

Traffic Noise Model vs. Extreme Topography

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Traffic noise exposures were measured at various locations adjacent to an Interstate highway and compared with sound levels predicted by the FHWA Traffic Noise Model (TNM). The prediction procedure underestimated the measured sound attenuation by 6 to 12 A-weighted decibels. Various TNM site model configurations were evaluated in an effort to improve agreement between measurements and predictions. For the site tested—a severe case with relatively distant receptors and extreme topography—variations in ground impedance (including a median ground zone) had little benefit or were counterproductive, while adding topographic detail via terrain lines helped somewhat. The best agreement resulted from the incorporation of a tree zone for the wooded site. However, this benefit is thought to be chance, because the site was not only relatively lightly wooded but also thinly foliated at the time of the on-site measurements.

A single-family detached residential development was proposed for a site situated adjacent to Interstate 97 (I-97) between Baltimore and Annapolis, Maryland. A local law specified minimum setbacks for residential development adjacent to certain limited-access highways [e.g., 640 ft (195 m) from the pavement edge, in the case of I-97] that applied to the development proposal and would have substantially restricted development of the tract. However, the law permitted development closer to the roadway if the sound levels at lot lines could be shown in a noise study to not exceed 66 A-weighted decibels (dBA) as a result of either existing site topography or additional specially designed mitigation features. Consequently, a study was performed to predict the I-97 noise exposures on the site and to determine the noise barriers necessary for the proposed development to comply with the county noise regulations.

The closest noise-sensitive locations on the mostly wooded site are about 400 ft (122 m) from the I-97 roadway centerline (Figure 1). The topography of the site is marked by considerable relief—some receptors 80 ft (24 m) above the nearby pavement, with highly irregular ridges and deep swales intervening. Near the proposed development, the right-of-way consisted of two directional roadways 25 ft (7.6 m) wide separated by a 55-ft (17-m) median alternating between deep cuts and substantial fills.

Traffic sound levels were predicted on the site using the FHWA Traffic Noise Model (TNM) (1). Initial traffic noise estimates (performed with a site geometric model that contained a fairly detailed representation of the site topography with several terrain lines and that characterized the ground surface as “lawn”) indicated the need for noise barriers to meet the local development requirements. Such barriers would have been difficult to implement because of the topography and would have necessitated clearing substantial areas of woods. Inclusion of a tree zone in the site model suggested sound levels 5 to

10 dBA lower, virtually eliminating the mitigation requirements. However, adding the tree zone in the TNM site model was considered unjustified unless substantiated by field measurements.

MEASURED TRAFFIC NOISE

Noise was measured to evaluate the extent to which sound may have been attenuated as it propagated across the tract in excess of the sound attenuation estimated by the TNM computational procedure and the initial site geometric model.

TEST PLAN

Procedures

Sound levels were measured at one reference and six receptor locations, as illustrated in Figure 1:

- Location 0, a reference location inside the I-97 right-of-way with nearly full line of sight to the roadway, and
- Locations P19, P20, P21, P22, P23, and R19, various noise-sensitive receptor positions.

Sound levels were sampled twice at each of the seven locations for relatively short, fixed intervals with an observer in attendance to identify noise sources and their exposure magnitudes. At Location 0, a noise monitor was placed for continuous, untended measurements concurrent with the six receptor-position measurements.

Attended-Measurement Instrumentation

The noise survey was performed using a Larson Davis model 2900 dual-channel, real-time frequency analyzer functioning as a precision (Type 1) sound level meter performing frequency-band statistical analysis. The analyzer was used in single-channel mode with a B&K 4189 0.5-in. (1.3 cm) electret microphone and a Larson Davis 900B preamplifier. The analyzer was set for third-octave band measurement over a 25- to 20-kHz frequency range and 0.125-s exponential time averaging (i.e., fast response).

