the existing right-of-way of a proposed interstate highway widening project or collection of data behind a front row receptor when no other receptors exist behind that receptor).

Examples of appropriate placement of sound level meters for other exterior areas of frequent human use are shown below in **Figure 7-2 through Figure 7-78**:

Figure 7-2. Ambient Noise Measurement Set Up

Figure 7.2 Notes: The sound level meters shown in the background and foreground of Figure 7.2 represent the 2nd and 3rd row receptors, respectively, in the array. See Figure 7-8 for proper microphone incidence.

Figure 7-3. Sound Level Meter Placed Near Apartment Balcony

Figure 7-4. Sound Level Meter Placed in a Park Near a Picnic Table

Figure 7-5. Sound Level Meter Placed Near Hole on Golf Course

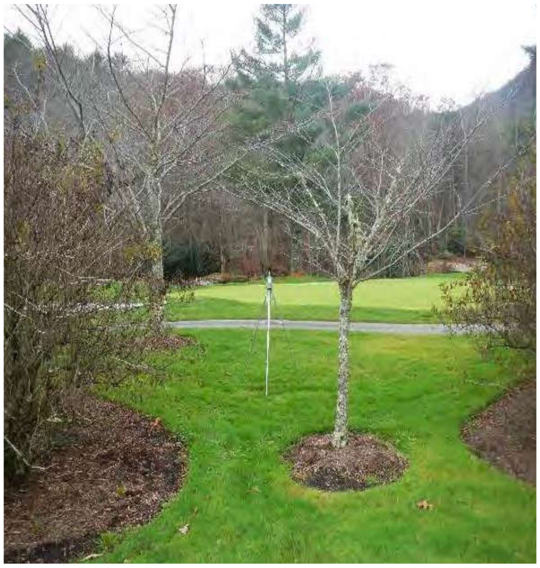


Figure 7-6. Sound Level Meter Placed at a Daycare Center Playground

Figure 7-7. Array of 3 Sound Level Meters in an Open Play Field

See Figure 7-8 for proper microphone incidence.

- Sound level meters used for ambient noise measurement data collection should be placed at locations easily identified on project plans or aerial photography, since measuring distances from existing or proposed roadway alignments to the far-field locations necessary to create a correctly validated TNM model will be difficult. For example, in **Figure 7-2**, the 2nd row receptor was placed at a slope break line conspicuous in the elevation contour data. The 3rd row receptor was placed at a survey stake marking the corner of a residential lot, also clearly identified in the electronic survey data.

- Simultaneous measurements may need to be conducted in front of and behind study area features such as privacy walls and other noise attenuating features that affect existing noise levels and / or for purposes of accurately validating a noise model.

- ANSI S1.4-1983, TYPE I or TYPE II logging sound level meters shall be used to collect existing ambient noise level data. All meters must be calibrated by an appropriately accredited laboratory within 2 years (or as recommended by manufacturer) of use on any project. All meters shall be field calibrated at the beginning of the day and when batteries are changed, during either a short-term or long-term noise measurement session.

- Sound level meters shall be set to the slow response setting for traffic noise measurement.

- Sound level meter microphones should be positioned at grazing incidence, or 90^{o} to the direction of the sound source, at a height of 5 feet above the ground, as shown in **Figure 7-8**. Note that due to limitations of the tilt of the tripod head, it may not be possible to achieve an exact 90-degree orientation.

Figure 7-8. SLM Microphone at 90 Degrees or Grazing Incidence

- For construction noise monitoring, set the sound level meter response rate based on the construction noise source. Use a fast response rate for impulse noise sources (e.g., jackhammer, impact pile driver, mounted impact hammer) and a slow response rate for other sources.

- If possible, sound level meters shall be set to capture the L_{eq}, L_{max}, L_{10}, and L_{90} sound level metrics. Minimally, sound level meters shall capture L_{eq} and L_{max}.

- Short-term ambient noise level data collection measurement sessions shall have a minimum duration of 20 minutes. A single measurement is all that is required for validating the model at a specific location, unless issues arise during the measurement period such as equipment failure or data contamination from aberrant noise events, at which time another measurement must be taken. Short-term ambient noise measurement in rural areas, or in the vicinity of low traffic-volume roadways may require longer measurement periods (e.g., 60 minutes or more) to account for greater fluctuations in noise levels.

- Noise measurement data shall be obtained in increments of not more than one minute (i.e., a 20-minute short-term noise measurement session shall be comprised of at least 20 data points; a 24-hour long-term noise measurement session shall be comprised of at least 1,440 data points).

- Long-term noise measurements may be appropriate at multiple locations and on both sides of a highway in order to ascertain the influence of directional flow on the worst noise hour(s), realizing that different worst noise hours may exist for different NSAs. Such long-term measurement periods can range from several hours up to 24-hours and include at least the typical or known loudest worst traffic noise and highest traffic noise hours of the day. Worst noise hour determinations cannot typically be determined from short-term measurements, since short-term measurements are usually taken at different times, at different locations, and at different distances from the roadway. The need for, and locations of, long-term measurements will be determined on a case-by-case basis and included in the Noise Analysis Work Plan.

- An event log or data sheet shall be created for all attended or manned noise measurement sessions to document general conditions and unusual events during noise measurement. They may also be used to document the existing noise environment, justify de-spiking of aberrant noise events from data sets, defend TNM model validation, etc. The event log or data sheet shall be submitted as part of the model validation report but does not need to be included in the TNR or DNR.

- Sound level meters shall never be turned off during a noise measurement session as a means to eliminate the effects of aberrant noise events, traffic or otherwise. However, if an aberrant noise source can be identified prior to it affecting a noise reading (such as a distant police siren approaching the measurement site), pausing the meter is acceptable as long as the time of the pause is noted. When appropriate, justified, and documented in an event log, removing affected data points from the noise measurement data set, or de-spiking, is encouraged. Whether the meter is paused or the data is de-spiked depends on a variety of factors including the relationship of sound level meters to each other, the relationship of each meter to the noise source, and how many meters a particular person can simultaneously operate. Either technique may be employed.

- Traffic counts collected in each direction of travel concurrent with noise measurements shall be made in accordance with the five vehicle classification types employed by the TNM model – automobiles (including pick-up trucks), medium trucks (two-axle, six-wheel trucks such as delivery trucks and small box trucks), heavy trucks (tractor-trailers), buses (school buses and transit buses), and motorcycles.

7.9. TNM Validation

Title 23 CFR 772.11(d)(2) requires that, for projects on new or existing alignments, the analyses of traffic noise impacts validate predicted noise levels through comparison between measured and predicted levels. A TNM model is considered validated if it is a reasonable representation of the existing noise study area and/or project area, and the TNM- predicted noise levels are within the acceptable FHWA tolerance value of +/- 3.0 dB(A) as compared to the noise level data obtained in the field at noise measurement locations. Acceptable TNM models represent actual existing conditions at receptors within the project study area. Refer to **Section 7.10** for guidance on TNM modeling.

Although the FHWA-accepted tolerance for TNM model validation is ±3.0 dB(A), it is desirable to strive for a closer tolerance, if it can be achieved by the application of consistent and justifiable modeling inputs. However, in no instance shall the noise analyst add additional input that is not appropriate or modify input parameters in an attempt to either meet or improve upon the +3.0 dB(A) tolerance value. On occasion, acceptable model validation may not be obtainable at a site because of unusual events or circumstances. If necessary, such locations may be re-measured. At a minimum, the reason for a site not validating shall be noted in the validation tables and in the report.

Validation of a TNM model is only possible if there are sources of traffic noise that are the predominant contributors to noise in an area. Most TNM validations are conducted for roadway widening and reconstruction projects or where a new feature, such as a new interchange or new intersection is being added to an existing facility. Therefore, TNM normally cannot be validated for projects on new alignment where no traffic noise sources exist. At best, validation can and should be performed for parallel or crossroads, if they exist within the project area.

Use the existing pavement as the pavement type in TNM for validation purposes only if use of existing pavement is needed to validate and note any pavement defects or unusual texturing observed during a measurement in the field notes.

The methodology and results of TNM model validation shall be documented in a TNM Model Validation Memorandum and submitted to the Traffic Noise and Air Quality Group for review and approval.

7.10. TNM Modeling

Only the FHWA-approved version (currently Version 2.5) of the FHWA Traffic Noise Model (TNM) Report No. FHWA-PD-96-010 is approved for predicting traffic noise levels, for assessing traffic noise impacts, and for determining abatement measure effectiveness. The Reference Energy Mean Emission Level (REMEL) data and the predictive algorithm of the TNM software are FHWA approved and must not be altered. All traffic noise analyses, assessments of impacts, and evaluations of potential abatement effectiveness shall be performed by means of appropriate application of the TNM software. Refer to *Traffic Noise Model: Frequently Asked Questions (FAQs)*:

http://www.fhwa.dot.gov/environment/noise/traffic_noise_model/tnm_faqs/faq00.cfm (USDOT-FHWA, 2017).

All reasonable efforts must be made to appropriately represent the project study area(s) for the purpose of accurately assessing existing and design year traffic noise levels and identifying all traffic noise impacts. Acoustically relevant features including, but not limited to, existing roadways, elevation contour changes, structures, areas of dense forestation, ground zones, and all receptor locations shall be modeled. Structures and buildings shall be modeled as individual structures, and the building rows input feature in TNM shall not be used. If sufficient data is not available in customary formats such as electronic drawing files, external resources should be examined (e.g., web-accessible county GIS data, Google Maps™, Google Earth™, Microsoft® Bing® maps, etc.). Detailed modeling – even for preliminary traffic noise analyses – is critical to limiting inaccurate results and misleading recommendations, and to optimizing the overall efficiency of the expenditure of resources in maintaining compliance with the requirements of 23 CFR 772. The Run Identification input shall be complete and accurate for all TNM models created in conjunction with NCDOT preliminary and final design noise analyses. The analyst inserted in the Run Identification must be prequalified as an analyst by NCDOT. Unless specified, the modeling guidance applies to both the TNR and DNR.

In performing TNM noise analyses, the guidance provided in the TNM Users Guide and the TNM Technical Manual should be used, along with any other noise-related guidance posted on the FHWA's website. Some additional guidance for commonly used TNM elements is provided in the following sections, including some best modeling practices guidance from The National Cooperative Highway Research Program (NCHRP) Report 791.

Collaboration with NCDOT Traffic Noise and Air Quality Group staff is encouraged for the resolution of anomalous TNM results and/or complex modeling scenarios such as interchanges with flyover ramps, overpasses, barriers on structures, retaining walls, median barriers, superelevated highways, or other uncommon situations.

7.10.1. Roadway Elements

In modeling roadway elements, noise analysts shall refer to the latest version of the FHWA Traffic Noise Model (TNM) Release Notes, and FHWA TNM FAQs (http://www.fhwa.dot.gov/environment/noise/traffic_noise_model/tnm_faqs/faq06.cfm#mir oadways1) (USDOT-FHWA, 2017), and the following general guidance. Unless specified, the following modeling guidance applies to both the TNR and DNR:

- Roadway elements shall not represent more than two (2) travel lanes for preliminary design traffic noise analyses (TNRs). Model each direction of travel with a separate TNM roadway(s). For final design traffic noise analyses in (DNRs), lane-by-lane modeling is required in the Build scenario. NOTE: secondary roadways with low traffic volumes (less than 500 ADT), may be represented with a single TNM roadway with the width set to match the entire paved surface.

- Average pavement type must be used for prediction of all noise levels unless NCDOT obtains FHWA approval to use a different pavement type.

- For validation models, the vehicle speed in the TNM model shall be the speed observed during validation measurements and concurrent traffic counts. For Existing, Design Year No Build and Design Year Build studies the vehicle speed in the TNM model shall be the posted speed plus five (5) miles per hour, not to exceed the design speed. Where the design speed is unknown, such as might be the case with cross streets or other minor roads, the posted speed may be used.

- Roadway widths shall be set to ensure overlapping between adjacent roadway elements, and so that no horizontal gaps occur. Avoid exactly matching the edges of roadways. For final design traffic noise analyses in DNRs, provide travel lane overlap distances between one (1) and ten (10) feet. For TNRs, there is no maximum overlap distance for travel lanes.

- When possible, local roadways (particularly local streets within noise-sensitive neighborhoods) should be modeled.

- Unless specific data is available for each travel lane or each TNM roadway, TNM roadways should be modeled as flat and at-grade, such that all modeled lanes of a roadway section are modeled at the same elevation. Note that flat applies to the roadway section; it means that, unless lane-by-lane elevation data is available, super-elevations should not be modeled into the TNM roadway elements. The term at-grade applies to the roadway profile; it means that roadway grade elevations should be modeled into the TNM roadway elements. Super-elevations are applicable for DNRs only.

- Roadway segment lengths should be established to accurately represent horizontal and vertical changes in the roadway alignment. While NCDOT encourages modeling TNM roadway element vertices at increments of no more than 200 feet (two 100-foot survey stations), modeling of segment lengths of 100 feet and 50 feet may be justified in order to accurately represent roadway horizontal and vertical alignment and to maintain the essential relationship of roadways and noise barriers. See **Section 7.10.5** for further discussion. The roadway segments should be extended past the last impacted receptor furthest from the dominant roadway far enough to capture the predicted noise condition for the design year, and so will vary by project, based on factors such as topography, roadway alignment, and potential feasible barrier alignments. Generally, the minimum length for TNM roadways is the length at which predicted noise levels do not change, provided that consideration includes with-barrier models.

- Standard NCDOT survey stations are in increments of 100 feet.

- Roadway vertical coordinates should be established to a resolution of at least 0.5-feet in the vertical direction. A greater degree of resolution in the vertical plane is acceptable, but not necessary.

- Roadway elements on structure should be appropriately bordered with applicable traffic barriers. Shielding for traffic barrier segments for roadways on structure must be correctly designated for applicable roadway segments. See **Section 7.10.4** for additional guidance on modeling median barriers.

- TNM traffic control devices should be designated as appropriate for ramps and stop-controlled and signalized intersections, particularly for on-ramps adjacent to the modeled study area. See **Section 7.10.8** for additional guidance. See **Appendix B** for guidance on modeling interchanges, intersections, and roundabouts.

- There is no off-ramp control device feature in TNM; TNM does not have a function to model true deceleration. NCDOT recommends modeling off-ramp deceleration by reducing vehicle speeds throughout the modeled off-ramp roadway segments. For cases in which off-ramp traffic is the dominant noise source, employing this practice will produce more accurate results than otherwise. For cases in which off-ramp traffic is not the dominant noise source, then the effects of reducing vehicle speeds for the modeled off-ramp roadway segments will be inconsequential. See **Appendix B** for guidance on modeling interchanges, intersections, and roundabouts

- As an example, for first-row receptors for which ramp traffic is the primary noise source, the difference between 65 miles per hour and 35 miles per hour can be as much as 6 dB(A). For example, a receptor located 200 feet horizontally distant from the centerline of a single lane ramp, with an unimpeded view, and with 1,000 vehicles per hour (2% medium trucks, 3% heavy trucks), the TNM-predicted traffic noise level at 65 miles per hour would be about 62 dB(A). The same conditions modeled at 35 miles per hour, the TNM-predicted traffic noise level would be about 56 dB(A) at the receptor.

- For preliminary design traffic noise analyses in TNRs, an acceptable methodology is to use a sufficiently wide TNM roadway to include the edge of inside and outside shoulders.

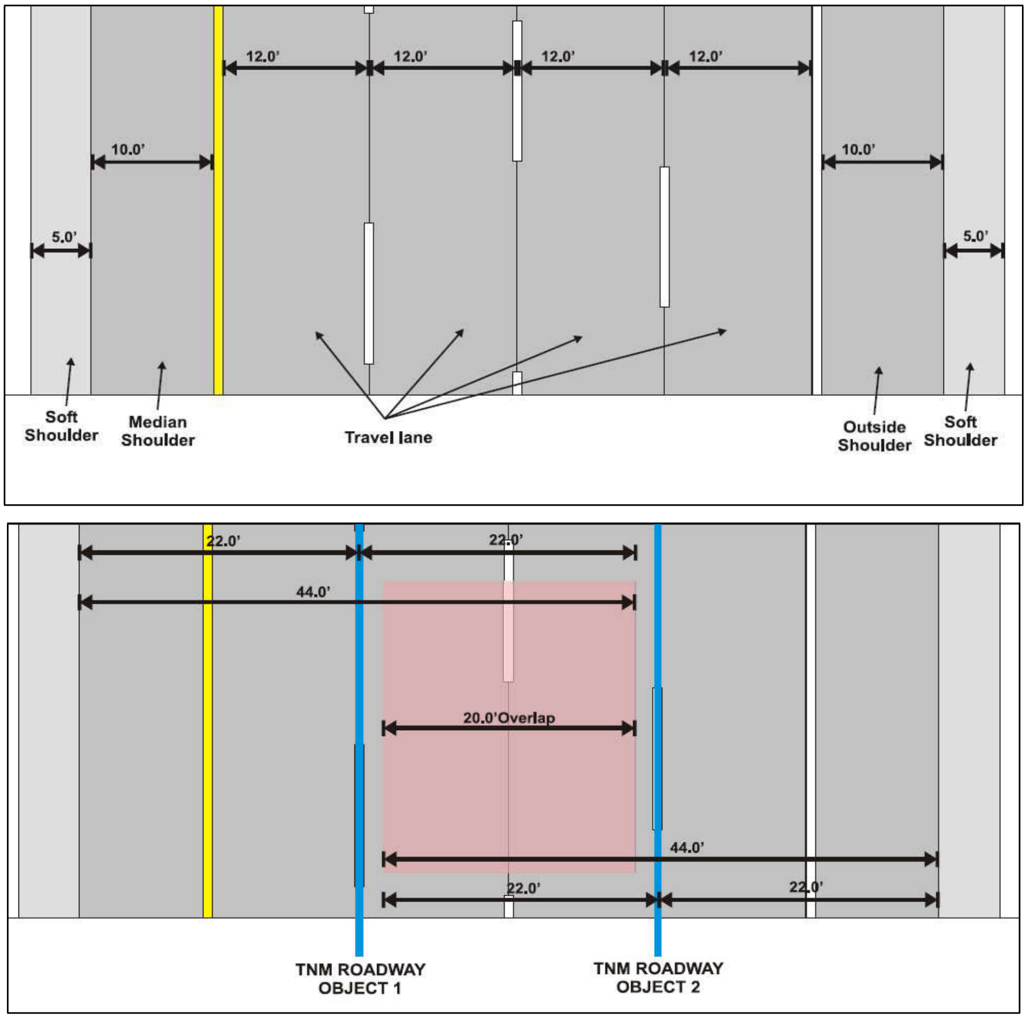
- For DNRs, use the Dummy Lane [shoulder modeled as a roadway with no traffic] technique to model shoulders, especially outside shoulders. It presents less potential for "illegal intersection" errors within TNM than using a ground zone to represent a shoulder and may not require the addition of a contour line that is definitely required with the Ground Zone technique. It also allows for a smaller lane overlap than that resulting from use of the Adjacent Lane Width technique and is more compatible with modeling super-elevated roadway sections. This approach is not meant to suggest that additional terrain lines or other ground zones should not be used in the TNM modeling process. If a wide area exists between the paved shoulder and a hinge point, this area will probably need to be modeled using an appropriate intervening ground zone and a terrain line at the hinge point. If the shoulder is represented by a ground zone and the intervening area is also represented by a ground zone, an "illegal intersection" error will occur if any point of one ground zone touches any point of the other ground zone.

- For preliminary design noise analyses in TNRs where there is grouping of travel lanes, roadway segment horizontal coordinates should be selected so that the modeled traffic is at the horizontal center of the actual travel lane(s), (e.g., to model the 4- lane northbound direction of an interstate highway with 12-foot wide travel lanes and 10-foot wide inside and outside shoulders, an acceptable methodology would be to model one 44-foot wide roadway element at the center of lanes 1 and 2 and another 44-foot wide roadway element at the center of lanes 3 and 4. The result will be a cumulative width = 68-feet (10-foot shoulder + four x 12-foot travel lanes + 10-foot shoulder), with a 20-foot overlap. Refer to **Figure 7-9**).

Figure 7-9. Modeling 4-Lane Interstate Roadways (Two TNM Roadway Elements per Direction)

(Applies to TNRs)

Plan View – (Roadway Elements Shown in Blue for Northbound Roadways Only)



- **TNM Skew – Section View: Southbound Lanes on Left, Northbound Lanes on Right**

- In most cases, using a 50/50 directional split in the total traffic is adequate for the analysis. If there are extreme directional splits (65/35 or more), then consult with the NCDOT Traffic Noise and Air Quality Group as part of the Noise Analysis Work Plan. Assuming that the PM directional flow of a highway is reversed from the AM directional flow, worst noise hour traffic data should be entered into the TNM with the peak direction traffic on the roadway closest to the NSA being evaluated when modeling an extreme directional split. See **Section 7.4** for more information on modeling traffic in TNM.

7.10.2. TNM Receptors

In the TNM modeling process, receptors are used to represent exterior areas of frequent human use. A receptor is a discrete point and is typically defined as a specific location of outdoor activity (e.g., swimming pool, athletic field, etc.), or the corner of the representative structure (e.g., house, place of worship, school) nearest to the primary roadway noise source.

Receptors to be displaced due to project right-of-way acquisition shall only be modeled for existing and no build conditions. For the build condition, displaced receptors do not require a noise analysis but shall be shown on figures in the TNR and DNR using standard NCDOT symbology. NCDOT will provide relocation reports if available at the time of the noise analysis.

