FINAL REPORT

On Project 25-34
Supplemental Guidance on the Application of FHWA's Traffic Noise Model (TNM)

APPENDIX I
Tree Zones

Prepared for:

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Prepared by:

Research Topic Lead Grant S. Anderson
in association with

HARRIS MILLER MILLER & HANSON INC.

Bowlby & Associates, Inc.

Environmental Acoustics

Douglas E. Barrett

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Appendix I Tree Zones

I.1 No overlaid Loose Soil zone needed with tree zones

Prior to this current study, it was believed that TNM would *incorrectly* compute attenuation for tree zones placed on ground types other than loose soil. Were this true, then a loose-soil ground zone would need to be input, overlaid on each tree zone, for TNM to compute correct tree attenuation.

This prior belief stemmed from prior, informal computations by the present author. The development of the *Automated TNM Sensitivity Tool* (Section 1 of the Topography appendix) has now allowed this prior belief to be tested much more thoroughly. And these more-thorough tests have *undercut the necessity of the overlaid, loose-soil ground zone.*

The remainder of this section describes the study/computation method and why no overlaid ground zones, of any type, are required for accurate TNM computations.

I.1.1 TNM's A-level tree attenuation

Table 1 repeats Table 16 in TNM's *Technical Manual.*[1] The table shows the octave-band tree attenuation that is coded into TNM.

Table 1. Attenuation through dense foliage

Octave-band center frequency (Hz)	**63**	**125**	**250**	**500**	**1K**	**2K**	**4K**	**8K**
Attenuation (dB, total) for d_f less than 10 meters	0	0	0	0	0	0	0	0
Attenuation (dB, total) for d_f between 10m and 20m	0	0	1	1	1	1	2	3
Attenuation (dB per meter) for d_f between 20m and 200m	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.12
Maximum attenuation (dB) for d_f 200m	4	6	8	10	12	16	18	24

This table derives from the 1996 ISO standard, in which "dense foliage" is defined as "sufficiently dense to completely block the view along the propagation path; i.e., when it is impossible to see a short distance through the foliage." [2]

To assess TNM computations with overlaid ground zones, we first converted Table 1 from octave-band attenuation to A-level attenuation. As always, such a conversion depends upon the noise-source spectrum. Within TNM, that spectrum depends upon vehicle type and speed, per the *Technical Manual*'s Eq.(5) and its associated Figures 17 through 32.

Our resulting Table 2 derives from a spreadsheet that was built to convert the octave-band attenuations in Table 1 to A-level attenuation. As shown, the resulting A-level attenuations are averages over three vehicle speeds (20, 40 and 60 miles per hour), while the three attenuation columns show the minimum,

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[1] Christopher W. Menge, Christopher F. Rossano, Grant S. Anderson, Christopher J. Bajdek, *FHWA Traffic Noise Model: Technical Manual*, Report FHWA-PD-96-010 / DOT-VNTSC-FHWA-98-2, U.S. Department of Transportation, Federal Highway Administration, Office of Environment and Planning, Washington DC (February 1998).

[2] International Organization for Standardization, *Acoustics—Attenuation of sound during propagation outdoors—Part 2: General method of calculation*, International Standard ISO 9613-2, Geneva, Switzerland (15 December 1996).

average and maximum over TNM's main three vehicle types: automobiles (AU), medium trucks (MT) and heavy trucks (HT).

Table 2 A-level Attenuation (dB) for TNM vehicles on average pavement (averaged over speeds)

	Stats over AU, MT, HT		
Dist (ft)	Min	**Avg**	Max
12	0.0	0.0	0.1
25	0.0	0.0	0.1
50	1.0	1.1	1.1
100	2.7	3.1	3.4
200	4.7	5.2	5.7
400	7.6	8.2	8.7
800	10.7	11.3	11.7

Figure 1 plots the average values from this table, as a function of distance through the trees. This figure provides a baseline to evaluate tree attenuations actually computed by TNM. In essence, this baseline shows what TNM's calculated tree attenuation should equal, per its underlying ISO values.

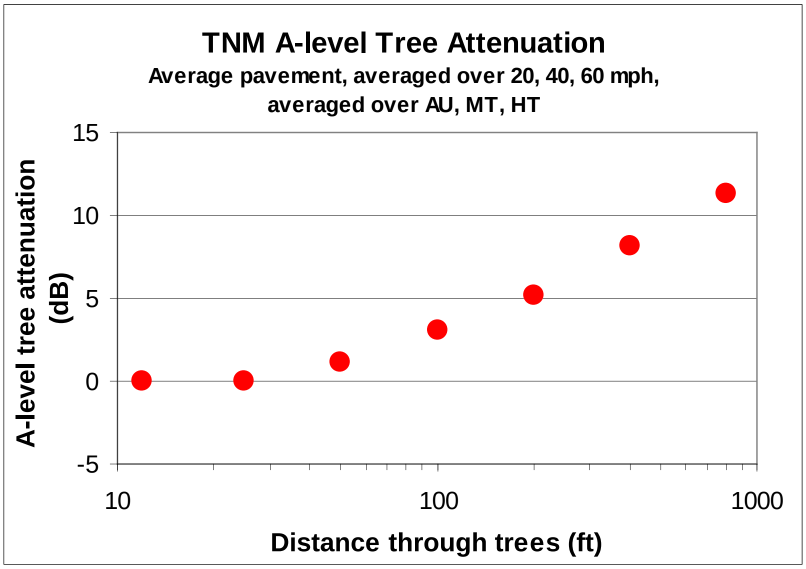

Figure 1. A-level Attenuation (dB) for TNM vehicles

It is important to note that this table and graph were not derived from TNM output. Instead, they were derived from the equations within TNM code along with the ISO attenuation table that underlies those equations. As a result, TNM output might not duplicate these exact values of tree attenuation for actual computed cases perhaps because TNM computations:

- May depend upon source and receiver elevations
- May depend upon the specific ground-line profile between source and receiver
- May contain code complexities that influence the computations.

As a result, actual TNM computations of tree attenuation must be tested against this table and figure. It was that type of prior, informal comparison that first indicated the need for an overlaid loose-soil ground zone as mentioned in the introduction.

We undertook such TNM computations and report them in the following section. For those computations, Table 1 and Figure 1 provide the "gold standard" for deciding what best input practice yields the proper tree attenuation.

I.1.2 Comparison with actual TNM results

To compare Figure 1 with actual TNM results, we used the *Automated TNM Sensitivity Tool* to compute tree attenuation over a large number of different input combinations:

- 5 default ground types: Field grass, lawn, loose soil, hard soil, pavement
- 4 ground-zone types: Field grass, lawn, loose soil, hard soil
- 3 vehicle types: Automobiles, medium trucks, heavy trucks
- 7 receiver distances through the trees: 12, 25, 50, 100, 200, 400, 800 feet
- 2 receiver heights: 5, 15 feet.

This input selection resulted in a total of 60 TNM runs: 5 default ground types, times 4 ground-zone types, times 3 vehicle types). Each of these TNM runs contained 14 receivers affected by the tree zone and a corresponding 14 receivers unaffected by the tree zone (on the other side of the "point-source" roadway).

For these computations, we used a very short source roadway because (1) the ISO table pertains to point noise sources and (2) TNM computes for very short roadway sub-segments before combining those results into line-source results.

Figure 2 shows the TNM input geometry, in plan view. The receivers to the right are inside the tree zone and its overlaid ground zone, while those to the left are outside. The A-level difference between these two sets of receivers, as computed by TNM, comprises the tree attenuation.

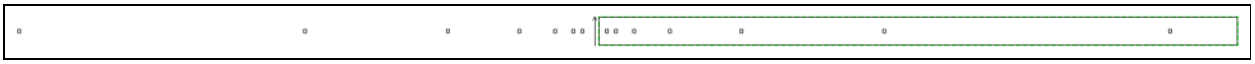

Figure 2 TNM input geometry

Even though hard to see in this figure, the ground zone is actually 1 foot inside the tree zone necessary to avoid a TNM input error. Before automatically computing the full set of TNM cases, we ran a subset of them to determine the effect of reversing this inside-outside relationship. From these TNM cases, we found that (within a maximum difference of 0.3 dB) it did not matter which zone was inside the other tree inside ground zone, or ground inside tree zone.