Measurements were performed for nominally 15-min durations. Instrumentation was calibrated regularly during the tests using a B&K 4231 acoustic calibrator. Each microphone was fitted with a foam windscreen and attached with a boom to the tripod-mounted analyzer and was generally oriented toward the roadway at a height of 5 ft (1.5 m). During these measurement periods, instantaneous sound levels due to discrete occurrences or specific conditions were observed

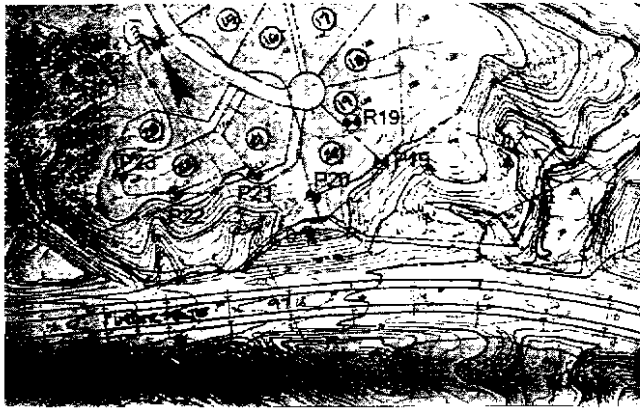


FIGURE 1 Study area.

and noted. At the completion of the measurement period, sampling-period statistics were obtained. Data stored by the analyzer were transferred to a computer for further analysis. The measured frequency-band levels were A-weighted and summed, permitting the results to be reported in terms of overall A-weighted sound levels.

Untended-Monitoring Instrumentation

Sound levels were measured using an untended noise monitor consisting of a B&K 4130 0.5-in. condenser microphone with wind-

screen, random incidence corrector, and B&K UA 0308 dehumidifier; a B&K 2642 microphone preamplifier; a B&K 2810 microphone power supply; and a Metrosonics dB-308 data-logging, general-purpose (Type 2) sound level meter. The meter was set for "fast" time weighting and "A" frequency weighting. This system sampled noise for a preset 5-min period, stored a summary of the measured sound levels with the period start date and time, then automatically initiated sampling for a new measurement period. The system was calibrated before and after the measurements using a B&K 4231 acoustic calibrator. Measurements were performed at a microphone height of 5 ft (1.5 m) with the microphone oriented vertically.

MEASUREMENT RESULTS

Sound levels were measured on April 13, 2000. Ambient weather conditions, recorded regularly on-site with the attended measurements, are summarized in Table 1. The attended measurements were performed between about 10:45 a.m. to 5:30 p.m. Data logging by the untended noise monitor commenced at 10:30 a.m. and continued until terminated at 5:40 p.m. Attended measurements were started at times corresponding to the start times of the automatic noise monitor recordings so that the results at the two locations could be directly compared for the same time interval. (Although the attended measurements were performed in third-octave bands, only the overall A-weighted sound levels were analyzed for this study.)

The site was almost entirely wooded in the test area, with deciduous second-growth trees approximately 40-ft (12-m) tall, some holly understory, and some pine along the right-of-way line. Foliation had

TABLE 1 Weather Conditions During Measurements

OBS. LOC.	TIME	TEMP. (°F)	RH (%)	WIND		SKY OVERCAST (%)	COMMENTS
				Speed (mph)	Dir.		
0	10:59	--*	--	calm	--	100	cirrostratus
	11:12	50	50	calm	--	--	
P19	--	--	--	--	--	--	
R19	12:09	--	--	0-3	NE	--	
	12:11	--	--	0-6	E	--	
P20	12:32	--	--	calm	--	95	high haze
	12:43	--	--	calm	--	--	
	12:51	50	39	--	--	--	
P21	13:00	--	--	calm	--	--	
P22	13:40	--	--	calm	--	--	
P23	13:53	--	--	calm	--	--	
	14:08	51	40	calm	--	100	high haze
0	14:46	--	--	calm	--	100	altostratus
	14:49	--	--	0-7	SSE	--	generally calm
	14:51	--	--	0-6	SSW	--	generally calm
	15:01	53	48	--	--	--	
P19	15:21	--	--	calm	--	--	
R19	15:37	--	--	calm	--	100	altostratus
P20	16:00	53	42	calm	--	--	
	16:09	--	--	0-2	WSW	--	
P21	16:28	--	--	calm	--	100	altostratus
P22	16:49	--	--	calm	--	--	
P23	17:12	--	--	calm	--	100	altostratus
	17:25	51	43	--	--	--	
AVERAGE		51	44				

