

# **BARRIER EFFECTIVENESS VALIDATION**

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## **DISCLAIMER**

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16. Abstract The primary goals of this project were to answer three specific questions:  <i>Are the barriers providing adequate protection for highway neighbors?</i> <i>Are the noise barriers that have been built in Florida performing as predicted?</i> <i>Is the new FHWA Traffic Noise Model significantly better than STAMINA2.0/2.1?</i>  To answer these questions, and fulfill the goals of this project, specific data were needed. These data were of two types: field data and computed data. The field data included measured sound levels, specific location geometrics, traffic counts, traffic speeds, weather data, and field notes of unusual occurrences. The computed data included prediction of sound levels at specific positions, calculation of insertion losses, shadow zone evaluations, overall trend analysis of the collected data, and comparative analysis of the measured versus modeled results. This report details the methods used, data collection method, a description of the computer modeling, analysis methods and results that were needed to answer these three basic questions. Final conclusions are then presented.			
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## EXECUTIVE SUMMARY

The research was designed to answer three key questions for the Florida Department of Transportation (FDOT) as well as provide useful information to other interested entities such as those using the new Federal Highway Administration (FHWA) traffic noise prediction model. These three questions were:

*Are the barriers providing adequate protection for highway neighbors?*

*Are the noise barriers that have been built in Florida performing as predicted?*

*Is the new FHWA Traffic Noise Model significantly better than STAMINA2.0/2.1?*

To answer these questions and complete the goals of the research, a detailed measurement program was used at twelve barrier locations around the state of Florida. The measurement program included collection of overall sound levels, 1/3 octave band levels, location geometrics, traffic characteristics and weather. The sound measurement positions were determined by using the American National Standards Institute standard (Methods for determination of insertion loss of outdoor noise barriers, ANSI S12.8-1998) which required measurements at various heights and distances above and behind the noise barrier.

After the measurements were taken, each location was modeled using the computer models STAMINA2.0 (the current FHWA regulatory model), STAMINA2.1 (Florida's version of STAMINA2.0 with state specific emission levels), and the Traffic Noise Model (often referred to as TNM, this model will replace STAMINA2.0 in the year 2002). The modeled results were then statistically compared to the measured results. In addition, insertion losses (the difference with and without the noise barrier), ground effects (reductions in sound levels caused by interaction with the ground), shadow zones (the area of reduced levels behind the barrier), and overall trends were determined and analyzed. The measured data, modeled results, and derived information permitted the three key questions to be answered.

The results of the measurement program when compared to the FHWA/FDOT Noise Abatement Criteria show that the highway neighbors are being protected (first question). While the barriers could have been slightly higher at four of the locations, significant decreases in the sound levels still occurred. Without the barriers, severe interference with communication and outdoor activities would have occurred due to the traffic noise.

A review of the amount of protection provided by the barriers, compared to that expected using computer modeling (second question) shows that the models that have been used (STAMINA2.0/2.1) performed adequately and, in some cases, better than the new TNM. However, statistical testing also tends to show that when only the propagation algorithms in TNM are compared to STAMINA2.0/2.1, TNM performed significantly better. This occurs because the propagation algorithm in the STAMINA models are not as complete as those in

TNM. For this reason, TNM would seem to be a better building block for future analysis.

During evaluation of the second question, the research also provided further insight about shadow zones (the area behind the barrier of reduced noise levels). An increased understanding of the shadow zone depth, effects due to interaction with the ground and sound wave, and how background levels change the actual shadow zone were accomplished as sub-goals to the research work. This will help noise analysts for FDOT to better understand the shadow zones formed behind the noise barrier during the design process.

Finally, in regard to the third question, the answer is mixed. As stated previously, when the measured values were statistically compared to the predicted values, TNM was similar to STAMINA2.1 (the FDOT version of STAMINA). However, when the propagation components were explored, by comparing reference levels to those behind the barrier, TNM was significantly better. This tends to point out other considerations in TNM that will be explored in later reports. Based on the improved propagation algorithms, the much easier use of TNM due to the graphical user interface, and that it will become the FHWA required model in the year 2002, it is recommended that TNM be used for future projects.

## TABLE OF CONTENTS

<b>ACKNOWLEDGMENTS</b>	i
<b>EXECUTIVE SUMMARY</b>	ii
<b>TABLE OF CONTENTS</b>	iv
<b>LIST OF TABLES</b>	v
<b>LIST OF FIGURES</b>	vi
<b>I. INTRODUCTION</b>	1
<b>II. OVERVIEW</b>	2
<b>III. METHODOLOGY AND COLLECTED DATA</b>	4
<b>A. Collection of Sound Data</b>	4
<b>B. Data Formatting</b>	11
<b>C. Modeling</b>	21
<b>D. Statistical Testing</b>	21
<b>E. Traffic Data</b>	22
<b>F. Meteorological Data</b>	23
<b>IV. FINDINGS AND CONCLUSIONS</b>	28
<b>A. Protection of Highway Neighbors</b>	28
<b>B. Prediction of Barrier Design Versus Measured Results</b>	30
<b>C. TNM Versus STAMINA2.0/2.1</b>	44
<b>V. RECOMMENDATIONS</b>	46
<b>VI. REFERENCES</b>	47
<b>APPENDICES</b>	48
<b>TECHNICAL NOTE</b>	162

## LIST OF TABLES

<b>Table 1. Barrier Study Locations</b>	5
<b>Table 2. Actual and Effective Barrier Heights of Project Locations</b>	6
<b>Table 3. List of General Equipment Used for Project</b>	8
<b>Table 4. Detailed Listing of Major Equipment</b>	9
<b>Table 5. Twenty Minute Average Measured Values for 1/3 Octave Band Analyzers</b>	16
<b>Table 6. Measured Sound Levels by Overall A-weighted Analyzers</b>	18
<b>Table 7. Differences in dB(A); (Reference Microphone SPL - Test Microphone SPL)</b>	20
<b>Table 8. Measured Traffic Data</b>	24
<b>Table 9. Predicted and Adjusted Insertion Losses</b>	31
<b>Table 10. Absolute (or Overall) Statistical Results Summary</b>	33
<b>Table 11. Propagation Losses (Reference Microphone - Other Microphone Positions) Statistical Results Summary</b>	33
<b>Table 12. Derived Correction Factors (Modeled Vs. Measured IL Differences)</b>	36
<b>Table 13. L<sub>90</sub> and L<sub>99</sub> Sound Level Determination</b>	41
<b>Table 14. FDOT Noise Study Report IL Compared to Project Derived ILs</b>	44

## LIST OF FIGURES

<b>Figure 1. Typical Layout of Microphones Positions</b>	7
<b>Figure 2. Octave Band Analyzer Setup in Mobile Van</b>	10
<b>Figure 3. Typical Frequency Spectra Comparison, Reference Position (Triangles) Compared to Position 1 (Circles).</b>	13
<b>Figure 4. Typical Contour Plot</b>	14
<b>Figure 5. Shadow Zone Shapes</b>	39
<b>Figure 6. Example of a Derived Shadow Zone Plot</b>	43

## I. INTRODUCTION

The primary goals of this project were to answer three specific questions:

*Are the barriers providing adequate protection for highway neighbors?*

*Are the noise barriers that have been built in Florida performing as predicted?*

*Is the new FHWA Traffic Noise Model significantly better than STAMINA2.0/2.1?*

To answer these questions, and fulfill the goals of this project, specific data were needed. These data were of two types: field data and computed data. The field data included measured sound levels, specific location geometrics, traffic counts, traffic speeds, weather data, and field notes of unusual occurrences. The computed data included prediction of sound levels at specific positions, calculation of insertion losses, shadow zone evaluations, overall trend analysis of the collected data, and comparative analysis of the measured versus modeled results.

This report details the methods used, data collection effort, computer modeling, analysis methods and results that were needed to answer these three basic questions. Final conclusions are then drawn from these results to answer the goals of this project.

## II. OVERVIEW

The first question, “*Are the barriers providing adequate protection for highway neighbors?*”, can be answered by measuring the absolute levels observed in the neighborhood yards behind sound barriers and then compare the measured data to defined criteria levels. Absolute levels, as used in this report, refer to the measured sound pressure levels after quality control measures have been applied. The criteria levels used in this report are those promulgated by the Federal Highway Administration (FHWA)[1] and the Florida Department of Transportation (FDOT)[2]. Both agencies have promulgated Noise Abatement Criteria (NAC). In practice, these criteria are threshold sound levels to determine when abatement should be considered. This can be construed to imply that the NAC levels define when impacts occur at highway neighbor locations near the roadway. According to FHWA the defined level is actually, “...when the noise levels approach or exceed the criteria levels.” FHWA has defined the term approach as being within one decibel on the A-weighted scale<sup>1</sup> of the NAC which results in an actual criteria level of 66 dB;  $L_{Aeq}$  for residential areas.<sup>2</sup> FDOT, in the Project Development and Environment Manual (PD&E Manual)[2] also defines approach as being 66 dB;  $L_{Aeq}$ . This chapter of the PD&E Manual also defines an impacted receiver as:

“A noise sensitive receiver that is or will be subjected to highway traffic noise that approaches or exceeds the noise abatement criterion or substantially exceeds existing noise levels.”

Based on these definitions, the NAC for FDOT and FHWA were compared to absolute measured sound levels in this report to determine if impacts existed behind the noise barriers.

In this study, the absolute levels determined by measurements were done during the day, when heavy traffic volumes existed. Unfortunately, due to staffing requirements and other considerations, it was not possible to be sure that the measurement times coincided with the worst hour of the day for traffic noise levels. Traffic levels near very heavily traveled roadways usually only vary by one to two dB;  $L_{Aeq}$  during the daytime. Less traveled roadways can vary more but sound barriers are not generally needed for these facilities. For this project, all measurements were made for substantial transportation facilities. Because of this, a two dB;  $L_{Aeq}$  variance was assumed and is later discussed.

The second question, “*Are the noise barriers that have been built in Florida performing as predicted?*” can also be determined by looking at the absolute sound levels and the difference when compared to the sound levels that would exist without the noise barrier. The difference in

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<sup>1</sup> Decibels, using the A-weighted scale are often referred to using the nomenclature, dB(A). More recent nomenclature,  $L_A$ , is also used extensively throughout this document except in cases where understanding by the reader is better served by using dB(A).

<sup>2</sup> In this case, the subscript eq has been added ( $L_{Aeq}$ ) to specify the sound level is the equivalent sound level, A-weighted.

sound levels, with and without the noise barrier, are called insertion loss (IL). The calculation of the difference in levels, or insertion loss, was also subsidized by the use of modeling.

The insertion loss, IL, can be defined as shown in Equation 1 below.

$$IL = SPL_{\text{before}} - SPL_{\text{after}} \quad [1]$$

where:  $SPL_{\text{before}}$  = sound pressure level before barrier (or without barrier)  
 $SPL_{\text{after}}$  = sound pressure level after barrier (or with barrier)

In this case  $SPL_{\text{after}}$  would be the absolute level measured for the project since all barriers were already in place. Except in the reference microphone positions, the  $SPL_{\text{before}}$  had to be predicted with the indirect method as described later in this report was used. Prediction techniques and methods are discussed later in this document.

Also in support of this question, shadow zones were determined and plotted. This required substantial work to determine background levels and ground effects. This derived procedure is discussed in detail in this report.

The third question, "*Is the new FHWA Traffic Noise Model significantly better than STAMINA2.0/2.1?*", required modeling each location, at each microphone position, for each measurement period with the Traffic Noise Model (TNM) [4], STAMINA2.0 (FHWA unmodified version)[5], and STAMINA2.1 (the FHWA model modified with Florida specific reference energy mean emission levels)[5]. This modeling effort provided a direct comparison to measured values and a partial validation of the three different computer models.

To better understand the exact methodology used in this analysis it is first important to understand how barrier walls work and how IL is predicted. To assist the reader, these concepts are briefly discussed in a technical note added to the end of this report. Readers unfamiliar with this topic may wish to read the technical note first. The reader is also referred to the references provided in the text and the technical note for a more complete discussion.

### III. METHODOLOGY AND COLLECTED DATA

The project was done in two key parts. Actual data was collected at twelve barrier locations around the State of Florida and modeling was done to evaluate model performance. Each of these major tasks are described in this chapter.

At the beginning of the project, standards and criteria from the U.S. Department of Transportation [6], the International Organization for Standardization (ISO)[7], and the American National Standards Institute (ANSI)[8] were thoroughly reviewed to help insure compliance with all required procedures and methodologies.

#### A. Collection of Sound Data

Data was collected at twelve barrier locations in the State of Florida. Table 1 lists these locations while Table 2 lists the actual and effective barrier heights. The actual height is the height above the base of barrier. The effective height is the height above the ground plane where receivers are located including any elevation increase due to berms or elevated roadways. Additional location specific data are reported separately and included in the attached Appendices A-L. Of note is the alphabetic labeling of each barrier location as shown in Tables 1 and 2. These location designations are used throughout this report for clarity as well as the label for each corresponding location appendix.

Criteria used in the selection of these locations included accessibility, a background level of at least 10 dB;  $L_{Aeq}$  below measured traffic levels<sup>3</sup>, a clear view from the microphone positions to the noise barrier, and cooperation of the local residents.

At each location, detailed information on location geometrics, traffic, weather and sound levels were recorded. Figure 1 shows a typical monitoring array of microphones used at the locations. This array is based on the American National Standards Institute (ANSI) defined procedures [8]. Because the ANSI standard uses metric dimensions, the English units reported in this report are not whole numbers, but include fractional feet, as shown in Figure 1. At some locations more microphone positions were added beyond what is shown in Figure 1 or microphone positions were shifted for location specific conditions. Any specific differences for individual locations that did occur are discussed in the field notes included in Appendices A-L.

In Figure 1, the microphone positions labeled with numbers (e.g., 1, 2, etc) represent microphone positions where 1/3 octave band data were collected. Positions labeled with a letter (e.g., A, B, etc) represent positions where overall sound level analyzers were placed that measured A-weighted sound levels. Multiple heights and distances behind the barriers were achieved by using portable towers that were set up for each run. It should be noted that Microphone Positions 1 and 4 are the same as Microphone Positions B and D. This was done intentionally

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<sup>3</sup> Location J, did have a nearby road that in some of the 10 second sample periods was within 10 dB of the main route, I-195 at some microphone positions.

Table 1. Barrier Study Locations

UCF Letter	City	County	Site Location	FDOT Project Number
A	Jacksonville	Duval	I-95 Dekalb Ave. near Conners Drive	72280-3424
B	Jacksonville	Duval	I-295 River Rd. (West of Buckham Bridge)	72001-3444
C	Daytona Beach	Volusia	S.R. 5A Nova Rd.	79190-3510
D	Sarasota	Sarasota	Albert Place off S.R. 72 (Clark Rd.)	17000-3502
E	Brandon	Hillsborough	I-75 wall on earthen berm north of Woodberry St.	10075-3499
F	Clearwater	Pinellas	Roosevelt Blvd. - S.R. 686 west of 62 <sup>nd</sup> St.	15030-3525
G	St. Petersburg	Pinellas	54 <sup>th</sup> Ave. South (East of 41 <sup>st</sup> St. South)	15190-3422
H	Ft. Lauderdale	Broward	NW 8 <sup>th</sup> St. and NW 20 <sup>th</sup> Ave. @ I-95 Northbound	86070-3506
I	Deerfield Beach	Broward	NE 1 <sup>st</sup> Terrace between NE 48 <sup>th</sup> & NE 52 <sup>nd</sup> St.	87004-3501
J	Miami	Dade	I-195 S.R. 112 Julia Tuttle Causeway (NE 6 <sup>th</sup> Ave. off NE 36 <sup>th</sup> St.)	99004-3420
K	Tamiami	Dade	S.W. 8 <sup>th</sup> St. and S.W. 93 <sup>rd</sup> Ave.	87120-3526
L	Hialeah	Dade	S.R. 924 Gratigny Pkwy/ West 81 <sup>st</sup> St. west of West 6 <sup>th</sup> Ave.	87300-3503

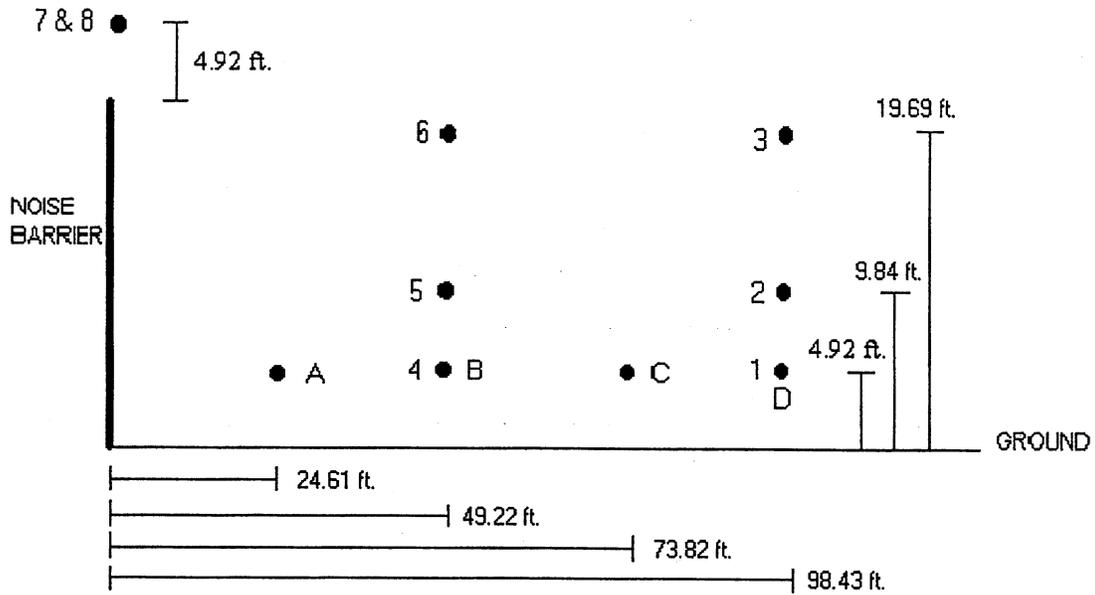
Table 2. Actual and Effective Barrier Heights of Project Locations

UCF Letter	City	Actual Barrier Height (feet)	Effective Barrier Height (feet)
A	Jacksonville	18.5	18.5
B	Jacksonville	15.6	13.5
C	Daytona Beach	11.0	14.5
D	Sarasota	11.0	11.0
E	Brandon	12.5	41.0
F	Clearwater	11.0	11.0
G	St. Petersburg	7.3	7.3
H	Ft. Lauderdale	14.5	14.5
I	Deerfield Beach	13.1	13.1
J	Miami	10.8	13.1
K	Tamiami	11.0	11.0
L	Hialeah	13.2	25.3

for quality control purposes which is discussed later in this report. It should be noted that the defined reference position was 4.92 feet above the top of the noise barrier as prescribed in the ANSI standard method [8]. This method was chosen because of microphone cable length requirements, the urban locations that would be used, and the fact that all noise barriers were already in place. As such, microphone positions 7 and 8 are always reference microphones and always placed at 4.92 feet directly above the noise barrier. Two microphones were placed at this reference position for quality control purposes and to insure that the most critical microphone position data was collected even if problems occurred for one microphone. Accordingly, sound levels were typically measured at twelve positions for each location, although some positions were the same to help with later quality control of the data.

A general listing of equipment used is shown in Table 3. Exact listing of major equipment with associated serial numbers is shown in Table 4. All overall A-weighted sound level analyzers were type 1 as defined by the ANSI [9]. The Octave Band Analyzers were ANSI type 2. Data were collected from the overall sound level analyzers by using internal storage and dumping of data to a laptop computer at the end of each day. The 1/3 octave band analyzers were a part of

Figure 1. Typical Layout of Microphones Positions



LEGEND FOR FIGURE 1:

- Microphone Position 1: 4.92 feet above the ground; 98.43 feet from barrier
- Microphone Position 2: 9.84 feet above the ground; 98.43 feet from barrier
- Microphone Position 3: 19.69 feet above the ground; 98.43 feet from barrier
- Microphone Position 4: 4.92 feet above the ground; 49.22 feet from barrier
- Microphone Position 5: 9.84 feet above the ground; 49.22 feet from barrier
- Microphone Position 6: 19.69 feet above the ground; 49.22 feet from barrier
- Microphone Position 7: 4.92 feet above barrier
- Microphone Position 8: 4.92 feet above barrier
- Microphone Position A: 4.92 feet above the ground; 24.61 feet from barrier
- Microphone Position B: 4.92 feet above the ground; 49.22 feet from barrier
- Microphone Position C: 4.92 feet above the ground; 73.82 feet from barrier
- Microphone Position D: 4.92 feet above the ground; 98.43 feet from barrier

Table 3. List of General Equipment Used for Project

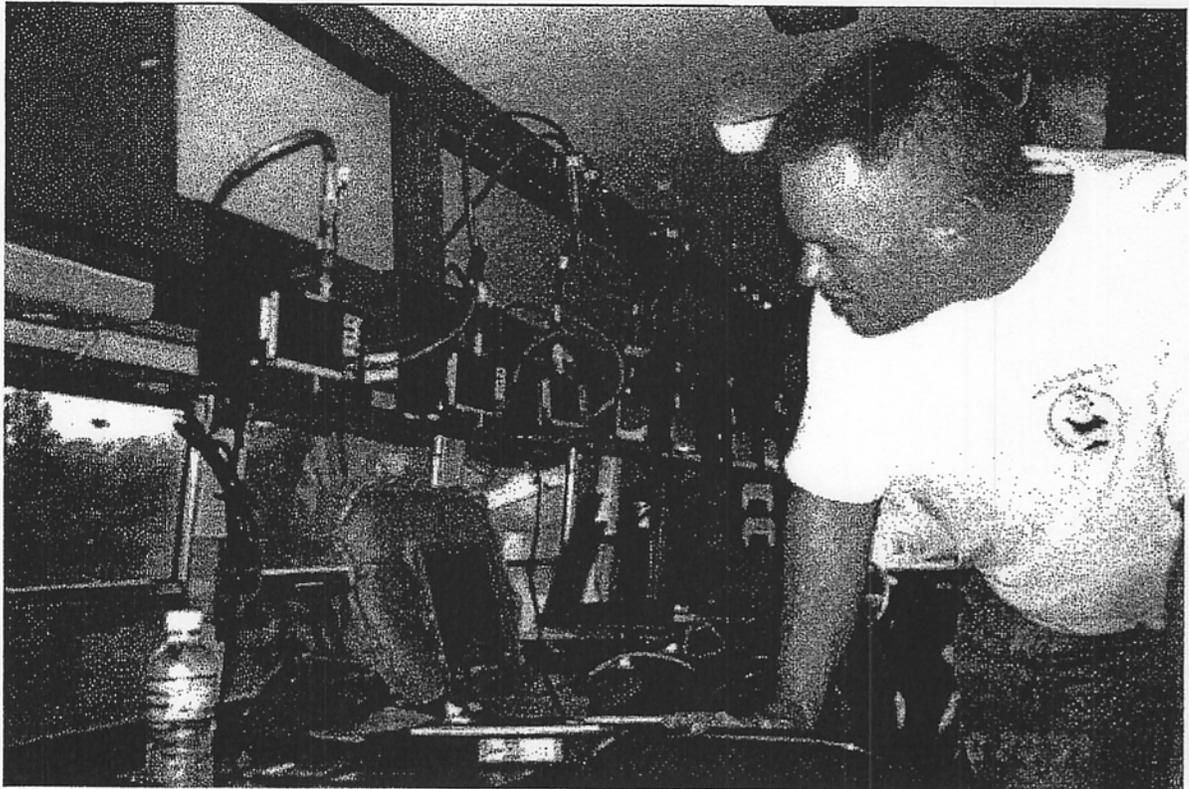
Vehicle	1981 Dodge Van
Portable Sound Analyzers	Metrosonic db-308 Calibrator cl-304 Tripods Heavy duty tape Wind screens Microphone holders
Sound Analyzer System	Ivie 1/3 Octave Band Analyzers GenRad multi-frequency calibrators Tower Assemblies GenRad Microphones/Preamps Wind screens Cables
Power Supply	Small generator Large generator Wooden boards/wall w/lead blanket Hi-voltage extension line Low-voltage extension line Automotive batteries
Meteorology Equipment	Tripod and tower RM Young u-v-w Anemometers (2 heights) Aspirated thermometers (2) Compass Sling Psychrometer Mercury thermometer (backup)
Data Acquisition Equipment	Sound Data Gateway laptop computer Omega Data Acquisition System Associated cables AC adapter Inverters (2) Car battery (2) Charger Meteorological Data Campbell data acquisition unit
Vehicle Speed Measurement	Radar Guns (2)
Communication Equipment	Motorola Walkie-talkies (2) Charger unit

Table 4. Detailed Listing of Major Equipment

Major Equipment	Project Designation	Serial Number
Metrosonic dB-308 Sound Level Meters		2134 2136 2137 2143 2146
Ivie Electronics IE 30A Audio Analyzers	Unit 1 Unit 2 Unit 3 Unit 4 Unit 5 Unit 6 Unit 7 Unit 8 Unit 9 Unit 10 Unit 11 Unit 12	805X034 805C418 805C861 805C392 805C246 805C372 805C415 805B325 805C850 805C840 805C859 992C986
Ivie Electronics IE 3P Preamplifiers	Unit 1 Unit 2 Unit 3 Unit 4 Unit 5 Unit 6 Unit 7 Unit 8 Unit 9 Unit 10 Unit 11 Unit 12	138 137 166 120 135 102 104 117 144 146 145 125
CL-304 Calibrator		2219
GenRad Sound Level Calibrators		2411 911642015 9146545009 2365
Aspirated Thermometers		41342a 41342b
R.M. Young UVW Anemometers		UV02192 UV02193
Omega InstruNet Model 100 Analog/Digital Input/Output System		43514
Campbell Scientific CR23X Micrologger		2055

an overall measurement system. The overall measurement system consisted of the microphones with associated preamplifiers connected to cables that were routed to a highway van. Inside the van, eight Ivie octave band analyzers were used to measure the sound levels based on the microphone input. The microphone positions have been previously described and were located as shown in Figure 1<sup>4</sup>. The output of the Ivie analyzers were connected to a commercial data collection system which provided some on-site processing and allowed direct recording to a laptop PC. Figure 2 shows a picture of this monitoring system inside the van.

Figure 2. Octave Band Analyzer Setup in Mobile Van



The recorded information from this measurement system included time, calibration levels, frequency and amplitude data on a real-time basis. Concurrently, traffic volumes were manually counted, vehicles were classified, vehicle speed data were collected using radar guns, and weather information was collected. The weather information was automatically recorded to a separate data recording system with the time base synchronized to the sound level measurement system. The weather data was collected at two heights (4.92 and 19.69 feet) and included wind speed, wind direction and temperature. Relative humidity was measured manually at 4 to 5 feet above the local ground surface.

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<sup>4</sup> To provide clarity for the reader, in this report, a location refers to a barrier measurement site and a position refers to the microphone location in reference to the barrier.

Again, for quality control purposes and to insure adequate samples were available at each location, four sample runs were made. These sample runs were twenty (20) minutes in length. This was more than required by the ISO standard [7] which suggests 15 minutes. The additional data allowed deletions to be made during quality control and still have a representative sample. The multiple sample periods permitted whole sample periods to be discarded if necessary and allowed any major variations in an individual sample period to be determined during quality control measures. Such variations would tend to show problems in data collection and were used as another quality control measure.

The overall A-weighted sound level analyzers collected data for a longer period than the twenty minute sample period, but only data collected during the actual sample period was used in this analysis. These analyzers were set to slow response (integration time of one second) and data averaging set to ten (10) seconds to match the data averaging times of the 1/3 octave band system and the weather data collection system.

While the averaging time for the 1/3 octave band analyzers was set to 10 seconds, the data collection system dictated the actual sampling rate for the octave band analyzers. The octave band analyzers actual sample rate was more than that usually recorded for fast response (eight samples per second) but the output to the data collection system could only be recorded from 1 to 3 times per second, depending on a timing sweep of the equipment. So, in effect, the octave band analyzers were also recorded in a fashion similar to slow response. These responses were further averaged to ten second intervals so that all data could be compared on a similar time basis.

Although a second phase of this information is looking at data in short time steps, only the overall averages for the entire twenty minute sample period were used in the results that are reported here. This was required to establish  $L_{Aeq}$  values for comparison to the FDOT and FHWA NAC and for later comparison to computer models which only report an hourly  $L_{Aeq}$  value.

All sound level analyzers, 1/3 octave band analyzers, and acoustic calibrators were sent to the manufacturer for calibration and testing. Then, using good field practices, acoustic calibrators were used to calibrate the equipment just prior to measurements. To insure correct operation, the calibration was checked again at the end of the sampling. During the sampling, if equipment was moved, or if any problems were suspected, calibration was performed for that piece of equipment before continuing the sampling. No data were used in this analysis if the final calibration values varied from initial calibration settings by more than 0.5 dB. In addition, adjustments were made to the levels using the initial and final calibration values as detailed in the ANSI standard [8]. Finally, the frequency response for each 1/3 octave band analyzer were also checked in the field by using tone calibrators.

## **B. Data Formatting**

The large amount of data collected represented a significant task in formatting. Commercially available spreadsheets were used to sort, format, perform some data derivation and to prepare graphics after returning to the University of Central Florida (UCF) Community Noise Laboratory

facilities. Great care and multiple data checks were used to avoid errors. While these multiple checks did add time in data reduction, it kept errors from being included in the final analysis.

The formatting and initial data derivation permitted a review of all information. An example of the data formatting and derivation process included developing overall A-weighted sound levels based on the 1/3 octave band data that were used in this analysis. Many data tables were also derived. Using these formatted data tables, multiple graphical representations of the data were drawn. Although too numerous to show here, graphical representations included average sound levels by location with the standard deviation, average spectra at each microphone position, comparison of the reference and other measured positions, contour plots, insertion loss plots, and shadow zone plots of sound levels on the neighborhood side of the barriers. Two of the more important types of graphics used, average spectra at each microphone position and shadow zone plots, are shown in Figures 3 and 4 as examples. Those figures, considered to be more significant than others, have been included in the location appendices (Appendices A-L).

It can be seen from these examples that these plots allowed a quick graphical look at the noise reduction compared to the reference position above the wall, a quick comparison of the measured versus predicted values (modeling is discussed in detail later in this report), and overall trends at microphone positions of varying distances behind the noise barrier and varying heights above the local ground elevation. This was quite useful in the quality control effort and in later analysis.

Plots such as Figure 3 were particularly useful to review the frequency spectra and to compare the change in spectra from the reference microphone positions to other positions behind the noise barrier. For example, in Figure 3, the decrease in levels is evident between the reference position and Position 1. It is also easy to see the change in the spectrums due to ground effects. It should be remembered that ground effects still remain important, even with noise barriers in place. These ground effects, in the lower frequencies (approximately 100 to 1000 Hertz), decrease significantly with height above the surface. Also important was the variation in each frequency band. Although not shown in Figure 3, similar plots showing the standard deviation of the measurements allowed variability of each position to be determined by 1/3 octave band. Finally, the reader should note that these spectra have been A-weighted, with the corrections applied to each 1/3 octave band. Other plots also helped in quality control by showing if data discontinuities existed. A discontinuity of measured data is a direct indication of equipment problems or large changes in the sound levels for some unexpected reason.

Many other plots were developed to allow a qualitative visualization of the shadow zone behind the barrier. Of most importance is the shape of the shadow zone. The shadow zone plots are discussed later in this report.

Figure 3. Typical Frequency Spectra Comparison, Reference Position (Triangles) Compared to Position 1 (Circles).

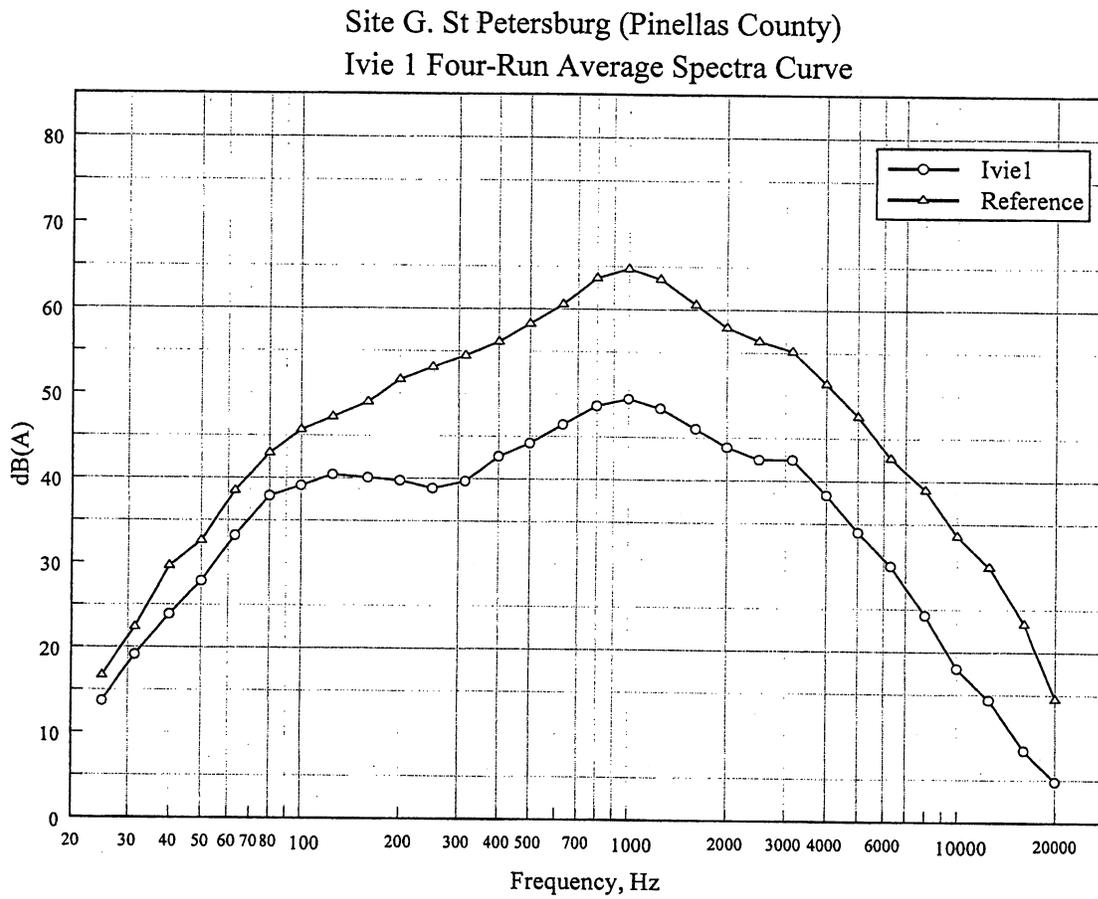
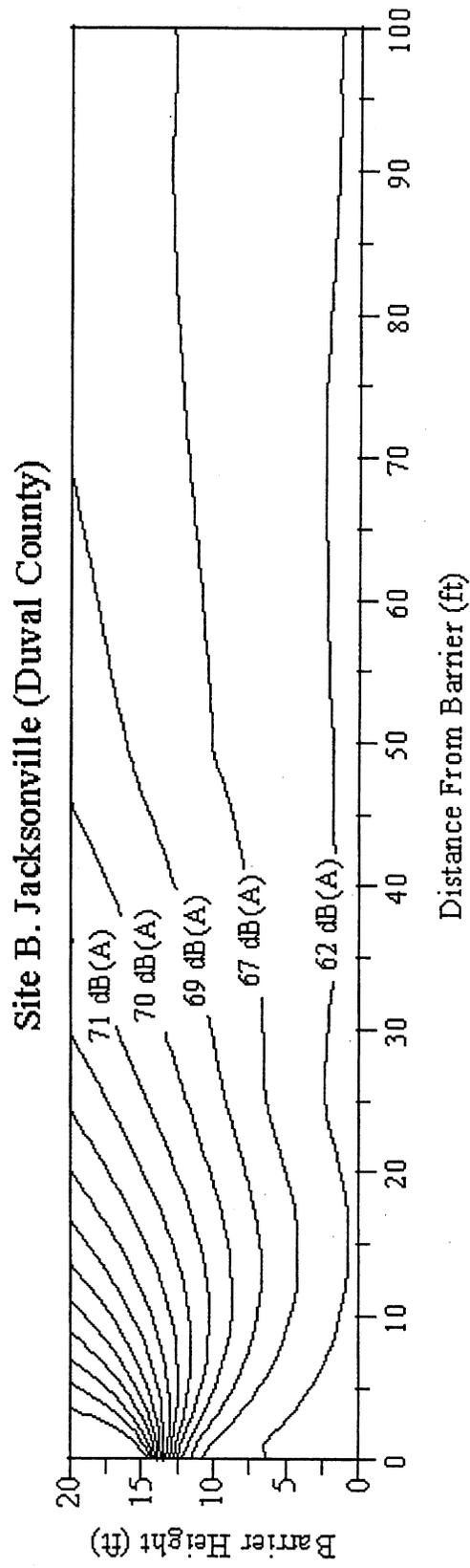


Figure 4. Typical Contour Plot



The next step in data processing was to complete multiple quality control measures. These quality control measures included:

- a comparison of the derived A-weighted levels to those measured with overall sound level analyzers where mutual positions existed;
- a comparison of the two reference microphone positions (by spectra comparison);
- comparison of the measured values from sample period to sample period;
- comparison of levels at each tower;
- comparison of levels from tower to tower;
- comparison of levels from one time step to the next;
- shape of spectrum curves;
- review of calibration results;
- field notes of unusual occurrences; and,
- review of the meteorology data.

If the criteria established for each of these quality control measures were not met, the data were discarded and not used in the final analysis. After deletion of all suspect data, reformatting occurred and new plots were developed.

The final data base, after quality control, was then used in project analysis. The analysis consisted of multiple tasks including:

- examination and analysis of absolute sound levels;
- examination and analysis of level differences between the reference position and microphone positions behind the barrier;
- comparisons to computer modeling results;
- quantitative and qualitative analysis of the shadow zone; and,
- comparison to previous analysis performed by FDOT during project analysis.

The quantitative look at the absolute noise levels permitted evaluation of the impacts experienced by the roadway neighbors. This evaluation also permitted the measured absolute values to be compared to modeling results. Modeling is discussed in the next section of this report. Besides the use of absolute measured values to determine the degree of impact on the highway neighbors, another important consideration is the difference between the reference position (microphone position above the barrier) and the microphone positions behind the barrier. This difference analysis allows a better review of propagation accuracy of the various computer models because the reference energy mean emission levels no longer influence the analysis results. Listed in Table 5 are the absolute values for the 1/3 octave band analyzers. In Table 6 the results for the overall A-weighted analyzers are included. Table 7 lists the computed differences from the microphone positions behind the wall as compared to the reference microphone positions.

Table 5. Twenty Minute Average Measured Values for 1/3 Octave Band Analyzers

Location	Run	Ivie 1	Ivie 2	Ivie 3	Ivie 4	Ivie 5	Ivie 6	Ivie 7	Ivie 8
A. Jacksonville (Duval County)	1	NA	63.5	67.6	NA	65.2	68.5	79.8	79.3
	2	63.0	63.4	67.5	NA	65.3	68.6	80.1	79.8
	3	62.8	63.3	68.2	NA	65.4	68.6	79.9	79.6
	4	62.9	63.4	68.4	NA	65.5	68.8	79.9	79.6
	Avg	62.9	63.4	67.9	NA	65.3	68.6	79.9	79.6
B. Jacksonville (Duval County)	1	NA	65.6	66.8	64.3	66.1	69.4	76.1	77.1
	2	NA	66.2	67.0	64.7	66.5	70.0	76.2	77.5
	3	64.0	66.4	67.0	64.7	66.6	69.7	76.1	77.5
	4	63.3	66.3	69.3	64.1	66.6	69.9	76.2	77.5
	Avg	63.7	66.1	67.7	64.5	66.5	69.8	76.2	77.4
C. Daytona (Volusia County)	1	55.3	56.9	61.9	57.6	59.2	NA	NA	73.0
	2	55.7	57.1	61.2	56.7	58.2	NA	NA	73.3
	3	55.8	57.4	61.7	58.3	59.4	NA	NA	74.2
	4	55.9	57.8	62.2	58.9	60.0	NA	NA	74.3
	Avg	55.7	57.3	61.8	58.0	59.2	NA	NA	73.7
D. Sarasota (Sarasota County)	1	Ivie Data Not Used							
	2								
	3								
	4								
	Avg								
E. Brandon (Hillsborough County)	1	62.1	63.1	65.5	62.3	63.4	64.6	83.1	83.1
	2	61.3	62.3	64.3	61.2	62.0	62.8	82.9	83.5
	3	63.0	64.0	66.1	63.0	64.6	65.2	83.5	84.0
	4	64.5	65.4	67.6	64.5	65.8	66.3	83.2	83.8
	Avg	62.9	63.9	66.0	62.9	64.2	64.9	83.2	83.6
F. Clearwater (Pinellas County)	1	54.9	56.4	61.7	55.4	57.1	65.5	72.8	72.0
	2	56.0	57.6	63.4	56.5	58.2	66.5	72.3	71.5
	3	55.6	57.4	63.4	56.3	58.1	65.8	71.4	71.5
	4	54.8	55.8	64.8	55.4	57.0	65.6	71.7	72.1
	Avg	55.4	56.9	63.5	55.9	57.6	65.9	72.1	71.8
G. St. Petersburg (Pinellas County)	1	56.5	57.7	59.3	58.0	58.7	NA	71.1	70.4
	2	56.9	58.1	60.1	58.4	59.1	NA	71.4	71.0
	3	57.2	58.4	60.5	58.8	59.2	NA	71.1	71.2
	4	57.1	58.5	60.7	58.9	59.4	NA	71.3	71.0
	Avg	56.9	58.2	60.2	58.5	59.1	NA	71.2	70.9

Table 5. Twenty Minute Average Measured Values for 1/3 Octave Band Analyzers (Continued)

Location	Run	Ivie 1	Ivie 2	Ivie 3	Ivie 4	Ivie 5	Ivie 6	Ivie 7	Ivie 8
H. Ft. Lauderdale (Broward County)	1	64.9	67.1	69.5	66.5	66.2	72.7	81.0	80.6
	2	64.4	66.9	70.7	66.2	66.3	72.6	80.9	80.6
	3	64.1	66.6	69.7	66.0	66.3	72.7	81.1	80.7
	4	63.3	65.8	68.8	65.4	65.7	72.1	81.0	80.4
	Avg	64.2	66.6	69.7	66.0	66.1	72.5	81.0	80.6
I. Deerfield Beach (Broward County)	1	63.2	65.1	69.3	65.1	66.4	72.2	79.0	78.4
	2	62.9	64.9	69.0	64.8	66.2	71.9	79.2	78.6
	3	63.3	65.4	69.3	65.0	66.4	72.1	79.1	78.5
	4	63.1	65.3	69.3	65.0	66.4	72.1	79.1	78.5
	Avg	63.1	65.2	69.2	65.0	66.4	72.1	79.1	78.5
J. Miami (Dade County)	1	64.7	64.9	66.9	65.2	66.0	69.5	80.7	80.2
	2	64.9	65.2	67.1	65.6	66.3	70.0	81.0	80.2
	3	65.2	65.3	67.3	65.9	66.6	70.2	81.3	80.7
	4	65.4	65.4	67.4	65.8	66.7	69.9	81.2	80.8
	Avg	65.1	65.2	67.2	65.6	66.4	69.9	81.1	80.5
K. Tamiami (Dade County)	1	52.6	54.4	58.3	55.4	56.5	62.6	73.6	NA
	2	53.0	54.0	58.0	55.3	56.6	62.5	73.5	NA
	3	53.1	54.1	58.8	55.9	56.9	63.0	74.1	NA
	4	53.3	54.2	58.4	55.8	57.0	62.8	74.6	NA
	Avg	53.0	54.2	58.4	55.6	56.8	62.7	74.0	NA
L. Hialeah (Dade County)	1	58.1	76.7	61.9	58.5	59.4	61.8	76.7	NA
	2	58.2	76.6	62.3	58.8	59.9	62.1	76.6	NA
	3	58.8	76.8	62.9	59.3	60.7	62.9	76.5	NA
	4	58.7	77.2	63.1	59.6	60.9	63.3	77.0	NA
	Avg	58.5	76.8	62.6	59.1	60.3	62.6	76.7	NA

Table 6. Measured Sound Levels by Overall A-weighted Analyzers

Location	Run	A	B	C	D
		24.61 ft	49.22 ft	73.82 ft	98.43 ft
A. Jacksonville (Duval County)	1	64.5	64.6	64.1	63.7
	2	64.5	64.6	64.0	63.5
	3	64.1	64.3	63.7	63.1
	4	64.2	64.3	63.7	63.1
	Avg	64.3	64.5	63.9	63.4
B. Jacksonville (Duval County)	1	64.8	64.3	63.6	63.1
	2	65.0	64.4	63.8	63.2
	3	64.8	64.5	63.7	63.3
	4	64.5	64.0	63.2	62.7
	Avg	64.8	64.3	63.6	63.1
C. Daytona (Volusia County)	1	58.6	58.1	57.0	55.6
	2	57.5	56.5	55.5	55.8
	3	59.4	58.2	57.0	56.0
	4	60.0	59.4	58.5	56.2
	Avg	59.0	58.2	57.1	55.9
D. Sarasota (Sarasota County)	1	52.4	52.2	53.4	56.3
	2	49.6	48.4	48.9	- <sup>1</sup>
	Avg	51.2	50.7	51.7	56.3
E. Brandon (Hillsborough County)	1	62.6	61.1	61.9	61.2
	2	62.0	60.2	60.8	60.1
	3	63.4	61.8	62.7	61.7
	4	64.2	63.4	64.1	63.0
	Avg	63.1	61.8	62.5	61.6
F. Clearwater (Pinellas County)	1	56.0	54.8	55.0	54.4
	2	57.6	56.2	56.4	55.8
	3	56.9	55.5	55.6	55.2
	4	56.3	54.9	55.0	54.0
	Avg	56.7	55.4	55.5	54.9
G. St. Petersburg (Pinellas County)	1	59.5	57.4	56.7	56.1
	2	60.1	58.0	57.3	56.5
	3	60.3	58.2	57.4	56.8
	4	60.2	58.2	57.5	56.7
	Avg	60.0	58.0	57.2	56.5

Table 6. Measured Sound Levels by Overall A-weighted Analyzers (Continued)

Location	Run	A	B	C	D
		24.61 ft	49.22 ft	73.82 ft	98.43 ft
H. Ft. Lauderdale (Broward County) <sup>2,3,4</sup>	1	65.3	65.5	64.6	64.1
	2	65.1	65.2	64.3	63.5
	3	65.1	64.8	63.9	63.0
	4	64.5	64.2	63.2	62.2
	Avg	65.0	65.0	64.0	63.3
I. Deerfield Beach (Broward County)	1	66.5	65.3	65.2	63.0
	2	66.2	65.0	64.8	62.6
	3	66.4	65.2	65.1	63.0
	4	66.2	65.0	64.9	62.8
	Avg	66.3	65.1	65.0	62.9
J. Miami (Dade County) <sup>5</sup>	1	65.3	65.3	65.0	64.7
	2	65.5	65.6	65.2	64.9
	3	65.9	66.0	65.6	65.3
	4	65.8	65.9	65.5	65.3
	Avg	65.6	65.7	65.3	65.1
K. Tamiami (Dade County)	1	58.5	56.2	54.5	53.3
	2	58.0	56.2	54.6	53.6
	3	58.7	56.6	54.8	53.7
	4	58.8	56.5	54.8	53.9
	Avg	58.5	56.4	54.7	53.6
L. Hialeah (Dade County)	1	57.6	57.9	59.1	-
	2	57.8	58.2	59.3	-
	3	58.4	58.8	60.2	-
	4	58.5	59.1	60.6	-
	Avg	58.1	58.5	59.8	-

<sup>1</sup> This 98.4 ft Metrosonic was moved to the reference position with  $L_{eq} = 58.6$  dB(A).

<sup>2</sup> The 98.4 ft Metrosonic was placed at 108.3 ft due to power lines.

<sup>3</sup> A Metrosonic was placed at 196.9 ft for runs 1-3 with  $L_{eq}$  values of 62.5, 62.1 and 61.4 dB(A). The average value was 62.0 dB(A).

<sup>4</sup> For run 4, the 196.9 ft Metrosonic was placed at 24.6 ft and past the end of the barrier with  $L_{eq} = 75.8$  dB(A).

<sup>5</sup> A Metrosonic was placed at 123.0 ft with  $L_{eq}$  values of 65.6, 65.7, 66.0, and 66.1 dB(A). The average value was 65.9 dB(A).

