FINAL REPORT

EFFECTIVENESS OF SIX NOISE BARRIERS ON I-495

by

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Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia
Department of Highways & Transportation and
the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

March 1982
VHTRC 82-R50

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ABSTRACT

While measurements made by the Virginia Highway and Transportation Research Council, other departments of transportation, and the Federal Highway Administration have generally shown that acoustical barriers perform as predicted, public acceptance has often been less than unanimous. Some complaints that barriers do not seem to reduce noise levels have been especially surprising. Thus, following a series of interviews of people residing adjacent to several barriers, an acoustical study of barriers was undertaken both to determine the effectiveness of the barriers and to find whether there was any correlation between the noise reductions perceived by the residents and those determined by analysis or measurement. At five of these barriers, pairs of measurements were made, one near a residence where a favorable comment had been made and one where an unfavorable comment had been made. At a sixth barrier, measurements were made only near a residence where an unfavorable comment had been made because of a paucity of good measurement sites near the residences where favorable comments had been made.

This very small study, although not statistically meaningful, revealed some interesting trends. For example, many individuals may react to non-acoustical factors, such as problems of maintenance of the areas behind barriers; and in other cases, individuals appear to react to their own perceptions of the physical parameters of the barrier rather than to its acoustical effectiveness. One particularly interesting conclusion was that the perception of the barriers' effectiveness tended to be negative when the ear level of a person standing at the door of his house was much closer to the same elevation as the top of the barrier than was the ear level of the person who responded positively.

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Within the decade of the seventies, building highway facilities to satisfy the transportation needs of areas of big population growth has, in some instances, resulted in considerable noise pollution. The departments of transportation responsible for noise abatement have needed a technique that would have widespread application and over which they would have total control, and many have adopted the practice of constructing noise barriers on highway rights-of-way between the sources of noise and the receivers. Inasmuch as high population density means that large numbers of people will be impacted, so it also means that relatively large numbers of people will be benefited by construction of the barriers. The considerable cost of constructing barriers, however, coupled with an uncertainty of the benefits to expect from them, created skepticism concerning their value.

PURPOSE

In light of the above, the study reported here was undertaken to determine the effectiveness of a group of noise barriers in Northern Virginia.(1) In addition, it was planned to correlate the results of this study with the results of a 1979 opinion survey in which people living adjacent to barriers were asked to give their perceptions of the structures.(2)

INSTRUMENTATION

The data acquisition system used was that described in reference 3, except that all eight channels of the digital tape recorder were used. Of these, four recorded measurements from microphones aligned on a vertical pole; three recorded wind speed, wind direction, and temperature from a Climatronics, Inc. meteorological unit; and one was used for an all-weather microphone mounted above the barrier being studied. A total of five B&K 2203, 2204, and 2209 meters were used in the van to reduce the readings to A-weighted form. While the system was designed to operate off either eight 12-volt batteries connected in parallel or 115 volt line current, as often as possible the equipment van was connected to line current to avoid the effects on the equipment and recordings of the drawdown on the batteries.

Calibration signals were available from activators on the five microphones and from the calibration system on the Climatronics, Inc. meteorological unit. These signals were recorded at the beginning of each tape, and together with the calibration levels recorded on the 'headers', provided sufficient information to allow processing of the recorded data.

Following the recording of the headers and of the calibration signals, readings of 15-minute duration were made at a rate of ten measurements per second. The recordings were later reduced in the CDC CYBER computer at the University of Virginia. The microphone readings were calculated in decibel form and the weather data in linear form.

Only the calculated L_{eq} values from the microphone readings were used for further analysis of the results. These values are shown later in the third column of Table 3. The weather data were obtained on a trial basis; however, the weather was fair throughout all the readings and no further use was made of the information. Because of a series of failures of one microphone, seven of the proposed measurements were not made and no values for that microphone location are included in the data for the periods of the failures.

PROCEDURES

Noise Measurements

The rationale underlying the choice of the measurement methodology is given in reference 4. However, the methodology used for this study was not identical to that described there because it was intended that the synthesized barrier insertion losses should be compared against judgements of the barriers' effectiveness as expressed by some of the people who lived near them. Measurements were taken at only two sites along each of five of the barriers included in the previously cited 1979 opinion survey; one site was near the home of a respondent who had said that the barrier had had no effect, and the other was near the home of one who had said that the barrier had decreased the traffic noise. At a sixth barrier protecting Campbell Drive in the vicinity of Telegraph Road, measurements were taken at only one site, #17, which was near the home of a respondent who had said that the barrier had had no effect. Measurements were not taken near the home of a respondent who had reacted positively to the barrier, because only 4 out of 40 respondents thought that the barrier had had a great effect on decreasing the noise, and none of those were located close enough to the barrier so that the equipment setup could be used to take measurements.

For each measurement site, microphones were placed at two locations. Because of the manner in which it was rigged, the Bruel and Kjaer outdoor microphone was located anywhere between 1.3 and 3.2 m (4.4 and 10.6 ft.) directly above the barrier so as to sense the traffic noise as if the barrier did not exist. A 9-m (30-ft.) pole with an array of four microphones (#1 at the top, #4 at the bottom) was placed near the house, as were the temperature, wind speed, and wind direction sensors. All the data were recorded in the digital mode. In addition, the sounds sensed by the barrier microphone and by the #1, #3, and #4 microphones were simultaneously recorded on two Nagra tape recorders in the analog mode.

Site Descriptions

The measurement sites are shown in Figure 1. The study area was moderately landscaped with trees and shrubs. One of the constraints on the choice of sites was the need to have enough space to raise the 9-m (30-ft.) pole.

All of the barriers were built at either the upper edge of a cut slope or on top of an earth berm. The reflective surfaces of the barriers were either steel, wood, cast-in-place concrete, or a combination of wood atop cast-in-place concrete. The particulars are presented in Table 1. Cross sections that are perpendicular to the roadway and that contain both microphone locations may be seen in Appendix A, Figures A-1 through A-11.

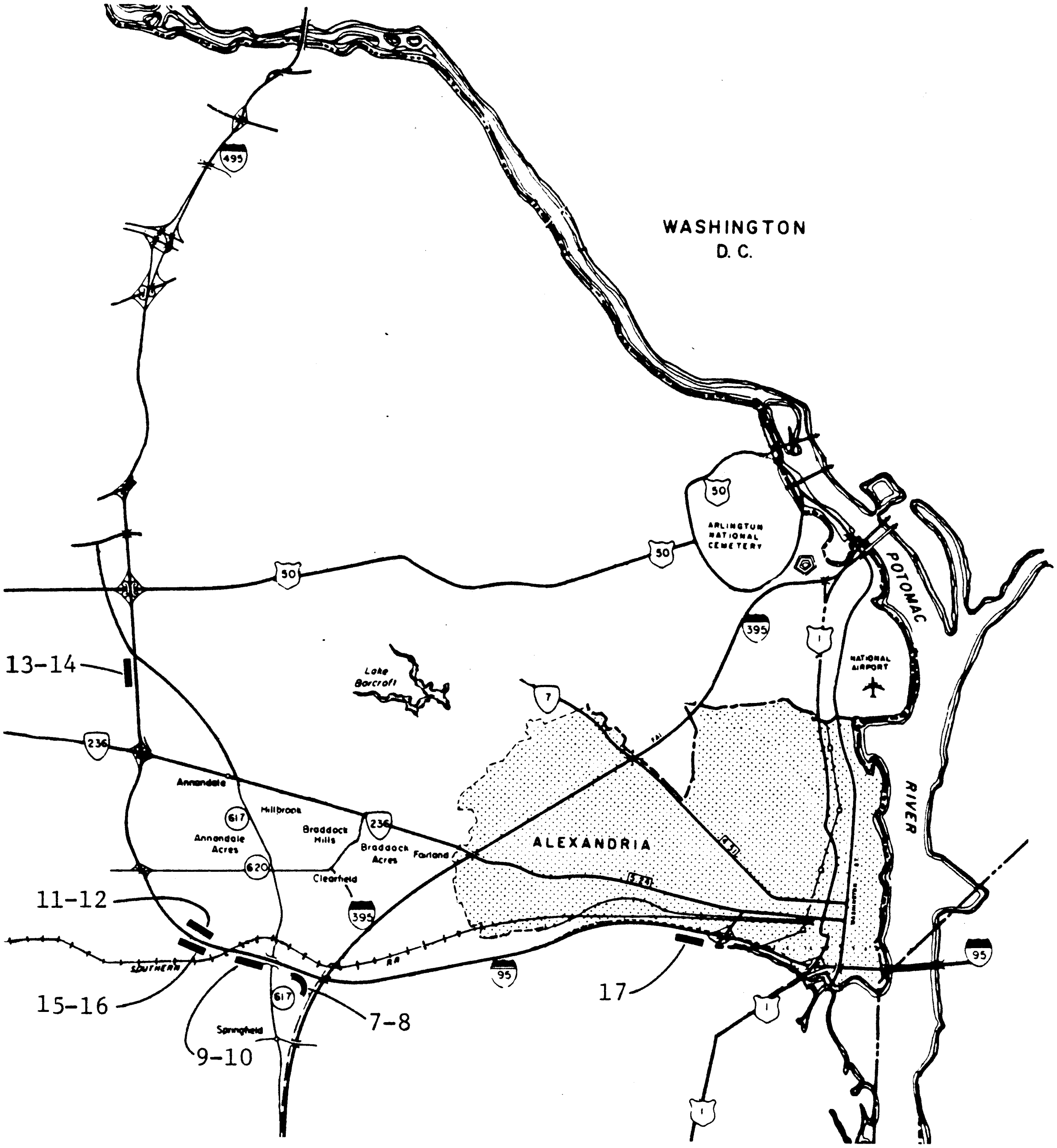
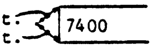


Figure 1. Barrier sites and measurement site numbers.