* Not recorded

OBS.LOC. = observation location; RH = relative humidity.

°C = 5(°F - 32)/9; km/h = 1.61 x mph.



FIGURE 2 Measurement Location R19.

just begun at the time of the measurements. At least three of the six evaluation locations were shielded from the roadway by topography. The road was visible from one location with about a 300-ft (92-m) depth of trees intervening. The remaining two locations may have enjoyed topographic shielding, or the road was merely obscured by the foliage. Generally, the visibility through the woods was estimated at about 200 ft (61 m); representative views are shown in Figures 2 and 3. The ground surface at most measurement locations consisted of a thick leaf litter.

From the untended reference measurements, the equivalent sound levels during the three 5-min measurement intervals corresponding to each of the attended measurements were combined to produce reference-location 15-min equivalent sound levels ($L_{Aeq15min}$). At all locations, I-97 traffic noise was the dominant noise source, although natural and distant sources became more significant at test locations more isolated from the roadway. At Location 0, the traffic noise was quite steady; the $L_{Aeq15min}$ values were within ± 1 dBA over the 14 measurements. Receptor-location sound levels ranged from 16- to 23-dBA lower than the reference location close to the road. The results of the measurements are given in Table 2.

Traffic was manually counted during the attended Location 0 measurements and a videotape of traffic approximately 2 h long also was recorded during the testing. The traffic counts made at Location 0 (extrapolated to 1 h) are given in Table 3. (The traffic count



FIGURE 3 Measurement Location P22.

TABLE 2 Measured Traffic Sound Levels

EVAL. LOCATION	Time	MEASURED $L_{Aeq15min}$ (dBA)		
		at Location		Receptor
		Reference [untended]	Receptor [attended]	
1st MEASUREMENT				
0	10:50	75.2	75.3	0.1
P19	11:45	75.6	58.8	-16.8
R19	12:05	75.0	52.3	-22.7
P20	12:30	75.6	59.8	-15.8
P21	13:00	75.1	56.8	-18.3
P22	13:25	75.7	59.2	-16.5
P23	13:50	75.2	54.2	-21.0
2nd MEASUREMENT				
0	14:40	75.7	75.7	0.0
P19	15:15	76.3	60.0	-16.3
R19	15:35	76.6	54.0	-22.6
P20	16:00	76.7	60.9	-15.8
P21	16:25	76.2	58.1	-18.1
P22	16:45	76.7	60.4	-16.3
P23	17:05	76.5	56.1	-20.4
AVERAGE				
0				0.0
P19				-16.6
R19				-22.7
P20				-15.8
P21				-18.2
P22				-16.4
P23				-20.7

* 10-min measurement duration
re = Referenced to.

at 2:40 p.m. at Location 0 included definition of the directional distribution of trucks. Therefore, the second measurement cycle was used in the subsequent analyses.) Vehicle speeds were not measured but were estimated to average 65 mph (105 km/h). [For the observed traffic, the sensitivity of the speed assumption at 400 ft (122 m) from a roadway centerline for a flat site with soft ground is ± 5 mph (8 km/h) $\approx \pm 0.7$ dBA and ± 10 mph (16 km/h) $\approx \pm 1.4$ dBA.]

