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THE EFFECT OF TREES ON NOISE BARRIER PERFORMANCE

by

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16. Abstract

This study investigated the possibility that trees adjacent to a noise barrier and higher than its top would scatter traffic noise and increase the level on the receiver side of the barrier. Two lines of microphones were set up perpendicular to the noise barrier on I-287 in Morristown, New Jersey. One set was at a wooded site and the other at a clear site, 500 feet downstream. Each group of microphones comprised a reference microphone, 5 feet above the barrier top, and two field microphones at 25 and 50 feet behind the barrier. Traffic noise from the same traffic stream was recorded, with a 5-second delay in starting the downstream recording to compensate for the distance between sites. Recording was done for both full-foliage and no-foliage conditions. Analysis of the LeqA data for the full-foliage condition showed that levels at the wooded site were from .9dB to 2.7dB higher than those at the clear site. A similar analysis of the no-foliage data was inconclusive. It showed either no difference between the clear and wooded sites, or that levels at the wooded site were higher by 0.9dB to 1.6dB, depending upon the analytical methods used. Analysis of selected frequencies from 1/3-octave band data for the full-foliage condition indicated that for frequencies up to 1000 HZ, the trees attenuated rather than scattered sound in most cases, and that major increases in levels at the wooded site occurred in the 4000 - 10,000 Hz range.

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TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

PAGE NUMBERS

SUMMARY AND CONCLUSIONS

Summary

This study investigated the possibility that trees adjacent to a noise barrier and higher than its top would scatter traffic noise and increase the level on the receiver side of the barrier. To determine this microphones were set up on a clear and a wooded site, adjacent to each other behind the traffic noise barrier on I-287 southbound in Hanover Township, N. J. Traffic noise was recorded for both the no-foliage and the full-foliage conditions in order to find out if the trunks, limbs, and bare branches as well as leaves caused scattering. The recording operation was broken into two-minute increments, so that 22 observations were recorded on each 45-minute tape. Details of the microphone placement and the data collection operation can be found in the Data Collection section and in Appendix I, page 29.

Reduction of the field data yielded a set of two-minute LeqAs for each microphone position. In addition, the full-foliage data was reduced to obtain 1/3-octave levels.

Data analysis was essentially a comparison of the Leqs from the wooded site with the corresponding Leqs from the clear site, for each foliage condition. These comparisons were made statistically, between data sets from corresponding microphones at each site. Because of the unusual barrier configuration (Figure 1, page 8), adjustments had to be made to the clear site data in order to bring each data point to the level it

would have been had the barrier been continuous. The details of this procedure are in the Data Analysis and RESULTS AND DISCUSSION sections.

Conclusions

Two conclusions resulted from the data analysis. The first was that the analysis of the Leq data showed that there were definitely higher noise levels at the wooded site than at the clear site, during the full-foliage condition. These levels ranged from 0.6dB to 2.9dB (taking into account the 95% confidence limits), depending upon microphone position. Table IV, page 18, shows the differences and confidence limits for each position.

It should not be inferred that the higher levels at the wooded site were due solely to scattering, however. The LeqLin levels for selected frequencies from the 1/3-octave data were analyzed to obtain further information on the source of these higher levels. This analysis indicated that the lower frequencies were attenuated by the trees, for the most part, and that the highest levels at the wooded site were for frequencies in the 4000 - 10,000 Hz range. However, the microphone which should have the greatest effect from the foliage showed the least effect, implying that factors other than scattering or attenuation were present.

The second conclusion was that the results of the analysis of the no-foliage data were indeterminate, since they varied with the analytical approach. For one method the results imply that the levels at both the clear and wooded sites are the same; for another method they imply that the levels are higher at the wooded site. In the latter case the increases ranged from 0.0dB to 2.1dB, depending upon the microphone position and taking into account the confidence limits. The differences and confidence limits determined by the second method are shown in Table V, page 22.

RECOMMENDATIONS

Although the higher levels of certain frequencies found at the wooded sites are substantial, the higher overall median levels found at the wooded site are low enough to be considered insignificant in terms human perception of traffic noise. It is therefore recommended that the Department not remove trees adjacent to existing barriers, or consider removing them prior to constructing new barriers, except as required for construction or safety considerations. In addition, the Department's present policy of planting trees adjacent to barriers as part of the landscape program should be continued.

By retaining existing trees and planting new ones, the Department will provide a more esthetically acceptable environment for those people whose properties adjoin barriers and for motorists. In this regard it is recommended that public comments in Appendix IV of the report Public Response to Noise Barriers be reviewed.

The Department must also give due consideration to any adverse effect on drainage, erosion, etc. that might occur if trees are removed.

None of the conclusions, recommendations, results, or discussion in this report should be applied to non-deciduous trees.

IMPLEMENTATION

A summary of project activities and findings will be sent to the Bureau of Environmental Analysis. This summary will include a brief discussion of the results and the recommendations that 1) trees not be removed from existing barriers, and 2) trees not be removed for new barrier construction except where necessary for construction or safety requirements.

INTRODUCTION

The primary objective of this study was to determine whether or not traffic noise is transferred over the top of a noise barrier by trees which are adjacent to the barrier and higher than its top. This objective applied to both the foliage and to the limbs and trunk, and therefore data collection took place during both the full-foliage and no-foliage conditions. A secondary objective was to ascertain what portion of the noise on the receiver side of the barrier was due to this scattering effect, if it could be shown that it existed.

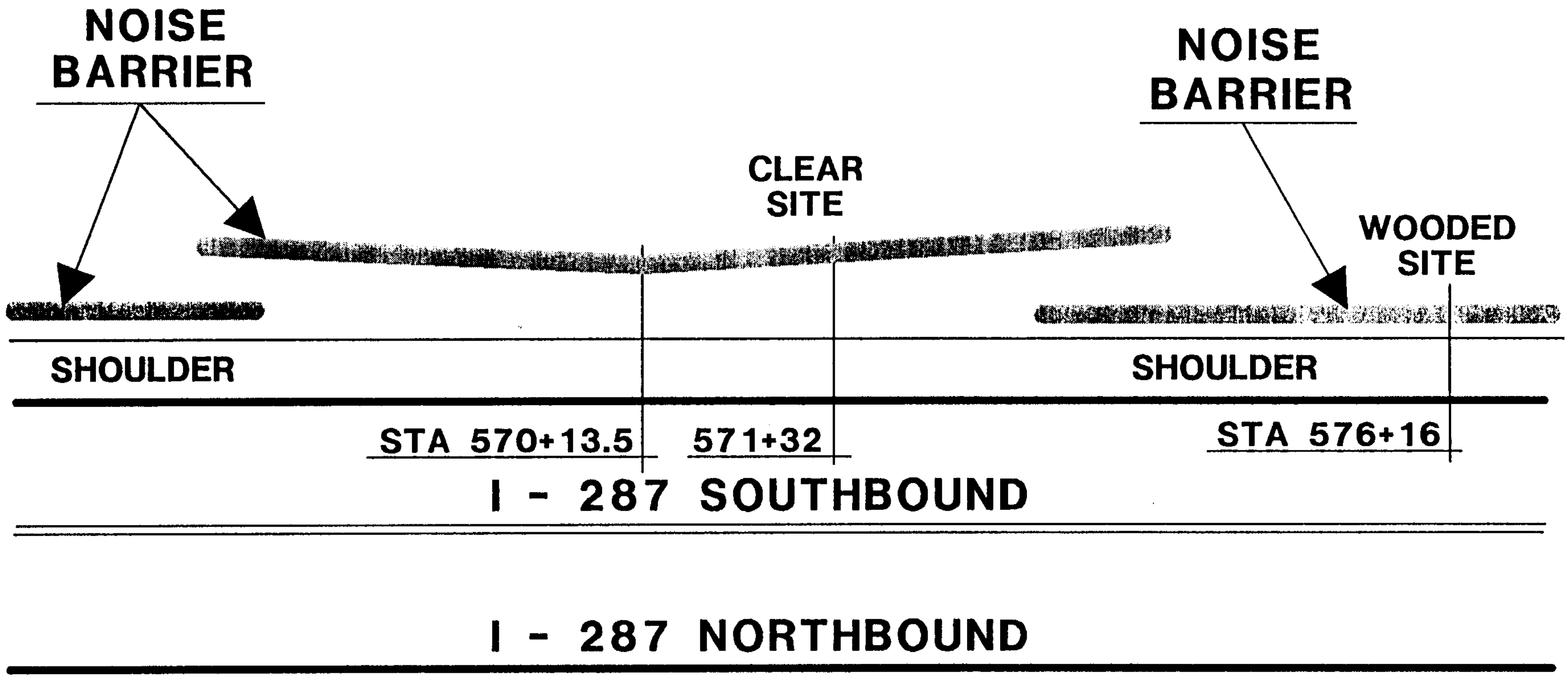
A literature search was started before the actual data collection and continued well into the project, but there was very little information available. What there was did not provide substantive experimental results which could be used to either support or contradict the concept of scattering.

Data collection site requirements were unusual in that traffic noise barriers are usually placed to protect urban and suburban areas of various types, few of which have stands of trees dense enough to qualify them as test sites. Furthermore, it is unusual to find large trees on the roadway side of the barrier. Last, the trees had to be deciduous, so that we could study the effects of the trunks and limbs during a no-foliage period.

The only satisfactory site available was adjacent to I-287 southbound in Hanover Township, Morris County where a clear and a wooded site were situated next to each other immediately behind the barrier. The clear site was completely on private property; the wooded site was continuous from the DOT right of way behind to barrier onto private property beyond the ROW fence. Permission was obtained from the property owners to set up microphones for data collection, which began on April 11, 1988.