The two pages of Figure 3 show the results of the full set of automated TNM computations. Each frame in the figure is for one particular default ground type, starting with field grass in the top row of frames and ending with pavement in the bottom row. The two frame columns are for the two receiver heights: 5 feet and 15 feet.

Each graph's key distinguishes among ground-zone types. In turn, each ground-zone type has three graphed lines: automobiles, medium trucks and heavy trucks (these are not individually labeled on the graphs).

On each graph, the dependence upon vehicle type derives from the spectral differences among vehicles. The dependence upon receiver height is probably an artifact of the quite-complex propagation mathematics in which the tree-attenuation adjustment is imbedded.

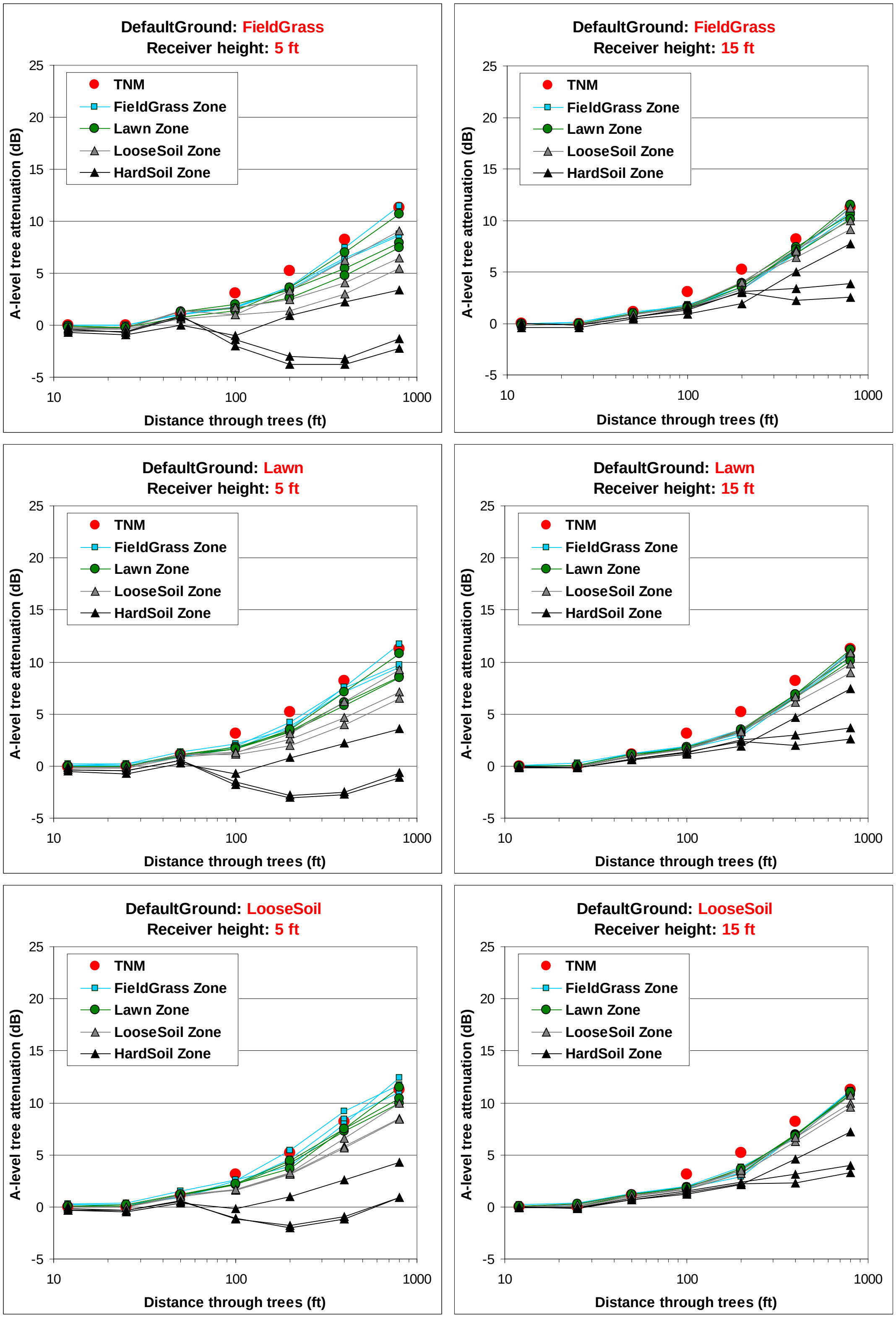

Figure 3 Results of computations

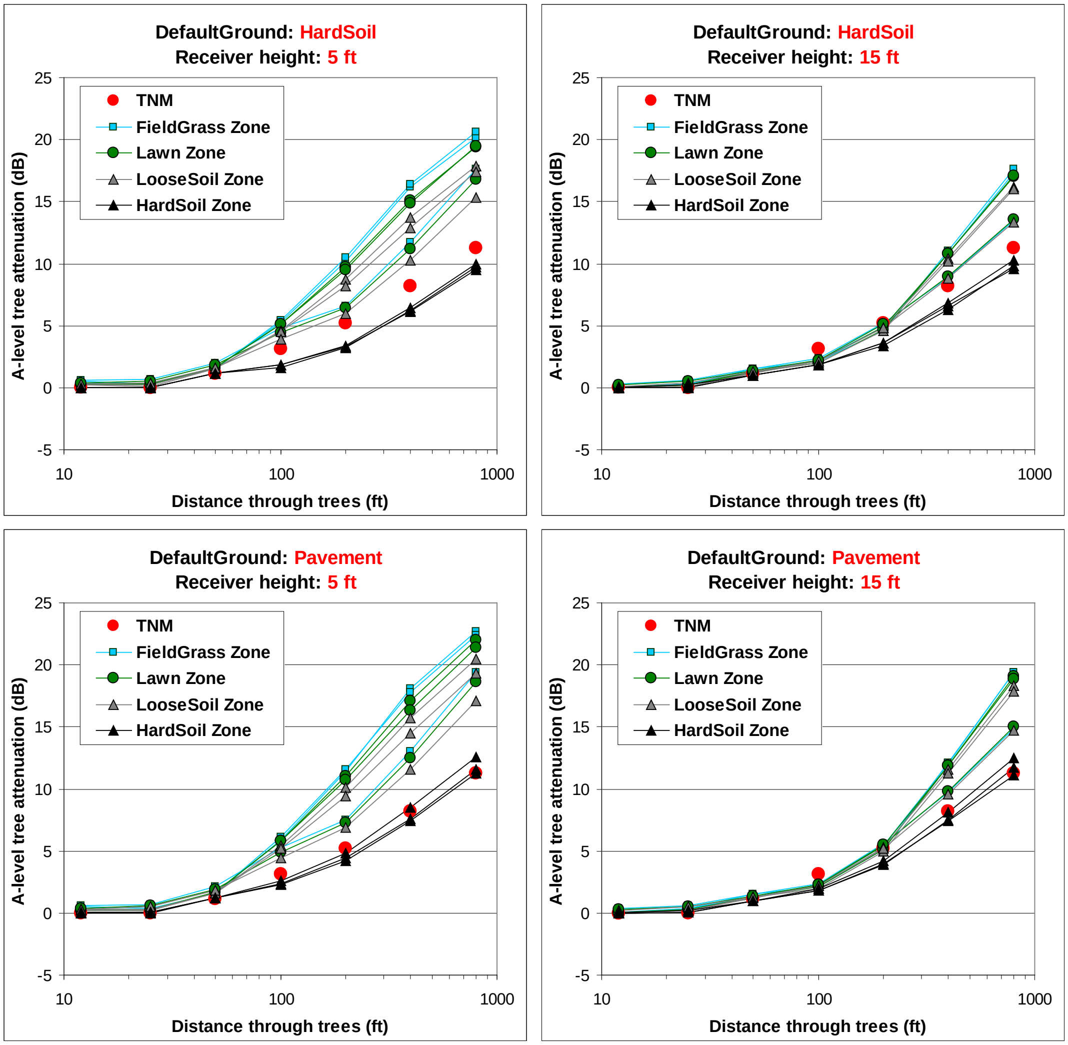

Figure 3 (continued) Results of computations

I.1.3 Best ground-zone type

Separately for each frame in Figure 3, the best ground-zone type is the one that best matches the red filled circles that is, the values directly computed in Section I.1.1from the ISO attenuations. Visual inspection shows these "best" ground-zone types to differ by default ground type, as follows:

Default ground	**Best ground-zone type**
Field grass	Field grass
Lawn	Field grass, but lawn very close second
Loose Soil	Field grass, but lawn close second and loose soil close third
Hard Soil	Hard soil
Pavement	Hard soil

Consistent with the "lawn" bullet here, the *prior informal computations* suggested that overlaid field-grass ground zones are needed to best compute tree attenuation over a lawn default ground.

However, the full set of results in Figure 3 casts doubt upon that conclusion. In particular throughout the figure, the actual TNM computations underpredict, by 1-to-2 decibels, the red-circle "target values" from Figure 1 that is, the values that derive directly from the ISO standard. This is especially true at distances of 100, 200 and 400 feet through the trees.

After adjusting out this general underprediction of tree attenuation, the best ground-zone types change to:

Default ground	**Best ground-zone type**
Field grass	Field grass
Lawn	Lawn
Loose Soil	Loose soil
Hard Soil	Hard soil
Pavement	Hard soil (since pavement ground zone was not computed)

In our judgment, this adjusted pairing is the proper one. It pairs each best ground-zone type against the *very same default ground*. And, most importantly, it matches what would be expected from the way tree attenuation is coded into TNM.

A complication

Laying a ground zone on top of the same type default ground is certainly counter-intuitive and a lot of extra input work. In other words, "matching" input (default ground matches the ground-zone type) seems redundant and therefore not necessary. But that is how these automated TNM cases were actually run.

So, as the last step, we confirmed that elimination of the apparently redundant ground zone does not change the computed tree attenuation. In detail, over each of the four default ground types (excluding pavement), tree attenuation computes exactly the same (to 12 decimal places) whether or not the "matching" ground zone is included. For example, a lawn ground zone on top of lawn default ground yields exactly the same tree attenuation as does no ground zone.

I.1.4 Conclusion

Consistent with the intrinsic variability due to receiver height and source spectrum (and roadway height on actual projects), we therefore conclude that no overlaid ground zone, of any type, is needed for TNM input, to properly compute tree attenuation.

I.2 Narrow tree zones

Figure 4 shows a narrow tree belt that intervenes between roadways and a receiver. As text in the figure indicates, the receiver can see some traffic when looking perpendicular to the roadway, towards its closest portions. However, when looking at a significant skew angle, no traffic is generally visible due to the much longer path through the trees.

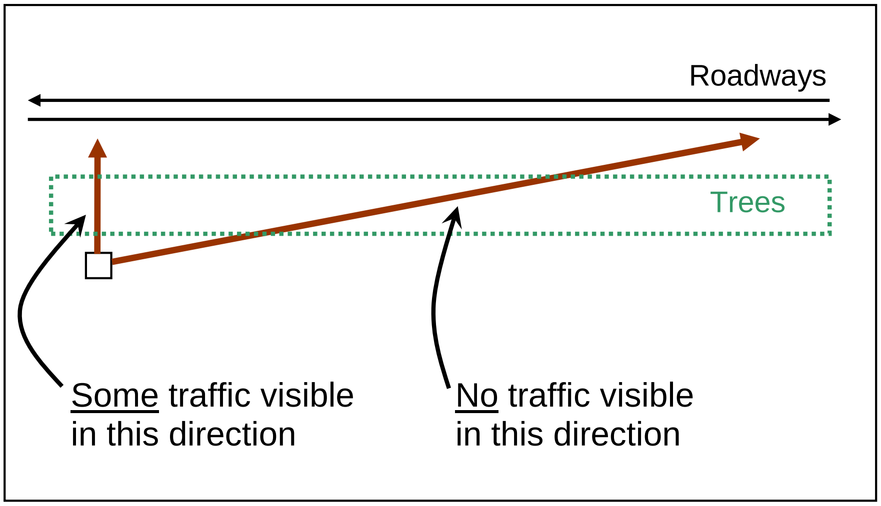

Figure 4 Roadway visibility through a narrow tree belt

In this section, we summarize our examination of these narrow tree belts examination aimed to determine when such narrow belts might be (1) justified in light of the ISO standard for tree attenuation and (2) essential to avoid unnecessary noise-barrier length.

I.2.1 TNM's A-level tree attenuation

Table 3 repeats Table 16 in TNM's *Technical Manual*.[3] The table shows the octave-band tree attenuation that is coded into TNM.

Table 3 Attenuation through dense foliage

Octave-band center frequency (Hz)	63	125	250	500	1K	2K	4K	8K
Attenuation (dB, total) for d_f less than 10 meters	0	0	0	0	0	0	0	0
Attenuation (dB, total) for d_f between 10m and 20m	0	0	1	1	1	1	2	3
Attenuation (dB per meter) for d_f between 20m and 200m	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.12
Maximum attenuation (dB) for d_f 200m	4	6	8	10	12	16	18	24

This table derives from the 1996 ISO standard, in which "dense foliage" is defined as "sufficiently dense to completely block the view along the propagation path; i.e., when it is impossible to see a short distance through the foliage." [4]

To assess TNM computations with overlaid ground zones, we first converted Table 3 from octave-band attenuation to A-level attenuation. As always, such a conversion depends upon the noise-source

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[3] Christopher W. Menge, Christopher F. Rossano, Grant S. Anderson, Christopher J. Bajdek, *FHWA Traffic Noise Model: Technical Manual*, Report FHWA-PD-96-010 / DOT-VNTSC-FHWA-98-2, U.S. Department of Transportation, Federal Highway Administration, Office of Environment and Planning, Washington DC (February 1998).

[4] International Organization for Standardization, *Acoustics—Attenuation of sound during propagation outdoors—Part 2: General method of calculation*, International Standard ISO 9613-2, Geneva, Switzerland (15 December 1996).

spectrum. Within TNM, that spectrum depends upon vehicle type and speed, per the *Technical Manual*'s Eq.(5) and its associated Figures 17 through 32.

Our resulting Table 4 derives from a spreadsheet that was built to convert the octave-band attenuations in Table 3 to A-level attenuation. As shown, the resulting A-level attenuations are averages over three vehicle speeds (20, 40 and 60 miles per hour), while the three attenuation columns show the minimum, average and maximum over TNM's main three vehicle types: automobiles (AU), medium trucks (MT) and heavy trucks (HT).

Table 4 A-level Attenuation (dB) for TNM vehicles on average pavement (averaged over speeds)

	Stats over AU, MT, HT		
Dist (ft)	Min	**Avg**	Max
12	0.0	0.0	0.1
25	0.0	0.0	0.1
50	1.0	1.1	1.1
100	2.7	3.1	3.4
200	4.7	5.2	5.7
400	7.6	8.2	8.7
800	10.7	11.3	11.7

Figure 5 plots the average values from this table, to allow interpolation.