Each residential unit in a project study area shall be modeled with a unique receptor. Non-residential land uses should be modeled with one or more equivalent receptors, as described in **Section 9.3**. In modeling receptors, the following guidance shall be followed:

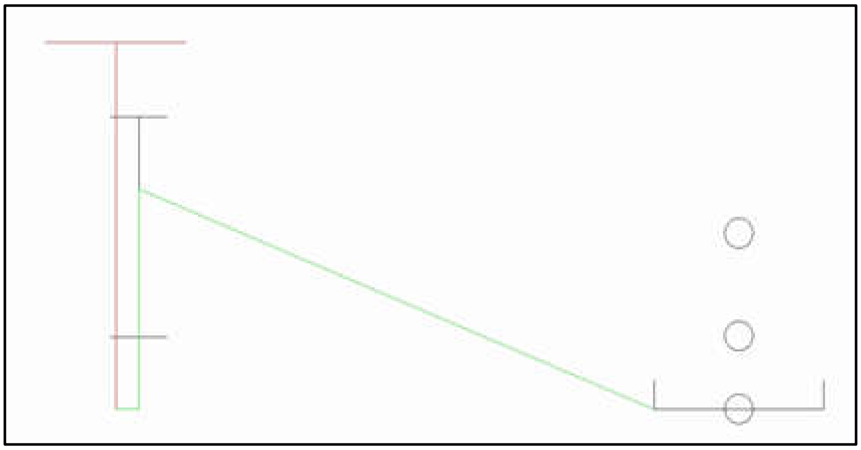
- Receptor numbers should include the NSA number. For example, receptor numbering options 5-125 and 5125 both would indicate this is the 125th receptor in NSA5. This allows for receptors to be more readily found on mapping and also prevents receptor numbering from getting too far out of order across a large project that may have multiple additions/deletions needed as the analysis progresses.

- TNM receptors at ground level shall be set to the TNM default height in the version of TNM used in the analysis. This height is 4.92 ft in TNM 2.5, and this may be different in later versions of TNM.

- When modeling balconies, TNM receptors shall be set at the TNM default height above the floor level plus ten feet for each story above ground level for multi-story areas of frequent human use (e.g., if the 4th story balcony of an apartment building is 30-feet above the adjacent ground level, then in TNM 2.5 the representative receptor height is 30 + 4.92 = 34.92-feet). **Figure 7-10** shows the incorrect and correct approaches to receptor input.

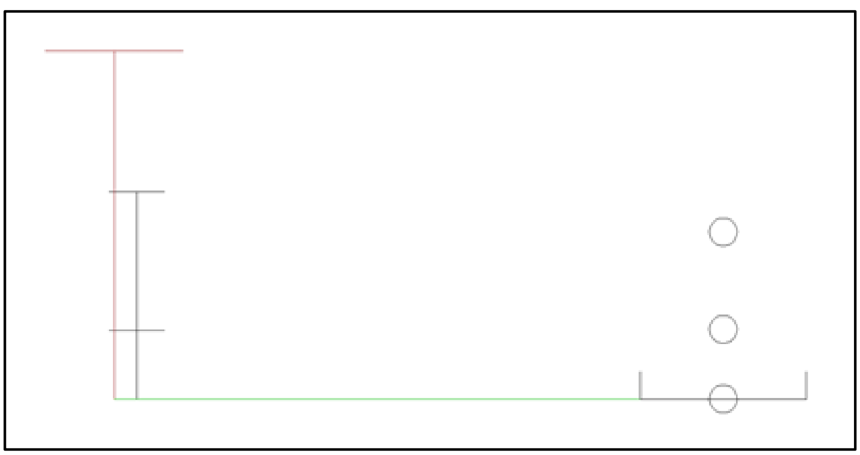
Figure 7-10. Modeling Multi-Story Areas of Frequent Human Use (2-Story Balconies)

TNM Skew – Section View
Incorrect Approach



Each receptor was entered with the TNM 2.5 default height of 4.92’ and the Z coordinate establishes the elevation of the receptor. Using this method, TNM draws a terrain line directly from the roadway to each receptor (NOTE: due to graphics limitations TNM only displays the terrain line between the source and the highest receptor when multiple receptors share the same X and Y coordinates). For the upper receptor TNM assumes the ground slopes upward from the roadway to the receptor and calculates accordingly when determining noise levels. This is not an accurate representation of the real-world condition.

Correct Approach



In this case, the Z coordinate remains the same for each receptor and the difference in receptor elevation is established using the Height input in TNM. Using this approach, TNM retains the same ground elevation information when calculating noise levels for each receptor and provides the correct results for this case.

- Hotel balconies may or may not be areas of frequent human use. At some hotels, balcony access may be sealed, or balconies may be rarely used (e.g., hotels serving primarily business travel). In other situations, the balconies may be frequently used (e.g., a resort hotel or an extended stay hotel). The hotel balcony should be considered an area of frequent human use unless documented coordination with the hotel's management indicates otherwise. Residential hotels and motels that function as apartment dwellings should be treated as Category B land uses.

- NCDOT does not consider parking lots or sidewalks to be noise sensitive and therefore shall not be considered for receptor placement. Any land uses within the NCDOT right of way also shall not be considered noise sensitive. Bicycle lanes or multi-use paths constructed for a transportation purpose shall not be considered noise sensitive, even outside NCDOT ROW.

- For instances where there may be a picnic area, gazebo, or outdoor sitting area or other outdoor use at a Category F land use, NCDOT does not consider these areas to be noise-sensitive areas of frequent human use. Receptors are not required to be modeled at these locations because there is no expectation of a quiet noise environment at these types of uses. Examples include a picnic table at a gas station/mini mart, outdoor seating at a manufacturing plant, a gazebo at a warehouse, etc.

- Outdoor recreational areas associated with multi-family developments, such as an apartment complex pool or playground or a townhome development's tennis courts or dog park, are considered Category B land uses because the primary use of the property is residential.

- Amusement parks and other non-noise sensitive land uses that generate noise should be considered Category F land uses.

- Although each TNM receptor defines the ground elevation at a specific point, TNM does not interpolate a ground line between two or more receptors. Do not model TNM receptors assuming that TNM will interpolate ground elevations between receptor points. A terrain line or roadway line is recommended in front of a row of receptors to define the ground elevations, as appropriate.

- Care should be taken when positioning TNM receptors to represent exterior areas of frequent human use outside of structures that totally shield the exterior use area from the highway. In no case shall a receptor be placed within the boundary lines used to define a building structure.

- Receptors should be placed approximately 10 feet from buildings. For example, when modeling a single-family residence, the receptor should be placed approximately 10 feet from the corner nearest the primary traffic noise source. When modeling a patio or balcony area at a dwelling unit like an apartment, the receptor should be placed approximately 10 feet from the building at the location of the outdoor patio or balcony.

- In verifying the extent of impacts associated with a highway project, sensitive receptors are often represented by TNM receptors located at varying distances from the highway project depending on a variety of project conditions, such as topography (see **Table 7.1** for additional guidance). When positioning such receptors, noise analysts should keep in mind that without a receptor there cannot be a noise impact. Therefore, only place receptors at locations that represent noise sensitive land uses. As an example, if a single row of homes exists fronting a highway project and the land use behind the homes is farmland, industrial land, retail facilities, or some other Activity Category F or G land use, placement of receptors in the area behind the homes is not necessary, regardless of the distance from the highway project.

- In establishing TNM receptor locations to model noise levels associated with a highway project, contributions from all highway noise sources are considered when determining noise impacts. At some distance from a highway project, the total noise levels often become more influenced by noise from other roadways or from other noise sources in the neighborhood than from the noise generated by the highway project. These factors should be considered in determining the limits of receptor placement necessary to evaluate the effects of the highway project on total noise levels.

- When modeling interior noise levels for Activity Category D land uses during TNRs, noise analysts may collect field measurements or use the TNM to estimate exterior levels and apply exterior/interior noise reduction factors. In the absence of calculations or field measurements, noise analysts shall compute the interior noise level by subtracting the noise reduction factor from the predicted exterior level for the building in question, using the information in **Table 7.2**, Building Noise Reduction Factors. NCDOT assumes that windows will be closed in buildings with air conditioning. During DNRs, noise analysts shall take interior noise measurements to verify the noise reduction from the building and windows if noise insulation is being considered as abatement. The FHWA publication titled Noise Measurement Handbook (June 2018) provides procedures for measuring building noise reduction.

Table 7.2. Building Noise Reduction Factors

Building Type	Window Condition	Noise Reduction Due to Exterior of the Structure
All	Open	10 dB
Light Frame	Ordinary Sash (closed)	20 dB
	Storm Windows	25 dB
Masonry	Single Glazed	25 dB
	Double Glazed	35 dB

*The windows shall be considered open unless there is air conditioning or there is firm knowledge that the windows are in fact kept closed almost every day of the year.

FHWA-HEP-18-065, Noise Measurement Handbook, Final Report, June 2018 provides procedures to measure building noise reductions.

- The only time impacts are considered for Category C land uses (that do not also appear on the Category D list), and Category E land uses is when there are exterior areas of frequent human use. Receptor locations coincide with the exterior areas of frequent human use associated with the land use.

7.10.3. Equivalent Receptors for Land Uses Other Than Single Family Dwelling Units

More than one receptor may be necessary to adequately model larger parcels of land that contain noise-sensitive land uses for which more than one project roadway noise source may be acoustically significant. Representation of several types of land uses as one or more equivalent receptors is appropriate in some cases. These receptors typically cover active sports areas, playgrounds, schools, pre- school and daycare facilities; places of worship, hospitals, retirement homes; parks, trails, campgrounds, cemeteries, and other exterior areas of frequent human use for the land uses found in the NAC Activity Categories A, C, D, and E. In addition, exterior activities associated with walking paths, pools, basketball courts, ball fields, etc. may occur on common use areas of Activity Category B lands (multi-family land uses being an example).

For some exterior activities associated with the above-listed land uses, a grid- or nodal-type array of receptors based on a 100-foot grid spacing is modeled to accurately assess the extent of impacts occurring over larger areas and to ensure adequate noise abatement design. While noise abatement must be considered for all modeled receptors within such a grid- or nodal-type array for which impacts are predicted, other grid points are also modeled for purposes of identifying receptors benefited by noise abatement. NCDOT must approve both the equivalent receptor calculations and the locations of the receptors modeled throughout the grid- or nodal-type array prior to beginning noise abatement design. The receptors within a grid are recommended to be assigned a single receptor number plus a letter. For example, a grid of six receptors would be assigned receptor numbers 5123a, 5125b, 5125c, etc. **Figure 7-11** through **Figure 7-14** are examples of grid type arrays of receptors for different land uses.

- **Figure 7-11** shows a park with multiple recreational activities that are represented by a grid of equally spaced receptors. The park is represented by a grid of receptor points that have ER values based on the usage of that area.

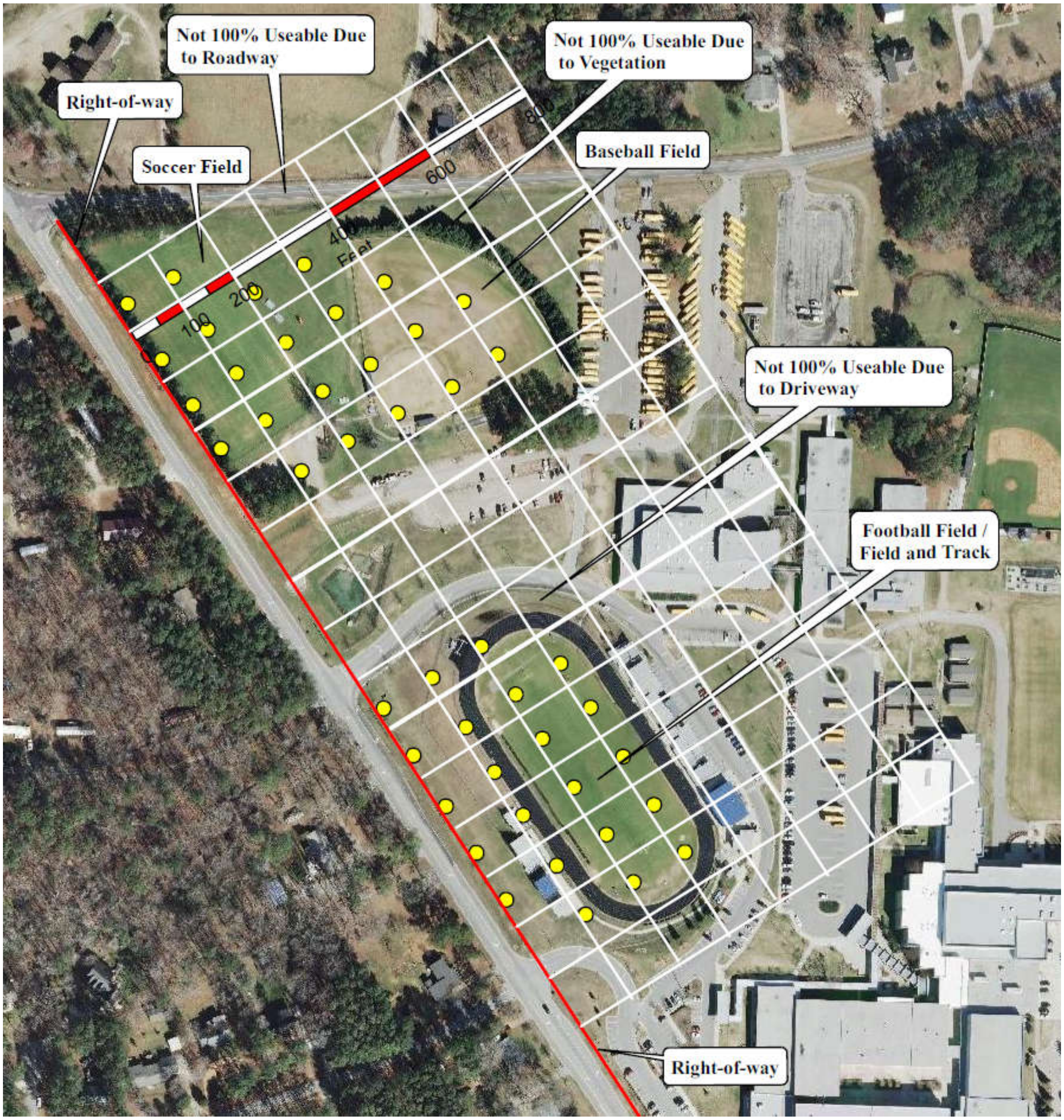
- **Figure 7-12** illustrates how ER points are to be distributed to represent greenways/walking trails. On this figure, a grid of ER points at approximately a 100-foot spacing is used to represent a greenway/walking trail.

- **Figure 7-13** shows ER points for exterior areas of frequent human use of an apartment complex with a swimming pool, playground, volleyball court, basketball court and tennis court. It should be noted that a small usage area, such as an outdoor dining area associated with a hotel, gets at least one receptor point in TNM. For all special use areas, the ER values are distributed equally across the individual receptor points in TNM. For example, an athletic field with 10 modeled receptor points and a total value of 5 ERs would feature a value of 0.5 ERs per receptor point. A motel with one modeled receptor point in TNM to represent an outdoor dining area and two ERs for that same dining area would feature a value of two ERs for the receptor point. Refer to the distances in **Table 7.1** to determine the distance to extend the grid from the highway.

- **Figure 7-14** shows ER points for a golf course. Only the areas of active use shall be modeled in the receptor array.

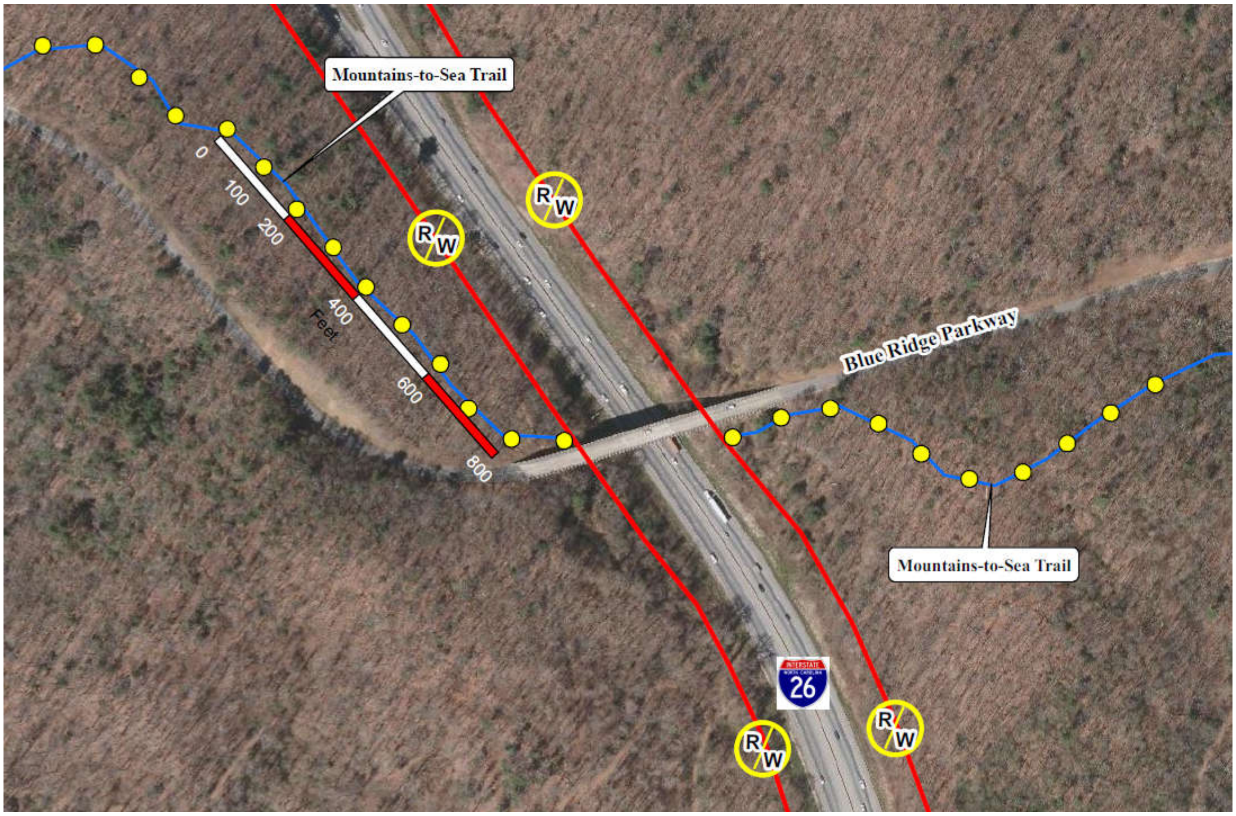
- For cemeteries, one receptor must be counted for each area of a formalized memorial gathering facility. Individual gravesites, access ways and informal activity areas are not considered individually sensitive receptors; however, each section of the cemetery, as defined through consultation with the operator or observed during site reconnaissance that may have informal gathering areas must be assigned a receptor. When no noise analysis is necessary for a site because there is no exterior area with frequent human use, this finding must be documented in the TNR or DNR.

Figure 7-11. Nodal Array Receptor Modeling Showing Various Activities Related to a Park and How They are Represented by Equivalent Receptors



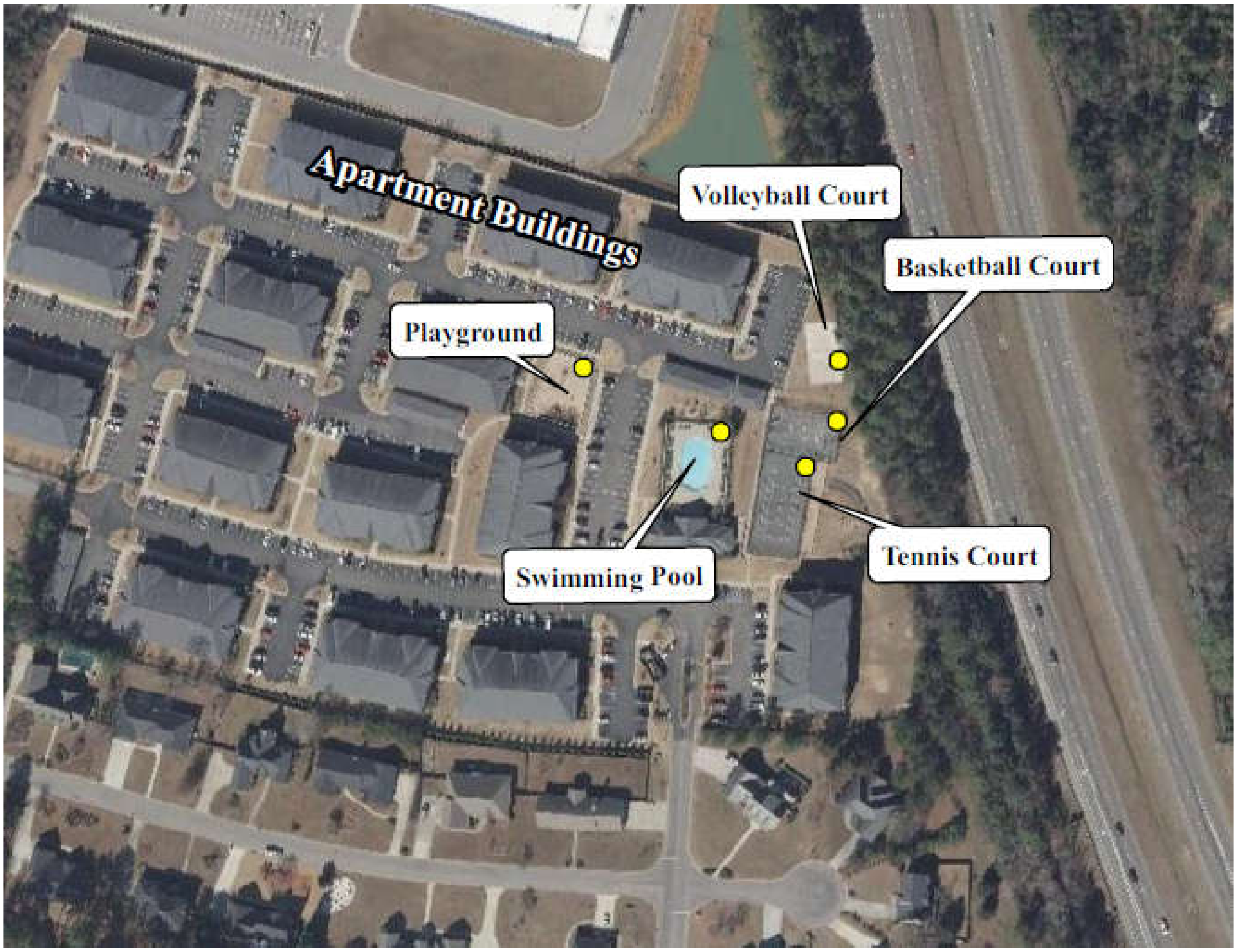
100-foot grid starts at the roadway right of way. If the roadway is curved, start grid at the right-of-way point closest to the activity area. Receptor points are placed within each grid at the center point closest to the roadway.