Table 7. Differences in dB(A); (Reference Microphone SPL - Test Microphone SPL)

Site/Run	$\Delta$ Ivie1	$\Delta$ Ivie2	$\Delta$ Ivie3	$\Delta$ Ivie4	$\Delta$ Ivie5	$\Delta$ Ivie6	$\Delta$ metroA 24.61'	$\Delta$ metroC 73.82'
A1	NA	15.80	11.70	NA	14.10	10.80	14.80	15.20
A2	16.80	16.40	12.30	NA	14.50	11.20	15.30	15.80
A3	16.80	16.30	11.40	NA	14.20	11.00	15.50	15.90
A4	16.70	16.20	11.20	NA	14.10	10.80	15.40	15.90
B1	NA	11.50	10.30	12.80	11.00	7.70	12.30	13.50
B2	NA	11.30	10.50	12.80	11.00	7.50	12.50	13.70
B3	13.50	11.10	10.50	12.80	10.90	7.80	12.70	13.80
B4	14.20	11.20	8.20	13.40	10.90	7.60	13.00	14.30
C1	17.70	16.10	11.10	15.40	13.80	NA	14.40	16.00
C2	17.60	16.20	12.10	16.60	15.10	NA	15.80	17.80
C3	18.40	16.80	12.50	15.90	14.80	NA	14.80	17.20
C4	18.40	16.50	12.10	15.40	14.30	NA	14.30	15.80
E1	21.00	20.00	17.60	21.00	19.70	18.50	20.50	21.20
E2	22.20	21.20	19.20	22.30	21.50	20.70	21.50	22.70
E3	21.00	20.00	17.90	21.00	19.40	18.80	20.60	21.30
E4	19.30	18.40	19.20	19.30	18.00	17.50	19.60	19.70
F1	17.10	15.60	10.30	16.60	14.90	6.50	16.00	17.00
F2	16.60	15.10	9.80	16.10	14.40	6.00	13.90	15.10
F3	15.90	14.10	8.10	15.20	13.40	5.70	14.60	15.90
F4	17.30	16.30	7.30	16.70	15.10	6.50	15.80	17.20
G1	13.90	12.70	11.10	12.40	11.70	NA	10.90	13.70
G2	14.10	12.90	10.90	12.60	11.90	NA	10.90	13.70
G3	14.00	12.80	10.70	12.40	12.00	NA	10.90	13.80
G4	13.90	12.50	10.30	12.10	11.60	NA	10.80	13.50
H1	15.70	13.50	11.10	14.10	14.40	7.90	15.30	16.00
H2	16.20	13.70	9.90	14.40	14.30	8.00	15.50	16.30
H3	16.60	14.10	11.00	14.70	14.40	8.00	15.60	16.80
H4	17.10	14.60	11.60	15.00	14.70	8.30	15.90	17.20
I1	15.20	13.30	9.10	13.30	12.00	6.20	11.90	13.20
I2	15.70	13.70	9.60	13.80	12.40	6.70	12.40	13.80
I3	15.20	13.10	9.20	13.50	12.10	6.40	12.10	13.40
I4	15.40	13.20	9.20	13.50	12.10	6.40	12.30	13.60
J1	15.30	15.00	13.10	14.60	13.90	10.20	14.70	15.00
J2	15.50	15.40	13.40	14.80	14.10	10.50	14.80	15.10
K1	21.00	19.20	15.30	18.20	17.10	11.00	15.10	19.10
K2	20.90	19.10	15.20	18.10	17.00	10.90	15.50	18.90
K3	21.00	20.00	15.30	18.20	17.20	11.10	15.40	19.30
K4	21.30	20.40	16.20	18.80	17.60	11.80	15.80	19.80
L1	18.60	NA	14.80	18.20	17.30	14.90	NA	17.60
L2	18.40	NA	14.30	17.80	16.70	14.50	NA	17.30
L3	17.70	NA	13.60	17.20	15.80	13.60	NA	16.30
L4	18.30	NA	13.90	17.40	16.10	13.70	NA	16.40

## C. Modeling

In order to evaluate current models in use, results from three models were compared to the measured results. These three models included the Traffic Noise Model (TNM) [3], STAMINA2.0 with national reference energy mean emission levels [4], and STAMINA2.1 with Florida specific emission levels [5]. These models were selected because:

- TNM is being phased in at this time to replace STAMINA2.0, the current regulatory model;
- STAMINA2.1 is the current regulatory model in Florida varying only in the Reference Energy Mean Emission Levels from STAMINA2.0.

In addition, in the case where noise barriers are in place and cannot be removed, the ANSI indirect method for determining insertion loss allows the use of prediction models for determination of the no barrier case [8]. For completeness, the indirect method was evaluated for both methodologies used in the computer models; TNM versus STAMINA2.0/STAMINA2.1<sup>5</sup>.

Modeling required that detailed input files be constructed for each sample. As such, input files were created for each location, at each microphone position, and each sample run. This required an extensive review of information for each location. Geometric data measured during sampling, maps, aerials, collected traffic volumes classified by vehicle type, traffic speed data that were collected, ground type and cover, and other data as needed were used to build the input files for all the models. While the input files were too voluminous to include in this report, they have been archived and stored.

It should also be noted that the prescribed input methodology, as promulgated by FHWA or FDOT depending on the model, was used during construction of the input files. For example, 50% relative humidity, 68 degrees Fahrenheit, and average pavement type were used in the TNM as prescribed by FHWA policy even though it was known that these were not the correct values since weather parameters were measured and pavement type was known. Further research is underway to explore the error introduced by the use of the FHWA policy input requirements.

## D. Statistical Testing

Statistical testing of the modeled vs. measured results was done in two ways. First, the absolute measured values were directly compared to the modeled values at each location, for each microphone position, for each sample run, and for each model. This testing allowed the overall model performance to be evaluated. Or in other words, how closely did the models predict the true sound levels ( $L_{Aeq}$ ).

Second, the difference between the reference microphone position and microphone positions behind

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<sup>5</sup> STAMINA2.0 and 2.1 use the same diffraction algorithms. See the technical note at the end of this report for more detail.

the wall were compared for both the measured data and modeled values. This second testing, a comparison of differences, permitted the propagation algorithms of the models to be tested independent of the reference energy mean emission levels. In more simple terms, this test compared the differences from the reference microphone and other microphone positions from the measured to the predicted values.

Seven standard statistical tests were used. These tests are well defined [10] and included:

1. Maximum Positive Error
2. Maximum Negative Error
3. Gross Error
4. Variance
5. Mean Sum of Squared Error (MSSE)
6. Average Bias
7. Fractional Bias

Maximum Positive Error was simply the greatest over-prediction at any location, for any position, for any sample run. Minimum Negative Error was the greatest under-prediction that occurred. Gross error is average of the difference between the predicted and measured values at each location. The other tests used are more involved, so for clarity, the other tests mathematical formulae are shown below.

$$\text{Variance of } \theta_p = E_a[\theta_p - E_a(\theta_p)]^2 = E_a(\theta_p)^2 - [E_a(\theta_p)]^2 \quad [2]$$

$$\text{Mean Sum of Squared Error (M.S.E.) of } \theta_p = [1/n [\sum(\theta_p - \theta_m)^2]]^{1/2} \quad [3]$$

$$\text{Average Bias of } \theta_p = E_a(\theta_p) - \theta_m \quad [4]$$

$$\text{Fractional Bias of } \theta_p = [2 (E_a(\theta_p) - E_a\theta_m)] / [E_a \theta_m + E_a \theta_p] \quad [5]$$

where:  $\theta_m$  = the measured value  
 $\theta_p$  = the predicted value  
 $E_a$  = the averaging with respect to the distribution

These tests permitted a review of the accuracy of the models reported later in this report.

## E. Traffic Data

Traffic data needed to be exact since modeling was to be used in the determination of insertion loss. To do this, traffic volumes on all significant, nearby roadways were counted manually during each sample period for each direction of travel. Vehicle classifications were also done at the same time using the FHWA defined vehicle classes of cars, medium trucks, heavy trucks, busses and

motorcycles.<sup>6</sup> As such, the volume of each vehicle class was known during each sample period.

Speed data were also important. Speed data were collected using radar guns for accuracy. Speeds in both traffic directions for the nearby major traffic facilities were obtained. These speed data were averaged for each 20 minute sample run to allow input into the three computer models. The traffic data are shown in Table 8.

## **F. Meteorological Data**

Since meteorological effects, primarily refraction, can have such a drastic effect on sound propagation, this data was also carefully collected. Wind speed, direction, and temperature were collected at two heights: 4.92 and 19.69 feet. Collection for the wind speed and direction was done by using U-V-W anemometers. Polypropylene propellers were used so that very low wind speeds could be measured. The temperature data was collected using aspirated thermometers. The aspirated thermometer shield helped to insure that bias due to case heating did not occur. The temperature sensors had a precision of 0.1 degrees Centigrade (0.18 degrees Fahrenheit) so that the lapse rate over the small elevation difference (14.87 feet) could be determined. Mercury thermometers were used to check the temperature as well, and used as a quality control measure. Relative humidity was also determined at each location using a sling psychrometer.

Recording of the wind speed, direction and temperature data were done using a data logger system. The system was programmed to report 10 second averages and the clock was synchronized with the sound level data collection system. Problems with the system prevented collection of automated data for the first two locations. At these locations, manual collection methods had to be used. Further analysis is being conducted on the atmospheric effects. In this report, no data was used if the wind speed exceeded 12 miles-per-hour.

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<sup>6</sup> In general, the FHWA methodology defines a car as any vehicle with 2 axles and 4 wheels, a medium truck as a vehicle with 2 axles but more than 4 wheels, and a heavy truck as a vehicle with more than 2 axles. Buses are considered to be large city busses and motorcycles are 2 or 3 wheeled vehicles.

Table 8. Measured Traffic Data

Site Location	Test No.	Autos	Speed		Speed		Speed		Speed		Speed	
			(mph)	MT	(mph)	HT	(mph)	MC	(mph)	Bus	(mph)	
A Dekalb St.	1	NB 2427	66	135	64	159	63	6	66	3	66	
A Dekalb St.	1	SB 2448	63	102	59	90	60	0	0	6	66	
A Dekalb St.	2	NB 2856	63	99	61	159	61	0	0	0	0	
A Dekalb St.	2	SB 3084	63	105	58	105	59	12	66	0	0	
A Dekalb St.	4	NB 2859	62	147	63	120	62	0	0	48	57	
A Dekalb St.	4	SB 3219	65	117	59	120	62	3	65	6	65	
A Dekalb St.	5	NB 2730	65	132	62	132	63	0	0	6	58	
A Dekalb St.	5	SB 3351	64	120	67	105	60	0	0	12	64	
B River Rd.	1	WB 2211	65	114	60	288	65	0	0	3	60	
B River Rd.	1	EB 2418	70	108	63	276	68	3	69	0	0	
B River Rd.	2	WB 2133	65	102	62	315	65	3	60	0	0	
B River Rd.	2	EB 2421	66	135	63	210	65	0	0	3	63	
B River Rd.	3	WB 2322	65	36	62	279	65	3	47	0	0	
B River Rd.	3	EB 2259	67	123	61	201	62	0	0	3	62	
B River Rd.	4	WB 2334	64	102	62	279	64	3	57	0	0	
B River Rd.	4	EB 2475	65	102	60	225	63	9	60	6	54	
C Nova Rd.	1	NB 807	47	30	42	6	52	105	44	6	47	
C Nova Rd.	1	SB 951	43	30	39	6	43	75	44	0	0	
C Nova Rd.	2	NB 894	48	27	39	6	44	96	43	0	0	
C Nova Rd.	2	SB 1023	40	30	36	15	35	117	41	9	40	
C Nova Rd.	3	NB 789	48	33	44	12	44	165	46	0	0	
C Nova Rd.	3	SB 951	42	51	45	6	34	102	45	6	45	
C Nova Rd.	4	NB 1038	47	36	46	6	51	105	55	15	47	
C Nova Rd.	4	SB 1098	43	21	38	12	30	117	44	6	39	

Table 8. Measured Traffic Data (Continued)

Site Location	Test		Speed		Speed		Speed		Speed		Speed	
	No.		Autos (mph)	MT (mph)	HT (mph)	MC (mph)	Bus (mph)					
E Woodberry	1	NB	2157	69	132	62	318	67	24	69	18	62
E Woodberry	1	SB	2619	68	183	65	243	65	9	68	6	58
E Woodberry	2	NB	2400	66	138	62	279	64	9	78	3	66
E Woodberry	2	SB	2520	68	126	61	246	64	6	71	24	67
E Woodberry	3	NB	2616	67	147	66	363	67	21	65	6	67
E Woodberry	3	SB	2910	69	186	63	189	66	6	68	12	72
E Woodberry	4	NB	2538	67	135	67	333	66	6	65	9	67
E Woodberry	4	SB	2838	70	165	61	183	63	3	70	30	58
F Roosevelt	1	WB	1365	47	27	41	21	37	0	0	9	34
F Roosevelt	1	EB	1470	43	48	36	12	30	0	0	18	36
F Roosevelt	2	WB	1479	48	39	38	15	47	0	0	3	28
F Roosevelt	2	EB	1509	41	36	39	21	44	0	0	12	35
F Roosevelt	3	WB	1518	43	33	38	15	41	6	48	6	28
F Roosevelt	3	EB	1365	41	39	37	12	34	3	41	6	36
F Roosevelt	4	WB	1278	44	18	37	6	27	12	46	9	43
F Roosevelt	4	EB	1299	40	48	38	30	38	9	35	18	38
G St. Pete	1	WB	672	43	15	41	3	43	0	0	0	0
G St. Pete	1	EB	1311	45	15	45	18	42	6	48	3	28
G St. Pete	1	BY	378	50	9	47	3	37	0	0	0	0
G St. Pete	2	WB	708	44	27	43	0	0	0	0	0	0
G St. Pete	2	EB	1122	44	24	40	9	41	0	0	0	0
G St. Pete	2	BY	384	49	9	49	9	42	0	0	0	0
G St. Pete	3	WB	669	45	18	40	3	41	6	41	0	0
G St. Pete	3	EB	1053	44	15	38	9	34	0	0	3	24

Table 8. Measured Traffic Data (Continued)

Site Location	Test No.		Speed		Speed		Speed		Speed		Speed	
			Autos (mph)	MT	(mph)	HT	(mph)	MC	(mph)	Bus	(mph)	
G St. Pete	3	BY	498	50	9	50	0	0	6	41	0	0
G St. Pete	4	WB	657	44	30	38	0	0	3	41	3	33
G St. Pete	4	EB	1164	44	9	40	3	33	0	0	0	0
G St. Pete	4	BY	369	49	12	46	3	41	0	0	0	0
H Ft. Laud	1	NB	8211	59	342	59	489	58	12	53	6	59
H Ft. Laud	1	SB	7080	55	360	55	480	56	15	55	15	56
H Ft. Laud	2	NB	8325	59	306	57	480	57	6	59	21	65
H Ft. Laud	2	SB	6561	56	408	56	507	60	0	0	15	56
H Ft. Laud	3	NB	8199	60	381	58	534	58	6	61	3	60
H Ft. Laud	3	SB	7320	57	414	55	429	59	0	0	12	57
H Ft. Laud	4	NB	8787	60	348	58	474	60	12	58	6	60
H Ft. Laud	4	SB	7200	60	387	56	456	56	6	60	12	45
I Ft. Laud	1	NB	6120	58	234	58	426	59	0	0	3	55
I Ft. Laud	1	SB	5676	61	252	57	402	59	3	61	3	54
I Ft. Laud	2	NB	6174	58	276	56	396	61	12	55	6	60
I Ft. Laud	2	SB	5700	59	246	58	312	61	33	55	6	56
I Ft. Laud	3	NB	6297	59	207	59	393	59	0	59	3	59
I Ft. Laud	3	SB	5700	62	240	60	324	59	3	62	3	58
I Ft. Laud	4	NB	6096	58	213	59	351	59	3	58	0	0
I Ft. Laud	4	SB	5832	60	276	57	342	59	0	0	6	60
J Ft. Laud	2	WB	2526	60	81	56	30	50	6	60	15	61
J Ft. Laud	2	EB	1956	59	33	54	18	54	0	0	18	52
J Ft. Laud	2	N3	735	45	18	45	0	0	0	0	3	45
J Ft. Laud	2	S36	735	45	18	45	0	0	0	0	3	45

Table 8. Measured Traffic Data (Continued)

Site Location	Test No.	Autos	Speed		Speed		Speed		Speed		Bus	Speed (mph)
			(mph)	MT	(mph)	HT	(mph)	MC	(mph)			
J Ft. Laud	3	WB 2253	62	78	56	24	56	3	62	15	60	
J Ft. Laud	3	EB 2160	61	33	58	15	60	0	0	12	52	
J Ft. Laud	3	N3 765	45	15	45	0	0	0	0	12	45	
J Ft. Laud	3	S36 765	45	15	45	0	0	0	0	12	45	
K Tamiami	1	EB 1659	46	24	46	3	46	3	46	0	0	
K Tamiami	1	WB 1359	46	21	41	9	62	0	0	0	0	
K Tamiami	2	EB 1734	45	36	36	15	43	0	0	6	41	
K Tamiami	2	WB 1692	45	21	44	27	38	9	42	6	40	
K Tamiami	3	EB 1911	45	72	41	18	43	3	44	0	0	
K Tamiami	3	WB 1494	44	24	42	15	41	0	0	6	44	
K Tamiami	4	EB 1779	43	63	37	6	45	3	43	15	41	
K Tamiami	4	WB 1593	45	39	44	9	36	0	0	6	41	
L Gratiigny	1	EB 984	60	102	56	90	57	3	60	0	0	
L Gratiigny	1	WB 1017	57	105	50	87	50	0	0	0	0	
L Gratiigny	1	81st 54	25	9	25	0	0	0	0	0	0	
L Gratiigny	2	EB 954	60	114	58	99	56	9	49	3	41	
L Gratiigny	2	WB 1185	53	54	48	81	48	3	43	6	46	
L Gratiigny	2	81st 84	25	0	0	0	0	0	0	0	0	
L Gratiigny	3	EB 981	59	93	56	84	54	3	64	3	55	
L Gratiigny	3	WB 1029	54	84	51	66	52	9	53	0	0	
L Gratiigny	3	81st 117	25	0	0	0	0	0	0	0	0	
L Gratiigny	4	EB 1116	59	66	57	102	55	6	57	21	52	
L Gratiigny	4	WB 1128	53	108	47	93	48	3	53	0	0	
L Gratiigny	4	81st 69	25	6	25	0	0	0	0	0	0	

## IV. FINDINGS AND CONCLUSIONS

The research has been very successful and all goals have been met. Each goal was stated earlier in the form of questions. These questions are answered in this chapter.

### A. Protection of Highway Neighbors

The first goal of the project was to answer the question:

*Are the barriers providing adequate protection for highway neighbors?*

This question can be answered by reviewing the absolute levels behind the wall, near the homes. The absolute levels were presented in Table 5 and 6 and represent the true measured values after quality control. The microphone positions that represented a typical standing height in the array at each location are 1, 4, B and D. Position 1 was at 4.92 feet above the ground height, 98.43 feet behind each barrier while position 4 was also at 4.92 feet in height, but 49.22 feet behind each barrier (see Figure 1). As such, these microphone positions would tend to represent the first row of homes, for a person standing outside. During quality control, the data for two locations were discarded for these key microphone positions. However, it was still possible to determine the sound levels at these microphone positions using the A-weighted results from the overall sound level analyzers. As previously described, these overall sound level analyzers at Position B and D were placed at the same position as microphone positions 1 and 4, primary as quality control data (again see Figure 1). But the measured data from the overall sound analyzers also provided useful information and in these two cases where other data were missing, by filling the gap.

The important average A-weighted values that were used from the overall sound level analyzers (Microphone Positions B and D) were taken from Table 6 and are:

Location A,	for Position 4: 63.0 dB; $L_{Aeq}$
Location D,	for Position 1: 56.3 dB; $L_{Aeq}$
	for Position 4: 50.3 dB; $L_{Aeq}$

If the sound levels at these key Microphone Positions (1 and 4) are compared to the FDOT and FHWA impact criteria level of 66 dB; $L_{Aeq}$ , it can be determined if the first row residents exceed the criteria, and then by definition, are impacted. From a review of Table 5 and the A-weighted results from the overall sound level analyzers that were presented in the previous paragraph, it can be concluded that the FDOT and FHWA criteria level is not exceeded at any location.

Further considerations were also needed. Testing was done during the midday hours. The FDOT and FHWA criteria are defined for the worst hour of the day. During heavy rush hour, the levels would most probably be lower for these heavily traveled roadways because of congestion and reduced speeds. But just prior and after rush hours it is possible that levels are

slightly higher than those presented here. This would be the time periods where a combination of high traffic volumes, and increased speeds, would generate the greatest average sound levels. Without 24 hour measurements, it is extremely difficult to determine the worst hour of the day for the average sound levels. Even then, the time may change from day to day depending on accidents, traffic density, and other variables. Experience shows that the levels from major highways during the worst hour could be as much as 2 dB:  $L_{Aeq}$  higher than in the midday, but more likely closer to 1 dB:  $L_{Aeq}$ . If a conservative approach is used and the 2 dB:  $L_{Aeq}$  assumption is made and added to the absolute level, then Locations B, E, H, I and J had excursions above the FDOT and FHWA criteria. The greatest exceedance of the criteria would be at Location H where a corrected value of 68.5 dB;  $L_{Aeq}$  (66.5 + 2) was calculated at microphone position 4 for one of the four sample periods.

These exceedances need to be explored in more detail. First, and probably most important, from a review of the reference levels in Table 5 (Microphone Positions 7 and 8), it is obvious that without the noise barriers outdoor activities and communications would be severely limited. The barriers have reduced the levels to conditions that these activities can occur with only minimal interference. This is reinforced by modeling. The modeled results, discussed later, show that without the barriers, sound levels of at least 70 and sometimes approaching 80 dB;  $L_{Aeq}$  would exist. These high values are even before the 2 dB(A) penalty is applied.

It is also of note that the average of all sample periods for Location E is below 64 dB;  $L_{Aeq}$  and as such would not be above the criteria on the average even with the 2 dB(A) penalty. In addition, the average values for Locations B and I are 65 dB;  $L_{Aeq}$  or below. These locations would be within 1 dB(A) of the criteria when the 2 dB(A) penalty was added. Even locations H and I would be with 2 dB(A) of the criteria with the 2 dB(A) penalty added. It can be concluded that even though there is some noise intrusion into the neighborhoods with the barriers in place, without the sound barrier the acoustic environment would be very unpleasant.

If we again refer to the FDOT criteria, and it is assumed that the local area background levels are not a problem (which may not be appropriate at Location J), more conclusions about the barrier design is possible. Using the rule of thumb that "for every two feet of barrier height a one dB(A) reduction can be expected" it appears that the noise barriers should have been about 1, 4, 2 and 3 feet taller than constructed for locations B, H, I and J, respectively. The wall at Location E would not be increased based on the average levels measured. This would have resulted in wall heights of 16.6, 18.5, 15.1 and 13.8 feet for locations B, H, I and J, respectively. Again, the conclusions on increased wall heights would depend greatly on local conditions and feasible/reasonable considerations. Exact computer modeling would be needed to specify exact heights. Changes in barrier heights reported in this discussion are only approximations.

Based on these results and conclusions, it can be determined that for most locations the residents are being well protected. At the four locations that exceed the criteria for the average of all sample periods after the 2 dB(A) correction is added (B, H, I and J) outdoor activities and communications could be somewhat affected but the degree of impact is slight compared to the no barrier case. In the same four cases (B, H, I and J), slightly higher noise barrier heights would have reduced levels to below the FDOT criteria of 66 dB;  $L_{Aeq}$ .

## B. Prediction of Barrier Design Versus Measured Results

The second goal was also in the form of a question:

*Are the noise barriers that have been built in Florida performing as predicted?*

This question can be answered by reviewing the insertion loss, by comparing the corrected modeled results from this project to past environmental project documents, by reviewing the plotted vertical sound contours, and by determining the extent of the shadow zone. Secondary findings that are directly related to this goal are the shapes of the shadow zones produced behind the sound barriers and the performance of the various noise prediction computer models.

Insertion loss was calculated using the indirect method in the ANSI standard [8]. As previously described, this method uses the measured levels and output from the noise prediction computer models. Predicted insertion losses from the models are corrected based on the measured results. All locations were modeled using the three models described previously. However, since STAMINA2.0 and STAMINA2.1 use the same method to determine diffraction effects, the predicted insertion losses (IL) were essentially the same. These uncorrected and corrected insertion losses, and the differences between the two computer methods, are presented in Table 9. Of note is that at Location D, difficulties in data collection prevented determination of insertion losses. As such, only 11 locations were used in the insertion loss analysis.

An interesting finding based on these 11 locations is that the TNM in most cases, but not always, tends to predict a greater insertion loss than do the STAMINA2.0/2.1 models (the reader is reminded that the IL for STAMINA2.0 and 2.1 are essentially the same). This implies that shorter walls would be designed using TNM than would be designed using STAMINA2.0 or STAMINA2.1. To go further with the analysis, a sub-goal question must then be answered; *which is the more accurate prediction?*

To answer this sub-goal question, the researchers statistically analyzed the measured results compared to modeled results using the seven statistical methods that were described earlier. All three models were evaluated for completeness, even though the primary goal analysis would only use the results of TNM and STAMINA2.1. The evaluation as described earlier was done for both predicted versus absolute measured values and predicted versus measured insertion losses. The final numeric results for all statistical tests are shown in Table 10 for the overall levels and in Table 11 for the insertion loss. The best results are shown in bold for each test.

The statistical testing for the overall values, or the predictions of the sound levels compared to the measured values, was done location by location, position by position, and for each sample period. Using the average over- and under-prediction, TNM was slightly better than the other models. The ranges (maximum over-prediction added to the maximum under-prediction) of prediction errors were: TNM, 4.31 dB;  $L_{Aeq}$ ; STAMINA2.0, 4.24;  $L_{Aeq}$ ; and, STAMINA2.1, 4.32;  $L_{Aeq}$ . Next, the other statistics were evaluated. In terms of location to location and again when all locations were grouped together, the STAMINA2.1 model performed the best in 3 of

Table 9. Predicted and Adjusted Insertion Losses

Location	Microphone Position	TNM IL $L_{Aeq}$	ST2.1 IL $L_{Aeq}$	TNM-ST2.1 $L_{Aeq}$	Diff (pred.-meas.) $L_{Aeq}$	Adjusted TNM IL $L_{Aeq}$	Difference $TNM_{adj} - ST2.1 L_{Aeq}$
A	Ivie 1	9.7	7.1	2.6	2.7	7.0	-0.1
	Ivie 2	11.0	6.3	4.7	2.2	8.8	2.5
	Ivie 3	10.9	4.8	6.1	4.6	6.3	1.5
	Ivie 4	12.2	8.9	3.3	NA	NA	NA
	Ivie 5	13.2	7.5	5.7	4.0	9.2	1.7
	Ivie 6	11.6	5.0	6.6	3.3	8.3	3.3
	Metro A	14.3	9.4	4.9	4.0	10.3	0.9
	Metro C	10.7	7.8	2.9	3.5	7.2	-0.6
B	Ivie 1	8.7	6.3	2.4	3.4	5.3	-1.0
	Ivie 2	8.6	4.4	4.2	4.2	4.4	0.0
	Ivie 3	5.4	1.8	3.6	0.1	5.3	3.5
	Ivie 4	12.0	8.1	3.9	4.0	8.0	-0.1
	Ivie 5	10.7	5.2	5.5	3.5	7.2	2.0
	Ivie 6	3.6	1.2	2.4	-1.9	5.5	4.3
	Metro A	13.9	10.3	3.6	5.1	8.8	-1.5
	Metro C	11.3	7.0	4.3	3.3	8.0	1.0
C	Ivie 1	7.4	6.5	0.9	-1.5	8.9	2.4
	Ivie 2	6.5	5.0	1.5	-1.5	8.0	3.0
	Ivie 3	4.2	2.8	1.4	-1.3	5.5	2.7
	Ivie 4	9.0	9.3	-0.3	-0.6	9.6	0.3
	Ivie 5	8.5	6.8	1.7	-1.1	9.6	2.8
	Ivie 6	4.9	2.9	2.0	NA	NA	NA
	Metro A	10.0	11.9	-1.9	-0.7	10.7	-1.2
	Metro C	9.0	7.9	1.1	0.2	8.8	1.0
E	Ivie 1	9.4	7.5	1.9	1.1	8.3	0.8
	Ivie 2	9.4	7.2	2.2	0.8	8.6	1.4
	Ivie 3	9.3	6.4	2.9	0.5	8.8	2.4
	Ivie 4	3.6	8.0	-4.4	1.4	2.2	-5.8
	Ivie 5	6.0	8.6	-2.6	1.5	4.5	-4.1
	Ivie 6	9.8	8.2	1.6	0.4	9.4	1.2
	Metro A	12.0	9.7	2.3	-1.2	13.2	3.6
	Metro C	5.5	8.0	-2.5	0.9	4.6	-3.4
F	Ivie 1	5.2	4.8	0.4	2.0	3.2	-1.6
	Ivie 2	5.4	2.8	2.6	-1.2	6.6	3.8
	Ivie 3	4.0	1.7	2.3	1.1	2.9	1.2
	Ivie 4	7.7	8.2	-0.5	1.3	6.4	-1.8
	Ivie 5	7.4	5.0	2.4	-1.1	8.5	3.5
	Ivie 6	2.7	1.4	1.3	-0.3	3.0	1.6
	Metro A	10.9	10.6	0.3	0.7	10.2	-0.4
	Metro C	6.4	6.3	0.1	2.1	4.3	-2.0

Table 9. Predicted and Adjusted Insertion Losses (Continued)

Location	Microphone Position	TNM IL $L_{Aeq}$	ST2.1 IL $L_{Aeq}$	TNM-ST2.1 $L_{Aeq}$	Diff (pred.-meas.) $L_{Aeq}$	Adjusted TNM IL $L_{Aeq}$	Difference TNM <sub>adj</sub> - ST2.1 $L_{Aeq}$
G	Ivie 1	3.8	2.9	0.9	1.0	2.8	-0.1
	Ivie 2	3.3	1.9	1.4	-0.6	3.9	2.0
	Ivie 3	1.4	0.7	0.7	-2.7	4.1	3.4
	Ivie 4	5.5	3.9	1.6	0.6	4.9	1.0
	Ivie 5	2.9	2.3	0.6	-3.2	6.1	3.8
	Ivie 6	-0.1	0.4	-0.5	NA	NA	NA
	Metro A	7.3	4.8	2.5	1.4	5.9	1.1
	Metro C	4.6	3.5	1.1	0.8	3.8	0.3
H	Ivie 1	9.8	6.3	3.5	1.2	8.6	2.3
	Ivie 2	9.5	4.6	4.9	2.2	7.3	2.7
	Ivie 3	7.6	1.9	5.7	1.5	6.1	4.2
	Ivie 4	11.8	8.9	2.9	3.0	8.8	-0.1
	Ivie 5	11.4	6.0	5.4	1.1	10.3	4.3
	Ivie 6	5.8	1.3	4.5	0.2	5.6	4.3
	Metro A	13.3	11.3	2.0	2.0	11.3	0.0
	Metro C	11.0	7.5	3.5	1.1	9.9	2.4
I	Ivie 1	5.8	4.8	1.0	0.6	5.2	0.4
	Ivie 2	6.2	3.5	2.7	0.3	5.9	2.4
	Ivie 3	4.8	1.3	3.5	0.1	4.7	3.3
	Ivie 4	8.6	7.3	1.3	2.6	5.9	-1.4
	Ivie 5	9.1	4.7	4.4	1.8	7.3	2.6
	Ivie 6	2.6	0.7	1.9	-1.5	4.0	3.3
	Metro A	10.9	7.3	3.6	4.6	6.3	-1.0
	Metro C	7.0	5.8	1.2	2.4	4.6	-1.2
J	Ivie 1	5.6	5.0	0.6	0.3	5.3	0.3
	Ivie 2	5.5	4.5	1.0	-1.3	6.8	2.3
	Ivie 3	5.2	3.2	2.0	-1.7	6.9	3.7
	Ivie 4	9.2	8.0	1.2	0.8	8.4	0.4
	Ivie 5	9.3	6.7	2.6	0.2	9.1	2.4
	Ivie 6	6.2	3.4	2.8	-0.8	7.0	3.6
	Metro A	11.8	10.4	1.4	1.6	10.2	-0.2
	Metro C	7.8	6.2	1.6	0.5	7.3	1.1
K	Ivie 1	9.2	7.1	2.1	2.1	7.1	0.0
	Ivie 2	9.5	5.0	4.5	1.8	7.7	2.7
	Ivie 3	6.7	3.7	3.0	-1.6	8.3	4.6
	Ivie 4	10.1	9.8	0.3	-0.4	10.5	0.7
	Ivie 5	11.1	7.2	3.9	-0.7	11.8	4.6
	Ivie 6	5.0	3.0	2.0	-2.4	7.4	4.4
	Metro A	13.0	11.4	1.6	1.0	12.0	0.6
	Metro C	10.6	9.1	1.5	2.2	8.4	-0.7

Table 9. Predicted and Adjusted Insertion Losses (Continued)

Location	Microphone Position	TNM IL $L_{Aeq}$	ST2.1 IL $L_{Aeq}$	TNM-ST2.1 $L_{Aeq}$	Diff (pred.-meas.) $L_{Aeq}$	Adjusted TNM IL $L_{Aeq}$	Difference TNM <sub>adj</sub> - ST2.1 $L_{Aeq}$
L	Ivie 1	9.3	10	-0.7	2.3	7.0	-3.0
	Ivie 3	14.8	10.1	4.7	3.0	11.8	1.7
	Ivie 4	9.7	9.8	-0.1	2.7	7.0	-2.8
	Ivie 5	11.7	10.2	1.5	3.3	8.4	-1.8
	Ivie 6	13.4	8.2	5.2	3.2	10.2	2.0
	Metro A	9.3	10.0	-0.7	1.9	7.4	-2.6
	Metro C	9.3	8.6	0.7	3.4	5.9	-2.7

Table 10. Absolute (or Overall) Statistical Results Summary

Model	MIN	MAX	Gross Error	Variance	Root MSSE	Avg. Bias	Frac. Bias
TNM	<b>-1.51</b>	2.80	1.93	2.43	2.14	<b>0.42</b>	.01
Stamina2.0	-1.80	<b>2.44</b>	1.82	2.12	2.12	0.68	.01
Stamina2.1	-1.65	2.67	<b>1.67</b>	<b>2.03</b>	<b>1.88</b>	0.94	.01

Table 11. Propagation Losses (Reference Microphone - Other Microphone Positions) Statistical Results Summary

Model	MIN	MAX	Gross Error	Variance	Root MSSE	Avg. Bias	Frac. Bias
TNM	<b>-2.35</b>	4.31	<b>1.86</b>	3.58	<b>2.24</b>	<b>1.10</b>	<b>0.07</b>
Stamina2.0	-6.06	0.72	3.03	2.72	3.35	-2.94	-0.23
Stamina2.1	-6.01	<b>0.39</b>	2.99	<b>2.45</b>	3.32	-2.93	-0.23

the 7 tests, TNM performed the best in 2 of the 7 tests, and STAMINA2.0 performed the best in 1 of the 7 tests.

This finding, that STAMINA2.1 performed the best, raised questions about the Reference Energy Mean Emission Levels (REMELs) used in the models for the researchers. Since the reference measurement positions were high above the surface, the ground effects are expected to be small. In addition, it is the closest position to the traffic sources so effects such as those due to meteorology should be minimal. The reference positions are also at a sufficient height above the barrier that diffraction effects should not be significant. Accordingly, this position should represent the best comparison (measured to predicted) of the REMELs in each model. Accordingly, this difference was analyzed to determine errors associated with the REMELs. It was found that the average error was 1.49, -1.72, and -1.80 dB;  $L_{Aeq}$  for TNM, STAMINA2.0, and STAMINA2.1 respectively. Three observations can be made. First, TNM would tend to over-predict while the other models under-predict at these locations. This would mean that the TNM REMELs are high while the other models are low. Second, TNM REMELs would seem to be slightly closer, on average, than either STAMINA model. Third, since the absolute predicted sound levels behind the barrier are statistically better for the STAMINA models, there must be compounding errors that causes this to happen. In other words, the STAMINA models provided better answers at positions behind the barrier because of a combination of errors in the REMELs and prediction algorithms.

This last finding, and the need to have the best IL values during barrier design for projects, is the reason for the statistical testing of the propagation algorithms accuracy. To determine this propagation prediction accuracy, especially for diffraction, the predicted differences between the reference position and each position behind the barrier were compared to the absolute or measured differences at these same positions. This tended to normalize the analysis and allow just the propagation routines to be evaluated. This testing showed TNM to be statistically better in 5 of the 7 tests and very close in the other two tests. As such, TNM is considered to be significantly better than the other two models in determining propagation effects. STAMINA2.1 was the best model in the other two statistical tests (2 out of 7).

As previously stated, TNM did not do as well in the absolute predictions indicating that other parameters may be influencing these results. This could be the REMELs but could also be other parameters such as using the required FHWA input for average pavement and weather conditions. It also tends to further substantiate that STAMINA2.0 and STAMINA2.1 predicted better in the absolute case due to compounding errors. In other words, multiple errors would seem to cancel, leading to a better absolute number. The fractional bias also points out that TNM has a tendency for over-prediction while the other models tend to under-predict, further substantiating the findings from the REMEL analysis.

The next test used corrected insertion loss values based on the indirect ANSI method to determine in a different way if the barriers are performing as predicted. Using these derived, corrected values for insertion loss, a comparison could be made to the noise study reports that were available and had previously been completed by FDOT. The data previously shown in Table 9 show the IL as predicted by TNM and STAMINA2.1 along with differences between the

two models. The correction factors that were calculated based on the ANSI indirect methodology are shown in Table 12. Using the correction factors, corrected insertion losses were predicted and have been shown in Table 9.

If the corrected insertion losses at the 4.92 foot positions are reviewed (Positions 1, 4, A and C), it can be determined that an audible difference occurs at the first row highway neighbors, at all but three locations; Locations E, F and G.<sup>7</sup> The reason for these three locations not providing an audible difference are quite different. At Location E, the highway is on an elevated fill section which provides significant shielding by itself. The berm and wall combination do not show significant insertion loss because of the existing shielding from the fill geometry. This was verified by running the models in many different ways both with and without the barriers. If the higher microphone positions are reviewed (Positions 3 and 6), which are at almost 20 feet, an audible difference does occur. The reason is as before, these locations would not see the shielding of the fill section but do see the effect of the berm and wall combination. At Location F, the close proximity of house trailers had an effect on the results. The trailers tended to reduce the levels and act as barriers. So, just as at Location E, the insertion loss is low at the far microphone position (Position 1) away from the wall and between the trailers due to this additional shielding. At the closer position (Position 4) the insertion loss is well above 5 dB(A) since it was not affected by the trailers. The site could have been modeled without the trailers and this was considered. However, this would have not given actual results as desired. At Location G, the 7.3 foot tall barrier creates a very shallow shadow zone so at 98 feet from the barrier only 2.8 dB of insertion loss occurs and the position is at the very edge of the shadow zone.

Overall, it can be stated that the barriers, with the exception of Locations E, F and G, form a shadow zone that extends past the first row of homes and provides protection for these receivers. Again, the reader is reminded of the reason for this at Locations E and F which do provide protection. The next question then becomes, "How far behind the noise barriers does the shadow zone extend?" Shadow zones are the "darkest" (more noise reduction) immediately behind the barrier near the ground surface. Very near the noise barrier, increases in height result in reductions to the barrier attenuation and just after the top of the barrier the noise attenuation disappears. However, as the receiver location is raised further from the ground surface, ground effects, or attenuation, become less. Additionally, as an observer gets further away from the barrier, on the receiver side, the insertion loss is also reduced but ground effects and reductions due to geometric spreading increase. Other parameters may also affect the depth of the shadow zone. A new methodology was derived to consider the shape and depth of the shadow zone behind the measure barriers. This methodology is explained, but first a brief discussion of the shadow zone is presented for the reader to allow understanding of this derived method.

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<sup>7</sup> It usually takes a 5 dB(A) difference to make an audible difference in the outdoor environment.

Table 12. Derived Correction Factors (Modeled Vs. Measured IL Differences)\*

Location / Run	Ivie 1	Ivie 2	Ivie 3	Ivie 4	Ivie 5	Ivie 6	Metro A	Metro C
A1	NA	2.7	4.6	NA	4.1	3.6	4.4	4.0
A2	2.6	1.9	3.9	NA	3.7	3.1	3.9	3.3
A4	2.6	2.1	4.7	NA	4.0	3.2	3.8	3.3
A5	2.8	2.2	5.0	NA	4.1	3.4	3.9	3.3
avg	2.7	2.2	4.6	NA	4.0	3.3	4.0	3.5
B1	NA	4.1	0.0	4.2	3.5	-1.7	5.5	3.7
B2	NA	4.2	-0.5	4.2	3.5	-1.8	5.3	3.4
B3	3.8	4.3	-0.7	4.1	3.5	-2.3	5.0	3.2
B4	3.1	4.2	1.7	3.4	3.5	-2.0	4.6	2.7
avg	3.4	4.2	0.1	4.0	3.5	-1.9	5.1	3.3
C1	-1.1	-1.2	-0.5	-0.1	-0.4	NA	-0.2	0.9
C2	-0.9	-1.2	-1.5	-1.2	-1.6	NA	-1.4	-0.8
C3	-2.0	-2.1	-1.9	-0.9	-1.7	NA	-1.0	-0.6
C4	-1.8	-1.5	-1.2	-0.2	-0.9	NA	-0.3	1.1
avg	-1.5	-1.5	-1.3	-0.6	-1.1	NA	-0.7	0.2
E1	0.5	0.3	1.0	0.8	1.1	0.4	-1.7	0.5
E2	-0.8	-1.0	-0.6	-0.6	-0.8	-1.9	-2.8	-1.1
E3	0.6	0.3	0.7	0.9	1.4	0.1	-1.7	0.5
E4	2.4	2.0	-0.5	2.7	2.9	1.5	-0.7	2.2
avg	0.7	0.4	0.1	1.0	1.1	0.0	-1.7	0.5
F1	1.9	-1.4	-0.2	1.0	-1.4	-0.5	0.0	1.6
F2	2.2	-1.1	0.0	1.4	-1.1	-0.3	1.9	3.3
F3	2.8	-0.1	1.8	2.2	0.0	0.2	1.2	2.5
F4	1.1	-2.3	2.7	0.5	-1.9	-0.4	-0.3	0.9
avg	2.0	-1.2	1.1	1.3	-1.1	-0.3	0.7	2.1

\* modeled values were derived using TNM

Table 12. Derived Correction Factors (Modeled Vs. Measured IL Differences\* (Continued)

Location / Run	Ivie 1	Ivie 2	Ivie 3	Ivie 4	Ivie 5	Ivie 6	Metro A	Metro C
G1	0.6	-1.1	-3.5	0.3	-3.5	NA	1.2	0.3
G2	0.8	-0.8	-2.8	0.3	-3.3	NA	1.4	0.6
G3	1.2	-0.5	-2.5	0.8	-3.3	NA	1.5	0.9
G4	1.4	-0.1	-2.0	1.2	-2.7	NA	1.7	1.3
avg	1.0	-0.6	-2.7	0.6	-3.2	NA	1.4	0.8
H1	1.9	2.7	1.3	3.4	1.1	0.4	2.2	1.7
H2	1.3	2.4	2.4	3.1	1.2	0.1	2.0	1.3
H3	1.0	2.1	1.4	2.8	1.1	0.3	1.9	0.9
H4	0.6	1.7	0.9	2.6	0.9	0.0	1.8	0.6
avg	1.2	2.2	1.5	3.0	1.1	0.2	2.0	1.1
I1	0.7	0.3	0.3	2.9	1.9	-1.2	4.9	2.7
I2	0.2	-0.1	-0.2	2.3	1.5	-1.7	4.4	2.1
I3	0.9	0.6	0.3	2.8	1.9	-1.4	4.8	2.6
I4	0.5	0.4	0.2	2.6	1.8	-1.5	4.4	2.3
avg	0.6	0.3	0.1	2.6	1.8	-1.5	4.6	2.4
J2	0.4	-1.1	-1.9	0.9	0.2	-0.7	1.6	0.5
J3	0.3	-1.4	-1.5	0.8	0.3	-0.8	1.6	0.5
avg	0.3	-1.3	-1.7	0.8	0.2	-0.8	1.6	0.5
K1	2.4	2.4	-1.3	-0.2	-0.5	-2.2	1.5	2.6
K2	1.9	2.1	-1.6	-0.3	-0.7	-2.5	0.8	2.3
K3	2.3	1.6	-1.1	-0.2	-0.6	-1.9	1.0	2.4
K4	1.8	1.0	-2.3	-1.0	-1.2	-3.2	0.5	1.6
avg	2.1	1.8	-1.6	-0.4	-0.7	-2.4	1.0	2.2

\* modeled values were derived using TNM

Table 12. Derived Correction Factors (Modeled Vs. Measured IL Differences\* (Continued)

Location / Run	Ivie 1	Ivie 2	Ivie 3	Ivie 4	Ivie 5	Ivie 6	Metro A	Metro C
L1	1.9	NA	2.3	2.2	2.5	2.6	1.4	2.8
L2	2.3	NA	3.0	2.8	3.3	3.3	1.9	3.3
L3	2.8	NA	3.5	3.1	3.9	3.6	2.4	3.9
L4	2.1	NA	3.3	2.9	3.5	3.5	1.9	3.7
avg	2.3	NA	3.0	2.7	3.3	3.2	1.9	3.4

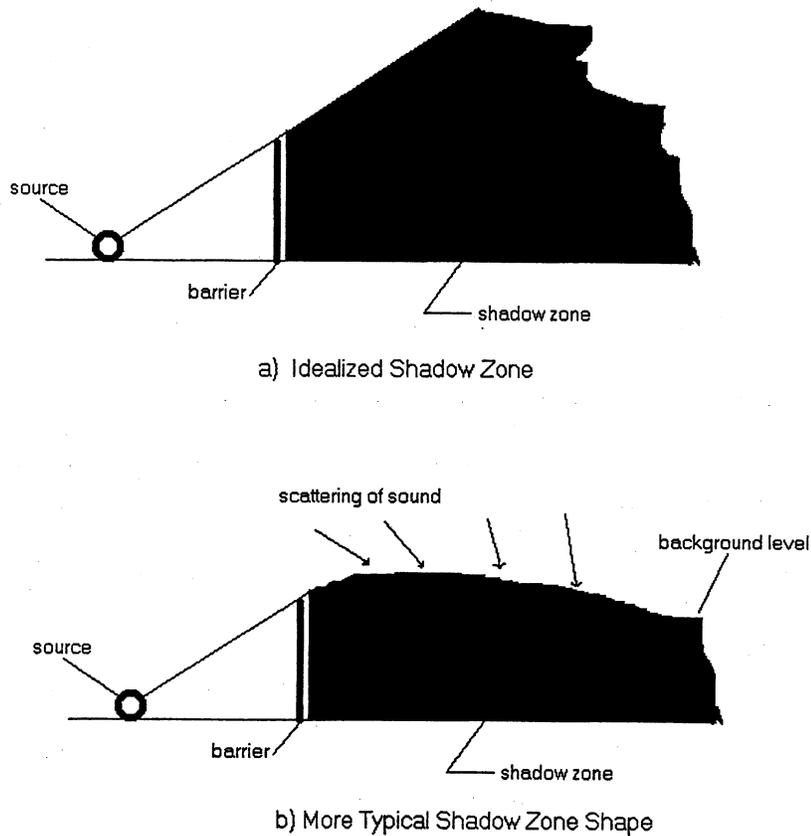
\* modeled values were derived using TNM

Consider Figure 5. The top figure, 5 a, shows an idealized shadow zone. The dark area represents the area of noise reduction. But, diffraction occurs which is the ability of the sound to turn corners. This frequency dependent phenomenon results in a smaller shadow zone than the idealized zone. Scattering of sound also occurs from the “illuminated zone” above. As a result, the shadow zone depth is reduced as an observer moves farther away from the barrier. But the shadow zone is also influenced by background noise levels and ground effects. The sound levels cannot be reduced below these background levels, although in some cases, the noise very near the barrier may be slightly lower since this area is further away from sources that contribute to the background.

Figure 5 b is a more typical shadow zone representation. Scattering and diffraction make the top of the zone irregular or “fuzzy”. Ground effects make the shadow zone less dark near the ground and away from the barrier. Background noise limits the depth of the shadow zone. The models do not account for background noise, so it must be considered independently during barrier design. Relying just on reported attenuations from the models may not lead to the expected sound levels after barrier installation due to these two effects. The methodology had to consider these effects.

A first trial to determine this zone was done by reviewing the insertion losses determined by measurements and modeling. However, the shadow zones are not the same as insertion losses. As defined at the beginning of this report, the insertion loss is equal to the difference of the sound levels, with and without the noise barrier. Insertion loss is generally thought of as the noise reduction at a defined position behind the barrier. Figure 4 shows an example of what the noise levels contours be with the barriers in place. It is obvious that insertion loss is occurring, reducing the noise levels behind the barrier. Insertion loss depends on the barrier construction techniques, barrier height, barrier length, local topography, obstructions in the sound path, receiver position, traffic variables and ground effects. However, the shadow zone is usually considered an area behind the noise barrier where sound levels are reduced. There are major

Figure 5. Shadow Zone Shapes



differences even if a single point is considered. For example, ground effects are reduced if a noise barrier is implemented because the noise wave travels over the barrier and is further removed from the ground plane. This causes the insertion loss for positions nearer the ground to often be less than those still receiving benefits from the barrier. The higher positions are still behind the barrier and below the line of sight to the traffic over the wall, but are at a greater height above the ground than lower positions. Both the higher and lower positions would be in the shadow zone, but the higher positions often have greater insertion losses because they have not lost as much attenuation from ground effects as those positions closer to the ground. That is, the reduction is greater for the receiver farther from the ground because of a smaller loss in ground effects attenuation. The result is a “darker” shadow zone away from the ground’s surface. This makes insertion loss different than we usually think of the shadow zone. Also, the shadow zone or area of noise reduction is limited by the background noise levels. Since STAMINA2.0, STAMINA2.1, and TNM do not consider the background noise levels, insertion losses are predicted even though in reality, the actual noise levels may be the same as before the wall was constructed due to the background noise levels. These problems had to be overcome to properly define the shadow zone.