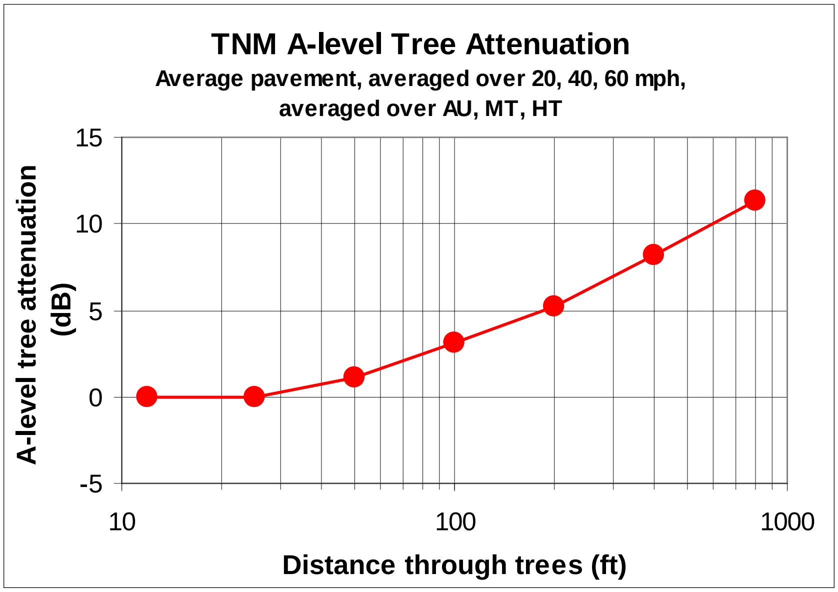


Figure 5 A-level Attenuation (dB) for TNM vehicles

As this table and figure show, TNM ascribes zero tree attenuation for sound paths less than 25 feet through the trees and minimal tree attenuation out to 50 feet.

Note that both the ISO tree attenuation and these A-level attenuations, derived from ISO, are for point noise sources. They therefore apply differently for the two sound paths in Figure 4. For a tree zone 25 feet wide, the table and figure show tree attenuation of 0 dB to the closet portion of the roadway, but some 4 dB of attenuation through 130 feet of trees along the skew line-of-sight.

I.2.2 The TNM tree-zone dilemma

If the tree zone is left out of the TNM input, because traffic is visible through it (to the closest roadway portions), then a noise-control barrier that extends to the east would have to be made longer than truly necessary. That unnecessary length would be needed to produce the additional reduction that is actually provided by the trees off to the east.

We examined this dilemma in two ways:

- **Diagnosis along the roadway:** Computed attenuation to different parts of the roadway
- **Example barrier design:** An example barrier design, in which this dilemma arises.

I.2.2.1 Diagnosis along the roadway

We first diagnosed the TNM tree attenuation for sound from different parts of the roadway.

Because TNM does not report a diagnosis by *roadway* segment, however, we substituted its ability to diagnose by *barrier* segment. To do this, we placed a segmented barrier very close to the roadway (1 foot from the roadway centerline). Then the sound-level contribution over each barrier segment is the identical contribution from that (barrier) segment's adjacent piece of roadway.

Figure 6 shows this input geometry, in various pieces and enlargements. Note that each receiver distance is the same as the thickness of the tree zone for that receiver, because the portion of the tree zone behind the receiver has no effect. For this reason, the receiver labels also denote the tree-zone thickness.

For this geometry:

- TreeZone: Northern edge at Y = 0 ft
- Roadway (width = 1ft) at Y = 1 ft
- Traffic at 50 mph:
  - 1000 automobiles per hour
  - 100 medium trucks per hour
  - 10 heavy trucks per hour
- Two groups of receivers:
  - Southern group in trees, as shown
  - Northern (reference) group not in trees
  - Distances from roadway identical
- Two barriers:
  - Y = 0.1 ft (slightly outside tree zone)
  - Y = 1.9 ft (to diagnose northern receivers)
  - Both barriers divided into 10-foot segments, centered on receiver transept.
  - Perturbed up once by 1 ft (to get diagnosis).

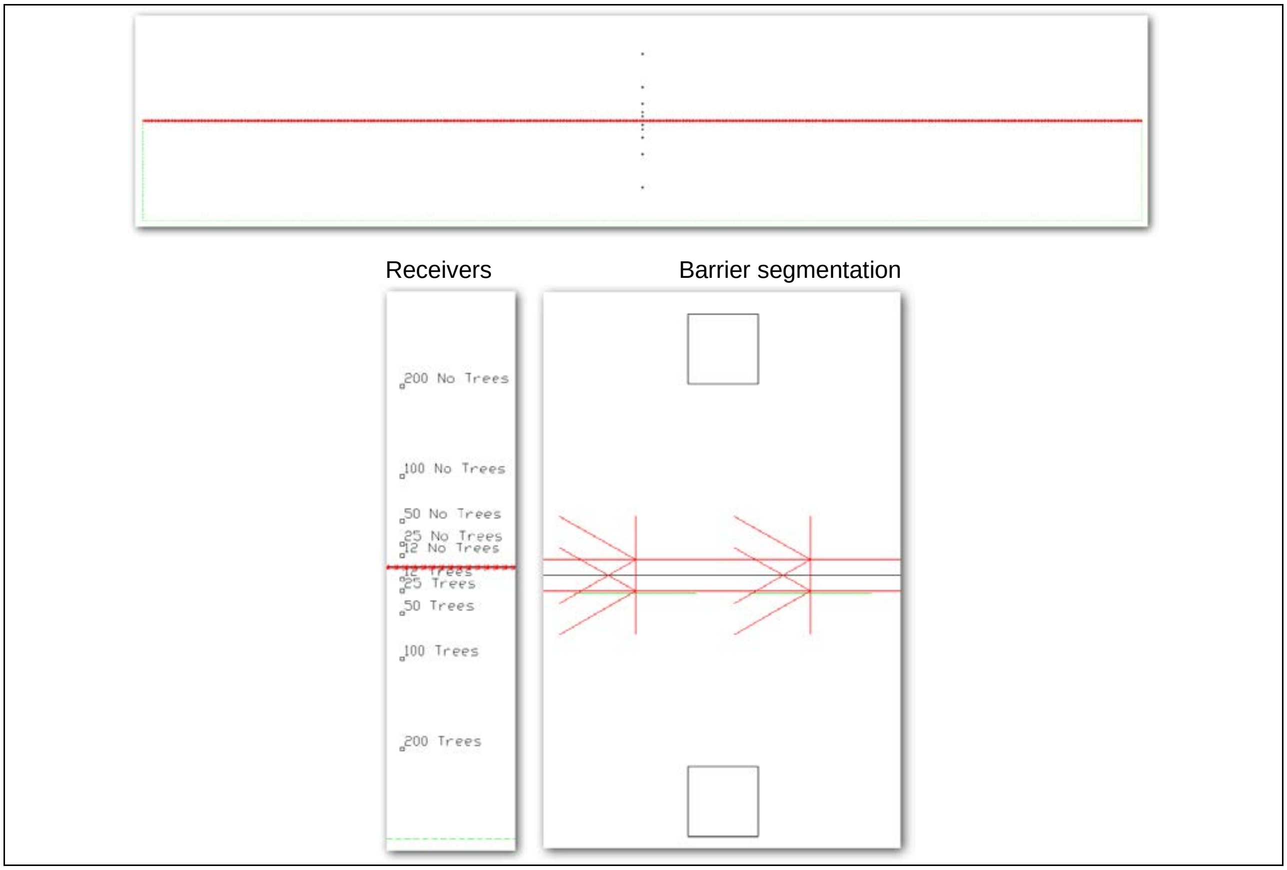


Figure 6 TNM diagnosis geometry

The barrier perturbation allows TNM to diagnose by barrier segment. Without that, TNM outputs no barrier diagnosis. In that way, we can analyze sound-level (and therefore tree-attenuation) results:

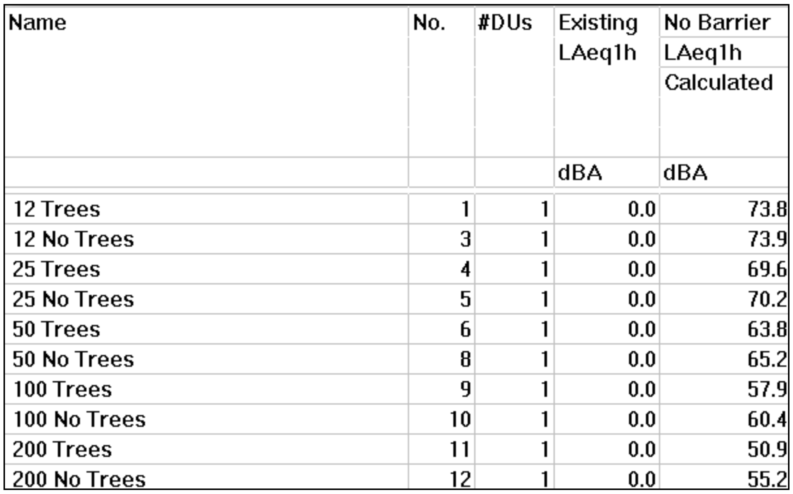
- For the full roadway, to determine the overall tree attenuation.
- By barrier segment, to determine the tree attenuation to various locations along the roadway.