The barrier at this site is unusual. Although it is a standard concrete post-and-panel structure feet high, it is not continuous because of the need to get behind it to maintain culverts, headwalls, and ditches which are part of the highway drainage system. The barrier therefore consists of three overlapping sections, as shown in Figure 1, page 8. The effect of this design on the noise levels is discussed in the section RESULTS AND DISCUSSION, which begins on page 17.

FIGURE 1
BARRIER CONFIGURATION



NOT TO SCALE

STUDY METHODS

Data Collection

Traffic noise was recorded from two lines of microphones about 500 feet apart, placed perpendicular to the highway. There were three microphones in each line: a reference microphone placed 5 feet above the center of the barrier top; two field microphones at 25 feet from the barrier and 5 feet above the ground; a second pair of field microphones at 50 feet from the barrier, also at 5 feet above the ground. A second set of measurements was made with the field microphones at 12 feet above the ground. Data collection took place during full-foliage and no-foliage periods. The was a 5 second delay between the start of the upstream and downstream recorders in order to insure as nearly as possible that the same traffic was passing both data collection sites.

All noise observations were 2 minutes long, during which a complete traffic count was kept by vehicle type, for both northbound and southbound roadways. At least 5 radar speed readings of nearside traffic were recorded during each noise observation. Wind speed and direction, and ambient temperature were recorded at various times, but especially at the beginning and end of each tape. No data collection took place during periods of precipitation or fog, when the roadway was not dry and clear, when traffic speed was obviously below normal, or when the wind was over 10 mph.

FIGURE 2
MICROPHONE POSITIONS

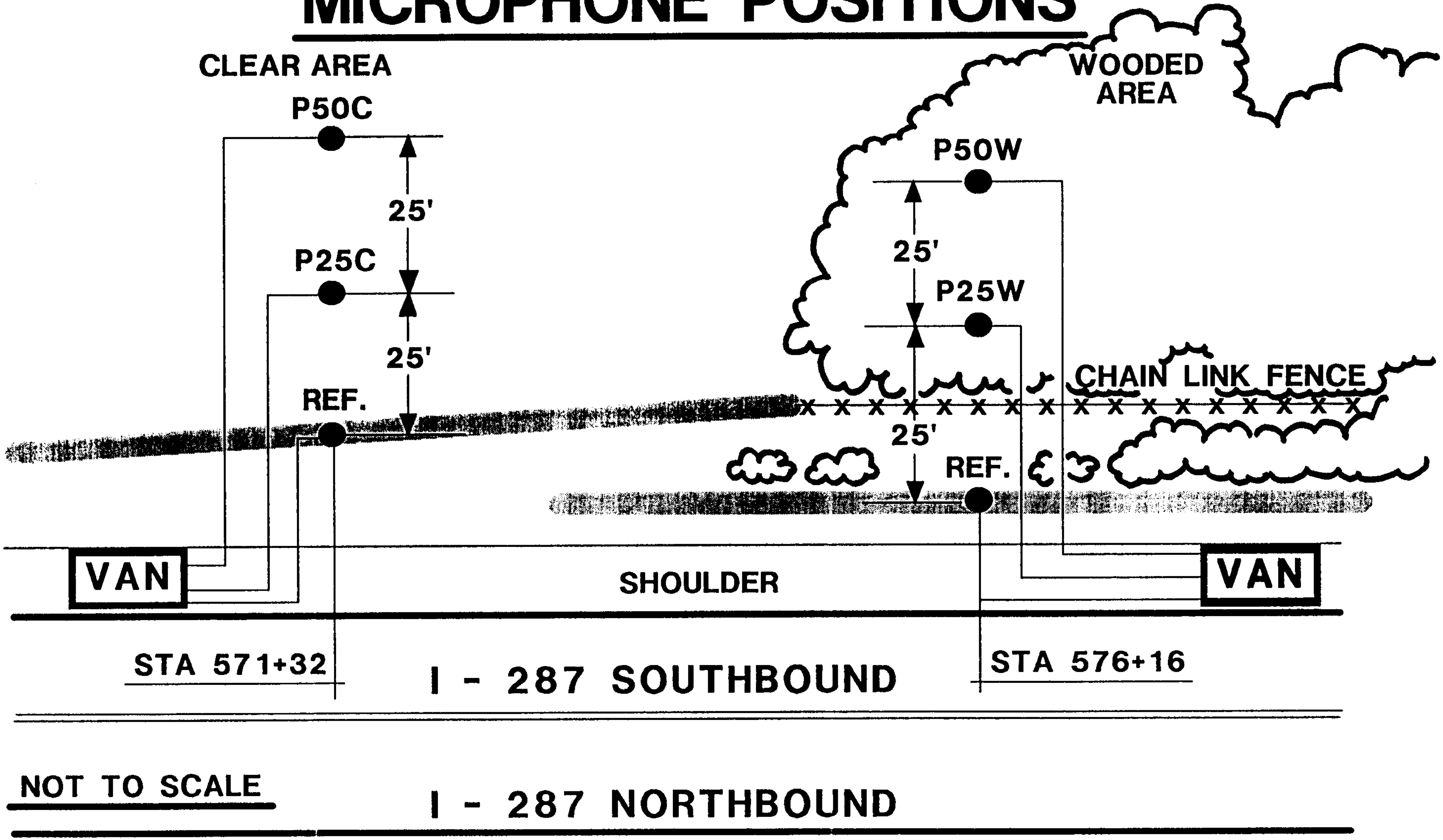


Figure 2, page 10, shows the site locations and the microphone placement. Appendix I, page 29, details the data collection procedure, and Appendix XI, page 52, lists the major items of equipment used in data collection.

Data Reduction

Data reduction served three purposes. The first was to verify that each observation included in the data set for analysis did not contain any noise from non-highway sources. Those that did were discarded and not used in the analysis. The second purpose was to obtain an LeqA for each usable observation, and the third was to determine the frequency content of each of these observations, for the full-foliage condition. The frequency content was to be analyzed if the analysis of the Leq data indicated that there might be scattering. It was thought that this would yield information on which frequencies were most susceptible to scattering under the full-foliage condition.

Sample sizes resulting from data reduction of the two data types are shown in Tables I, II, and III, pages 12 and 13. A detailed description of the data reduction process, and a diagram of the equipment setup is in Appendix II, page 35. The LeqA data reduction results are included in Appendices III - VI, pages 39-43. Those for the LeqLin data were not included.

In addition to the reduction of the noise observations, the radar speed readings taken during each observation were averaged to obtain the nearside traffic speed for each of the usable noise observations. The traffic counts and speeds can be found in Appendices VII - X, pages 46 -50.

TABLE I

NUMBER OF TWO-MINUTE OBSERVATIONS FROM DATA REDUCTION

LeqA - FIVE AND TWELVE-FOOT MICROPHONE HEIGHTS

	Ref.-5'	P25-5'	P50-5'	Ref.-12'	P25-12'	P50-12'
Clear	69	69	70	68	57	60
Wooded:Foliage	62	56	61	70	68	71
Clear	20	20	20	23	23	23
Wooded:No Foliage	20	20	20	23	24	24

Ref: Reference position; P25, P50: 25-foot and 50-foot positions.

TABLE II

NUMBER OF TWO-MINUTE OBSERVATIONS FROM DATA REDUCTION

LeqLin - FIVE-FOOT MICROPHONE HEIGHT

Frequency Hz	RefC	P25C	P50C	RefW	P25W	P50W
125	36	36	36	29	28	26
250	36	36	36	29	28	26
500	36	36	36	29	28	26
1000	36	36	36	29	28	26
2000	36	36	36	29	28	26
4000	36	36	36	29	28	26
8000	36	36	36	29	28	26
10,000	36	36	36	29	28	26
12,500	36	36	36	29	28	26

C: Clear site W: Wooded site; Ref: Reference position; P25, P50: 25-foot and 50-foot positions.

TABLE III

NUMBER OF TWO-MINUTE OBSERVATIONS FROM DATA REDUCTION

LeqLin - TWELVE-FOOT MICROPHONE HEIGHT

Frequency Hz	RefC	P25C	P50C	RefW	P25W	P50W
125	19	19	18	35	33	34
250	19	19	18	35	33	34
500	19	19	18	35	33	34
1000	19	19	18	35	33	34
2000	19	19	18	35	33	34
4000	19	19	18	35	33	34
8000	19	19	18	35	33	34
10,000	19	19	18	35	33	34
12,500	19	19	18	35	33	34

C: Clear site; W: Wooded site; Ref: Reference position; P25, P50: 25-foot and 50-foot positions.

Data Analysis

Data analysis for the LeqA data was carried out in two major parts, one for the no-foliage condition and the other for the full-foliage condition. The purpose was straightforward in both cases in that we sought to determine if there was difference in the particular data populations between the clear site and the wooded site, under each condition. This was carried out on a microphone-by-microphone basis. That is, comparisons were made between corresponding field microphones at the two sites: P25-5' Wooded:No Foliage vs. P25-5' Clear:No Foliage, etc.

In practice data analysis was rather involved and comprised the steps listed below, for the 2-minute LeqA data.

1. It was first necessary to determine if the reference microphone data sets from the clear and wooded sites were from the same population, for each foliage condition. The Wilcoxon rank sum test was used for this, since not all of the data sets were normally distributed. This first step in the analysis showed that neither pair of reference microphone data sets (no-foliage - clear; full-foliage - clear) was from the same population at the 95% confidence level.

2. Since the traffic passing the reference microphones was the same at both the clear and wooded sites, the differences in data must have been a result of the unusual barrier configuration (Figure 1, page 8). It was therefore necessary to adjust the reference data from the

clear site, which had lower levels than the wooded site, by an amount which would make the adjusted clear site reference data from the same population as the wooded site reference data. This, in effect, yielded reference data from the clear site which would have been obtained from field measurements had the barrier been continuous and the same distance from the near lane throughout its length.