The first step was to determine the background levels. To do this, the  $L_{90}$  and  $L_{99}$  sound levels were determined.<sup>8</sup> Since these values are exceeded most of the time, it is appropriate to assume that the levels occurred during lulls or quiet periods in the traffic noise. The  $L_{90}$  and  $L_{99}$  derived sound levels values are shown in Table 13. After review and coordination with FDOT, it was determined that the  $L_{99}$  values would be used as background levels since the heavily traveled highways that were sampled had very constant traffic. These levels, determined for each location, then became a constraint for the shadow zone. When the sound levels reached the background, there was no sound reduction in the local area. That is, the shadow zone could only occur when the sound was above the background but below what would have occurred without the noise barrier.

Next the ground effects were carefully reviewed. In STAMINA2.0 or 2.1, the insertion losses were always predicted to be greater at the lower receiver heights and the insertion losses decreased with increased receiver height at the same distance from the noise barrier. This same trend does not occur in TNM, with more complete ground effect prediction algorithms. To test that TNM was accurately accounting for ground effects, an independent program was written using the method of Embleton, Piercy and Daigle [11]. This is the method used in TNM and has been documented to be more accurate than the alpha factor concept used in STAMINA2.0/2.1. The independent program was written to evaluate if the results from TNM were indeed correct or if some problem existed with the ground effect algorithm. Each location was manually checked for consistency with TNM. Using this external model as a check, it was found that the alpha value concept used in STAMINA2.0 and 2.1 was inadequate and that TNM more accurately predicted the ground effects.

After the background levels were determined and the ground effects were determined to be real, the next step was to apply this to the measured data. The measured data from Positions 1- 6 and A-D were used to establish if the sound levels were above or below the background levels. If the sound levels at any position were above the background level, one of the developed methodology criteria was met. But it still had to be determined if reductions below the no

barrier case were occurring. For this determination, the corrected insertion losses (see Table 9) were used. This second methodology criteria permitted the determination if a position was in the shadow zone or the illuminated zone. Use of the insertion losses also allowed the determination of how far the measured sound levels were below the non-barrier case in dB(A). In other words, this allowed the determination if a position was 5 dB(A) or 10 dB(A) into the shadow zone. This was very difficult since the insertion losses were often less near the ground. To overcome this difficulty, it was assumed that as long as the insertion losses were greater than the 5 dB(A) or 10 dB(A) determination, then the highest point above the ground would be determined to be the "edge" of the shadow zone.

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<sup>8</sup> The  $L_{90}$  and  $L_{99}$  sound levels refer to the sound levels exceeded 90 and 99 percent of the time, respectively.

Table 13.  $L_{90}$  and  $L_{99}$  Sound Level Determination

Location	Total Samples at Position 1	$L_{90}$ [dB(A)]	Number of Samples < $L_{90}$	$L_{99}$ [dB(A)]	Number of Samples < $L_{99}$	Difference $L_{90} - L_{99}$
A	510	61.8	48	60.4	4	1.4
B	495	60.5	39	58.7	4	1.8
C	457	52.3	43	51.6	3	0.7
E	593	58.7	49	56.9	4	1.8
F	644	50.3	63	48.0	5	2.3
G	582	54.7	57	53.3	3	1.4
H	599	61.6	54	60.2	5	1.4
I	464	61.4	41	60.3	4	1.1
J	372	62.9	35	61.7	3	1.2
K	471	48.4	44	45.8	4	2.6
L	575	55.5	52	53.6	5	1.9

In most cases, the levels at the farthest tower from the noise barrier were reduced and still not at the background levels. In these cases, the predicted values from TNM were adjusted at the last tower to match the measured sound levels. The predicted falloff rate from TNM was then used to predict the position or distance where the shadow dissipated, or reached the background levels. These shadow zones were then plotted as shown in Figure 6. In the figure the 5 dB(A) shadow zone and 10 dB(A) shadow zone are displayed. As expected, the 10 dB(A) zone is much closer to the barrier wall while the 5 dB(A) zone extends much farther. The shadow zone plots for all locations, with the exception of Location D are shown in Appendices A-L. The shadow zone and contour plots contained for the locations in Appendices A-L reinforce that the shadow zones of the measured barriers more closely resemble the shape as shown in Figure 5b.

In some cases, such as Location E, unusual shapes occurred. At Location J, this was due to noise from a nearby roadway causing the shadow zone to quickly reach the background level at a distance and suddenly end. At other locations, shielding other than the barrier sometimes caused smaller shadow zones than expected. The shadow zone plot for Location E shows two separate 10 dB(A) IL zones, separated by distance. This occurs because without the noise barrier/berm combination that has been added, shielding is provided by the elevated roadway edge. The roadway is on a slope and some flanking noise is occurring at the measurement site. The end result is the two “bubbles” of greater insertion loss. But, these plots for the most part effectively show the limits of protection from the barriers. It is also of note that in some locations, with low background sound levels and relatively tall barriers, the shadow zone was predicted to extend very far behind the barrier. An example of this is shown in Appendix H (Location H). It is very obvious that the distance behind the wall that the shadow zone extends is a function of the barrier height and background noise levels. The plots provide additional information that the barriers are protecting the nearby highway neighbors and performing as intended. This function is being further reviewed.

As a final analysis to determine if the barriers are performing as expected, a comparison was made to the values reported in environmental documents by FDOT (where available) to the results of TNM, STAMINA2.0 and STAMINA2.1. Unfortunately, only three reports contained information that could be directly compared to this study. Table 14 presents this information, along with comparative details from this report.

It can be seen in Table 14 that the reported results do not match results from this research very well. The reasons for these differences are:

- differences in the wall heights, actual to those in the documents;
- shielding from objects such as the trailers (Location F) not being included by FDOT;
- slight differences in location;
- traffic differences; and,
- other possible causes.

Figure 6. Example of a Derived Shadow Zone Plot

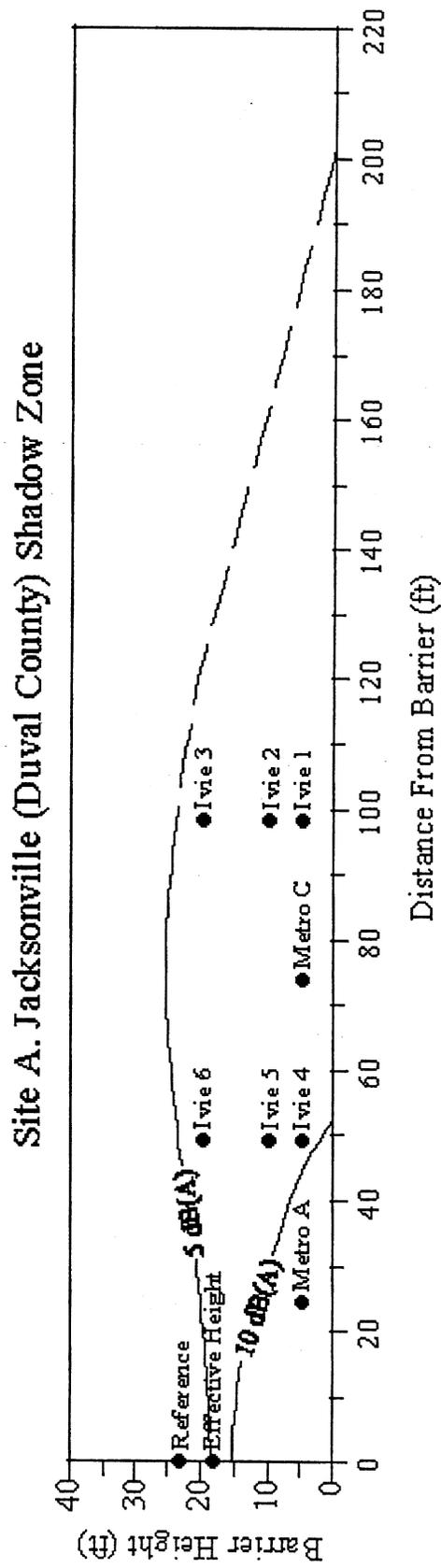


Table 14. FDOT Noise Study Report IL Compared to Project Derived ILs

Location	FDOT Document	FDOT Height (feet)	Actual Height (feet)	Reported IL ( $L_{Aeq}$ )	TNM adjusted IL ( $L_{Aeq}$ )
A	Noise Study Report, April 1992, Project No. 72280-1423 Model Used: STAMINA2.0	16.0	18.5	6.8 (ST2.0/Opt.)	9.2 (Ivie 4)
B	Noise Study Report, Sept. 1990, Project No. 72001-3479 Model Used: STAMINA2.0	19.0	15.6	13.0 (ST2.0/Opt.)	8.0 (Ivie 4)
F	Noise Study Report, July 22, 1996, PBSJ Report Model Used: STAMINA2.1	11.0	11.0	7.9 (ST2.1)	3.2* (Ivie 1)

\*trailer influence, Ivie 4 IL = 6.4 dB

Accordingly, this comparison did not compare well, but no actual judgement can be made about the modeling practices with one exception. Existing significant, structures such as homes or other large buildings may need to be added during project design.

### C. TNM Versus STAMINA2.0/2.1

Finally, the last goal was to answer the question;

*Is the new FHWA Traffic Noise Model significantly better than STAMINA2.0/2.1?*

Based on the result presented for the other two goals it can be concluded that the propagation algorithms in TNM are significantly better. Statistical testing and comparison to measured differences have proven this. However, it can not be stated that absolute levels are significantly better. The range of prediction was closer, but TNM did not prove during statistical testing that it was better at predicting the absolute sound level values behind the barrier. In fact, STAMINA2.1 was better in 3 of the 7 statistical tests when absolute values were compared. Further consideration is required. However, the propagation algorithms for TNM did perform better (better in 5 of 7 statistical tests). This tends to point out that other problems must exist, such as the REMELs, as was previously discussed. This problem could be exacerbated by the use of average pavement and prescribed weather inputs required by FHWA policy. Additionally, it appears that one reason the absolute results are better for STAMINA2.0 and STAMINA2.1 are compounding errors. In other words, the less accurate propagation algorithms, along with older

REMELs, resulted in absolute numbers closer to that measured. While accuracy is the goal of modeling, this result from the STAMINA models does not appear to be a good foundation to continue to build on.

It was also advantageous to compare the predicted insertion loss from TNM to measured values and to STAMINA2.1 predicted results. This comparison was shown in Table 9. This comparison shows that greatest under prediction for TNM when compared to measured data was -3.2 dB(A). The greatest over prediction was 5.1 dB(A). The average and standard deviation were 1.09 and 1.87 dB(A), respectively. When STAMINA2.1 was compared to these measured insertion losses, the maximum under prediction was -5.8 dB(A). The greatest over prediction was 4.6 dB(A) by STAMINA2.1. Finally, the average error was 1.07 dB(A) with a standard deviation of 2.23 dB(A). This shows that when both TNM and STAMINA2.1 performed in a similar fashion and from these results it can only be stated that TNM is slightly better than STAMINA2.1. It can also be stated that for both models the average error is only about 1 dB(A) and the standard deviation is not too drastic. However, there is also a large range of values that can occur. This points out the problem in prediction for some cases. These findings would tend to show that FDOT has been predicting insertion loss relatively well during barrier design.

One other note should be made. The design process using TNM is significantly easier. The TNM graphical user interface also has a tendency to reduce errors and require less time during input and analysis.

In summary, it can be concluded the highway neighbors are being protected. Outside noise levels either are below criteria or just above allowing outside activities and communication to occur with minimal impacts. It can also be concluded that the propagation algorithms in TNM show a significant improvement over the methodology used in STAMINA2.0 and STAMINA2.1. Absolute levels are not significantly improved with TNM, but it is a better building block.

## V. RECOMMENDATIONS

This project has found that the noise barrier design process has been performing well in Florida. Barrier designs are providing significant noise reductions and providing areas with little or no impact on outdoor activities or communications near very busy roadways. Improvements can be made and in some cases, perhaps the barriers should have been slightly taller. These barriers were designed with STAMINA2.0 or STAMINA2.1 which has been shown to slightly over predict impacts and wall heights so it is uncertain why the walls are lower. The insertion loss algorithms in TNM have proven to be significantly better and use of TNM over the STAMINA models should be considered and is recommended. However, the absolute values are not significantly better from TNM modeling and at this time verification may be needed on a project by project basis. It is recommended that measurements be used to substantiate the accuracy of TNM before any barriers are implemented. The measurements would provide the before case that could be compared to the TNM no barrier predictions, thus allowing the barrier design process to be more accurate. The propagation algorithms have been shown to be significantly better, so after the no barrier case is validated, good results in barrier design would be expected.

Another recommendation is that when existing structures are present, care should be taken in the prediction process. These structures may need to be added in an appropriate fashion in the model.

More research is needed. More measurements and consideration of source height, pavement type and weather inputs should be done. Some locations should be revisited and measurements done at the ends of the barrier to permit a more direct method for insertion loss comparison.

## VI. REFERENCES

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[5] Wayson, R.L. and T.W.A. Ogle, *Extension of Reference Emission Factors for the STAMINA 2.0 Model to include 55-65 MPH*, FDOT Report No. FL-ER-51-92, Tallahassee, FL, July, 1992.

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[8] American National Standards Institute, *Methods for Determination of Insertion Loss of Outdoor Noise Barriers*, ANSI S12.8-1998, New York, 1998.

[9] American National Standards Institute, *Specifications for Sound Level Meters*, ANSI S1.4-1983, New York, 1985.

[10] Anderson, S., A. Auquier, W.W. Hauck, D. Oakes, W. Vandaele, and H.I. Weisberg, *Statistical Methods for Comparative Studies, Techniques for Bias Reduction*, John Wiley & Sons, New York, 1980.

[11] Embleton, T.F.W., Piercy J.E., Daigle G.A., "Effective flow resistivity of ground surfaces determined by acoustical measurements." *Journal of the Acoustical Society of America*, 74(4), pp. 1239-1243, 1983.

**APPENDIX A**  
**I-95; JACKSONVILLE**

**Site A. Jacksonville (I-95 De Kalb Avenue near Connors Drive pedestrian overpass)  
21 January 1999 [Project # 72280-3424]**

UCF staff: Dr. R.L. Wayson, John MacDonald, Patricia Tom, Rita Newton, Chris Corbisier, and Michael Elliot

FDOT staff: Scott, Perry, and Win

Assisting staff: Tim, Mark

**1<sup>st</sup> RUN – 11:02 (10second-120intervals)**

Bright, sunny, light winds with low cloud cover

IVIE #1	Weight	Response		DB Ref	SL beginning	SL ending
1	A	SW	CT	70	97	
2	A	FT	CT	70	65	
3	A	FT	CT	70	68	
4	A	FT	CT	70	58	
5	A	FT	CT	70	65	
6	A	FT	CT	70	70	
7	A	SW	CT	80	80	
8	A	FT	CT	80	79	

Note: Corrected cable induction by straightening out the cable loop on connection to IVIE #1

**2<sup>nd</sup> RUN – 11:41 (10second-120intervals)**

Bright, sunny, light winds with low cloud cover

IVIE #1	Weight	Response		DB Ref	SL beginning	SL ending
1	A	FT	CT	70	65	65
2	A	FT	CT	70	63	63
3	A	FT	CT	70	68	67
4	A	FT	CT	70	28	63
5	A	FT	CT	70	64	68
6	A	FT	CT	70	69	71
7	A	FT	CT	80	80	80
8	A	FT	CT	80	80	81

Note: No 60 cycle on any IVIE reading. Every IVIE is set uniformly  
Problem: IVIE #4 reading as noticed at 11:43, IVIE #5 has a 10K spike

**3<sup>rd</sup> RUN – 13:48 (10second-120intervals)**

Bad cable connection to IVIE #4 causes all data input as fed in series to not be logged in. After the 20 minute time interval run ends, it is realized that no data has been processed due to wiring problem on IVIE #4

**4<sup>th</sup> RUN – 14:24 (10second-120intervals)**

Bright, sunny, light winds with low cloud cover

IVIE #1	Weight	Response		DB Ref	SL beginning	SL ending
1	A	FT	CT	70	61	64
2	A	FT	CT	70	59	63
3	A	FT	CT	70	67	68
5	A	FT	CT	70	63	65
6	A	FT	CT	70	68	70
7	A	FT	CT	80	79	81
8	A	FT	CT	80	79	83

Note: IVIE #5 Row8/24 400Hz digital display diode out.

**5<sup>th</sup> RUN – 14:50 (10second-120intervals)**

Bright, sunny, light winds with low cloud cover

IVIE #1	Weight	Response		DB Ref	SL beginning	SL ending
1	A	FT	CT	70	64	63
2	A	FT	CT	70	63	62
3	A	FT	CT	70	68	68
5	A	FT	CT	70	63	63
6	A	FT	CT	70	70	70
7	A	FT	CT	80	77	78
8	A	FT	CT	80	80	80

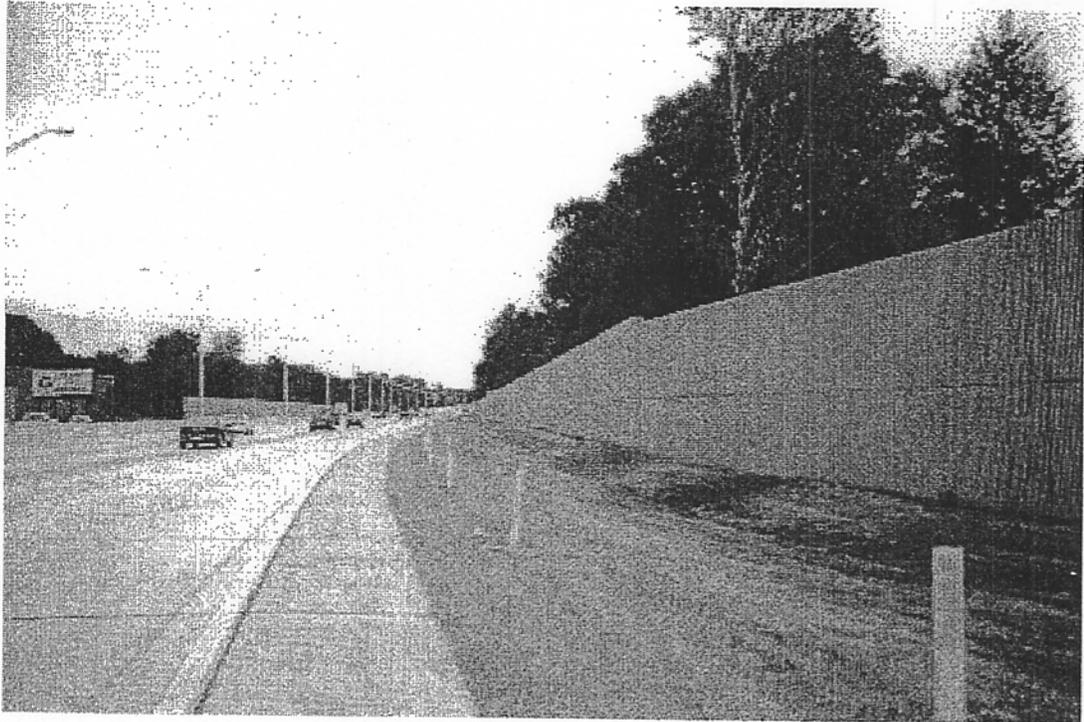
**Metro:**

ID #	Distance from Barrier	Closest IVIE mics	Height	Final Calibration
SN2137	7.5 m	-	1.5 m	102 db
SN2134	15 m	4,5,6	1.5 m	101.9 db
SN2143	22.5 m	-	1.5 m	102 db
SN2136	30 m	1,2,3	1.5 m	101.8 db

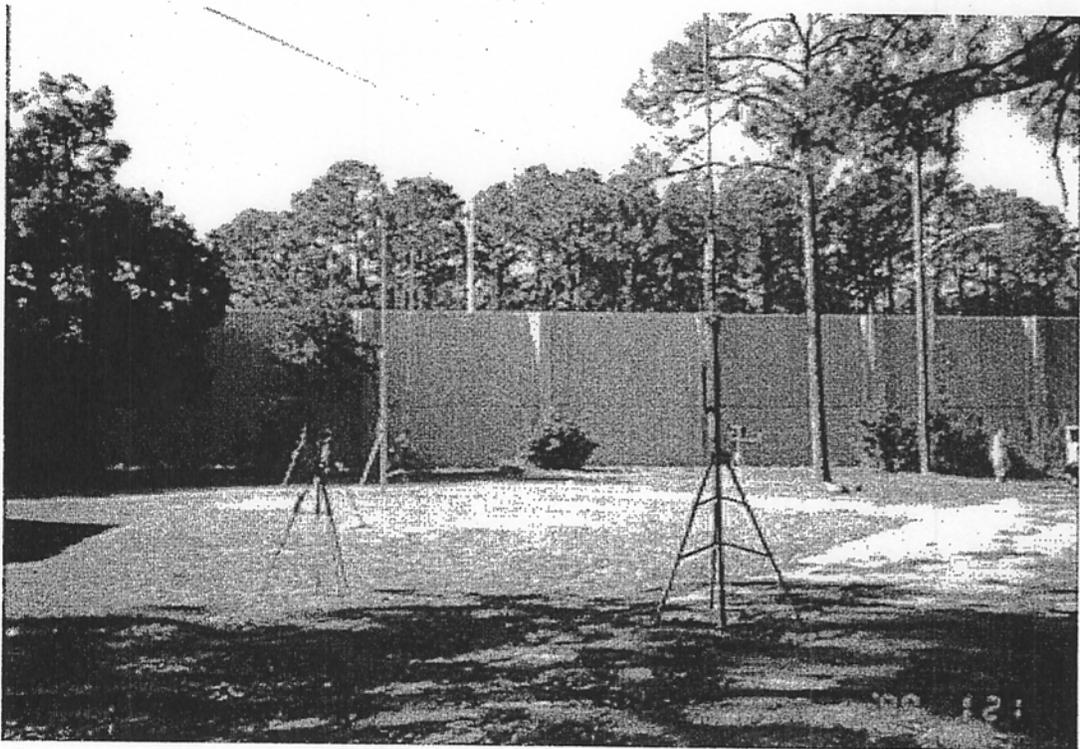
**Barrier Height:**

Wall Post in Panel 18'6" – mics 7 and 8 are 5' above barrier at 45 degree to barrier

Jacksonville (Duval County)



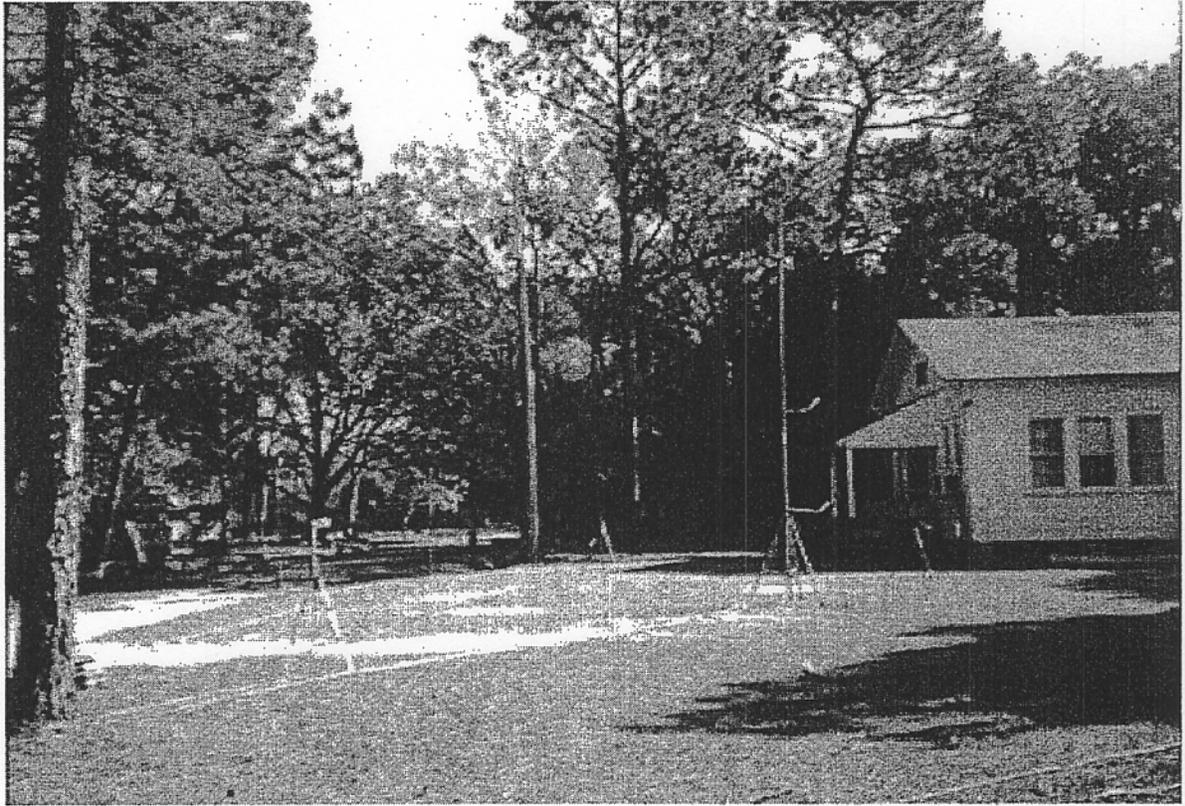
Roadway view of Noise Wall



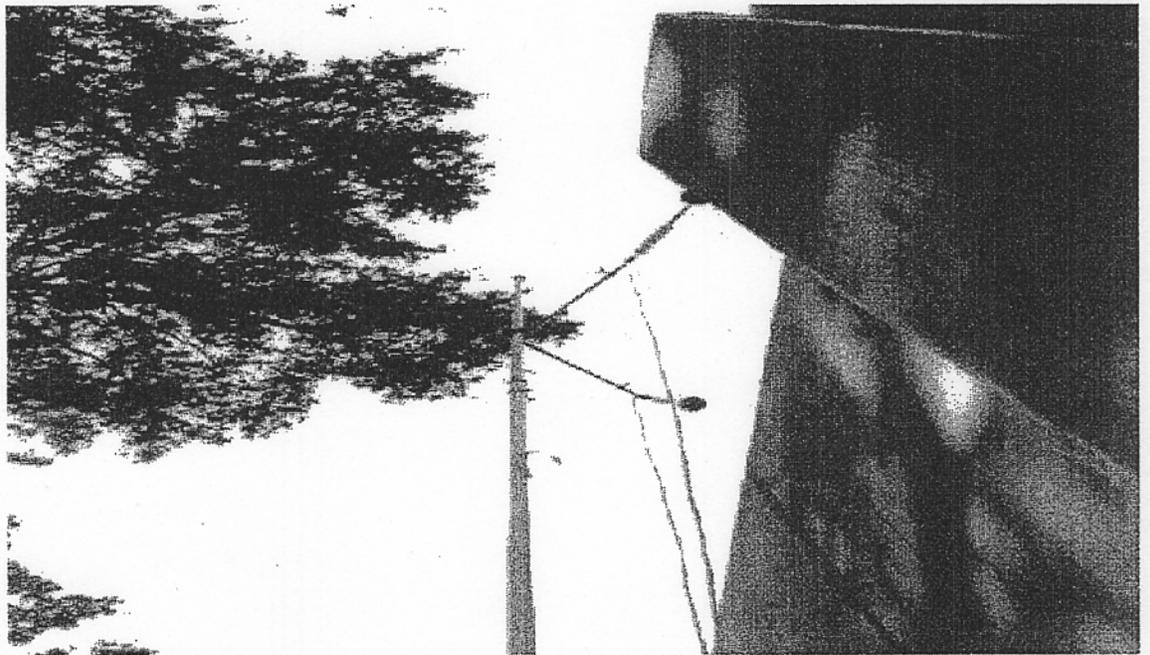
Residential view of Noise Wall

I-95 De Kalb Avenue near Connors Drive (pedestrian overpass)  
Project # 72280-3424

Jacksonville (Duval County)



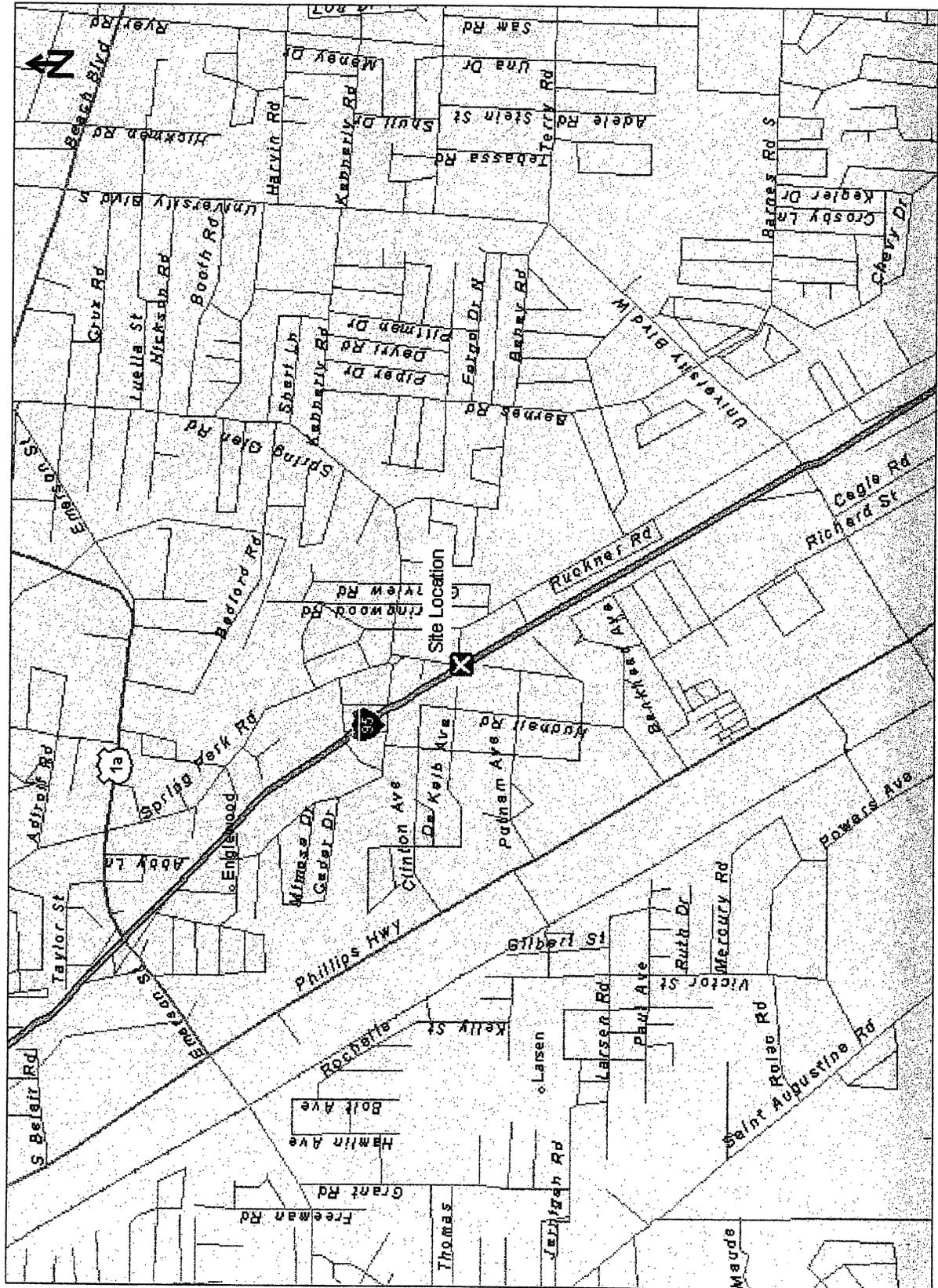
Residential area behind Noise Wall



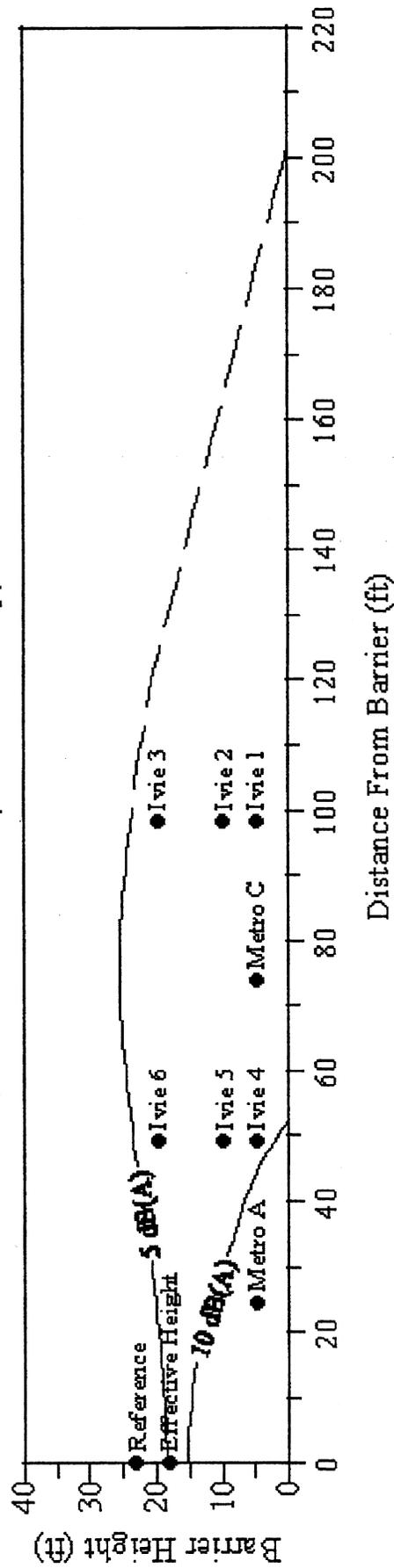
Up-close view of reference microphones by Noise Wall

I-95 De Kalb Avenue near Connors Drive (pedestrian overpass)  
Project # 72280-3424

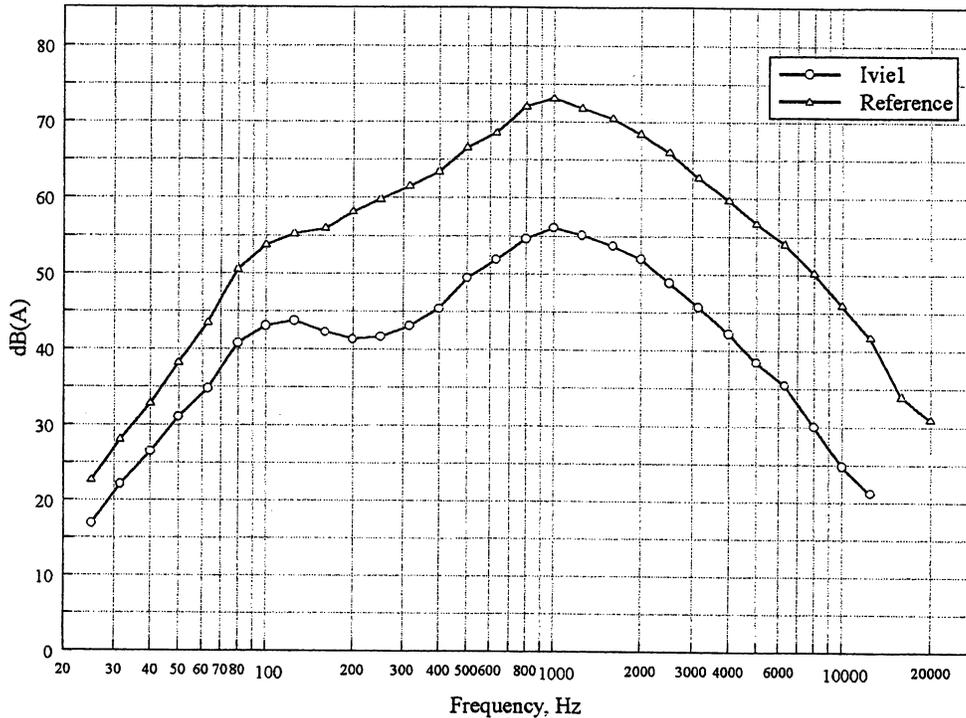
Site A. Jacksonville (Duval County)



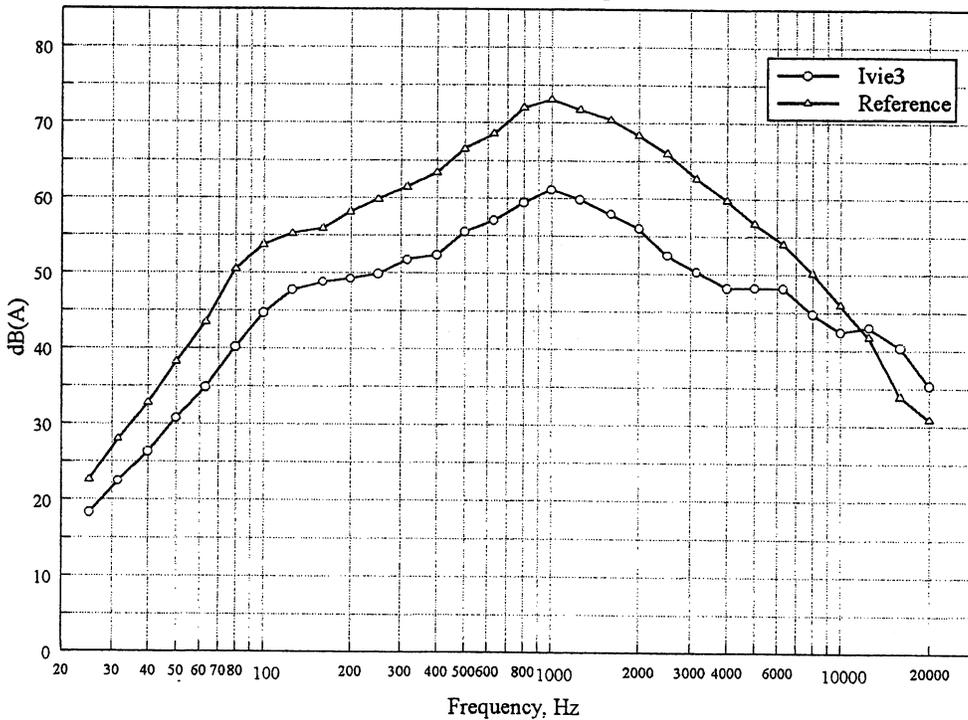
### Site A. Jacksonville (Duval County) Shadow Zone



Site A. Jacksonville (Duval County)  
Ivie 1 Four-Run Average Spectra Curve



Site A. Jacksonville (Duval County)  
Ivie 3 Four-Run Average Spectra Curve



**APPENDIX B**  
**I-295; JACKSONVILLE**

**Site B. Jacksonville (I-295 River Road west of Buckman Bridge)**  
**9 February 1999 [Project # 72001-3444]**

UCF staff: Dr. R.L. Wayson, John MacDonald, Patricia Tom, and Michael Elliot

FDOT staff: Scott, Joan, Mariano, and Win

**1<sup>st</sup> RUN – 11:27 (10second-120intervals)**

Cloudy overcast with no wind, dry 68, wet 66, RH 90%

IVIE #1	Weight	Response		DB Ref	SL beginning
1	A	FT	CT	90	71
2	A	FT	CT	80	62
3	A	FT	CT	80	73
4	A	FT	CT	80	64
5	A	FT	CT	80	71
6	A	FT	CT	80	67
7	A	FT	CT	90	84
8	A	FT	CT	90	71

Note: Dog barking near mics 1,2, and 3 at 11:28. Aircraft at 11:41 and 11:43. Dog barking again at 11:44 and 11:45.

**2<sup>nd</sup> RUN – 11:55 (10second-120intervals)**

Partially cloudy, wind at 5 mph with gust to 8mph, wet 68, dry 75

IVIE #1	Weight	Response		DB Ref	SL beginning
1	A	FT	CT	90	72
2	A	FT	CT	80	61
3	A	FT	CT	80	65
4	A	FT	CT	80	57
5	A	FT	CT	80	53
6	A	FT	CT	80	64
7	A	FT	CT	90	76
8	A	FT	CT	90	78

Note: Dog barking near mics 1,2, and 3 at 12:11. Aircraft at 12:11.

**3<sup>rd</sup> RUN – 12:50 (10second-120intervals)**

Partially cloudy, wind at 5 mph with gust to 8mph, wet 68, dry 75

IVIE #1	Weight	Response		DB Ref	SL beginning
1	A	FT	CT	90	65
2	A	FT	CT	80	63
3	A	FT	CT	80	68
4	A	FT	CT	80	60
5	A	FT	CT	80	61
6	A	FT	CT	80	67
7	A	FT	CT	90	79
8	A	FT	CT	90	79

Note: Dog barking near mics 1,2, and 3 at 13:02 and 13:08. Aircraft at 12:51, 12:52, 12:57, 13:06, and 13:07.

**4<sup>th</sup> RUN – 13:18 (10second-120intervals)**

Cloudy < 0.3 cumulus overcast with wind < 3mph, wet 69, dry 77, RH 48%

IVIE #1	Weight	Response	DB Ref	SL beginning
1	A	FT CT	80	66
2	A	FT CT	80	65
3	A	FT CT	80	72
4	A	FT CT	70	63
5	A	FT CT	80	63
6	A	FT CT	80	67
7	A	FT CT	90	73
8	A	FT CT	90	67

Note: Dog barking near mics 1,2, and 3 at 13:37. Aircraft at 13:19.

**Metro:**

ID #	Distance from Barrier	Closest IVIE mics	Height	Final Calibration
SN2136	7.5 m	-	1.5 m	101.9 db
SN2143	15 m	4,5,6	1.5 m	101.9 db
SN2134	22.5 m	-	1.5 m	101.9 db
SN2137	30 m	1,2,3	1.5 m	101.9 db

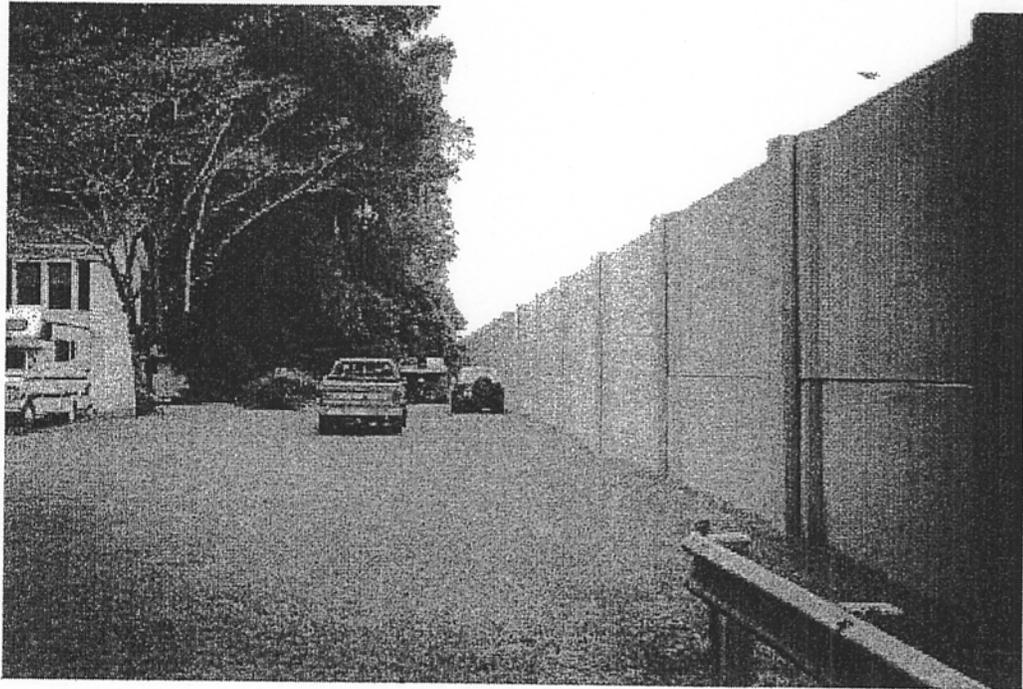
**Barrier Height:**

Variable but at measurement location it is 15'7" with drop off to West and drainage slots & fire hose opening too – mics 7 and 8 are 1.5 m above barrier at measurement location

Jacksonville (Duval County)



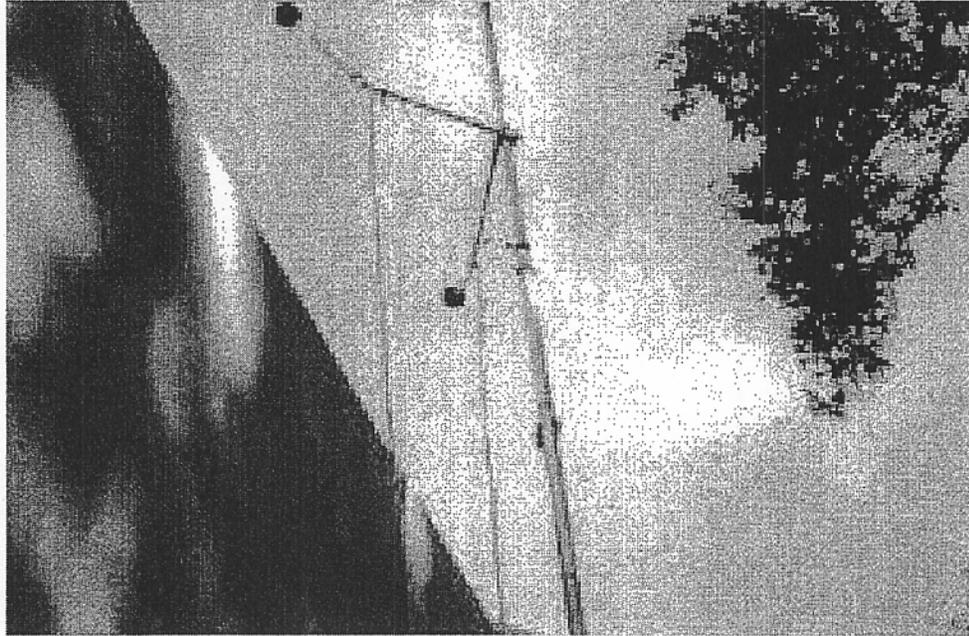
Roadway view of Noise Wall



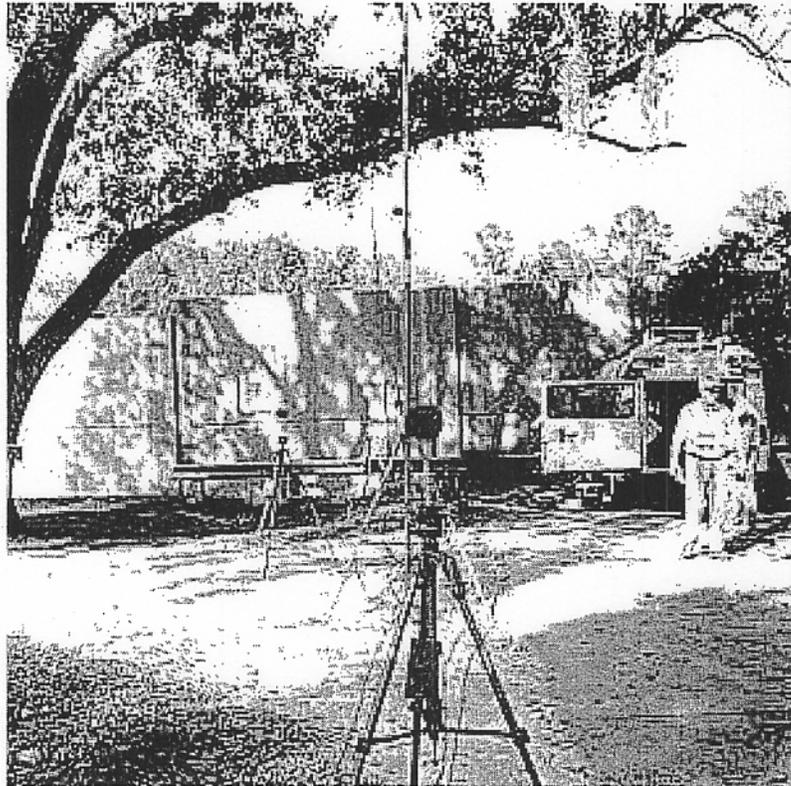
Residential area behind Noise Wall

I-295 River Road (West of Buckman Bridge)  
Project # 72001-3444

Jacksonville (Duval County)