Overall tree attenuation

Table 5 shows the resulting A-weighted sound levels, with and without trees. In the table, the receivers are named with their distances from the roadway, supplemented by whether they were behind trees (Trees: the southern receiver group) or not (No Trees: the northern receiver group).

For each tree-zone thickness, the "no-tree" sound level minus the "tree" sound level is the tree attenuation for that thickness. These values are tabulated in the next section, along with their corresponding angular diagnoses.

Table 5 A-level results



Name	No.	#DUs	Existing LAeq1h dBA	No Barrier LAeq1h Calculated dBA
12 Trees	1	1	0.0	73.8
12 No Trees	3	1	0.0	73.9
25 Trees	4	1	0.0	69.6
25 No Trees	5	1	0.0	70.2
50 Trees	6	1	0.0	63.8
50 No Trees	8	1	0.0	65.2
100 Trees	9	1	0.0	57.9
100 No Trees	10	1	0.0	60.4
200 Trees	11	1	0.0	50.9
200 No Trees	12	1	0.0	55.2

Tree attenuation to various locations along the roadway

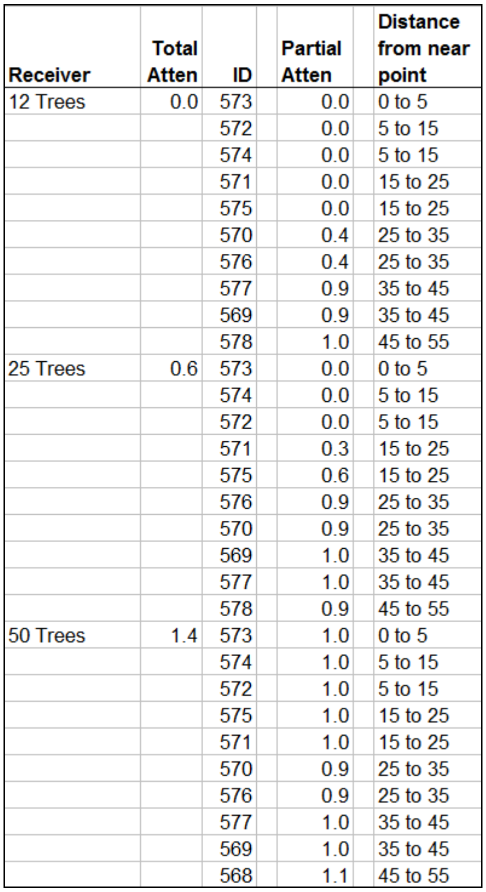
Table 6 contains the resulting diagnosis by barrier segment. Respective columns in the table show:

- The receiver name, which includes the effective tree-zone depth for that receiver
- The total tree attenuation to that receiver (pulled from Table 5, above)
- The ID number of the ten "loudest-level" barrier segments for this receiver, per TNM output
- The attenuation for this part of the sound level ("no-tree" diagnosis minus "tree" diagnosis)
- Distance of this roadway portion from the receiver transept line.

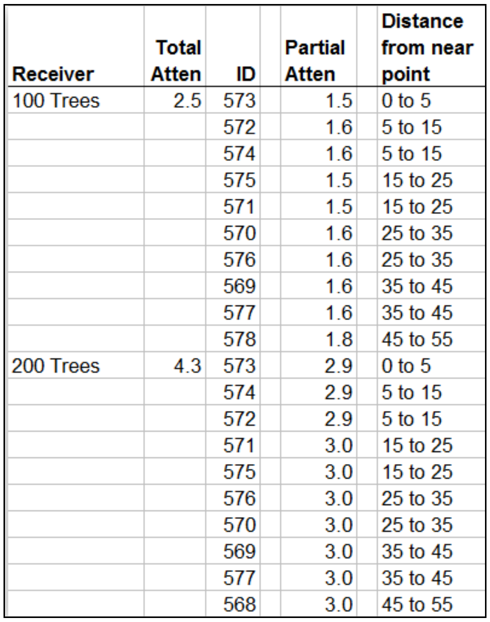
As this table shows:

- 12-foot wide tree zone
  - 0.0 dB overall
  - 0.0 dB to closest roadway location
  - 1 dB only 40 feet down the roadway.
- 25-foot wide tree zone
  - 0.6 dB overall
  - 0.0 dB to closest roadway location
  - 1 dB only 20 feet down the roadway.
- 50-foot wide tree zone
  - 1.4 dB overall
  - 1.0 dB to closest roadway location
- 100-foot wide tree zone
  - 2.5 dB overall
  - 1.5 dB to closest roadway location
- 200-foot wide tree zone
  - 4.3 dB overall
  - 2.9 dB to closest roadway location

Table 6 Tree attenuation to different portions of the roadway, separately by receiver



Receiver	Total Atten	ID	Partial Atten	Distance from near point
12 Trees	0.0	573	0.0	0 to 5
		572	0.0	5 to 15
		574	0.0	5 to 15
		571	0.0	15 to 25
		575	0.0	15 to 25
		570	0.4	25 to 35
		576	0.4	25 to 35
		577	0.9	35 to 45
		569	0.9	35 to 45
		578	1.0	45 to 55
25 Trees	0.6	573	0.0	0 to 5
		574	0.0	5 to 15
		572	0.0	5 to 15
		571	0.3	15 to 25
		575	0.6	15 to 25
		576	0.9	25 to 35
		570	0.9	25 to 35
		569	1.0	35 to 45
		577	1.0	35 to 45
		578	0.9	45 to 55
50 Trees	1.4	573	1.0	0 to 5
		574	1.0	5 to 15
		572	1.0	5 to 15
		575	1.0	15 to 25
		571	1.0	15 to 25
		570	0.9	25 to 35
		576	0.9	25 to 35
		577	1.0	35 to 45
		569	1.0	35 to 45
		568	1.1	45 to 55



Receiver	Total Atten	ID	Partial Atten	Distance from near point
100 Trees	2.5	573	1.5	0 to 5
		572	1.6	5 to 15
		574	1.6	5 to 15
		575	1.5	15 to 25
		571	1.5	15 to 25
		570	1.6	25 to 35
		576	1.6	25 to 35
		569	1.6	35 to 45
		577	1.6	35 to 45
		578	1.8	45 to 55
200 Trees	4.3	573	2.9	0 to 5
		574	2.9	5 to 15
		572	2.9	5 to 15
		571	3.0	15 to 25
		575	3.0	15 to 25
		576	3.0	25 to 35
		570	3.0	25 to 35
		569	3.0	35 to 45
		577	3.0	35 to 45
		568	3.0	45 to 55

And therefore:

- A 12-foot and 25-foot belt of trees is consistent with "no attenuation to closest points, where vehicles are visible."
- A 50-foot belt of trees is *marginally* consistent with "no attenuation to closest points, where vehicles are visible."