PREDICTED VERSUS MEASURED SOUND LEVELS

Analysis Procedures

Sound levels were initially computed for the traffic and ambient conditions observed during the tests on April 13 based on the 2:40 p.m. traffic count, as given in Table 3. The roadway pavement type was taken as dense graded asphalt concrete. The average air temperature and relative humidity observed during the noise measurements were incorporated into the TNM computations. Noise contributions for the two directional roadways were computed separately and summed. Noise exposures were predicted in terms of hourly equivalent sound levels ($L_{Aeq,t}$).

TABLE 3 Observed I-97 Traffic During Testing

		I-97 TRAFFIC OBSERVED at TIME	
		10:30	14:40
Hourly Volume ^a (veh)		3,896	4,956
Directional Split (%NB)		50%	53%
Vehicle Mix (%)	Light Vehicles	87%	90%
	Medium Trucks	4%	5%
	Heavy Trucks	10%	6%
Average Speed ^b (mph)		65	65

^a Extrapolated^b Estimated

veh = vehicles; %NB = percentage of vehicles traveling northbound.

Sound levels were calculated at the seven field measurement test locations illustrated in Figure 1. The predictions were made for receivers 5 ft (1.5 m) above existing ground elevation. Excess attenuation is determined as the difference between the traffic sound level (relative to the reference location) computed by the TNM prediction procedure and that observed in the field measurements:

$$(L_{\text{Receptor}} - L_{\text{Reference}})_{\text{predicted}} - (L_{\text{Receptor}} - L_{\text{Reference}})_{\text{measured}}$$

Consequently, excess attenuation is the sound attenuation not explained by the sound propagation algorithms incorporated into the computer prediction.

Initial Results

Initially, ground surfaces other than I-97 directional roadways 25 ft (7.6 m) wide were taken as "lawn." Shielding and ground-effect attenuation influences of the site topography were incorporated into the site model by means of terrain lines representing the roadway cuts and natural topographic features. The terrain lines depict a mix of ridges, swales, and constant-elevation contours. The evaluated receiver, terrain, and roadway geometry are shown schematically in Figure 4.

TNM calculated sound levels at receptor Locations 7 to 13 dBA lower than at reference locations. The receptor noise exposures at the various measurement locations were overpredicted as a result of the underestimation of sound attenuation by 6 to 12 dBA (average 9 dBA). (The magnitude of the underestimated attenuation is the excess attenuation not included in the mathematical procedure.) At the reference location, predicted sound levels agreed closely with the unadjusted measurements; these results are given in Table 4.

Effect of Site Model Design

Because TNM predicted traffic noise exposures at the evaluation locations were substantially greater than measured, refinements were incorporated into the site model to obtain better agreement between measurement and prediction. When the default ground surface was changed from "lawn" to "field grass," the average excess attenuation remained 9 dBA. On the other hand, if a tree zone was included instead, then the average excess attenuation dropped to 3 dBA. However, the validity of the result with the tree zone appeared questionable, and other explanations were sought.

In TNM, incorporation of a tree zone is considered valid if the vegetation is "sufficiently dense to completely block the view along the propagation path; i.e., it is impossible to see a short distance through the foliage" (1). By comparison, the previous FHWA highway traffic noise prediction model, implemented in the STAMINA computer program, qualified woods if they are "very dense, i.e., there is no clear line of sight from the receiver to the source, and if the height of the trees extends at least 5 metres above the line of sight" (2). Although the old FHWA method estimated tree attenuation in terms of overall A-weighted sound levels, TNM computes attenuation in third-octave frequency bands.

In Figure 5, the two FHWA tree attenuation algorithms are compared along with the observed excess attenuation. (TNM tree attenuation is given for the 500-Hz band, probably the most representative of the overall A-weighted attenuation for road traffic.) As shown, TNM tends to predict less tree attenuation than the older procedure, but the observed excess attenuation seems to be better predicted by the old algorithm. However, the verbal characterizations for "dense woods" in either method were judged to exclude the tree growth noted at the test site.