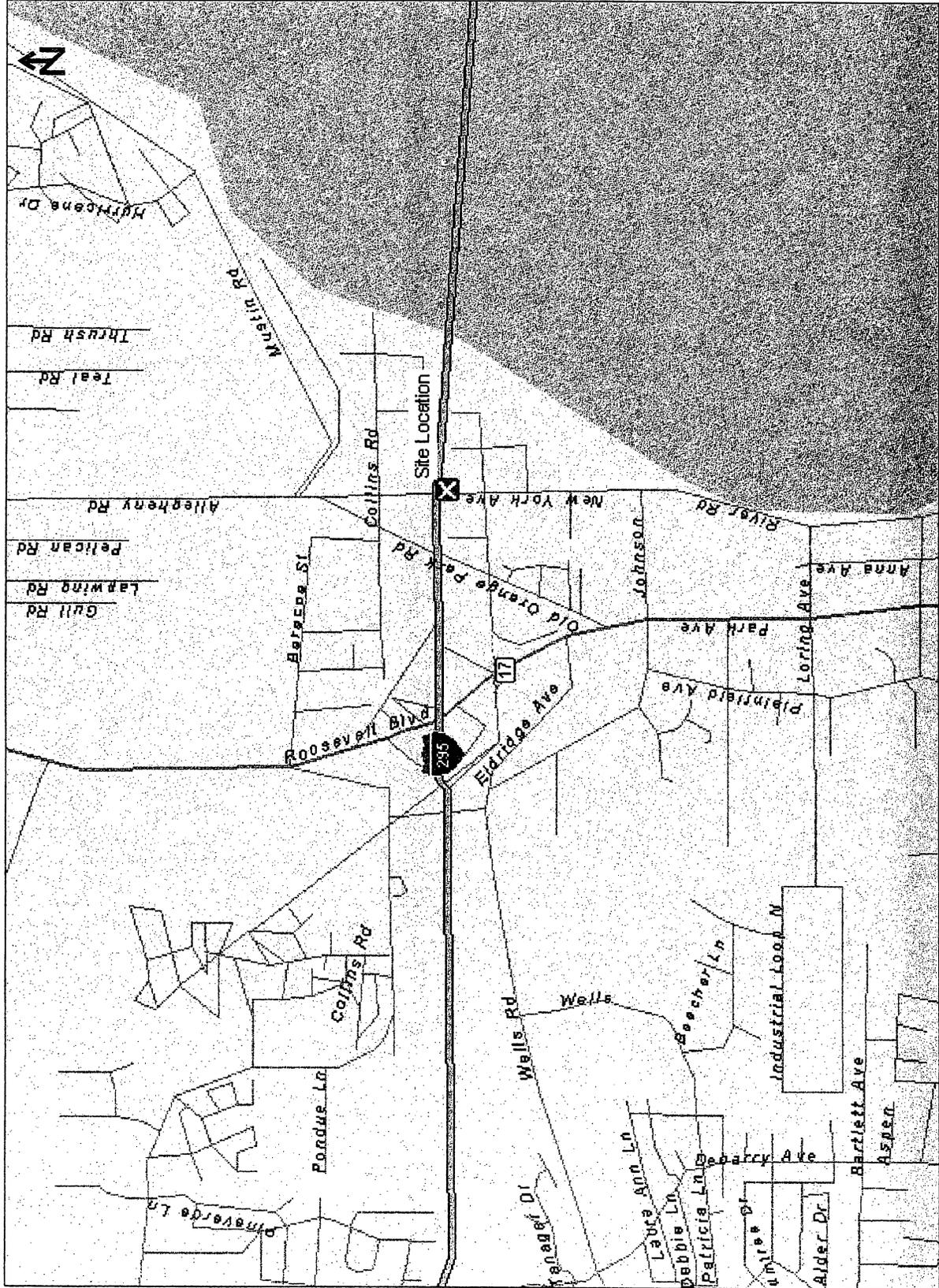
Up-close view of reference microphones by Noise Wall



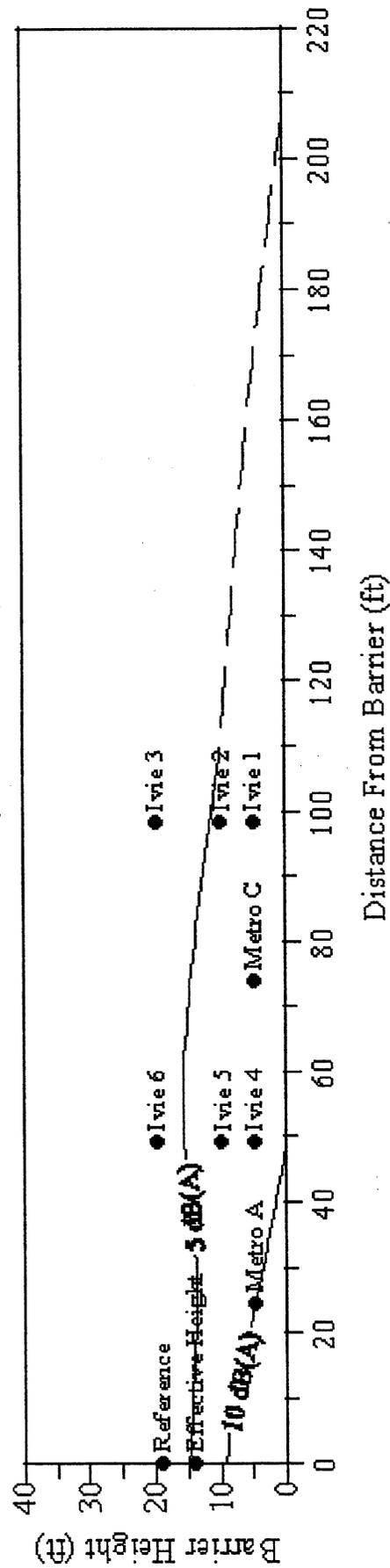
Residential view of Noise Wall

I-295 River Road (West of Buckman Bridge)  
Project # 72001-3444

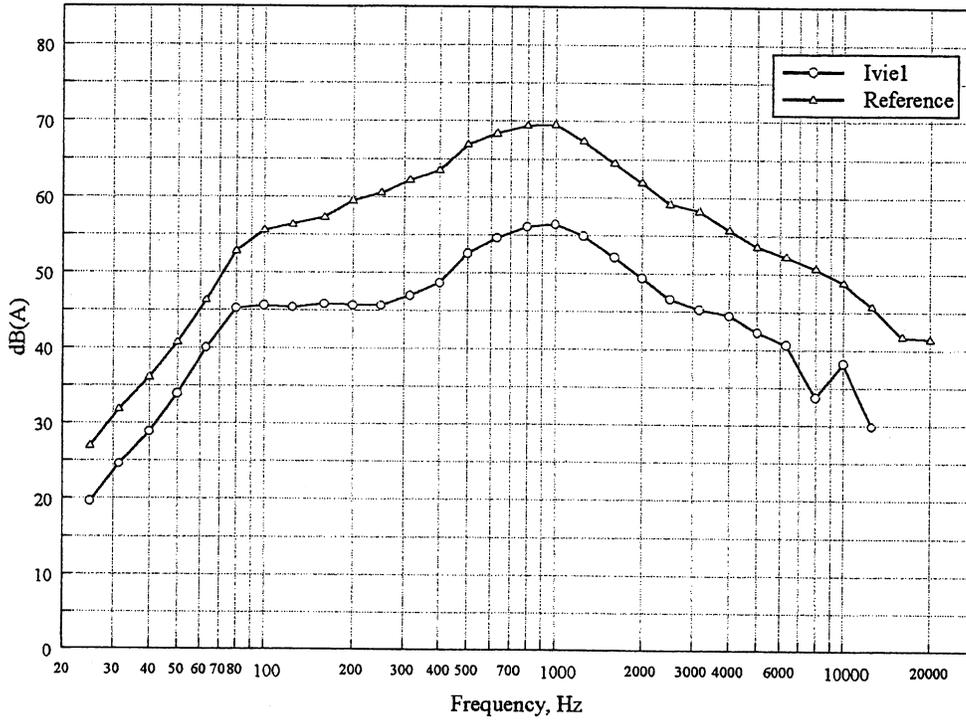
Site B. Jacksonville (Duval County)



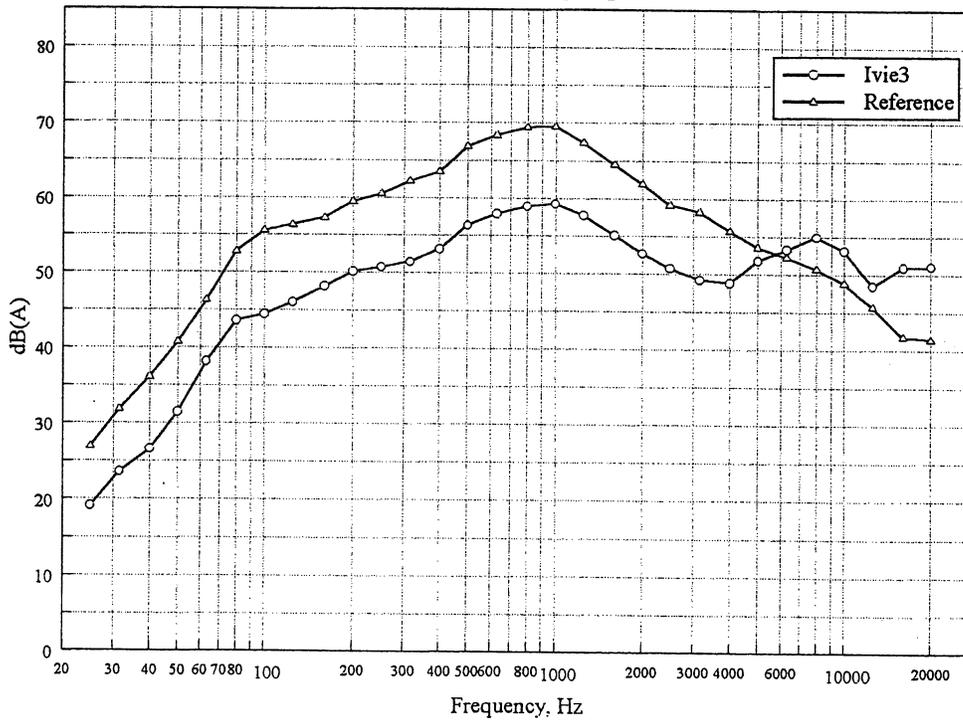
### Site B. Jacksonville (Duval County) Shadow Zone



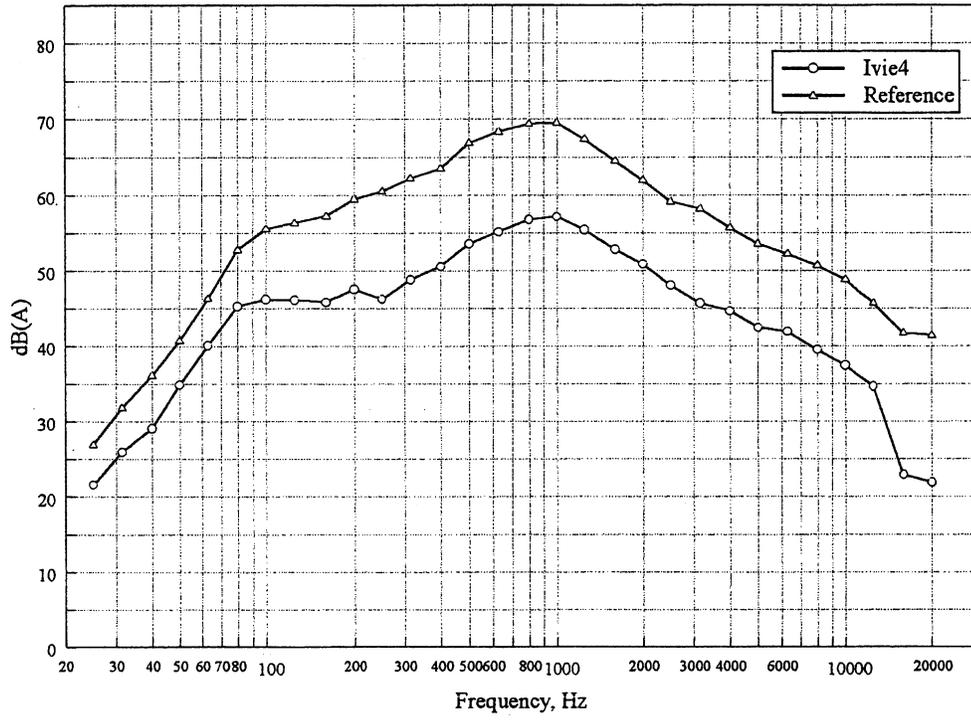
Site B. Jacksonville (Duval County)  
Ivie 1 Four-Run Average Spectra Curve



Site B. Jacksonville (Duval County)  
Ivie 3 Four-Run Average Spectra Curve



Site B. Jacksonville (Duval County)  
Ivie 4 Four-Run Average Spectra Curve



**APPENDIX C**  
**SR 5A; DAYTONA**

**Site C. Daytona (SR 5A Nova Road)**  
**2 March 1999** [Project # 79190-3510]

UCF staff: Dr. R.L. Wayson, John MacDonald, Patricia Tom, and Michael Elliot

FDOT staff: Natalie, Bill, and Win

**1<sup>st</sup> RUN – 12:37 (10second-120intervals)**  
 Sunny with no wind, dry 75, wet 61, RH 44%

mic #	IVIE unit #	Weight	Response		DB Ref	SL beginning
1	1	A	FT	CT	80	56
2	4	A	FT	CT	80	55
3	12	A	FT	CT	80	60
4	6	A	FT	CT	80	52
5	7	A	FT	CT	80	58
6	11	A	FT	CT	80	74
7	9	A	FT	CT	80	73
8	8	A	FT	CT	80	68

Note: Generator #1 failure had to get gas in order to then use generator #2 as replacement. #8 mic did not print out calibration file. Reprint does have mic #8. Cable #6 had no signals...corrected. 12:43pm heavy Jake Breaker (???) taking near rear microphones. 12:45pm truck pulls out from nearby driveway...60 cycle showing up on #6 may have dropped data. #4 below threshold-problem.

**2<sup>nd</sup> RUN – 13:05 (10second-120intervals)**  
 Sunny with no wind, dry 75, wet 61, RH 44%

mic #	IVIE unit #	Weight	Response		DB Ref	SL beginning	SL ending
1	1	A	FT	CT	70	60	57
2	4	A	FT	CT	70	54	53
3	12	A	FT	CT	70	56	56
4	6	A	FT	CT	70	47	42
5	7	A	FT	CT	70	50	49
6	11	A	FT	CT	80	74	72
7	9	A	FT	CT	80	78	61
8	8	A	FT	CT	80	72	65

Note: Sawing activity at 1:07pm, 1:15pm and 1:25pm. Vehicle passby at 1:21pm. Street sweeper comes to clean accessible area at 1:24pm until 1:26pm (throw out data).

**3<sup>rd</sup> RUN – 13:39 (10second-120intervals)**  
 Sunny with wind 2-4 mph gusting to 6 mph from SE, dry 75, wet 64, RH 54%

mic #	IVIE unit #	Weight	Response		DB Ref	SL beginning	SL ending
1	1	A	FT	CT	70	57	57
2	4	A	FT	CT	70	53	53
3	12	A	FT	CT	70	58	56
4	6	A	FT	CT	70	50	46
5	7	A	FT	CT	70	65	59
6	11	A	FT	CT	80	74	73
7	9	A	FT	CT	80	79	70
8	8	A	FT	CT	80	67	63

Note: Sawing activity at 1:48pm and 1:52pm. Vehicle passby at 1:48pm, 1:49pm, 1:51pm, and 1:54pm. Owner of house/driveway where we are set up returns via car at 1:53pm.

**4<sup>th</sup> RUN – 14:07 (10second-120intervals)**

Sunny with wind 2-4 mph gusting to 6 mph from SE, dry 75, wet 64, RH 54%

mic #	IVIE unit #	Weight	Response		DB Ref	SL beginning	SL ending
1	1	A	FT	CT	70	55	56
2	4	A	FT	CT	70	53	53
3	12	A	FT	CT	70	55	55
4	6	A	FT	CT	70	42	42
5	7	A	FT	CT	70	52	52
6	11	A	FT	CT	80	73	72
7	9	A	FT	CT	80	62	72
8	8	A	FT	CT	80	66	60

Note: Saw and voices at 2:13pm. Car is started near last mics. Postal vehicle delivers mail at 2:26pm.

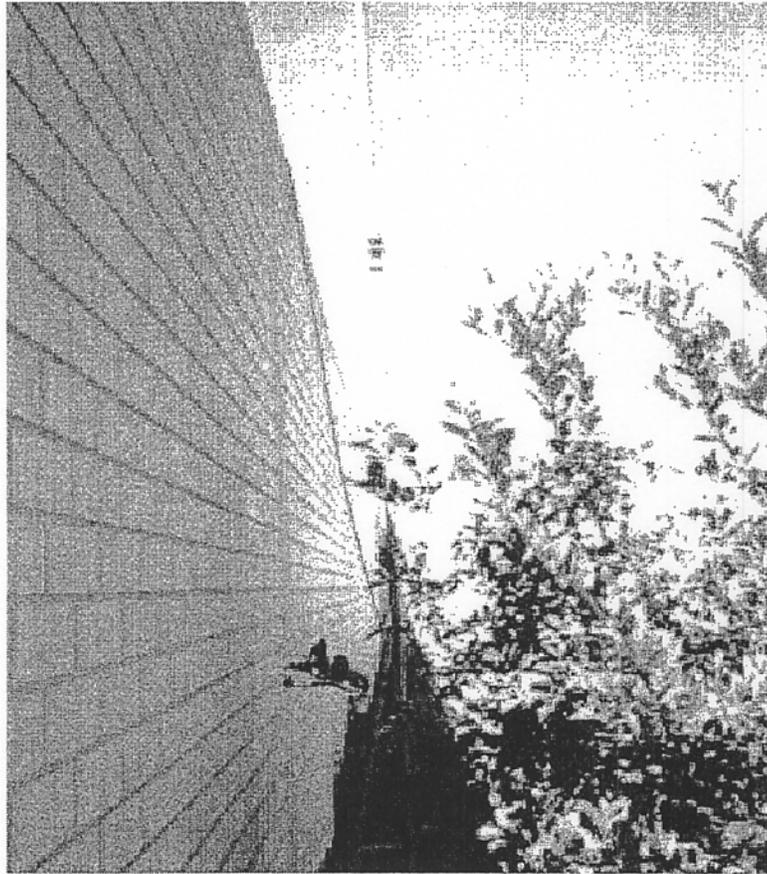
**Metro:**

ID #	Distance from Barrier	Closest IVIE mics	Height	Final Calibration
SN2134	7.5 m	-	1.5 m	101.9 db
SN2143	15 m	4,5,6	1.5 m	101.8 db
SN2137	22.5 m	-	1.5 m	101.8 db
SN2136	30 m	1,2,3	1.5 m	101.9 db

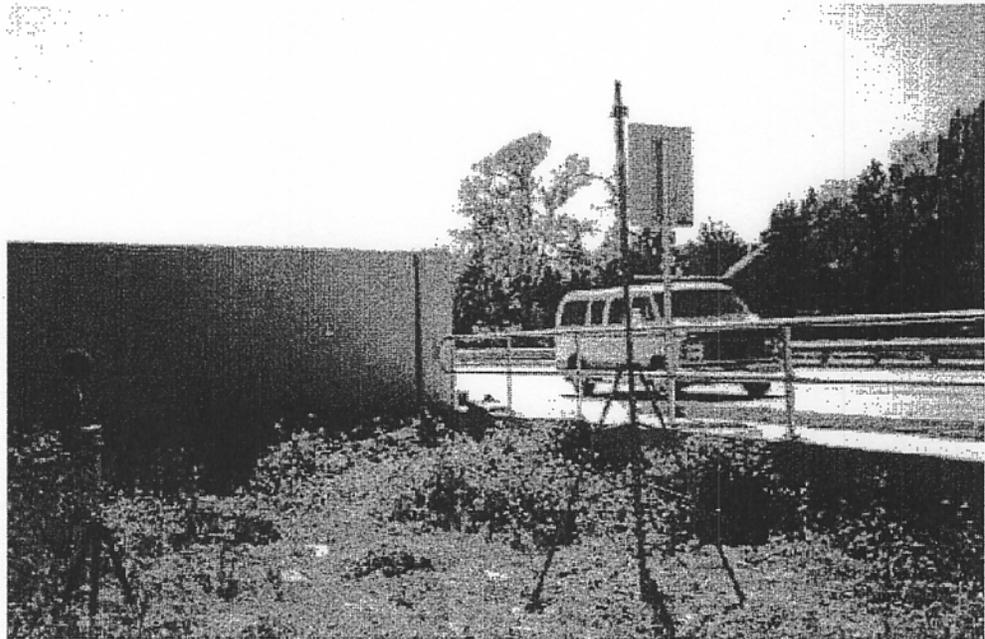
**Barrier Height:**

As measured on the house side it is 11' while as measured on the roadside it is 7.5'. Ground is hard with underlying limestone.

Daytona (Volusia County)



Up-close view of reference microphone stand by Noise Wall



View of Noise Wall and roadway

SR5A Nova Road  
Project # 79190-3510

Daytona (Volusia County)



Residential view of Noise Wall

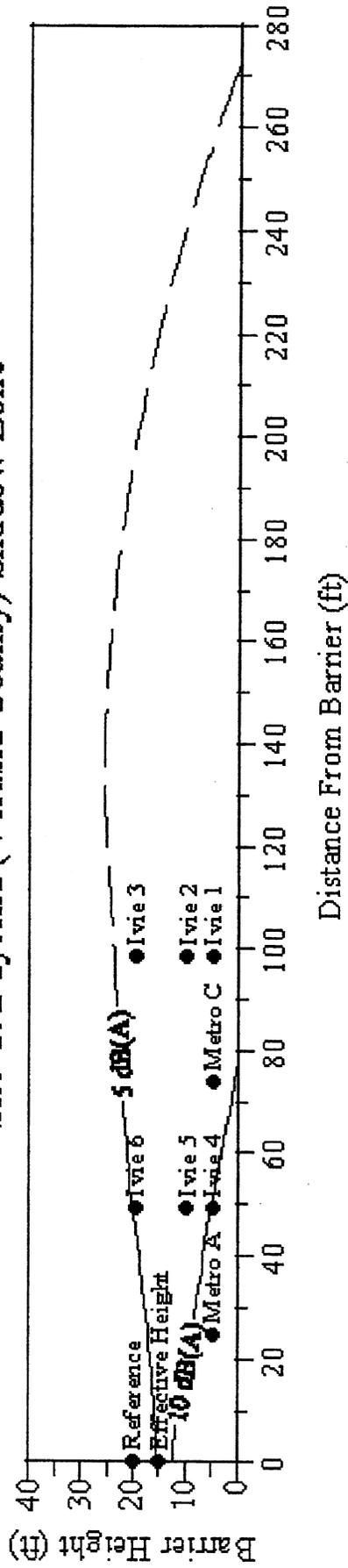


Residential area behind Noise Wall

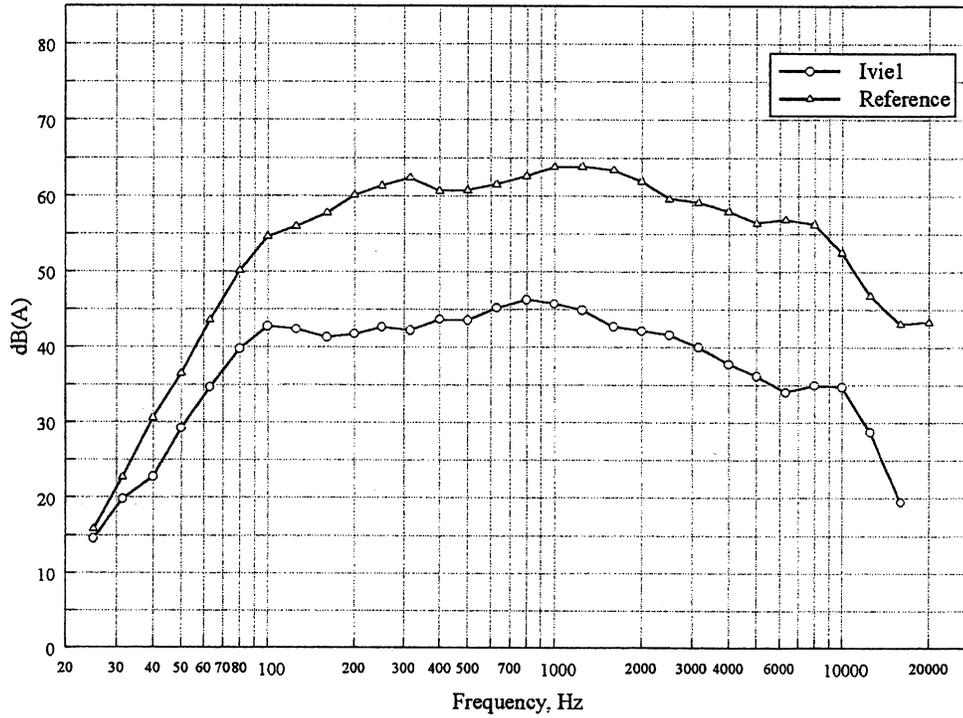
SR5A Nova Road  
Project # 79190-3510



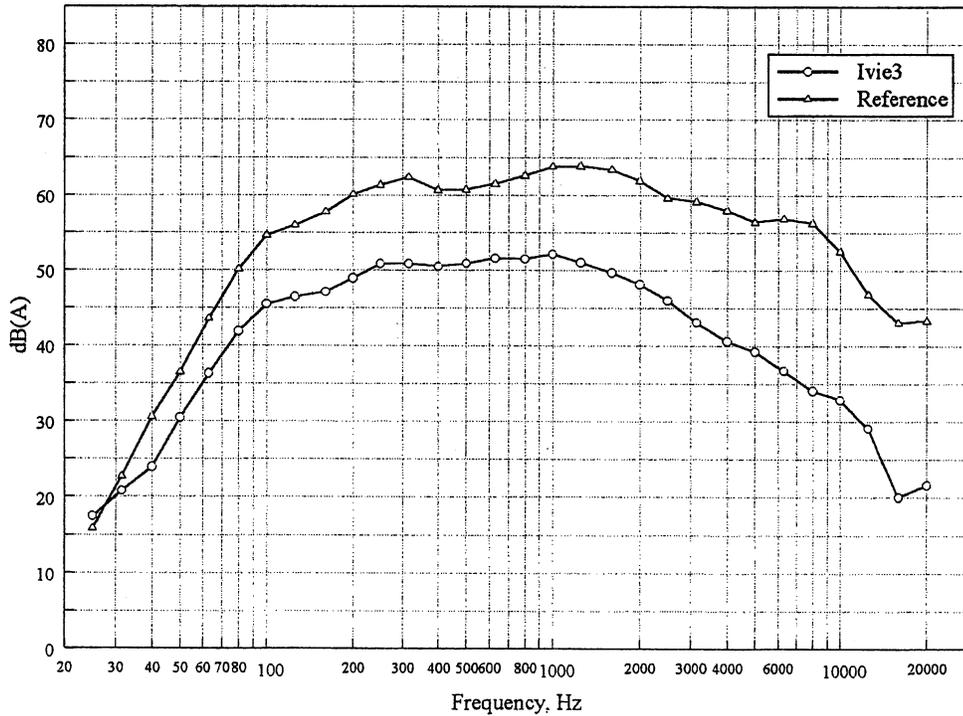
### Site C. Daytona (Volusia County) Shadow Zone



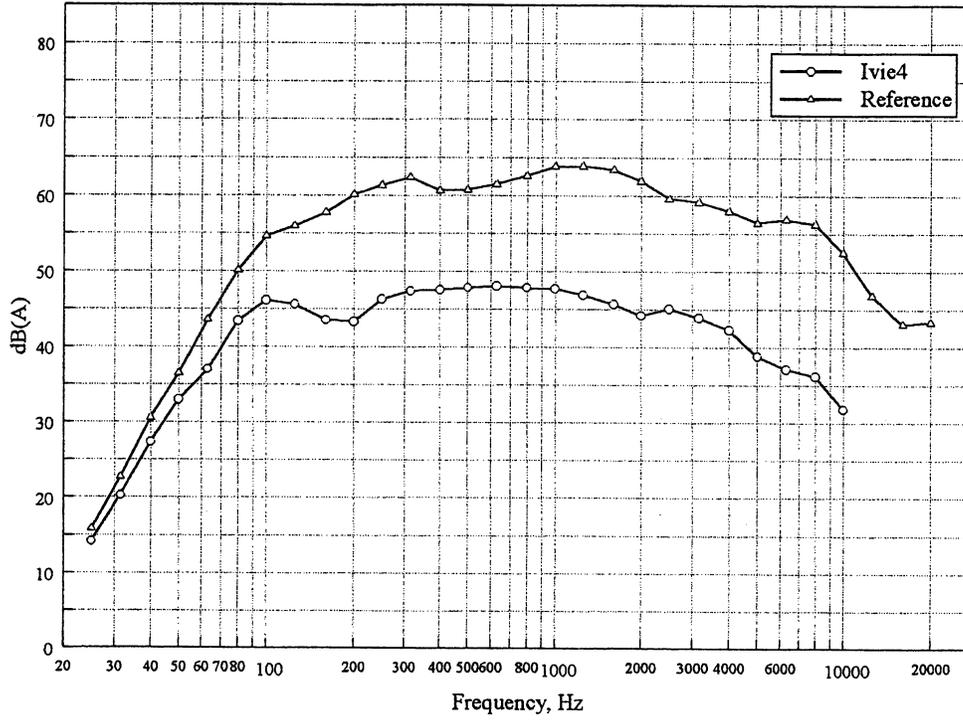
Site C. Daytona (Volusia County)  
Ivie 1 Four-Run Average Spectra Curve



Site C. Daytona (Volusia County)  
Ivie 3 Four-Run Average Spectra Curve



Site C. Daytona (Volusia County)  
Ivie 4 Four-Run Average Spectra Curve



**APPENDIX D**

**SR 72; SARASOTA**

**Site D. Sarasota (Albert Place off SR-72/Clark Road)**  
**6 April 1999 [Project # 17000-3502]**

UCF staff: Dr. R.L. Wayson, John MacDonald, Patricia Tom, Michael Elliot, DSRK

FDOT staff: Mariano, Liz, Robin

Beginning calibration:

mic #	IVIE unit #	Calibration	Average
1	10	-2.5	-2.5
2	1	-4.2	-4.2
3	2	1.5	1.5
4	3	1.4	1.4
5	12	-1.3	-1.3
6	11	4.3	4.3
7	7	2.2	2.2
8	4	-1.0	-1.0

**1<sup>st</sup> RUN – 12:45 (3.375 second-120intervals)**

Sunny with minor gust 3-4 mph from ENE, dry 85, wet 77, RH 66%

mic #	IVIE unit #	Weight	Response	
1	10	A	FT	CT
2	1	A	FT	CT
3	2	A	FT	CT
4	3	A	FT	CT
5	12	A	FT	CT
6	11	A	FT	CT
7	7	A	FT	CT
8	4	A	FT	CT

Note: car at 12:49, car and door alarm at 12:55, crashes from next door at 13:03, siren at 13:07

**2<sup>nd</sup> RUN -- 14:15 (3.375 second-120intervals)**

Sunny with minor gust 3-4 mph from E, dry 89, wet 78, RH 61%

mic #	IVIE unit #	Weight	Response	
1	10	A	FT	CT
2	1	A	FT	CT
3	2	A	FT	CT
4	3	A	FT	CT
5	12	A	FT	CT
6	11	A	FT	CT
7	7	A	FT	CT
8	4	A	FT	CT

Note: car passing with loud stereo and door slams at 14:26

**3<sup>rd</sup> RUN – 14:50 (3.375second-60intervals)**

Sunny with winds 2 mph from E, dry 89, wet 78, RH 61%

mic #	IVIE unit #	Weight	Response		End calibration
1	10	A	FT	CT	96.8
2	1	A	FT	CT	94.9
3	2	A	FT	CT	92.8
4	3	A	FT	CT	93.1
5	12	A	FT	CT	96.5
6	11	A	FT	CT	90.7
7	7	A	FT	CT	91.8
8	4	A	FT	CT	95.1

Note: Siren at 14:51.

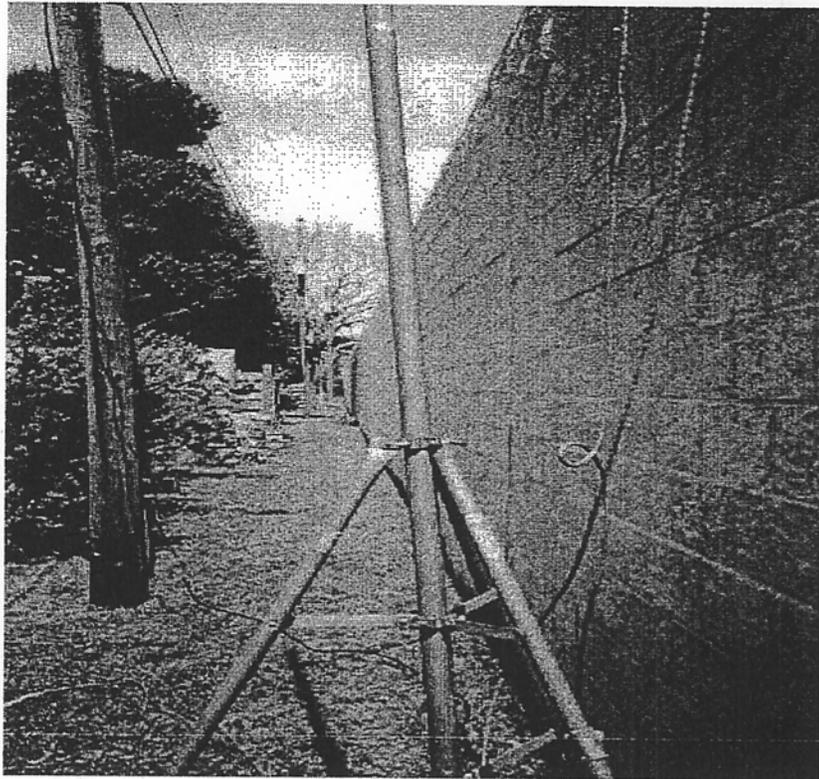
**Metro:**

ID #	Distance from Barrier	Closest IVIE mics	Height	Final Calibration
SN2136	7.5 m	-	1.5 m	102.0 db
SN2134	15 m	4,5,6	1.5 m	101.9 db
SN2143	22.5 m	-	1.5 m	101.9 db
SN2137	30 m	1,2,3	1.5 m	101.9 db

**Barrier Height:**

Wall height varies from 11' to 11'4"

Sarasota (Sarasota County)



Up-close view of reference microphone stand by Noise Wall



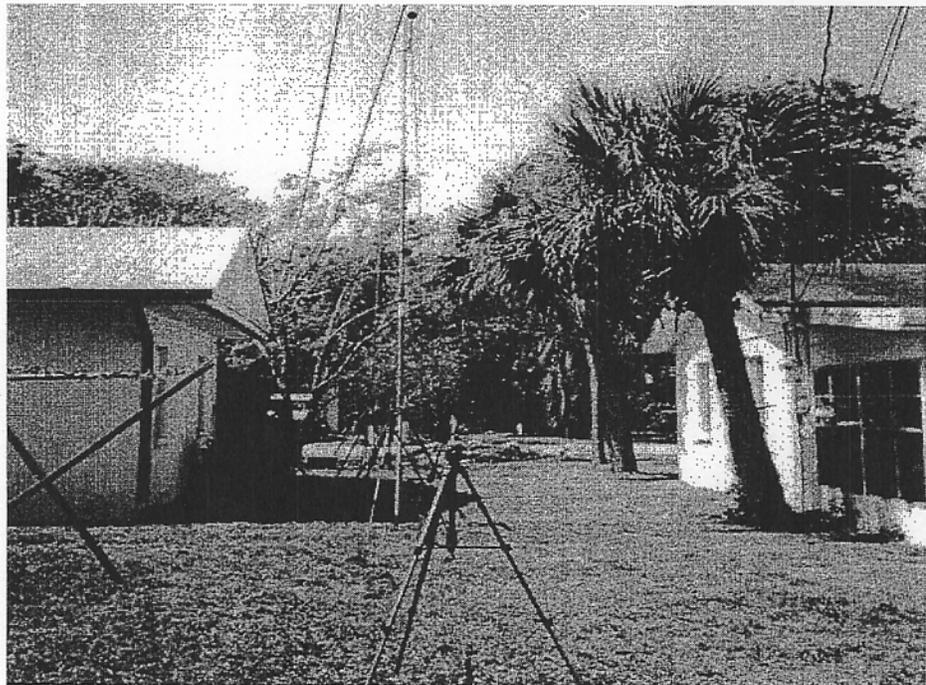
Data sampling equipment aligned to Noise Wall

Albert Place off SR72 (Clark Road)  
Project # 17000-3502

Sarasota (Sarasota County)



Residential view of Noise Wall



Residential area behind Noise Wall

Albert Place off SR72 (Clark Road)  
Project # 17000-3502



**APPENDIX E**

**I-75; TAMPA**

**Site E. Brandon (I-75 Earthen Berm/Wall north of Woodberry Road)**

**20 October 1999** [Project # 10075-3499]

UCF staff: Dr. R.L. Wayson, John MacDonald, Wayne Arner, Brian Kim, Chris Corbisier and Patricia Tom  
FDOT staff: Mariano, Robin, Dan and Roberto

Hillsborough County Earthen berm/wall I-75 (Woodberry Estates) near SR 60. Measurements collected by Elizabeth Drive.

**Calibration notes:**

1. #8 had readings ~58dB(A) with null microphone... we think bad cable.
2. Ran calibration on #5 and #6 twice with 94 dB calibrator, had wrong dB ref., getting only 77dB on #5, had samples 34 & 36 skipped..fixed it.
3. Watch dB ref for IVIEs #1-6 different for IVIEs 7&8.
4. IVIE #1 looks higher than #2, possible cable problem.
5. IVIE #5 1kHz band is near edge of 800Hz

**New DasyLab System:**

**1<sup>st</sup> RUN – 13:39:07- 13:59:07**

Weather: winds at ... mph from ..., dry 90°F, wet 80°F, RH 64%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	5	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8	8	A	FT	CT

**2nd RUN – 14:05:30- 14:25:30**

Weather: winds at ... mph from ..., dry 90°F, wet 80°F, RH 64%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	5	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8	8	A	FT	CT

**3rd RUN – 14:32:45- 14:52:45**

Weather: winds at ... mph from ..., dry 90°F, wet 80°F, RH 64%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	5	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8	8	A	FT	CT

**4<sup>th</sup> RUN – 14:56:10- 15:16:10**

Weather: winds at ... mph from ..., dry 90°F, wet 80°F, RH 64%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	5	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8	8	A	FT	CT

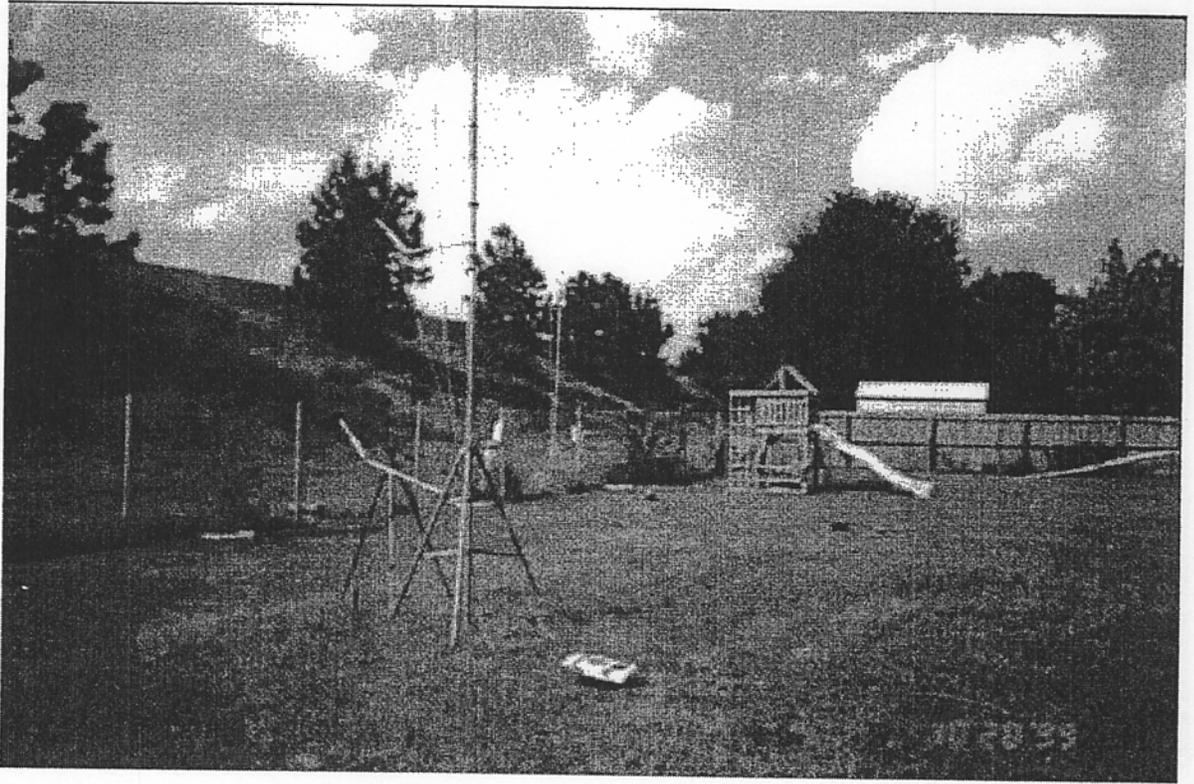
***Metro:***

ID #	Distance from Barrier	Height	Final Calibration
SN2136	7.5 m	1.5 m	102.0 dB
SN2146	15 m	1.5 m	101.9 dB
SN2143	22.5 m	1.5 m	101.8 dB
SN2134	30 m	1.5 m	102.0 dB

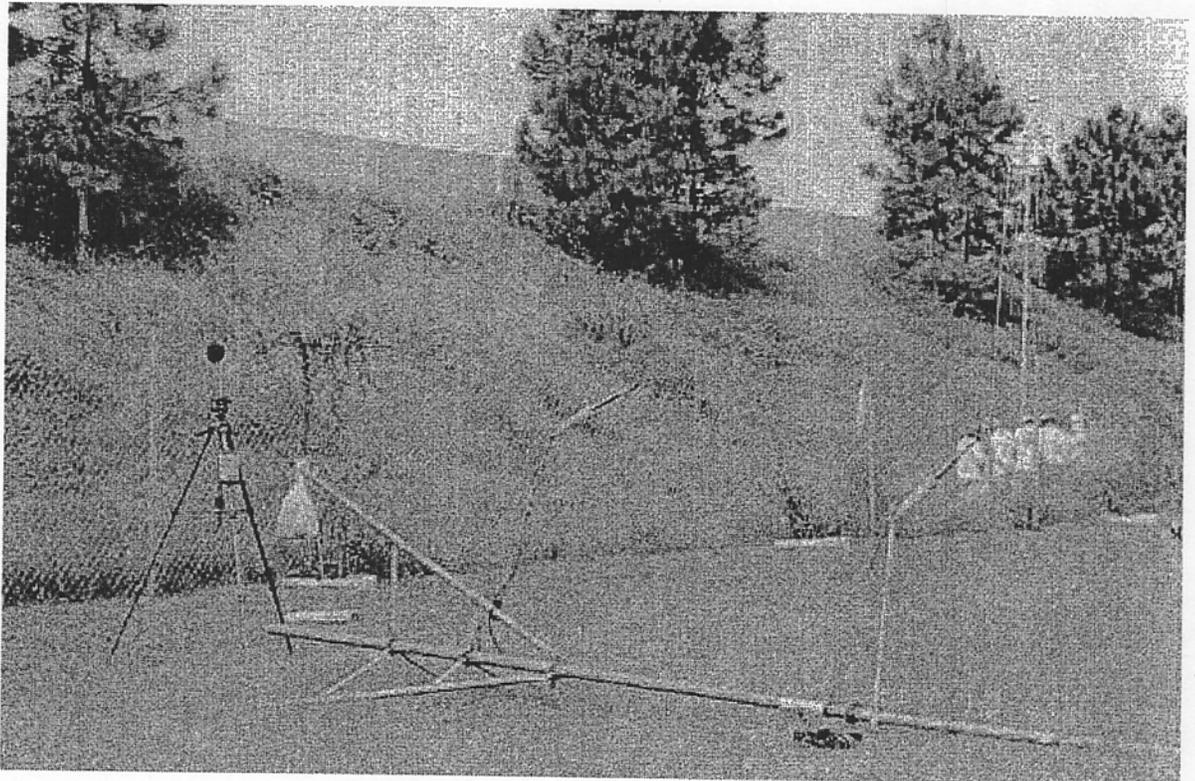
***Barrier Height:***

Wall on berm with wall height at approximately 6'5"

Brandon (Hillsborough County)



Residential backyard behind Noise Wall



Residential view of Noise Wall during equipment set up

I-75 Earthen Berm north of Woodberry Road  
Project # 10075-3499

Brandon (Hillsborough County)



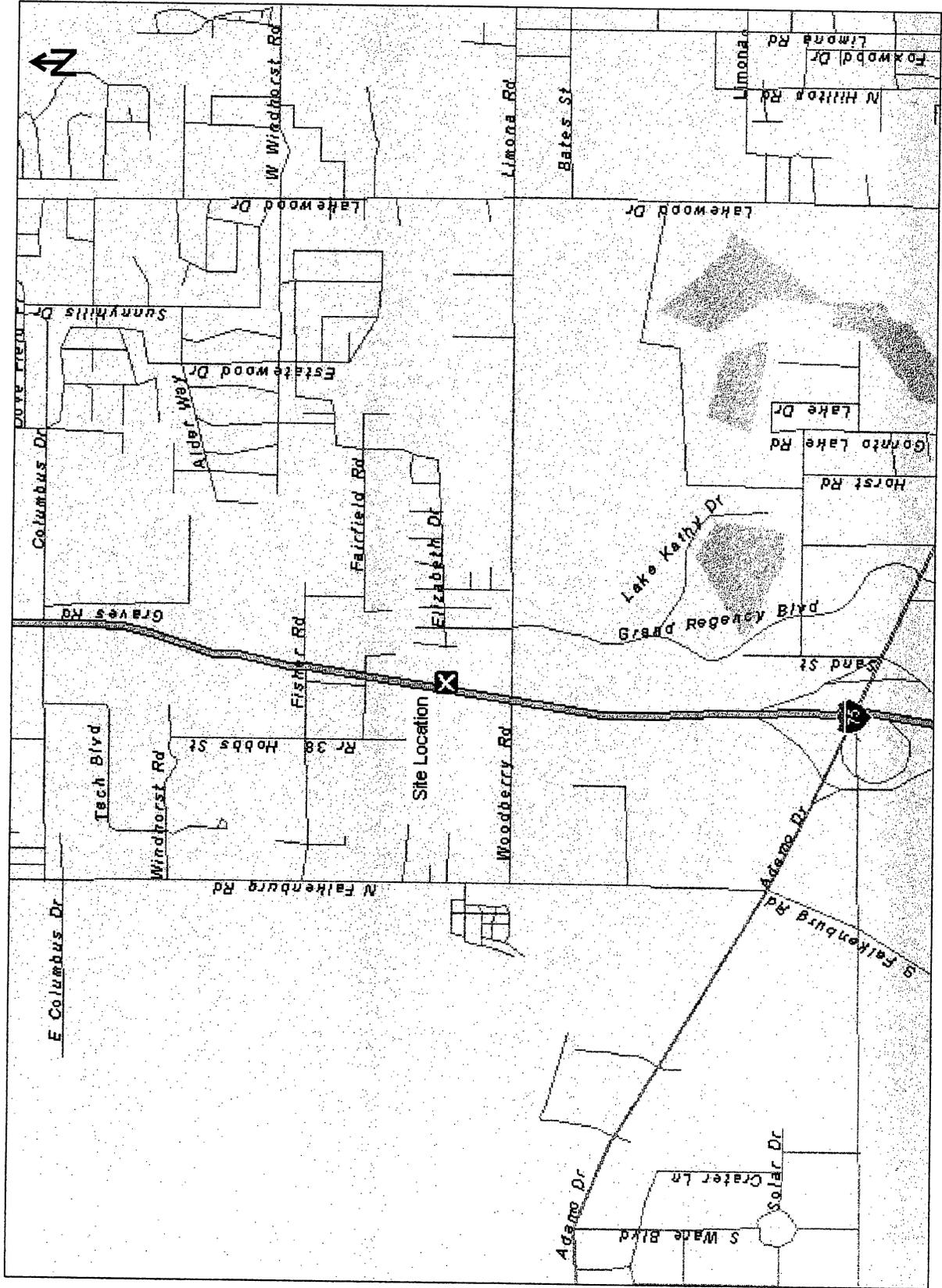
Residential view of Noise Wall



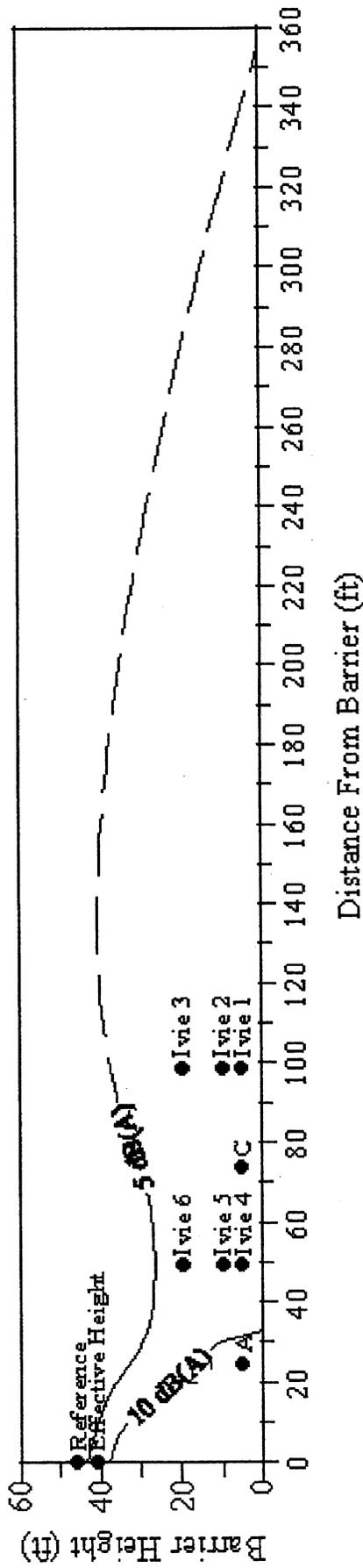
Residential area behind Noise Wall

I-75 Earthen Berm north of Woodberry Road  
Project # 10075-3499

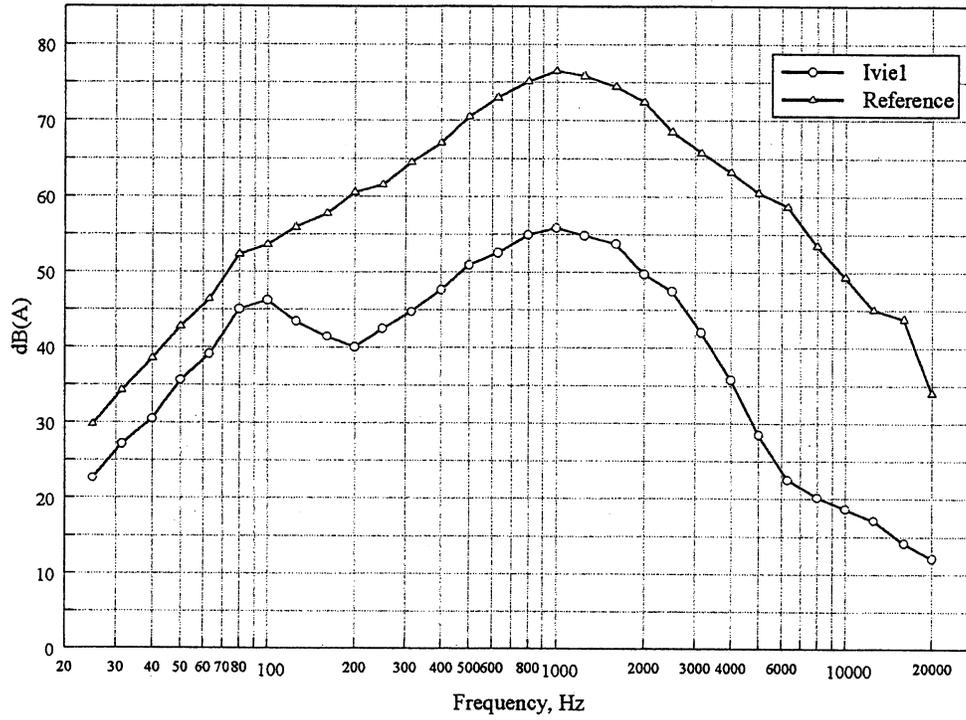
Site E. Brandon (Hillsborough County)



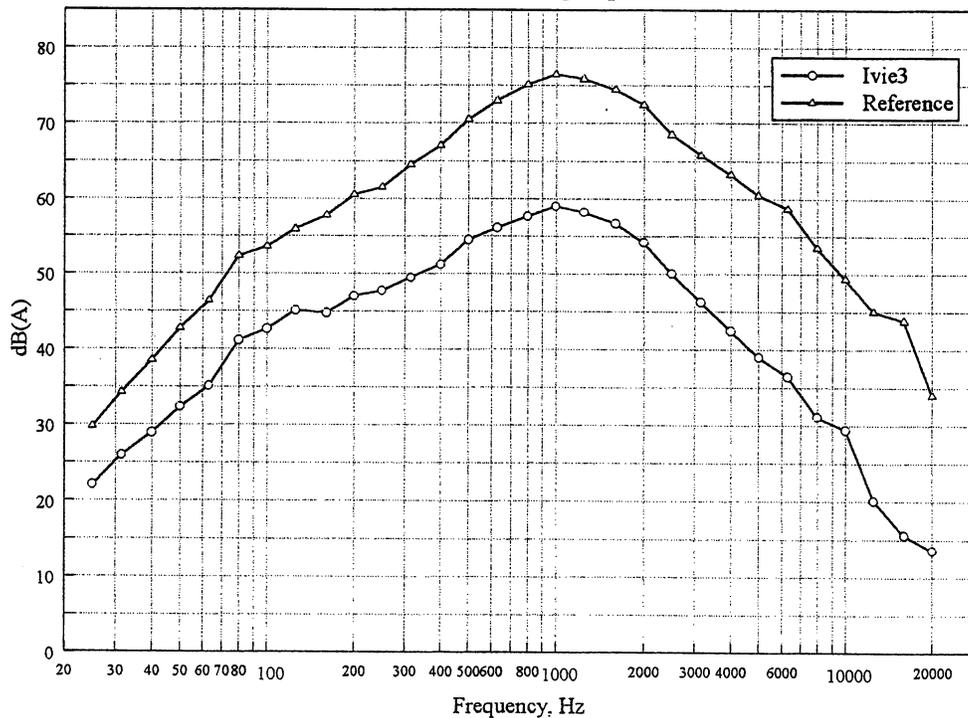
### Site E. Brandon (Hillsborough County) Shadow Zone



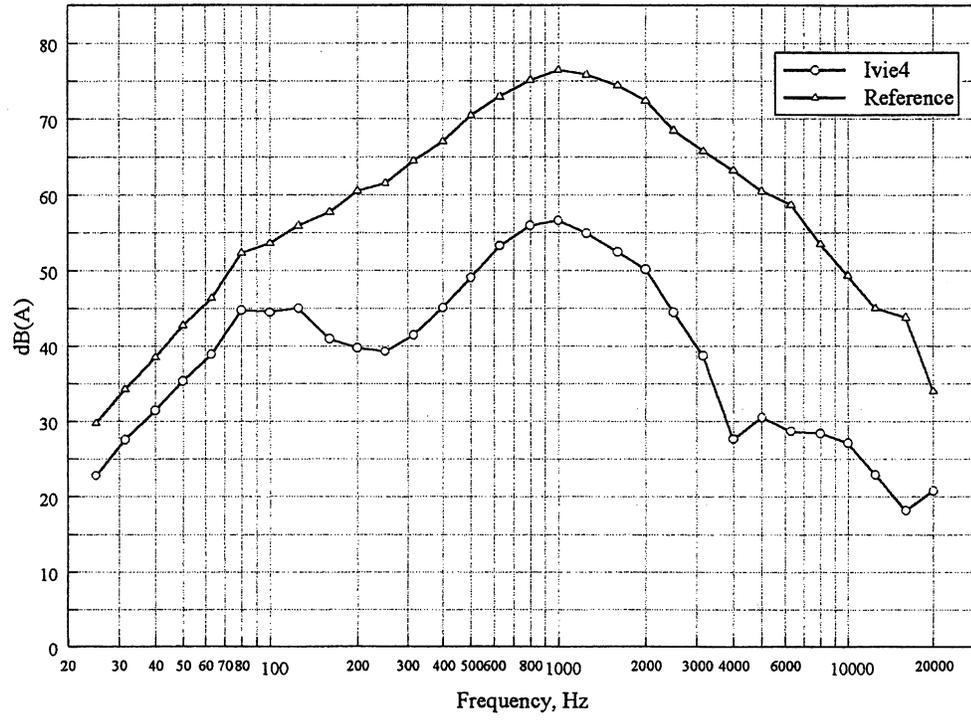
Site E. Brandon (Hillsborough County)  
Ivie 1 Four-Run Average Spectra Curve



Site E. Brandon (Hillsborough County)  
Ivie 3 Four-Run Average Spectra Curve



Site E. Brandon (Hillsborough County)  
Ivie 4 Four-Run Average Spectra Curve



**APPENDIX F**  
**SR686; CLEARWATER**

**Site F. Clearwater (Roosevelt Blvd.-SR686 west of 62<sup>nd</sup> Street)**  
**9 November 1999** [Project # 15030-3525]

UCF staff: Dr. R.L. Wayson, John MacDonald, Wayne Arner, Brian Kim and Patricia Tom  
FDOT staff: Win, Mariano, Robin, Dan and Roberto

The wall is on the south side of the road attenuating the noise created from the four lane two-way traffic of Roosevelt Blvd. This wall serves the Satellite Bay Mobile Home Park in Clearwater of the Tampa area.