Figure 7-12. Receptor Modeling for Greenway/Walking Trails



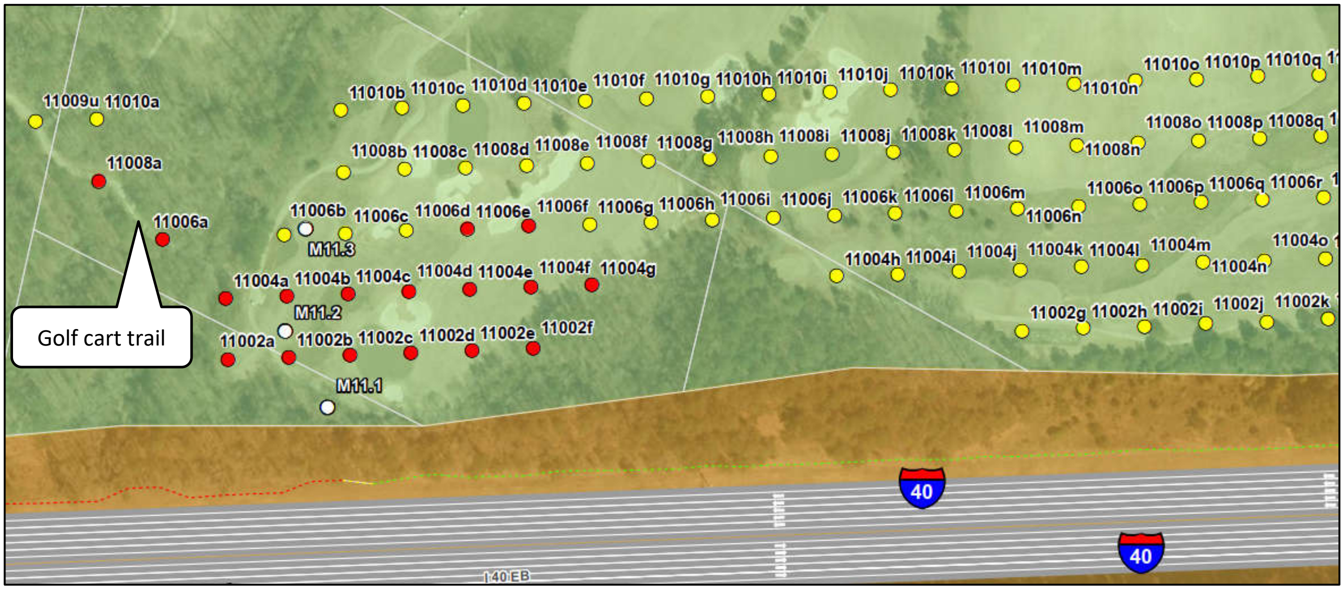
Greenway/walking trails shall be plotted approximately every 100 feet starting at the right of way and continuing until there are no further impacts or benefits, whichever is greater.

Figure 7-13. Receptor Modeling at an Apartment Complex with Multiple Exterior Areas of Frequent Human Use



Plot TNM Receptors at the closest point to the roadway project for each exterior area of frequent human use. Each TNM Receptor represents all equivalent receptors for its respective activity. Refer to **Section** Error! Reference source not found. for additional information regarding equivalent receptors.

Figure 7-14. Receptor Modeling at a Golf Course



For a golf course, model only the areas of active use. These include the tee boxes, fairways, greens, and golf cart/walking trails between holes.

A total ER value is determined by calculating the person-hours of use per year associated with each of the activities listed above and comparing that value with the average available person-hours of use associated with a residential dwelling unit in North Carolina. In general, the total ER value is calculated using the following formula:

Total Equivalent Receptor Value = (Person-hours per Year Associated with the Land Use) / (Person-hours per Year Associated with a Single-Family Residence)

In the calculation of the denominator in the above equation, NCDOT assumes that the average family in North Carolina is comprised of three (3) people and that homes are available for use at all times.

If none of the modeled receptors for a non-residential land use are impacted or benefited, then there is no need to complete a calculation of ER value.

Appendix C provides guidance for calculating ER values for various land uses. The following tables are included in **Appendix C**:

Table C1 – An apartment complex pool (Activity Category B) or community/municipal pool (Activity Category C)

Table C2 – A park / recreation area (Activity Category C)

Table C3 – A trail (Activity Category C)

Table C4 – Exterior and interior activities at a daycare center (Activity Categories C and D)

Table C5a – Interior use at a school (Activity Category D)

Table C5b – Exterior use area at a school (Activity Category C)

Table C6 – A hotel / motel with an outdoor use area (Activity Category E)

Table C7 – Golf course (Activity Category C)

Table C8 – Restaurant with an outside use area (Activity Category E)

These tables illustrate and perform several functions related to the above-listed land uses:

- The tables list example cases of various land uses and illustrate how an ER value is to be calculated by using a spreadsheet tailored to each land use activity. Case examples and input values are presented for illustrative purposes only.
- The tables provide guidance regarding the distribution of the ER value throughout a land use in cases where multiple receptors are used to model activities associated with the land use. The spreadsheet nature of the tables enables calculation of the distributed values.

In all cases, the overall total ER value for a land use shall be a minimum of 1 equivalent receptor. If the calculated total ER value mathematically is less than 1, a minimum total ER value of 1 shall be used. If a non-residential land use is represented by a grid of receptors, each grid point can have a receptor value less than one. If only some receptors within a grid are impacted, to get the impact value for that non-residential land use, add up the values of each impacted grid receptor and round to the nearest whole number. Do not round the values for individual grid points.

Some non-residential land uses are small enough or have infrequent use such that they can be assumed to have an ER value of one equivalent receptor without completing a form from **Appendix C**. This should be considered on a case-by-case basis, and if a value of one ER is assumed, this assumption must be documented in the text of the TNR or DNR. Examples of such potential areas are provided below and are not all inclusive.

- Gazebo
- Picnic area or outdoor eating area with just a few tables
- Small recreational areas such as playgrounds, dog parks, volleyball courts, etc., at a land use whose function is not primarily recreational (place of worship, apartment complex, etc.)
- Outdoor gathering place at a cemetery

7.10.4. Terrain Lines

TNM terrain lines shall be modeled as necessary to represent acoustically significant elevation changes between the most-distant roadway edge of pavement (EOP) and the most- distant receptor(s). TNM terrain lines shall be modeled in consideration of the latest version of the TNM User's Manual, the TNM Technical Manual, TNM Release Notes, and TNM Frequently Asked Questions.

http://www.fhwa.dot.gov/environment/noise/traffic_noise_model/tnm_faqs/faq07.cfm#miterlines1 (USDOT-FHWA, 2017).

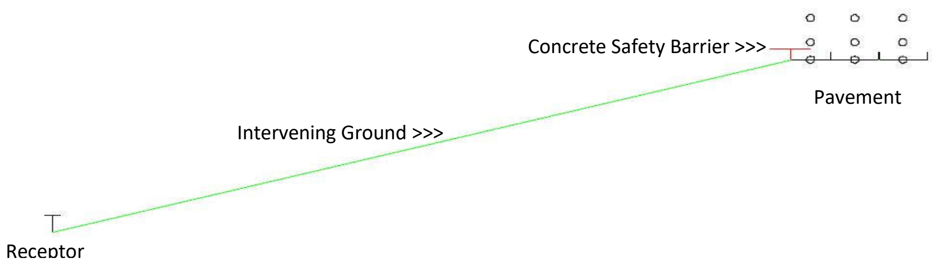
Recent research related to the modeling of topography is documented in Chapter 8 of *NCHRP Report 791, Supplemental Guidance on the Application of FHWA's Traffic Noise Model (TNM)*. The findings of this report support many of the general guidance items listed below and provide additional guidance on minimum terrain line spacing, vertical positioning of terrain lines, and flat top berm modeling.

- All roadway median and shoulder ditches should be modeled with terrain lines. Differences in elevation of less than 5 feet do not need to be modeled.
- All defining grade changes such as top-of-cut sections and bottom-of-fill sections should be modeled (i.e., model any intervening cut/fill line(s) between roadway(s) and receptors).
- When possible, terrain lines should be modeled generally parallel to the primary roadway (terrain lines modeled at skewed or perpendicular angles to the roadway can result in anomalous TNM-predicted noise levels).
- While a noise barrier defines the ground elevations along its horizontal alignment in the TNM model, the build no-barrier ground elevation at the location of a noise barrier horizontal alignment may not be the same as the base elevation that will exist at that same location in the with-barrier case. Therefore, different terrain lines may be necessary to accurately define topography for the no-barrier and with-barrier conditions.
- Terrain line vertices should be added where terrain lines are modeled in proximity to receptors so that the terrain line does not create anomalous vertical elevation changes in the source-to- receptor path(s).
- Terrain lines shall be modeled just outside the horizontal limits of roadways on structure to define the depressed ground elevation under the structure. Otherwise, TNM will interpret the ground elevation immediately adjacent to the structure as the roadway elevation, even though the roadway is on structure. This is applicable to highways on

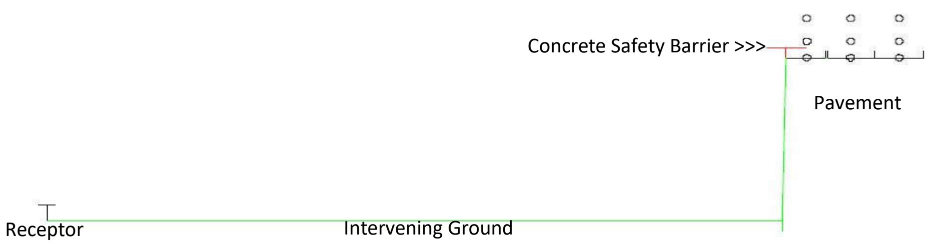
bridges or on elevated sections supported by retaining walls. **Figure 7-15** provides an example.

Figure 7-15. Terrain Lines Adjacent to Highways on Structure

Incorrect Highway Structure Terrain Line (Skew Section)



Correct Highway Structure Terrain Line (Skew Section)



- Terrain lines should be modeled at the top and bottom of retaining walls, with a minimal horizontal distance between the two, so that TNM perceives the surface between the top and bottom of the retaining wall to be nearly vertical.
- Since TNM does not interpolate ground elevations between the point locations of two or more receptors, a terrain line should be modeled just in front of any row or array of receptors.
- Terrain lines should not be directly copied into TNM from exported design exchange formatted (.dxf) elements because the large number of vertices (points) in the .dxf elements will dramatically increase the number of calculations necessary to complete the running of the TNM model. Rather than converting .dxf elements into TNM terrain lines, create TNM terrain lines by snapping as few vertices as possible to appropriately represent the terrain feature.

7.10.5. Buildings, Median Barriers, and Safety Barriers

Buildings

Existing buildings shall be modeled in TNM when they can affect the noise levels at modeled receptors. Buildings are modeled as follows:

- The building row feature in TNM shall not be used. Each building must be modeled separately, even if closely spaced.
- Individual buildings shall be modeled as barriers with no perturbations.
- Buildings shall be modeled with three sides. Do not close off a building with a fourth side.
- Single-family and multi-family building heights generally should be 10 feet in height per story. Split level homes can be up to 15 feet in height if the top of roof is consistent. Variations in roof elevations shall not be modeled.
- Commercial building heights can be 15 ft for a single-story building, then 10 feet per additional story. Variations in roof elevations shall not be modeled.
- Many buildings are on a level pad, but if a building foundation is on a slope with base elevations different for each corner, model the top elevation of the building to be consistent by varying the building height for each point. Take for example, a home that is constructed on a slope and is one story tall in the front and two stories tall in the back. The front two corners of the building will have a ground elevation of 200 ft, and heights of 10 ft. The back corners of the building will have a ground elevation of 190 ft and heights of 20 ft so that the top of the building is at a consistent elevation of 210 ft. The goal is for buildings to have a flat top.
- Rows of townhomes or other types of building units may be on a single sloping pad. The barrier modeled for this type of situation would not be level along its length, although the top elevation of the building should be the same for the front and back of the pad width. Model the base elevation for each corner of the pad, then the top of the building (10 ft for one-story buildings, 20-feet for two-story buildings, etc.). Ensure the top elevation of the building unit represents a flat top.

Median Barriers and Safety Barriers

- Median barriers should be included in TNM models when there are adjacent receptors because they can have an acoustic effect, such as blocking traffic noise from the far travel lanes.

- Concrete safety barriers along the outside of a roadway are modeled in TNM as fixed height barriers with no perturbations. These safety barriers attenuate traffic noise to a varying degree, dependent upon the relationship of the highway to adjacent receptors. This attenuation typically affects receptors located at lower elevations than the highway but can also be important to consider for receptors that are at or near the same elevation of the highway. The horizontal relationship of receptors to the roadway can also affect the attenuation provided by such safety barriers.
- Outside safety barriers also can reflect noise. However, usually such reflections are not sufficient to adversely affect noise levels to receptors on the opposite side of the roadway due to their short height, and so this is not a concern for modeling.
- Elevated roadway sections should be modeled with safety barriers, as applicable.
- Shielding for traffic barrier segments for roadways on structure must be correctly designated for applicable roadway segments. For a barrier on a bridge, use the Structure tab in TNM and select each segment of the safety barrier that is on the bridge as "On Struct?". Shielded roadway segments are those segments of roadway that are on the bridge adjacent to the safety barrier on the bridge. To designate the roadway segments as shielded, go to the Structure tab for the safety barrier. Select the bridge safety barrier on the plan view, then select each adjacent roadway segment on the plan view. On the Structure tab, press the "Select" button for each segment.

7.10.6. Noise Barriers

TNM noise barriers are modeled to ensure potential noise barrier designs have an adequate level of detail. It is important in TNM noise barrier modeling to determine the appropriate barrier design that meets feasibility and reasonableness criteria (refer to **Section 9**). Common shortcomings of coarsely detailed TNM noise barrier element inputs are unnecessarily large barriers (length and/or segment heights), aesthetically unpleasing barriers (jagged, notched, and/or undulating top-of-barrier vertical profiles), recommendations to build inappropriately justified barriers, and recommendations to not build barriers when justifiable.

The following provides information on areas with existing noise walls, noise barrier modeling that applies to both TNRs and DNRs, and noise barrier modeling that applies to just TNRs and just DNRs.

Areas with Existing Noise Walls

Appendix D – Noise Analysis Procedure for Noise Study Areas with Existing Walls covers most situations likely to be encountered when there are existing noise walls in a project area. Whenever there are existing noise walls in a noise analysis study area, consult with the NCDOT

Traffic Noise and Air Quality Group to determine the appropriate analysis process.

Appendix D describes the procedures for evaluating traffic noise impacts, assessing traffic noise abatement, and reporting results when there is an existing noise wall (or an acoustically dependent noise wall system) in a project area. This guidance applies to Traffic Noise Reports (TNRs) and Design Noise Reports (DNRs).

FHWA guidance regarding this topic can be found in FHWA-HEP-12-051, "Consideration of Existing Noise Barrier in a Type I Noise Analysis".

Noise Barrier Modeling for TNRs and DNRs

- When using stepped rectangular noise wall panels, step the top of panels in a uniform manner. For rectangular noise wall panels, keep steps at a maximum of one (1) foot unless deemed impractical due to topography.

- For modeling noise barriers on structures in TNM, the maximum height is 10 feet (see **Section 10.2**). Any exceptions must be coordinated with the NCDOT Traffic Noise and Air Quality Group and the NCDOT Structures Management Unit.

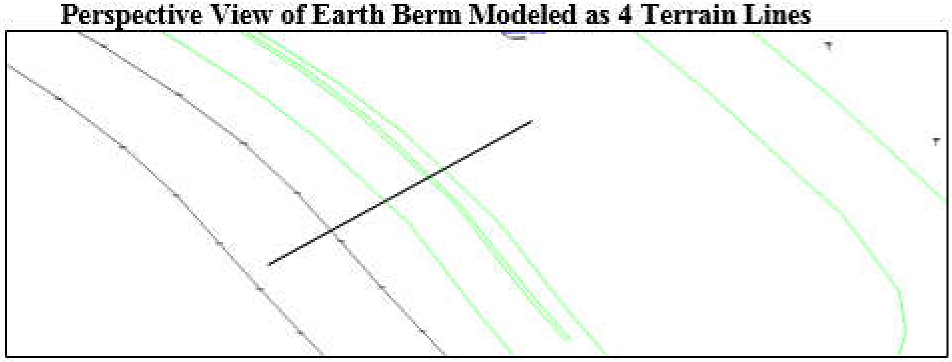
- For modeling noise barriers not on structure in TNM, the minimum height is 6 feet above the ground. The maximum total panel height is 30 feet, which includes embedment under the ground level. See **Section 10.2** for more information about maximum noise wall panel heights. Use of a maximum height of 28 feet is generally recommended for wall heights in TNM models to account for embedment and potential height adjustments to achieve smooth top-of-wall profiles during final design, Any exceptions to the 30-foot maximum panel height must be coordinated with the NCDOT Traffic Noise and Air Quality Group and the NCDOT Structures Management Unit.

- Noise barriers should be located within existing NCDOT right of way or the proposed right of way needed to construct the non-noise barrier elements of a project. If a barrier that meets acoustic feasibility and reasonableness criteria cannot be designed within this right of way, then locations outside this right of way can be considered for all or portions of the noise barrier alignment. However, the new right of way needed for the noise barrier must be contiguous with the existing/proposed right of way. The need for new right of way solely to construct a noise barrier (including the right of way needed for maintenance access) must be coordinated with NCDOT Traffic Noise and Air Quality Group and the Division Engineer and discussed in the project's TNR and DNR.

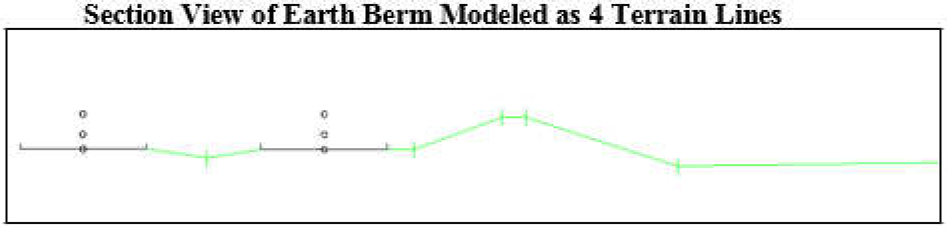
- Prior to recommendation in a Design Noise Report, the acoustic effectiveness of berm noise barriers shall be proven in a TNM model(s). Berm noise barriers will be considered only if adequate right-of-way is available, and no drainage issues exist. Another consideration for feasibility of berm noise barriers is the availability of waste or other earthen material to construct the berm. As shown in the example in **Figure 7-16** below, berm noise barriers shall be modeled as four or more terrain line TNM elements that represent the bottom of berm (roadway side), top of berm (roadway side), top of berm (receptor side), and bottom of berm (receptor side). Guidance on such modeling is provided in Chapter 8 of the previously referenced NCHRP Report 791.

Figure 7-16. Modeling TNM Earth Berm Noise Barriers

Perspective View of Earth Berm Modeled as 4 Terrain Lines



Section View of Earth Berm Modeled as 4 Terrain Lines



Noise Barrier Modeling for TNRs

During a TNR for preliminary design noise analysis, identification of one preliminarily feasible and reasonable noise barrier (likely noise barrier) will be satisfactory to justify a recommendation for further study in a DNR. General guidance for modeling barriers during this phase of project development is included below.

- The resolution of modeled noise barriers in the horizontal plane is equally important as the resolution in the vertical plane. Barrier segment lengths should be established to accurately represent horizontal and vertical changes in the barrier alignment. Model TNM barrier points opposite TNM roadway points at increments of no more than two (2) survey stations (English units). Standard NCDOT survey stations are in increments of 100 feet. The importance of this is stated in the TNM User's Guide, which stresses the importance of preserving the relative horizontal and vertical relationship between roadways and barriers and indicates that noise analysts should try to match the barrier segments with the adjacent roadway segments.

- NCDOT prefers that noise barriers in TNRs and DNRs be modeled as equally spaced segments of logical lengths of multiples of 15 feet. These segment lengths are optimal to coincide with multiples of 15-foot constructed panel lengths. However, maintaining the relationship of barriers to roadways is as important as the actual segment length. TNR analyses also can use 50 feet or 100 feet increments to match roadway data (plan, profile, and most importantly cross-section data). This guidance in the manual is based on language in Section 8.5.1 of the TNM User's Guide, which states: "Barrier XY Coordinates. When digitizing barriers that lie along roadways, try to match the straight-line segments you used for roadway digitizing. In this manner, you will preserve the relative horizontal distance between roadway and barriers, which is important to calculations. Try to maintain the relative roadway/barrier distance to within approximately 10 percent. With no nearby roadways or receivers, you may relax this barrier XY precision."
- Roadway segment lengths must be established in order to adequately define the roadway geometry and take into consideration the potential for a noise barrier being evaluated parallel to the roadway. To do this and also to meet the optimal and maximum barrier segment lengths suggested in the second bullet, roadway and barrier segment length of less than 200 feet (e.g., 50 feet and 100 feet roadway and barrier segment lengths) could be required if dictated by roadway or barrier geometrics, topography, intervening features, etc. A barrier with 50-foot stationing is indicated in **Table 9.1**.
- Modeling noise barrier vertical profiles should be performed using vertical height perturbations of not more than two feet. Shorter horizontal segments may be required to accomplish this.
- Do not assume that the no-barrier (i.e., zero-height barrier) values reported in a TNM output table in a with-barrier model represent the true no-barrier noise levels. The no-barrier values shall be determined from separate TNM runs and compared using spreadsheets. The no-barrier model shall not include a zero-height barrier.
- A barrier envelope drawing is not required for TNRs.