The attenuation of sound by vegetation is considered to be the result of (3, 4)

- Scattering of sound by tree trunks and limbs in middle frequencies and by leaves at very high frequencies, and
- Enhanced ground attenuation at lower frequencies as a result of tree roots making the ground more porous.

In TNM, tree attenuation increases monotonically with frequency, implicitly ignoring the ground-effect mechanism.

The relatively sparse character of the woods suggested that "tree attenuation," as assumed in the TNM "tree zone," was not the explanation so much as ground-effect attenuation enhanced by very low ground impedance. Typical published values for ground surface impedance (in terms of flow resistance in rayls) are

- Forest floor, pine or hemlock: 20 to 80 rayls;
- Grass (rough pasture, airport, public buildings, etc.): 150 to 300 rayls; and
- Roadside dirt, ill-defined, small rocks up to 4 in. in diameter: 300 to 800 rayls (5).

These impedance values compare to the standard TNM values of "lawn" (300 rayls) and "field grass" (150 rayls).

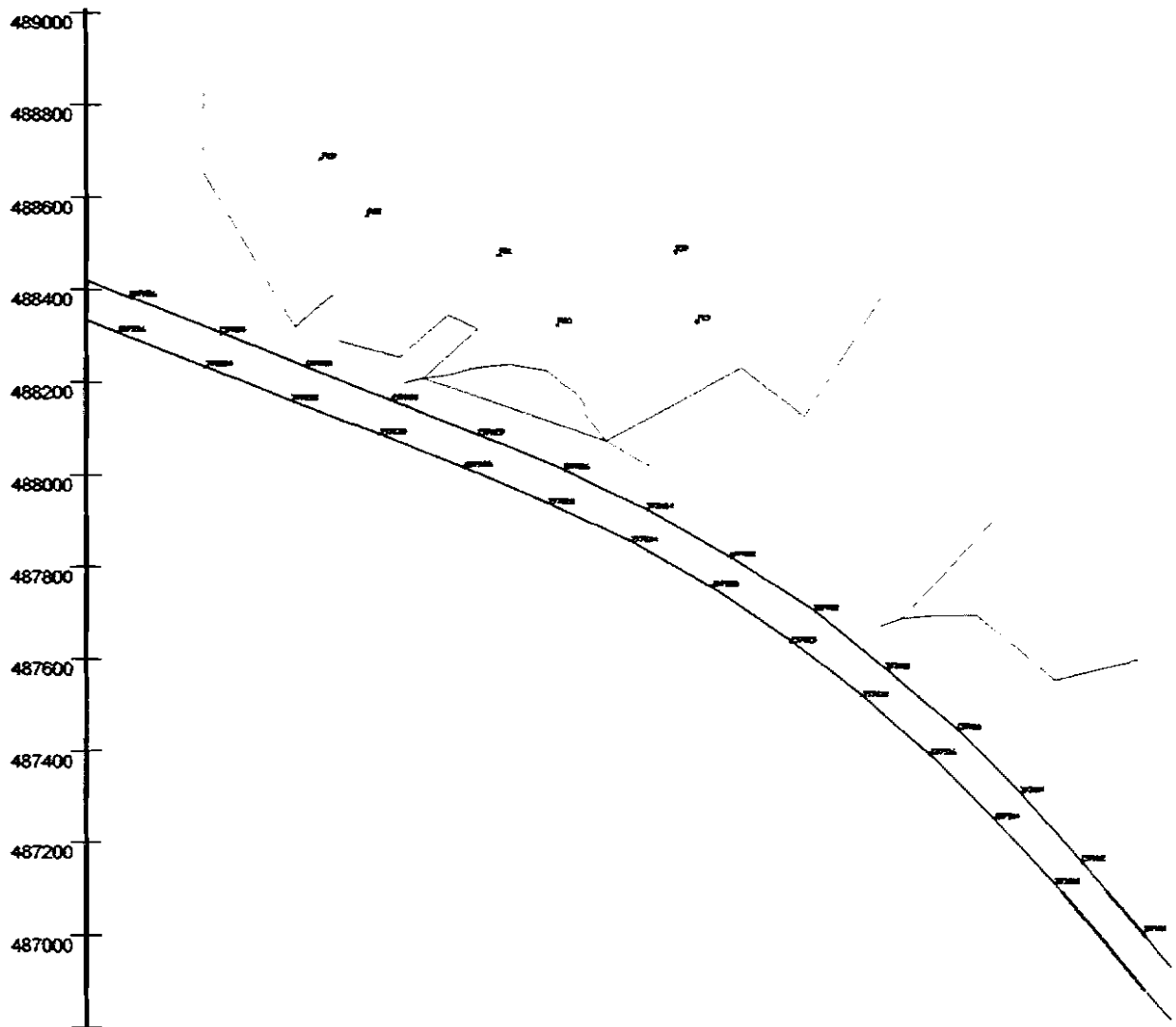


FIGURE 4 Initial site model geometry.

TABLE 4 Initial Traffic Noise Prediction Results

EVAL. LOCATION	ROAD DISTANCE* (ft)	TREE DEPTH† (ft)	PREDICTED SOUND LEVEL (dBA) at LOCATION		
			L _{Aeq1hr}	re Loc. 0	EA‡
0	160	0	75.8	0.0	-0.0
P19	410	300	65.3	-10.5	5.8
R19	530	360	63.1	-12.7	9.9
P20	280	75	67.4	-8.4	7.4
P21	365	250	67.4	-8.4	9.7
P22	345	270	68.7	-7.1	9.2
P23	420	310	66.9	-8.9	11.5
AVERAGE				-9.3	8.9

* Distance to roadway pavement at closest approach.

† Estimated depth of trees at closest approach of roadway

‡ Excess attenuation per 2nd measurement
 $m = ft/3.28$.