Table 1

Descriptive Information for Measurement Sites

Address	Number	Reflective Surface	Location of Barrier	Terrain Barrier to Pole	Pole Location Relative to House
3433 Luttrelle	14	Wood on concrete	On embankment	Relatively level, lower than hwy., row of trees, grass	Diagonally off N.W. corner, 16.5 ft. N., 11 ft. W.
3415 Luttrelle	13	Wood on concrete	Top of cut	Relatively level, some grass, hard soil, parking	20 ft. S. of mid-point of south wall of extension
7411 Long Pine Dr.	15	Wood	Berm on embankment	Relatively level, much lower than hwy., lightly wooded	Diagonally off N.E. corner, 4 ft. N., 12 ft. E.
7402 Estaban Pl.	16	Wood	Top of cut	Relatively level, much higher than hwy., lightly wooded	33 ft. off S. wall of 7402, 17.5 ft. off N. wall of 7400, 23.7 ft. 22.2 ft. 
7508 Leesville Blvd.	12	Steel single wall	Berm and shallow cut	Relatively level, row of trees, roadway and grass	24.5 ft. ⊥ to W. wall at point 4 ft. S. of N.W. corner
7410 Leesville Blvd.	11	Steel single wall	Berm and shallow cut	Relatively level, row of pines, roadway and grass	Diagonally off S.W. corner, 21.5 ft. S., 14.5 ft. W.
7203 Evanston	9	Wood	Berm on embankment	Relatively level, lower than hwy., weeds and grass, roadway	35 ft. N. of N.E. corner, 180 ft. W. of Belfast La.
7115 Evanston	10	Wood	Berm	Relatively level, grassed	19.5 ft. off S.E. corner of 7115, 19.5 ft. off S.W. corner of 7113 Evanston
6717 Cabin John Rd.	8	Concrete	Top of cut	Relatively level, hard poor soil, roadway and grass	Diagonally of N.E. corner, 13.5 ft. N., 17 ft. E.
6811 Cabin John Rd.	7	Concrete	Top of cut	Relatively level, hard poor soil, roadway and grass	23.4 ft. off N.W. corner, 33 ft. on a line ⊥ and S. of curb
5524 S. Quaker La.	17	Steel single wall	Berm on shallow embankment	Relatively level, drainage ditch, heavily grassed	At least 50 ft. from all structures, clear line to barrier

Conversion: 1 ft. = 0.3048 m.

The measurement sites are numbered in the order that each pair of measurements was begun. As in Table 1, in the remaining tables the sites are paired, with the site at the home of the person who had given a positive response in the earlier opinion survey being listed first. The data for site 17 stand alone because measurements for that barrier were taken at only one site for reasons cited previously.

Geometrics

The geometrical data needed for predicting L_{eq} levels to be used in predetermining the attenuation to be gained with a barrier also are given in Appendix A, Figures A-1 through A-11.

Traffic

Traffic counts and composition were recorded manually during the 15-minute periods of the recordings, and results are given in Table 2.

ANALYSIS

Modeling of Noise Attenuation Due to Barrier

In order to model the noise level at any one of the four microphone locations on the pole, the attenuations due to the barrier must first be modeled for each traffic source. For this purpose, two traffic sources were assumed, each traveling on two infinite roadway groups (the four eastbound lanes and the four westbound lanes). Because the three different heights — i.e., at 4.1 m (13.5 ft.) for heavy trucks, 0.7 m (2.3 ft.) for medium trucks, and at road level for automobiles — there are 4 (microphone hts.) x 3 (source hts.) x 2 (roadway groups) = twenty-four calculations for every site studied. The attenuations were calculated on a programmable TI59 hand calculator using the program(5) of the FHWA highway traffic noise model.(6)

Table 2

15-Minute Traffic Counts on Interstate Roadway

Site	Date Time	Lane	No. Vehicles Hour			
			Autos	Medium Trucks	Heavy Trucks	Average Speed, mph.
14	4/16/81 1630-1645	EB WB	1,757 1,135	19 30	35 25	57 55
13	4/10/81 1145-1200	EB WB	834 674	12 48	51 26	58 55
15	4/22/81 1500-1515	EB WB	954 881	26 51	54 46	57 53
16	4/27/81 1515-1530	EB WB	1,085 930	17 51	34 38	58 54
12	4/28/81 1600-1615	EB WB	1,385 1,270	23 64	36 40	58 53
11	4/29/81 1015-1030	EB WB	763 549	22 49	41 49	59 53
9	9/18/80 1010-1025	EB WB	652 656	36 18	40 45	57 58
10	9/18/80 1305-1320	EB WB	653 600	43 38	52 46	54 55
8	4/29/81 1400-1415	EB Ramps	624 482	20 38	21 100	59 45
7	8/21/81 1330-1345	EB Ramps	539 534	23 28	32 57	57 45
17	4/28/81 1045-1100	EB WB	469 559	33 26	52 58	55 59

Conversion: 1 mph = 1.61 km./hr.

Analysis of Results

Table 3 summarizes the measured and modeled noise levels. In discussing these results, the point must be made that it is not possible to measure the true insertion loss of a barrier directly. To do so would require that the barrier simultaneously be there and not be there, or that it be possible to reproduce exactly the same traffic conditions before and after erection of the barrier. The purpose of the no-barrier, or before - the-barrier, measurement would be to measure the effect of the various parameters (distance, ground condition, etc.) that affect the transmission of noise between two points, so that this value could be subtracted from the with-barrier measurement to determine the true insertion loss.

Lacking the ability to impose such experimental controls, a synthetic insertion loss* was developed by using the experimental results with some modeled data, and these results were used to verify the completely modeled results. Thus the intrinsic uncertainties associated with modeled data taint the final comparison with a degree of uncertainty.

The approach used for measurement and analysis is described below, and the steps are tied into the data presented in Table 3 by noting the appropriate column number in brackets.

1. A microphone was installed immediately above the barrier [2], under the assumption that the noise level is least disturbed by the barrier at this point [3].
2. A microphone was installed near the residence [2], 1.5 m (5 ft.) above the ground [3].
3. Three more microphones were installed above this [2], the highest at about 9.1 m (30 ft.), to verify the predicted increase of noise level with height and thus to confirm the reading made at 1.5 m (5 ft.)[3].
4. The modeled noise levels [4,5,6, and 7], expressed in L_{eq}, were modeled for the various microphone positions using measured traffic data, a "no-barrier" and "with-barrier" condition, and ground effect coefficients of 0 and 0.5.
5. The measured drop-offs [8] were determined by subtracting the value for the microphone located above the barrier [3] from the values for the four microphones in the array [3] near the residence, which gave negative values.

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*This term and related terms on pp. 8 and 11 are defined in Appendix B.

Measured and Modeled L_{eq} with Synthesized and Modeled Insertion Losses

Meas. Site No.	Mike Locn.	L_{eq}					Drop-off			Dist. Effect		Barrier Effect			
		Meas.	Modeled				Meas.	Modeled		Modeled		Synthesized		Modeled	
			No-Barrier		With-Barrier										
			α=0	α=.5	α=0	α=.5		α=0	α=.5	α=0	α=.5	α=0	α=.5	α=0	α=.5
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
#14	Barr.	75.5	80.7	78.8	80.7	78.8	---	---	---	---	---	---	---	---	---
	#1	64.6	77.6	74.1	71.0	67.8	-10.9	- 9.7	-11.0	- 3.1	- 4.7	- 7.8	- 6.2	- 6.6	- 6.3
	2	60.5	77.6	74.1	67.9	64.3	-15.0	-12.8	-14.5	- 3.1	- 4.7	-11.9	-10.3	- 9.7	- 9.8
	3	---	77.6	74.1	65.4	61.8	---	-15.3	-17.0	- 3.1	- 4.7	---	---	-12.2	-12.3
	4	58.9	77.6	74.1	63.8	60.3	-16.6	-16.9	-18.5	- 3.1	- 4.7	-13.5	-11.9	-13.8	-13.8
#13	Barr.	75.4	77.7	74.5	77.7	74.5	---	---	---	---	---	---	---	---	---
	#1	71.3	76.0	72.0	75.9	71.8	- 4.1	- 1.8	- 2.7	- 1.7	- 2.5	- 2.4	- 1.6	- 0.1	- 0.2
	#2	69.8	76.0	72.0	75.0	71.0	- 5.6	- 2.7	- 3.5	- 1.7	- 2.5	- 3.9	- 3.1	- 1.0	- 1.0
	#3	66.5	76.0	72.0	71.3	67.4	- 8.9	- 6.4	- 7.1	- 1.7	- 2.5	- 7.2	- 6.4	- 4.7	- 4.6
	#4	60.3	76.0	72.0	68.6	64.6	-15.1	- 9.1	- 9.9	- 1.7	- 2.5	-13.4	-12.6	- 7.4	- 7.4
#15	Barr.	80.1	80.9	79.1	80.9	79.1	---	---	---	---	---	---	---	---	---
	#1	60.8	75.7	71.1	68.7	64.0	-19.3	-12.2	-15.1	- 5.2	- 8.0	-14.1	-11.3	- 7.0	- 7.1
	#2	---	75.7	71.1	67.8	63.2	---	-13.1	-15.9	- 5.2	- 8.0	---	---	- 7.9	- 7.9
	#3	59.7	75.7	71.1	66.3	61.7	-20.4	-14.6	-17.4	- 5.2	- 8.0	-15.2	-12.4	- 9.4	- 9.4
	#4	58.3	75.7	71.1	65.0	60.5	-21.8	-15.9	-18.6	- 5.2	- 8.0	-16.6	-13.8	-10.7	-10.6
#16	Barr.	78.6	78.6	75.7	78.6	75.7	---	---	---	---	---	---	---	---	---
	#1	65.1	75.3	70.7	73.1	68.5	-13.5	- 5.5	- 7.2	- 3.3	- 5.0	-10.2	- 8.5	- 2.2	- 2.2
	#2	---	75.3	70.7	70.3	65.6	---	- 8.3	-10.1	- 3.3	- 5.0	---	---	- 5.0	- 5.1
	#3	62.5	75.3	70.7	68.6	64.0	-16.1	-10.0	-11.7	- 3.3	- 5.0	-12.8	-11.1	- 6.7	- 6.7
	#4	60.2	75.3	70.7	67.0	62.4	-18.4	-11.6	-13.3	- 3.3	- 5.0	-15.1	-13.4	- 8.3	- 8.3
#12	Barr.	79.7	80.9	79.0	80.9	79.0	---	---	---	---	---	---	---	---	---
	#1	67.8	77.2	73.3	69.9	65.8	-11.9	-11.0	-13.2	- 3.7	- 5.7	- 8.2	- 6.2	- 7.3	- 7.5
	#2	---	77.2	73.3	67.5	63.4	---	-13.4	-15.6	- 3.7	- 5.7	---	---	- 9.7	- 9.9
	#3	64.7	77.2	73.3	65.4	61.3	-15.0	-15.5	-17.7	- 3.7	- 5.7	-11.3	- 9.3	-11.8	-12.0
	#4	62.7	77.2	73.3	64.0	60.0	-17.0	-16.9	-19.0	- 3.7	- 5.7	-13.3	-11.3	-13.2	-13.3
#11	Barr.	78.7	80.1	78.2	80.1	78.2	---	---	---	---	---	---	---	---	---
	#1	67.3	76.0	71.9	71.8	67.6	-11.4	- 8.3	-10.6	- 4.1	- 6.3	- 7.3	- 5.1	- 4.2	- 4.3
	#2	---	76.0	71.9	69.5	65.5	---	-10.6	-12.7	- 4.1	- 6.3	---	---	- 6.5	- 6.4
	#3	63.5	76.0	71.9	67.9	63.9	-15.2	-12.2	-14.3	- 4.1	- 6.3	-11.1	- 8.9	- 8.1	- 8.0
	#4	61.1	76.0	71.9	66.2	62.3	-17.6	-13.9	-15.9	- 4.1	- 6.3	-13.5	-11.3	- 9.8	- 9.6
# 9	Barr.	78.5	80.0	78.1	80.0	78.1	---	---	---	---	---	---	---	---	---
	#1	63.4	74.6	69.8	68.1	63.3	-15.1	-11.9	-14:8	- 5.4	- 8.3	- 9.7	- 6.8	- 6.5	- 6.5
	#2	62.0	74.6	69.8	67.3	62.5	-16.5	-12.7	-15.6	- 5.4	- 8.3	-11.1	- 8.2	- 7.3	- 7.3
	#3	60.6	74.6	69.8	66.1	61.3	-17.9	-13.9	-16.8	- 5.4	- 8.3	-12.5	- 9.6	- 8.5	- 8.5
	#4	59.5	74.6	69.8	64.4	59.6	-19.0	-15.6	-18.5	- 5.4	- 8.3	-13.6	-10.7	-10.2	-10.2
#10	Barr.	77.2	78.7	75.9	78.7	75.9	---	---	---	---	---	---	---	---	---
	#1	66.7	75.2	70.6	69.9	65.2	-10.5	- 8.8	-10.7	- 3.5	- 5.3	- 7.0	- 5.2	- 5.3	- 5.4
	#2	62.0	75.2	70.6	68.7	64.1	-15.2	-10.0	-11.8	- 3.5	- 5.3	-11.7	- 9.9	- 6.5	- 6.5
	#3	59.6	75.2	70.6	6[illegible].1	62.5	-17.6	-11.6	-13.4	- 3.5	- 5.3	-14.1	-12.3	- 8.1	- 8.1
	#4	56.5	75.2	70.6	64.6	60.0	-20.7	-14.1	-15.9	- 3.5	- 5.3	-17.2	-15.4	-10.6	-10.6