Noise Barrier Modeling for DNRs

- For a DNR, the analysis typically begins with the likely barriers identified in the associated TNR. Barriers determine feasible and reasonable in the DNR are labeled the recommended barriers.

- Noise barriers should be modeled as equally spaced segments where final design horizontal and vertical data and information are of sufficient detail and where other engineering features (utilities, overhead signs, access requirements, maintenance requirements, etc.) do not preclude it. The guidance and direction regarding roadway and barrier segment lengths provided above for the preliminary design noise analysis phase should be followed.

- Baseline, or TNM input height noise barriers should be modeled with a level top, with a consistent top-of-barrier grade, or with a convex top-of-barrier vertical profile. Focus should be placed upon consistent top-of-barrier elevations and uniform barrier segment elevation changes without notches, bumps, undulations, or concavities in the overall top-of-barrier profile.

- Modeling barriers and/or barrier segments with nominal heights (e.g., 14.0 feet, 16.0 feet, 18.0 feet, etc.) should be avoided unless the barrier is immediately adjacent to the roadway edge of pavement.

- Modeling barriers with specific segment heights to achieve top-of-barrier segment elevations is highly recommended (e.g., if a barrier segment has a ground elevation of 320.63 feet, model the segment height at 24.37 feet for a top-of-barrier segment elevation of 325.00 feet).

- Final optimization of noise barrier vertical profiles shall be performed to a resolution of 1.0-foot segment perturbations.

- Noise walls on existing retaining walls are discouraged. Coordination with NCDOT shall occur prior to noise wall modeling on existing retaining walls.

- For noise walls adjacent to proposed retaining walls, a six (6)-foot minimum horizontal separation shall be provided between the noise wall and retaining wall. See standard drawing for noise wall/retaining wall clearance requirements in **Appendix E**.

- Noise wall offsets on roadway shoulders should not reduce the usable shoulder width and should be wide enough to provide for full paved shoulder widths plus placement of a protective barrier (guardrail, single faced barrier, etc.) in front of the noise wall. There should be two to three feet of offset behind the noise wall to the shoulder break point. If drainage accommodations are needed behind the noise wall, offsets will need to be greater.

- Noise wall offsets at the top of cut sections should be sufficient for the noise wall to be placed outside the clear zone on the roadway side and five (5) to 10 feet from the right of way on the property owner side.

- Noise walls must be designed with existing and proposed utilities in mind. For underground utilities, noise wall posts should be placed at least 10 feet horizontally, preferably middle span, from the utility. For aerial utilities, vertical and horizontal clearances may vary and will need to be reviewed and approved by NCDOT and the impacted utility owner.

- Features such as streams or roadside ditches may also require consideration in the design of noise barriers. Noise barriers must not reduce the amount of water able to flow through the channel.

- All potentially feasible and reasonable noise barrier horizontal alignments should be evaluated and optimized as part of a DNR. Optimization of a single noise barrier horizontal alignment is not sufficient justification to recommend that specific noise barrier for construction. While noise analysts may develop an acoustical profile, (minimum top of barrier elevation) for each potentially feasible and reasonable noise barrier to aid in the barrier selection process, such a profile is only required for the recommended barrier.

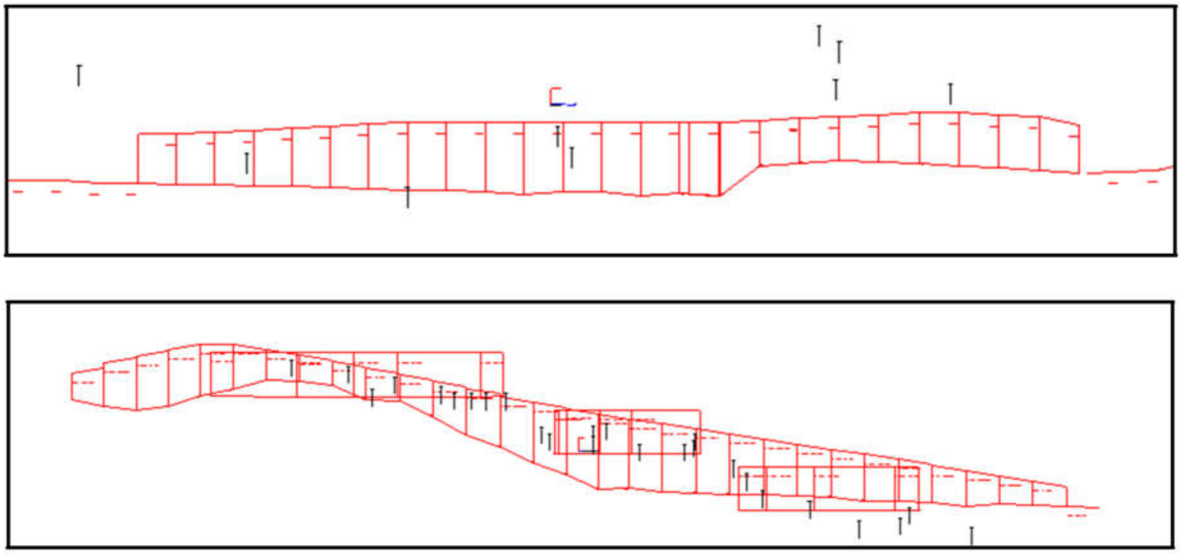
- A minimum six (6)-inch embedment of the bottom noise wall panel is required on noise wall envelope drawings.

- The acoustic profile (minimum top of barrier elevation) will provide the basis for the development of any noise barrier envelope drawings prepared by the designers for the recommended barriers. Noise barriers for which barrier envelope drawings are developed will have their own independent stationing. Envelope drawings are required only for recommended barriers. See **Section 11.19** for guidance on drawing the acoustic profile on the envelope drawing.

- NCDOT’s desire is for the final recommended noise barrier’s top of barrier profile to consist of extended lengths with consistent vertical grades. Refer to **Figure 7-17** for an example. The decision on whether to taper the ground-mounted noise barrier heights on either end of a bridge (where the barrier is limited to 10 feet in height) is the responsibility of the Division Engineer. The purpose of tapering is to achieve a gradual rather than an abrupt change in height between the ground-mounted barriers and those on structure. Sometimes it may not be possible to taper the ground-mounted barrier heights if doing so would compromise the acoustic feasibility and reasonableness of the barrier.

Figure 7-17. Final Recommended Noise Barrier Top of Wall Profiles

TNM Noise Barrier Analysis Elevation Views



(Note townhouses modeled as noise barriers in background)

7.10.7. Tree Zones

TNM tree zones should be modeled to represent existing forested areas as necessary to accurately predict traffic noise levels. Tree zones consist of long, wide regions of heavy, non-deciduous woods and undergrowth (not just individual trees or several rows of trees) that intervene between roadway and receptors, thereby reducing noise levels. The trees and undergrowth should obstruct vision of the traffic along the noise propagation path. Potential modeled tree zones shall be presented initially in the Noise Analysis Work Plan following field reconnaissance. Final NCDOT approval to model tree zones for the existing and build alternative(s) should typically be provided concurrently with the approval of model validation efforts. Inclusion of tree zones in TNM modeling for existing, no build and build alternative(s) is rare for NCDOT projects.

- Although the widely accepted criteria for sound attenuation is that an area of dense forestation must be 100-feet thick for it to reduce noise levels by ~5 decibels, inclusion of thinner TNM tree zones has been shown to appreciably affect TNM-predicted traffic noise levels. Inclusion of actual forested areas less than 100 feet wide into TNM models will be considered acceptable if all other features have been modeled (e.g., terrain lines, structures, ground zones, etc.) and the modeled tree zone appreciably improves the predictive accuracy of the validation model.
- TNM computes tree attenuation per the International Standards Organization. This standard requires that trees be sufficiently dense to completely block the view along the

propagation path. This requires dense undergrowth as well as dense treetop foliage. According to FHWA, tree zones shall not be modeled unless they have this vegetative density. NCDOT approval, typically considered during review of model validation efforts, is required prior to including tree zones when modeling existing and future noise levels.

- TNM tree zones should be limited to the area beyond the limit of disturbance. If the limit of disturbance is unknown, include the tree zones that exist beyond the right-of-way line.
- Chapter 10 of the NCHRP Report 791 concludes, "No overlaid ground zone of any type is needed for TNM input to properly compute tree attenuation. However, it is important to use default ground type or a ground zone type for the tree zone that is consistent with the actual ground present under the vegetation." Therefore, if a default ground zone of pavement was specified in TNM, then a tree zone should be overlaid on a field grass or lawn ground zone. The referenced Chapter provides additional guidance on modeling tree zones.

7.10.8. Ground Zones

TNM ground zones should be modeled to represent existing and/or proposed areas of acoustically significant ground surface conditions, including transitions between two or more different types of surfaces, and the representation of oddly shaped hard or reflective surface areas such as parking lots, highway exit ramp gore areas, paved medians, and bodies of water, etc. Chapter 9 of the NCHRP Report 791 states:

- Ground zones are not needed for small patches of non-default ground such as suburban sidewalks and driveways. In general, a ground zone must cover about 20% of the source-receptor distance to have more than a one (1) dB effect.
- It is not necessary to be precise when entering X and Y coordinates for ground zones. Ground zone effects are very insensitive to the precise size and location of the zone. For example, it might take a change in width of 30 feet to cause a one (1) dB(A) change in the ground zone's effect, and even then, the change might only occur under the most critical input geometry.
- Ground zones are needed more toward the middle of the propagation path, generally in the area where the sound wave bounces off the ground toward the receptors. In general, ground zones are needed in this central area as long as they cover more than 10 to 20% of the source- receptor distance. If in doubt, it is best to include them to determine their effect.

Chapter 9 of NCHRP Report 791 also includes an expanded set of effective flow resistivity (EFR) values that can be entered into TNM as custom values. NCDOT approval, typically considered during review of the Noise Analysis Work Plan, is required prior to including alternate EFR values for ground zones when modeling existing and future noise levels.

7.10.9. Signalized Interchanges, Intersections, and Roundabouts

Correct TNM modeling of traffic on ramps, intersections, local crossroads, and roundabouts is essential where receptors exist in proximity to these noise sources. This requirement pertains to both signalized and unsignalized intersections and ramp termini. While vehicles accelerating on roadway segments are often the most predominant noise sources in the vicinity of intersections and ramps, vehicles operating on free-flow roadway segments and on decelerating segments approaching ramp termini or intersections also require consideration. **Appendix B**, based upon Chapter 3 of the NCHRP Report 791, provides detailed guidance on modeling the decelerating, accelerating, and free flow operations for:

- a normal signalized diamond's entrance and exit ramps
- a folded diamond signalized interchange's entrance loop ramp, entrance diamond ramp, exit loop ramp, and exit diamond ramp
- full and partial modeling of a signalized single-point urban interchange's exit ramps, entrance ramps, and crossing road
- unsignalized intersections with two-way and four-way stops and signalized intersections with one-way and two-way roadways
- roundabouts with one-lane and two-lane circulatory roads

7.10.10. Parallel Barriers

Chapter 12 of the NCHRP Report 791 provides additional guidance to that included in the TNM Users Guide regarding the modeling of parallel barriers. TNM evaluates parallel barriers by a separate Parallel Barrier Module that runs outside of the main TNM program. It provides an indication of the degradation of a noise wall's effectiveness created by the presence of a parallel barrier (which could be another noise wall or a retaining wall).

Rather than being used to adjust the noise wall insertion loss values predicted by the main TNM program, the Module should be used to identify the need for absorptive treatment on one or both of the parallel noise walls necessary to essentially eliminate the degradation. A parallel barrier analysis shall be performed where there are parallel reflective surfaces (either noise walls, retaining walls, or any combination thereof) on both sides of a roadway that meet the following conditions:

- Both surfaces are at least six (6) feet high.
- The ratio of the closest distance between each reflective surface and the average of the heights of both reflective surfaces is less than 10:1 for TNRs.
- The ratio of the closest distance between each reflective surface and the average of the heights of both reflective surfaces is 20:1 or less for DNRs.

Such analyses must be conducted for receptors behind both reflective surfaces, even in situations where a new noise wall is being designed opposite of a previously constructed noise wall. A reflective surface should be assumed for previously constructed noise walls unless an absorptive surface was included as verified through field inspection, measurement, or as-built plans. Absorptive surface materials shall be considered for noise walls or other reflective surfaces in accordance with **Section 10.3**.

7.10.11. Traffic Noise Level Contours

Per 23 CFR 772.7(9)(c), noise level contours may be used for project alternative screening or for land use planning to comply with 23 CFR 772.17; however, noise level contours shall not be used for determination of highway traffic noise impacts. For TNRs and DNRs, noise level contours shall be determined by screening the build-condition TNM models of the actual project for appropriate locations at which the contour noise levels approach the NAC for Activity Category B and C uses (66 dBA) or Activity Category E uses (71 dBA). Using arbitrary TNM models, not representative of the actual project, is not an acceptable methodology to assess project traffic noise level contours for TNRs and DNRs.

7.11. Analysis Requirements for NEPA as Compared to 23 CFR 772 Requirements

While the above-discussed techniques for performing a noise analysis meet the requirements of 23 CFR 772, there is a major difference between NEPA and 23 CFR 772 requirements for determining highway traffic noise impacts.

As discussed in **Section 8**, 23 CFR 772 defines highway traffic noise impacts as occurring when a build alternative's predicted noise level approaches or exceeds the NAC or represents a substantial increase over existing noise levels. Even if predicted noise levels decrease in the future as a result of the project, e.g., from 72 dB(A) to 69 dB(A) at a Category B site, there is still a highway traffic noise impact under 23 CFR 772, and abatement must be considered.

It is FHWA's view that the noise analysis performed to satisfy the requirements of 23 CFR 772 generally satisfies the requirements under NEPA. 23 CFR 772 ignores the no-build alternative in determining "impacts" because absent a project, there is no requirement for abatement. To satisfy NEPA requirements, NCDOT traffic noise analyses for roadway widening projects will include noise levels for the design year no-build alternative to provide a benchmark to allow decision makers and the public to compare the levels of effects between alternatives. Comparison of future no build and future build noise levels is useful in circumstances where project construction reduces future noise levels. For example, if a project's purpose is to straighten out a curve, in which the alignment moves away from sensitive receptors, comparing the future build to future no-build could potentially show reductions in noise levels due to the project.

7.12. Analysis Requirements for Section 4(f) Resources

The requirements of Section 4(f) of the DOT Act of 1966 are separate from 23 CFR 772, but also call for consideration of noise impacts to lands subject to Section 4(f). A noise impact does not necessarily constitute a Section 4(f) use. However, even when noise increases do not constitute a Section 4(f) use, noise impacts may still require consideration for abatement under 23 CFR 772. For example, abatement measures may result in additional impacts that require consideration under Section 4(f), NEPA, Section 106, or as visual impacts.

Section 23 CFR 774.15 of FHWA's regulations governing implementation of Section 4(f) include specific discussion to aid in assessing whether noise impacts would constitute a constructive use and require a Section 4(f) evaluation. In general, a constructive use occurs when "The projected noise level increase attributable to the project substantially interferes with the use and enjoyment of a noise-sensitive facility of a property protected by Section 4(f)". Examples include hearing performances at an outdoor amphitheater, sleeping in a campground, visiting a historic site where a quiet setting is related to the site's significance, enjoying an urban park where serenity and quiet are significant attributes, or viewing wildlife in an area of a refuge intended for such viewing.

According to 23 CFR 774.15(f), a constructive use does not occur when the impact of projected traffic noise levels of the proposed highway project on a noise-sensitive activity do not exceed the FHWA noise abatement criteria or the increase in the projected noise levels of the proposed project is barely perceptible (3 dB(A) or less). The TNR and DNR only need to report the noise levels at these receptors, and do not need to report a constructive use impact, as that will be reported either in Section 4(f) documentation or the NEPA document. Constructive use determinations are made by FHWA.

Noise levels and any proposed abatement for Section 4(f) lands will be identified in Traffic Noise Reports and Design Noise Reports. As necessary, the NCDOT Project Manager will use this information for further coordination with FHWA on whether noise levels and any proposed abatement constitute a use in the context of Section 4(f).

7.13. Analysis Requirements for Section 106 Resources

As with Section 4(f), the consideration of historic properties on or eligible for listing on the National Register of Historic Places (NRHP) under Section 106 of the National Historic Preservation Act is a separate requirement but may be related to the assessment of noise impacts under 23 CFR 772. There is no metric for analyzing when a change in noise constitutes an effect under the regulations implementing Section 106 (36 CFR Part 800), since that will be dependent on the contributing characteristics and use of the historic resource.

Some historic or eligible properties, such as designed or cultural landscapes where the landscape itself is the significant feature or where the setting is especially important, may be extremely sensitive to any change that can be perceived by the human ear. In such cases FHWA considers anything above three (3) dB(A) to be a change that should be considered an effect. These cases should be assessed to determine whether the change could adversely affect the contributing characteristics of the property. Other historic properties, such as historic transportation facilities, could be relatively unaffected by noise. It depends on the resource as to when noise impacts may diminish the integrity of a property's significant historic features, including a change in character of the property's setting or use [see 36 CFR 800.5(a)(1) and (2)]. Mitigation to address impacts of noise to a historic property is a separate matter from any abatement determined justified under 23 CFR 772, and as with Section 4(f) properties, the abatement measures may present additional impacts to be considered.

Noise levels and any proposed abatement for historic properties under Section 106 will be identified in Traffic Noise Reports and Design Noise Reports. As necessary, the NCDOT Project Manager will use this information for further coordination with FHWA and the North Carolina State Historic Preservation Office (NC-HPO) for a finding of effects (no effect, no adverse effect, or adverse effect).

8. PROJECT NOISE IMPACT ASSESSMENT

Highway noise impacts generally occur as either traffic noise impacts and/or construction noise impacts. When traffic noise and construction noise impacts are identified, abatement must be assessed, and if possible, implemented.

8.1. Traffic Noise Impacts

Traffic noise impacts occur when predicted design year build condition worst hour noise levels either approach or exceed the FHWA noise abatement criteria, and/or when the predicted design year build condition worst hour noise levels substantially exceed the existing worst hour noise levels. Noise abatement shall be considered for all traffic noise impacts. Regarding the determination of noise impacts, it is important to emphasize the following points:

- Consistent with FHWA's position contained in the 23 CFR 772 Final Rule's Supplementary Information and FHWA guidance contained in the FHWA Analysis and Abatement Guidance document, "an effective noise analysis should consider major noise sources in the environment including transportation, industry, and background noise." This means that in identifying both existing and future worst hour noise levels, the total noise level must be considered.

- This total noise includes not just the modeled noise from an existing or proposed highway, but also noise from the "combination of natural and mechanical sources and human activity usually present in a particular area." The methods in which non-traffic noise sources are considered in the analysis depend on the particular situation for each project, and should be discussed with the NCDOT Traffic Noise and Air Quality Group and included in the Noise Analysis Work Plan

- In determining worst hour noise impacts associated with the design year build condition, the total noise level associated with the design year build condition is compared with the appropriate NAC level as well as with the total worst hour existing noise level.
    - According to 23 CFR 772, there cannot be a traffic noise impact for existing conditions and no-build alternatives under NEPA since only a project can create an impact.

- All identified traffic noise impacts require the consideration of noise abatement and the construction of abatement features determined to be both feasible and reasonable.

Table 8.1 lists the FHWA Noise Abatement Criteria (NAC) land use activity categories, and the noise levels that, when approached, met, or exceeded with the project build condition, constitute an impact. Note that at an apartment complex, areas such as pools, tennis courts, and playgrounds are considered Activity Category B – Residential since the primary use of the property as an apartment complex is residential. Similarly, a hotel pool is Activity Category E since the primary use of the property is as a hotel. NCDOT considers funeral homes under Activity Category E.

NCDOT defines approach as reaching one decibel less than the applicable FHWA NAC L_{eq}(h) values below. As an example, NCDOT considers a TNM model value of 65.5 dB(A) or greater (rounded to 66 dB(A)) to approach the FHWA Activity Category B or C Criteria and therefore constitute a noise impact. Other activity category criteria values are treated similarly.

Table 8.1. Noise Abatement Criteria

Hourly Equivalent A-Weighted Sound Level (decibels (dB(A))

Activity Category	Activity Criteria[1][2] Leq(h)	Evaluation Location	Activity Description
A	57	Exterior	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B [3]	67	Exterior	Residential
C [3]	67	Exterior	Active sport areas, amphitheaters, auditoriums, campgrounds, cemeteries, daycare centers, hospitals, libraries, medical facilities, parks, picnic areas, places of worship, playgrounds, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, recreation areas, Section4(f) sites, schools, television studios, trails, and trail crossings
D	52	Interior	Auditoriums, day care centers, hospitals, libraries, medical facilities, places of worship, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, schools, and television studios
E [3]	72	Exterior	Hotels, motels, offices, restaurants/bars, and other developed lands, properties or activities not included in A- D or F
F	--	--	Agriculture, airports, bus yards, emergency services, industrial, logging maintenance facilities, manufacturing, mining, rail yards, retail facilities, shipyards, utilities (water resources, water treatment, electrical), and warehousing
G	--	--	Undeveloped lands that are not permitted

[1] The $L_{eq(h)}$ Activity Criteria values are for impact determination only and are not design standards for noise abatement measures.
[2] The equivalent steady-state sound level which, in a stated period of time, contains the same acoustic energy as the time-varying sound level during the same time period, with $L_{eq(h)}$ being the hourly value of L_{eq}.

[3] Includes undeveloped lands permitted for this activity category

Noise impacts can also result from predicted design year build condition worst hour equivalent noise levels increasing substantially over existing worst hour equivalent noise levels. NCDOT defines substantial to be 10 dB(A) or greater. Therefore, if the existing worst hour rounded noise level is 60 dB(A) and the predicted design year worst hour rounded noise level is 70 dB(A), then a noise impact exists (increase over existing = 10 dB(A)).

A sample summary table for the identification of traffic noise impacts along the project is shown below in **Table 8.2**.