3. The next step was to determine the relationship between the clear site reference data and the clear site field microphone data, for all four field microphone (2 - 5 ft.; 2 - 12 ft.), for both no-foliage and full-foliage conditions. Of the eight relationships, four were linear, two quadratic, and two exponential.

4. The adjusted reference data from the clear site was used in each relationship to obtain an "adjusted" set of data for each of the field microphones under each foliage condition. As with the reference microphone data, the "adjusted" data set from each field microphone was essentially what would have been measured if the barrier had been continuous.

5. The "adjusted" sets from field microphones at the clear site were compared to the comparable data sets from the field microphones at the wooded site, again by the Wilcoxon rank sum test at the 95% confidence level.

6. In those cases where the data sets from corresponding clear and wooded microphones were not from the same population, 95% confidence limits were obtained for the differences using a method associated with the Wilcoxon test.

As previously noted, the frequency content of each observation was obtained during the data reduction process. The analysis of 1/3-octave LeqLin data was basically the same as described above, except that Step 3 was simplified by assuming a linear relationship between the reference data and the each of the field microphone data sets. Step 6 was also eliminated for these data sets. Details of the data analysis are discussed fully in the following section, RESULTS AND DISCUSSION.

RESULTS AND DISCUSSION

Unusual emphasis on precision was placed on determining the most accurate relationship between the reference and field microphones at the clear site. There were a number of reasons for this. First, in the course of analyzing data for previous noise barrier studies it had been found that the relationship between the reference and field microphone data was often non-linear. (This information was not included in reports of these projects since adjustments of the type necessary for this study were not required.) Second, when Stamina 2.0 was used to determine the adjustments between the reference data from the two sites, the results were grossly different from the field measurements, so it certainly could not be applied to find the adjustments to the field microphone data. Third, the literature provided no guidance. Fourth, while changes of .1 or .2 dB are virtually meaningless in discerning changes in traffic noise levels, they are most meaningful in carrying out the statistical analyses necessary to determine if there was a difference in the overall levels at the two sites. Last, the results of testing for homogeneity were the main criteria upon which the conclusions and recommendations were based. It was therefore necessary to as accurate as reasonably possible to provide a firm foundation for these statements.

The results of the LeqA data analysis for the full-foliage condition clearly show higher levels at the wooded site, for all four field microphone positions. The median differences between the data sets from corresponding microphones reported in Table IV are the results of Steps 3 and 4 of the Data Analysis (see page 15). In each case the differences between the adjusted data from the clear site and the data from the wooded site were so great that the two sets of data tested as being from different populations.

TABLE IV

MEDIAN DIFFERENCES BETWEEN CLEAR AND WOODED SITES

FOR TWO-MINUTE LeqA DATA - FULL FOLIAGE

Microphone Position	Difference (dB)	95% Conf. Limits (dB)
P25 - 5 ft.	2.7	+0.2, -0.3
P50 - 5 ft.	1.3	+0.3, -0.4
P25 - 12 ft.	0.9	+0.3, -0.3
P50 - 12 ft.	1.5	+0.3, -0.3

With the possible exception of the P25 - 5 ft. position, it is unlikely that the slight increases in overall levels which caused the medians at the wooded sight to be higher would be discernible to most people. The usual accepted minimum change considered to be discernible is 3 dB.

In examining these results it should be kept in mind that leaves will produce a pronounced rustling noise even at low wind speeds. Therefore it is possible that some portion of the higher levels at the wooded site (full foliage) are due to the leaves themselves, rather than being completely a result of scattering. Thus the fact that no data collection took place unless the wind speed was 10 mph or less (with the no precipitation or fog, roadway dry and clear, normal traffic speed) did not preclude this possibility.

At wind speeds greater than 10 mph the noise generated by the wind in the trees may well serve to partially mask highway noise, especially if the direction is toward the highway. In this case the trees provide would protection, assuming that people would prefer the wind noise to the traffic noise.

In contrast, data analysis for the no-foliage condition yielded inconclusive results. The method of least squares was used to determine the relationships between the clear site reference and field microphones (Step 3, page 15). This technique yields the best fit (as indicated by the sum of squares) for the particular form of equation chosen, but the form itself may not provide the best fit of all possible forms. Therefore it is necessary to select and test other forms of relationships (within reason) to determine if there is one which has a sum of squares smaller than those from other relationships. In this instance linear, quadratic, and exponential forms were tested.

An an example, for P25 - 12 ft. the best fit relationship was

$$P25 = A \times REF^2 + B \times REF + C,$$

which yielded a sum of squares of 8.9. However, the when the relationship was used to "adjust" the clear site data and compare that data set with the comparable one for the wooded site (Steps 4 and 5, page 15), the result was that the two sets tested as being from different populations.

When the equation

$$P25 = A/B \times REF^{1.82}$$

was used, the two sets tested as being from the same population, but the sum of squares was 12.9, a substantial increase over the previous one. The data derived from this relationship tested as being from the same population as the wooded site data, however.

Since we were attempting to find the equation which most accurately described the relationship between the reference and field microphone, rather than the one which provided the best fit between the wooded and clear site data, it was reasonable to choose the one which had the smallest sum of squares of those tested. This choice seemed clear, except for the fact that the relationship with the <u>larger</u> sum of squares yielded an R^2 of .56, as compared to .52 for the other.

The case for all four microphone positions for the no-foliage condition was that the relationship yielding the smallest sum of squares did not result in "adjusted" clear site data which was from the same population as the wooded site data. The relationship yielding a much larger sum of squares resulted in "adjusted" data which was from the same population as the wooded site data. Furthermore, each of the latter relationships resulted in an R^2 which was the same or slightly larger than that obtained from the former relationships.

If the sum of squares is taken as the criterion, then there is a difference in the wooded and clear data populations for each field microphone and it must be concluded that there is some scattering due to the trunks, limbs, and branches of the bare trees. Table V, page 22 shows the "worst case" increase; i. e., that resulting from using the smallest sum of squares as the analytical criterion. Note, however, that even at the upper end of the confidence interval the differences are well under 3 dB, indicating that the corresponding increase in overall levels ould not be noticed by listeners.

TABLE V

MEDIAN DIFFERENCES BETWEEN CLEAR AND WOODED SITES

FOR TWO-MINUTE LeqA DATA - NO FOLIAGE

Microphone Position	Difference (dB)	95% Conf. Limits (dB)
P25 - 5 ft.	1.6	+0.5, -0.6
P50 - 5 ft.	0.5	+0.6, -0.5
P25 - 12 ft.	1.0	+0.4, -0.4
P50 - 12 ft.	0.9	+0.3, -0.6

However, if R^2 is used as the criterion, the wooded and clear data populations test as being the same (at the 95% level) and there is no difference between the data sets for corresponding microphones; i. e., scattering did not occur.

In addition to the analysis of LeqA data for full foliage, an analysis of selected frequencies from the LeqLin 1/3-octave data was also undertaken. This was done as a means of determining whether the increased levels at the wooded site was due to scattering, leaves rustling, or both.

Nine frequencies from 125 - 12,500 Hz were examined in an attempt to determine whether or not leaf rustling contributed to the higher levels at the wooded site. As with the LeqA data, adjustments had to made to the reference microphone levels at the clear site, with corresponding adjustments made to the field microphones. For this part of the analysis it was assumed that the relationship between the reference and field microphones was linear. This eliminated testing three different equations for each of four field microphones, for each of nine frequencies. This would have been extremely time-consuming and would have produced very little useful information, since the outcome of this analysis was used only to indicate the possible source(s) of the higher levels at the wooded site. The results are presented in Tables VI and VII, pages 24 and 25.

TABLE VI

MEDIAN DIFFERENCES BETWEEN CLEAR AND WOODED SITES FOR TWO-MINUTE LeqLin DATA - FULL FOLIAGE FIVE-FOOT MICROPHONE HEIGHT

Frequency Hz	P25W - P25C dB	P50W - P50C dB
125	-3.7	1.3
250	0.0 (=)	-0.3 (=)
500	0.5	1.6
1000	0.3	2.9
2000	1.7	3.6
4000	4.4	6.3
8000	4.6	8.4
10,000	2.1	4.2
12,500	-2.0	1.3

(=): indicates the difference is not statistically significant

TABLE VII

MEDIAN DIFFERENCES BETWEEN CLEAR AND WOODED SITES

FOR TWO-MINUTE LeqLin DATA - FULL FOLIAGE

TWELVE-FOOT MICROPHONE HEIGHT

Frequency Hz	P25W - P25C dB	P50W - P50C dB
125	-1.6	1.3
250	-1.1	0.0 (=)
500	0.0 (=)	-1.4
1000	0.8	-2.2 (=)
2000	2.3	0.4 (=)
4000	4.0	2.1 (=)
8000	4.1	1.8
10,000	4.1	1.6 (=)
12,500	-1.3	-3.2 (=)

(=): indicates the difference is not statistically significant

For the 5-foot microphone height, at the 25-foot microphone location, six of the nine median differences at the wooded site are either not statistically significant, or differ from the corresponding medians at the clear site by less than 3dB. Similar remarks apply to five of the medians from the 50-foot location. Five of the seven differences which are greater than 3dB occur in the 4000-10,000 Hz range.

For the 12-foot height, at the 25-foot location the same remarks apply to six of the medians, and for the 50-foot location to all nine medians. All of the differences which are greater than 3dB are in the 4000-10,000 Hz range.

From Tables VI and VII it can be concluded that there is no scattering of any real significance for the four lowest frequencies examined. Furthermore, there is either no statistical difference in the levels at the two sites, or lower levels at the wooded site in 9 of the 16 cases.