Table 3 (continued)

Measured and Modeled L_{eq} with Synthesized and Modeled Insertion Losses

Meas. Site No.	Mike Locn.	L_{eq}					Drop-off			Dist. Effect		Barrier Effect			
		Meas.	Modeled				Meas.	Modeled		Modeled		Synthesized		Modeled	
			No-Barrier		With Barrier										
(1)	(2)	(3)	$\alpha=0$ (4)	$\alpha=.5$ (5)	$\alpha=0$ (6)	$\alpha=.5$ (7)	(8)	$\alpha=0$ (9)	$\alpha=.5$ (10)	$\alpha=0$ (11)	$\alpha=.5$ (12)	$\alpha=0$ (13)	$\alpha=.5$ (14)	$\alpha=0$ (15)	$\alpha=.5$ (16)
# 8	Barr.	73.3	75.1	71.2	75.1	71.2	---	---	---	---	---	---	---	---	---
	#1	63.7	73.2	68.2	69.4	63.9	- 9.6	- 5.7	- 7.3	- 1.9	- 3.0	- 7.7	- 6.6	- 3.8	- 4.3
	#2	---	73.2	68.2	66.4	61.0	---	- 8.7	-10.2	- 1.9	- 3.0	---	---	- 6.8	- 7.2
	#3	60.2	73.2	68.2	64.1	58.6	-12.5	-11.0	-12.6	- 1.9	- 3.0	-10.6	- 9.5	- 9.1	- 9.6
	#4	57.6	73.2	68.2	61.7	56.4	-15.7	-13.4	-14.8	- 1.9	- 3.0	-13.8	-12.7	-11.5	-11.8
# 7	Barr.	72.4	73.7	69.2	73.7	69.2	---	---	---	---	---	---	---	---	---
	#1	67.1	72.2	66.9	70.1	64.6	- 5.3	- 3.6	- 4.6	- 1.5	- 2.3	- 3.8	- 3.0	- 2.1	- 2.3
	#2	65.6	72.2	66.9	68.0	62.5	- 6.8	- 5.7	- 6.7	- 1.5	- 2.3	- 5.3	- 4.5	- 4.2	- 4.4
	#3	62.5	72.2	66.9	65.7	60.2	- 9.9	- 8.0	- 9.0	- 1.5	- 2.3	- 8.4	- 7.6	- 6.5	- 6.7
	#4	59.2	72.2	66.9	62.3	56.9	-13.2	-11.4	-12.3	- 1.5	- 2.3	-11.7	-10.9	- 9.9	-10.0
#17	Barr.	77.9	79.5	77.1	79.5	77.1	---	---	---	---	---	---	---	---	---
	#1	64.9	75.9	71.6	72.5	68.1	-13.0	- 7.0	- 9.0	- 3.6	- 5.5	- 9.4	- 7.5	- 3.4	- 3.5
	#2	---	75.9	71.6	69.9	65.6	---	- 9.6	-11.5	- 3.6	- 5.5	---	---	- 6.0	- 6.0
	#3	61.2	75.9	71.6	68.2	63.9	-16.7	-11.3	-13.2	- 3.6	- 5.5	-13.1	-11.2	- 7.7	- 7.7
	#4	59.1	75.9	71.6	66.2	61.9	-18.8	-13.3	-15.2	- 3.6	- 5.5	-15.2	-13.3	- 9.7	- 9.7

Microphone #4 is located 1.5 m (5 ft.) above ground.

6. The total modeled drop-off [9 and 10] attributed to the combined barrier and distance effects was determined using the modeled noise levels for the with-barrier condition [6 and 7].

7. The modeled distance effect [11 and 12] was determined using the modeled noise levels for the no-barrier condition [4 and 5].

8. The synthesized barrier effect [13 and 14] was determined using the measured drop-off [8] and the modeled distance effect [11 and 12].

9. The modeled barrier effect [15 and 16] was determined using the total modeled drop-off [9 and 10] and the modeled distance effect [11 and 12] so that it could be compared with the synthesized barrier effect [13 and 14].

Because the results are so sensitive to miscalculation of the distance effect, all of the above modeled levels were repeated using two sets of conditions. In one, characterized by $\alpha = 0$, the ground plane was assumed to be perfectly reflective. In the other, characterized by $\alpha = 0.5$, the ground plane was assumed to be partially absorptive. In all cases, the modeled levels of L_{eq} were calculated on a TI59 calculator using a program based on the "Free Field Calculation" of reference 5. As might be anticipated, the value used for α has little effect on the modeled insertion losses, whereas there is an appreciable effect on the synthesized insertion losses.

Using the synthesized insertion losses as the best approximation of the barriers' effectiveness, the secondary purpose of this study, to compare the actual barrier insertion losses against comments by residents who live near the barriers, was undertaken. The first step in this process was to determine the actual barrier insertion losses, which would be greatly simplified if it could be shown that the analytical methods available are reliable by comparing synthesized and modeled insertion losses. The last four columns of Table 3 provide such a comparison. Columns 13 and 14 show the synthesized, i.e., partially measured, values for what are presumably the extreme values for the ground absorptive values of α, thus the true value should lie between these two extremes. These can be compared with the modeled values in columns 15 and 16.

The following points can be made about the results of the study.

1. In all but two cases, the modeled insertion loss was less than the upper limit on the synthesized value, and in all but 6 cases, it was less than the lower limit on this value. Thus the method of modeling can be noted as being conservative.
2. For each of the 11 sites, the synthesized insertion loss decreased with height, as predicted, thus tending to show that the results were not erratic.

Comparison of Perceived, Synthesized, and Modeled Barrier Effectiveness

Table 4 was prepared to facilitate the comparison of the citizen's perception of barrier effectiveness with the synthesized and modeled barrier effectiveness. Data, factual information, and information founded on the opinion of the researcher after conversing with the citizen and observing his domicile and grounds are presented in this table. Some of the data and information presented has no psychological effect on the citizen's perception because the parameter described is not observed by the citizen. Then, it is suggested that other portions of the data and information have both a real influence on the barrier's effectiveness and an inferred psychological effect on the citizen's perception, while some of the information appears to have only a psychological effect.

The comparisons are best made in pairs of measurement sites per barrier, with the site at the home of the citizen having given a positive response being listed first. Here, correlation is used in the general sense of indicating a causal relationship. Since three types of factors affect both the performance of a barrier and the perception of that performance, it is understandable that finding a correlation between performance and perception is difficult. However, there are indications that certain of the factors have a strong effect on perception. Before the data and information for each pair of measurement sites are discussed, it is helpful to look at the anticipated effects of the various factors on the perceived usefulness of the barrier and on the actual effectiveness of the barrier.

Table 4

Data and Observations for Making Comparisons of Data with Perceptions

Site	Perception of Effectiveness	Height	Diff. in El. Top Of Barrier To			Barrier Topographic Siting	Horizontal Dist. Barrier To		Proximity Of Prop. To Right-Of-Way	Time Spent In Yard	Pre-Barrier Involvement With Barrier Site [View, etc.]	Δ Barrier #4 Microphone			
			Source	Receiver			Source	Receiver				Synthesized		Modeled	
				No. 4 Microphone	At House Door							α=0	α=0.5	α=0	α=0.5
14	Positive	20.6	- 6.1	-18.8	-19.7	Slight Embank.	57	70	Contiguous	Moderate	Very Little	-13.5	-11.9	-13.8	-13.8
13	Negative	10.0	- 3.5	- 3.0	+ 1.8	Top of Cut	95	58	Contiguous	Much	Much	-13.4	-12.6	- 7.4	- 7.4
15	Positive	7.4	- 0.4	-26.1	-24.3	High Embank. Plus Berm	54	158	Contiguous	Much	Very Little	-16.6	-13.8	-10.7	-10.6
16	Negative	4.8	- 6.3	- 7.4	- 3.5	Top of Deep Cut	85	120	Contiguous	Much	Very Little	-15.1	-13.4	- 8.3	- 8.3
12	Positive	16.5	-11.0	-14.2	- 9.5	Slight Cut and Berm	54	95	Separated	Moderate	Moderate	-13.3	-11.3	-13.2	-13.3
11	Negative	11.5	- 5.0	-10.6	- 6.1	Slight Cut and Berm	54	111	Separated	Moderate	Moderate	-13.5	-11.3	- 9.8	- 9.6
9	Positive	9.9	- 2.9	-16.9	-16.0	Moderate Embank. and Berm	54	178	Separated	Very Little	None	-13.6	-10.7	-10.2	-10.2
10	Negative	10.5	- 4.5	-14.5	- 8.0	Slight Embank. and Berm	87	127	Contiguous	Much	Much	-17.2	-15.4	-10.6	-10.6
8	Positive	11.3	-29.3 -14.3	- 7.7	- 6.8	Top of Very Deep Cut	134 600	95	Separated	Very Little	Little to Moderate	-13.8	-12.7	-11.5	-11.8
7	Negative	11.1	-32.6 -18.6	- 4.9	- 3.8	Top of Very Deep Cut	181 340	93	Separated	Much	Much	-11.7	-10.9	- 9.9	-10.0
17	Negative	10.1	- 2.6	-13.5	-12.1	Slight Embank. and Berm	68	110	Contiguous	Moderate	Moderate	-15.2	-13.3	- 9.7	- 9.7

Units in feet. 1 ft. = 0.3048 m.