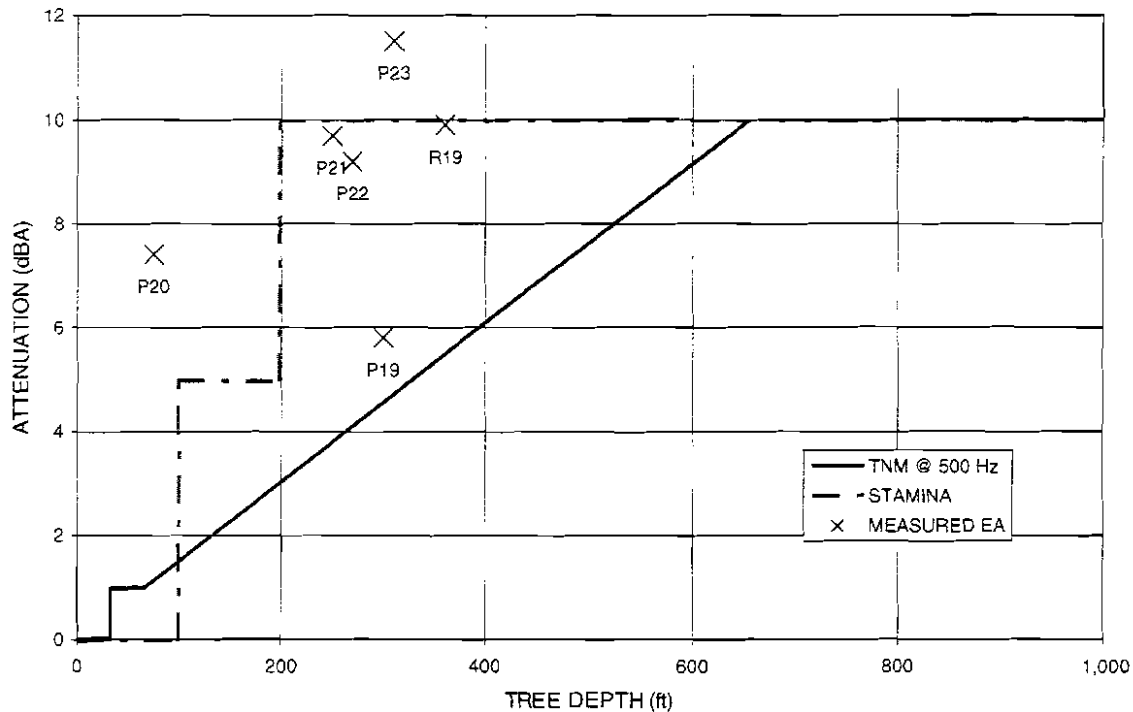


FIGURE 5 Measured excess attenuation (EA) and predicted tree attenuation.

Ground Impedance

The default ground surface was maintained as "field grass," and a ground zone was defined for the wooded area to enable the incorporation of published values. Ground impedances of 80, 40, and 20 rayls were considered successively. The excess attenuation was not only unexplained (it averaged 10 dBA) but also showed a slight tendency to increase with decreasing impedance.

Additional Terrain Lines

Terrain lines were added to account for previously unconsidered topographic shielding. This more detailed site model is illustrated in Figure 6. The resulting predictions improved somewhat, with an average excess attenuation of 8 dBA. However, reducing ground impedance in conjunction with the detailed site model again increased excess attenuation.

Median Ground Zone

Recently, some investigators have informally reported improved agreement with measurements after defining a ground zone between the directional lanes where a grass median exists. A site model with a "lawn" ground zone median was examined with a "field grass" default surface and additional terrain lines. The results improved slightly, but not substantially, to 7-dBA average excess attenuation.

Tree Zone

The best results with the initial site model were obtained when a tree zone was incorporated. When a tree zone was evaluated with a "field

grass" default surface and additional terrain lines, better results again were obtained—a 2-dBA average excess attenuation.

STAMINA Analysis

The site also was analyzed using the FHWA STAMINA procedure, assuming propagation over "soft" ground per the initial site model with the terrain lines represented as barriers but with no other shielding or adjustment factors. Using this method, the average excess attenuation was 12 dBA, although the mean difference between predicted and measured sound level was 7 dBA, probably in part because of unaccounted elevated propagation paths. (The reference location was underpredicted by 3.6 dBA.)

CONCLUSIONS

Various TNM site model configurations were evaluated in an effort to improve agreement between measurements and predictions. The results of these analyses are summarized in Table 5 in terms of overall A-weighted sound levels. For the specific site tested—a severe case with relatively distant receptors and extreme topography, variations in ground impedance (including a median ground zone) had little benefit or were counterproductive, while adding topographic detail via terrain lines helped somewhat.

The best agreement came with incorporation of a tree zone for the wooded site. However, this benefit is thought to be chance, because the TNM tree-attenuation mechanism is primarily a sound-scattering effect and the study site was relatively lightly wooded and thinly foliated at the time of the on-site measurements. Better understanding of the excess attenuation will require analysis of the frequency-band measurement data.