If scattering were actually occurring, it should be most noticeable at the microphone most completely in the wooded area and most completely under the leaf canopy, which was the 12-foot microphone at the 50-foot position. However, all of the median levels from this microphone indicate that the levels from the wooded site are either essentially the same or less than those at the clear site. Therefor a second conclusion is that neither scattering nor rustling of leaves contributed significantly to the slightly higher LeqA levels at the wooded site for this position.

The higher median levels 4000-10,000 Hz range at the other microphone locations may be due to two factors. The 25-foot locations were much nearer to the edge of the wooded area. Therefore, any attenuation (as opposed to scattering) afforded by the foliage would have affected these microphones less than the ones at 50 feet. At the 50-foot location there was some standing water adjacent to the microphone location. This might have caused reflected sound to add to the levels at this location.

REFERENCES

(1) Fundamental Concepts in the Design of Experiments: Charles R. Hicks Saunders College Publishing, Fort Worth, Texas Third Edition 1982

(2) Effect of Trees on Noise Barrier Performance: Christopher N. Blair Master's Thesis, Massachusetts Institute of Technology February, 1975

(3) Effectiveness of Trees and Vegetation in Reducing Highway Noise - A Literature Review: E. G. Kerby II Virginia Highway Research Council, Charlottesville, Va. Report VHRC 73-R30 January, 1974

4) Handbook of Research Methods: a guide for practitioners and students in the social sciences: Natalie L. Sproull The Scarecrow Press, Inc. Metuchen, N. J. 1988 pp.189-211

(5) "A New Type of Noise Barrier constructed from Living Plants": Maurice J. M. Martens, et al. Internoise 85 V1 pp.499-502 1985

(6) Nonparametric Statistical Methods: Myles Hollander and Douglas A. Wolfe John Wiley and Sons, New York, N. Y. 1973

(7) Numerical Mathematical Analysis: James B. Scarborough Johns Hopkins Press, Baltimore, Md. Sixth Edition 1966

(8) SAS/STAT Guide for Personal Computers Version 6 Edition: SAS Institute, Inc. Cary, N. C. 1987

(9) SAS User's Guide: Statistics Version 5 Edition: SAS Institute, Inc. Cary, N. C. 1985

(10) "Sound Propagation in Homogeneous Deciduous and Evergreen Woods": T. F. W. Embleton Journal of the Acoustical Society of America V35 N8 pp.1119-1125 1963

(11) Tree-Covered Land Forms for Noise Control: D. Cook and D. VanHaverbeke U. S. Department of Agriculture Forest Service Research Bulletin 263 1974

(12) "Vegetative Barriers: An Alternative Highway Noise Abatement Measure": R. A. Harris Noise Control Engineering Journal V27 N1 pp.4-8 July/August, 1986

APPENDIX I

DATA COLLECTION PROCEDURE

Two equipment vans were placed on the source side of the barriers, one at each site. The vans were parked so as to minimize the length of the microphone cables, but in positions where they could not effect measurements. Traffic counts and radar speed readings were made from the downstream van.

Microphone placement is shown in Figure 2 , page 10. The reference microphones were centered five feet above the barrier tops and the field microphones placed at 25 and 50 feet from the receiver side of the barrier, along a line perpendicular to the roadway.

The equipment layout was as shown in Figures 3 and 4, pages 30 and 31. Noise observations were two minutes long. Approximately half of the total number of observations were made using direct readouts of Leqs from sound level meters. This was done to eliminate a large part of the data reduction effort necessary for reducing tape recorded data. The tapes were nominally 45 minutes long, so that 22 observations were recorded on each channel of each tape simultaneously with the 22 Leqs on each of the direct readout meters.

The data collection procedure comprised the steps listed on pages 32 - 34.

FIGURE 3
EQUIPMENT LAYOUT - DIRECT READOUT

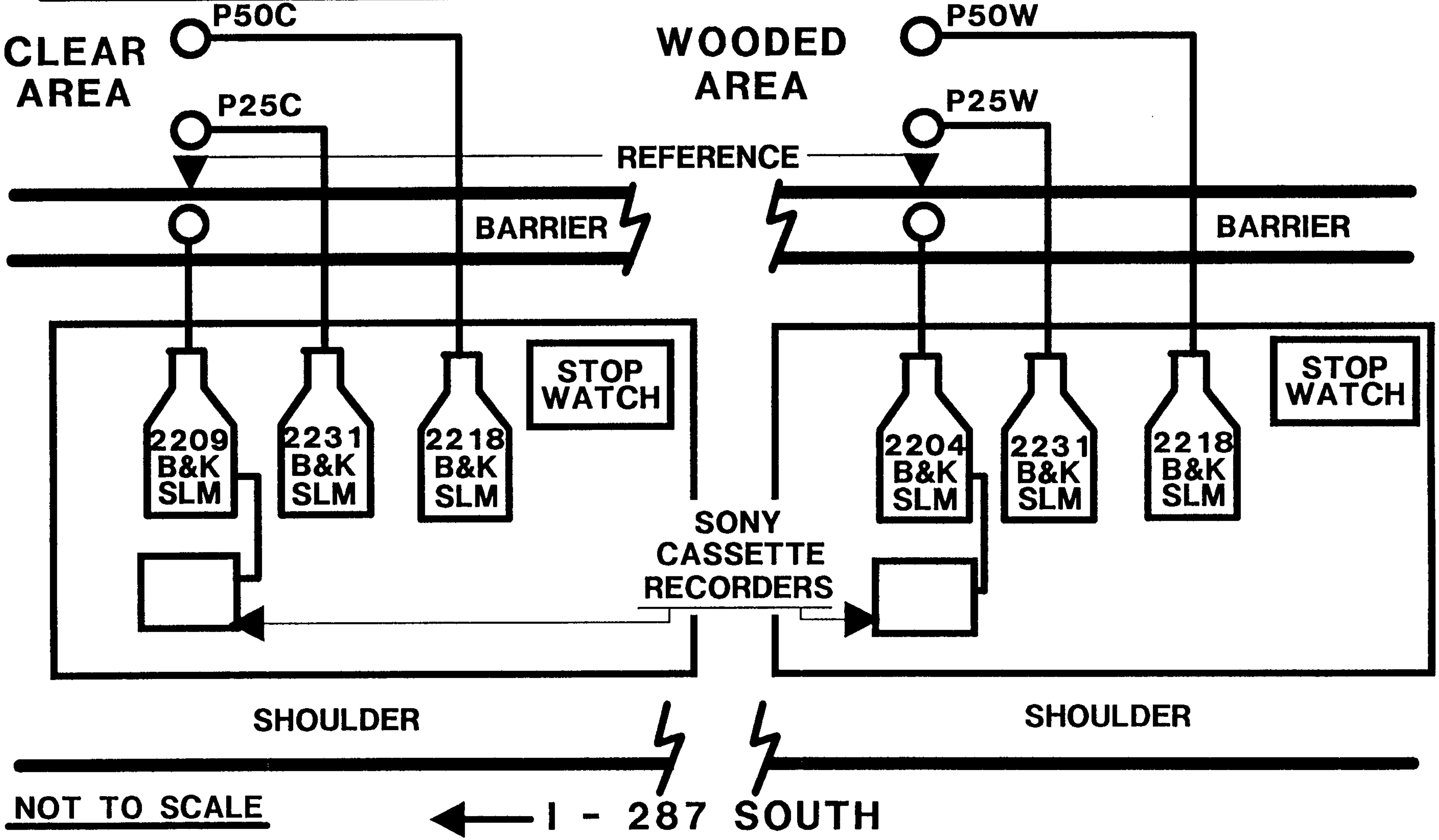
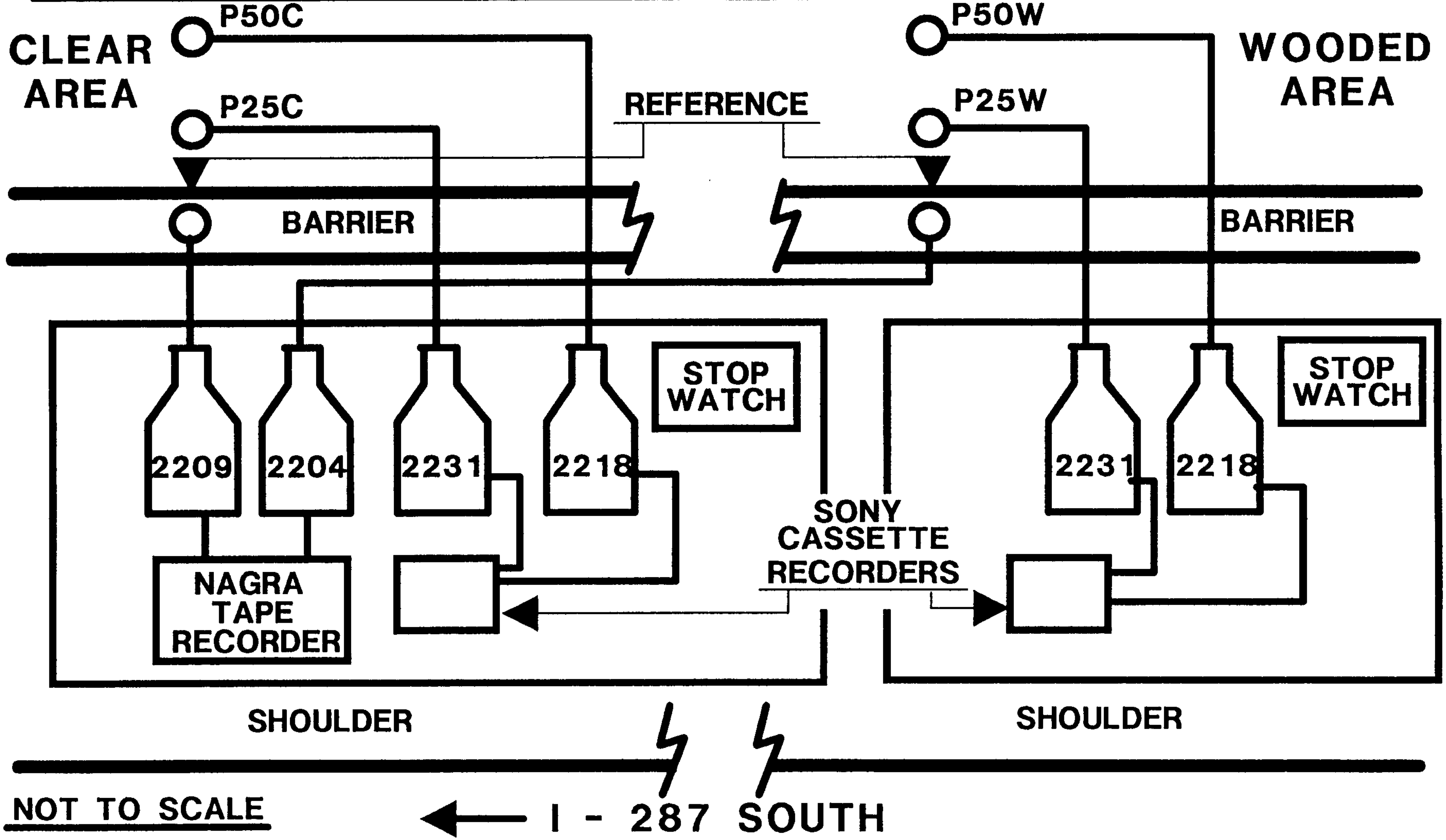