Factor	Anticipated Perceptual Effect	Actual Effect
Height	Higher is better	Directly decreases noise
Difference in Elevation Top of Barrier to Source	Greater is better	Directly decreases noise
Difference in Elevation Top of Barrier to Receiver	Greater is better	Directly decreases noise
Topographic Siting	Is perceived as it affects the height of the barrier. Top of cut, shorter barrier	Affects height neede
Horizontal Distance Barrier to Source	No perceived effect	Complex, affects diffraction, shorter is better
Horizontal Distance Barrier to Receiver	Greater is better	Complex, affects position relative to shadow zone
Proximity to Right-of-Way	More distant, the better	Depends on other distance factors
Time Spent in Yard	Negative— living with barrier and noise, a constant reminder	None
Pre-Barrier Involvement with Barrier Site [View, Maintenance, etc.]	Negative— wall routine, the greater the more negative the effect	May decrease upkeep of area that had bee done prior to construction
Synthesized Barrier Insertion Loss	The smaller the difference, the more negative the effect	N.A.
Modeled Barrier Insertion Loss	The smaller the difference, the more negative the effect	N.A.

Table 5 has been prepared to aid in the analysis of the data and information presented in Table 4. Each data pair is considered as it correlates (C) or does not correlate (N) with the perceived effectiveness of the barrier. When there was no difference (ND) between the two bits in the pair, it was so noted, and no comparison between the data and the perception was attempted. The information for the first pair of barriers will be discussed in detail, then the extent to which there was a correlation for the other pairs of barriers will be noted. It was fortunate, with the data for measurement sites 14-13 placed first in the tables, that most of the bits in the pairs differed, because comparisons with the public perception could then be made. As the comparisons are made, it should be noted that only the vertical and horizontal distances from the barrier to the source and the barrier attenuation had no psychological impact on the perceived effect of the barriers.

Height

The height at measurement site 14 was 6.3 m (20.6 ft.) vs. 3.1 m (10 ft.) at site 13. With 3.2 m (10.6 ft.) more barrier, the positive response at site 14 is understandable. Similar correlations were elicited at sites 15, 16 and 12, 11 even though the differences in height were much less. The barriers at sites 9, 10 and 8, 7 were not different enough in height to invite comparison.

Difference in Elevation, Top of Barrier to Source

The height of truck stacks is 0.8 m (2.6 ft.) lower from the top of the barrier at site 14 than at site 13. With the greater attenuation of traffic noise that should be anticipated for the former site, the responses correlate with the values for the factor. Otherwise, responses with similar correlations occurred only at sites 12 and 11. As will be obvious when the next factor is considered, there was no correlation at sites 15 and 16 because the effect of the difference in elevation for the source at site 15 favoring a negative response was overridden by the effect of the other factors for that site. No correlation was found at sites 9 and 10 or 8 and 7 because of a strong personal bias held by the citizens, which will be discussed later.

Difference in Elevation from Top of Barrier to Receiver

This may be the most significant real factor that affects the response of citizens to noise barriers. At site 14 a 1.5 m (5 ft.) tall receiver was 5.7 m (18.8 ft.) below the

Table 5

Correlation of Factors Affecting Perception of and Actual Barrier Effect with the Perception of Effectiveness

Site	Perception of Barriers' Effectiveness	Height of Barrier	Diff. In El. Top Of Barrier To		Barrier Topographic Siting	Horizontal Dist. Barrier To		Proximity of Prop. to Right-of-Way	Time Spent In Yard	Pre-Barrier Involvement with Barrier Site [View, etc.]	Δ Barrier			
											#4 Microphone			
											Synthesized		Modeled	
			Source	Receiver		Source	Receiver				$\alpha = 0$	$\alpha = 0.5$	$\alpha = 0$	$\alpha = 0.5$
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
14	Pos.	C	C	C	C	C	C	ND	C	C	ND	ND	C	C
13	Neg.													
15	Pos.	C	N	C	C	C	C	ND	ND	ND	C	ND	C	C
16	Neg.													
12	Pos.	C	C	C	ND	ND	N	ND	ND	ND	ND	ND	C	C
11	Neg.													
9	Pos.	ND	N	C	ND	C	C	C	C	C	N	N	ND	ND
10	Neg.													
8	Pos.	ND	N	C	ND	C	ND	ND	C	C	C	C	C	C
7	Neg.													
17	Neg.													

C - Correlation N - No Correlation ND - No difference within a pair of data top of the barrier, while at site 13 the receiver was only 0.91 m (3.0 ft.) below the top. The responses correlate with the data. Although to a differing degree, there is a similar correlation for this factor at all the other sites.

In particular, at sites 15 and 16 there was a differential in this factor of 5.7 m (18.8 ft.) favoring a positive response for site 15. As was mentioned in the preceding discussion, it is possible for the effect of one factor to be overridden by the effect of the other factors involved. Thus, with the just mentioned differential of 5.7 m (18.8 ft.) favoring a positive response for site 15, it is easy to see how the differential of 1.8 m (5.9 ft.) for the difference in elevation from the top of the barrier to the source, which favors the opposite correlation, that is, a negative response for site 15, could be overridden.

Barrier Topographic Siting

This factor has both a real and psychological effect, but is not important very often in understanding responses, because it may frequently be the same for different sites behind the same or continuous barrier. At sites 14, 13 and 15, 16, this factor differed and in both situations the information correlated with the responses. The other sites did not have significant differences. It appears that the advantages of being at the top of a cut with the correspondingly shorter barrier are not easily perceived by the public. The negative response may be more of a reaction to the short barrier than to actually perceived poorer performance. However, being at the top of a cut may also mean that the barrier is farther from the source, which will be discussed next.

Horizontal Distance, Barrier to Source

The distance of the barrier from the source is a factor not easily perceived visually by the citizen. Within limits, the closer the source is to the barrier, the more benefit is derived during the diffraction of the noise over the barrier. Thus, closer is better. At site 14 the source was 17.4 m (57 ft.) from the barrier and at site 13 the source was 29 m (95 ft.) from the barrier because of the cut and an intervening ramp. These data correlate with the response, as do like data at the rest of the sites except at 12 and 11, where there was no difference to permit a comparison.

Horizontal Distance, Barrier to Receiver

This is another factor that has a rather complex real relationship to the diffraction of sound over the barrier, but also appears to have a psychological effect. Psychologically, the greater the distance, the better. While the data correlate with the response for sites 14 and 13, the difference in distance is not great, and the correlations at sites 15, 16 and 9, 10 are more easily understood. There was no correlation at sites 12 and 11 and not sufficient difference at sites 8 and 7 to make a comparison.

Proximity of Property to Right-of-Way

This factor seems to be primarily psychological, in that sharing the right-of-way fence with the Department gives the citizen a sense of being close to the Department's activities. However, like barrier topographic siting, this factor may not differ often enough for widely separated sites behind the same barrier to allow for comparisons. For four of the five pairs of sites, this factor did not differ. At sites 9 and 10 the factor differed and the information correlated with the perception.

Time Spent In Yard

When there was a known difference this factor correlated with the perception. No comparison was possible at sites 15 and 16 or 12 and 11. In the section "Difference in Elevation, Top of Barrier to Source," it was stated that the lack of a correlation would be discussed later. This factor and the one that follows illustrate how a strong personal bias can affect perception. At site 9 the dwellings are row or town houses that have virtually no space, other than parking, at the front of the dwelling facing I-495 that could be used for family activities. The activity area is in backyards or a somewhat isolated, park-like area that is protected by the rows of dwellings. At site 10, a single dwelling, the resident spends considerable time in the yard on upkeep and gardening and viewed the barrier as a considerable intrusion into his space. Similarly, the family at site 7 had three or four children, teenage and younger, and spent considerable time in the yard with family activities. The family at site 8 appears to spend considerable time indoors, or in the backyard with their house between them and I-495. The family at site 13 was more active out-of-doors than was the retired person at site 14, and this information correlated with the perception.

Pre-Barrier Involvement with the Barrier Site (view, etc.)

Some citizens, though they had no legal responsibility, maintained the land between their property and the interstate road. In some situations, the grass was cut, and in others trees were planted to form a screen between the citizen's property and the highway. The more involved the citizen was, the more he was aggravated by the barrier and the construction process. The information correlated with the perception when comparisons could be made (sites 14 and 13, 9 and 10, 8 and 7). In particular, the residents at sites 10 and 7 were strongly involved with the areas that were affected by construction. In both situations, the citizen put considerable effort into cutting the grass and generally maintaining the public land because its improved appearance enhanced the area in which he lived. Barrier construction greatly interferred with this process.

Synthesized Barrier Insertion Loss

Between no correlations and no differences this factor has the fewest correlations of any of the factors. Sites 8 and 7 show a correlation of the synthesized data with perception for both $\alpha = 0$ and $\alpha = 0.5$, while sites 15 and 16 show a correlation for only the $\alpha = 0$ values. No explanation of this phenomenon is known.

Modeled Barrier Insertion Loss

Though it could be argued whether the differences in this factor for most of the sites were discernible by the citizen, a value of -13.8 for site 14 and -7.4 for site 13 is a discernible difference and it correlates with perception. The data for all sites but 9 and 10 (no difference) correlate with perception.

Summary — Understanding Perception of Barriers

Eleven factors for five pairs of measurement sites were reviewed in the preceding paragraphs. These factors have both a real effect on the noise and a psychological effect on the person receiving the noise. No one factor can be used to explain why a person had a positive or negative reaction to the barrier. However, despite the admittedly small sample, it is thought that the combination of factors just discussed provides enough information that the analyst can understand why a citizen reacted to the barriers in the manner recorded.

Sites 14 and 13

The positive and negative responses to the barrier at sites 14 and 13 are not difficult to understand, in that all the comparable data and information compare favorably with the perceptions. Yet a negative response to a 3.1 m (10 ft.) high barrier makes one wonder. Knowing that the ground elevation rises away from the barrier such that **a** 1.5-m (5-ft.) receiver is only 0.9 m (3 ft.) below the elevation of the top of the barrier; that stepping up to the entrance to the kitchen would put the receiver at about the same elevation as the top of the barrier; and that the resident who owns the house is thirty-some years old, works the second shift, and thus spends many daylight hours at home improving the property explains the negative response to a 3.1 m (10 ft.) high barrier. The personal information on the resident at site 14 simply reinforces the physical data. The resident rents, is elderly, retired, and uses a cane, all of which leads one to believe she would be less active outside the house. In addition, she benefits from twice the height of barrier as the residents at site 13.