Table 8.2. Traffic Noise Impact Summary for Build Condition

DETAILED STUDY ALTERNATIVE (DSA) [Can use NSA if only 1 alternative is analyzed.]	REASON FOR NOISE IMPACT	SUMMARY OF IMPACTED RECEPTORS[7]							
		BY ACTIVITY CATEGORY							
		A	B	C	D	E	F[5]	G[6]	ALL ACTIVITY CATEGORIES
1	Based on NAC Criteria Only[1]	0	14	3	2	2			21
	Based on Substantial Increase Criteria Only[2]	1	11	1	1	0			14
	Based on Both Criteria[3]	0	10	1	0	0			11
	TOTAL DSA IMPACTS[4]	1	25	4	3	2			35
2	Based on NAC Criteria Only[1]	0	19	2	0	0			21
	Based on Substantial Increase Criteria Only[2]	0	2	0	1	1			4
	Based on Both Criteria[3]	0	10	0	0	0			10
	TOTAL DSA IMPACTS[4]	0	21	2	1	1			25
3	Based on NAC Criteria Only[1]	0	17	1	2	1			21
	Based on Substantial Increase Criteria Only[2]	0	2	1	1	0			4
	Based on Both Criteria[3]	0	10	1	0	0			11
	TOTAL DSA IMPACTS[4]	0	19	2	3	1			25
4	Based on NAC Criteria Only[1]	0	10	3	1	0			14
	Based on Substantial Increase Criteria Only[2]	0	5	1	3	0			9
	Based on Both Criteria[3]	0	2	0	0	0			2
	TOTAL DSA IMPACTS[4]	0	15	4	4	0			23
Note 1: Predicted traffic noise level impacts due to design year worst hour build-condition noise levels approaching or exceeding the NCDOT Noise Abatement Criteria (NAC)									
Note 2: Predicted design year worst hour noise levels exceeding existing worst hour noise levels by 10 dB(A) or greater. (NCDOT Substantial Increase Criteria).									
Note 3: Predicted traffic noise level impacts due to both 1 and 2 above.									

Note 4: Only one of the Note 1 and Note 2 conditions must be met for an impact to exist.
Note 5: There are no impact criteria for land use facilities in this activity category and no analysis of noise impacts is required.
Note 6: There are no impact criteria for undeveloped lands but some noise levels may need to be provided to local officials to aid them in future land use planning efforts.
Note 7: Values noted for Activity Category C, D, and E represent Equivalent Receptor values for these non-residential land uses.

8.2. Construction Noise Impacts

The assessment of highway construction noise impacts and potential abatement options is a requirement of 23 CFR 772 and shall be completed in a comprehensive manner for all Type I projects. NCDOT requires noise analysts to perform the following tasks to assess, and if possible, minimize the effects of construction noise for all Type I and other State-Funded projects requiring a noise analysis:

- In all noise reports (TNR and DNR), identify land uses or activities that may be affected by noise from construction of the project.
- Determine the measures that are needed in the plans and specifications to minimize or eliminate adverse construction noise impacts to the community. This determination shall consider the benefits achieved and the overall social, economic, and environmental effects and costs of the abatement measures.
- Consider construction techniques and scheduling to reduce construction noise impacts to nearby receptors and incorporate the needed abatement measures in the project plans and specifications.

Table 8.3 lists typical construction equipment noise level emissions. Common factors of project construction noise that should be addressed as part of all traffic noise analyses include, but are not limited to:

- Proximity of project construction activities to noise sensitive receptors.
- Schedule of project construction activities in the context of localized land use(s), both in terms of the hour(s) of the day (e.g., daytime, evening, nighttime), and in terms of the number and type(s) of days, weeks or months specific activities might occur (e.g., weekday, weekend, holiday, season, etc.).
- Likelihood of any severe construction noise emissions, particularly from impact-type equipment, that might occur in the vicinity of noise sensitive receptors.

Table 8.3. Construction Equipment Typical Noise Level Emissions[1]

	Noise Level Emissions (dB(A)) at 50 Feet from Equipment[2]				
	70	80	90	100	
Pile Driver[3]					
Jack Hammer					
Tractor					
Road Grader					
Backhoe					
Truck					
Paver					
Pneumatic Wrench					
Crane					
Concrete Mixer					
Compressor					
Front-End Loader					
Generator					
Saws					
Roller (Compactor					

[1] Adapted from Noise Construction Equipment and Operations, Building Equipment, and Home Appliances. U.S. Environmental Protection Agency. Washington D.C. 1971.

[2] Cited noise level ranges are typical for the respective equipment. For point sources such as the construction equipment listed above, noise levels generally dissipate at a rate of -6 dB(A) for every doubling of distance over a hard surface or through the air. For example, if the noise level from a pile driver at a distance of 50 feet = 100 decibels (dB(A)), then at 400 feet, it will generally be 82 decibels (dB(A)) or less.

[3] Due to project safety and potential construction noise concerns, pile driving activities are typically limited to daytime hours.

9. FEASIBILITY AND REASONABLENESS OF NOISE ABATEMENT

Title 23 CFR 772.13(d) requires the examination and evaluation of feasible and reasonable noise abatement measures for reducing noise impacts. Since FHWA and NCDOT require any noise abatement measure to be both feasible and reasonable, reasonableness evaluations are not performed for noise abatement measures that have been clearly determined to be not feasible.

Noise abatement shall be designed to benefit impacted receptors only, although it is recognized that in doing so there will sometimes be non-impacted benefits provided by an abatement measure. Each noise wall must be evaluated independently in terms of its ability to be acoustically effective, feasible, and cost reasonable.

This chapter expands on the feasibility and reasonableness information contained in the 2021 NCDOT *Traffic Noise Policy*.

9.1. Feasibility

Determination of feasibility is the combination of acoustical and engineering factors considered in the evaluation of a noise abatement measure. The following factors apply to the determination of feasibility, as stated in the 2021 NCDOT *Traffic Noise Policy*:

- *Any receptor that receives a minimum noise level reduction of 5 dB(A) due to noise abatement measures shall be considered a benefited receptor. A noise reduction of 5 dB(A) must be achieved for at least two impacted receptors.*
- *Engineering feasibility of the noise abatement measure(s) shall consider adverse impacts created by or upon property access, drainage, topography, utilities, safety, and maintenance requirements.*

Although projects with full control of access are optimal for the design of traffic noise abatement measures, noise abatement can sometimes meet feasibility requirements on uncontrolled access and partial access control of access roadway facilities. A comprehensive examination of possible traffic noise abatement measures shall be conducted for the benefit of all predicted traffic noise impacts – regardless of project roadway access.

If the results of feasibility evaluations determine that the acoustical requirements associated with a noise abatement measure are clearly not met, then no evaluation of its reasonableness is required, since any constructed barrier must be both feasible and reasonable. Note that the effects of secondary traffic noise (e.g., non-project traffic noise) and non-traffic noise sources on attainable Noise Level Reduction may be considered when evaluating effectiveness of noise abatement measures per guidance in the *FHWA Noise Measurement Handbook* (FHWA-HEP-18-065, June 2018) (USDOT-FHWA, 2018).

Similarly, if the evaluation of engineering or safety factors clearly indicate that a barrier is not feasible, then no evaluation of an abatement measure's reasonableness is required, even if the measure is acoustically feasible. Reference **Section 9.2** for a list of factors that can affect noise barrier constructability.

In some cases, particularly during a preliminary design noise analysis process, the degree of detail related to the project may not be sufficient to make a determination of an abatement measure's feasibility, or such details may only be sufficient to make a preliminary determination of feasibility.

9.2. Constructability

NCDOT practices a comprehensive approach to traffic noise analysis and design that includes the constructability of recommended noise walls. Solutions to project-specific constructability issues shall be developed as-needed specifically for each barrier analyzed.

NCDOT's approach includes, but is not limited to, the following items:

- Lateral clearance
- Drainage
- Maintenance access
- Noise wall installation on existing structures
- Wind and earth loads
- Foundation design
- Construction specifications
- Utilities
- Roadside hazard and crash protection
- Safe sight distances for stopping and merging

9.3. Reasonableness

Determination of the reasonableness of a barrier includes a combination of social, economic, and environmental factors considered in the evaluation of a noise abatement measure. Per NCDOT *Traffic Noise Policy*, noise abatement reasonableness determination is based upon the following factors:

a) Noise reduction design goal
b) Cost reasonableness of abatement measures
c) Preferences of property owners and tenants

These factors are discussed in more detail in **Sections 9.3.3**, **9.3.2,** and **9.3.1**.

9.3.1. Noise Reduction Design Goal

In accordance with 23 CFR 772, NCDOT has established a noise reduction design goal (NRDG) of 7 dB(A). As stated in the 2021 NCDOT *Traffic Noise Policy*,

> *A noise reduction design goal of 7 dB(A) must be achieved for at least one benefited receptor, whether impacted or not. If it can be achieved for one benefit, then the barrier shall be optimized to achieve 7 dB(A) at as many impacted receptors as possible. The initial evaluation of at least one NRDG is focused on all benefits. The subsequent assessment of achieving NRDG at additional receptors is focused only on impacts.*

The emphasis of NCDOT traffic noise abatement is on the impacted receptors. Although designing noise abatement for impacted receptors may result in non-impacted receptors being benefited, the focus of abatement design should not be on maximizing benefits to non-impacted receptors. It is also not necessary to achieve a maximum noise level reduction at impacted receptors, as long as the 5 dB(A) reduction for impacted receptors and the 7 dB(A) noise reduction design goal have been met.

9.3.2. Cost-Reasonableness of Abatement Measures

NCDOT evaluates the square feet of barrier per benefited receptor (SF/BR) value in determining the cost-reasonableness of an abatement measure. **Table 9.1** shows the allowable quantities per benefited receptor that are used to determine this value and a barrier's cost reasonableness.

The allowable SF/BR base quantities are shown in **Table 9.1**. The square footage for noise walls shall be the areas of the optimized barriers in TNM for both TNRs and DNRs. Noise wall areas on panel drawings in DNRs shall not be used in determining cost reasonableness. When a 4:1 or 3:1 overlap is needed in a noise wall to accommodate maintenance or other needs for access, the quantity of the overlapping segment in the TNM model shall not be counted for the purposes of determining reasonableness. Where barriers have overlapping segments in the TNM model, only one of the walls in the overlap area (the largest wall segment) should be counted in the overall area of the barrier for determining cost reasonableness.

Table 9.1. Allowable Noise Abatement Base Quantities

Maximum Allowable Base Quantity	Noise Level Consideration	Noise Wall[1]	Berm	Noise Insulation[2]
		1,500 sq ft	4,200 cu yd	$45,000
Average dB(A) Increase Between Existing and Future Build for All Impacted Receptors	< 5 dB(A)	+ 0 sq ft	+ 0 cu yd	+ $0
	5-10 dB(A)	+ 500 sq ft	+ 1,400 cu yd	+ $15,000
	> 10 dB(A)	+ 1,000 sq ft	+ 2,800 cu yd	+ $30,000
Average Exposure to Absolute Noise Levels for All Impacted Receptors	5-10 dB(A) Over NAC Activity Category	+ 500 sq ft	+ 1,400 cu yd	+ $15,000
	> 10 dB(A) Over NAC Activity Category	+ 1,000 sq ft	+ 2,800 cu yd	+ $30,000

[1] Cost effectiveness for noise walls shall be based on the barrier area quantities in the TNM models for both TNRs and DNRs. Barrier areas from panel drawings in DNRs shall not be used.
[2] Noise insulation is only considered for Category D land use facilities (23 CFR 772.15(c)(5)).

NOTE: The incremental increases to the base quantity are cumulative when both criteria (average increase and average exposure) apply. The incremental increase is based on impacted receptors regardless of whether such impacted receptors are benefited or not.

- The maximum allowable base quantity of noise walls per benefited receptor shall not exceed 1,500 per square foot (ft^2), and the maximum allowable base quantity of earthen berms per benefited receptor shall not exceed 4,200 per cubic yard (yd^3). Additionally, an incremental increase of up to 2,000 ft^2 for noise walls and 5,600 yd^3 for earthen berms shall be added to the base quantity to reflect the average degree of increase in dB(A) between existing and predicted exterior noise levels of all impacted receptors within each noise study area (NSA) within the general vicinity of the analyzed noise barrier. The general vicinity is defined as a geographically limited area within an NSA in which noise sensitive land uses exist that are, or may be exposed to, similar noise sources.

- In addition to the adjustments to the base square feet values associated with average increases over existing levels, the build alternative's absolute noise level for impacted receptors can also result in adjustments to the base square feet value. If the build alternative's average absolute noise level for impacted receptors within each noise study area (NSA) within the general vicinity of the analyzed noise barrier is predicted to be 5 dB(A) or more above the NAC level, 500 ft^2 will be added to the base square feet value for noise walls and 1,400 yd^3 for berms. If the build alternative's average absolute noise level for impacted receptors in the general vicinity of a noise barrier is predicted to be more than 10 dB(A) above the NAC level, 1,000 ft^2 will be added to the base square feet value for noise walls and 2,800 yd^3 for berms. For purpose of calculating the additional square foot or cubic yard credits, the NAC values for Activity Categories A, B, C, D, and E are assumed to be 57 dB(A), 67 dB(A), 67 dB(A), 52 dB(A), and 72 dB(A), respectively. Note that these NAC values represent the values listed in **Table 8.1** as opposed to the NCDOT approach values used in impact determinations and are more appropriate to use since the intent is to help those most severely impacted by traffic noise.

- If the build alternative's average noise level is predicted to be 5 dB(A) or more above the existing level, $15,000 will be added to the $45,000 base dollar value listed above for noise insulation. If the build alternative's average noise level is predicted to be more than 10 dB(A) above the existing level, $30,000 will be added to the base dollar value.
- When considering the cost reasonableness of noise insulation, if the build alternative's average absolute noise level is predicted to be 5 dB(A) or more above the appropriate NAC level, $15,000 (500 SF/BR times $30/SF) will be added to the base dollar value for a total of $60,000 per benefited receptor. If the build alternative's average absolute noise level is predicted to be more than 10 dB(A) above the NAC level, $30,000 (1,000 SF/BR times $30/SF) will be added to the base dollar value, resulting in a total value of $75,000 per benefited receptor. The increases may be applied in addition to the increases associated with build alternative increases over NAC levels. The maximum allowable dollar value of $105,000 per benefited receptor for noise insulation would occur if both the NAC value is exceeded and the increase over existing value exceeds 10 dB(A).
- Per FHWA regulations in 23 CFR 772.15(c)(5), noise insulation as an abatement measure is only applicable to Activity Category D land use facilities. Post-installation maintenance and operational costs for noise insulation are not eligible for Federal-aid funding.

9.3.3. Preferences of Property Owners and Tenants

During the final design noise analysis process after the DNR is finalized and recommended noise abatement is identified, the preferences of the property owners and tenants of all benefited receptors (including properties represented by equivalent receptors) for each recommended noise barrier shall be solicited. The noise wall balloting process is handled by staff in the Traffic Noise and Air Quality Group.

One ballot will be provided to the owner of each Activity Category A, B, C, D, and E benefited receptor and one ballot will be provided to the tenant (non-owner occupant) of each benefited Category B residential dwelling unit. No tenant ballots are distributed for vacant rental property.

If a Public Noise Barrier Balloting Meeting is held, the ballots can be submitted by the benefited owners and tenants at the meeting.

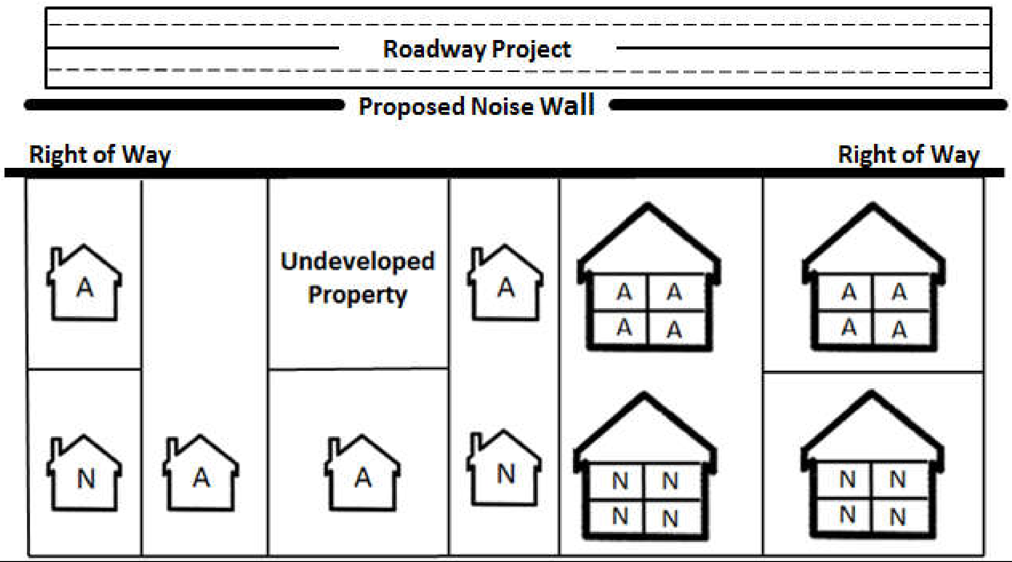
Points per ballot shall be distributed to benefited receptors in the following weighted manner:

- 5 points/ballot for adjacent property owners who reside at property
- 4 points/ballot for adjacent property owners who rent property to others
- 3 points/ballot for all non-adjacent property owners who reside at property
- 2 points/ballot for all non-adjacent property owners who rent property to others
- 1 point/ballot vote for all tenants of rental property

An Adjacent Receptor is a benefited receptor that 1) represents a property that abuts the highway right of way, or 2) has no benefited receptor between it and the highway. Where multiple buildings containing benefited receptors are on the same property, such as an apartment or condominium complex, only the building closest to the highway is an adjacent receptor. Adjacent receptors will most often, but not always, be part of the front row of benefited receptors. A Non-Adjacent Receptor is a benefited receptor located where there is another benefited receptor between it and the highway. **Figure 9-1** provides graphic examples of Adjacent and Non-Adjacent Receptors. For commercial properties (Activity Category E), all points are distributed to the property owner, because the uses (and their noise sensitivity) on a commercial property can change from sensitive to non-sensitive uses.

Owners of multi-unit rental locations will receive the applicable number of owner points for each individual benefited receptor (rental unit) owned.

Figure 9-1. Examples of Adjacent Receptors



A = Adjacent Receptor
N = Non-Adjacent Receptor
Undeveloped Property = Vacant property for which no building permit has been issued and is not a park or recreation area

If 50 percent or greater of all possible voting points from benefited receptors for each noise barrier are received on the first solicitation, a simple majority of voting points cast will be used to determine if the proposed noise barrier will be constructed. If less than 50 percent of all possible points for each noise barrier are received on the first solicitation, a second solicitation will be sent to benefited receptors who did not respond to the first solicitation.

If a second solicitation is conducted and 50 percent or greater of all possible voting points for each noise barrier are received after the second solicitation, a simple majority of voting points cast will be used to determine whether or not the proposed noise barrier will be constructed. If less than 50 percent of total possible points for a noise barrier are received after the second solicitation, the noise barrier will not be constructed.

Noise barriers will be constructed in the case of a tie (equal number of points for and against a noise barrier). All balloting soliciting the viewpoints of benefited property owners and applicable residents/tenants that occurs after the effective date of the 2021 Traffic Noise Policy, regardless of the Date of Public Knowledge, shall comply with the criteria of this policy.

9.3.4. Interior Noise Level Reduction

In accordance with 23 CFR 772.11(c)(2)(iv), interior noise analyses for Activity Category D land use facilities shall only be conducted after exhausting all outdoor analysis options and only after outdoor abatement options have been determined to be not feasible or not reasonable. If conditions warrant the evaluation of interior noise levels at an Activity Category D land use facility, the facility shall be represented by an analysis point or points having an equivalent receptor value(s) as determined by the procedures described in **Section 7.10.3**. Interior noise levels must be reduced by at least 7 dB(A) for at least one of the facility's analysis points. This situation is not expected to occur frequently. Consult with the Traffic Noise and Air Quality Group if this situation occurs.

If there are no outdoor areas of frequent human use at a Category D use, then document this in the report and no further action is needed for the exterior. If there are outdoor areas of frequent human use and modeling proves there are no impacts, then document this in the report and assign 1 ER. The ER spreadsheet does not need to be completed if there are no impacts.

For interior noise levels at a Category D use, model an exterior receptor and subtract from that value the appropriate noise reduction factor for the building (**Table 7.2**). If no impact, which is usually the case, then document this in the report, and there is no need to complete the ER spreadsheet. For medical facilities, per FHWA guidance, interior impacts only need to be considered if inpatient services are provided (i.e., an overnight stay at the facility is required). In the unlikely event there is an interior impact, coordinate with the NCDOT Traffic Noise and Air Quality Group to coordinate the proper procedures for analysis.

If there is an impact at an interior use, then the noise analyst must assess the uses inside the building where the impact is occurring to calculate the ER values for the interior uses, using the appropriate form found in **Appendix C**. For example, a classroom is considered a sensitive use inside a school, but not a gym or janitors closet in the same building. The impact should be calculated only for the specific interior activity inside the building where the impact is predicted.

10. NOISE BARRIER DESIGN CONSIDERATIONS

The following are noise barrier design considerations generally accepted by NCDOT, grouped in the following topics: acoustical; engineering and maintenance; and aesthetics. Certain factors may combine considerations that fit into several categories, an example being the design of a barrier's acoustical profile, which includes both aesthetic and acoustical factors.

10.1. Acoustical Considerations (including feasibility and reasonableness)

As a starting point in a noise barrier design process, modeled noise barrier termini should extend beyond the last benefited receptor in an NSA by four (4) times the perpendicular distance from the last benefited receptor to the barrier. As the barrier design progresses, factors may lead to a longer barrier or a shorter barrier. Determinations of barrier termini points are greatly influenced by many factors, including the horizontal and vertical relationships of receptors to roadways and barriers, intervening topography, and the geometric configuration of the highway.