The next section illustrates that including such narrow tree belts are necessary to avoid unneeded noise-barrier length (and cost).

I.2.2.2   A tree zone and barrier example

To illustrate the effect on noise-barrier design and costs, we computed the sample TNM case in Figure 7.

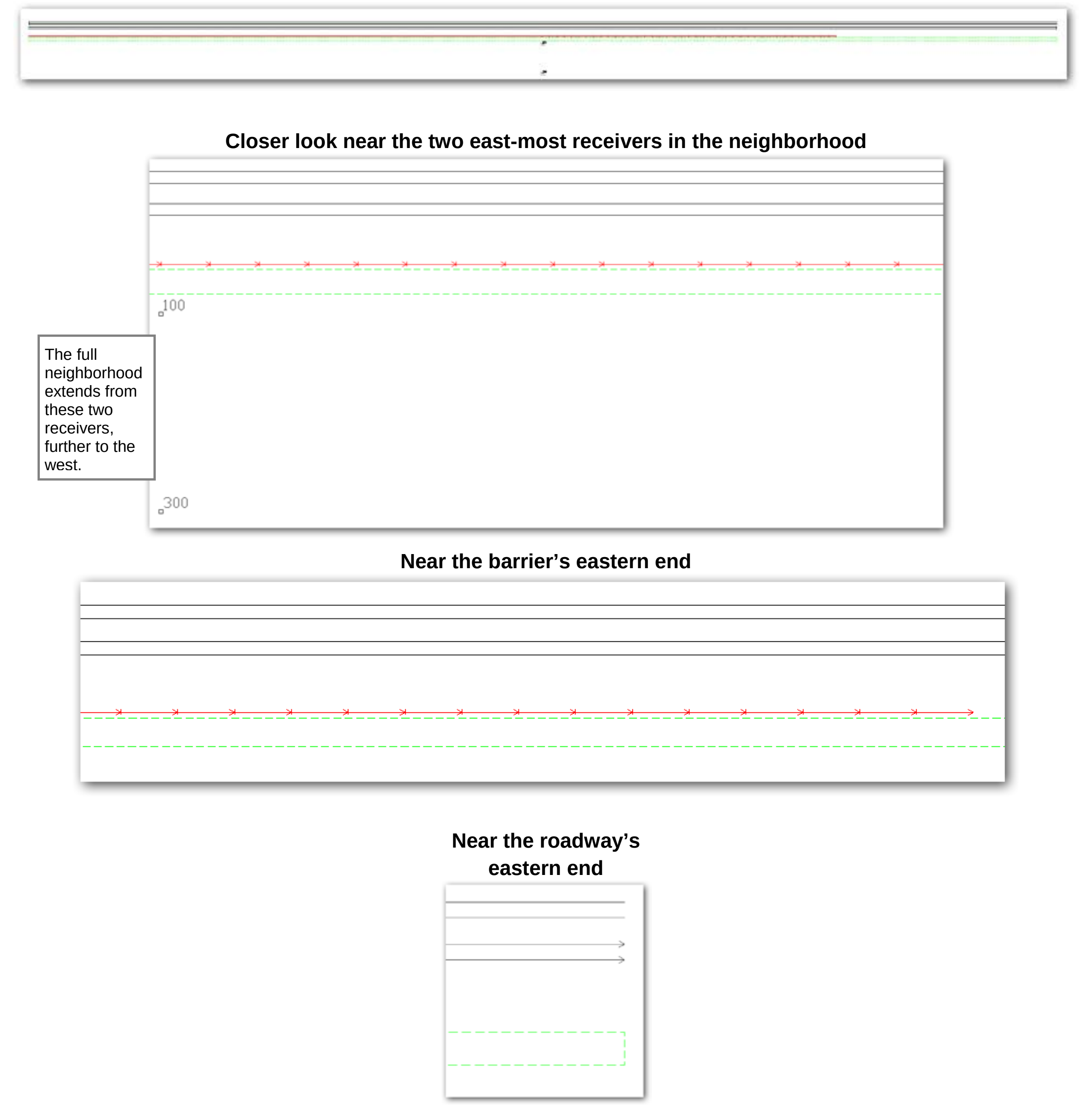


Figure 7 Barrier example: Plan view

This example includes:

- Four traffic lanes, each with heavy mixed traffic.
- A 25-foot-wide tree zone.
- Receivers at two distances from the barrier: 50 and 250 feet. These receivers represent the eastern-most receivers of a large neighborhood. Further receivers exist to the west of them, but are not included in the example.
- A barrier that comes in from the west (where it protects the bulk of the neighborhood), and then extends further to the east to also protect these two east-most receivers. *Of concern is the required length of the barrier extension to the east of the neighborhood.*

With this TNM input:

1. We first designed several barriers of different heights, each with the appropriate length extension (east of the receiver positions) to provide 8 decibels of noise reduction to the receivers. The appropriate lengths were larger, of course, for the lower barriers. And they were also larger for the 250-foot receiver than for the 50-foot receiver.

   Table 7 contains those height-length combinations that produced an 8-decibel barrier.

Table 7 With 25-foot wide tree zone: Barrier designs for 8 dB noise reduction

Receiver distance behind barrier (ft)	With-trees barrier height (ft)	With-trees required barrier length (ft) to the east of the receiver transept
50	13	200
50	11	300
250	18	1,000
250	16	1,700

2. Next we removed the tree zone and recalculated. This resulted in a loss of barrier noise reduction, due to the additional sound coming around the barrier's end to the east.
3. Then we held each barrier length constant and *increased barrier height* - to restore the 8-decibel barrier performance.
4. Then we held barrier height constant and then *increased barrier length* (starting with its original length) - to also restore the 8-decibel barrier performance.

   Table 8 contains the height and length changes to restore barrier performance.

Table 8 After removal of tree zone: Change in barrier designs to restore 8 dB noise reduction

Receiver distance behind barrier (ft)	With-trees barrier height (ft)	With-tree required barrier length (ft) to the east of the receiver transept	To restore barrier to 8 dB performance	
			For same length, increase height by:	For same height, increase length by:
50	13	200	4 feet (+$13,000)	100 feet (+$8,000)
50	11	300	no significant change	no significant change
250	18	1,000	4 feet (+$40,000)	300 feet (+$54,000)
250	16	1,700	2 feet (+$34,000)	900 feet (+$144,000)

Cost increases assume unit barrier costs to be $10 per square foot.

I.2.3 Conclusions

In all, these computations show that belts of trees up to 25 feet thick (and marginally up to 50 feet thick) provide no attenuation to the nearest portions of a roadway. For this reason, including them as TNM input seems consistent with the ISO requirement that trees must be "sufficiently dense to completely block the view along the propagation path."

Nevertheless, these computations also show that attenuation down the roadway from the receiver does receive significant attenuation, automatically per TNM, because of the extra depth of trees in those skew directions.

In addition, omitting narrow tree belts up to 50 feet in width could increase noise-barrier costs by some $100,000 (at each end of the barrier) to protect receivers at neighborhood boundaries.

I.3 Attenuation dependence on visibility through tree zones

During a brief look into the acoustical literature, we found an especially useful article by Fang and Ling about the dependence of tree/shrub attenuation on visibility distances into the vegetation (Fang 2003). Here we summarize relevant portions of that paper and compare its results with TNM's built-in tree attenuation. Such a comparison should help TNM users (1) to compare TNM computations with field measurements, in tree/shrub locations along a project roadway, and (2) to decide when to include TNM tree zones or both tree zones and additional adjustment factors, to account for vegetative shielding that is more effective than TNM computes.

I.3.1 Measured attenuation due to vegetation (Fang 2003)

Figure 8 summarizes the vegetation-attenuation measurements made and analyzed by Fang and Ling, for a large selection of non-deciduous tree/shrub types. Figure 9 repeats this figure, but with Latin names for the various tree/shrub types, instead of common English names.