Sites 15 and 16

The positive and negative responses for the barrier at sites 15 and 16 are understandable, in that only one of the comparable bits of data did not compare favorably with the perceptions. This pair was for the difference in elevation between the top of the barrier and the source. Note that this factor is not expected to have any psychological effect. There was no difference in the factors that had only a psychological effect. The parents in three out of the four families involved were over fifty years old, the fourth were in their thirties, a swimming pool and a workshop were behind two of the houses, and a play area for children and a patio were behind the other two. All the people involved spent considerable time outside. The effect of the factor that did not correlate with the perception seems to have been overwhelmed by the effect of the factor that did correlate. Previously, in the discussion of the factors, it was mentioned that the difference in elevation between the top of the barrier and the receiver might be the most important real factor affecting the response of citizens to noise barriers. There was a differential in this factor of 5.7 m (18.8 ft.) between sites 15 and 16, and the horizontal distances between the barrier and the source and receiver also favored a positive reaction at site 15. In addition, at the site of the negative response (16) the 2.3 m (7.4 ft.) difference in elevation between the top of the barrier and the receiver was decreased if one walked up the steps to the entrance to the kitchen or up the grade to the level of the patio. The negative aspects of the real data for site 16 and an insignificant looking 1.46 m (4.8-ft.) barrier seem to explain the negative response.

Sites 12 and 11

The conditions for the barrier at sites 12 and 11 were so similar that only six of the eleven pairs of data and information could be used for comparison. The only pair that did not compare favorably with the perceptions was that for the horizontal distance from the barrier to the receiver. In all cases, the receiver was the microphone positioned 1.5 m (5 ft.) above ground level. When considering the psychological effect of factors, a 4.9 m (16 ft.) difference in horizontal distance is not particularly significant, especially when that difference is for the location of the microphone pole. For the two sites considered here, the front doors of the respective houses were approximately the same distance from the barrier. Thus, if the horizontal distances to the receiver for the pair of data are considered to be similar, then the relationship of the responses to this barrier is understandable, because the five pairs of data that are comparable compare favorably with the responses. Why a negative perception of an 3.5 m (11.5-ft.) barrier? There is a difference in elevation of 1.4 m (4.5 ft.) between the location of the microphone pole and the front door to the house at site 11. Thus the citizen's ear level is 1.9 m (6.1 ft.) below the elevation of the top of the barrier when he is standing at the front door. In addition, the citizen stated that the traffic on Leesville Blvd. was more noticeable and more annoying with the barrier in place.

Sites 9 and 10

The barrier at sites 9 and 10 had the lowest percentage (67%) of comparable pairs of data or information that compared favorably with the perception. Three pairs of data did not correlate with the perceptions. One pair, the difference in elevation between the top of the barrier and the source, is not thought of as being too important in that it did not correlate with perception 3 out of 5 times. The fact that it is not visually perceived by the citizen and thus has no psychological influence may explain its lack of importance. The other two pairs are the synthesized barrier insertion losses, which differ significantly, with the larger values being perceived negatively at site 10. That the citizen who received the greater benefit from the barrier reacted to it negatively is difficult to understand. However, the three factors that have a strong psychological effect do compare favorably with the perceptions. This citizen's property is adjacent to the right-of-way, he spends considerable time in the yard on maintenance and vegetable gardening, and has maintained public lands to enhance the appearance of his property. He was quite aggravated at the time of construction because of the abuse the area he tended suffered from the construction workers. Thus, it appears that the factors that had a strong psychological effect controlled the negative response at site 10.

Sites 8 and 7

For the barrier at sites 8 and 7, 8 out of 9 comparable factors correlated with the responses. The factor that did not correlate was the difference in elevation between the top of the barrier and the source. Thus, the relationship of the responses to the barrier are understandable. However, with a barrier of the same height and not much difference in several of the other physical factors, why the negative response? The differences in the barrier insertion losses, which correlate with the responses, were barely discernable. Thus, it is unlikely that those differences affected the negative response. As was stated in the discussion of the factors, the resident at site 7 spent considerable time in out-of-doors activities and was involved in the maintenance of the area in which the barrier was constructed. In addition, he did not want the barrier in the first place, because it would totally eliminate his view of the region to the north and east of his property.

Site 17

While the response to the barrier at site 17 cannot be discussed as a pair, it might be beneficial to discuss why the citizen's reaction to the barrier was negative. None of the values and information for the various factors were so inadequate as to explain the negative response. The respondent was a long-time resident of the area and the highway seems to have become a part of his life-style. As he mentioned during a telephone conversation, the respondent did not like being unable to see what was happening on I-495.

Public Perception

This study was not designed to be a survey of public perception. Nevertheless, it is impossible to meet the public without picking up considerable information concerning how the people feel about the Department and the activities pursued by the Department that affect them in some way. Contact was made with citizens to obtain permission to take noise measurements on their property and to purchase line current to provide electrical power for running the instrumentation in the van. Courtesy demanded that the authors spend some time with the citizens talking about noise barriers and the manner in which the Department dealt with the public concerning noise barriers. The preceding analysis made use of the attitudes observed and the comments heard to help explain the reaction of citizens to the noise barriers. The most frequently heard comments are listed below.

1. The area between the barriers and the right-of-way fence was not maintained. The grass was overgrown and weedy, thus the area was unsightly and a haven for vermin and snakes.

2. Areas that had been maintained by the citizens prior to construction of the barrier were left rutted and puddled (in worse condition than they were found), such that it was dangerous to run a lawn mower over them.

3. The multiplicity of colors for the steel barriers was disliked. Earth tone colors such as brown, dark green, or mauve were preferred to blue or light gray.

4. The barriers caused a loss of breeze that was especially noticeable in the summer.

5. The barriers interrupted the view of the terrain and of the traffic.

CONCLUSIONS

1. The noise barriers included in this study were effective. A synthesized insertion loss of over 10 decibels was achieved by all the barriers.

2. The standard methods of analysis by modeling yield results which tend to be conservative, in that they under predict losses determined by measurement, i.e. synthesis. As a result, barriers that are properly designed using the FHWA model have the required effect.

3. Because all the comparable values (8) for the modeled barrier insertion losses (10) correlated with the people's perception of the barriers, it is concluded that the FHWA model can be used to determine the effectiveness of barriers and, in conjunction with the analytical procedure used in this study, it might be used to focus on those sections of barrier that may be poorly received by the public for real, or psychological reasons, or both.

4. Based on the previous conclusions, it might be anticipated that the measured effectiveness of the barriers would correlate well with the public's perception of their effectiveness. However, only five of the pairs of data were sufficiently different to allow comparisons and only three of those pairs correlated with the perception. Thus, the measured values do not correlate well with perception, and no explanation for this fact is known.

5. The relationship of the pair of perceptions (positive or negative) for each barrier correlates quite well with the data that describe both the cross section between the source and receiver and certain aspects of the residents' life-style.

6. Because of the complex mix of factors that affect personal opinion, no one parameter of the barrier or characteristic of the citizen can be used to predict how or explain why a citizen reacts to the barrier the way he does.

7. Some negative factors mentioned by residents to the authors were:

    a. Lack of upkeep of area behind barriers.

    b. Overall appearance, especially color. Colors other than brown or dark green draw unfavorable comments.

    c. Trash, vermin, snakes, etc., in areas behind barriers which are not maintained.

    d. Loss of breeze in summer.

    e. Loss of view of terrain and traffic.

8. Some positive factors, other than noise reduction, were privacy and reduction of dust and fumes.

9. The perception of the barriers' effectiveness tended to be negative when the ear level of a person standing at the door of his house was much closer to the same elevation as the top of the barrier than was the ear level of the person who responded positively.

RECOMMENDATIONS

Based on the findings of this study and their correlation with the public perception of the effectiveness of noise barriers determined by the Perfater study,(2) the following recommendations are presented.

1. When doubt is cast on the effectiveness of a noise barrier by either the public or a member of the Department, it is recommended that the effectiveness should be verified by:
    a. Using the FHWA highway traffic noise model to model the insertion losses along the barrier at several different locations where both the physical parameters and the reactions to the barrier differ.
    b. Using the analytical procedure used in this study in an attempt to understand the reasons for positive and negative reactions.
    c. Taking noise measurements at several locations behind the barrier in proximity to the sites of positive and negative responses, only if the preceding steps have left some of the doubt unresolved.
2. Colors should be restricted to browns or greens, or traditional wall finishes such as concrete or brick.
3. Residents should be given long leases or rights of access to areas behind barriers, and should be encouraged to maintain these areas. It would probably be wise to selectively remove the right-of-way fences from behind properties that are contiguous with the right-of-way.
4. Contractors should be required to clean up areas behind barriers and to remove all debris created by construction.

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APPENDIX A

CROSS SECTIONS FOR MEASUREMENT SITES

In each figure:

1. All units are in feet. 1 ft. = 0.3048 m.
2. The relationship of the vertical to the horizontal scale is shown in the upper left corner.
3. A vertical scale is in the right half.
4. The base of the barrier is designated 0.0 elevation, with all the other elevations being referenced to it as either positive or negative.
5. The horizontal distances are from the middle of the four lanes (east- and westbound) to the barrier and from the microphone pole to the barrier.