GPS: 27° 54' 59"  
82° 43' 18"

**Starting Calibration notes:**

Mic #	IVIE	Dasy
1	96.9	94.3
2	97.4	94.6
3	96.8	93.7
4	96.9	93.9
5	97.6	94.2
6	96.7	93.97
7	96.4	94.03
8	97.2	94.7

***New DasyLab System:***

**1<sup>st</sup> RUN – 13:22:00- 13:42:00**

Weather: Sunny with winds at 5-10 mph from East, dry 88°F, wet 71°F, RH 42%

mic #	IVIE unit #	Cable #	Weight	Response		Ref dB
1	1	1	A	FT	CT	70
2	2	2	A	FT	CT	70
3	3	3	A	FT	CT	80
4	4	4	A	FT	CT	70
5	10	5	A	FT	CT	70
6	6	6	A	FT	CT	80
7	7	7	A	FT	CT	90
8	8	8	A	FT	CT	90

Note: Had problem with IVIE 7 data connector, will have to delete that data, vacuum cleaner sound nearby at 13:24

**2nd RUN – 13:48:30- 14:08:30**

Weather: Sunny with winds at 5-10 mph from East, dry 88°F, wet 71°F, RH 42%

mic #	IVIE unit #	Cable #	Weight	Response		Ref dB
1	1	1	A	FT	CT	70
2	2	2	A	FT	CT	70
3	3	3	A	FT	CT	80
4	4	4	A	FT	CT	70
5	10	5	A	FT	CT	70
6	6	6	A	FT	CT	80
7	7	7	A	FT	CT	80
8	8	8	A	FT	CT	80

Note: 13:49 aircraft flyover until 13:50, cable unraveling causing "clink" sounds nearby.

**3rd RUN – 14:13:00- 14:33:30**

Weather: Sunny with winds at 5-10 mph from East, dry 88°F, wet 71°F, RH 42%

mic #	IVIE unit #	Cable #	Weight	Response		Ref dB
1	1	1	A	FT	CT	70
2	2	2	A	FT	CT	70
3	3	3	A	FT	CT	80
4	4	4	A	FT	CT	70
5	10	5	A	FT	CT	70
6	6	6	A	FT	CT	80
7	7	7	A	FT	CT	80
8	8	8	A	FT	CT	80

Note: 14:32 “chopper” aircraft flyover (Loud-delete data) until end of test.

**4<sup>th</sup> RUN – 14:43:00- 15:03:00**

Weather: Sunny with winds at 5-10 mph from East, dry 88°F, wet 71°F, RH 42%

mic #	IVIE unit #	Cable #	Weight	Response		Ref dB
1	1	1	A	FT	CT	70
2	2	2	A	FT	CT	70
3	3	3	A	FT	CT	80
4	4	4	A	FT	CT	70
5	10	5	A	FT	CT	70
6	6	6	A	FT	CT	80
7	7	7	A	FT	CT	80
8	8	8	A	FT	CT	80

Note: IVIE 3 had some problem-“skipped???” data at 14:54-delete this data, 14:49:50 flyover.

**Ending Calibration notes:**

Mic #	IVIE	Dasy
1	95.8	93.6
2	96.6	94
3	97.8	94.3
4	96.2	93.3
5	97.9	94.7
6	96.8	94.2
7	96.5	94.2
8	96.7	94.6

**Metro:**

ID #	Distance from Barrier	Height	Final Calibration
SN2134	7.5 m	1.5 m	102.0 dB
SN2143	15 m	1.5 m	101.9 dB
SN2137	22.5 m	1.5 m	102.0 dB
SN2136	30 m	1.5 m	101.9 dB

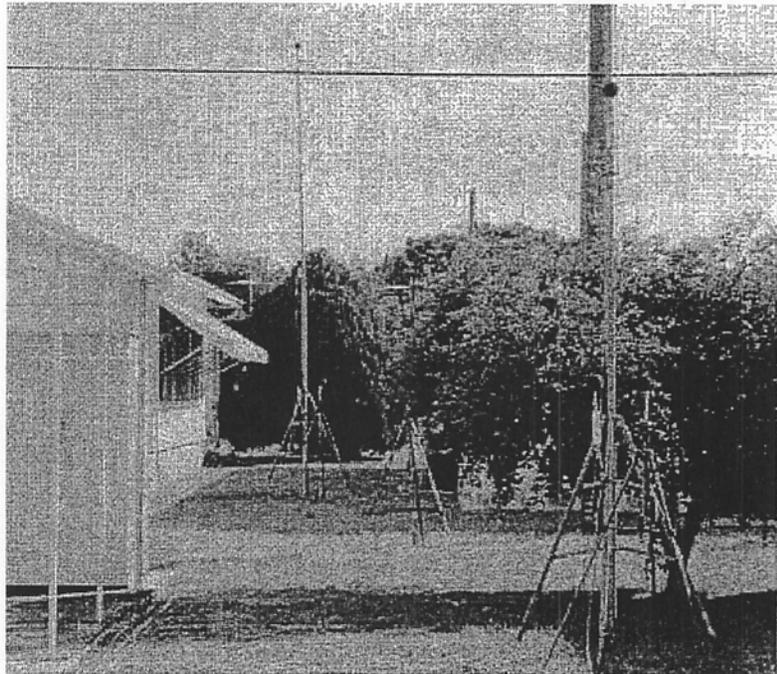
**Barrier Height:**

Concrete wall height at approximately 11’ where reference mics (7 &8) are at 16’ from ground.

Clearwater (Pinellas County)



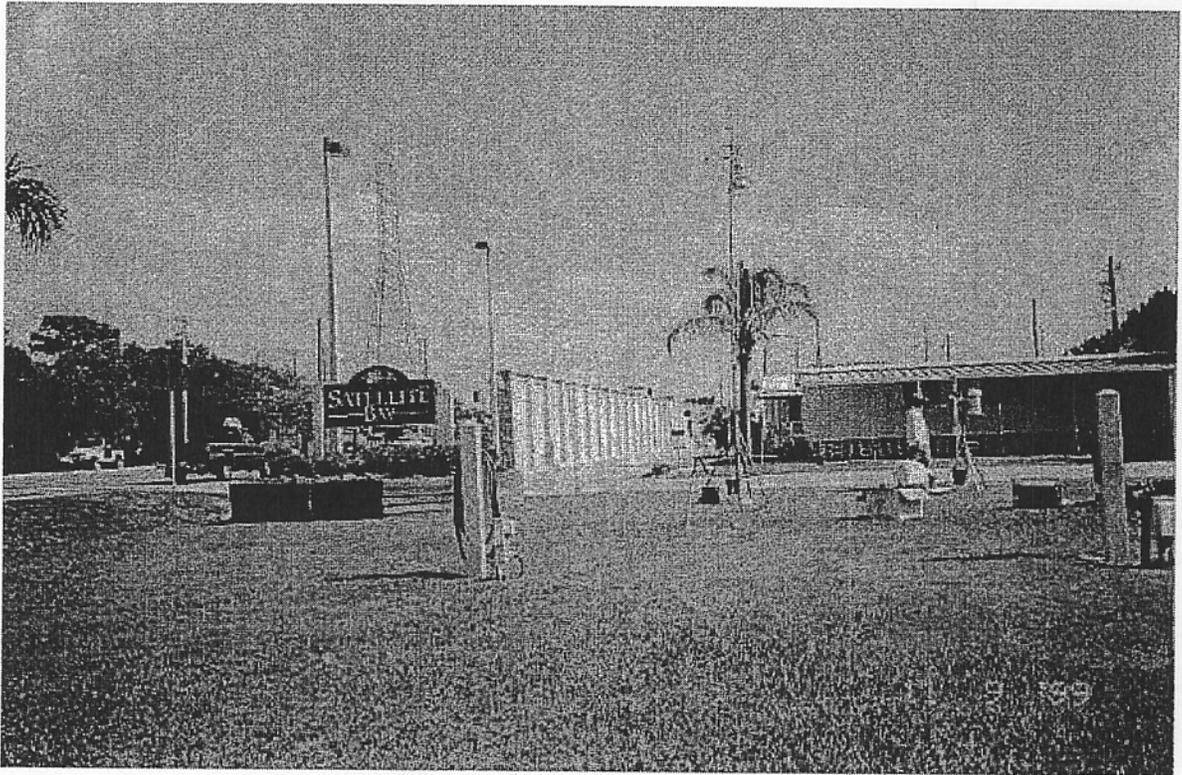
Roadway view of Noise Wall



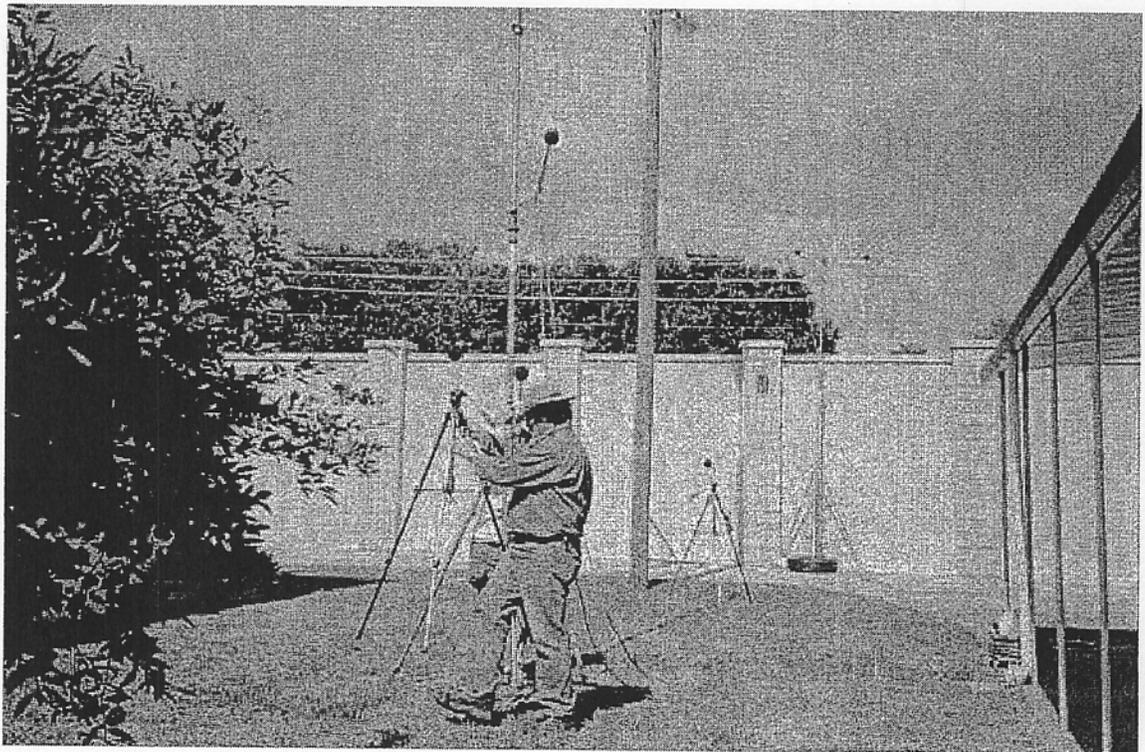
Residential area behind Noise Wall

Roosevelt Blvd.-SR686 west of 62<sup>nd</sup> Street (Satellite Bay Mobile Home Park)  
Project # 15030-3525

Clearwater (Pinellas County)



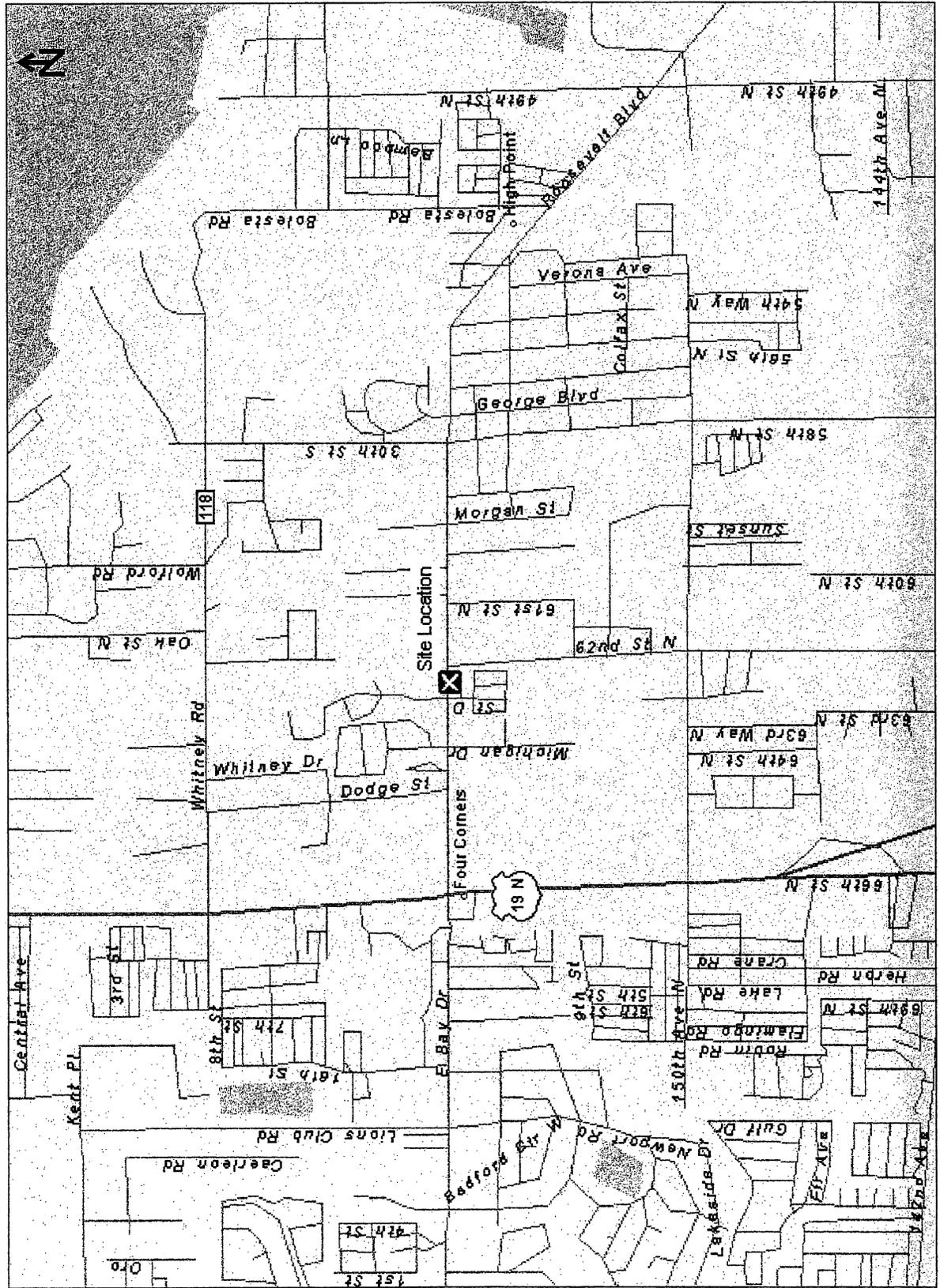
Recreational yard area adjacent to Noise Wall



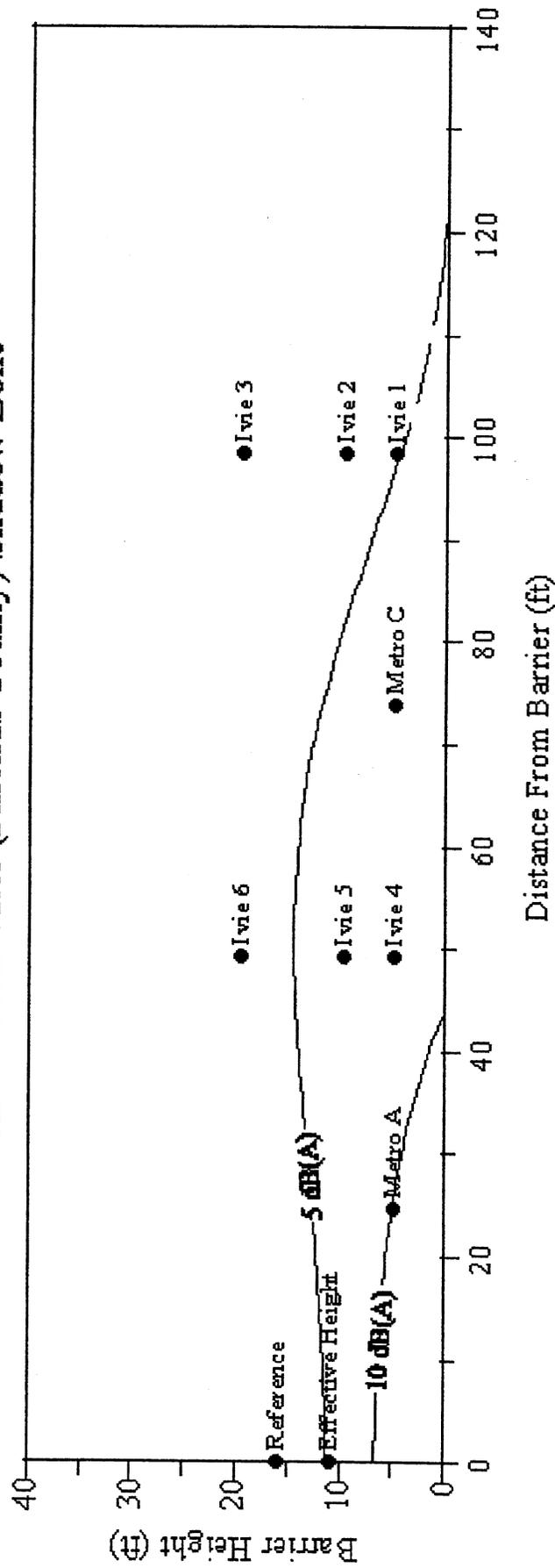
Residential view of Noise Wall during equipment set up

Roosevelt Blvd.-SR686 west of 62<sup>nd</sup> Street (Satellite Bay Mobile Home Park)  
Project # 15030-3525

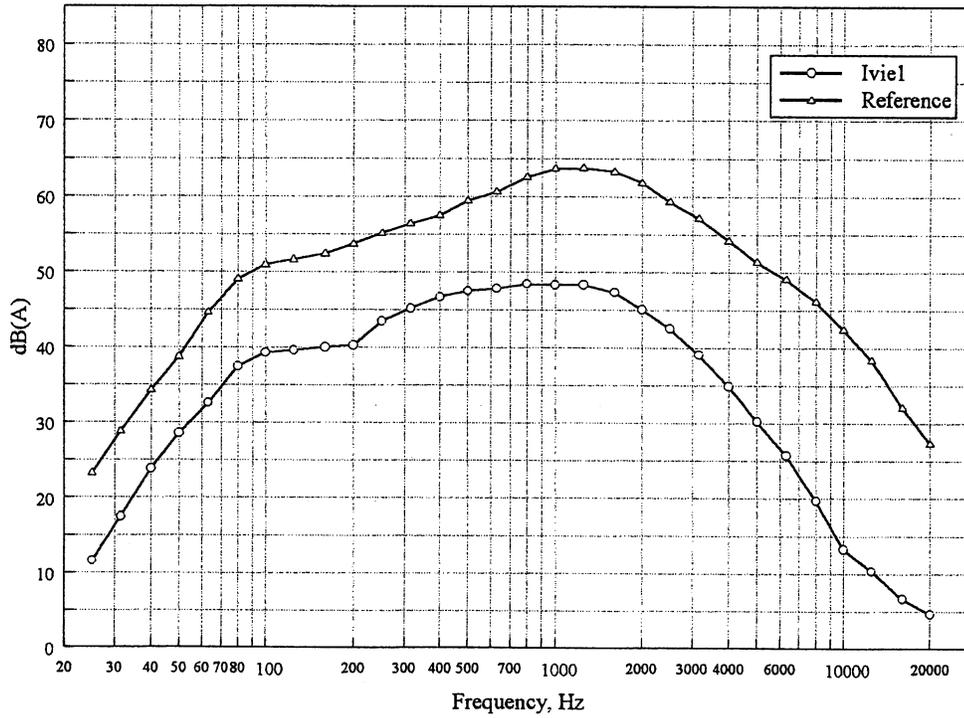
Site F. Clearwater (Pinellas County)



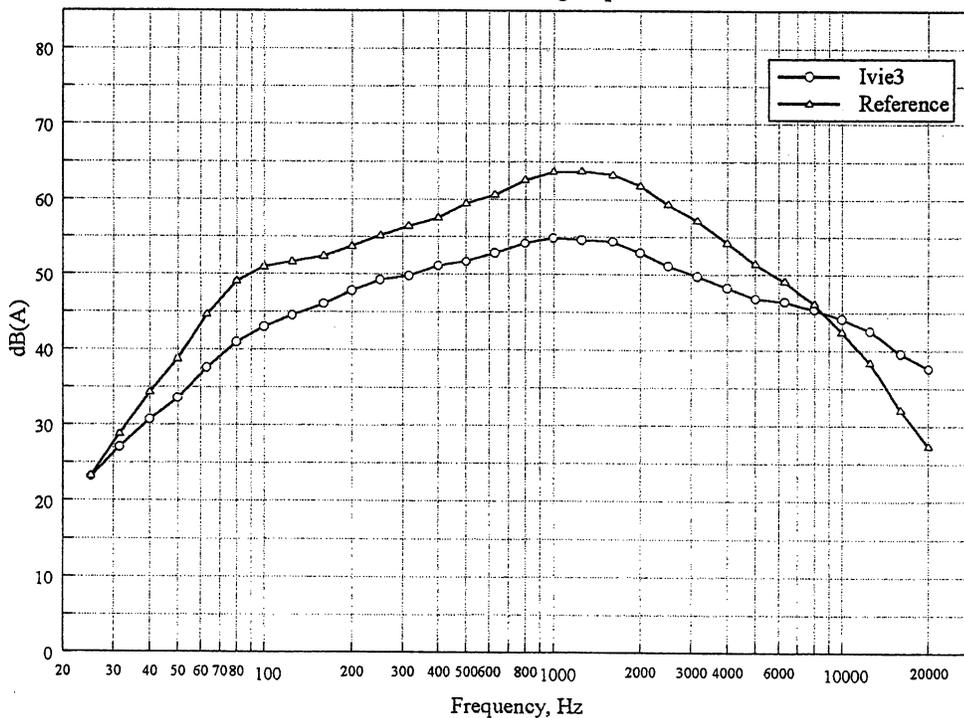
### Site F. Clearwater (Pinellas County) Shadow Zone



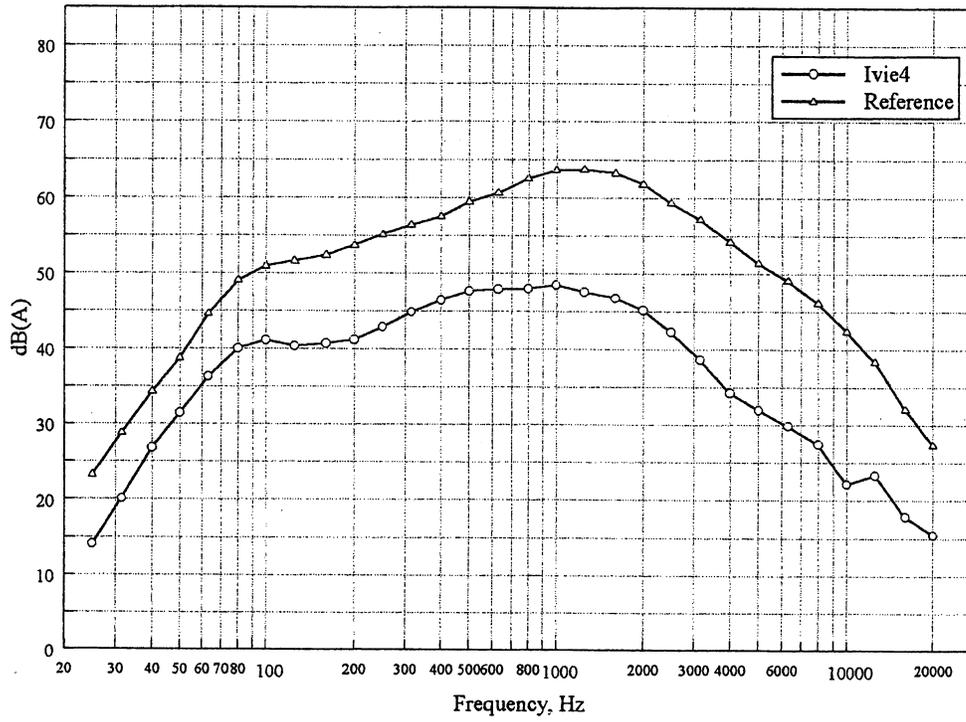
Site F. Clearwater (Pinellas County)  
Ivie 1 Four-Run Average Spectra Curve



Site F. Clearwater (Pinellas County)  
Ivie 3 Four-Run Average Spectra Curve



Site F. Clearwater (Pinellas County)  
Ivie 4 Four-Run Average Spectra Curve



**APPENDIX G**

**54<sup>th</sup> AVE. S.; ST. PETERSBURG**

**Site G. St. Petersburg (54<sup>th</sup> Ave. South east of 41<sup>st</sup> Street South)  
10 November 1999 [Project # 15190-3422]**

UCF staff: Dr. R.L. Wayson, John MacDonald, Wayne Arner, Brian Kim and Patricia Tom  
FDOT staff: Win, Mariano, Robin, Dan and Roberto

The wall is on 54<sup>th</sup> Avenue South near 41<sup>st</sup> Street in St. Petersburg of the Tampa area.

**Starting Calibration notes:**

Mic #	IVIE	Dasy
1	96.5	93.9
2	96.3	93.4
3	97.3	94.2
4	96.3	93.4
5	97.9	94.5
6	100.6	95.8
7	97.6	94.6
8	97.8	95.05

**New DasyLab System:**

**1<sup>st</sup> RUN – 12:08:00- 12:28:00**

Weather: dry 83°F, wet 73°F, RH 62%

mic #	IVIE unit #	Cable #	Weight	Response	Ref dB
1	1	1	A	FT CT	70
2	2	2	A	FT CT	70
3	3	3	A	FT CT	70
4	4	4	A	FT CT	70
5	10	5	A	FT CT	70
6	6	6	A	FT CT	
7	7	7	A	FT CT	80
8	8	8	A	FT CT	80

Note: #6 appears to be no good, 12:09 throw out data, 12:09:30 power saw nearby, 12:11:20 car passby on local road, 12:12:00 car passby on local road, 12:12:15 car passby on local road, #3 has 20kHz spike-delete- also 16kHz band, 12:18:30 car passby on local road, 12:21:50 car passby on local road, 12:22:20 car passby on local road, 12:23:00 – 12:23:30 aircraft flyover, 12:25:25 car passby on local road, 12:26:10 car passby on local road, 12:26:50 car passby on local road and 12:27:30 car passby on local road.

**2nd RUN – 12:32:00- 12:52:00**

Weather: dry 83°F, wet 73°F, RH 62%

mic #	IVIE unit #	Cable #	Weight	Response	Ref dB
1	1	1	A	FT CT	70
2	2	2	A	FT CT	70
3	3	3	A	FT CT	70
4	4	4	A	FT CT	70
5	10	5	A	FT CT	70
6	6	6	A	FT CT	
7	7	7	A	FT CT	80
8	8	8	A	FT CT	80

Note: Delete first 2 min of sample due to Bus and car passby and aircraft flyover, 12:35:20 car passby on local road, 12:36:50 car passby on local road, 12:37:20 – 12:37:30 car passby on local road, 12:38:40 car passby on local road, 12:38:50 car passby on local road, 12:41:15 car passby on local road, 12:43:00 car passby on local road, 12:45:20 car passby on local road, 12:46:15 car passby on local road, 12:47:50 car passby on local road,

12:48:20 car passby on local road, 12:49:00 car passby on local road, 12:50:30 car passby on local road and 12:51:10 car passby on local road.

**3rd RUN – 12:56:30- 13:16:30**

Weather: dry 83°F, wet 73°F, RH 62%

mic #	IVIE unit #	Cable #	Weight	Response		Ref dB
1	1	1	A	FT	CT	70
2	2	2	A	FT	CT	70
3	3	3	A	FT	CT	70
4	4	4	A	FT	CT	70
5	10	5	A	FT	CT	70
6	6	6	A	FT	CT	
7	7	7	A	FT	CT	80
8	8	8	A	FT	CT	80

Note: 12:56:35 car passby on local road, 12:56:40 car passby on local road, 12:59:40 car passby on local road, 13:01:00 car passby on local road, 13:02:20 car passby on local road, 13:04:35 bus passby on local road, 13:05:20 car passby on local road, 13:06:30 car passby on local road, 13:09:15 car passby on local road, 13:10:10 car passby on local road, 13:12:00 aircraft flyover, 13:14:50 car passby on local road, 13:15:10 car passby on local road

**4<sup>th</sup> RUN – 13:21:30- 13:41:30**

Weather: dry 83°F, wet 73°F, RH 62%

mic #	IVIE unit #	Cable #	Weight	Response		Ref dB
1	1	1	A	FT	CT	70
2	2	2	A	FT	CT	70
3	3	3	A	FT	CT	70
4	4	4	A	FT	CT	70
5	10	5	A	FT	CT	70
6	6	6	A	FT	CT	
7	7	7	A	FT	CT	80
8	8	8	A	FT	CT	80

Note: 13:22:40 car passby on local road horn honk, {had some problems in van, check data carefully during this time-13:23:?? car passby on local road, 13:25 IVIE#1 back in line after dropping off, 13:25:00 car passby on local road}, 13:25:40 car passby on local road, 13:25:50 car passby on local road, 13:26:10 car passby on local road, 13:28:20-30 car passby on local road, had problem with some IVIEs check data for drop off from 13:28-13:31-got back on line, 13:31:50 bus passby on local road, 13:32:10 car passby on local road, 13:32:30 car passby on local road, 13:33 talking at van-data no good-seems to be ok, 13:33:50 car passby on local road, 13:37:40 car passby on local road, 13:38:40 car passby on local road, 13:39:00 car passby on local road and 13:39:40 car passby on local road.

**Ending Calibration notes:**

Mic #	IVIE	Dasy
1	95.8	93.6
2	96.6	94
3	97.8	94.3
4	96.2	93.3
5	97.9	94.7
6	96.8	94.2
7	96.5	94.2
8	96.7	94.6

*Metro*

ID #	Distance from Barrier	Height	Final Calibration
SN2136	7.5 m	1.5 m	101.9 dB
SN2134	15 m	1.5 m	102.0 dB
SN2137	22.5 m	1.5 m	102.0 dB
SN2143	30 m	1.5 m	102.1 dB

***Barrier Height:***

Concrete wall height at approximately 7'4" where reference mics (7 & 8) are at 12'4" from ground.

St. Petersburg (Pinellas County)

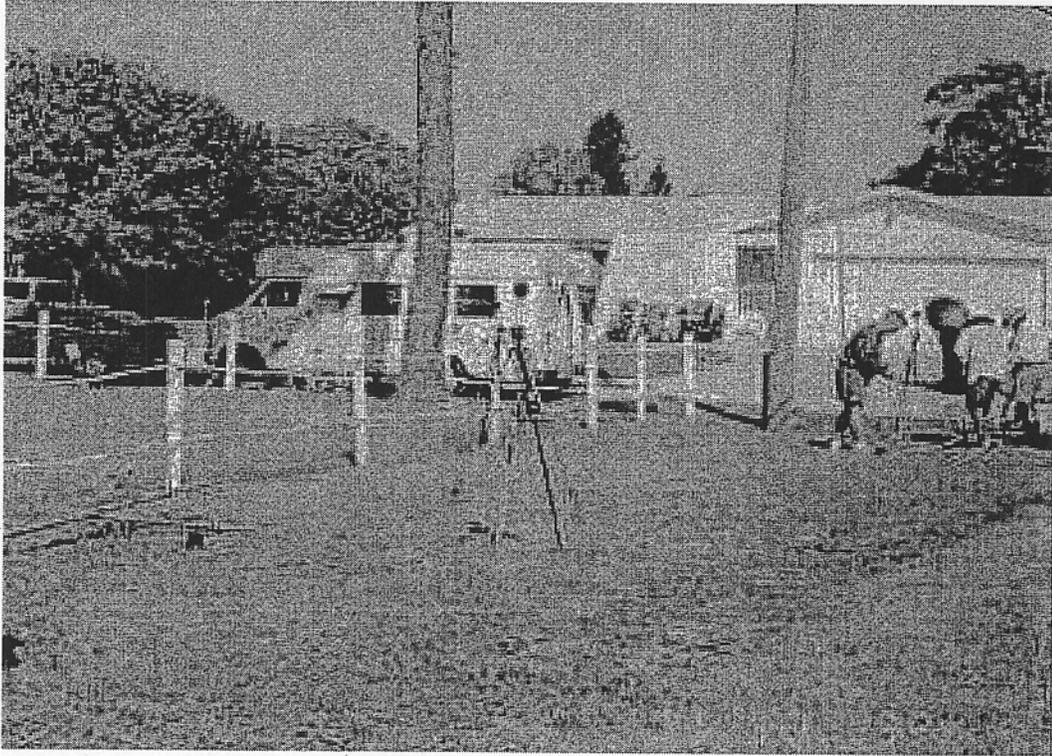


Roadway view of Noise Wall

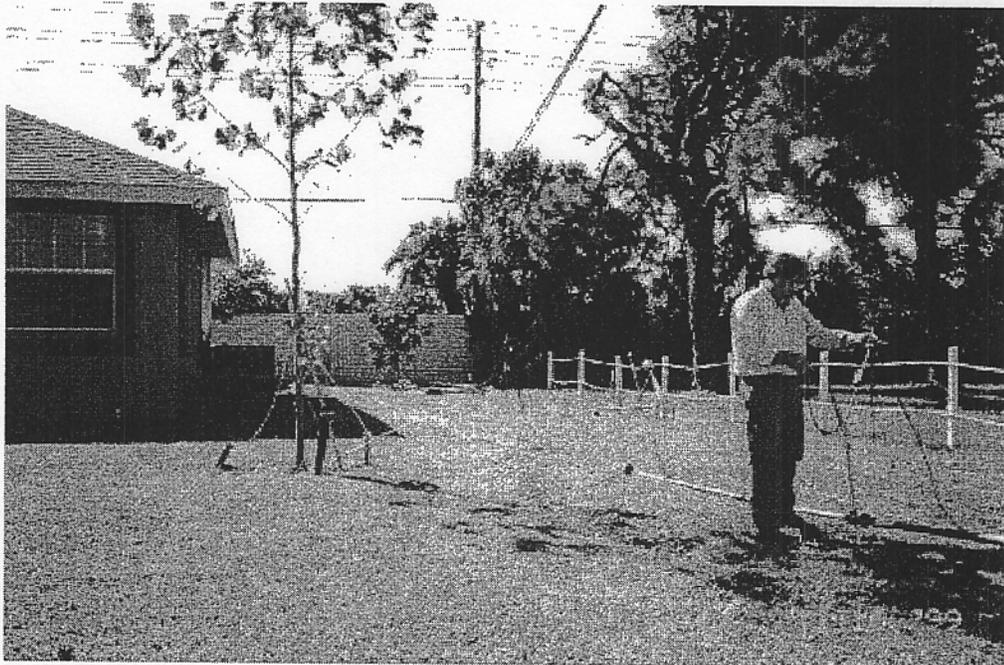


Residential view of Noise Wall

St. Petersburg (Pinellas County)

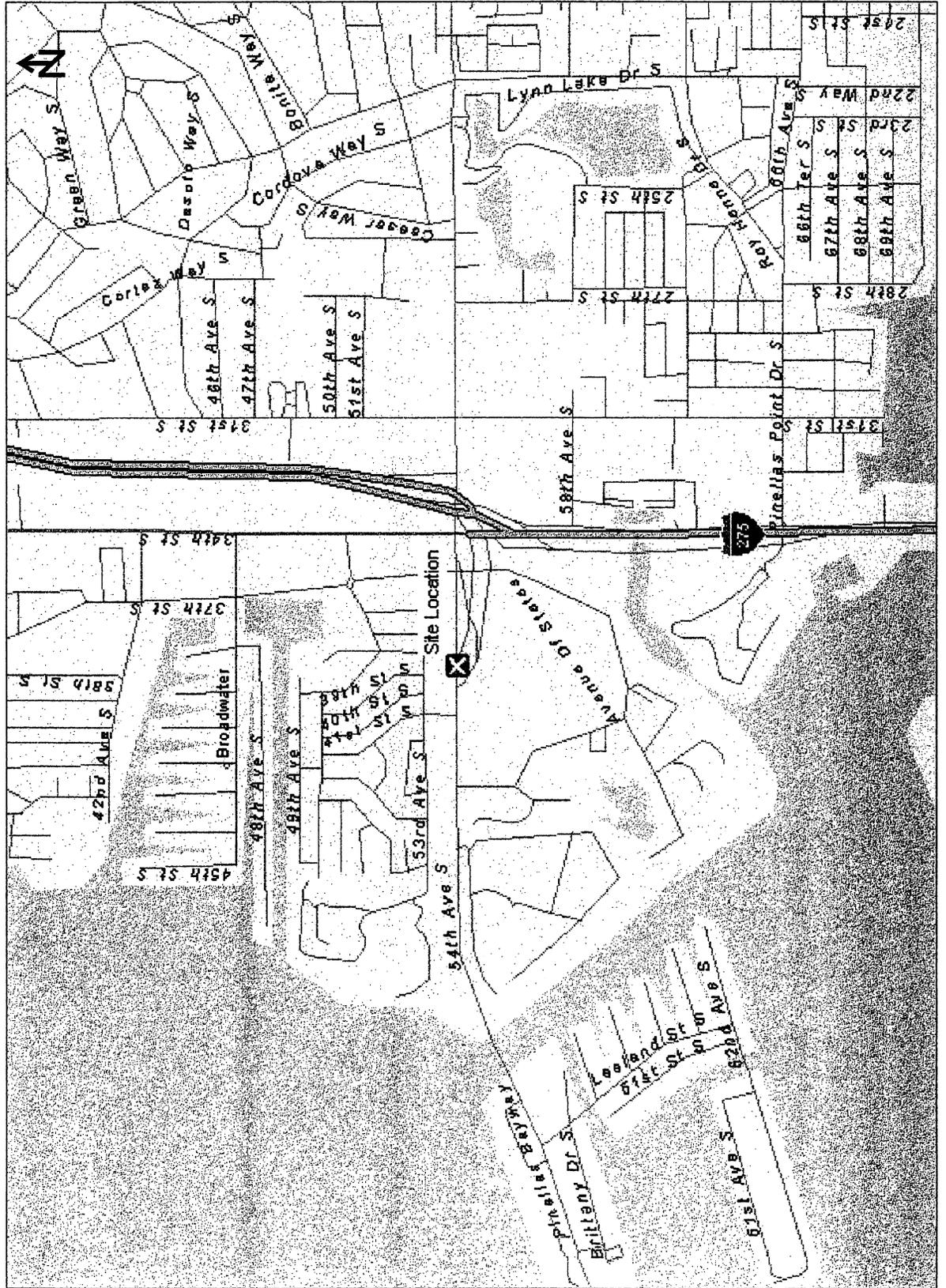


Residential area behind Noise Wall

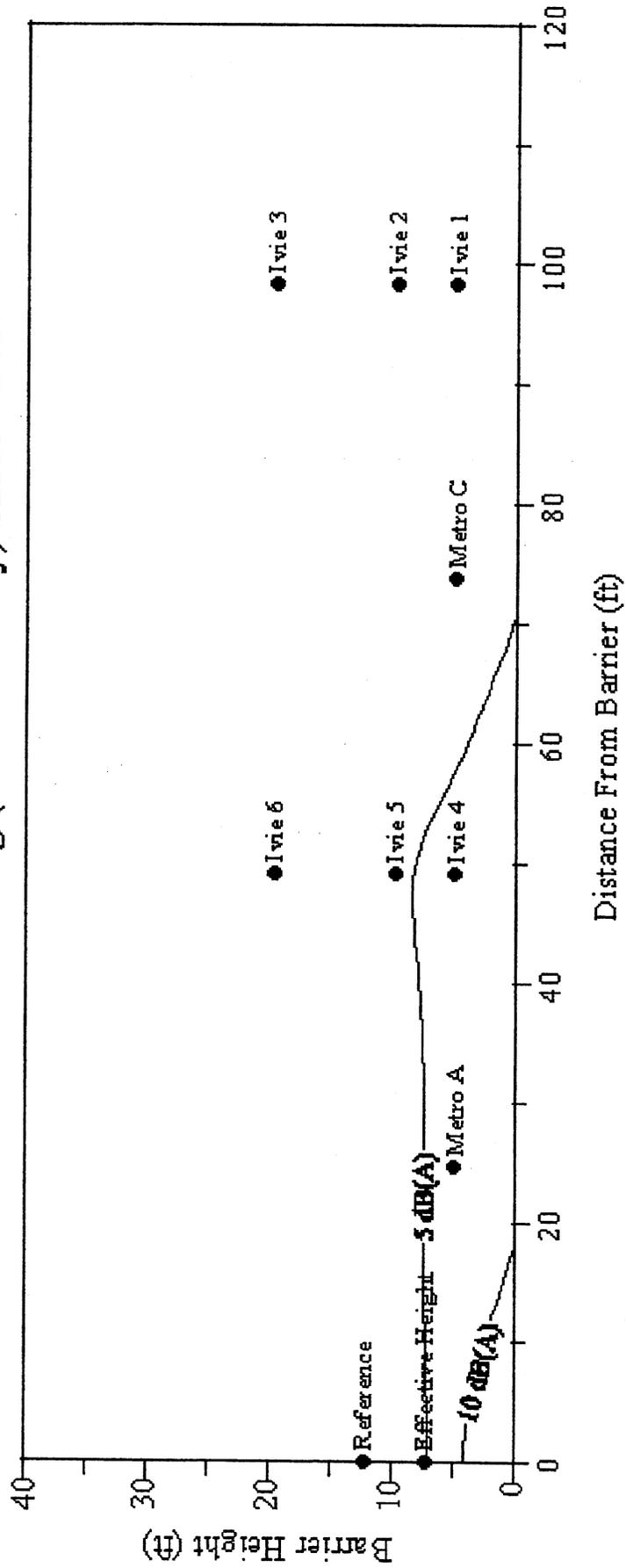


Residential view of Noise Wall during equipment set up

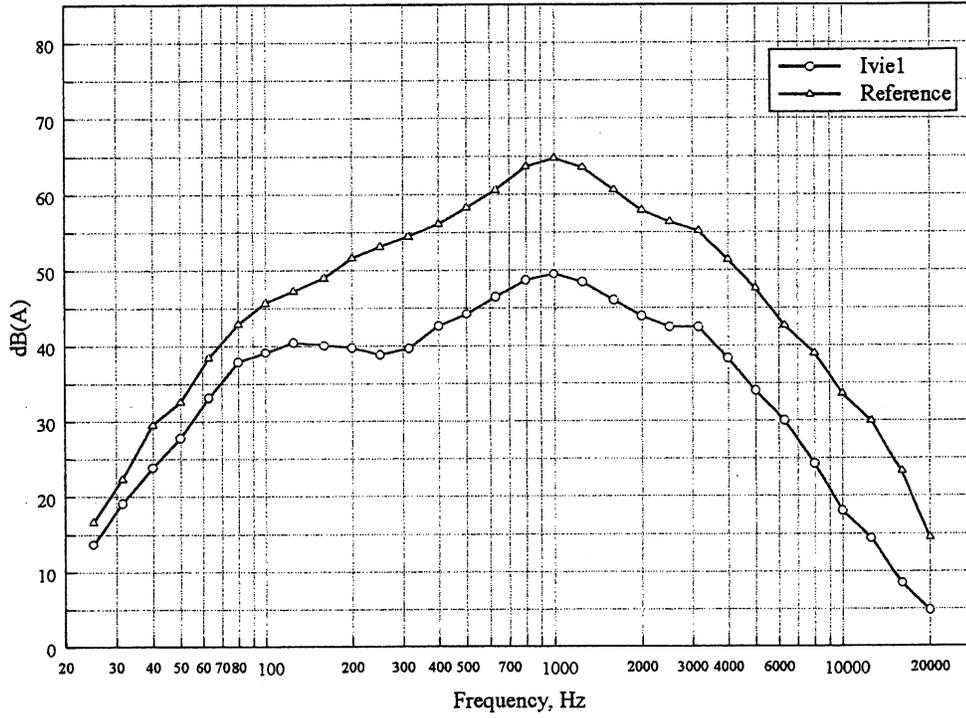
Site G. St. Petersburg (Pinellas County)