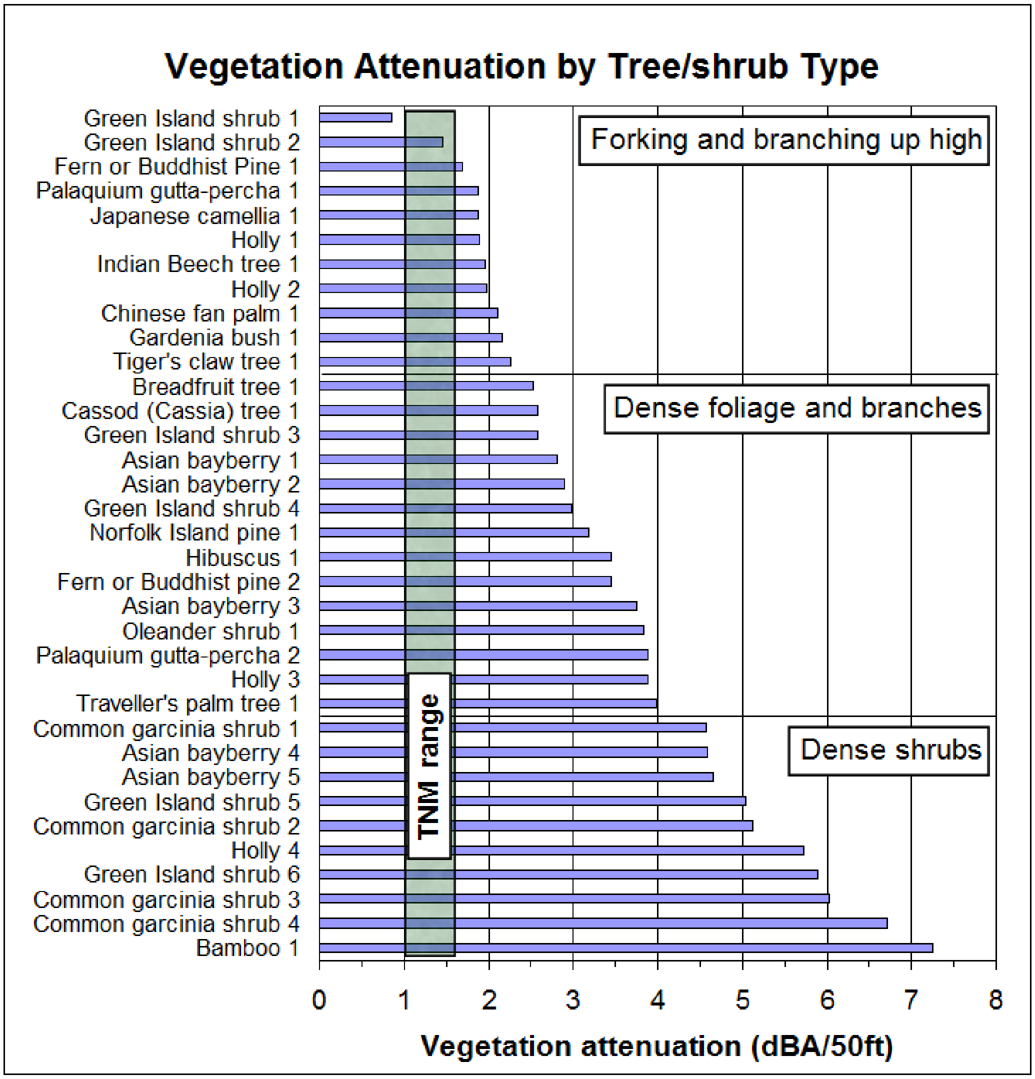


Figure 8 Vegetation attenuation by tree/shrub type (Fang 2003), English names

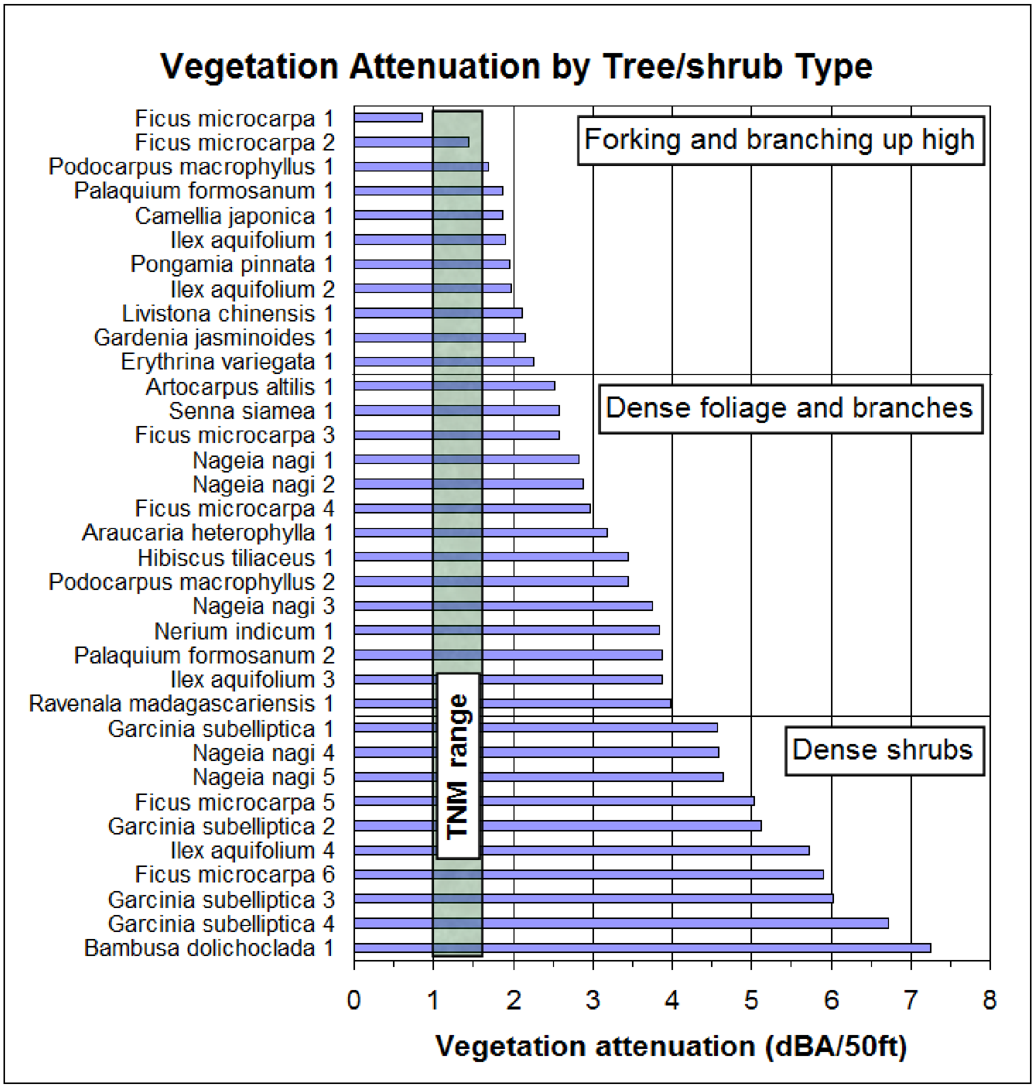


Figure 9 Vegetation attenuation by tree/shrub type (Fang 2003), Latin names

These figures also contain the tree-attenuation range built into TNM (for 50 feet of trees/shrubs). Note that TNM under-computes tree attenuation for the great majority of these extensive tree/shrub measurements.

I.3.1.1 Effect of tree/shrub type on attenuation

Many of the tree/shrub types appear multiple times in Figure 8 and Figure 9 (the numbers along the vertical axis document their multiple presence). For example, Green Island shrub appears six times: twice at the top (with very low attenuation), several times towards the middle, and several times near the bottom (with very high attenuation). The same is true for Holly and other many other tree/shrub types in the figure.