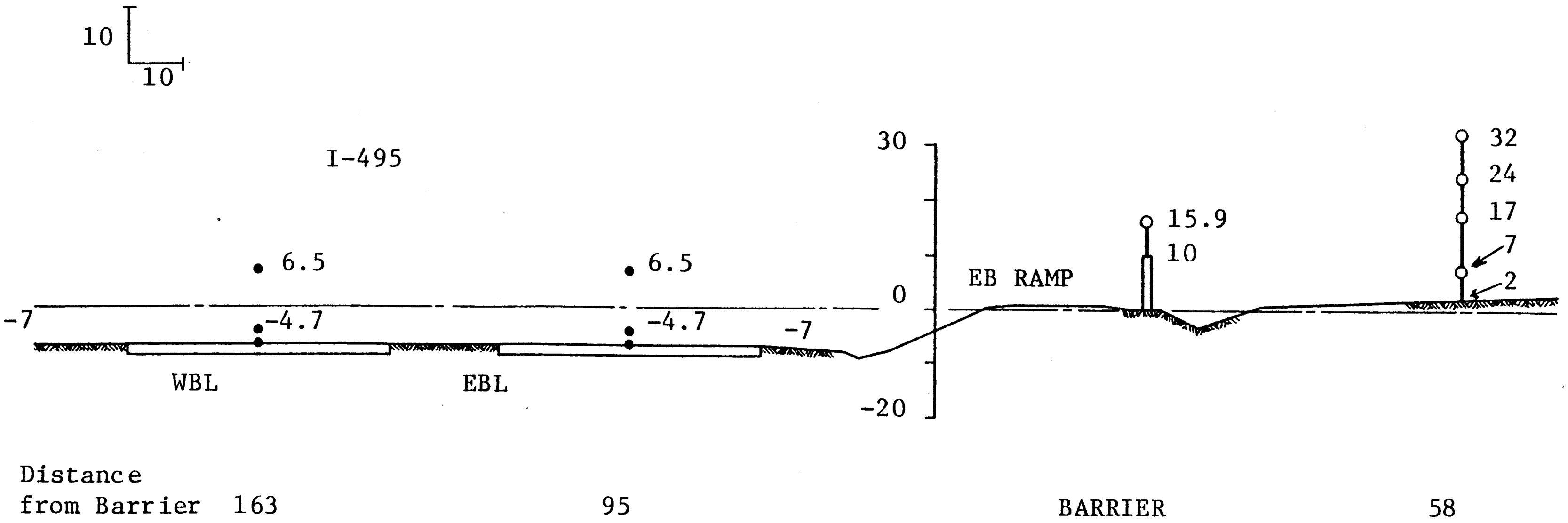

Figure A-1. Cross section with geometrical data for site 13.

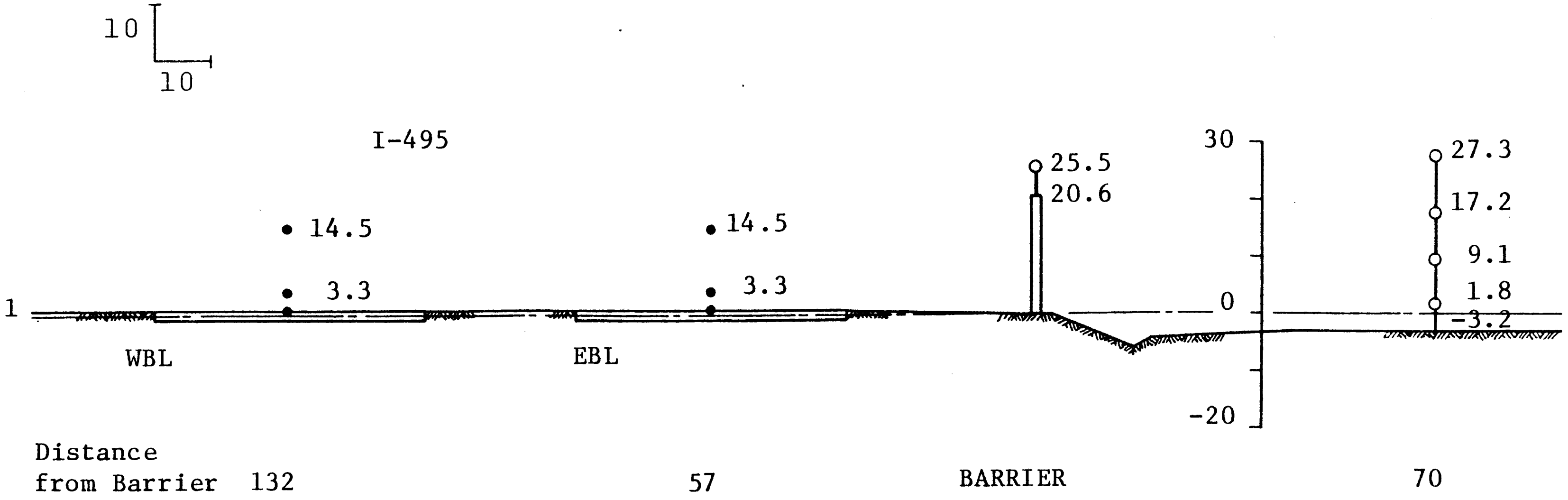

Figure A-2. Cross section with geometrical data for site 14.

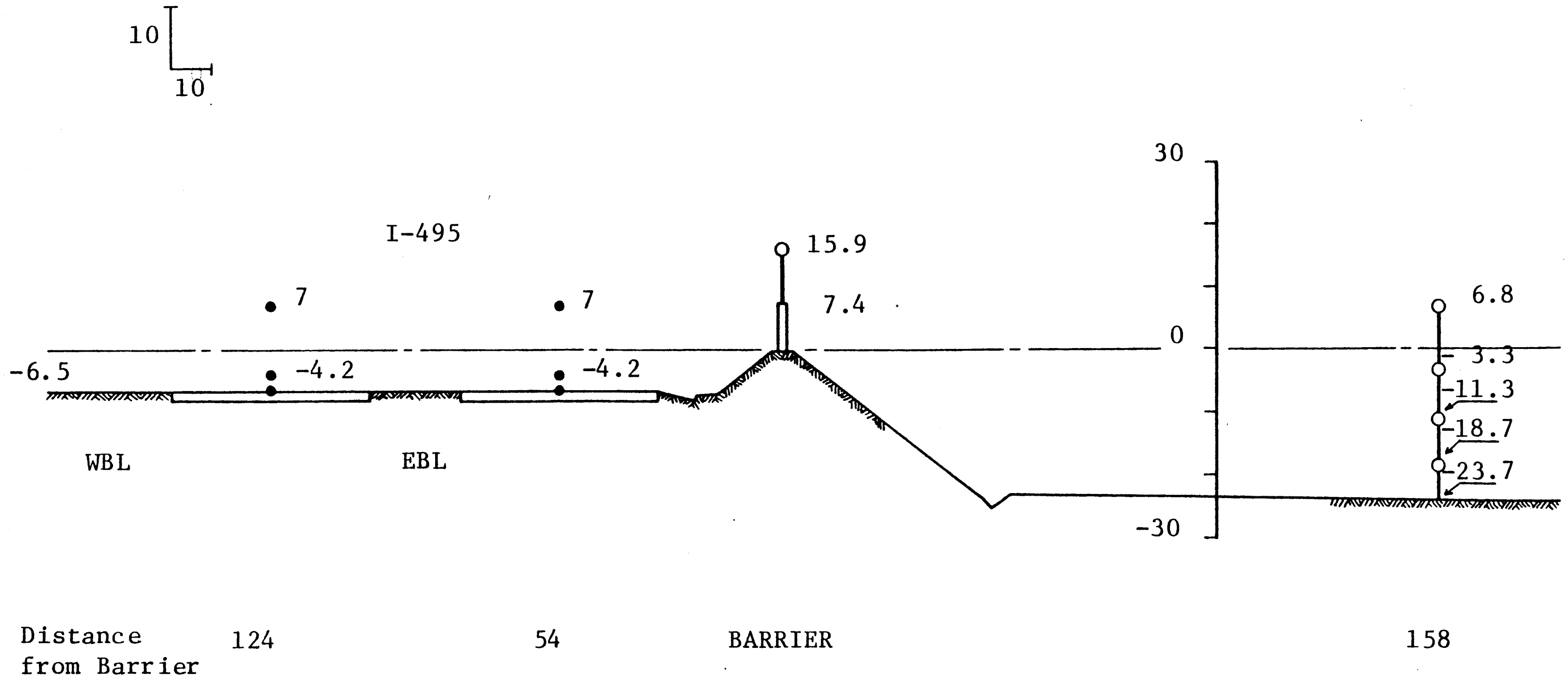

Figure A-3. Cross section with geometrical data for site 15.

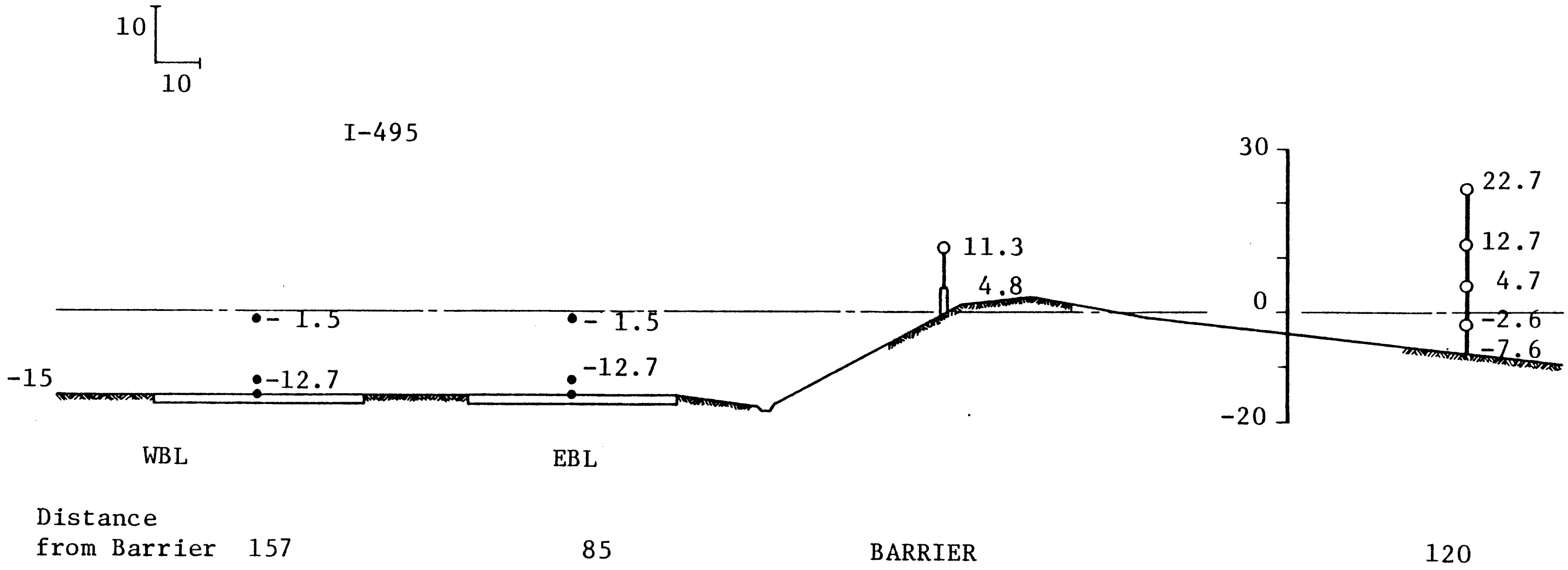

Figure A-4. Cross section with geometrical data for site 16.