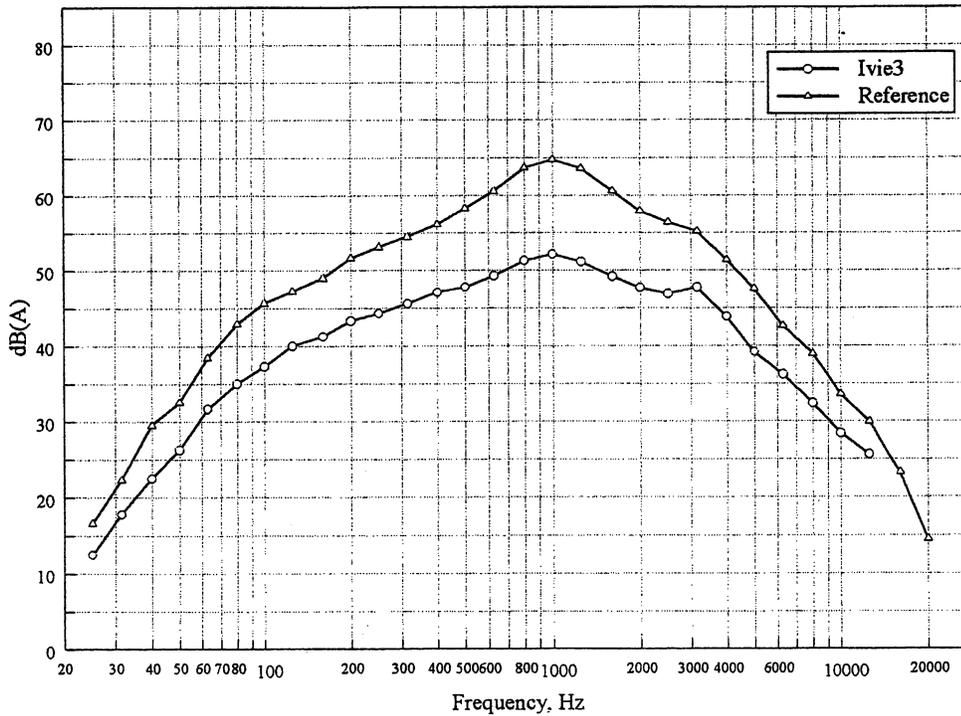
### Site G. St. Petersburg (Pinellas County) Shadow Zone



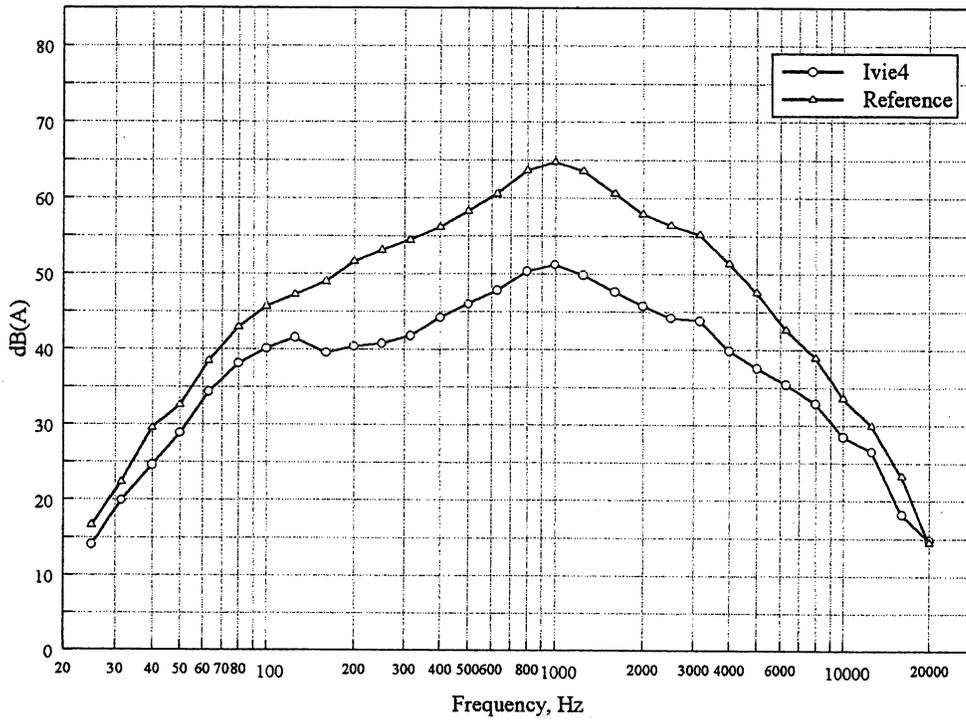
Site G. St Petersburg (Pinellas County)  
Ivie 1 Four-Run Average Spectra Curve



Site G. St Petersburg (Pinellas County)  
Ivie 3 Four-Run Average Spectra Curve



Site G. St Petersburg (Pinellas County)  
Ivie 4 Four-Run Average Spectra Curve



**APPENDIX H**  
**I-95; FT. LAUDERDALE**

**Site H. Ft. Lauderdale (NW 8<sup>th</sup> street and NW 20<sup>th</sup> Avenue @ I-95 NorthBound)**  
**21 December 1999** [Project # 86070-3506]

UCF staff: Dr. R.L. Wayson, John MacDonald, Wayne Arner, Brian Kim, Chris Corbisier and Patricia Tom  
FDOT staff: Win, Mariano, Ken, Dave, and Bernie

The wall is on the East side of I-95 near exit 30 by NW 8th street and NW 20th avenue.

***New DasyLab System:***

**1<sup>st</sup> RUN – 12:18:00- 12:38:00**

Weather: cloudy and drizzling from time to time

mic #	Location from Wall	IVIE unit #	Weight	Response		Ref dB
1	108'	1	A	FT	CT	
2	108'	2	A	FT	CT	
3	108'	3	A	FT	CT	
4	50'	4	A	FT	CT	
5	50'	10	A	FT	CT	
6	50'	6	A	FT	CT	
7	0'	7	A	FT	CT	
8	0'	8	A	FT	CT	

Note: #3 looks like it's inducing from power lines. Remove 60Hz band. #3 no good due to power line induction 60Hz is 86dB. Campbell time ~30sec lagging of laptop time. Lost generator power and laptop hung up.

**2nd RUN – 12:46:00- 13:06:00**

Weather: cloudy and drizzling from time to time

mic #	Location from Wall	IVIE unit #	Weight	Response		Ref dB
1	108'	1	A	FT	CT	
2	108'	2	A	FT	CT	
3	108'	3	A	FT	CT	
4	50'	4	A	FT	CT	
5	50'	10	A	FT	CT	
6	50'	6	A	FT	CT	
7	0'	7	A	FT	CT	
8	0'	8	A	FT	CT	

Note: Train blowing horn at 13:00 in the distance.

**3rd RUN – 13:13:00- 13:32:00**

Weather: cloudy and drizzling from time to time

mic #	Location from Wall	IVIE unit #	Weight	Response		Ref dB
1	108'	1	A	FT	CT	
2	108'	2	A	FT	CT	
3	108'	3	A	FT	CT	
4	50'	4	A	FT	CT	
5	50'	10	A	FT	CT	
6	50'	6	A	FT	CT	
7	0'	7	A	FT	CT	
8	0'	8	A	FT	CT	

Note: #1,#2, #3 IVIE's spiked at 60Hz-may want to remove. Aircraft flyover at 13:23:58. Big truck on highway at 13:24:11. Aircraft flyover at 13:25:00. Aircraft flyover at 13:29:00. Truck on local road at 13:33.

**4<sup>th</sup> RUN – 13:37:00- 13:57:00**

Weather: cloudy and drizzling from time to time

mic #	Location from Wall	IVIE unit #	Weight	Response		Ref dB
1	108'	1	A	FT	CT	
2	108'	2	A	FT	CT	
3	108'	3	A	FT	CT	
4	50'	4	A	FT	CT	
5	50'	10	A	FT	CT	
6	50'	6	A	FT	CT	
7	0'	7	A	FT	CT	
8	0'	8	A	FT	CT	

Note: Car horn blows at 13:38:42. Aircraft flyover at 13:49:50. Siren in the distance at 13:43. Aircraft flyover at 13:50. IVIE #3 missing 500 Hz band-need to check.

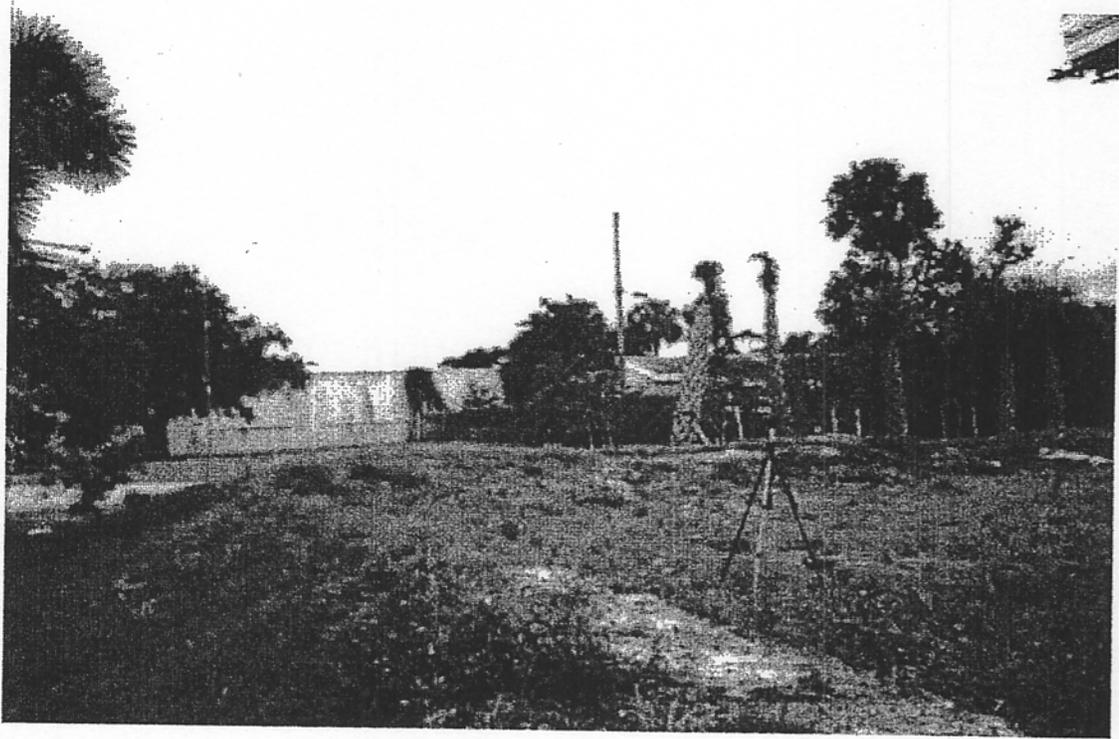
***Metro:***

ID #	Distance from Barrier	Height	Final Calibration
SN2146	7.5 m	1.5 m	102.1 dB
SN2137	15 m	1.5 m	102.1 dB
SN2136	22.5 m	1.5 m	101.9 dB
SN2134	30 m	1.5 m	102.0 dB
SN2143	1 <sup>st</sup> – 3 <sup>rd</sup> runs 60 m, 4th run no barrier at 0m	1.5 m	102.0 dB

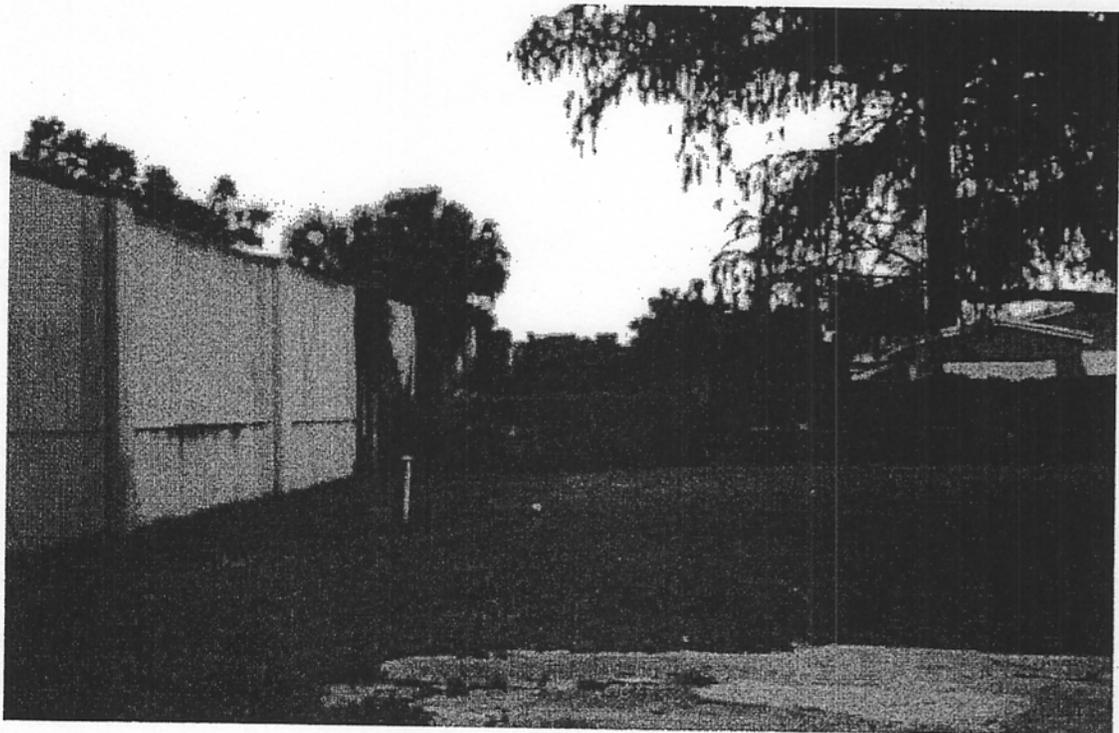
***Barrier Information:***

Concrete wall height at approximately 16'4" on the higher panel and 14'6" on the lower panel (step down from higher to lower from the southern to the northern direction) where reference mics (7 & 8) are located 5' above top of lower wall. Roadway is 3' above barrier base elevation. Mic towers are situated 300' from northernmost end of wall.

Ft. Lauderdale (Broward County)



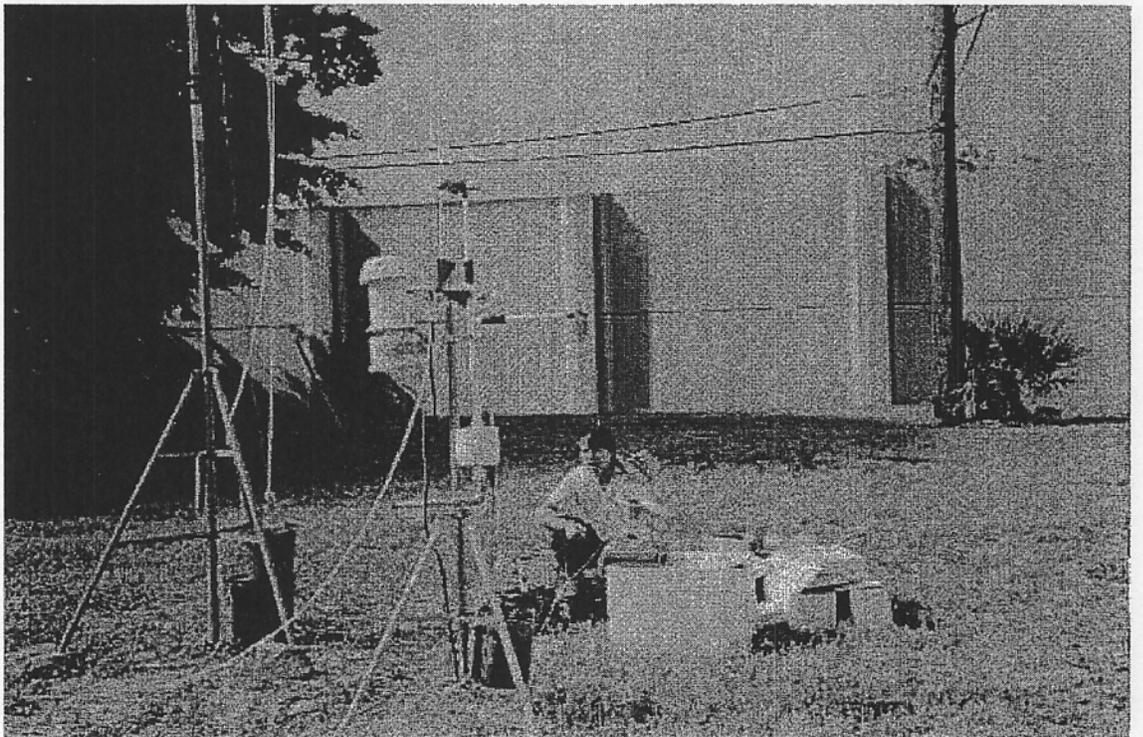
Residential view of Noise Wall



Up close residential view of Noise Wall



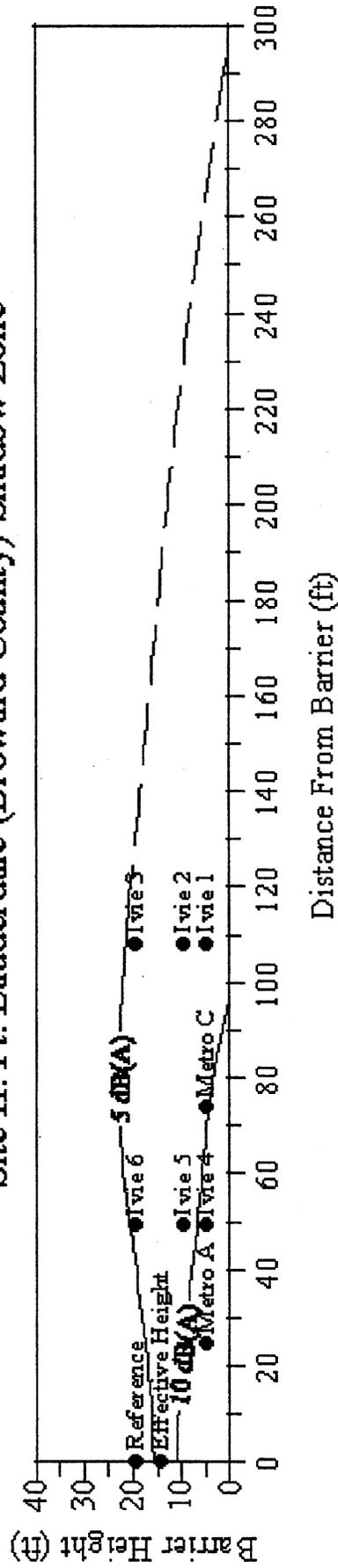
Distant residential view of Noise Wall



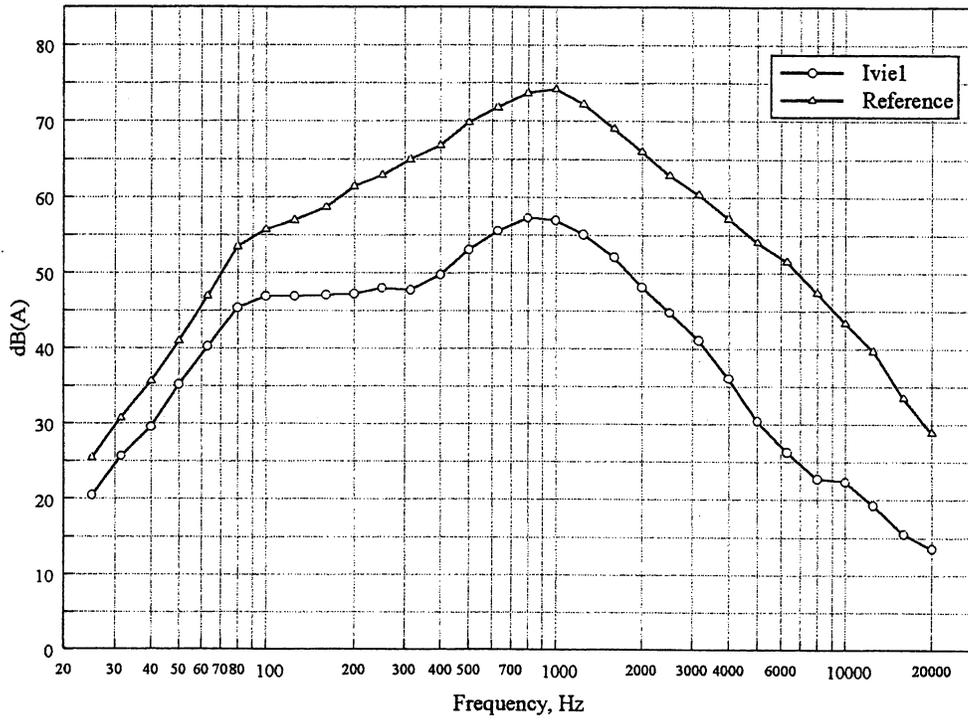
Residential view of Noise Wall during meteorology equipment set-up



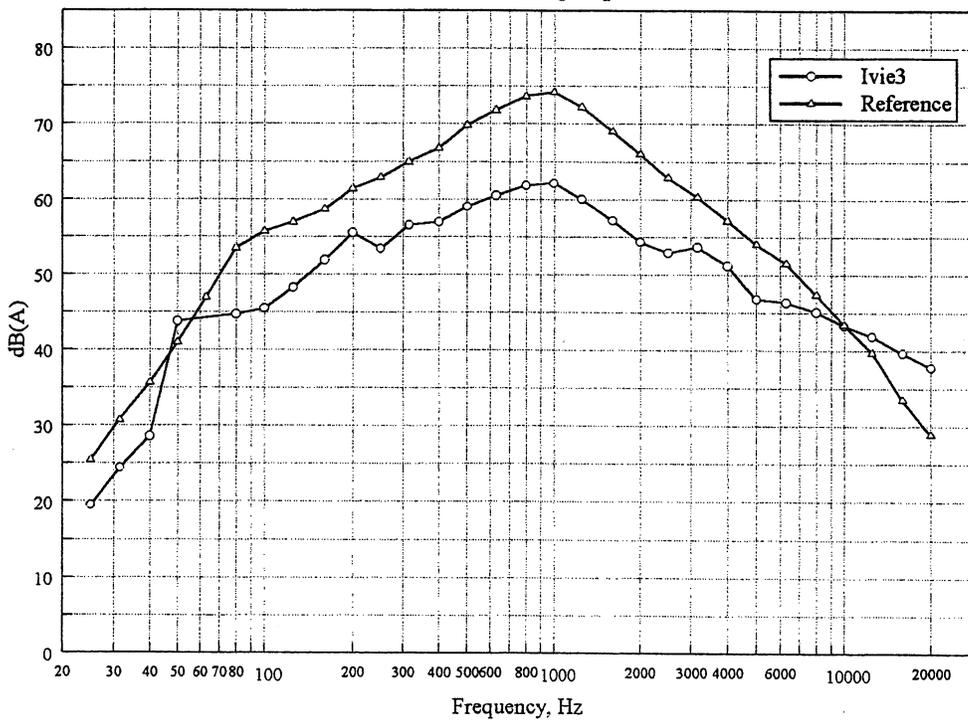
### Site H. Ft. Lauderdale (Broward County) Shadow Zone



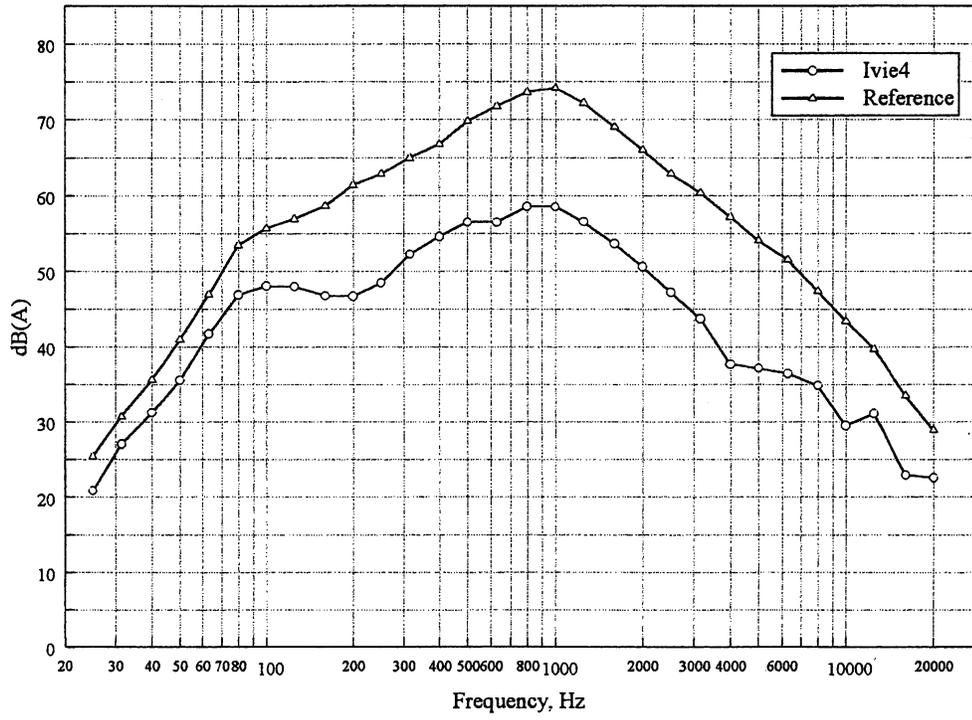
Site H. Ft Lauderdale (Broward County)  
Ivie 1 Four-Run Average Spectra Curve



Site H. Ft Lauderdale (Broward County)  
Ivie 3 Four-Run Average Spectra Curve



Site H. Ft Lauderdale (Broward County)  
Ivie 4 Four-Run Average Spectra Curve



**APPENDIX I**  
**I-95; DEERFIELD BEACH**

**Site I. Deerfield Beach (NE 1<sup>st</sup> Terrace between NE 48<sup>th</sup> Street and NE 52<sup>nd</sup> Street)  
22 December 1999 [Project # 87004-3501]**

UCF staff: Dr. R.L. Wayson, John MacDonald, Wayne Arner, Brian Kim, Chris Corbisier and Patricia Tom  
FDOT staff: Win, Mariano, Ken, and Dave

The wall is on the East side of I-95 in the Deerfield area abating noise for the High Village Trailer Park. The measurements are being taken between trailer homes #5119 and #109. The non running home number sequence is due to our being situated at a corner or two ending rows of homes.

***New DasyLab System:***

**1<sup>st</sup> RUN – 11:37:00- 12:57:00**

Weather: dry bulb 81°, wet bulb 75°, 76 %RH

mic #	IVIE unit #	Weight	Response		Ref dB
1	1	A	FT	CT	
2	2	A	FT	CT	
3	3	A	FT	CT	
4	4	A	FT	CT	
5	10	A	FT	CT	
6	6	A	FT	CT	
7	7	A	FT	CT	
8	8	A	FT	CT	

Note: Aircraft flyover at 11:37:40-11:43:46. Car passby at 11:50:50. Winds picked up near end of sample period.

**2nd RUN – 12:01:13- 12:21:13**

Weather: cloudy and drizzling from time to time

mic #	IVIE unit #	Weight	Response		Ref dB
1	1	A	FT	CT	
2	2	A	FT	CT	
3	3	A	FT	CT	
4	4	A	FT	CT	
5	10	A	FT	CT	
6	6	A	FT	CT	
7	7	A	FT	CT	
8	8	A	FT	CT	

Note: Aircraft flyover at 12:01:44. Aircraft flyover at 12:02:31-12:02:56. Aircraft flyover at 12:05:11. Siren horn blows from traveling vehicle on I-95 at 12:12. Mail truck passby on local road at 12:20:00

**3rd RUN – 12:25:13- 12:45:13**

Weather: cloudy and drizzling from time to time

mic #	IVIE unit #	Weight	Response		Ref dB
1	1	A	FT	CT	
2	2	A	FT	CT	
3	3	A	FT	CT	
4	4	A	FT	CT	
5	10	A	FT	CT	
6	6	A	FT	CT	
7	7	A	FT	CT	
8	8	A	FT	CT	

Note: Aircraft flyover at 12:25:30-12:25:43. Car passby on local road at 12:27:02. Aircraft flyover at 12:27:04-12:27:20. Aircraft flyover at 12:31:10-12:31:30. Aircraft flyover at 12:32. Aircraft flyover at 12:33. Local noise

from grinder at 12:33:45-50. Car passby on local road at 12:35:27. Car passby on local road at 12:37:08-12:38:02. UPS passby on local road at 12:38:02. Car passby on local road at 12:38:48-12:39:00. Aircraft flyover at 12:39:52-12:40:24.

**4<sup>th</sup> RUN – 12:47:55- 13:07:55**

Weather: cloudy and drizzling from time to time

mic #	IVIE unit #	Weight	Response		Ref dB
1	1	A	FT	CT	
2	2	A	FT	CT	
3	3	A	FT	CT	
4	4	A	FT	CT	
5	10	A	FT	CT	
6	6	A	FT	CT	
7	7	A	FT	CT	
8	8	A	FT	CT	

Note: Aircraft flyover at 12:50:50. Aircraft flyover at 12:54:00-12:54:28. Aircraft flyover at 12:58:30-12:58:4. Aircraft flyover at 13:04:28-13:04:48.

***Metro:***

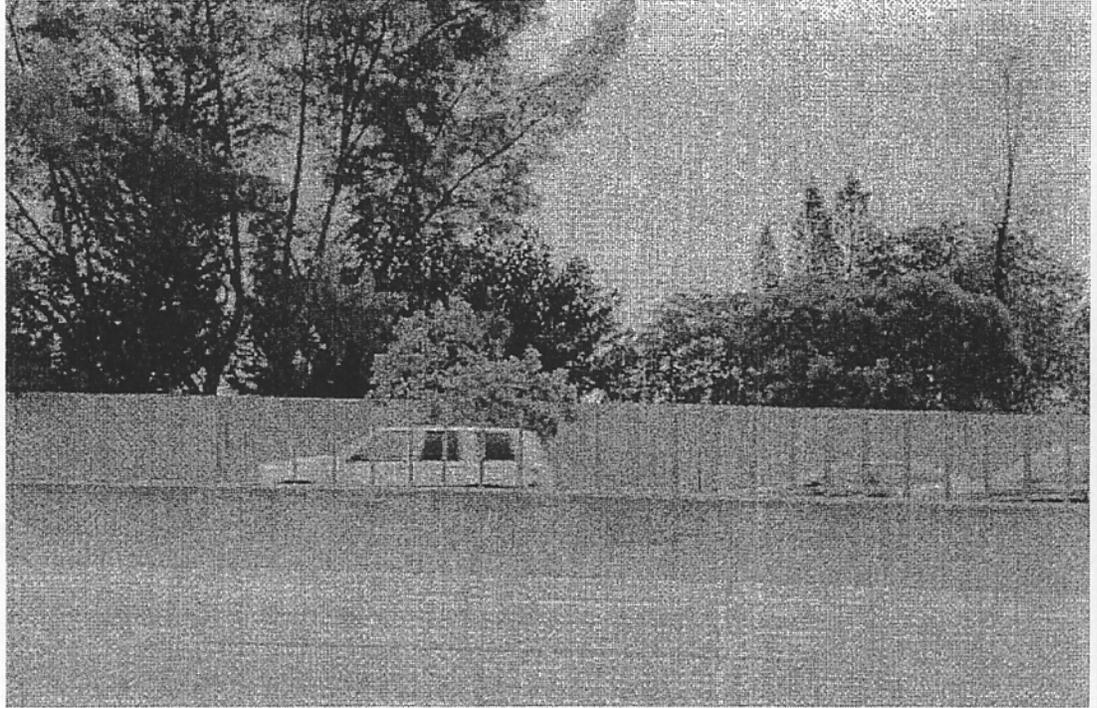
ID #	Distance from Barrier	Height	Final Calibration
SN2137	7.5 m	1.5 m	102.1 dB
SN2143	15 m	1.5 m	102.1 dB
SN2146	22.5 m	1.5 m	102.0 dB
SN2134	30 m	1.5 m	102.1 dB

Note: Metrosonics are 39 secs ahead of laptop clock.

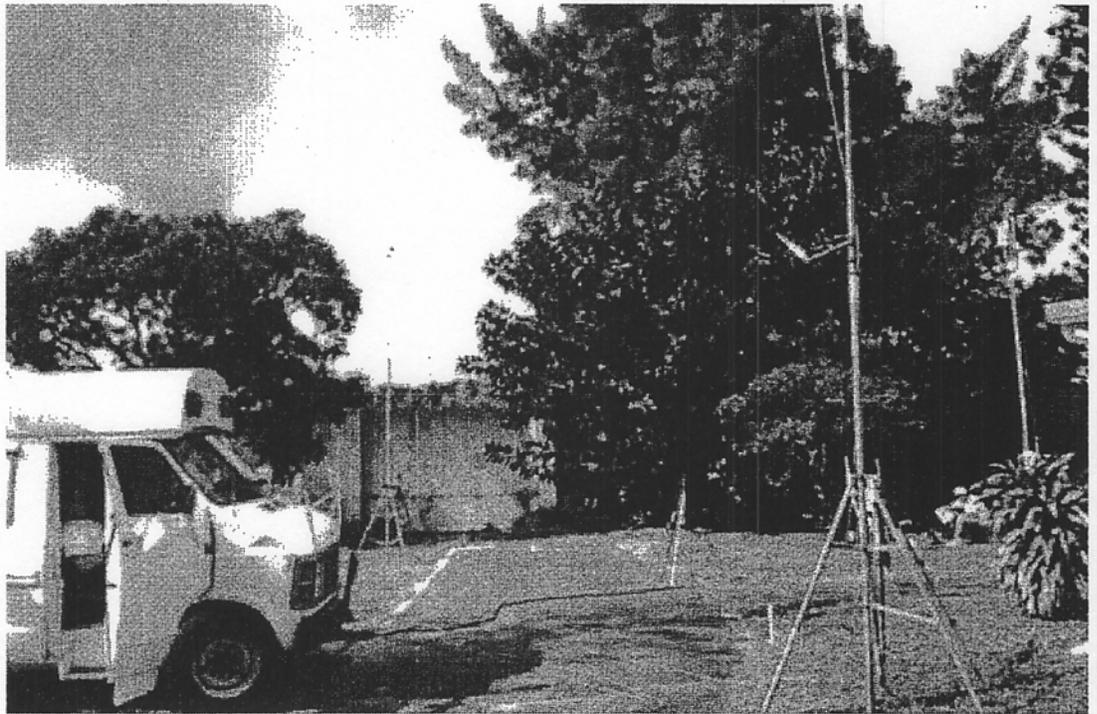
***Barrier Information:***

Concrete wall height at approximately 13'1". The highway and grade are at the same elevation.

Deerfield Beach (Broward County)

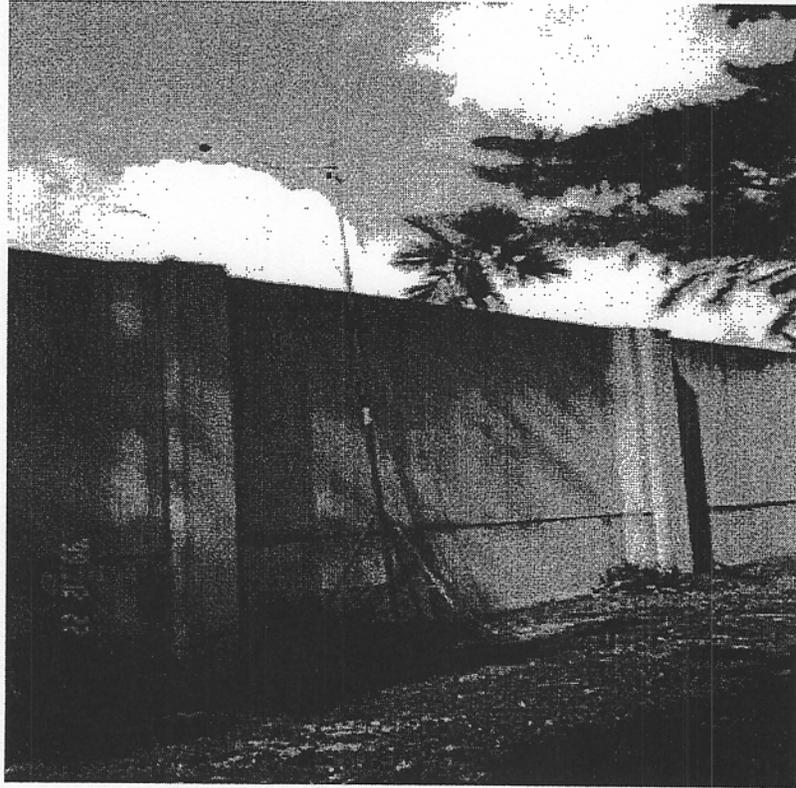


Roadway view of Noise Wall

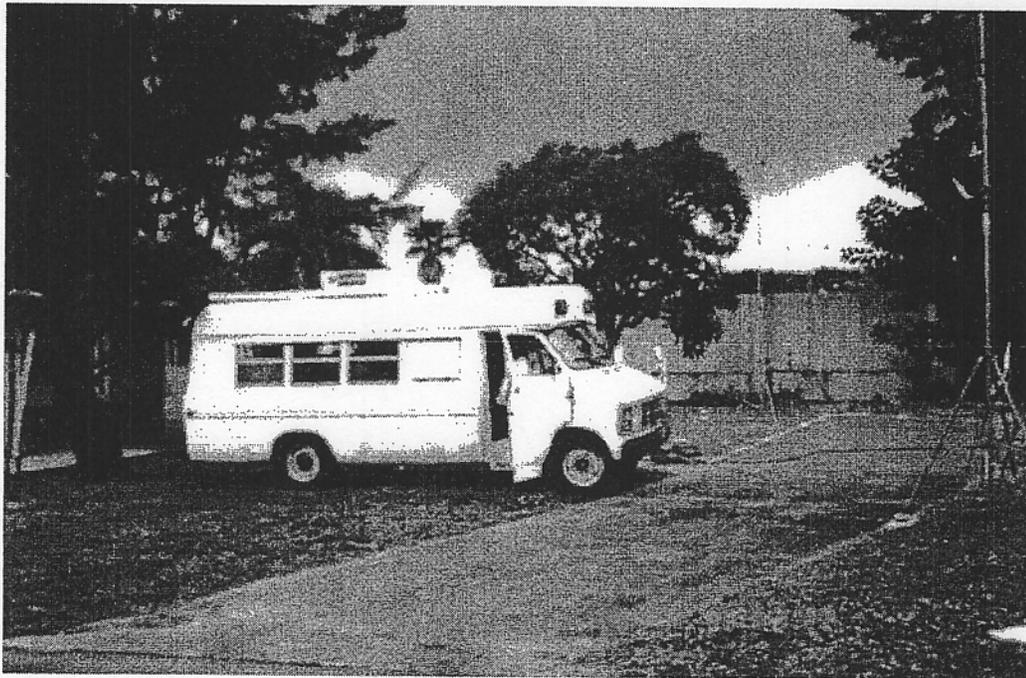


Residential view of Noise Wall

Deerfield Beach (Broward County)



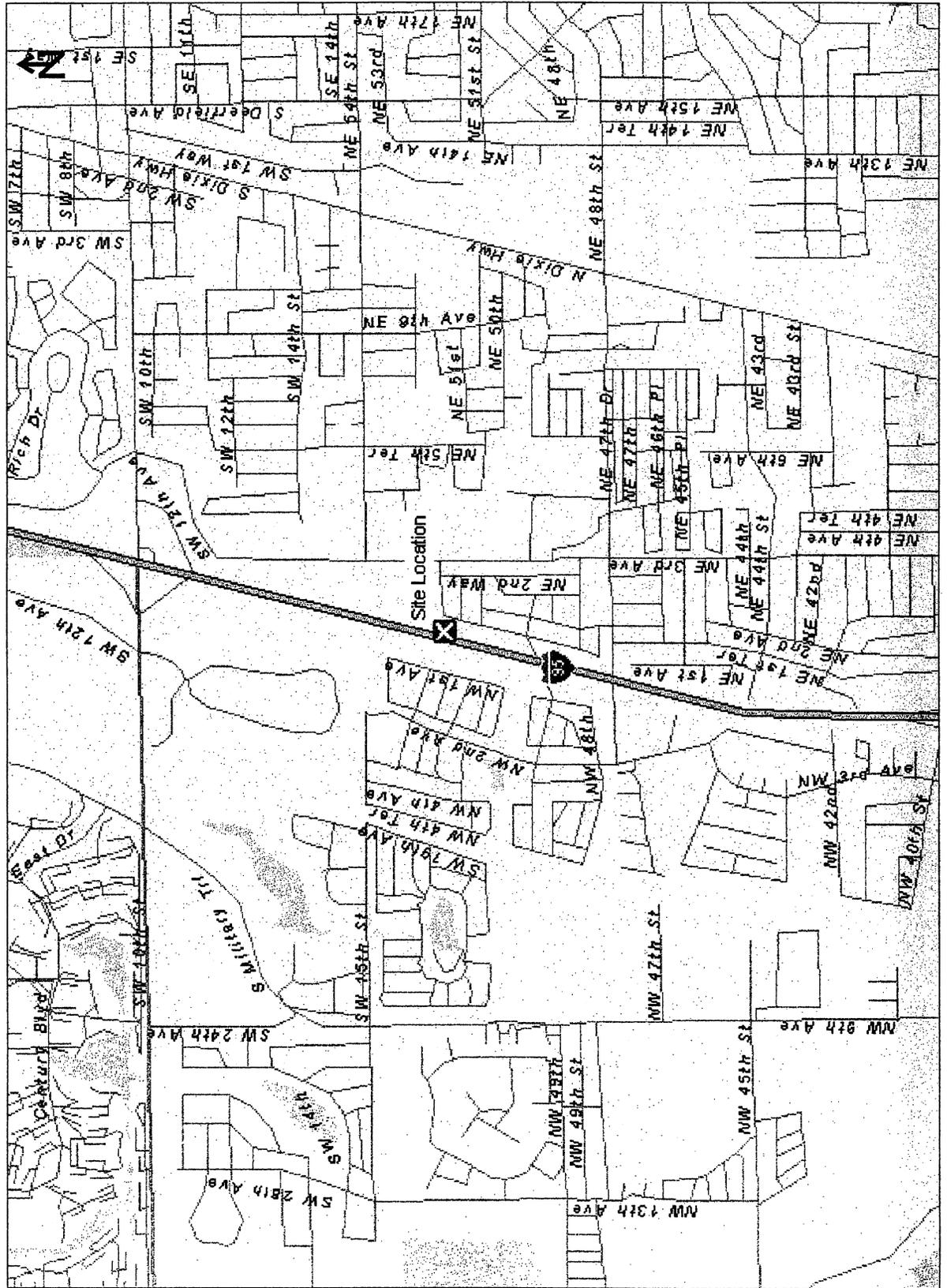
Up-close view of reference microphones by Noise Wall



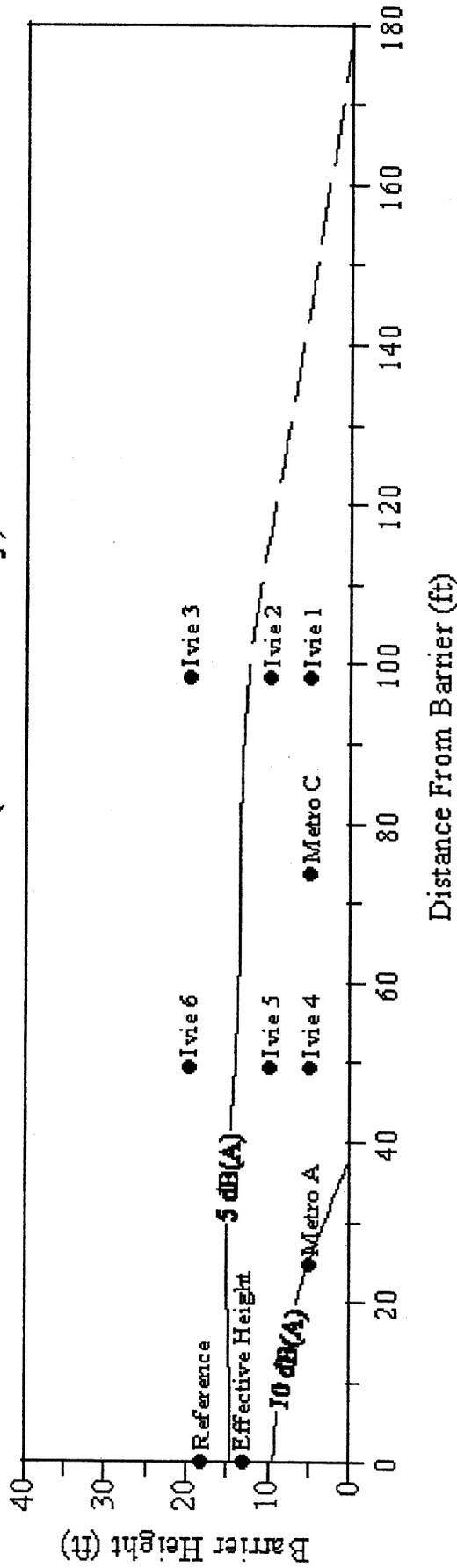
Noise mobile in action as parked in residential yard

NE 1<sup>st</sup> Terrace between NE 48<sup>th</sup> Street and NE 52<sup>nd</sup> Street  
Project # 87004-3501

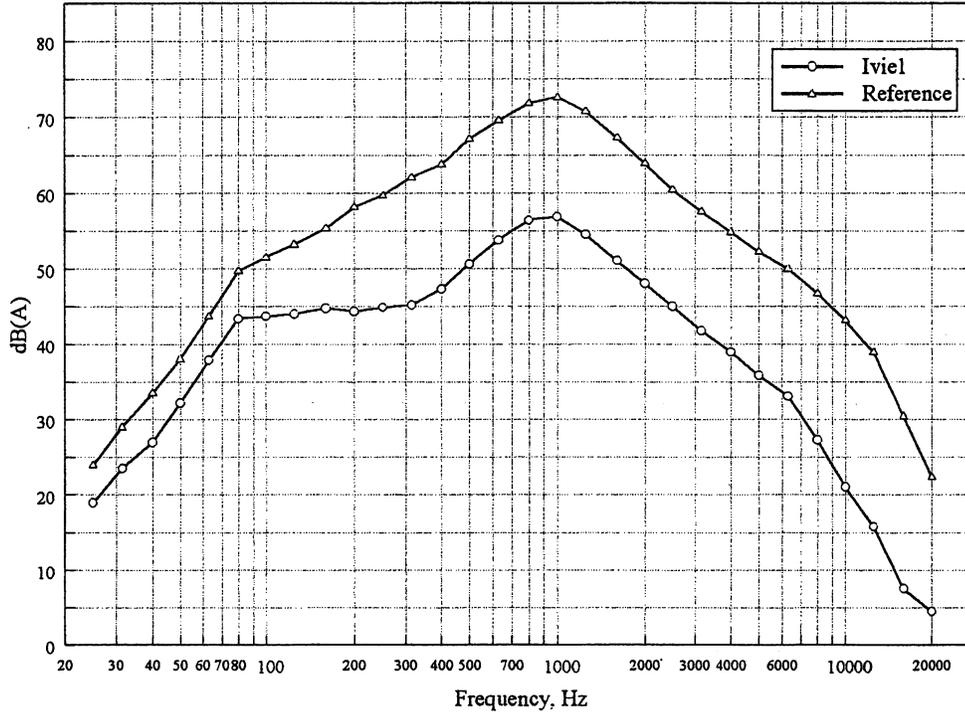
Site I. Deerfield Beach (Broward County)



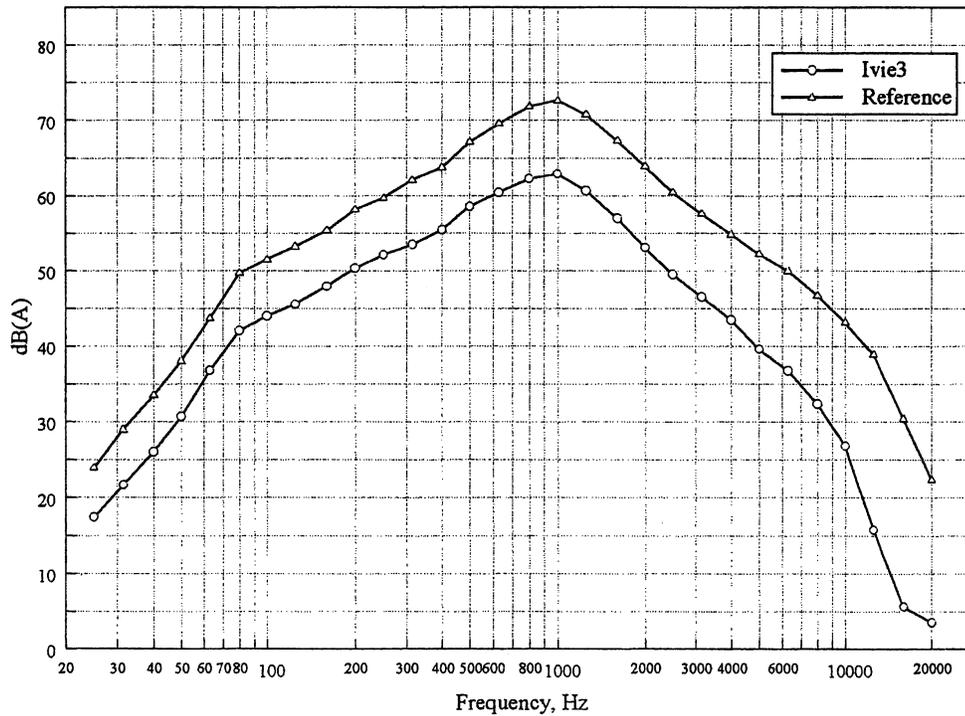
### Site I. Deerfield Beach (Broward County) Shadow Zone



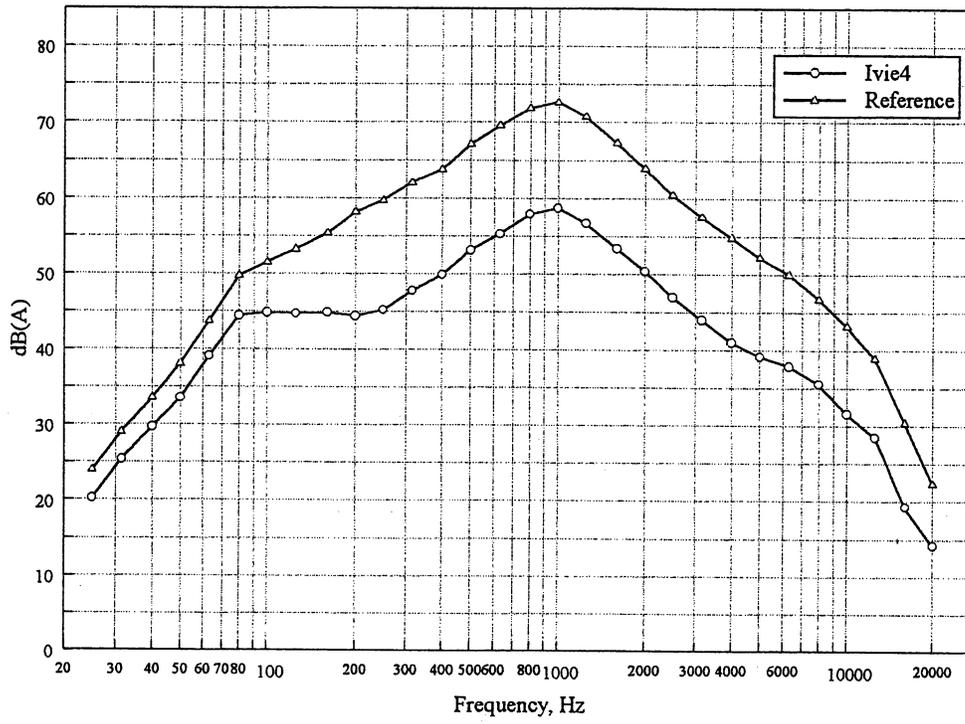
Site I. Deerfield Beach (Broward County)  
Ivie 1 Four-Run Average Spectra Curve



Site I. Deerfield Beach (Broward County)  
Ivie 3 Four-Run Average Spectra Curve



Site I. Deerfield Beach (Broward County)  
Ivie 4 Four-Run Average Spectra Curve



**APPENDIX J**

**I-195; MIAMI**

**Site J. Miami I-195 SR112 Julia Tuttle Causeway (NE 6<sup>th</sup> Avenue off NE 36<sup>th</sup> street)  
19 January 2000 [Project # 99004-3420]**

UCF staff: Dr. R.L. Wayson, John MacDonald, Wayne Arner, Brian Kim, Chris Corbisier and Patricia Tom  
FDOT staff: Win, Mariano, Ed, and Victor

The wall is on the East bound lanes between NE 2<sup>nd</sup> Avenue and NE 7<sup>th</sup> Avenue. It is on the South side of I-195 near US 1. Measurements were taken by NE 6th avenue and NE 36th street. Arterial road (36<sup>th</sup> Street) has accelerating traffic to get onto I-195 eastbound (two lanes) and one lane of westbound traffic.