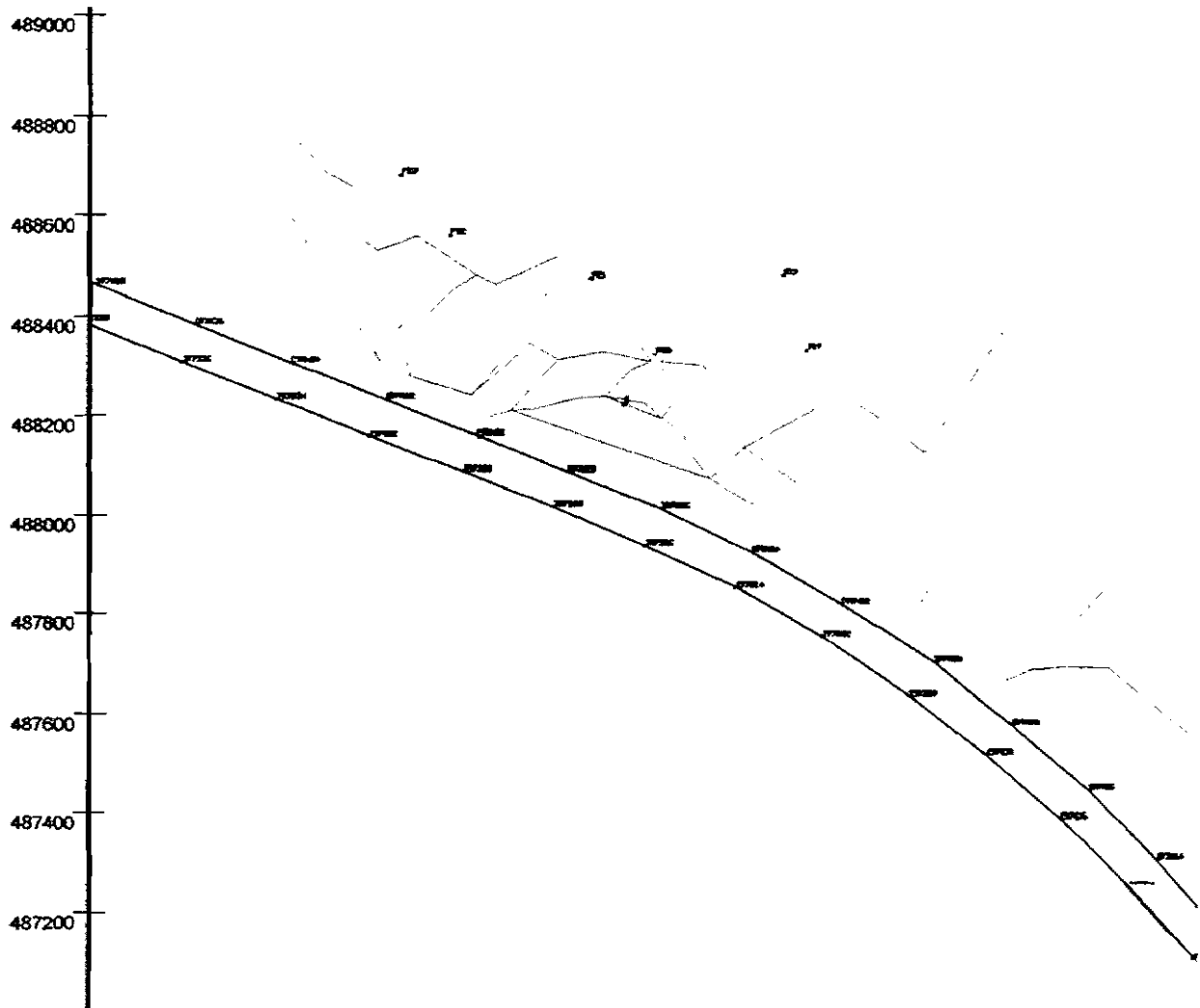


FIGURE 6 Detailed site model geometry.

TABLE 5 Excess Attenuation with Various TNM Site Models

GROUND SURFACE (rays)			TREE ZONE	AVG. EXCESS ATTN. (dBA) for TERRAIN DEFINITION ²	
Default	Woods	Median		Initial	Detailed
300	-- ¹	--		no	8.9
150	--	--	no	9.0	7.5
300	--	--	yes	3.2	1.9
150	--	--	yes		1.8
300	150	--	no	9.0	
150	80	--	no	9.9	8.6
150	40	--	no	10.0	
150	20	--	no	10.1	
150	--	300	no		7.3
150	--	300	yes		1.6

¹ Unspecified (i.e., default value).

² Median area NOT identical to case without Tree Zone

³ "Initial" per Figure 4; "Detailed" per Figure 6

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