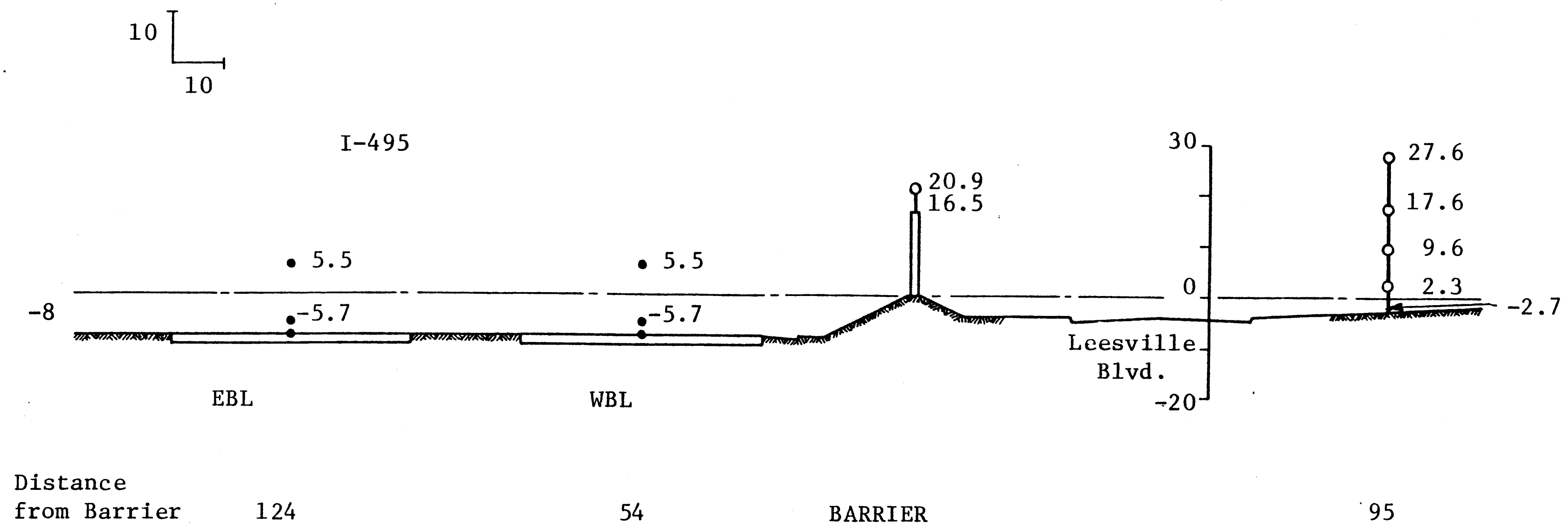

Figure A-5. Cross section with geometrical data for site 12.

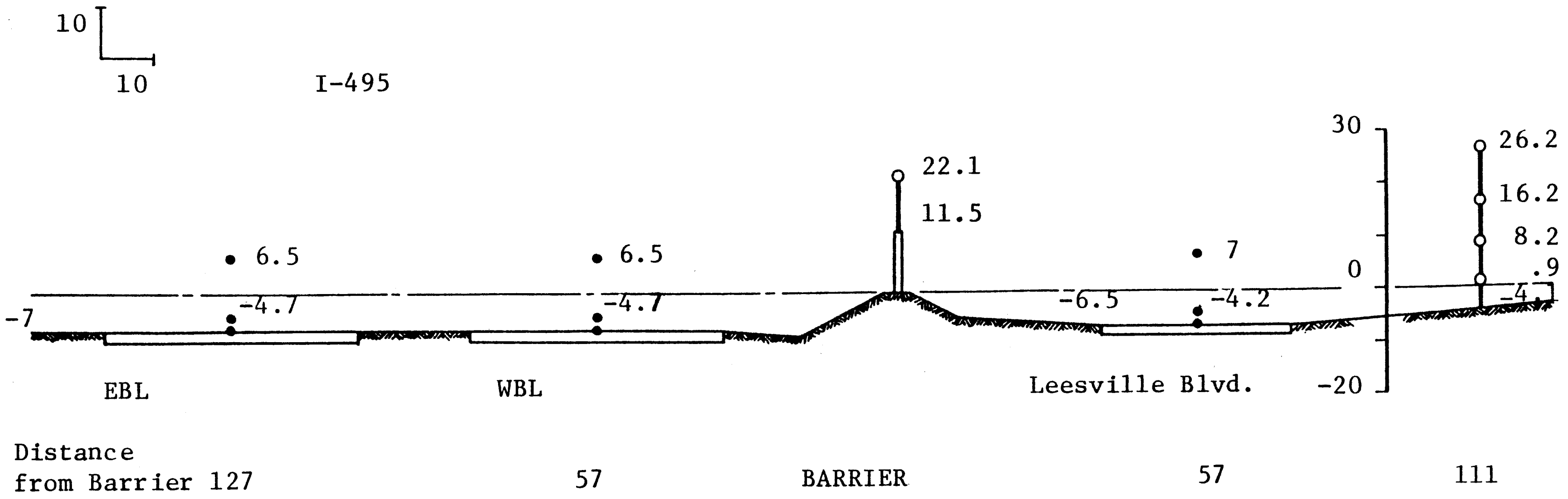

Figure A-6. Cross section with geometrical data for site 11.

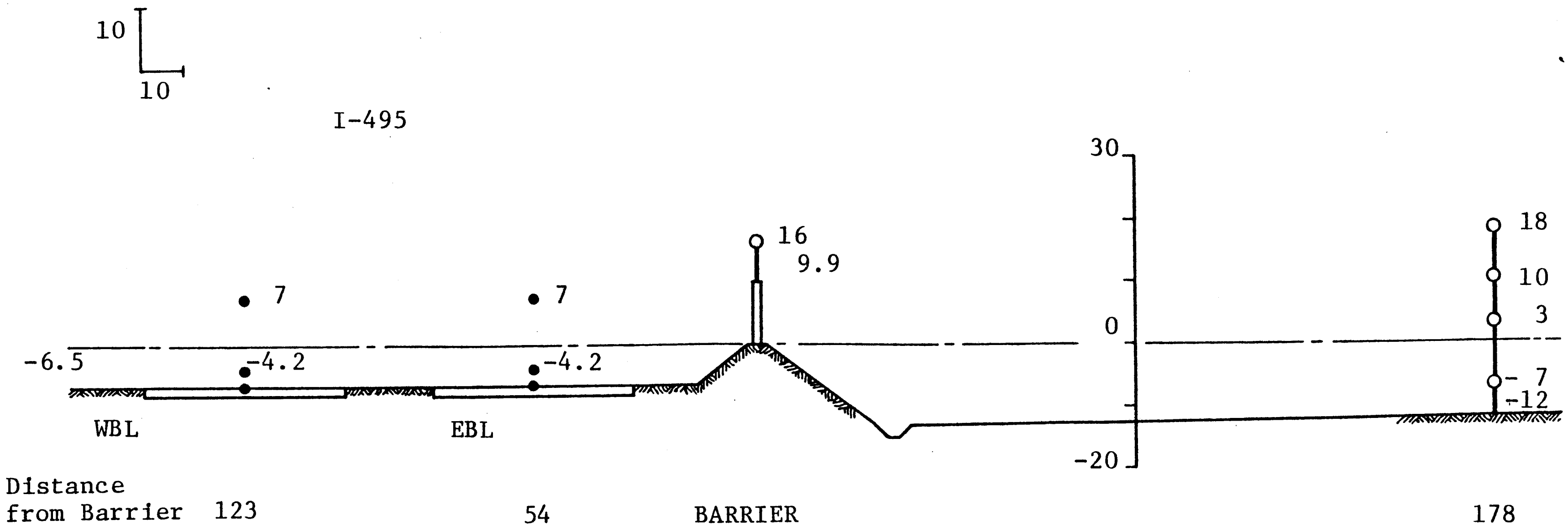

Figure A-7. Cross section with geometrical data from site 9.

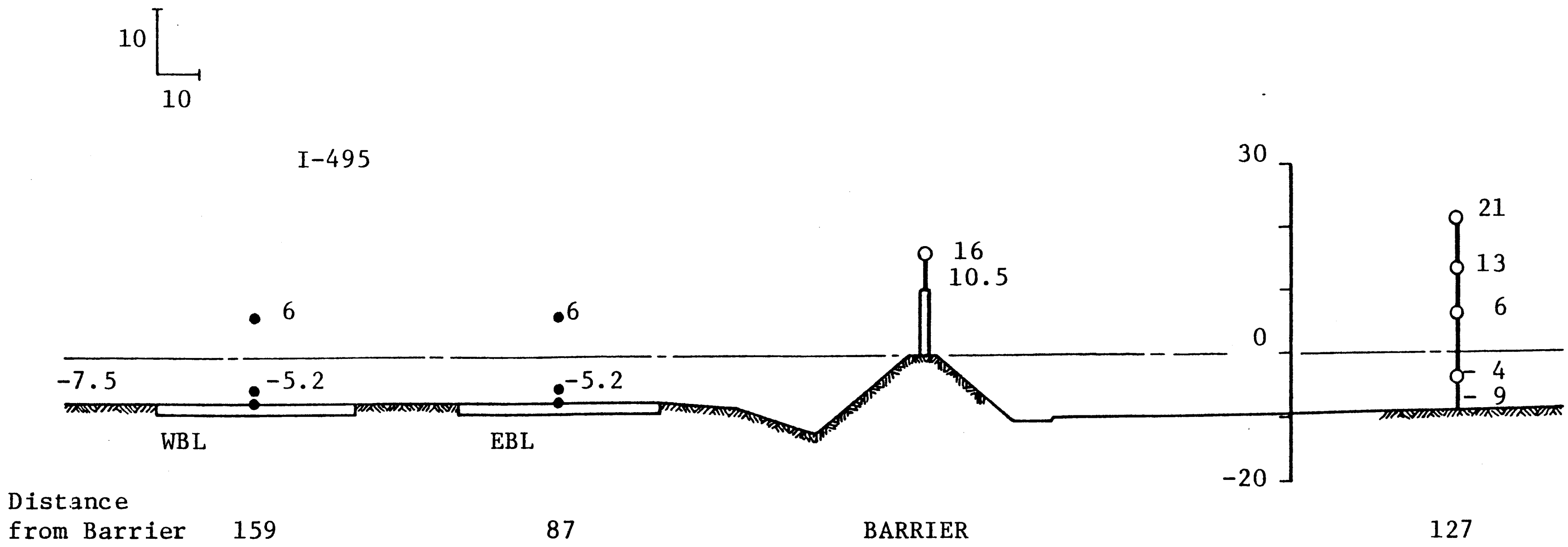

Figure A-8. Cross section with geometrical data for site 10.