**DasyLab System:**

**1<sup>st</sup> RUN – 13:42:10- 14:02:10**

Weather: winds at 2.5 mph (10° clockwise from North) dry 81°F, wet 69°F, RH 56%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	10	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8	8	A	FT	CT

Note: 13:43:49 tire explosion, 13:46:00-:30 flyover, 13:48:10-:31 flyover, 13:50:15 motorcycle passby, 13:52:15-:30 flyover loud, 13:54:50-:55:10 flyover, 13:55:50-:56:24 flyover, 13:59:39-14:00:06 flyover, 14:01:54-EOT flyover

	Cars	Med-trucks	Heavy-trucks	Buses	Motorcycle
Eastbound	221	4	2	1	1
Westbound	10	1	0	0	0

**2nd RUN – 14:08:20- 14:28:20**

Weather: winds at 2.5 mph (10° clockwise from North) dry 81°F, wet 69°F, RH 56%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	10	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8	8	A	FT	CT

Note: 14:13:20-:14:05 flyover, 14:15:45 flyover, 14:16:50 power shutdown=lost 10 seconds, 14:18:20 flyover, 14:19:19 motorcycle passby, 14:22:08-:26 flyover, 14:24:28-:48 flyover, 14:25:15 loud truck passby, 14:26:50-:27:10 flyover, 14:27:55 flyover

	Cars	Med-trucks	Heavy-trucks	Buses	Motorcycle
Eastbound	245	6	0	0	1
Westbound	0	0	0	0	0

**3rd RUN – 14:34:10- 14:54:00**

Weather: winds at less than 2 mph (10° clockwise from North) dry 78°F, wet 68°F, RH 60%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	10	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8	8	A	FT	CT

Note: 14:35:50-:36:15 flyover, 14:36:25 loud truck accelerating, 14:38:14 loud truck, 14:39:06-:39:29 flyover, 14:40:24 motorcycle passby, 14:43:36-:43:36 flyover, 14:48:53-:49:13 flyover, 14:50:28 horn, 14:50:40-:51:10 flyover, 14:51:40-:52:20 flyover, 14:59:05-EOT flyover

	Cars	Med-trucks	Heavy-trucks	Buses	Motorcycle
Eastbound	253	5	0	4	0
Westbound	2	0	0	0	0

**4<sup>th</sup> RUN – 15:10:14- 15:30:17**

Weather: winds at 3 mph (15° clockwise from North) dry 80°F, wet 70°F, RH 60.5%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	10	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8	8	A	FT	CT

Note: 15:10:15-:35 flyover, 15:12:20-:31 flyover, 15:14:15-:35 flyover, 15:15:30- flyover, 15:17:40-:54 flyover, 15:20:30-:44 flyover, 15:22:16-:33 flyover, 15:23:53-:24:24 flyover, 15:25:12-:32 flyover, 15:26:36-:27:05 flyover, 15:28:40-:29:00 flyover, 15:29:54-EOT flyover

	Cars	Med-trucks	Heavy-trucks	Buses	Motorcycle
Eastbound	282	8	1	1	0
Westbound	13	0	0	0	0

**DasyLab Calibration notes:**

Mic #	Start	End
1	94.4	94.23
2	93.9	95.2
3	94.3	95.2
4	93.9	93.5
5	93.5	93.2
6	94.7	95.0
7	93.6	94.8
8	94.5	93.0

***Metro:***

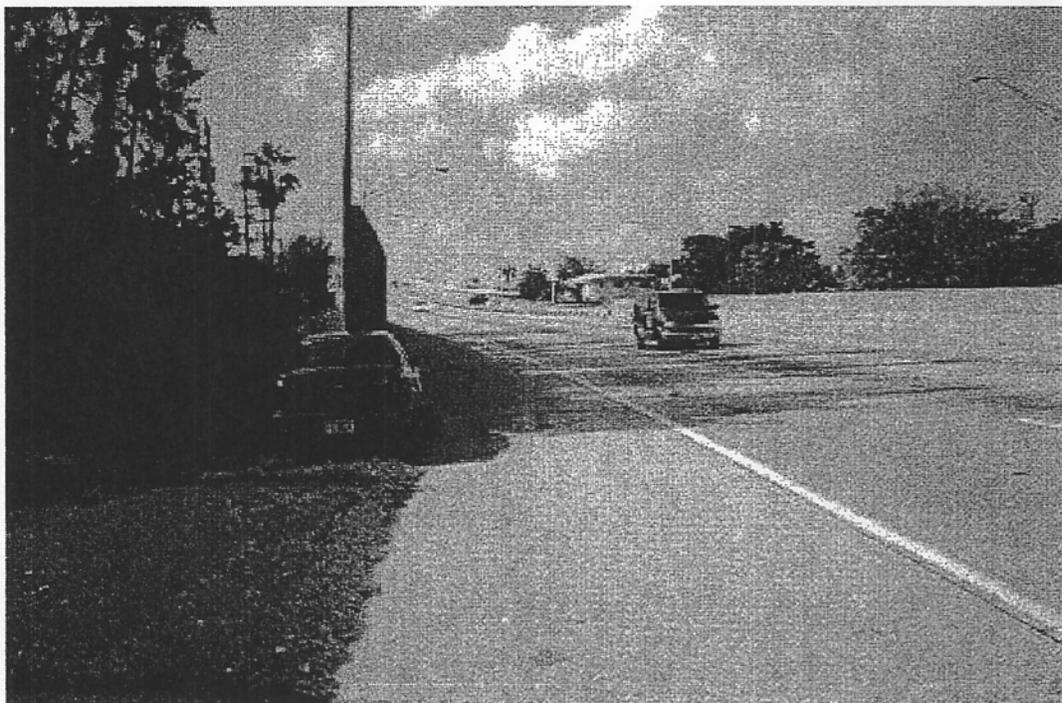
ID #	Distance from Barrier	Height	Final Calibration
SN2134	7.5 m	1.5 m	101.8 dB
SN2137	15 m	1.5 m	101.8 dB
SN2136	22.5 m	1.5 m	101.9 dB
SN2146	30 m	1.5 m	101.9 dB
SN2143	37.5 m	1.5 m	101.9 dB

Note: Distance from Metro SN#2143 to arterial road (36<sup>th</sup> Street) is 83.5'.

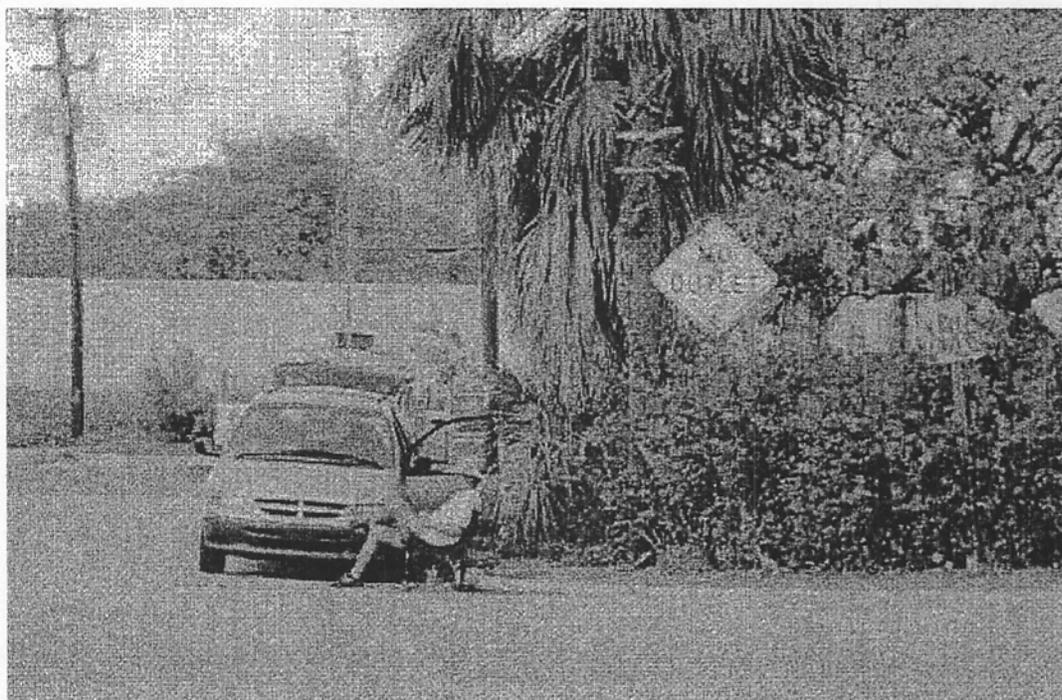
***Barrier Information:***

Concrete wall height at 10'10" on 3.25' berm with ground height at 1' above base of berm. Stands and mic towers at ground height level. Distance from reference microphones (7&8) to eastern most end of wall is 200'.

Miami (Dade County)

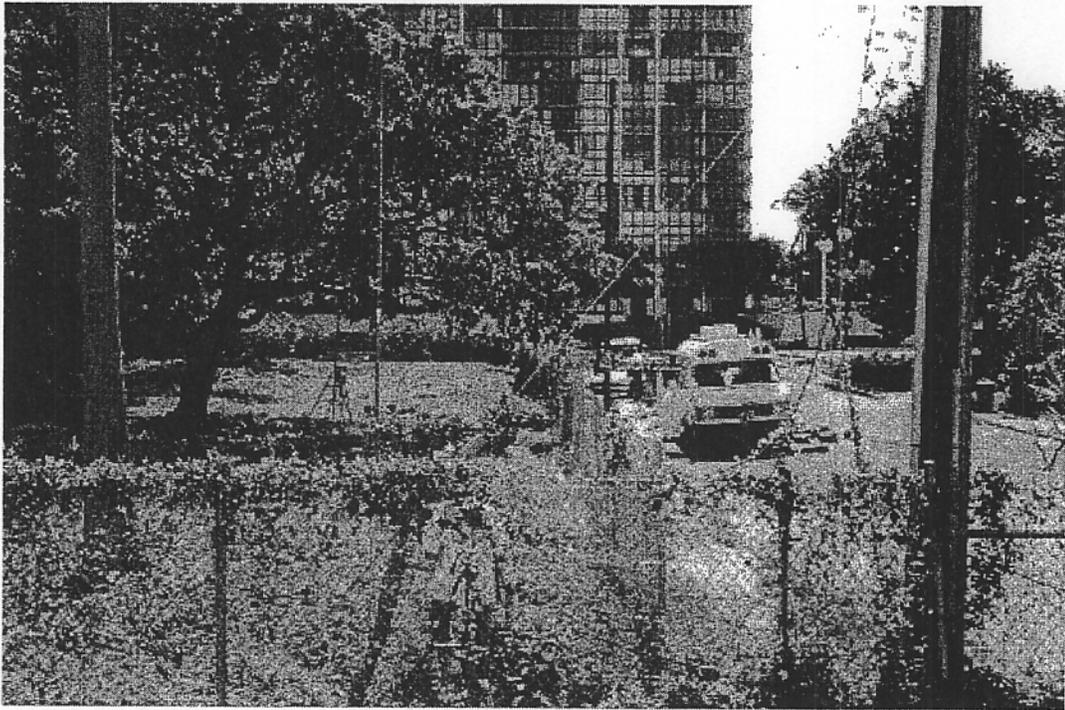


Roadway view of Noise Wall

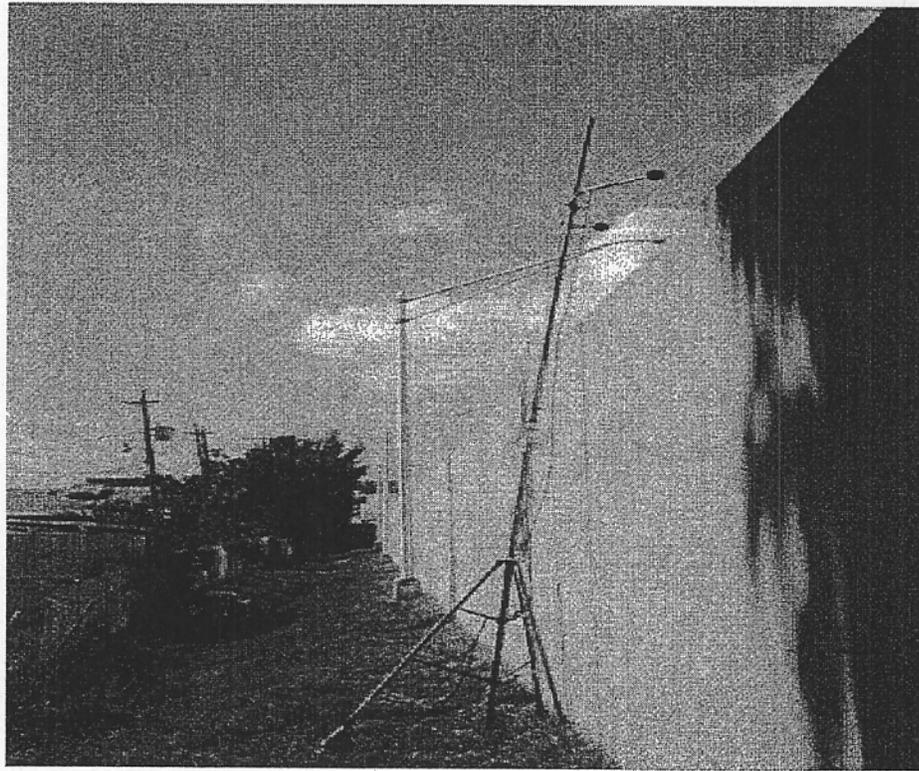


Residential view of Noise Wall

Miami (Dade County)



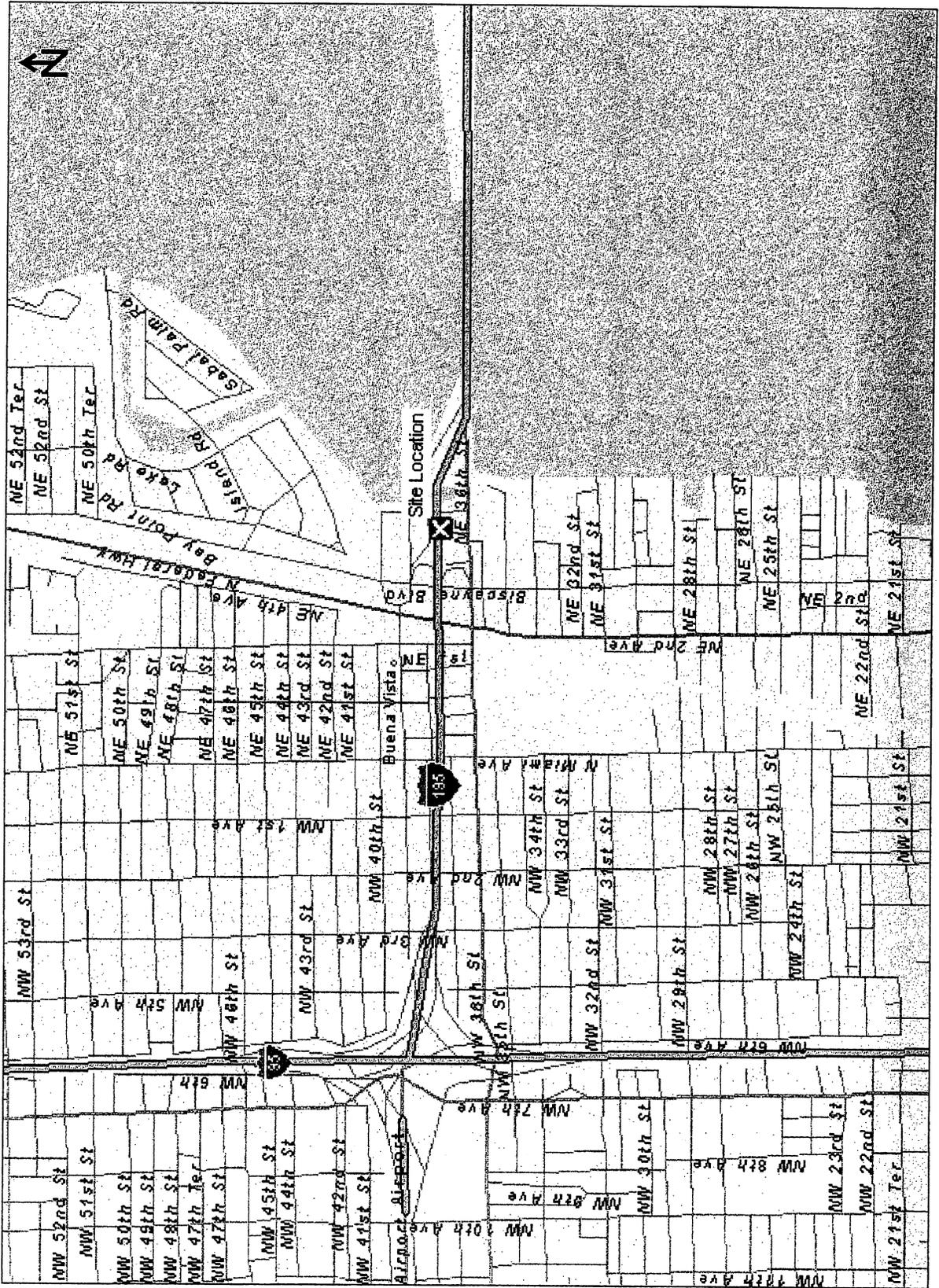
Area behind Noise Wall



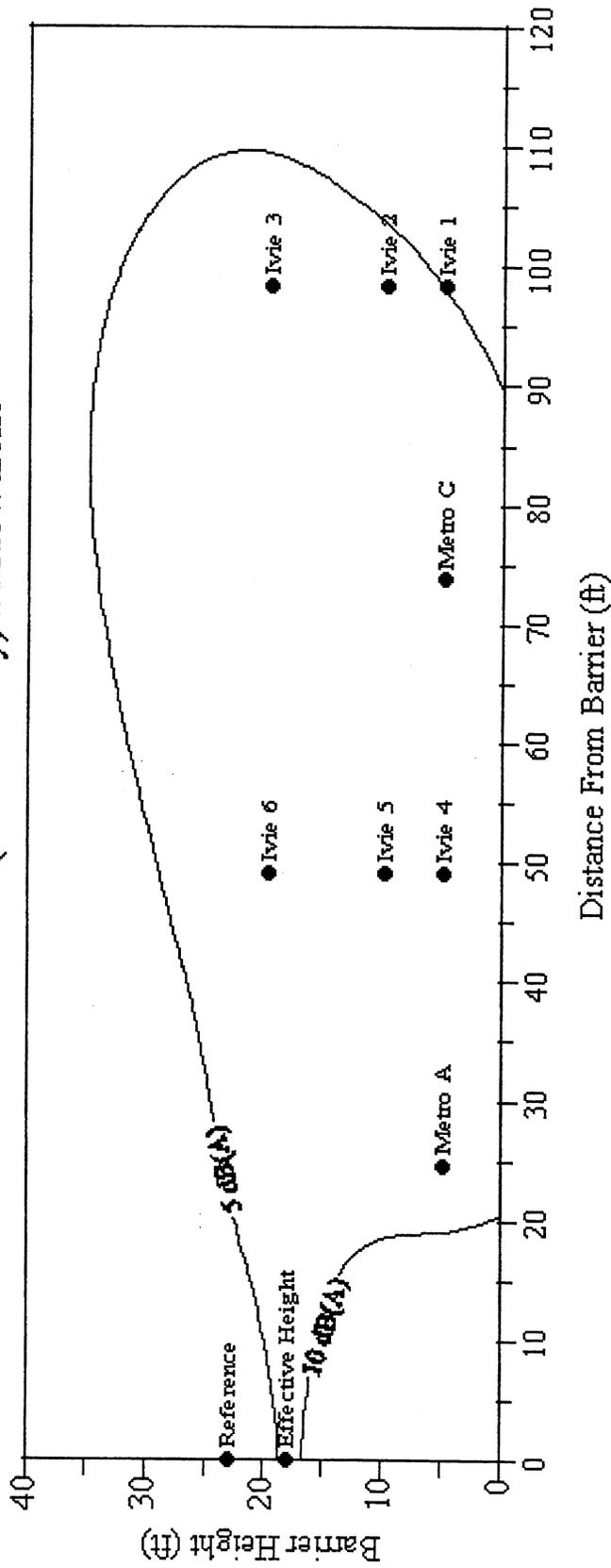
Up-close view of reference microphones by Noise Wall

I-195 SR112 Julia Tuttle Causeway (NE 6<sup>th</sup> Avenue off NE 36<sup>th</sup> Street)  
Project # 99004-3420

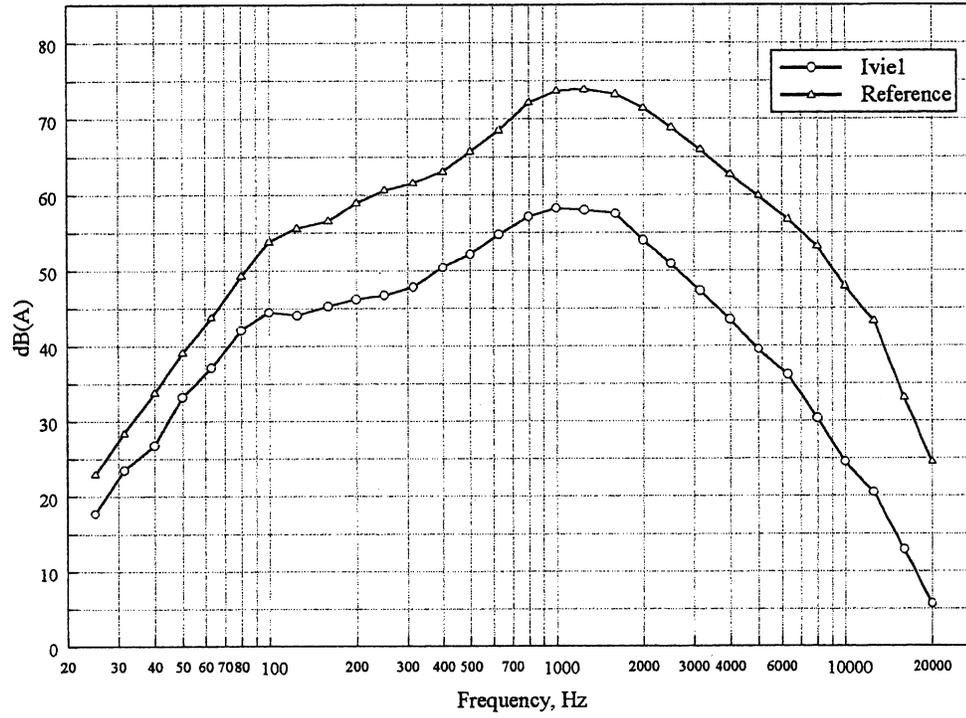
Site J. Miami (Dade County)



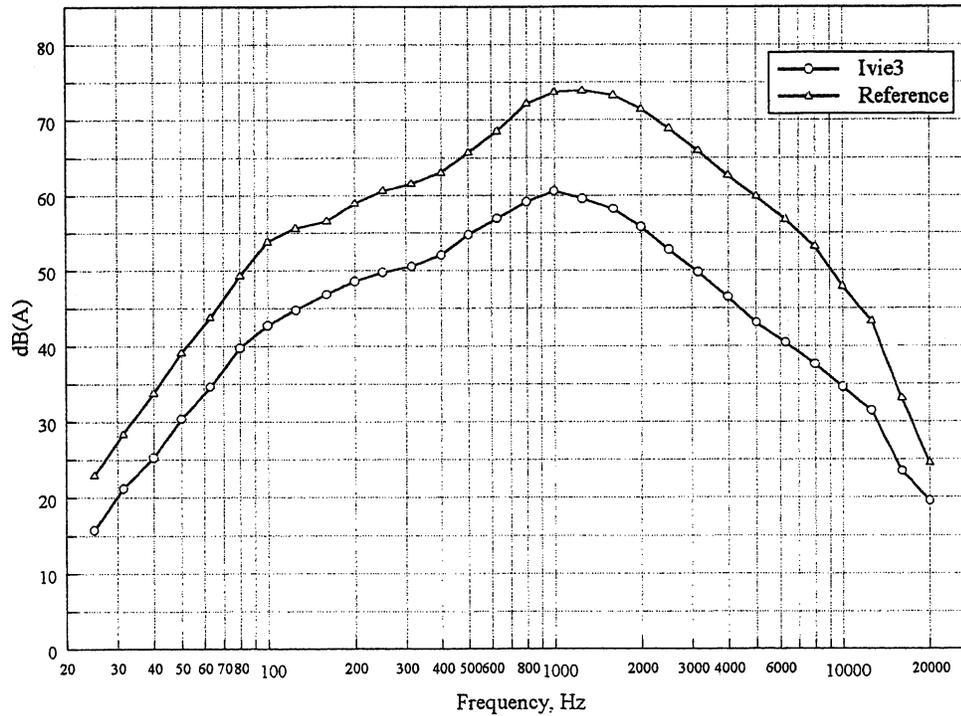
### Site J. Miami (Dade County) Shadow Zone



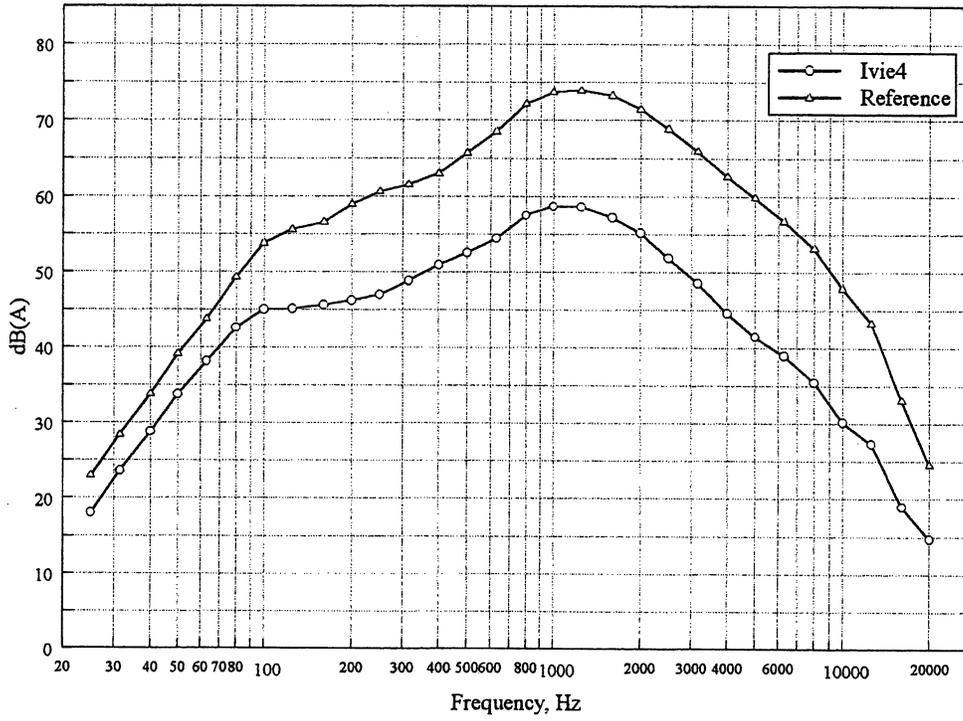
Site J. Miami (Dade County)  
Ivie 1 Four-Run Average Spectra Curve



Site J. Miami (Dade County)  
Ivie 3 Four-Run Average Spectra Curve



Site J. Miami (Dade County)  
Ivie 4 Four-Run Average Spectra Curve



**APPENDIX K**

**SR90; MIAMI**

**Site K. Tamiami Trail SR 90 (S.W. 8<sup>th</sup> Street and S.W. 93<sup>rd</sup> Avenue)  
29 February 2000 [Project #87120-3526]**

UCF staff: Dr. R.L. Wayson, John MacDonald, Wayne Arner, Brian Kim, Chris Corbisier and Patricia Tom  
FDOT staff: Mariano, Ed, Victor and Claire

The wall is on the Eastbound lanes of SR90 or S.W. 8<sup>th</sup> Street. It is in the Miami area of Tamiami. Driveway is near Metro #4 and towers with mics 1,2,and 3.

**DasyLab System:**

**1<sup>st</sup> RUN – 11:27:00- 11:47:00**

Weather: partly cloudy, winds calm with gust up to 7 mph dry 81°F, wet 73°F, RH 71%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	10	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8*	8	A	FT	CT

Note: \*Cable for mic #8 is bad so no data is collected for this IVIE. Car passby 11:33:47, car passby 11:34:48, flyover 11:35:15-28, car passby 11:38:20, flyover 11:39:30, car passby 11:40:30  
IVIE #1- 94.51dB(A), IVIE #4 - 93.70

**2nd RUN – 11:59:00- 12:19:00**

Weather: partly cloudy, winds calm with gust up to 7 mph dry 81°F, wet 73°F, RH 71%

Mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	10	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8*	8	A	FT	CT

Note: \*Cable for mic #8 is bad so no data is collected for this IVIE. Car passby 12:07:58  
IVIE #1- 94.27dB(A), IVIE #4 - 93.6

**3rd RUN – 12:23:00- 12:43:00**

Weather: partly cloudy, winds calm with gust up to 7 mph dry 81°F, wet 73°F, RH 71%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	10	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8*	8	A	FT	CT

Note: \*Cable for mic #8 is bad so no data is collected for this IVIE. Car passby 12:25:18, flyover 12:25:48-26:45, car passby 12:30:50, car passby 12:33:28, car passby 12:35:50, car passby 12:39:00, car passby 12:42:40, IVIE #1-94.3dB(A), IVIE #4 - 93.6

4<sup>th</sup> RUN – 12:47:00- 13:07:00

Weather: partly cloudy, winds 5 mph with gust up to 8 mph dry 80°F, RH 56%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	10	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8*	8	A	FT	CT

Note: \*Cable for mic #8 is bad so no data is collected for this IVIE. Car passby 12:48:48, car door slams across street 12:51:18, car passby 12:54:50, car passby 12:55:00, car passby 12:57:28, birds chirp @2200Hz 13:03:00, car w/ bad muffler passby 13:05:28

**DasyLab Calibration notes:**

Mic #	Start	End
1	94.6	94.3
2	94.3	93.4
3	94.3	94.3
4	93.6	94.0
5	93.2	93.8
6	93.4	93.5
7	94.8	94.9
8	94.6	94.6

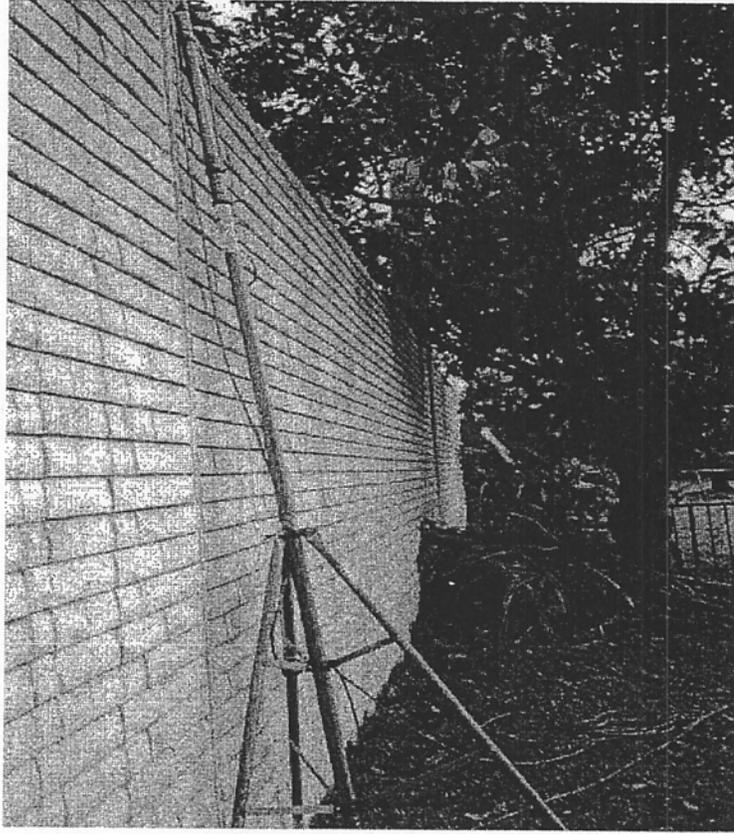
**Metro:**

ID #	Distance from Barrier	Height	Final Calibration
SN2134	7.5 m	1.5 m	102.0 dB
SN2146	15 m	1.5 m	101.9 dB
SN2137	22.5 m	1.5 m	102.0 dB
SN2143	30 m	1.5 m	102.0 dB

**Barrier Information:**

Concrete wall height at 11' with bottom of barrier at same elevation as ground on residence side. Setup was at a distance of 208' from the fence line of end of barrier at westernmost of wall. Reference mic offset but nil effect.

Tamiami Trail SR 90 (Dade County)

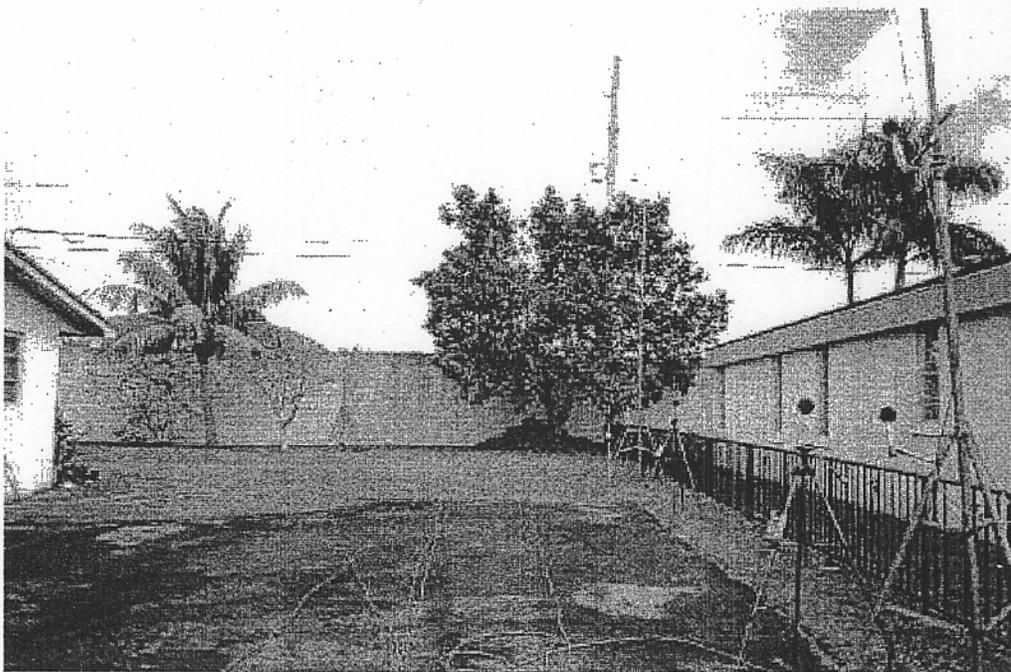


Up-close view of reference microphone stand by Noise Wall

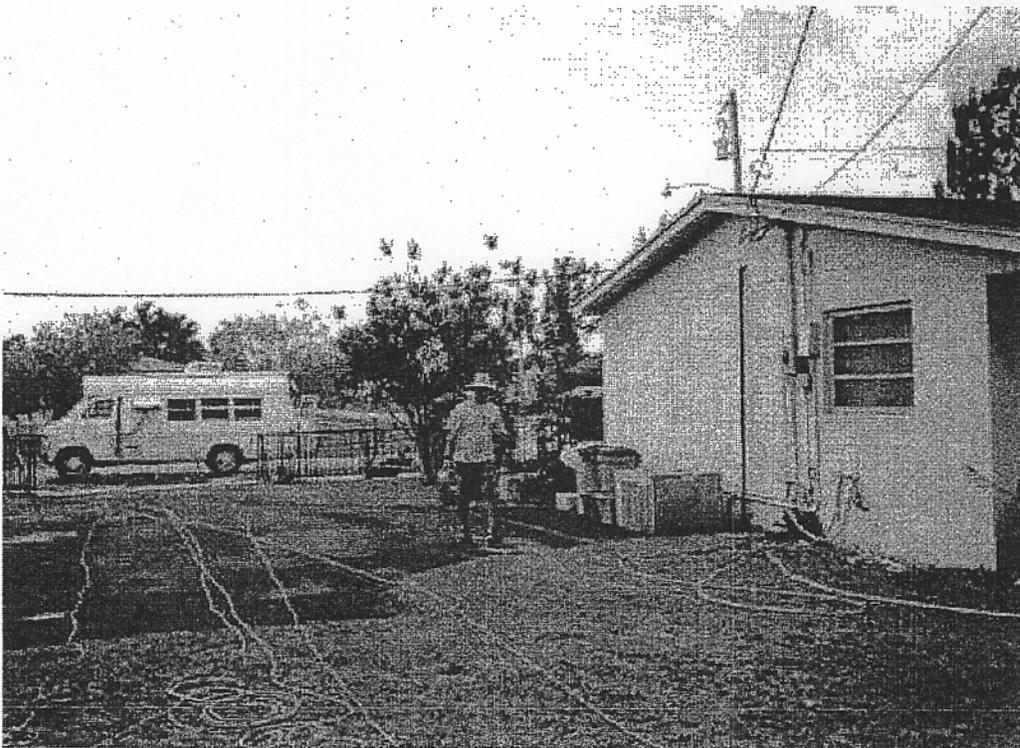


Distant residential view of Noise Wall

Tamiami Trail SR 90 (Dade County)

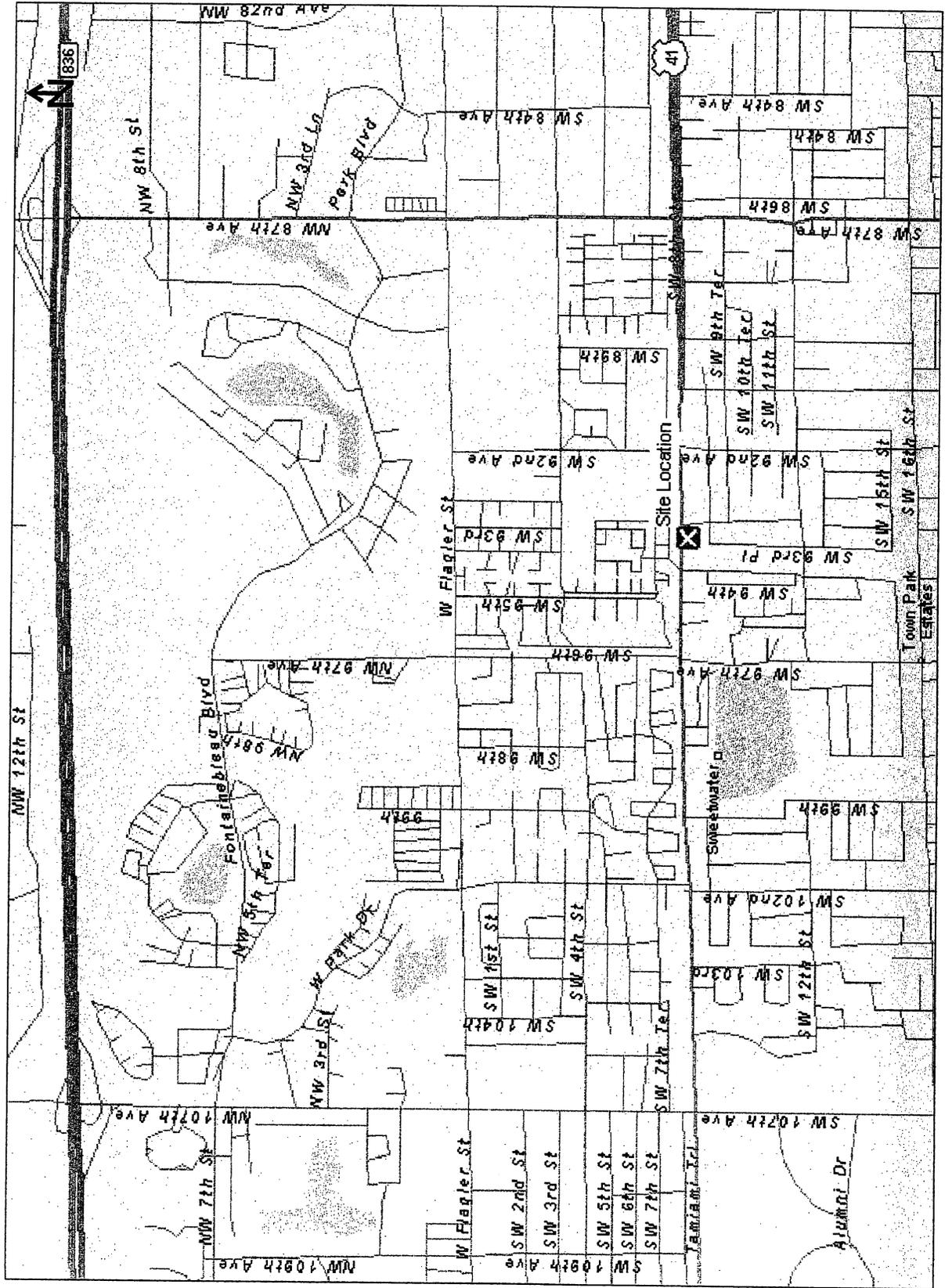


Residential view of Noise Wall

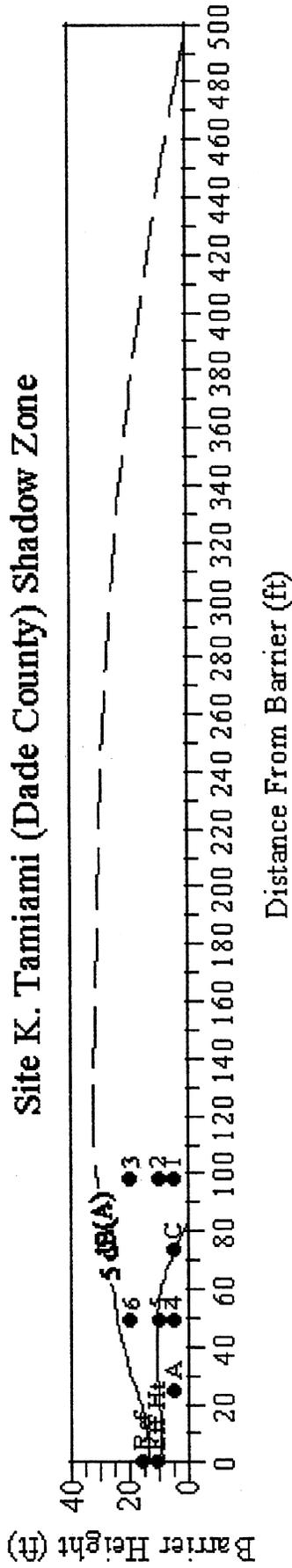


Residential area behind Noise Wall

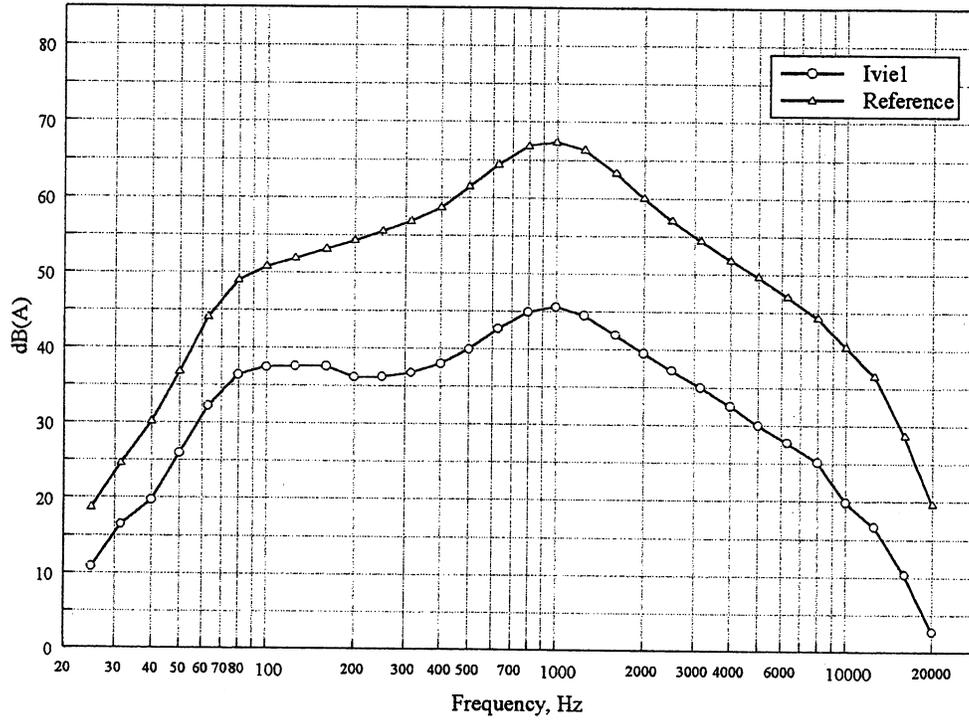
Site K. Tamiami (Dade County)



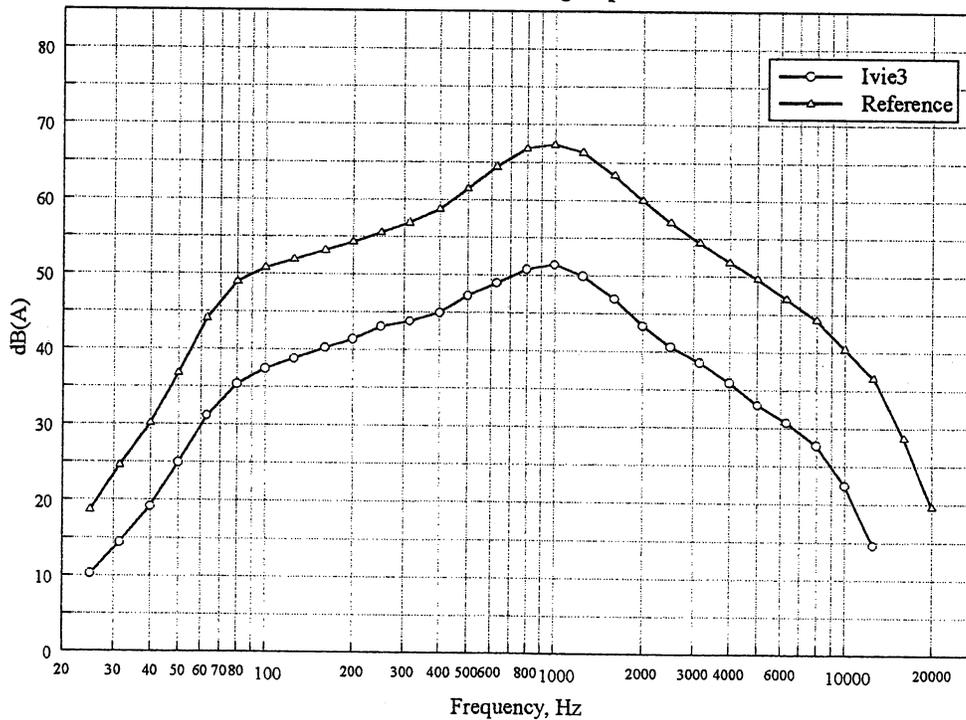
### Site K. Tamiami (Dade County) Shadow Zone



Site K. Tamiami (Dade County)  
Ivie 1 Four-Run Average Spectra Curve

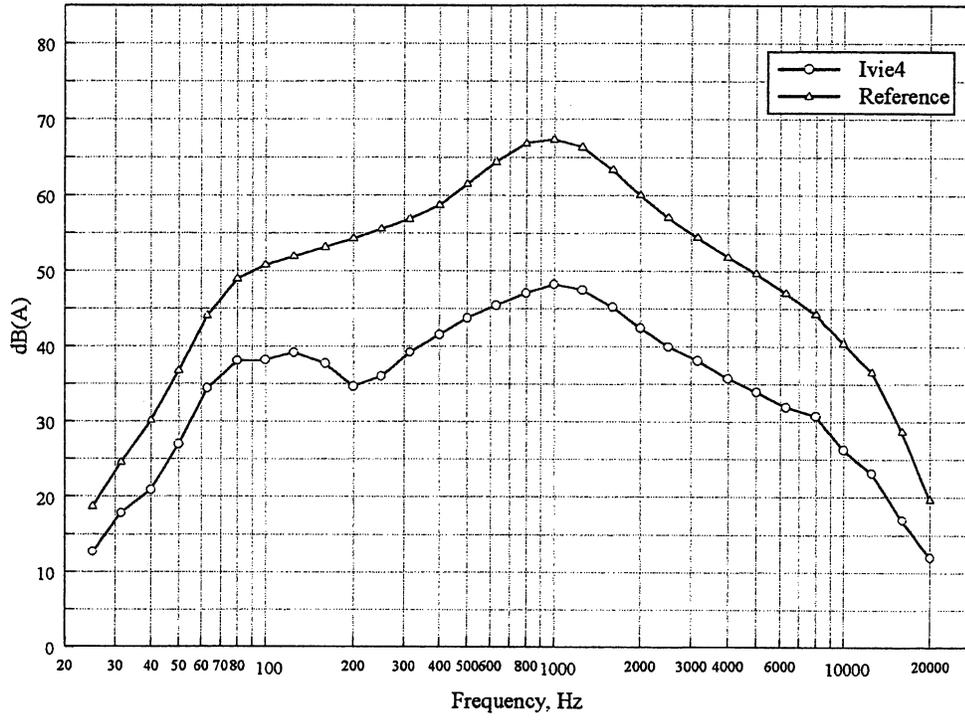


Site K. Tamiami (Dade County)  
Ivie 3 Four-Run Average Spectra Curve



Site K. Tamiami (Dade County)

Ivie 4 Four-Run Average Spectra Curve



**APPENDIX L**  
**SR924; MIAMI**

**Site L. Hialeah SR 924 Gratigny Parkway (West 81<sup>st</sup> Street west of West 6<sup>th</sup> Avenue)  
1 March 2000 [Project #87300-3503]**

UCF staff: Dr. R.L. Wayson, John MacDonald, Wayne Arner, Brian Kim, Chris Corbisier and Patricia Tom  
FDOT staff: Mariano, Ed, Victor and Claire

The wall is on a berm off the Gratigny Parkway. The setup was on the eastbound traffic or south side of the parkway. The local roadway, West 81<sup>st</sup> Street, ran east-west and also had traffic.