FIGURE 4
EQUIPMENT LAYOUT - TAPE RECORDING



1. An announcement consisting of the tape number, date, location, route and section, project name, and signal weighting was recorded at the beginning of each channel on each tape.

2. A pistonphone calibration signal was recorded immediately after the voice announcement on each channel of each tape. This was followed by a voice announcement for the start of Observation 1.

3. Those microphones connected to the two direct readout sound level meters were also calibrated with the pistonphone. The meters were then programmed for a two-minute Leq readout.

4. Concurrent with Steps 1 - 3, the radar and the weather instruments were set up on the source side of the barrier near the downstream van, and calibrated.

5. An initial wind speed, wind direction, and temperature were recorded and the information relayed to the Operator 1 (upstream) by walkie-talkie.

6. Operator 1 (wooded site; upstream) gave the signal to start recording to Operator 2 (clear site; downstream), and to the traffic counters simultaneously. The clocks at both locations were started at time zero, but recording and counting was started at Location 2 five

seconds later, to compensate for the distance between sites that the nearside traffic would have to travel.

During the ensuing two minutes while noise was being recorded, traffic counters recorded traffic counts for both nearside and farside traffic, categorized by heavy trucks, medium trucks, and light vehicles. They also recorded at least five radar speed readings for nearside traffic.

7. At the end of two minutes Operator 1 gave the signal to stop recording, at which time noise recording at Location 1 was stopped. Operator 2 and the traffic counters stopped five seconds later. The traffic counts and direct readout Leqs were recorded on forms, and all equipment readied for the next observation.

8. After recording the voice announcement for Observation 2 and receiving a ready indication from Operator 2 and the traffic counters, Operator 1 gave the signal to start recording. Steps 6 and 7 were repeated from this point until the end of the tape was reached. Meteorological data was recorded intermittently during this period, and the operators informed of the readings.

9. At the end of 22 observations, another calibration signal was recorded on each channel of each tape. New tapes were then installed, and Steps 1 - 8 were repeated, starting with Observation 23.

The same basic routine was also used when all observations were tape recorded. The only modification was that there were no direct readouts to record at the end of each two-minute observation.

APPENDIX II

DATA REDUCTION PROCEDURE

Data reduction was carried out by one person throughout, in order to insure uniformity of of results. Observations containing noise from aircraft, highway maintenance and construction equipment, stopped vehicles, and other non-highway sources were discarded.

The data reduction equipment layout is shown in Figure 5, page 37. Data reduction proceeded as follows:

1. The voice announcement at the beginning of each channel was checked for the necessary information (tape number, data, observation number, etc.), and the recorded calibration signal used to set the equipment;

2. The first observation was played back to obtain an LeqA and a linear one-third octave frequency content analysis. A correction factor (necessary for the particular equipment used) was applied to determine the LeqLin;

3. The GLR graph was examined for anomalies which might void the observation. These were compared with field notes and the findings of audio playback to determine the final disposition of the observation;

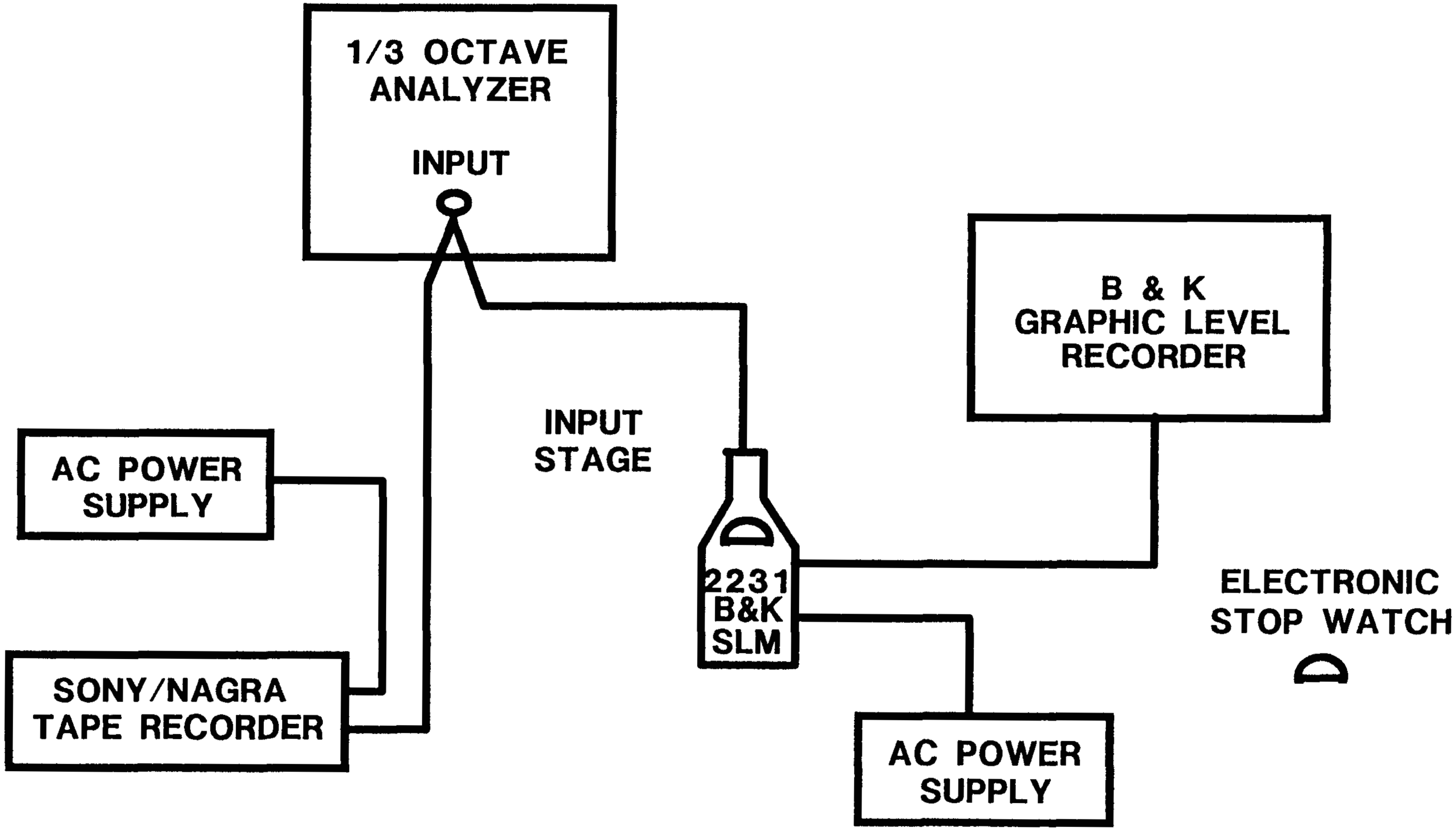
4. Steps 2 and 3 were repeated for all other observations on the tape;

5. At the end of the tape the final calibration signal was checked for accuracy;

6. The tape was rewound to the start of the second channel and Steps 1 - 5 were repeated.

The speed readings were reduced by averaging the speeds from the readings taken during each observation. A minimum of five readings were taken each time.

FIGURE 5
DATA REDUCTION EQUIPMENT LAYOUT



NOTES ON APPENDICES III - VI

DATE - Date the observation was recorded.

OBSNO - Sequential number of the two-minute recording or direct readout. Missing numbers indicate the observation was discarded because of contamination by non-highway noise.

REFC - Two-minute Leq from tape or direct readout for the reference microphone at the clear site.

P25C - Two-minute Leq from tape or direct readout for the field microphone placed 25 feet behind the barrier at the clear site.

P50C - Two-minute Leq from tape or direct readout for the field microphone placed 50 feet behind the barrier at the wooded site.

REFW - Corresponding to REFC, for the wooded site.

P25W - Corresponding to P25C, for the wooded site.

P50W - Corresponding to P50C, for the wooded site.