These attenuation disparities—for the same tree/shrub type are striking. The clear lesson from this figure: Tree/shrub type does not correspond closely with vegetation attenuation. Something else is going on (see next section). This conclusion is bolstered by other measurements in the literature, especially from those collected by Borthwick (1978) in Table 9.

Table 9 Vegetation attenuation from Borthwick 1978

Atten (dB/50 ft) at 500 Hz	Vegetation	Primary author	Specific source
7.50	Planted rows of various tree types, generally including undergrowth	Cook 1977	Fig. 8
7.50	Red pine plantation	Leonard 1971	Fig. 9
7.50	Christmas tree farms	Mecklenburg 1972	Fig. 12
7.50	Hedges	Yamada 1977	Fig. 17
7.00	White spruce	Lanphear 1971	Fig. 10
6.00	Arborvitae	Lanphear 1971	Fig. 10
5.00	American Holly	Lanphear 1971	Fig. 10
5.00	Red pine forest	Aylor 1972	Fig. 11
4.50	Hemlock plantation	Aylor 1972	Fig. 11
4.50	Dense hardwood brush (summer)	Aylor 1972	Fig. 11
4.25	Dense corn crop	Aylor 1972	Fig. 11
4.25	Average of coniferous and deciduous	Linskens 1976	Fig. 16
3.50	Sassafras	Lanphear 1971	Fig. 10
2.75	Dense hardwood brush (autumn)	Aylor 1972	Fig. 11
1.75	Very dense pine forest	Wesler (TSC) 1972	Fig. 6
0.83	**Dense foliage**	**TNM Manual**	**Tab. 12**
0.75	Dense evergreen woods	Wiener 1959	Fig. 3
0.75	Hemlock and fairly heavy undergrowth	Carlson 1977	Fig. 15
0.75	Dense oak, birch and white pine, plus undergrowth	Carlson 1977	Fig. 15
0.25	Bare trees	Wesler (TSC) 1972	Fig. 6

Except for several entries, this table shows no regularity at all. For example, pine trees range between 0.75 and 7.5 dB/50 ft, while hemlock ranges between 0.75 and 4.5 dB/50 ft. And so this table confirms that tree/shrub type does not correspond closely with vegetation attenuation. It also confirms that TNM under-computes tree attenuation for the great majority of these measurements.

I.3.1.2   Effect of underbrush density and visibility (back to Fang 2003)

The trees/shrubs in Figure 8 and Figure 9 are ordered from lowest to highest attenuation (dBA per 50 feet) and were grouped as shown from low to high underbrush density by Fang and Ling, themselves. As seen from the figure, dense shrubs produce the largest attenuations, followed by dense foliage and branches. Least attenuations occur for trees that fork and branch up high that is, vegetation with a high tree canopy.

As shown by the figure's horizontal axis, underbrush density is closely associated with visibility into the vegetation. Using regression analysis, Fang and Ling analyzed the relation between attenuation and visibility distance into the vegetation, obtaining this regression equation (but here converted to English units):

$$\frac{A_{Veg}}{\text{dBA/50ft}} = \left[4.08 - 2.87\log\left(\frac{D_{Vis}}{1\text{ ft}}\right) + 2.32\log\left(\frac{L_{VegProp}}{1\text{ ft}}\right) \right]. \qquad (1)$$

In this equation:

- A_{Veg} is the vegetation attenuation (in dBA per 50 ft)
- $L_{VegProp}$ is the vegetation path length (in ft).
- D_{Vis} the visibility distance into the vegetation (in ft) measured by walking into the vegetation until no longer visible from the outside, then averaging this visibility distance over three tries at each of two locations.

In this equation, the denominator entries force correct units in the numerators. Otherwise, units do not properly cancel.

Equation (1) appears graphically in Figure 10. This figure plots vegetation attenuation (in dBA per 50 feet) as a function of two regression parameters: (1) the visibility distance into the vegetation (horizontal axis) and (2) the vegetation path length (separate curves).

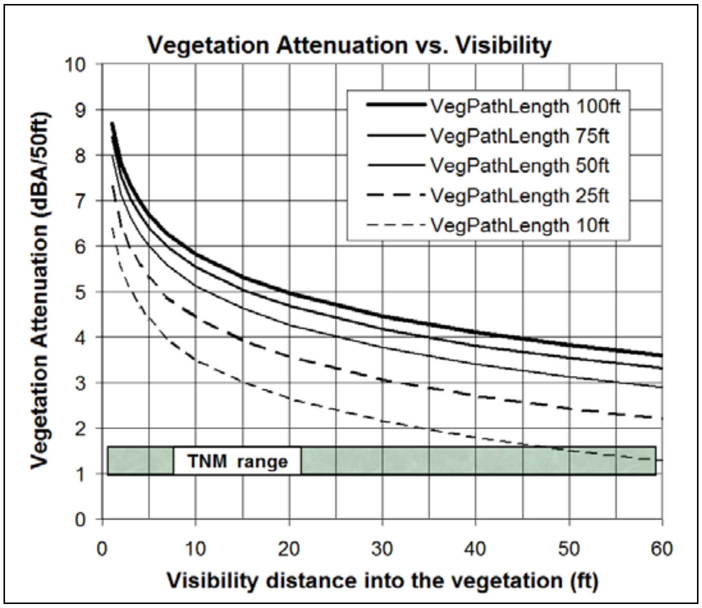


Figure 10 Tree-attenuation dependence on visibility (from Fang Ling Table 2)

As seen in the figure, Fang and Ling's regression analysis clearly shows that restricted-visibility vegetation provided the most attenuation as might be expected. More particularly in this figure:

- The horizontal axis characterizes the vegetation itself. The plotted parameter, visibility, is an easily measured standby for tree and undergrowth density. Where density is high, visibility into the vegetation is low and vice versa.
- Attenuation rises for lower and lower visibility distances as expected.
- Attenuation (per 50 ft) also rises with increasing vegetation-path distances. In other words, the attenuation effectiveness (per 50 ft) increases with more and more intervening vegetation.
- Once the vegetation path length is known, the curve for that path length converts visibility to attenuation (per 50 feet through the vegetation).

Consider the point on the lowest curve in Figure 10, furthest to the right. That point corresponds to (1) tree/shrub density so low that visibility extends 60 feet into the vegetation (per the horizontal scale), and (2) a receiver positioned 10 feet into this vegetation (per that curve's label). For that receiver, the figure shows attenuation of 1.3 dBA per 50 feet. Therefore, for this receiver only 10 feet into the vegetation:

$$\text{Total attenuation} = \left(1.3\ \text{dBA}/50\ \text{ft}_{\text{VegPathLength}}\right)\left(10\ \text{ft}_{\text{VegPathLength}}\right) = 0.26\ \text{dBA},$$

a trivial amount. Notice how the presence of units in Eq. (1) helps use the equation here, where proper cancellation of units is necessary.

As with Figure 8 and Figure 9, note here that TNM greatly under-computes attenuation from most tree/shrub densities.

I.3.2 Use of this information on roadway projects

We suggest the following "best use" of this information. Whenever vegetation intervenes at a TNM measurement site, also measure visibility into the vegetation at that site, perpendicular to the roadway. Then to interpret those sound-level measurements:

- Determine TNM's vegetation attenuation, by computing TNM with and without an intervening tree zone.
- Determine a visibility-based attenuation, from either Eq. (1) or Figure 10 above.
- Compare the two attenuations:
  - If they are both nearly zero, then conclude that a tree zone is not needed.
  - If they are *not* zero but are nearly the same, then conclude that the TNM tree zone is computing properly.
  - If they are *not* zero and are *not* the same:
    - Interpret the measurements twice, using (1) TNM's attenuation and (2) the visibility-based attenuation.
    - Use this comparison to decide how you wish to compute at this site. Accurate computation may require combined use of TNM tree zones and an additional negative adjustment factor, to compensate for TNM's under-prediction of tree attenuation.

I.3.3 References

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