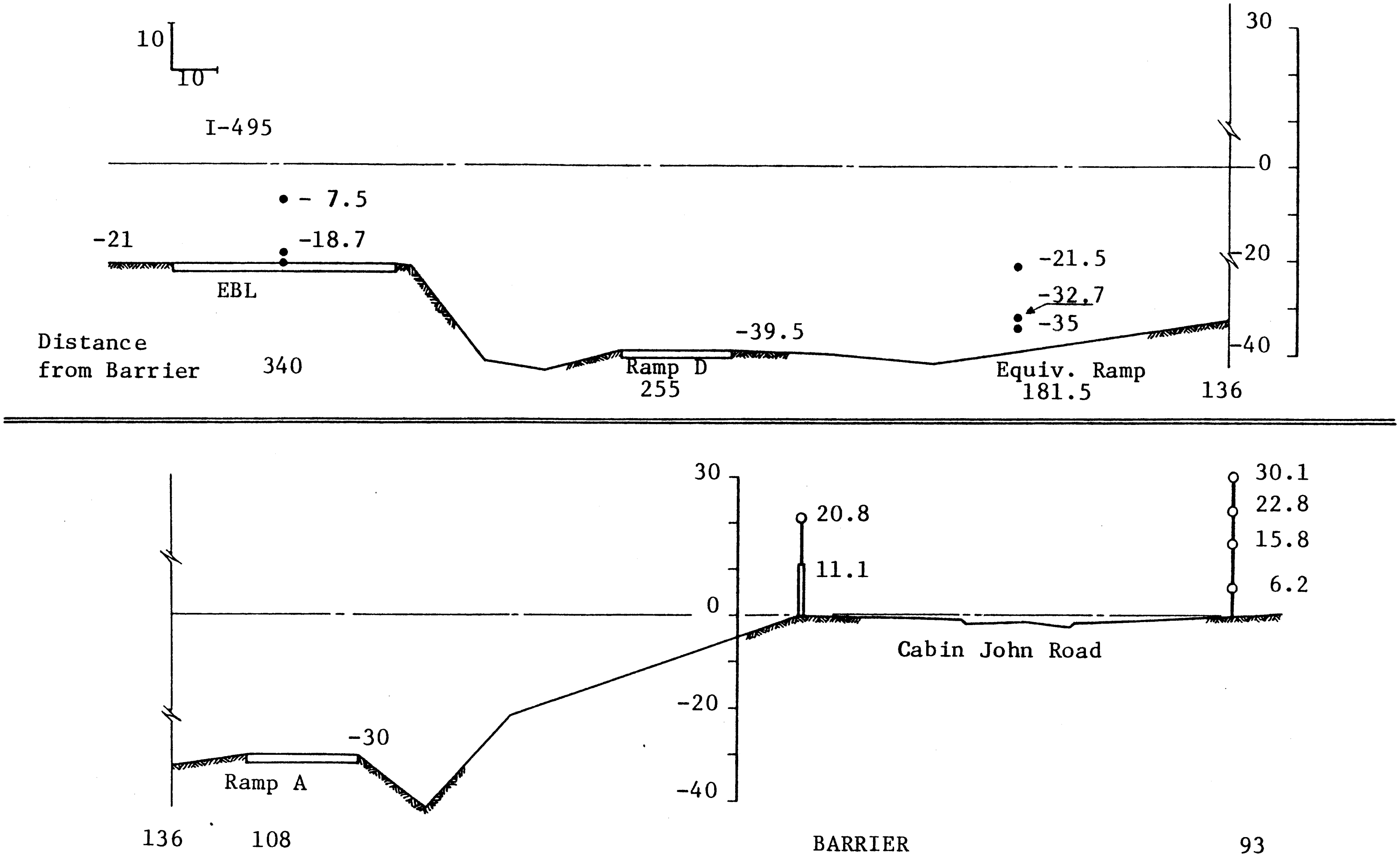

Figure A-9. Cross section with geometrical data for site 7.

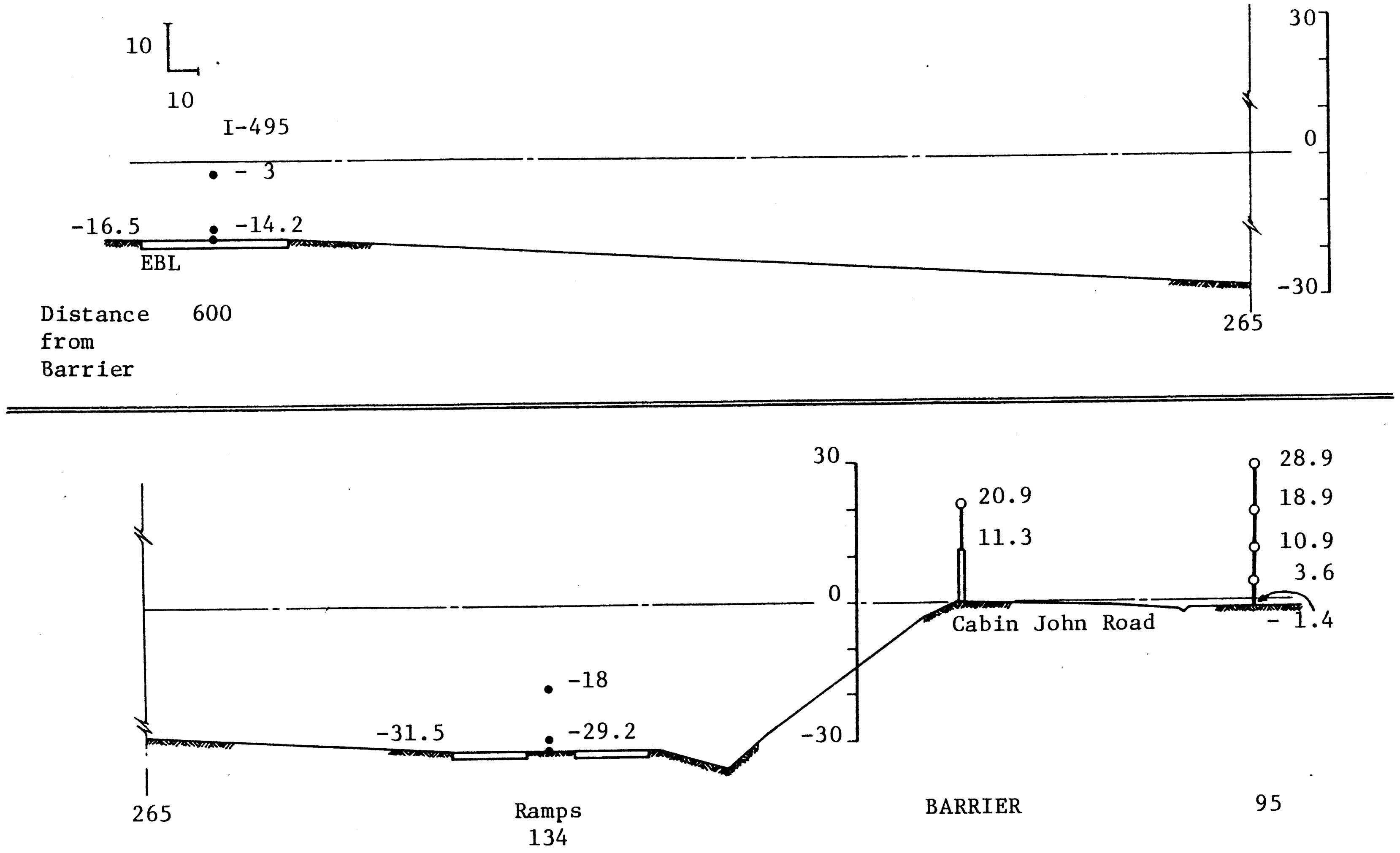

Figure A-10. Cross section with geometrical data for site 8.

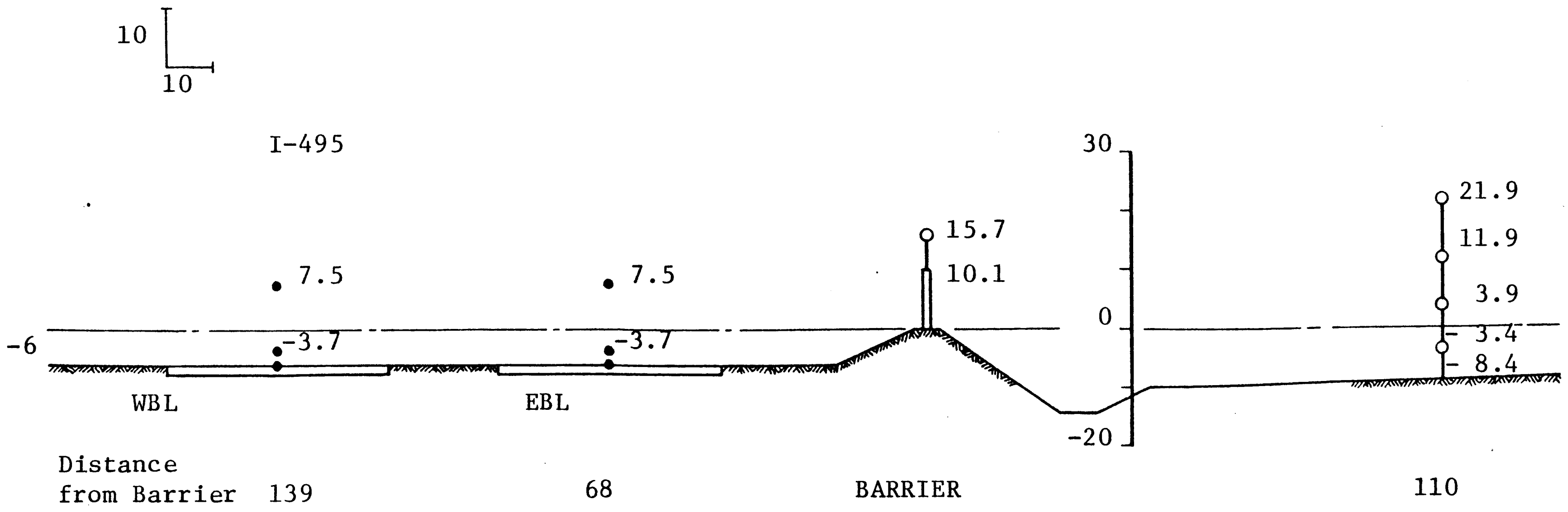

Figure A-11. Cross section with geometrical data for site 17.

APPENDIX B

DEFINITION OF TERMS

1. Barrier effect — The reduction in noise level in the community that can be attributed to the presence of the barrier.
2. Distance effect — The difference in noise level between two locations that is attributed to the distance between the locations.
3. Drop-off — The difference in noise level between two locations that may be attributed to a combination of parameters, such as the presence of a barrier, the ground effect, and the distance effect.
4. Insertion loss — The difference in noise level that can be attributed to the presence of the barrier; considered to be synonymous with "barrier effect".
5. Measured value — A value derived solely from measurements.
6. Modeled value — A value derived solely from the application of an algorithm representing an idealized model of the real system.
7. Synthesized value — A value obtained by synthesizing measured and modeled values, typically when such a value cannot be obtained solely by measurements.