APPENDIX III

Leqs FOR FIVE - FOOT FIELD MICROPHONE HEIGHT

NO FOLIAGE

DATE	OBSNO	REFC	P25C	P50C	REFW	P25W	P50W
04/11/88	3	77.0	60.1	59.9	78.3	62.9	61.4
04/11/88	4	78.5	61.2	61.1	79.6	63.7	62.1
04/11/88	5	78.5	60.6	60.3	79.5	62.9	61.2
04/11/88	7	80.1	61.8	61.2	81.3	64.5	62.6
04/11/88	10	78.8	60.8	60.3	80.0	63.6	61.8
04/11/88	11	81.2	63.8	63.2	82.3	65.9	64.6
04/11/88	12	80.5	62.7	61.9	81.8	65.0	63.2
04/11/88	13	79.3	61.3	61.1	80.3	63.8	62.1
04/11/88	14	78.9	62.6	62.3	79.5	65.1	63.6
04/11/88	16	80.4	62.6	61.8	80.8	65.0	63.6
04/11/88	17	79.0	61.9	61.5	79.3	64.0	62.5
04/11/88	18	79.8	62.1	61.6	80.4	64.2	62.7
04/11/88	19	78.8	61.7	61.4	79.9	63.7	62.3
04/11/88	20	78.5	61.6	61.3	79.4	64.0	62.5
04/11/88	22	78.1	61.1	60.7	79.2	63.2	61.7
04/11/88	23	78.2	60.4	59.8	79.5	64.0	62.2
04/11/88	24	77.7	61.3	61.2	78.9	63.5	61.9
04/11/88	25	80.4	63.0	62.5	81.5	65.3	63.6
04/11/88	26	78.1	60.6	60.5	79.0	63.0	61.5
04/11/88	27	79.5	62.1	61.8	80.7	64.7	63.1

APPENDIX IV

Leqs FOR TWELVE - FOOT FIELD MICROPHONE HEIGHT

NO FOLIAGE

DATE	OBSNO	REFC	P25C	P50C	REFW	P25W	P50W
04/14/88	3	79.1	62.5	61.2	79.7	64.5	63.1
04/14/88	4	78.1	62.1	60.6	.	63.8	62.4
04/14/88	5	78.1	62.8	61.6	79.4	64.2	63.1
04/14/88	6	78.8	63.0	61.8	80.1	65.0	63.8
04/14/88	7	77.5	62.3	61.0	79.0	63.8	62.7
04/14/88	8	77.9	62.5	61.5	79.3	64.1	62.7
04/14/88	9	78.7	63.7	63.0	80.0	65.2	63.9
04/14/88	10	78.4	63.3	62.0	79.8	64.7	63.2
04/14/88	11	78.5	62.9	61.5	79.4	63.8	62.4
04/14/88	12	77.4	62.6	61.4	78.8	63.3	62.0
04/14/88	14	77.8	62.6	61.7	79.2	64.3	63.4
04/14/88	15	78.7	63.7	62.4	79.9	65.1	63.8
04/14/88	16	76.0	60.1	58.8	77.4	62.2	60.7
04/14/88	19	79.0	63.1	61.9	79.8	64.7	63.3
04/14/88	20	78.2	61.7	60.5	78.4	63.4	62.0
04/14/88	21	78.4	63.3	62.2	79.1	65.1	64.0
04/14/88	22	78.7	63.9	62.8	79.3	64.9	64.1
04/14/88	23	76.9	62.2	61.3	77.4	63.4	62.6
04/14/88	24	.	.	.	.	66.5	65.6
04/14/88	25	78.1	62.7	62.0	78.7	64.2	63.0
04/14/88	26	77.4	63.3	62.1	77.7	64.2	62.9
04/14/88	27	78.2	62.8	61.8	78.7	64.5	63.4
04/14/88	28	77.5	61.2	59.6	78.2	63.5	62.0
04/14/88	29	78.8	64.6	63.5	79.8	65.7	64.6

APPENDIX V

Leqs FOR FIVE-FOOT FIELD MICROPHONE HEIGHT

FULL FOLIAGE

DATE	OBSNO	REFC	P25C	P50C	REFW	P25W	P50W
8/15/88	1	79.5	61.8	60.2	80.0	63.1	61.2
8/15/88	3	78.4	59.7	58.0	78.7	61.4	59.4
8/15/88	4	78.7	60.0	58.4	79.0	.	60.0
8/15/88	5	77.9	61.5	60.1	78.4	63.3	60.8
8/15/88	6	79.0	60.0	59.2	79.5	62.8	61.1
8/15/88	7	79.6	62.1	60.5	80.4	.	61.6
8/15/88	8	79.3	61.3	59.6	79.2	.	60.5
8/15/88	9	80.1	62.4	61.1	80.5	.	61.9
8/15/88	10	78.3	60.9	59.9	80.4	.	60.5
8/15/88	11	78.2	60.6	59.4	78.8	.	60.0
8/15/88	12	78.9	60.7	58.9	79.6	62.5	60.3
8/15/88	13	79.1	61.5	59.8	79.7	63.2	61.2
8/15/88	14	79.2	61.2	59.6	80.3	63.0	60.9
8/15/88	16	78.3	61.9	59.7	.	62.1	60.3
8/15/88	18	77.4	59.5	58.1	78.8	62.2	59.8
8/15/88	19	77.4	59.8	58.5	79.4	.	59.7
8/15/88	20	77.6	60.1	58.9	79.8	62.1	60.1
8/15/88	21	77.4	59.6	58.3	78.8	61.9	59.2
8/15/88	22	79.2	59.7	58.1	79.8	62.5	59.9
8/15/88	23	79.3	59.1	60.6	80.0	62.7	60.2
8/15/88	24	78.5	59.5	58.0	79.5	62.1	59.6
8/15/88	25	78.9	60.0	59.9	79.7	62.3	59.5
8/15/88	28	79.6	60.9	59.2	81.1	63.5	60.5
8/15/88	30	79.3	59.8	59.3	79.7	62.7	60.7
8/15/88	31	.	.	59.3	80.1	63.1	60.6
8/15/88	32	79.3	59.4	61.1	80.7	63.6	61.1
8/15/88	33	80.0	63.5	61.4	80.7	64.0	61.8
8/15/88	34	80.1	60.7	59.0	80.6	63.3	60.8
8/15/88	35	79.2	60.9	59.3	80.9	63.4	60.6
8/15/88	36	80.4	58.9	60.5	80.7	63.2	60.4
8/15/88	37	79.4	60.3	60.7	80.4	63.1	60.5
8/15/88	38	80.0	61.0	59.6	80.8	63.3	60.5
8/15/88	39	80.0	62.8	60.5	80.3	64.2	61.9
8/15/88	40	79.8	61.4	60.0	80.7	63.9	61.1
9/09/88	1	79.7	60.5	60.3	80.4	62.7	61.9
9/09/88	2	79.5	59.5	59.5	79.7	62.3	61.3
9/09/88	3	79.9	60.2	60.2	80.8	62.8	61.9
9/09/88	6	79.4	59.3	59.2	79.9	62.2	61.3
9/09/88	7	80.3	60.4	60.2	81.3	63.5	62.4
9/09/88	8	81.3	61.1	61.3	81.6	64.0	.
9/09/88	9	80.4	60.4	60.5	81.1	63.2	62.2
9/09/88	10	79.4	59.1	59.3	80.1	62.8	61.5
9/09/88	11	80.7	60.5	60.7	81.4	63.7	63.0
9/09/88	12	80.1	60.4	60.6	81.0	63.5	.
9/09/88	13	80.3	60.9	61.1	81.1	63.7	62.7
9/09/88	14	79.6	59.7	59.7	80.2	62.7	61.7
9/09/88	15	79.8	59.4	59.5	80.2	62.4	61.5

9/09/88	16	80.1	59.5	59.6	80.5	62.7	61.7
9/09/88	17	81.2	60.9	61.1	81.8	63.9	63.0
9/09/88	18	79.7	59.6	59.5	79.8	62.4	61.4
9/09/88	19	79.2	59.4	59.3	80.1	62.4	61.4
9/09/88	20	80.6	60.5	60.4	80.0	63.2	62.1
9/27/88	1	79.3	59.6	59.7	80.7	63.7	62.1
9/27/88	2	80.5	60.3	60.1	82.0	63.8	62.6
9/27/88	3	80.6	60.7	60.6	82.2	64.3	63.0
9/27/88	4	80.9	60.8	60.9	82.5	64.8	63.4
9/27/88	5	80.7	61.5	62.3	82.5	64.0	63.2
9/27/88	7	.	.	.	82.2	64.5	63.1
9/27/88	8	79.0	58.7	58.4	80.7	62.5	60.7
9/27/88	9	79.3	59.9	59.8	81.0	63.4	62.3
9/27/88	10	80.9	60.8	60.8	82.9	64.1	62.4
9/27/88	11	80.4	61.0	61.1	82.0	64.1	62.7
9/27/88	12	80.4	60.4	60.2	82.4	64.2	62.8
9/27/88	13	80.6	60.2	59.9	.	.	.
9/27/88	14	78.6	58.4	58.6	.	.	.
9/27/88	15	79.2	59.7	59.9	.	.	.
9/27/88	16	80.6	60.9	61.3	.	.	.
9/27/88	17	79.6	60.1	60.4	.	.	.
9/27/88	18	80.7	60.4	60.4	.	.	.
9/27/88	19	80.3	60.4	60.8	.	.	.
9/27/88	20	80.4	61.0	61.1	.	.	.