In analyzing receptors within an NSA located at or beyond a project's construction termini, abatement must be considered for all receptors impacted by the project within that NSA, even if such receptors are located beyond the project termini. In addition, all benefited receptors within such an NSA must be identified and considered in feasibility and reasonableness evaluations. If, as the result of a barrier extension to adequately protect impacted receptors within such an NSA, benefits are obtained for additional receptors outside of the NSA, these additional receptors may be included in feasibility and reasonableness evaluations. However, these added benefited receptors shall not be considered in selecting one barrier option over another. In addition, any extension of a barrier beyond what is required to abate noise for impacted receptors within the NSA itself is not permitted.

Noise barriers function by extending the noise transmission path length. The most efficient noise barriers are often, but not always, located either near a roadway or near a receptor. The barrier location should take advantage of local terrain conditions to benefit from higher elevations; however, a higher barrier elevation does not always result in greater traffic noise attenuation. Priority should be given to overall noise barrier performance.

For example, a *shorter* barrier may be justified if:

1) the horizontal curvature of the highway away from the receptor allows a shorter barrier to adequately block flanking noise, or
2) the grade of the highway results in it descending in elevation as it extends farther from the receptor (if the grade is sufficient enough, no extension at all may be required), or

3) the topography allows the construction of a barrier that wraps in at its end in order to adequately block flanking noise.

A *longer* barrier may be necessary if:

1) the horizontal curvature of the highway inward towards the receptor requires a longer barrier to adequately block flanking noise, or
2) the grade of the highway results in it ascending in elevation as it extends farther from the receptor.

An optimal noise barrier process strives to develop a barrier that breaks the line of sight between receptors and the roadway noise sources. The TNM line-of-sight check tool is recommended for likely barriers in TNRs and is required for recommended barriers in DNRs. See **Section 11.20.4** for information on documenting the line-of-sight checks in DNRs.

Barrier designs should strive to break the line of sight for as many ground-floor, front-row, impacted receptors as possible while conforming to other acoustical, engineering, and aesthetic criteria. For the line-of-sight tool in TNM, use the TNM default values for sub-source height and distance limits. Analysts should limit each line of site check to just the ground-floor, first-row impacted receptors behind a single barrier or barrier system.

10.2. Engineering and Maintenance Considerations

Engineering and maintenance factors need to be considered during preliminary (TNR) and final (DNR) design noise analyses, but especially during final design. These factors include the following:

- Noise barriers must not be located where they create a safety hazard, such as blocking safe vehicle line-of-sight distances.
- Noise walls must not block property access unless the project improvements are eliminating the access.
- Combining the barrier with natural terrain features and structures (e.g., berms and retaining walls), particularly at the barrier termini, can reduce required barrier length and/or area.
- To maintain consistent costs and aesthetics, standard noise barrier designs and details are available and should be used whenever possible. When estimating the cost of ground-mounted noise barriers, taller noise barriers generally require closer pile spacings (more piles) and deeper foundations. In addition, noise barriers founded in poor soil require deeper foundations.

- Noise wall panels anchored on the ground should be no shorter than 6 feet above ground and no taller than 30 feet (including embedment depth below the ground) without explicit NCDOT approval. The maximum height of ground-mounted noise barrier panels was established by the NCDOT Structures Management Unit, based upon the geometry of the barrier's elements (piles and panels) and the corresponding feasible design for wind pressures prescribed in the AASHTO LRFD Bridge Design Specifications. Exceptions must be coordinated with the NCDOT Traffic Noise and Air Quality Group and the NCDOT Structures Management Unit.

- Noise barriers on structures should be no taller than 10 feet above the bridge deck. The maximum height for structure-mounted noise barriers was established by the NCDOT Structures Management Unit to minimize force effects on the bridge and prevent impediments to routine bridge inspections. Coordinate with the NCDOT Structures Management Unit to determine if a structure-mounted noise barrier is feasible. Certain bridge types may not be able to accommodate a structure-mounted noise barrier.

- Noise barriers should be designed with a 10-foot traversable area behind the barrier for maintenance of the barrier that is accessible to standard groundskeeping maintenance equipment.

- Grade cut-fill transitions do not universally require noise barrier horizontal alignment shift to/from the edge of pavement to/from the right of way limits. Optimal noise barrier designs have the most cost-effective application of all roadway design elements (e.g., grading, drainage, utilities, etc.) resulting in the greatest reduction in traffic noise.

- NCDOT prefers to construct maintenance openings in noise barriers to accommodate access to and around noise barriers for maintenance of the wall itself and the adjacent ROW. Constructing maintenance gaps is preferable to providing doorways or other closable openings at locations for through-wall access.
    - However, through-wall access can be included in a project if it is needed for special project conditions.
    - Maintenance gaps shall be flanked by overlapping noise wall sections at least four times the gap width in length (i.e., for a 10-foot wide gap, the noise wall should have panels that overlap at least 40-feet), the noise wall top profile elevation(s) shall be maintained on both sides of the opening, and the overlapping panels shall be oriented as parallel to the roadway as possible to minimize the potential for roadway traffic noise reflections.
    - FHWA's Noise Barrier Design Handbook Section 3.5.5.1 states: "A general rule-of-thumb is that the ratio between overlap distance and gap width should be at least 4:1 to ensure negligible degradation of barrier performance (see Figure 21)." Sound

barrier top elevations should be equal on both overlapping sides of maintenance gap openings.

- NCDOT will accept a minimum 3:1 horizontal gap overlap ratio if the gap opening does not allow a clear line of sight from benefited receptors through the gap opening to the roadway. Unless constructing a 4:1 horizontal gap overlap ratio is not feasible, NCDOT shall otherwise require that the ratio between overlap distance and noise abatement gap width be 4:1 to ensure negligible degradation of barrier performance.

- In designing noise barriers, be considerate of secondary effects of a noise barrier that could relate to aesthetic factors, drainage and utility conflicts, structural implications, and safety factors. Refer to Chapters 6 through 9, respectively, of the FHWA Highway Noise Barrier Design Handbook for guidance.

- Where necessary, NCDOT will consider providing access to fire hydrants or other sources of water and coordinate the design and implementation of related features with the appropriate jurisdictional entity.

10.3. Absorptive Noise Walls

An absorptive noise wall surface may be recommended to optimize the benefits of the proposed traffic noise abatement. NCDOT requires that absorptive noise walls provide a minimum Noise Reduction Coefficient of 0.7. Cases where it may be appropriate to consider noise wall panels with absorptive surface(s) include:

- Where there are noise walls along both sides of a highway

- Where there is a retaining wall with a reflective surface on the other side of the highway from a proposed reflective-surface noise wall

- When there are impacted receptors on the other side of the highway for whom a noise wall on their side was determined not to be feasible and reasonable.

The following guidelines should be followed on all projects where absorptive-faced noise walls are being considered. The decision on the application of absorptive treatments will be made during the final design noise analysis process.

- Absorptive-faced noise walls will be considered for a single wall configuration (a noise wall on only one side of the highway) where there are impacted noise-sensitive receptors on the opposite side of the highway that are not receiving a noise wall and there are two or more impacted receptors at a distance from the noise wall no greater than 10 times the proposed average noise wall height.

- Absorptive-faced noise walls will be analyzed where the parallel barrier analysis shows that the noise reduction degradation results in noise levels and/or insertion loss values that cause either noise wall not to be feasible and reasonable compared to a single wall configuration scenario.
- Absorptive-faced noise walls will be analyzed where the parallel barrier analysis results in two or more impacted receptors no longer being benefited or no longer meeting the NRDG.

Documentation of the parallel barrier analysis should include a discussion of methodology and results, including a table showing the noise level increase associated with the parallel reflective barriers at receptors studied in the cross-section analysis. This table should include the prediction of results for a reflective and an absorptive wall. A statement shall be included that the final determination on absorptive treatment will be made during final design.

10.4. Aesthetic Considerations

Noise barriers should be designed with linear or convex top-of-wall or top-of-berm vertical profiles. Design focus should be placed upon top-of-wall segment or top-of-berm profile elevations, not heights. While jagged undulations, notches, bumps, and concavities in the top-of-wall or top-of-berm vertical profiles are aesthetic considerations, they also are acoustical considerations since they can allow traffic noise to reach noise-sensitive receptors more easily – reducing the overall effectiveness and efficiency of the noise barrier.

Default TNM noise barrier analysis orthogonal views can be misleading with respect to the representation of noise barrier top-of-wall profiles. All recommended noise barriers must be supported by TNM-predicted noise levels; however, the NCDOT Traffic Noise and Air Quality Group encourages the use of spreadsheets and/or other computational tools outside of TNM model(s) as an intermediate step to derive the basis for the assessment of acoustically efficient and cost-effective – optimal – noise barriers (refer to

Table 10.1). The results of this intermediate step should then be input into TNM to calculate the noise levels included in the report.

Table 10.1. Use of a Spreadsheet for Noise Barrier Profile Optimization

STA	Length	TNM		Optimized		RECOMMENDED		
		Top El.	% Grade	Top El.	% Grade	Input Ht.	Area	Length
392+00.00	49.26	649.20	3.3%	650	4.1%	12.8	664	49
392+50.00	49.32	650.85	5.4%	652	4.1%	14.15	731	49
393+00.00	52.33	653.50	2.4%	654	1.9%	15.5	831	52
393+50.00	52.26	654.75	2.4%	655	1.9%	16.25	869	52
011+00.00	50.91	656.00	1.2%	656	2.0%	17.0	901	21
011+50.00	50.69	656.00	-0.8%	657	0.0%	18.4	943	21
012+00.00	98.83	656.20	-0.2%	657	-1.0%	18.8	1,818	99
013.00.00	101.42	656.00	0.0%	656	0.0%	18.0	1,876	101
014+00.00	99.89	656.00	-1.0%	656	-1.0%	19.0	1,898	100
015+00.00	99.72	655.00	0.1%	655	0.0%	19.0	1,940	100
016+00.00	100.61	655.10	-2.4%	655	-2.0%	19.9	2,022	101
017+00.00	98.73	652.70	-3.3%	653	-3.0%	20.3	2,019	99
018+00.00	98.90	649.40	-3.7%	650	-3.0%	20.6	2,070	99
019+00.00	101.01	645.70	-1.9%	647	-3.0%	21.3	2,096	101
020+00.00	100.16	643.80	-2.3%	644	-3.0%	20.2	1,938	100

Note: The Optimized % Grade changes represent a more consistently convex shape – a more optimal top-of-wall-profile – than the TNM % Grade changes.

10.5. Other Noise Barrier Design Considerations

There may be instances where a feasible and reasonable noise barrier is designed for a cluster of impacted receptors, and there are distant isolated impacted receptors that might benefit if the wall were extended to them, even though these distant receptors would not otherwise qualify for a likely wall on their own. These situations should be evaluated on a case-by-case basis in consultation with the NCDOT Traffic Noise and Air Quality Group.

An example of this situation is as follows. An apartment complex with many benefited receptors is determined to have a proposed likely noise wall with a low wall area/benefit value. The low value for area/benefit means that a wall with substantially more area in length and/or height could be constructed within the allowable area/benefit. Approximately 1,000 feet away from the complex is an isolated impacted single-family residential receptor. This receptor, because it is isolated, would not normally be eligible for a noise wall. Extending the apartment complex noise wall over 1,000 feet (with the additional area greater than the allowable square feet/benefit for one benefit) solely to benefit this isolated receptor would not be reasonable, even if the resulting wall overall would be within the allowable total area/benefit.

11. REPORTING

NCDOT does not intend to dictate the exact content and formatting of Traffic Noise Reports and Design Noise Reports. However, because consistency in reporting and report formatting is desirable, a TNR template and a DNR template are available for download on the NCDOT website. All NCDOT traffic noise reports shall be written in a manner necessary to adequately and appropriately document:

- the relevant noise conditions (traffic and otherwise),
- the assessment of traffic noise impacts
- the assessment of construction noise effects,
- the analysis of feasibility of all potential traffic noise abatement measures
- the analysis of reasonableness of all feasible noise abatement measures
- locations where noise abatement was determined not to be feasible or reasonable
- all recommendations for feasible and reasonable abatement, and
- other information pertinent to traffic noise in the context of the subject project(s).

With the exception of TNM model validation, all noise levels shall be rounded to the nearest whole decibel prior to conducting traffic noise impact assessment and insertion loss/noise level reduction calculations (See **Section 7.2**). Unless explicitly requested otherwise, all other noise levels shall be stated in units of whole decibels in all NCDOT traffic noise reports. All noise level descriptors such as metric, time, and spatial references (e.g., $L_{eq(h)}$) shall be included as appropriate. NCDOT shall consider the qualification of one or more noise level descriptors for the ease of reporting. For example, L_{eq} may be qualified to represent $L_{eq(h)}$ throughout an entire report.

The guidance provided in this section is intended to be comprehensive; however, specific features of individual projects will dictate the requirements of each traffic noise report that must be fulfilled to satisfy 23 CFR 772. The subsections in **Section 11** are listed below and reflect the order this information should appear in the TNR or DNR.

11.1 Cover Page

11.2 Signature Page

11.3 Executive Summary

11.4 Table of Contents

11.5 Project Location, Description, and Background

11.6 Procedure

11.7 Characteristics of Noise

11.8 Noise Abatement Criteria

11.9 Ambient Noise Levels

11.10 Noise Model Validation

11.11 Procedure for Predicting Existing Noise Levels

11.12 Procedure for Predicting Future Noise Levels

11.13 Traffic Noise Impacts

11.14 Potential Traffic Noise Abatement Measures

11.15 Construction Noise

11.16 Traffic Noise Levels for Undeveloped Lands Where No Building Permits Have Been Issued

11.17 Conclusion

11.18 References

11.19 Project Mapping

11.20 Appendices

11.1. Cover Page

The Cover Page for the report shall include:

a) Project Description or Name, the County(ies) where the project is located

b) STIP Project Number and WBS Project Number

c) A statement that the report is prepared for the NCDOT Environmental Analysis Unit Traffic Noise and Air Quality Group

d) The name of the firm that prepared the report

e) The month and year the report was accepted

f) The version of the NCDOT Traffic Noise Policy used in the TNR or DNR. For DNRs, the date of public knowledge also shall be included on the cover page

11.2. Signature Page

The Signature Page for the TNR or DNR does not need to be signed and sealed by a Professional Engineer (PE). The Signature Page shall contain the following information:

a) The project name, STIP Project number, State Project number, Federal Aid Project number

b) The name of the NCDOT unit the report was prepared for

c) The name of firm that prepared the report

d) The signatures of the preparers of the report, including the Traffic Noise Analyst and the Traffic Noise Reviewer. The Traffic Noise Analyst and the Traffic Noise Reviewer must be prequalified by NCDOT. Do not provide the date of the signatures.

e) A blank signature line and date line to be filled in by the NCDOT Environmental Analysis Unit, Traffic Noise and Air Quality Group Leader, and the date signed

11.3. Executive Summary

The Executive Summary shall contain the following information:

a) General project description

b) Date of Public Knowledge (if known)

c) The number, type, and general location of any predicted traffic noise impacts

d) The location of any likely (TNRs) or recommended (DNRs) noise barriers

e) The general, summarized conclusion/recommendation, including whether abatement is likely/unlikely (TNRs), or recommended/not recommended (DNRs).

11.4. Table of Contents

The Table of Contents shall contain the following information:

a) Section and subsection numbers, titles, and pages

b) List of Tables, with table numbers, titles, and pages

c) List of Figures, with figure numbers, titles, and pages

d) List of Appendices, with titles and appendix letters

11.5. Project Location, Description, and Background

The project location, description, and background should expand upon the general description found in the Executive Summary and include:

a) a detailed project description, including the project location, TIP number, length, posted/design speeds, and design year,

b) a description of existing land uses and proposed land uses (if known),

c) a description of and location map showing each noise study area (NSA).

d) a discussion of all previous traffic noise analyses for the project,

e) the phase of the project (e.g., preliminary design or final design),

f) the type of project (e.g., widening, reconstruction, new highway construction), and

g) any other unique information related to the project and/or the project area.

11.6. Procedure

Briefly state that the noise analyses reported herein were performed:

a) using noise measurement procedures that considered the methodologies contained in FHWA publication titled *Noise Measurement Handbook* (June 2018). [NOTE: Do not say "in conformance with" since rarely do States have the time or budget to conduct measurements that strictly conform to the procedures in the document.] If applicable, note that these measurements assisted in validating the project's prediction model.

b) using the latest version of the FHWA Traffic Noise Model® (TNM) (currently Version 2.5) described in FHWA Traffic Noise Model® Users Guide to model existing, no-build (if needed), and build condition noise levels; to help determine noise impacts; and to help evaluate noise abatement feasibility and reasonableness.

c) applying NCDOT Noise Abatement Criteria (NAC) and substantial increase over existing criteria to evaluate potential noise impacts and to evaluate the feasibility and reasonableness of potential noise abatement measures.

d) using the FHWA Roadway Construction Noise Model (RCNM) or other quantitative or qualitative means to evaluate project-related construction noise.

Reference the sections of the report where the detailed results of these procedures are contained.

11.7. Characteristics of Noise

An informative description of the characteristics of noise shall be included in all NCDOT TNRs and DNRs.

11.8. Noise Abatement Criteria

An informative description of NCDOT noise policy and criteria for the assessment of traffic and construction noise impacts and impact related abatement measures shall be included in all NCDOT traffic noise reports.

11.9. Ambient Noise Levels

An informative description of the ambient noise level data obtained as part of the field work shall be included in all NCDOT traffic noise reports. At a minimum, the description of ambient noise levels shall include the following information:

a) A general definition of ambient noise

b) An explanation of why measurements were taken (e.g., model validation; determining worst-hour noise levels; establishing existing levels; determining building attenuation; and/or determining abatement characteristics of existing features such as privacy walls, etc.)

c) A general description of the ambient noise environment(s) in the vicinity of the project, including dominant and otherwise significant sources of existing noise

d) The number, general descriptions, and photographs of the locations of ambient noise level data collection

e) The range and general discussion of the noise levels obtained in the ambient noise level data collection

f) The range and general discussion of the noise levels obtained in the ambient measurement process, including short-term and long-term measurements

g) A description of traffic data collected simultaneously with short-term noise measurements and at any other times

h) A reference to the appendix citing the ambient noise levels measured ($L_{eq(h)}$) and/or predicted ($L_{eq(h)}$) for all receptors in the project area, including a description of NSAs where field measurements were used as the existing noise level instead of the TNM predicted noise levels.

11.10. Noise Model Validation

A discussion of how TNM was validated shall be included in this section and accompanied by appropriate table(s). Notes shall be included to explain where model validation was beyond the 3 dB(A) tolerance level and the reasons, if known. The discussion should state that the validation process was the basis upon which the TNMs for predicting existing year and design year noise levels were built.

11.11. Procedure for Predicting Existing Noise Levels

This section shall include an informative description of how and where existing noise levels were determined, a listing of the existing noise levels, and how worst-hour existing noise levels were determined. The descriptions, locations (addresses) and types (land use activity areas) of noise sensitive receptors can be identified in this section and located within the previously described NSAs. It shall include a description of the source of traffic data and how the traffic data was used to predict existing noise levels.

11.12. Procedure for Predicting Future Noise Levels

This section shall include an informative description of the TNM analysis process for predicting future noise levels associated with design year traffic for the build scenarios reported in a TNR or a DNR; and for the no-build alternative typically reported only in a TNR. It shall include a description of the source of traffic data and how it was used to predict future noise levels.

11.13. Traffic Noise Impacts

This section shall reiterate the definitions of a noise impact based on NCDOT criteria. Design year worst-hour noise levels shall be compared with existing worst-hour noise levels and with the appropriate NAC level(s) with the location and number of noise-impacted receptors identified via color-coding on plans and in tables. For each NSA, describe the primary noise sensitive land uses, the number of receptors modeled, and the number and nature of impacts. Impacts shall be designated as either Design Year Build condition noise levels approaching or exceeding the FHWA NAC, Design Year Build condition noise levels causing a substantial increase over existing ambient noise levels, or by both criteria being met.

11.14. Potential Traffic Noise Abatement Measures

As part of all NCDOT traffic noise reports, a comprehensive discussion of potential traffic noise abatement measures shall be provided, including, but not limited to, discussion of the following:

a) Highway alignment selection

b) Traffic system management measures

c) Noise barriers (noise walls and earthen berms)

d) If insulation is warranted, discussion on the topic must be included

All traffic noise abatement assessments shall be described in detail, including the measures that do not meet feasibility and reasonableness criteria. Discussion and tables shall be included that document:

- the results of acoustical and engineering feasibility evaluations performed for all noise abatement measures,
- the results of reasonableness determinations for all noise abatement measures determined to be feasible from both an acoustical and engineering standpoint, and
- the results of reasonableness determinations for noise abatement measures where it is not clear if the measure is feasible from either an acoustical or engineering standpoint.

In the noise report, provide information for each noise abatement measure evaluated. The section may discuss each NSA in numerical order, or it may be grouped by likely noise abatement measures first, then unlikely noise abatement measures next. If multiple alignments or lengths of noise barriers were modeled, describe the optimized wall primarily, but also state other versions that were evaluated and why they are not preliminarily recommended. For each barrier evaluated in a TNR, conclude with a statement that NW X is likely or unlikely. For DNRs, conclude with a statement that noise walls are either recommended or not recommended for construction.

For all impacted receptors that will not benefit from the proposed noise abatement measures for a project, discussion about why noise abatement will not benefit those impacted receptors (23 CFR 772.13(g)(2)) or why barriers cannot achieve the 7dB(A) NRDG shall be included.

11.15. Construction Noise

All NCDOT TNRs and DNRs shall include a general discussion of construction noise, as well as a comprehensive discussion of the project- specific construction noise effects and recommended noise-control measures.

A general example of acceptable construction noise impact evaluation and abatement assessment documentation text is provided below. It should not be considered boilerplate or universally acceptable for all traffic noise analyses. To fulfill the requirement of 23 CFR 772.19, the evaluation of construction noise impacts and assessment of construction noise abatement shall be performed on a project-by-project basis.

Example: Construction Noise Sample Text:

[The following text shall be altered to fit the specific circumstances of the project.]

"The predominant construction activities associated with this project are expected to be earth removal, hauling, grading, and paving. Temporary and localized construction noise impacts will likely occur as a result of these activities. During daytime hours, the predicted effects of these impacts will be temporary speech interference for passers-by and those individuals living or working near the project. During evening and nighttime hours, steady-state construction noise emissions such as from paving operations will be audible and may cause impacts to activities such as sleep. Sporadic evening and nighttime construction equipment noise emissions, such as those from backup alarms, lift gate closures, "slamming" of dump truck gates, etc., will be perceived as distinctly louder than the steady-state acoustic environment, and will likely cause impacts to the general peace and usage of noise- sensitive receptors – particularly residences, hospitals, and hotels. Extremely loud construction noise activities such as use of pile-drivers and impact-hammers (jack hammer, hoe-ram) will cause temporary, sporadic, and acute construction noise impacts in isolated areas.

Generally, low-cost and easy-to-implement construction noise control measures should be incorporated into the project plans and specifications (e.g., work-hour limits, equipment exhaust muffler requirements, haul-road locations, elimination of "tail gate banging", ambient-sensitive backup alarms, construction noise complaint mechanisms, and consistent and transparent community communication and rapport).

While discrete construction noise level prediction is difficult for a particular receptor or group of receptors, it can be assessed in a general capacity with respect to distance from known or likely project activities. For this project, earth removal, grading, hauling, and paving is anticipated to occur in the near vicinity of three residential neighborhoods, two schools, and one commercial area (shopping center). Additionally, impact hammer and pile-driving activities are anticipated to occur in the near vicinity of one school as part of the removal and replacement of the "US 1234 – SR 5678" interchange. Although construction noise impact abatement should not place an undue burden upon the financial cost of the project or the project construction schedule, pursuant to the requirements of 23 CFR 772.19, it is the recommendation of this traffic noise report that:

- *Earth removal, grading, hauling, and paving activities in the vicinity of the three residential neighborhoods (provide neighborhood names and project station limits, if known) should be limited to weekday daytime hours.*

- *Earth removal, grading, hauling, and paving activities in the vicinity of the two schools (provide names of schools and project station limits, if known) should be performed during evening and nighttime hours, or any hours during weekends and/or holidays. (Note: Address appropriate construction activity scheduling recommendations per project-specific noise sensitive land uses in this section).*

- *If meeting the project schedule requires that earth removal, grading, hauling and/or paving must occur during nighttime hours in the vicinity of one or more of the three nearby residential neighborhoods (provide neighborhood names and project station limits, if known), the Contractor shall notify NCDOT as soon as possible. In such instance(s), all reasonable attempts shall be made to notify and to make appropriate arrangements for the abatement of the predicted construction noise impacts upon the affected property owners and residents.*

- *If construction noise activities must occur during context-sensitive hours in the vicinity of noise-sensitive areas, discrete construction noise abatement measures including, but not limited to portable noise barriers and other equipment-quieting devices shall be considered.*

For additional information on construction noise, please refer to the *FHWA Construction Noise Handbook (FHWA-HEP-06-015)* (USDOT-FHWA, 2006) and the *Roadway Construction Noise Model (RCNM)* (USDOT-FHWA, 2006).

11.16. Traffic Noise Levels for Undeveloped Lands Where No Building Permits Have Been Issued

For undeveloped lands where no building permits for development have been issued, noise level information shall be developed for use by public officials and others in future planning efforts. At a minimum, provide this information in tabular form. 23 CFR 772(9)(c) infers that such information "may be used for project alternative screening or for land use planning to comply with § 772.17 of this part but shall not be used for determining highway traffic noise impacts".

Distances from the edge of the nearest lane of travel for roadways and interchange ramps and loops to where the 71 dB(A) and 66 dB(A) noise levels are predicted to occur shall be identified in the table. These levels are representative of where exterior noise level impacts occur for NAC B and C, and NAC E land uses, respectively. The basis for noise level contour prediction shall be worst-hour design year TNM-predicted noise levels at a grid of representative receptors modeled in one or more validated project TNM runs. Arbitrary or flat and level TNM models shall not be used to develop traffic noise level contours for TNRs and DNRs.

11.17. Conclusion

A conclusion shall be made as part of all NCDOT TNRs and DNRs. The conclusion shall cite the project name (including TIP number), the process/procedure by which traffic noise levels were determined, and how impacts were determined (e.g., ambient noise monitoring, TNM modeling, etc.). For each Build Alternative analyzed, summarize the traffic noise impacts. For each noise abatement measure evaluated, state in the TNR which are Likely and Unlikely. In a DNR state which are Recommended and Not Recommended. Likely does not mean a firm commitment. The final decision on the installation of an abatement measure shall be made upon completion of the project design, the public involvement process, and concurrence with the NCDOT *Traffic Noise Policy*.

11.18. References

A list of applicable references shall be included as part of all NCDOT traffic noise reports. Typical references can be found in the TNR template and DNR template on the NCDOT website.

11.19. Project Mapping

Project mapping shall include a representation of the entire project (study area) on one image, and detailed small-scale images as necessary to appropriately document project designs, receptor locations, traffic noise levels, impacts, and abatement. All project maps shall include a title block, a legend (as applicable), properly oriented north arrow, and map creation date. Additional graphics such as tables and figures are typically included in a noise report to supplement or expand upon information presented on maps.

- A Project Map uses aerial photogrammetry or other appropriate base mapping to display the entire project. It is defined by a logical scale or denoted as being not to scale.
- Detailed Study Area Maps use aerial photogrammetry to show the project and all noise receptors and analyzed noise barriers on one or more images, defined by a consistent logical scale based upon receptor density. Guidance on format is provided below:
  - Noise Study Area boundaries shall be shown and labeled.
  - Receptors indicating field measurement locations shall be shown with a solid white circle,

- Receptors located within proposed right of way limits or otherwise being displaced shall be shown with a white X,
- Receptors predicted to be impacted but not benefited shall be shown with a solid red circle,
- Receptors predicted to be impacted and benefited shall be shown with a solid blue circle,
- Receptors predicted to be benefited but not impacted shall be shown with a solid green circle, and
- Receptors predicted to be not impacted and not benefited shall be shown with a solid yellow circle.
- Land use activities that are not noise sensitive and therefore do not require a noise analysis (Activity Category B, C, and E land uses with no exterior areas of frequent human use and Activity Category F) shall be shown with a solid black circle.
- Noise barriers determined likely and unlikely (TNR) or recommended and not recommended (DNR) shall be shown on the mapping using different line patterns. Receptors behind an unlikely/not recommended noise barrier shall show results predicted to occur without the noise barrier. For example, an impacted receptor that would have been benefited by a barrier that is unlikely would be shown as a red dot (impacted, not benefitted).
- The full length of an evaluated noise barrier shall be shown on the mapping, with the segments determined likely/recommended as one line pattern and the remaining segments determined unlikely/not recommended as another line pattern.
- NCDOT recommends including the slope stake lines or cut and fill slopes as appropriate, using green to denote cut lines and red to denote fill lines (or C/F nomenclature). Transitions between cut slopes and fill slopes can be shown with yellow lines.
- In DNRs, any noise-sensitive receptors that have received a building permit after the Date of Public Knowledge shall be shown on project mapping with a solid yellow triangle and should not be included in the analysis.

Related tables are often used to provide more details than can be displayed on plans or mapping. Color-coding is sometimes used to help highlight various information contained in tables, such as impacted and benefited receptors.

11.20. Appendices

The appendices of all NCDOT TNRs and DNRs contain the details about the analysis conducted, including measured noise levels, traffic noise model validation, predicted noise levels, noise level impacts, TNM noise barrier analyses, abatement recommendation(s), and other significant information. Appendices in TNRs and DNRs shall include but are not limited to, the appendices listed below. Guidance on the content for each appendix follows.

- Appendix A – Ambient Noise Level Measurements
- Appendix B – Hourly Equivalent Traffic Noise Level Tables
- Appendix C – Traffic Noise Models
- Appendix D – Noise Barrier Analysis
- *For DNRs only* - Appendix E - Noise Barrier Envelope Drawings and Noise Wall Panel Design Tables
- Appendix F – Traffic Information *(Appendix E for a TNR)*
- Appendix G – NCDOT Traffic Noise Policy *(Appendix F for a TNR)*

11.20.1. Appendix A – Existing Noise Level Measurements

Appendix A shall include the following information. Additional information may be required to describe the noise level measurement data and activities on a project-specific basis.

- A noise measurement summary table that lists for each measurement, the measurement site location, date and start/stop time, land use category, noise source(s), and measured L_{eq}. **Table 11.1** is an example.
- A table listing the weather conditions (e.g., temperature, dew point, pressure, wind direction and speed, relative humidity, precipitation) during each measurement event. Data can be obtained using an anemometer or handheld wind speed and direction instrument. A source of weather information is http://www.wunderground.com/ (Weather Underground, 2022) and can also be used to supplement field data. NOTE: noise measurements should be discontinued when wind speeds exceed 11 mph and during precipitation events.
- Mapping showing the locations of the noise measurements.
- Photographs of the sound level meters set up in the field at each location.
- Traffic volumes and vehicle mixes counted during each measurement period.

- Observed vehicle speeds during each measurement period. Heavy truck speeds should be noted if traveling at a different speed than general traffic.
- The sound level meter manufacturer, model number and serial number and calibration certificates (excluding the charts and graphs associated with laboratory backup data) for each sound level meter used.

Table 11.1. Measured Ambient Equivalent Noise Levels, L_{eq} in dB(A)

Setup	Meter #	Land Use / Activity Category	Address	Roadway Noise Source(s)[1]	Date Start/Stop Time	Measured Leq (dB(A))
1	1.1	Residential/B	123 Smith Road	US 29	5/15/20 8:50 am – 9:10 am	73.2
	1.2	Residential/B	123 Smith Road	US 29		57.7
	1.3	Residential/B	123 Smith Road	US 29		47.5
2	2.1	Residential/B	456 Jones Street	US 29	5/15/20 9:50 am – 10:10 am	51.1
	2.2	Residential/B	456 Jones Street	US 29		54.9
3	3.1	Residential/B	123 Black Drive	US 29	5/15/20 10:30 am – 10:50 am	69.3
	3.2	Residential/B	125 Black Drive	US 29		66.5
	3.3	Residential/B	127 Black Drive	US 29		65.6
4	4.1	School/C	454 White Avenue	US 29	5/15/20 11:20 am – 11:40 am	57.0
	4.2	School/C	456 White Avenue	US 29		64.4
	4.3	School/C	458 White Avenue	US 29		57.8

[1] For each setup, sound level meters were located at logical locations for the assessment of existing highway traffic

11.20.2. Appendix B – Hourly Equivalent Traffic Noise Level Tables

Information defining all noise-sensitive receptors, noise-sensitive land uses (NAC category), number of dwelling units (equivalent receptors), property address for each receptor, and predicted worst-hour equivalent noise levels for existing, no-build (TNR only), and build conditions (refer to example in Error! Reference source not found.).

Table 11.2. Project Name, STIP #, NSA#, and DSA # Receptors, Noise Levels and Noise Impacts

Receptors					Predicted Noise Levels, $L_{eq(h)}$ (dB(A))			
Rec. No.	Use	NAC	ERs	Address	Ex.	No-Build	Build	Change (Build-Ex)
1-01	Res	B	1	909 Fowler Rd	48[1]	49	60	12
1-02	Res	B	1	600 Maple Hill Rd	48[1]	49	67	19
1-03	Res	B	1	516 Maple Hill Rd	48[1]	48	66	18
1-04	Worship	C/D	1	2701 Concord Hwy	64/39	65/40	72/47	8
1-05	Res	B	1	2635 Concord Hwy	67	67	72	5
1-06	Res	B	1	2629 Concord Hwy	67	68	72	5
1-07	Res	B	1	120 Maple Hill Rd	56	56	59	3
1-08	Worship	C/D	1	2613 Concord Hwy	69/44	70/45	73/48	4
1-09	Res	B	1	2613 Concord Hwy	73	74	75	2
1-10	Res	B	1	714 Fowler Rd	48[1]	59	71	23
2-01	Res	B	1	715 Fowler Rd	48[1]	57	66	18
2-02	Res	B	1	713 Fowler Rd	48[1]	54	64	16
2-03	Res	B	1	219 Ridge Rd	48[1]	48	60	12
2-04	Res	B	1	709 Fowler Rd	48[1]	58	63	15
2-05	Res	B	1	2907 Concord Hwy	65	66	72	7
2-06	Res	B	1	3613 Concord Hwy	70	71	70	0
2-07	Res	B	0	809 Fowler Rd	48[1]	49	R/W	N/A
Predicted DSA 2 Design Year 2040 Traffic Noise Impacts[2]					**N/A**	**N/A**	**11[3]**	**6[4]**

Impact = Right-of-Way Acquisition =

[1] Existing ambient noise levels based on $L_{eq(20\text{-}min)}$ = 48.1 dB(A) at #1204 Back Road, obtained 10:15 a.m. – 10:35 a.m. on June 15, 2015.

[2] Total number of predicted traffic noise impacts under the DSA 2 Build alternative = 13. The number of predicted impacts is not duplicated if receptors are predicted to be impacted by more than one criterion (e.g., if a receptor is impacted by NAC criteria and also by Substantial Increase criteria, it is counted as only one impact).

Predicted traffic noise impact due to approaching or exceeding NAC (refer to Table 3).

[3] Predicted substantial increase traffic noise impact (refer to Table 4).

Notes on table preparation: a) All receptors must be listed individually with street addresses; b) Where existing and no-build noise levels are identical, the columns may be combined; c) Use red to denote impacts. Do not use different colors to distinguish between an NAC impact and a Substantial Increase impact; d) Do not show existing and/or no build noise levels as impacts. This is because there must be a proposed highway improvement project for there to be a traffic noise impact; e) An explanation for any decreases greater than 2 dB(A) in Build-No Build Condition traffic noise levels should be explained in the text of the report to demonstrate there is a physical reason for the decrease and is not a modeling error; and f) It is acceptable to use landscape orientation if needed to represent all data on one table.

11.20.3. Appendix C – Traffic Noise Models

Information pertaining to the input and implementation of all FHWA Traffic Noise Model (TNM) runs for the purpose of assessing project-related traffic noise levels. At a minimum, this information should include a general description of all modeled TNM elements (roadways, receptors, terrain lines, etc.), the validation process and accuracy (refer to example in **Table 11.3**), and a description of the modeling iterations by which traffic noise levels were assessed.

In previous manuals, plan views printed from the TNM models were required to be included in this appendix. Plan view prints from TNM are no longer required to be included.

All TNM data files associated with the traffic noise analyses must be included in electronic format as part of each draft and final report submission. NCDOT requires approval of the TNM validation model(s) prior to the initiation of TNM runs for existing, no-build (if appropriate), and build alternatives.

Table 11.3. TNM Model Validation Table

Measurement Location	Measured Leq dB(A)1	TNM-Predicted Leq(h) dB(A)1	Validation Delta (Pred. – Meas.)1
M-1.1	62.1	62.2	+0.1
M-1.2	62.4	63.2	+0.8
M-1.3	61.8	61.9	+0.1
M-2.1	83.1	79.2	-3.92
M-2.2	70.9	72.0	+1.1
M-2.3	64.2	63.3	-0.9
M-3.1	67.1	66.9	-0.2
M-3.2	61.9	62.4	+0.5
M-3.3	55.4	51.9	-3.53

[1] Hourly equivalent noise levels, $L_{eq(h)}$, are expressed to the nearest one-tenth decibels to ensure that TNM-predicted noise levels validate to within ±3.0 dB(A) of measured noise levels without the benefits of rounding.
[2] The 1st-row noise measurement location M-2.1 is approximately 50 ft east of existing roadway and is not indicative of a noise-sensitive land use in the vicinity of the project.
[3] The 3rd-row noise measurement location M-3.3 is approximately 400 ft southeast of the adjacent ramp, and it is approximately 50 ft higher in elevation. Ramp vehicle traffic was audible during the short-term noise measurement session; however, local community non-traffic-related noise sources (e.g., air conditioning units) were perceived to be dominant. Given that the 1st- and 2nd-row receptors M-3.1 and M-3.2 validated to a high degree of tolerance to the monitored noise levels (-0.2 and +0.5 dB(A), respectively), and that the TNM-predicted noise levels at M-3.3 are *lower* than the field-monitored noise levels, traffic noise is considered to be an insignificant component of worst-hour noise levels at the M-3.3 location.

11.20.4. Appendix D – Noise Barrier Analysis

As applicable, a detailed summary of the assessment of noise barrier feasibility and reasonableness is required in all traffic noise reports. This must be provided in tabular form, with the elements shown in the example **Table 11.4**. Additional discussion and tables may be included in the appendix to supplement (but not repeat) information presented in **Section 11.12**.

Separate feasibility and reasonableness worksheets that were previously required for each analyzed noise barrier are no longer required to be included in a TNR or DNR because the information on these worksheets is already provided in the TNR and DNR in other report sections.

As stated in **Section 10.1**, the TNM line-of-sight tool is required to be used for recommended barriers in DNRs, and the results should be documented in DNR Appendix D. Include a screenshot of the line-of-sight check for each recommended barrier that shows the barrier and the ground floor, front row, impacted receptors. The screen shot should be labeled with the barrier name, TNM model name, and TNM barrier analysis scenario name.

If all line-of-sight symbols are green or yellow, no further documentation is required. If there are some symbols that are red, then a discussion about why it is not possible or practicable for the barrier design to achieve all green symbols should be included in the text of the report. Reasons why a recommended barrier may not break line of sight at all locations for all ground floor first row impacted receptors might be that the enhanced barrier design exceeds allowable maximum barrier heights, the design is not cost reasonable, or the design does not confirm to aesthetic guidelines (i.e.: a choppy barrier top profile).

Noise Wall 7A (-NW7A-):
Location: Adjacent to the westbound lanes of the Insert Roadway Name mainline in the vicinity of Insert Roadway Name

-NW7A- does NOT preliminarily meet NCDOT feasibility and reasonableness criteria due to Area / Benefit exceeding the Allowable Area / Benefit.
-NW7A- is NOT likely to be incorporated into the project.

TNM Run: 4 BLD07.1 NW7A r1.5 SBA: NW7A r1.5 LTSD

Table 11.4. Noise Barrier Performance Table

-NW7A- Acoustical Performance Summary	
Impacts: 8	Benefited Receptors @ ≥ 7 dB(A) NLR: 1
Impacted Receptors Benefited: 2	Total Benefits: 2
Non-Impacted Receptors Benefited: 0	

-NW7A- Parameters	
Terminus (Northwest): -NW7A- Sta. 10+00.00 / -L- Sta. 610+60.00 61.00’ LT	
Terminus (Southeast): -NW7A- Sta. 14+80.00 / -L- Sta. 615+40.00 61.00’ LT	
Length: 480 ft	Area / Benefit: 3,165 ft^2
Average Height: 13.2 ft.	Allowable Area / Benefit: 2,750 ft^2
Area 6,330 ft^2	

Receptors					Noise Wall Performance		
Rec. No.	Use	NAC	E.R.s	Address	Build	With Wall	NLR
1-01	Res	B	1	3211 Poplin Rd	68	68	0
1-02	Res	B	1	1418 Clear Creek Drive	68	68	0
1-03	Res	B	1	1404 Clear Creek Drive	59	59	0
1-04	Res	B	1	1419 Clear Creek Drive	75	67	8
1-05	Res	B	1	1415 Clear Creek Drive	69	64	5
1-06	Res	B	1	3017 Poplin Rd	68	68	0
1-07	Res	B	1	3101 Poplin Rd	66	66	0
1-08	Res	B	1	3010 Poplin Rd	65	65	0
1-09	Res	B	1	3008 Poplin Rd	66	66	0
1-10	Res	B	1	1418 Roanoke Church Road	62	62	0
-NW7A- Predicted Build Condition With-Wall Benefits[1]							2

Impact = (red) 5 to 6 dB(A) NLR = (blue) ≥ 7dB(A) NLR = (green)

[1] A receptor is considered benefited if the predicted Noise Level Reduction (NLR) is at least 5 dB(A).

11.20.5. For DNRs only - Appendix E - Noise Barrier Envelope Drawings and Noise Wall Panel Design Tables

Noise Barrier Envelope Drawings and Noise Wall Panel Design Tables are required only for recommended barriers and only in DNRs. Example envelope drawings and Noise Wall Panel Design Tables are posted on the NCDOT website: https://connect.ncdot.gov/resources/Environmental/EAU/TNAQ/Pages/default.aspx.