APPENDIX VI

Leqs FOR TWELVE-FOOT FIELD MICROPHONE HEIGHT

FULL FOLIAGE

DATE	OBSNO	REFC	P25C	P50C	REFW	P25W	P50W
8/22/88	1	80.0	62.4	59.9	80.8	63.0	61.2
8/22/88	2	79.2	61.6	59.7	80.1	62.7	60.7
8/22/88	3	78.8	61.0	58.6	79.5	62.4	60.5
8/22/88	4	78.8	63.5	60.8	80.3	63.9	62.5
8/22/88	5	79.3	62.5	59.9	80.6	63.7	62.0
8/22/88	6	80.3	63.2	60.5	80.9	63.8	62.0
8/22/88	7	77.9	62.9	60.0	79.6	63.0	61.5
8/22/88	8	79.4	63.8	61.4	80.2	63.9	62.4
8/22/88	9	81.7	64.7	62.3	82.5	65.7	64.0
8/22/88	10	77.7	62.2	59.9	79.6	63.3	61.9
8/22/88	11	79.5	62.9	61.2	80.5	63.5	61.9
8/22/88	12	79.2	62.2	60.1	81.4	63.4	61.4
8/22/88	14	80.2	63.7	60.8	81.7	64.5	62.6
8/22/88	15	77.2	60.4	58.1	78.1	61.9	60.4
8/22/88	16	79.2	62.5	60.3	80.3	64.1	62.8
8/22/88	17	77.8	61.4	59.4	79.1	63.6	62.8
8/22/88	18	79.9	62.9	60.4	80.9	64.2	62.3
8/22/88	19	79.3	62.5	60.2	80.1	63.8	62.4
8/22/88	20	80.3	63.6	61.2	.	.	.
8/22/88	22	.	61.5	59.0	79.8	62.7	60.6
8/22/88	24	78.4	61.4	59.3	80.4	62.8	60.8
8/22/88	25	81.0	64.5	62.6	82.3	65.3	62.7
8/22/88	26	80.5	64.4	62.6	81.7	64.9	63.3
8/22/88	28	80.0	62.7	60.4	81.2	64.5	62.6
8/22/88	29	78.5	61.6	59.4	80.1	64.5	61.7
8/22/88	30	79.9	62.7	60.3	80.9	64.0	62.1
8/22/88	31	78.7	61.9	59.5	80.7	63.8	61.7
8/22/88	32	80.0	63.0	60.8	81.0	64.1	62.4
8/22/88	33	79.9	62.3	59.9	81.2	63.9	61.9
8/22/88	34	79.7	63.0	60.7	81.2	64.1	63.0
8/22/88	35	79.2	62.1	60.0	80.3	63.3	61.2
8/22/88	36	80.7	63.5	61.7	81.7	64.2	62.1
8/22/88	37	80.2	63.5	61.6	81.6	64.9	63.2
8/22/88	38	80.6	65.0	63.6	82.1	65.4	63.7
8/22/88	39	80.0	63.5	61.7	81.1	64.5	62.8
8/31/88	1	80.3	.	62.8	82.0	64.9	63.9
8/31/88	3	80.1	62.2	61.2	80.0	62.9	62.9
8/31/88	4	80.2	.	.	79.4	62.1	62.8
8/31/88	5	81.0	62.6	61.7	80.4	62.3	62.9
8/31/88	8	79.8	60.9	60.1	79.3	61.2	61.8
8/31/88	9	79.7	60.9	59.8	79.5	61.0	61.8
8/31/88	10	81.1	62.5	61.6	.	62.4	62.9
8/31/88	12	80.5	.	.	80.8	62.3	62.9
8/31/88	15	78.0	60.5	59.7	78.8	60.6	60.9
8/31/88	16	79.4	62.2	.	79.9	61.5	62.2
8/31/88	17	79.9	62.2	61.1	80.4	62.4	62.6
8/31/88	18	.	61.4	60.4	79.5	60.9	62.0

8/31/88	19	79.3	62.2	61.3	80.6	61.7	62.4
8/31/88	20	80.8	.	.	81.7	63.0	63.3
8/31/88	21	.	61.9	60.7	80.2	61.7	62.0
8/31/88	22	80.2	.	61.2	81.3	62.5	62.8
8/31/88	23	80.1	.	.	81.0	62.4	62.6
8/31/88	24	78.0	.	.	80.2	63.8	62.7
8/31/88	26	80.2	.	61.7	80.7	63.5	62.2
8/31/88	27	80.0	.	61.4	80.7	.	62.2
8/31/88	28	79.9	.	61.5	80.7	.	62.7
8/31/88	29	.	.	61.0	80.9	.	62.3
8/31/88	30	80.4	63.4	62.2	81.5	64.5	63.3
8/31/88	31	80.0	62.8	61.5	81.2	64.2	63.0
8/31/88	32	79.2	61.5	60.4	80.3	63.2	61.9
8/31/88	33	79.8	.	.	80.6	63.8	62.5
8/31/88	34	80.8	63.3	62.0	81.8	65.0	63.8
8/31/88	35	80.5	63.3	.	81.5	64.4	63.3
8/31/88	36	81.0	63.8	62.4	82.1	64.9	63.9
8/31/88	37	79.4	62.9	61.7	80.2	64.0	63.2
8/31/88	38	80.4	.	.	81.4	64.4	63.3
8/31/88	39	79.6	62.7	.	80.7	64.0	63.0
8/31/88	40	79.4	62.5	.	80.7	63.9	62.8
8/31/88	41	80.4	63.1	61.9	81.2	64.5	63.3
8/31/88	42	78.8	.	.	79.7	62.7	61.5
8/31/88	43	78.8	.	60.5	80.0	63.0	62.2
8/31/88	44	79.8	62.8	61.6	81.3	64.4	63.2

NOTES ON APPENDICES VII - X

DATE - Date observation was recorded.

OBSNO - Sequential number of the observation. Missing numbers indicate the observation was discarded because of contamination by non-highway noise.

SPD - Speed of nearside traffic, determined by averaging a minimum of five radar speed readings recorded during each two-minute noise observation.

NL - Number of light vehicles in the nearside lanes during the two-minute noise observation.

NM - Number of medium trucks in the nearside lanes during the two-minute noise observation.

NH - Number of heavy trucks in the nearside lanes during the two-minute noise observation.

FL - Corresponds to NL, for the farside lanes.

FM - Corresponds to NM, for the farside lanes.

FH - Corresponds to NH, for the farside lanes.

APPENDIX VII

TRAFFIC COUNTS AND SPEEDS - FIELD MICROPHONES AT FIVE FEET

NO FOLIAGE

DATE	OBSNO	SPD	NL	NM	NH	FL	FM	FH
04/11/88	3	66.3	53	3	3	62	6	2
04/11/88	4	63.8	54	8	5	64	2	8
04/11/88	5	60.0	59	3	2	68	2	6
04/11/88	6	64.3	68	7	4	72	4	7
04/11/88	7	65.0	83	14	7	71	2	2
04/11/88	10	60.8	54	6	7	49	3	6
04/11/88	11	63.3	81	7	13	63	1	6
04/11/88	12	59.5	82	11	11	80	4	6
04/11/88	13	59.9	72	7	11	68	3	6
04/11/88	14	56.4	66	4	6	54	3	10
04/11/88	16	59.3	59	8	12	55	8	5
04/11/88	17	65.8	60	4	5	65	4	6
04/11/88	18	64.8	59	6	8	47	3	1
04/11/88	19	61.2	53	4	8	61	4	11
04/11/88	20	59.8	63	4	4	61	1	8
04/11/88	21	62.6	73	5	4	54	4	6
04/11/88	22	58.2	59	3	3	55	1	6
04/11/88	23	60.5	59	2	8	60	2	4
04/11/88	24	62.0	71	6	2	71	3	3
04/11/88	25	59.0	69	2	17	85	2	2
04/11/88	26	64.0	75	7	6	54	3	3
04/11/88	27	61.4	64	6	13	60	4	6

APPENDIX VIII

TRAFFIC COUNTS AND SPEEDS - FIELD MICROPHONES AT TWELVE FEET

NO FOLIAGE

DATE	OBSNO	SPD	NL	NM	NH	FL	FM	FH
04/14/88	3	61.5	59	6	5	81	2	11
04/14/88	4	58.8	53	1	10	68	3	6
04/14/88	5	61.6	57	6	6	77	3	7
04/14/88	6	61.0	65	3	11	66	5	6
04/14/88	7	59.5	57	3	6	64	1	7
04/14/88	8	57.3	79	3	3	72	2	6
04/14/88	9	58.0	47	2	8	68	3	9
04/14/88	10	59.7	58	2	9	70	2	5
04/14/88	11	60.8	75	0	7	59	2	7
04/14/88	12	61.3	69	4	3	62	2	5
04/14/88	14	59.3	68	3	5	69	0	9
04/14/88	15	59.3	73	4	10	67	0	3
04/14/88	16	59.7	76	0	2	80	1	5
04/14/88	19	57.0	65	5	10	60	8	10
04/14/88	20	60.0	79	7	7	54	2	5
04/14/88	21	58.0	82	3	9	70	3	3
04/14/88	22	59.0	72	5	6	61	3	7
04/14/88	23	61.0	55	2	3	52	5	4
04/14/88	24	56.4	53	3	9	68	1	3
04/14/88	25	57.5	62	2	5	67	5	8
04/14/88	26	59.6	63	5	4	65	1	1
04/14/88	27	58.3	71	7	8	74	5	2
04/14/88	28	60.2	71	8	5	61	2	5
04/14/88	29	59.8	87	2	6	73	8	5

APPENDIX IX

TRAFFIC COUNTS AND SPEEDS - FIELD MICROPHONES AT FIVE FEET

FULL FOLIAGE

DATE	OBSNO	SPD	NL	NM	NH	FL	FM	FH
8/15/88	1	60.8	66	3	11	64	2	5
8/15/88	3	61.4	64	4	3	73	5	4
8/15/88	4	59.0	62	0	6	64	2	7
8/15/88	5	56.8	72	4	3	46	5	4
8/15/88	6	58.8	59	1	6	65	1	9
8/15/88	7	58.2	65	7	8	56	6	2
8/15/88	8	59.8	52	0	8	61	5	5
8/15/88	9	59.2	68	7	6	55	8	6
8/15/88	10	58.2	85	8	7	57	4	7
8/15/88	11	60.2	53	9	3	69	2	8
8/15/88	12	61.2	71	0	7	42	3	4
8/15/88	13	60.2	70	5	9	65	0	3
8/15/88	14	59.6	60	4	8	48	1	2
8/15/88	16	59.4	71	1	6	60	1	3
8/15/88	18	60.6	81	5	3	58	3	4
8/15/88	19	59.8	57	5	4	62	2	2
8/15/88	20	61.2	71	4	6	60	1	3
8/15/88	21	61.4	91	1	1	87	3	5
8/15/88	22	61.6	114	4	2	98	2	2
8/15/88	23	61.4	109	5	3	132	0	1
8/15/88	24	66.4	92	0	1	138	2	1
8/15/88	25	61.6	102	3	2	105	0	3
8/15/88	28	59.8	105	3	6	162	4	6
8/15/88	30	59.2	110	2	2	152	2	4
8/15/88	31	60.8	102	3	5	128	1	0
8/15/88	32	57.2	134	2	3	159	1	1
8/15/88	33	58.8	119	3	4	157	2	3
8/15/88	34	61.0	135	3	4	195	2	5
8/15/88	35	60.0	161	1	3	194	3	3
8/15/88	36	59.4	139	1	3	207	2	1
8/15/88	37	61.4	157	1	3	152	2	3
8/15/88	38	65.8	127	1	7	182	1	5
8/15/88	39	59.2	133	3	3	191	2	3
8/15/88	40	60.0	127	2	7	152	3	6
9/09/88	1	56.0	5	4	59	1	4	5
9/09/88	2	60.0	53	0	6	71	9	6
9/09/88	3	60.2	96	6	6	76	0	4
9/09/88	6	62.2	74	3	3	83	2	6
9/09/88	7	57.2	93	2	11	70	4	4
9/09/88	8	59.2	98	4	10	100	4	10
9/09/88	9	59.4	57	6	11	95	3	4
9/09/88	10	57.2	72	6	5	67	7	2
9/09/88	11	58.6	90	4	10	81	3	7
9/09/88	12	59.4	72	2	8	83	4	1
9/09/88	13	58.2	90	4	7	93	5	3
9/09/88	14	56.4	78	2	5	95	1	3

9/09/88	15	58.2	75	3	8	82	6	6
9/09/88	16	58.6	71	6	11	79	4	5
9/09/88	17	60.6	97	10	9	83	7	4
9/09/88	18	58.0	67	3	5	80	7	6
9/09/88	19	59.0	92	2	4	98	7	5
9/09/88	20	59.0	73	4	6	86	6	7
9/27/88	1	62.8	42	20	8	69	5	3
9/27/88	2	60.0	79	1	9	71	6	4
9/27/88	3	61.8	57	6	9	68	4	5
9/27/88	4	58.2	67	6	8	67	7	14
9/27/88	5	60.0	57	6	10	97	11	8
9/27/88	7	58.4	80	7	7	70	8	6
9/27/88	8	66.4	60	4	6	75	5	1
9/27/88	9	59.2	75	5	6	69	1	9
9/27/88	10	63.8	72	13	8	78	5	5
9/27/88	11	58.3	69	12	6	75	4	7
9/27/88	12	57.4	76	8	7	69	5	7
9/27/88	13	59.8	75	5	6	74	4	4
9/27/88	14	59.8	69	5	4	58	4	4
9/27/88	15	58.6	76	5	0	77	3	6
9/27/88	16	60.4	57	6	7	72	1	3
9/27/88	17	61.2	68	4	3	61	2	7
9/27/88	18	60.6	68	6	5	75	8	7
9/27/88	19	58.6	63	2	10	88	4	3
9/27/88	20	58.6	85	5	3	78	4	10

APPENDIX X

TRAFFIC COUNTS AND SPEEDS - FIELD MICROPHONES AT TWELVE FEET

FULL FOLIAGE

DATE	OBSNO	SPD	NL	NM	NH	FL	FM	FH
8/22/88	1	55.2	65	3	8	64	2	4
8/22/88	2	55.4	56	5	4	59	1	4
8/22/88	3	55.4	75	2	5	68	2	1
8/22/88	4	53.2	59	4	6	63	4	2
8/22/88	5	58.2	64	1	8	69	5	7
8/22/88	6	58.4	86	4	8	64	6	3
8/22/88	7	58.8	64	1	5	61	4	7
8/22/88	8	57.8	70	6	6	62	4	6
8/22/88	9	60.8	55	3	4	59	4	7
8/22/88	10	59.0	61	1	4	60	3	2
8/22/88	11	61.0	65	5	2	68	4	6
8/22/88	12	58.6	64	4	7	66	2	4
8/22/88	14	57.6	83	4	12	50	5	7
8/22/88	15	58.2	64	3	1	50	4	2
8/22/88	16	58.8	66	6	6	62	0	8
8/22/88	17	60.4	72	5	2	59	1	3
8/22/88	18	60.4	69	4	8	76	3	1
8/22/88	19	58.2	57	9	3	61	5	5
8/22/88	20	58.4	71	6	13	84	5	5
8/22/88	22	57.6	64	3	6	81	5	4
8/22/88	24	57.8	61	2	4	72	2	3
8/22/88	25	57.6	79	3	13	84	3	8
8/22/88	26	56.6	75	3	9	98	4	5
8/22/88	28	56.4	74	7	9	86	0	4
8/22/88	29	59.6	89	5	7	93	5	4
8/22/88	30	60.8	85	0	1	113	6	2
8/22/88	31	56.0	81	3	4	85	4	4
8/22/88	32	60.0	64	1	6	98	2	3
8/22/88	33	60.0	81	1	10	91	6	10
8/22/88	34	60.4	84	2	9	93	3	3
8/22/88	35	60.4	82	3	7	97	5	8
8/22/88	36	58.4	91	1	3	123	3	4
8/22/88	37	60.0	96	5	7	123	4	5
8/22/88	38	56.0	102	1	7	139	5	6
8/22/88	39	55.6	84	5	10	102	2	5
8/31/88	1	58.6	67	4	2	76	4	7
8/31/88	3	59.0	53	4	5	72	6	5
8/31/88	4	58.0	74	3	4	68	4	7
8/31/88	5	58.6	63	4	9	73	4	6
8/31/88	8	57.4	71	1	5	80	3	6
8/31/88	9	58.0	71	2	7	76	4	2
8/31/88	10	60.2	51	7	7	80	2	6
8/31/88	12	59.6	64	5	11	70	4	4
8/31/88	15	57.0	66	2	4	83	8	4
8/31/88	16	58.8	78	6	4	69	2	7
8/31/88	17	58.0	77	2	6	75	3	6

8/31/88	18	57.0	88	2	4	83	2	6
8/31/88	19	58.8	62	3	12	82	4	4
8/31/88	20	56.8	76	2	9	88	7	7
8/31/88	21	57.4	58	4	8	92	3	4
8/31/88	22	58.4	75	6	10	73	7	3
8/31/88	23	57.8	74	6	6	92	7	3
8/31/88	24	60.5	62	3	5	82	1	3
8/31/88	26	59.8	69	3	7	78	4	4
8/31/88	27	59.0	76	3	9	79	3	2
8/31/88	28	59.2	74	1	7	83	7	8
8/31/88	29	57.4	60	4	8	94	4	0
8/31/88	30	61.4	67	6	5	86	4	5
8/31/88	31	58.4	70	2	10	97	8	2
8/31/88	32	58.8	72	2	4	90	2	2
8/31/88	33	59.6	65	4	2	114	1	3
8/31/88	34	59.8	76	4	6	101	15	6
8/31/88	35	61.8	82	3	4	121	2	1
8/31/88	36	58.0	67	3	3	115	7	2
8/31/88	37	60.4	75	5	1	116	9	8
8/31/88	38	59.2	108	3	7	105	6	2
8/31/88	39	61.8	101	2	3	100	3	5
8/31/88	40	60.0	87	6	4	87	6	1
8/31/88	41	59.2	89	4	3	123	7	4
8/31/88	42	60.8	83	3	2	102	2	2
8/31/88	43	61.4	82	5	2	104	9	5
8/31/88	44	62.2	89	4	3	143	5	5

APPENDIX XI

MAJOR EQUIPMENT ITEMS USED IN DATA COLLECTION AND DATA REDUCTION

1 - 2204 BRUEL AND KJAER SLM

1 - 2209 BRUEL AND KJAER SLM

2 - 2218 BRUEL AND KJAER INTEGRATING SLMS

2 - 2231 BRUEL AND KJAER MODULAR SLMS

2 - TC-D5 PROII SONY CASSETTE RECORDERS

1 - IV-SJ NAGRA TAPE RECORDER

2 - 4420 BRUEL AND KJAER PISTONPHONES

6 - BRUEL AND KJAER 1/2" MICROPHONES WITH PREAMPS AND WINDSCREENS

1 - MPH K-55 RADAR

1 - 2305 BRUEL AND KJAER GRAPHIC LEVEL RECORDER

1 - SPECTRAL DYNAMICS SD312-22 1/3-OCTAVE ANALYZER

NUMEROUS ANCILLARY ITEMS INCLUDING MICROPHONE CONNECTING CABLES, STOP WATCHES, WALKIE-TALKIES, MICROPHONE MASTS AND TRIPODS