The noise barrier envelope drawings shall include the following:

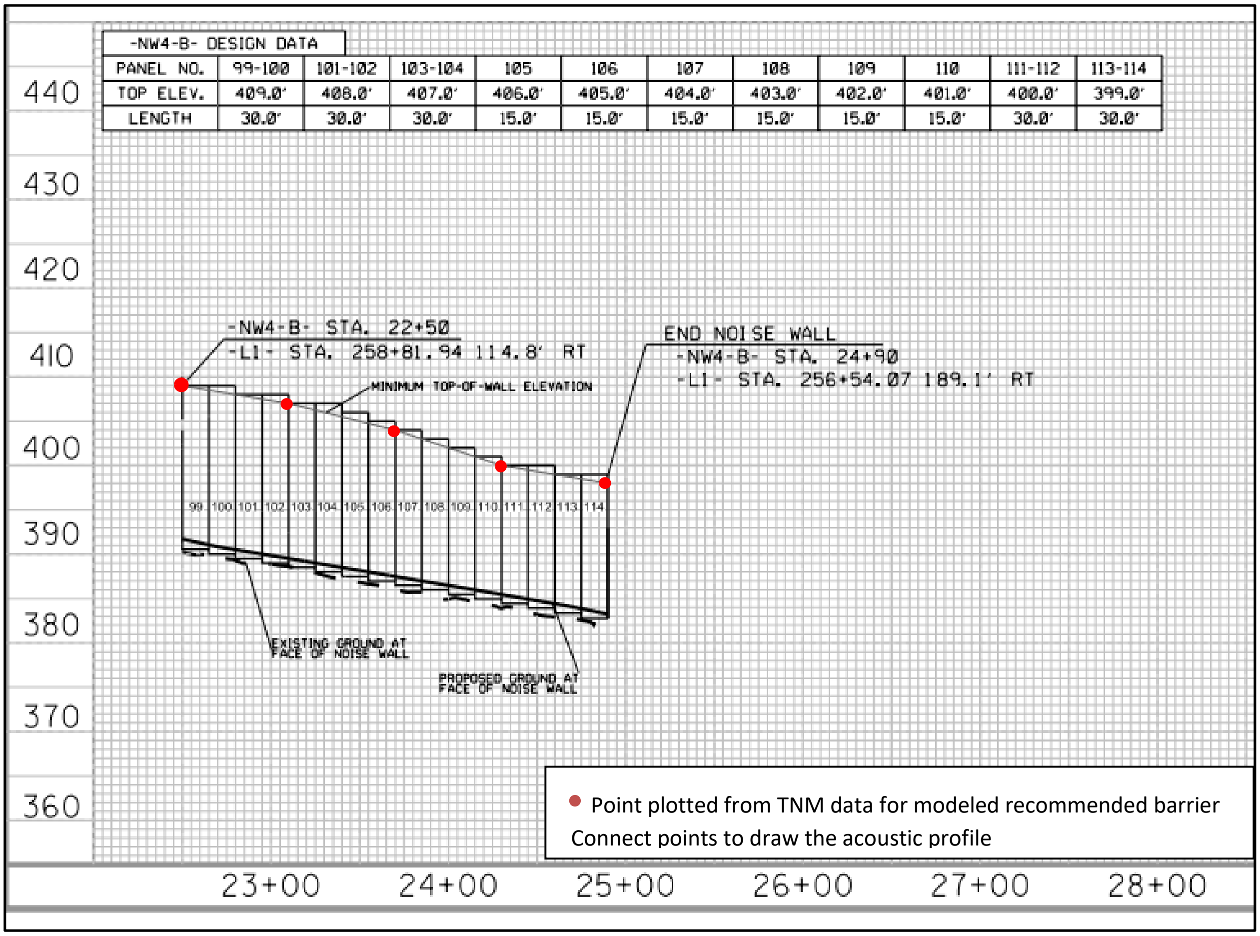
- Scaled plan and profile envelope drawings shall be consistent with NCDOT CADD standards and shall be prepared using MicroStation and GEOPAK software, or the most current design software used by NCDOT. Aerial photography should not be included in the envelope drawings because aerial backgrounds cannot be included in the design plan sets.
- Horizontal and vertical scales shall be shown.
- Noise wall and/or earth berm termini or other significant barrier points may be defined in reference to the alignment and project survey stationing of the adjacent roadway.
- The beginning and end of the noise barrier shall be labeled.
- All recommended noise walls and/or earth berms shall have distinct horizontal alignments and stationing.
- All panels along a noise wall shall be consecutively numbered.
- The envelope drawings shall include a table listing the noise barrier segment top elevations, either by wall panel numbers or segment lengths.
- The plan view shall include the appropriate layers of the final survey and the proposed design so that the relationship of the noise wall to the design and surroundings can be readily seen.
- The profile view shall include the acoustic profile (minimum top-of-wall elevations), the existing ground line, the proposed ground line, and the barrier segments/panels.

Guidance on how to create the acoustic profile (minimum top-of-wall elevation) is provided below.

For noise barriers recommended in a Design Noise Report, the envelope drawings shall include profile views that display the acoustic profile. Preferably labeled the “minimum top of wall elevation,” the acoustic profile must be drawn to represent the elevation at which sound is blocked by the barrier, as shown in the graphic below. The acoustic profile is developed from the top of wall elevations modeled in TNM for the recommended noise barrier.

An example of a correctly drawn acoustic profile on an envelope drawing is provided below on **Figure 11-1** (labeled on exhibit as minimum top-of-wall elevation). As shown on the exhibit, each panel is at an elevation equal to or higher in elevation than the acoustic profile line. This exhibit shows the end panels 99-114 of a barrier named NW4-B.

Figure 11-1. Example Acoustic Profile on an Envelope Drawing



To create an acoustic profile for a barrier, information from two tables in the TNM model is needed.

- TNM Barrier Input Table – The Z(bottom) elevation for each point modeled along the barrier is used. It is helpful, but not necessary, to have the barrier point names correspond to their station numbers for ease of translating the profile onto the envelope drawing, as they are in this example for Barrier NW4-B. The green boxes indicate the needed data.

Point Name	Point No	X(ft)	Y(ft)	Z(bottom)(ft)
22+50.00	420	2,082,981.40	735,829.20	391.70
23+10.00	421	2,082,938.50	735,787.30	389.51
23+70.00	422	2,082,899.30	735,741.90	387.49
24+30.00	423	2,082,861.80	735,695.20	385.47
24+90.00	424	2,082,824.90	735,647.70	383.25

- TNM Barrier Segment Description Table for the optimized recommended barrier – The optimized First Point Height for each modeled point along the barrier and the length of each modeled barrier segment is used, along with the Second Point Height for the last segment (green boxes). If stationing is not available, it can be calculated using the length of each modeled segment (yellow boxes) and starting at station 10+00.00.

Segments						
Name	No.	Heights			Length	If Wall
		First Point	Average	Second Point		Area
		ft	ft	ft	ft	sq ft
22+50.00	420	17.3	16.89	16.49	60	1013
23+10.00	421	17.49	16.5	15.51	60	991
23+70.00	422	16.51	16.02	15.53	60	959
24+30.00	423	14.53	14.64	14.75	60	880

Using the information from the TNM tables above, a table of the acoustic profile points (Z Top of Wall Elevation at each station) can be created, as shown below. Note that for the last point in the table for station 24+90.00, the height of the second point in the Barrier Segment Description Table for station 24+30.00 (second to last station) is used. These points are then plotted on the noise barrier envelope drawing profile view.

Station	**Z(bottom)(ft)**	**Z(Height)(ft)**	**Z Top of Wall (ft)** Z(bottom)+Z(height)
22+50.00	391.70	17.30	409
23+10.00	389.51	17.49	407
23+70.00	387.49	16.51	404
24+30.00	385.47	14.53	401
24+90.00	383.25	14.75	398

The Noise Wall Panel Design Table shall include the following:

- Panel Number
- Panel Start Station Number
- Bottom of Panel Elevation (feet above mean sea level)
- Top of Panel Elevation (feet above mean sea level)
- Height of Panel (feet)
- Length of Panel (feet)
- Area of Panel (square feet)
- Total wall length and total wall area

11.20.6. Appendix F – Traffic Information (Appendix E for a TNR)

The base year existing, predicted design year no-build, and predicted design year build-condition traffic volume diagrams and/or tables for all detailed study alternatives shall be included. The table should also include the appropriate LOS C traffic volumes applicable for each of the modeled roadways.

11.20.7. Appendix G – NCDOT Traffic Noise Policy (Appendix F for a TNR)

This appendix contains the NCDOT Traffic Noise Policy version used in the report: Do not include a copy of the NCDOT Traffic Noise Manual.

12. PUBLIC INVOLVEMENT

12.1. Communication and Public Outreach

Communication with the community regarding noise impacts and possible noise abatement shall occur early in the project development process and continue beyond the project public hearing. NCDOT will communicate with citizens to present information on the nature of highway traffic noise and discuss the types and effects of noise abatement measures that may be considered.

As needed, public outreach may include smaller-scale meetings with individual communities and neighborhoods, as well as project-wide workshops and hearings. These meetings may be in-person or virtual. Educational materials pertaining to traffic noise will be presented and distributed at public meetings. Potential Noise Abatement Areas, areas where noise abatement measures are likely, based on an NCDOT- accepted TNR, will be shown for all alternatives on the maps displayed at public hearings or meetings and will be defined in the environmental document.

The location(s) of any noise abatement measures found to be likely in the TNR will not be shown on maps displayed at public hearings or meetings. Public meeting maps shall include cross-hatching in noise study areas where a noise barrier has been determined likely to be of benefit, but the noise barrier alignment will not be shown. The location(s) and design of such abatement measures may change due to changes in the noise environment, the project design, or to findings in the detailed DNR prepared during the final design noise analysis process. The intent of not showing proposed noise abatement alignment locations on maps displayed at public hearings or meetings is to minimize public confusion should the noise abatement measures be modified or eliminated during the final design noise analyses and preparation of the Design Noise Report.

The definition and discussion of the Date of Public Knowledge shall be included in DNRs. The actual Date of Public Knowledge is not included in TNRs since they are completed prior to approval of the final environmental document; DNRs normally do include the actual Date of Public Knowledge since they are completed after the final environmental document is approved.

12.2. Public Documents

NCDOT NEPA or SEPA decision documents shall identify the following prior to CE approval or issuance of a FONSI or ROD:

a) Locations where noise impacts have been predicted to occur.

b) Noise abatement measures and locations that have been preliminarily determined to be feasible and reasonable (likely measures).

c) Noise impacts at locations for which abatement measures have been preliminarily determined not to be feasible and reasonable.

d) A statement that NCDOT is committed to the construction of feasible and reasonable highway traffic noise abatement measures at the noise-impacted locations identified in (table, figure, chart, etc.) contingent upon the following conditions: 1) detailed noise analyses during the final design phase; 2) determination of the feasibility and reasonableness of highway traffic noise abatement measures evaluated during final design; and 3) input from benefited owners and tenants regarding desires for a noise abatement measure.

e) Final recommendations on the construction of any noise abatement measure(s) will be determined following the completion of the DNR. Recommended noise barriers are based on final design noise analyses and are usually identified in a DNR after the environmental document is completed.

f) Property owners and tenants who are being balloted for a recommended noise barrier will be provided a visual representation of the noise barrier location prior to their casting a ballot.

12.3. Final Determination

The final decision on the installation of traffic noise abatement measures shall be made upon completion of the project's final design, the acceptance of the Design Noise Report by the NCDOT, and the completion of the noise-related public involvement process. This decision will be based upon the feasibility and reasonableness criteria established in the applicable version of the NCDOT *Traffic Noise Policy*. The reasonableness criteria include the solicitation of viewpoints from property owners and tenants of all traffic noise receptors predicted to be benefited by recommended noise abatement measures along the project.

The NCDOT Traffic Noise and Air Quality Group will prepare a memorandum to the applicable NCDOT Division Office that summarizes the solicitation process and the balloting results. It is in this memorandum that a final determination of feasibility and reasonableness is made. A copy of this memorandum will also be distributed to FHWA and the NCDOT Structures Management Unit. The property owners and tenants that were involved in the solicitation process will also be notified of the final results of the balloting process.

12.4. Public Involvement Process

The following describes the public involvement process related to traffic noise topics during the project development and design stages.

Project Development Stage

1. Attend Public Meetings as needed to discuss the traffic noise analysis for the project and general traffic noise topics.
2. Complete Traffic Noise Report (TNR) to identify all traffic noise impacted receptors, preliminary feasible and reasonable noise barriers (likely barriers) and preliminary benefited receptors for all detailed study alternatives.
3. Attend Public Hearings as needed to provide all available traffic noise information.

Design Stage

1. Complete Design Noise Report (DNR) using final project design files to determine recommended feasible and reasonable noise barriers and determine all benefited receptors.
2. Perform the balloting of benefited property owners and tenants. This task is performed by NCDOT staff.
    a. Develop initial Benefited Receptor Mailing List using any of the following data sources available.
        i. Tax records
        ii. Multi-unit residential and commercial management companies
        iii. Local Homeowners' Associations
        iv. Local government records
    b. Assemble the balloting package for all benefited receptors. The package includes a letter explaining the purpose of the ballot and balloting process and how to submit a ballot via USPS mail, a figure that shows the location of the recommended noise

wall and benefited receptors on a map and a rendering of its appearance, and a postage-paid postcard ballot.

c. Sometimes there may be a need to hold a noise wall balloting meeting to kick-off the balloting process. If a meeting is held, a meeting notice must be mailed to all benefited receptors. Pre-addressed balloting packages as described above are handed out at the meeting, and any addressed to people who did not attend are mailed the following business day. Eligible voters who attend the meeting can fill out their ballot and leave it with NCDOT at the meeting, or they can mail them in in the subsequent days. NCDOT may also distribute and accept ballots by email or other digital means.

d. If no noise wall balloting public meeting is held, distribute balloting packages to all benefited owners and tenants.

e. Determine the public preference for or against recommended noise barriers using Noise Barrier Balloting Process.

f. A second distribution and/or additional outreach is required if the required number of votes are not returned after the first mailing. Additional outreach can include phone calls, neighborhood visits, or working through an HOA representative or community advocate.

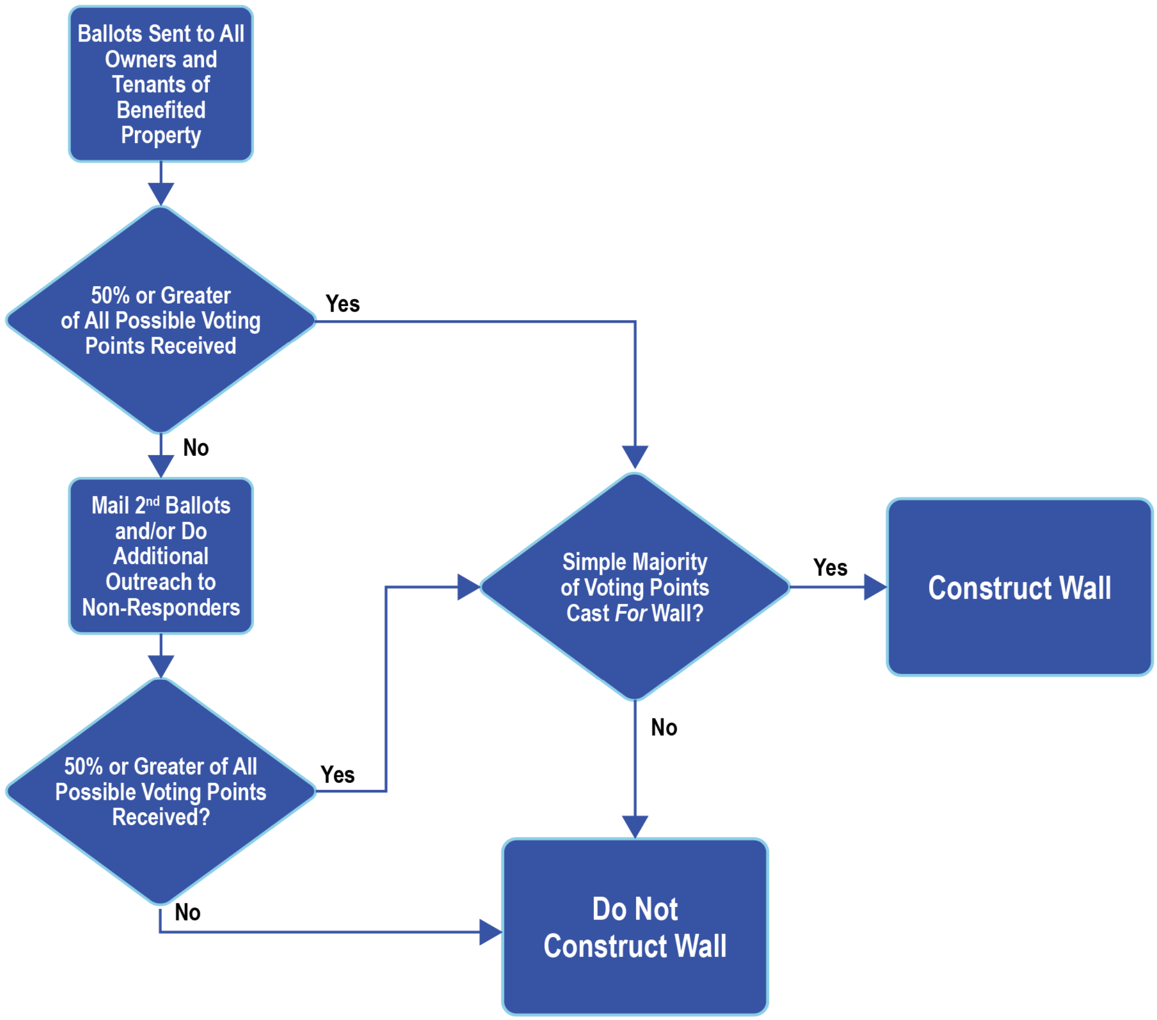
g. Validate the balloting process.

h. Finalize and distribute noise barrier ballot results – via postcard to voters, and via letter to NCDOT and FHWA staff.

3. The NCDOT Traffic Noise and Air Quality Group will prepare a memorandum to the parties described in **Section 12.3** that summarizes the solicitation process and the balloting results. It is in this memorandum that a final determination of feasibility and reasonableness is made.

For design build projects, NCDOT will conduct balloting after project award and upon completion of the Design Noise Report.

Figure 12-1. Noise Barrier Balloting Process



13. DESIGN BUILD PROJECTS

For design-build projects, 23 CFR 772 requires that "the preliminary technical noise study shall document all considered and proposed noise abatement measures for inclusion in the NEPA document, and that the final design of design-build noise abatement measures shall be based on the preliminary noise abatement design developed in the technical noise analysis". The regulation also requires that "noise abatement measures shall be considered, developed, and constructed in accordance with this standard and in conformance with the provisions of 40 CFR 1506.5(c)" [which relates to the preparation of environmental impact statements by contractors in a manner that avoids conflicts of interest], "and 23 CFR 636.109" [which addresses how the NEPA process relates to the design-build procurement process]. It is important to note that 23 CFR 636.109(b)(6) states that "the design-builder must not prepare the NEPA document or have any decision-making responsibility with respect to the NEPA process."

In addition, in its 23 CFR 772 Final Rule Supplementary Information, FHWA encourages States to "consider developing performance-based specifications within their noise policies that apply to design build project[s] to accommodate the project flexibility inherent in the design build process and ensure constructed noise abatement is effective."

In consideration of the above FHWA requirements and suggestions, NCDOT will provide any design-build team a copy of the NCDOT's accepted Traffic Noise Report (TNR) and associated TNM models and will require the design-build team to meet the requirements contained in a design build noise specification (i.e., the Request for Proposal (RFP)). Contents of such a specification include, but are not limited to, the following:

- General section describing the applicable NCDOT standards, policies, and criteria
- A listing of the required acoustical expertise of those performing noise analyses
- NCDOT requirements for the noise barrier system(s) associated with the engineering, acoustical, and aesthetic design requirements established by NCDOT

The Design Build team is responsible for completing a Design Noise Report based on their final engineering designs in accordance with NCDOT requirements for a DNR, including 23 CFR 772, the applicable NCDOT Traffic Noise Policy and Manual, and the RFP.

14. MISCELLANEOUS

14.1. Noise Barrier Standards

To provide standard structural design criteria for the preparation of noise barrier plans and specifications, the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Bridges and Structures developed "Guide Specifications for Structural Design of Sound Barriers", published in 1989 and amended in 1992 and 2002. These specifications allow for more consistency in barrier design. FHWA encourages highway agencies to apply realistic noise barrier structural design practices and to avoid overly conservative design procedures, especially those related to wind load criteria. Also, the AASTHO Green Book is recommended for site design requirements. Finally, noise barrier material types should be selected based on economics, effectiveness, and aesthetic considerations.

Noise walls anchored on the ground should be no shorter than 6 feet in height above the ground and no taller than 30 feet in total height, including embedment depth below the ground. Noise barriers on structures should be no taller than 10 feet in height. Any exceptions must be coordinated with the NCDOT Traffic Noise and Air Quality Group and the NCDOT Structures Management Unit. Consideration of maintenance areas behind barriers, maintenance openings, sight distance requirements, how far from top of cut, drainage constraints and utility conflicts should be included in barrier design decisions, as detailed in **Section 10** above. These considerations are especially important during the development of the Design Noise Report.

14.2. Aesthetics

NCDOT has initiated a program for the improvement of noise wall aesthetics. Good engineering, architectural, and aesthetic judgment shall be applied toward context-sensitive noise wall design. The standard noise wall architectural treatment, as defined below, will apply to all projects regardless of the Date of Public Knowledge.

The standard noise wall architectural treatment consists of:

a) Concrete columns; steel piles may be used when necessary to address site conditions adverse to the use of concrete columns;

b) Precast concrete panels textured on both sides;

c) No texture on the uppermost foot of each wall segment;

d) A single color of stain in brown or gray tones applied to both sides of textured panels, although some Divisions may choose to not apply any stain;

e) No stain applied to the uppermost foot of each wall segment and the concrete columns, although some Divisions may choose to stain the entirety of the wall and columns.

All enhancements to this standard noise wall must be paid for in accordance with the Third-Party Participation provisions in the 2021 NCDOT Traffic Noise Policy.

NCDOT Division Engineers are responsible for determining noise wall textures and colors in their respective Divisions. Noise wall textures and stains are included in **Appendix F**.

15. REFERENCES

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APPENDIX A. NORTH CAROLINA DEPARTMENT OF TRANSPORTATION TRAFFIC NOISE POLICY

of the

TRAFFIC NOISE MANUAL

North Carolina Department of Transportation
Traffic Noise and Air Quality Group

APPENDIX B. MODELING GUIDANCE FOR INTERCHANGES, INTERSECTIONS, AND ROUNDABOUTS

of the

TRAFFIC NOISE MANUAL

North Carolina Department of Transportation
Traffic Noise and Air Quality Group

APPENDIX C. EQUIVALENT RECEPTOR CALCULATION TABLES (THIS APPENDIX IS AN EXCEL FILE)

of the

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APPENDIX D. NOISE ANALYSIS PROCEDURE FOR NOISE STUDY AREAS WITH EXISTING NOISE WALLS

of the

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APPENDIX E. NOISE WALL/RETAINING WALL CLEARANCE REQUIREMENTS

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APPENDIX F. NOISE WALL MATERIALS, TEXTURES AND COLORS

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APPENDIX G. LEGACY NCDOT TRAFFIC NOISE POLICIES

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