***DasyLab System:***

**1<sup>st</sup> RUN – 12:34:00- 12:54:00**

Weather: calms with some wind gust up to 7 mph (from east) dry 83°F, wet 70°F, RH 51%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	10	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8*	8	A	FT	CT

Note: \*Off and not collecting data. 12:34:10-:30 noise from truck, car passby 12:42:50, car passby with honking 12:44:00-:10

	Cars	Med-trucks	Heavy-trucks	Buses	Motorcycle
Sum of both directions	18	3	0	0	0

**2<sup>nd</sup> RUN – 12:49:00- 13:09:00**

Weather: calms with some wind gust up to 7 mph (from east) dry 83°F, wet 70°F, RH 51%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	10	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8*	8	A	FT	CT

Note: \*Off and not collecting data. IVIE #5 went off 12:50:30-:45, Car passby 12:55:35, car passby 12:55:50, ice cream truck 12:58:50-:59:05, car passby 13:00:40-:50, ice cream truck 13:01:05-:19, truck passby 13:02:04-:10, car passby 13:03:50, car passby 13:04:40, car passby 13:06:48, car passby 13:07:55, car passby 13:08:26

	Cars	Med-trucks	Heavy-trucks	Buses	Motorcycle
Sum of both directions	28	0	0	0	0

**3rd RUN – 14:34:10- 14:54:00**

Weather: calms with some wind gust up to 7 mph (from east) dry 83°F, wet 70°F, RH 51%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	10	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8*	8	A	FT	CT

Note: \*Off and not collecting data. 13:13:50-13:14:25 car passby, 13:15:25 flyover, 13:15:40 car passby, 13:16:15 car passby, 13:16:50 car passby, 13:17:15 car passby, 13:17:40 car passby, 13:19:05 car passby, 13:19:25-30 car passby, 13:21:15 car passby, 13:21:30 car passby, 13:22:15 car passby, 13:22:35-23:10 flyover, 13:23:40 car passby, 13:24:00 beep, 13:24:30 car passby, 13:25:05 car passby, 13:25:25-40 car passby, 13:26:20 car passby, 13:26:34 car passby, 13:27:23-28:00 flyover, 13:28:16 car passby, 13:28:35-29:05 car passby, 13:29:35-43 car passby, 13:29:48 car passby, 13:29:55 car passby, 13:30:55 beep and car passby, 13:31:40-32:20 car passby, 13:33:28-46 car passby

	Cars	Med-trucks	Heavy-trucks	Buses	Motorcycle
Sum of both directions	39	0	0	0	0

**4<sup>th</sup> RUN – 13:39:25- 13:59:25**

Weather: calms with some wind gust up to 7 mph (from east) dry 83°F, wet 70°F, RH 51%

mic #	IVIE unit #	Weight	Response	
1	1	A	FT	CT
2	2	A	FT	CT
3	3	A	FT	CT
4	4	A	FT	CT
5	10	A	FT	CT
6	6	A	FT	CT
7	7	A	FT	CT
8*	8	A	FT	CT

Note: \*Off and not collecting data. 13:41:02-49 guy yelling and van moving, 13:41:35 car passby, 13:42:22-32 car and truck passby, 13:44:07-23 car passby, 13:44:30-36 car horn and people talking, 13:45:10 car passby, 13:45:19 car passby, 13:46:12 car passby, 13:46:33-56 car passby, 13:47:04-14 two car passby, 13:48:35-47 car passby, 13:49:17 car passby, 13:49:27 car passby, 13:49:48 people yelling, 13:54:10 car passby, 13:55:44-48 car passby, 13:55:59 car passby, 13:56:54 car passby, 13:57:24 car passby, 13:57:53 car passby, 13:58:45 car passby

	Cars	Med-trucks	Heavy-trucks	Buses	Motorcycle
Sum of both directions	23	2	0	0	0

**DasyLab Calibration notes:**

Mic #	Start	End
1	93.9	94.1
2*	94.4	94.5
3	94.1	94.5
4	93.8	93.5
5	93.6	94.3
6	93.6	94.2
7	94.9	94.9
8	-	-

Note: #2 is used as reference mic position #8 with #7 at top of wall.

***Metro:***

ID #	Distance from Barrier	Height	Final Calibration
SN2137	7.5 m	1.5 m	101.9 dB
SN2134	15 m	1.5 m	101.9 dB
SN2143	22.5 m	1.5 m	101.9 dB

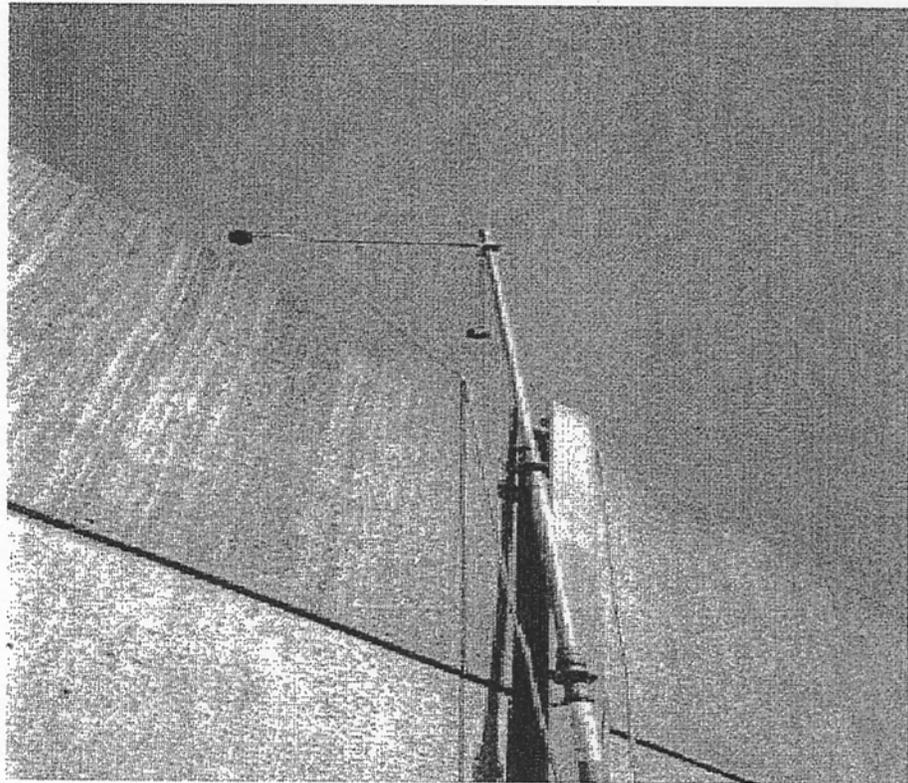
Note: The 30m Metro was not used due to location limitations. This distance would have been in the middle of the local road. The 22.5m Metro was 18' from the northern most edge of West 81<sup>st</sup> Street.

***Barrier Information:***

Concrete wall height including Jersey barrier at 13'2" on 8'6".

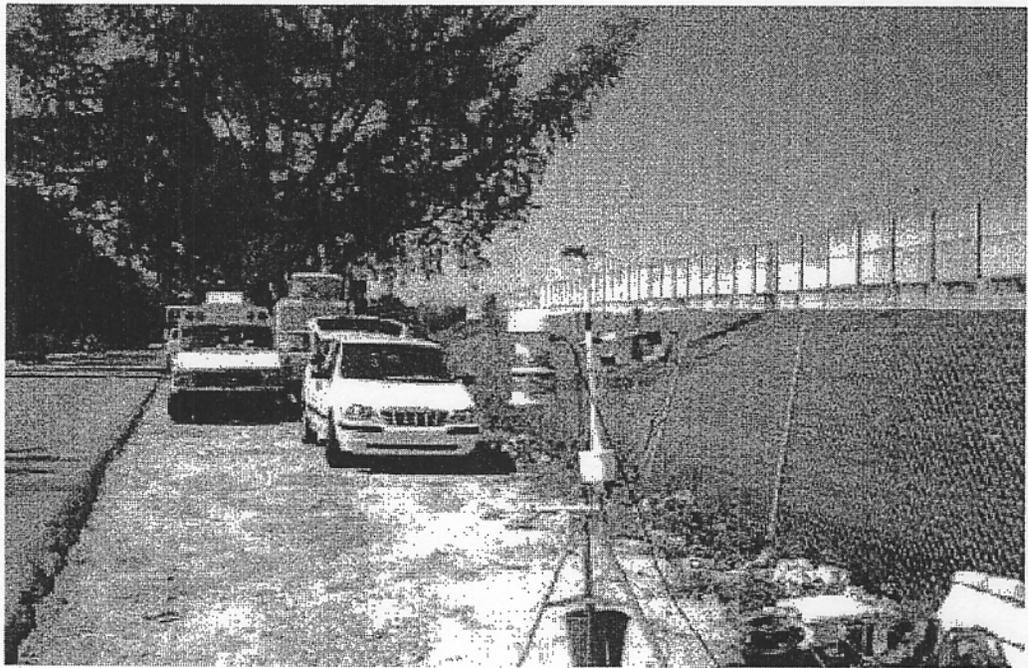


Reference microphones by Noise Wall



Close up of reference microphones by Noise Wall

Hialeah SR 924 Gratigny Parkway (Dade County)

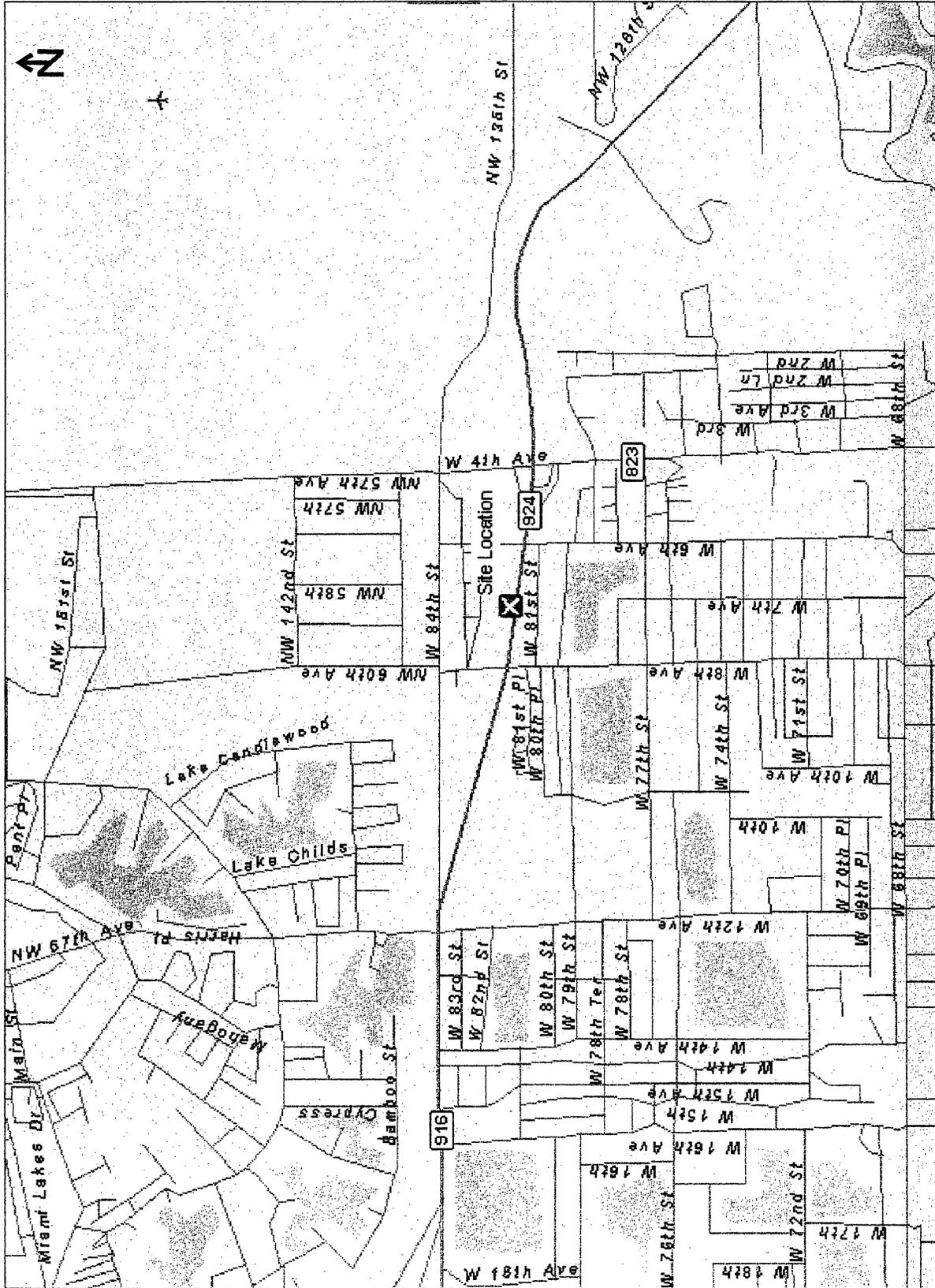


Residential view of Noise Wall

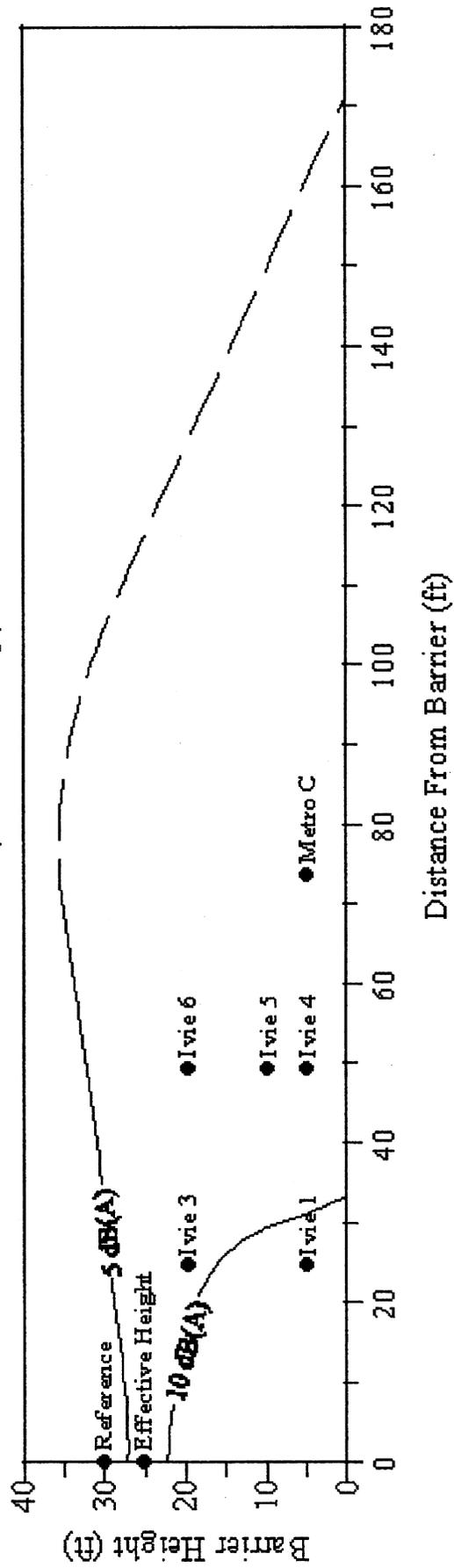


Residential area behind Noise Wall

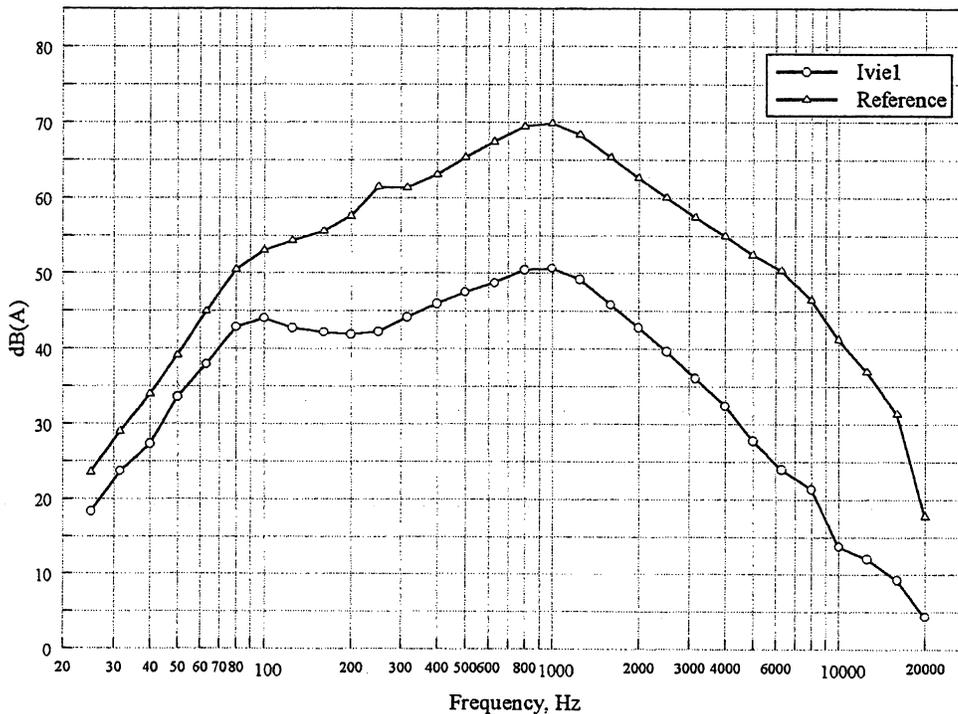
Site L, Hialeah (Dade County)



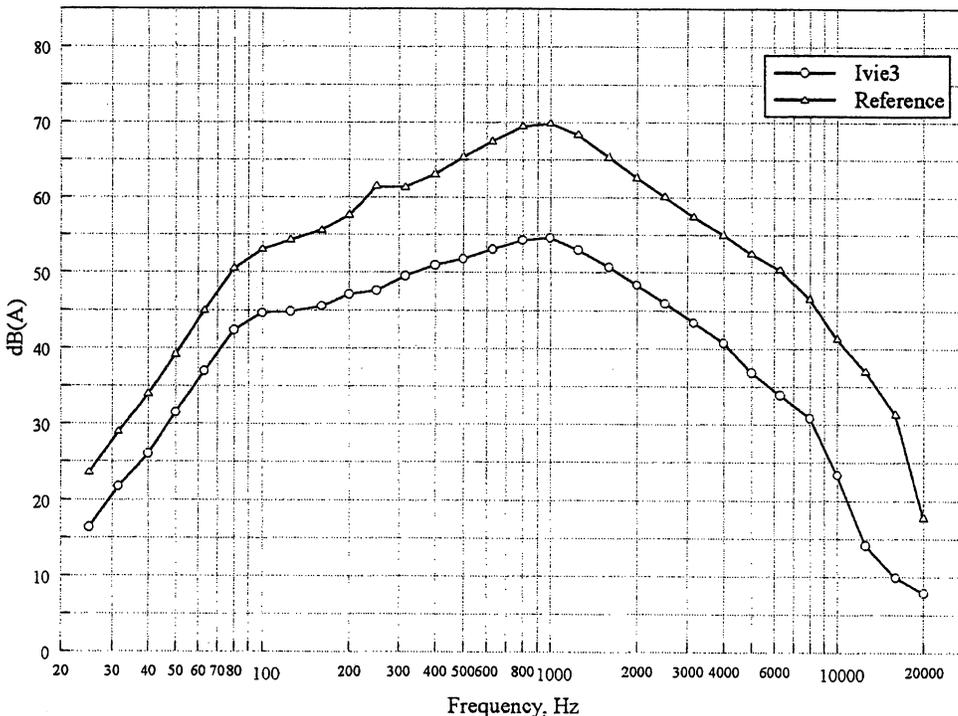
### Site L. Hialeah (Dade County) Shadow Zone



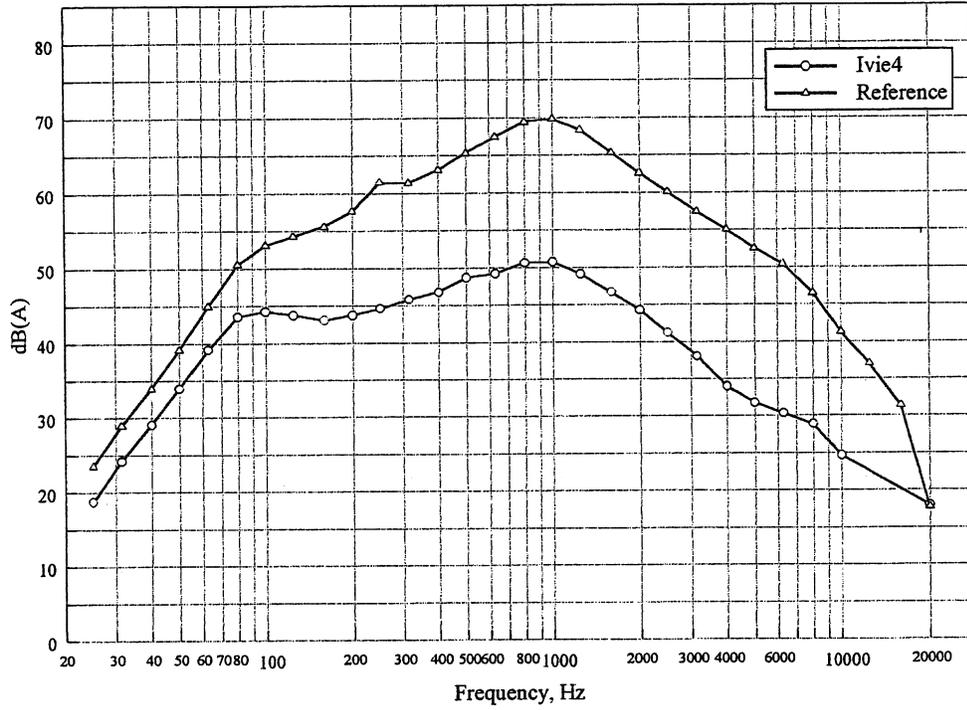
Site L. Hialeah (Dade County)  
Ivie 1 Four-Run Average Spectra Curve



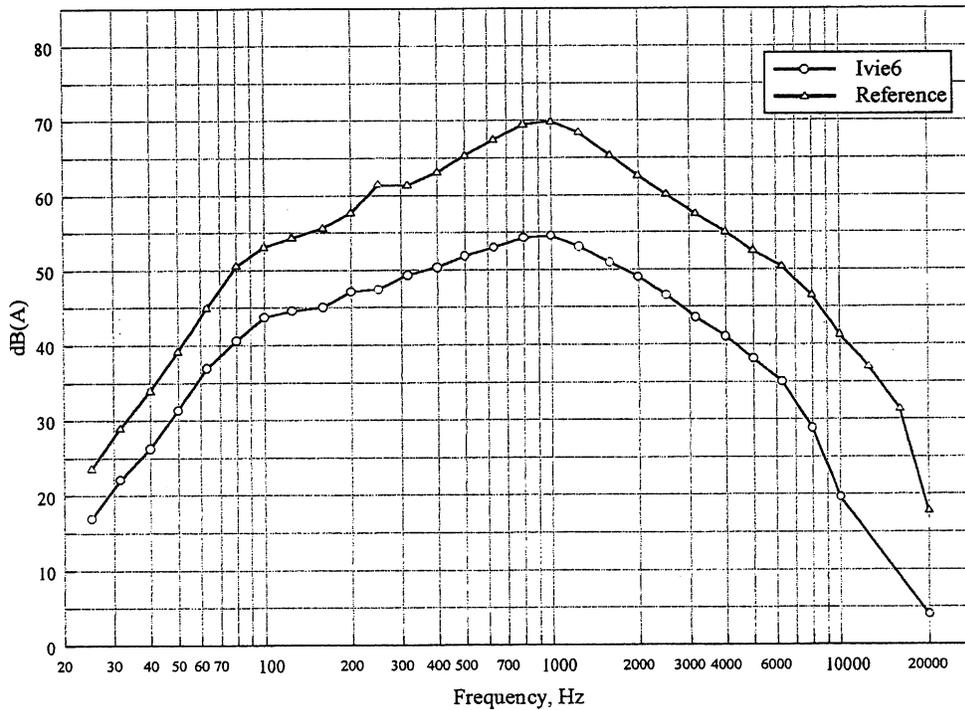
Site L. Hialeah (Dade County)  
Ivie 3 Four-Run Average Spectra Curve



Site L. Hialeah (Dade County)  
Ivie 4 Four-Run Average Spectra Curve



Site L. Hialeah (Dade County)  
Ivie 6 Four-Run Average Spectra Curve



**APPENDIX M**  
**TECHNICAL NOTE**

## TECHNICAL NOTE

### Diffraction Theory and Methods used by Computer Noise Models

Although other noise abatement measures exist and are used, noise barriers are the most common method used to abate sound levels from transportation noise sources. Barriers are built to specifications that normally require them to break the line of sight and must provide a sufficient IL between the highway traffic and affected residences to reduce impacts. The FDOT must model noise impacts of highway projects and, if reasonable and feasible, incorporate noise abatement into project planning, frequently using noise barriers. A complete description of the methodology used is contained in Chapter 17 of the FDOT PD&E Manual.[T1]

Abatement using barriers is based on the principle that sound can turn corners, but the sharper the corner, the less effective the propagation. This is called diffraction and occurs over the top and around the ends of a barrier. A “shadow zone” is created behind the barrier. Because the sound cannot turn sharp corners effectively, the taller the barrier the larger and “darker” the shadow zone. In other words, as barrier heights increase, the diffraction angle increases and the sound levels behind the barrier decrease. This so called shadow zone is an area of reduced sound levels, caused by the diffraction effects. Huygen’s Principle [T2] states that the top of the barrier can be considered a new source. Using these ideas, barriers can be designed, noise levels predicted, and insertion loss determined.

The object of highway barrier design is to build the most cost effective barrier that provides adequate noise abatement for residences along the highway. Predicting the shadow zone boundary, which is dependent on the geometry of the project site, determines how much each resident is benefitted from the barrier insertion loss. Methods of modeling diffraction effects vary widely. Three common approaches are: empirically derived methods from scale modeling and actual barriers, approximate analytical methods from diffraction theory, and numerical methods to solve the differential equation that governs sound wave propagation. Of these, the empirical and approximate analytical methods have been the most widely used, due to their simplicity. The numerical methods are the least practiced due mainly to the complexity of the method requiring detailed input by the user.

The empirical methods are really only valid for the specific environmental conditions of the original testing. For these reasons the empirical methods are subject to error when applied toward other project locations and geometry. However, substantial monitoring at multiple locations has been used to validate derived models for use in a more general case.

Diffraction theory has been used to try to obtain more generality with sound level prediction than the empirical methods. These analytical methods differ mainly in their approach to the diffraction theory and to the ground interaction. The theoretical methods basically have two approaches, geometrical approximation methods and numerical methods that attempt to solve the wave equation in the presence of a barrier and absorptive boundary, the ground. Geometrical approximation uses the concepts of rays which describe the propagation path of acoustic wavefronts. A Huygens superposition of the rays can then be represented by an integral containing the spherical wavelets that have phase terms dependent on the geometry of the

situation. A solution of the wave equation is the most rigorous mathematical method since it starts with a governing differential equation describing the sound field. However, the wave equation is generally difficult to solve with the boundary conditions that we encounter with a barrier and absorptive ground. Additionally the wave equation has a unique solution for different source-barrier-receiver geometry and therefore has to be evaluated for each barrier design project. Boundary element methods are capable of solving the wave equation if boundary conditions are assumed.

As previously stated, diffraction theory is more often used since it can be applied in a more general way. Table T1 lists some of the diffraction theory models in use today and their foundation, empirical, approximate or rigorous solutions of the wave equation.

**Table T1. Diffraction Theory Methods**

Type of model	Models	comments
Analytical/Approx. Solutions to wave equation or geometric methods	Kurze and Anderson [T3], Keller [T4], Pierce [T5], DeJong [T6], Thomasson [T7], Kirchoff-Fresnel [T8], ISO 9613:2 [T9]	based on Huygens principle or wave equation, accuracy not known
Rigorous methods	Sommerfeld [T10], Boundary Element methods	solution of wave equation with project boundary conditions, most difficult to implement

Also of interest is the work by Maekawa which used empirical methods to further derive diffraction theory [T11]. Kurze and Anderson later validated this method and made accuracy improvements for low Fresnel numbers. The Fresnel number, borrowed from optical wave theory <sup>1</sup>, relates the additional distance the sound wave must travel over or around the barrier to the direct path, source to receiver and the frequency of the sound. This additional distance is often called the path length distance. The frequency is inversely proportional to the wavelength of the sound. Mathematically, the Fresnel number (N) is given in Equation ET1 below.

$$N = 2 \delta / \lambda \quad \text{[ET1]}$$

where:

$\delta$  = the path length difference

$\lambda$  = the wavelength

The geometrical approach seeks to approximate the diffraction phenomenon through the concept

---

<sup>1</sup> Many of the analytical methods of acoustic diffraction are based on principles and theories from wave optics.

of propagating rays that describe the path of the acoustic pressure waves. A coordinate system describes the positions of the source, barrier and receiver and allows calculation of the corresponding path length differences of the Huygens wavelets. A superposition of the wavelets produces the total sound field. The path length differences are present in the phase terms of the wavelets and these produce the quadratic terms found in the phase component of the wavelets. These quadratic terms many times result in the presence of the Fresnel integrals which are found in Pierce's [T5] model and other models.

Kurze and Anderson [T3] use Keller's [T4] expression of the asymptotic form (large  $kr$ , where  $k$  is the wave number and  $r$  is the distance from screen to receiver) of the Sommerfeld [T10] wave equation solution. Keller extends the idea of geometrical optics to include diffracted rays that hit the edges or corners of apertures and screens. Keller's geometrical theory of diffraction leads to relatively simple formulas, which combine the practicability of Kirchoff's approximations with the greater accuracy of the Sommerfeld solutions and can be generalized to treat diffraction by three dimensional objects of any shape. Kurze and Anderson state that Keller's reduction of sound pressure level due to the insertion of a barrier is given by the following equation.

$$L_K = -20 \log \frac{d}{2 \sin \beta [2\pi / (\lambda)^{1/2}] [AB(A+B)]^{1/2}} \left| \sec \frac{\theta - \alpha}{2} \pm \csc \frac{\theta + \alpha}{2} \right| \quad [\text{ET2}]$$

where:

$L_k$  = barrier attenuation

$A + B$  = diffracted path

$d$  = direct path

$\beta$  = angle between the incident ray and edge of screen (barrier)

$\alpha, \theta$  = angles in vertical plane,  $\alpha$  subtended source to x axis,  $\theta$  subtended x axis to receiver

Kurze and Anderson [T3] simplify the above expression and show that the exact solution for  $N = 0$  is 5 dB which requires a correction for large  $N$ . They conclude that the following expression is a simplified form of the above equation by Keller and is satisfactory for low Fresnel numbers:

$$L_k = 5 \text{ dB} + 20 \log (2 \pi N)^{1/2} / \tanh(2 \pi N)^{1/2} \quad [\text{ET3}]$$

An equation of this form is used in the Federal Highway Administration Traffic Noise Prediction Model (FHWA-RD-77-108) [T12] and has been implemented into STAMINA2.0 and STAMINA2.1. Kurze and Anderson plot this equation against Maekawa's measurements and show good agreement for  $N$  greater than unity (1.0). Some oscillation of the solution is observed at  $N$  less than unity. An updated form of this equation is given by:

$$L_k = 10 \log (3 + 20N) \quad [\text{ET4}]$$

Also of interest is the ISO 9613 standard [T9] which uses an approach based on the Kurze and Anderson model along with a term that adjusts for downwind propagation conditions that degrade the barrier performance.

The FHWA model, TNM, probably has the most rigorous approach to diffraction of the computer prediction models evaluated in this report. TNM uses the diffraction approach by DeJong which is based on rigorous work by Pierce and Jonasson. DeJong modified the approach heuristically to account for discontinuities at the barrier/ground interface and discontinuities in the admittance of the ground surface. Validation efforts by the TNM development team showed good agreement between predicted and measured barrier sound level attenuation and results of recent field work also indicate the TNM seems to do a better job of barrier attenuation prediction than the simpler Kurze and Anderson approach.

DeJong's approach, as implemented into TNM is shown in Equation ET5.

$$L_k = \left[ \left[ R \exp(-i(\pi/4)) / L\pi^{-1/2} \right] \exp[ik(L - R)] \exp(-i\chi^2) F(\chi) \right] \quad [ET5]$$

where:

R = direct path length, source to receiver

L = diffraction parameter (diffracted path length)

k = wave number =  $2\pi f / c$

f = frequency

c = speed of sound

$F(\chi)$  = the Fresnel integral =  $\int \exp(it^2) dt$

t = dummy variable within the Fresnel integral

The DeJong model described above is only applicable in a limited frequency range. The model is not justifiable at low frequencies where the wavelength is comparable with the dimensions of the surfaces.

Embleton [T13] reminds us that grazing angles of reflection for sound fields diffracted over the top of the barrier are greater than the very small grazing angles without the barrier, for which there is a large phase change on reflection. The cost effectiveness of constructing a new barrier therefore depends on the pre-existing ground surface. This explains why a barrier calculated to provide 10 dB of noise reduction sometimes provides much less IL than attenuation in practice due to the ground reflections. Also a prime consideration are other ground effects. Ground effects can have a profound effect on IL. Isei [T14] also reported that the ground plays a large role in propagation, even in the presence of a barrier.

In summary, Table T2 lists some of the noise prediction computer models in use today and their approach to diffraction.

This review of diffraction theory has attempted to give the theoretical background of diffraction theory and review background behind some of the methods currently used in the computer noise prediction models. It also points out the key variables that must be considered during insertion loss predictions: site geometrics, barrier heights, ground conditions, and frequency.

Although not discussed, meteorological effects can have a significant effect on barrier performance as well. The speed of sound changes slightly with temperature. Temperature can also change the source levels since the tires and pavement become more pliable with increased

**Table T2. Computer Models Approaches Evaluated**

Computer model	Diffraction Approach	comments
STAMINA2.0/2.1, UCF Community Noise Model, ISO 9613:2	Kurze and Anderson based on Keller geometric diffraction	easy to use
FHWA TNM model	DeJong method based on Pierce and Jonasson asymp. Solutions	provides for impedance discontinuity, accuracy unknown other than DeJong tests

temperature, reducing the source level. Most importantly, temperature and wind gradients can cause refraction, changing the propagation direction.

To be complete, this project measured and/or reported these variables.

## References

[T1] Florida Dept. of Transportation, *Project Development and Environment Manual*, Chapter 17, Tallahassee, August, 2000.

[T2] Skudrzyk, E., *The Foundations of Acoustics*, Springer-Verlag, New York, 1971.

[T3] Kurze, U. J., Anderson, G. S., "Sound Attenuation by Barriers." *Applied Acoustics*, vol. 4, pp.35-53, 1971.

[T4] Keller, J. B., "Geometrical Theory of Diffraction", *Journal of the Optical Society of America*, 52, pp.116-130, 1962.

[T5] Pierce, A. D., "Diffraction of sound around corners and wide barriers." *Journal of the Acoustical Society of America*, 1972.

[T6] DeJong, R., B. A. Moerkerken, J. D. van der Toorn. "Propagation of sound over Grassland and Over an Earth Barrier." *Journal of Sound and Vibration*, 86(1), pp. 23-46, 1983.

[T7] Thomasson, Sven-Ingar, "Reflection of waves from a point source by an impedance boundary." *Journal of the Acoustical Society of America*, 59(4),pp. 780-785, 1976.

[T8] Elmore, W.C., Heald, M. A., *Physics of Waves*, Dover Publications, 1969.

[T9] International Standards Organization, *Acoustics – Attenuation of sound during propagation outdoors, Parts 1 and 2*, ISO 9613-1, ISO 9613-2, Geneva, 1996.

[T10] Sommerfeld, A, *Optics*, Academic Press Inc., 1964.

[T11] Maekawa, Z., "Noise reduction by screens", *Applied Acoustics*, 1, pp. 157-173, 1968.

[T12] Federal Highway Administration, *Traffic Noise Prediction Model*, FHWA-RD-77-108.

[T13] Embleton, T.F.W., "Line integral theory of barrier attenuation", *Journal of the Acoustical Society of America*, 67(1), pp. 42-45,1980.

[T14] Isei, "Noise reduction by barriers on finite impedance ground", *Journal of the Acoustical Society of America*, 67(1), pp. 46-58,1980.

## TECHNICAL NOTE

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Diffraction theory has been used to try to obtain more generality with sound level prediction than the empirical methods. These analytical methods differ mainly in their approach to the diffraction theory and to the ground interaction. The theoretical methods basically have two approaches, geometrical approximation methods and numerical methods that attempt to solve the wave equation in the presence of a barrier and absorptive boundary, the ground. Geometrical approximation uses the concepts of rays which describe the propagation path of acoustic

wavefronts. A Huygens superposition of the rays can then be represented by an integral containing the spherical wavelets that have phase terms dependent on the geometry of the situation. A solution of the wave equation is the most rigorous mathematical method since it starts with a governing differential equation describing the sound field. However, the wave equation is generally difficult to solve with the boundary conditions that we encounter with a barrier and absorptive ground. Additionally the wave equation has a unique solution for different source-barrier-receiver geometry and therefore has to be evaluated for each barrier design project. Boundary element methods are capable of solving the wave equation if boundary conditions are assumed.

As previously stated, diffraction theory is more often used since it can be applied in a more general way. Table T1 lists some of the diffraction theory models in use today and their foundation, empirical, approximate or rigorous solutions of the wave equation.

**Table T1. Diffraction Theory Methods**

Type of model	Models	comments
Analytical/Approx. Solutions to wave equation or geometric methods	Kurze and Anderson [T3], Keller [T4], Pierce [T5], DeJong [T6], Thomasson [T7], Kirchoff-Fresnel [T8], ISO 9613:2 [T9]	based on Huygens principle or wave equation, accuracy not known
Rigorous methods	Sommerfeld [T10], Boundary Element methods	solution of wave equation with project boundary conditions, most difficult to implement

Also of interest is the work by Maekawa which used empirical methods to further derive diffraction theory [T11]. Kurze and Anderson later validated this method and made accuracy improvements for low Fresnel numbers. The Fresnel number, borrowed from optical wave theory <sup>1</sup>, relates the additional distance the sound wave must travel over or around the barrier to the direct path, source to receiver and the frequency of the sound. This additional distance is often called the path length distance. The frequency is inversely proportional to the wavelength of the sound. Mathematically, the Fresnel number (N) is given in Equation ET1 below.

$$N = 2 \delta / \lambda \quad [ET1]$$

where:

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<sup>1</sup> Many of the analytical methods of acoustic diffraction are based on principles and theories from wave optics.

$\delta$  = the path length difference  
 $\lambda$  = the wavelength

The geometrical approach seeks to approximate the diffraction phenomenon through the concept of propagating rays that describe the path of the acoustic pressure waves. A coordinate system describes the positions of the source, barrier and receiver and allows calculation of the corresponding path length differences of the Huygens wavelets. A superposition of the wavelets produces the total sound field. The path length differences are present in the phase terms of the wavelets and these produce the quadratic terms found in the phase component of the wavelets. These quadratic terms many times result in the presence of the Fresnel integrals which are found in Pierce's [T5] model and other models.

Kurze and Anderson [T3] use Keller's [T4] expression of the asymptotic form (large  $kr$ , where  $k$  is the wave number and  $r$  is the distance from screen to receiver) of the Sommerfeld [T10] wave equation solution. Keller extends the idea of geometrical optics to include diffracted rays that hit the edges or corners of apertures and screens. Keller's geometrical theory of diffraction leads to relatively simple formulas, which combine the practicability of Kirchoff's approximations with the greater accuracy of the Sommerfeld solutions and can be generalized to treat diffraction by three dimensional objects of any shape. Kurze and Anderson state that Keller's reduction of sound pressure level due to the insertion of a barrier is given by the following equation.

$$L_K = -20 \log \frac{d}{2 \sin \beta [2\pi / (\lambda)^{1/2}] [AB(A+B)]^{1/2}} \left| \sec \frac{\theta - \alpha}{2} \pm \csc \frac{\theta + \alpha}{2} \right| \quad [\text{ET2}]$$

where:

$L_k$  = barrier attenuation

$A + B$  = diffracted path

$d$  = direct path

$\beta$  = angle between the incident ray and edge of screen (barrier)

$\alpha, \theta$  = angles in vertical plane,  $\alpha$  subtended source to x axis,  $\theta$  subtended x axis to receiver

Kurze and Anderson [T3] simplify the above expression and show that the exact solution for  $N = 0$  is 5 dB which requires a correction for large  $N$ . They conclude that the following expression is a simplified form of the above equation by Keller and is satisfactory for low Fresnel numbers:

$$L_k = 5 \text{ dB} + 20 \log (2 \pi N)^{1/2} / \tanh(2 \pi N)^{1/2} \quad [\text{ET3}]$$

An equation of this form is used in the Federal Highway Administration Traffic Noise Prediction Model (FHWA-RD-77-108) [T12] and has been implemented into STAMINA2.0 and STAMINA2.1. Kurze and Anderson plot this equation against Maekawa's measurements and show good agreement for  $N$  greater than unity (1.0). Some oscillation of the solution is observed at  $N$  less than unity. An updated form of this equation is given by:

$$L_k = 10 \log (3 + 20N) \quad [ET4]$$

Also of interest is the ISO 9613 standard [T9] which uses an approach based on the Kurze and Anderson model along with a term that adjusts for downwind propagation conditions that degrade the barrier performance.

The FHWA model, TNM, probably has the most rigorous approach to diffraction of the computer prediction models evaluated in this report. TNM uses the diffraction approach by DeJong which is based on rigorous work by Pierce and Jonasson. DeJong modified the approach heuristically to account for discontinuities at the barrier/ground interface and discontinuities in the admittance of the ground surface. Validation efforts by the TNM development team showed good agreement between predicted and measured barrier sound level attenuation and results of recent field work also indicate the TNM seems to do a better job of barrier attenuation prediction than the simpler Kurze and Anderson approach.

DeJong's approach, as implemented into TNM is shown in Equation ET5.

$$L_k = [ [ R \exp(-i(\pi/4)) / L \pi^{-1/2} ] \exp[ i k(L - R) ] \exp(-i \chi^2) F(\chi) ] \quad [ET5]$$

where:

R = direct path length, source to receiver

L = diffraction parameter (diffracted path length)

k = wave number =  $2\pi f / c$

f = frequency

c = speed of sound

$F(\chi)$  = the Fresnel integral =  $\int \exp(it^2) dt$

t = dummy variable within the Fresnel integral

The DeJong model described above is only applicable in a limited frequency range. The model is not justifiable at low frequencies where the wavelength is comparable with the dimensions of the surfaces.

Embleton [T13] reminds us that grazing angles of reflection for sound fields diffracted over the top of the barrier are greater than the very small grazing angles without the barrier, for which there is a large phase change on reflection. The cost effectiveness of constructing a new barrier therefore depends on the pre-existing ground surface. This explains why a barrier calculated to provide 10 dB of noise reduction sometimes provides much less IL than attenuation in practice due to the ground reflections. Also a prime consideration are other ground effects. Ground effects can have a profound effect on IL. Isei [T14] also reported that the ground plays a large role in propagation, even in the presence of a barrier.

In summary, Table T2 lists some of the noise prediction computer models in use today and their approach to diffraction.

This review of diffraction theory has attempted to give the theoretical background of diffraction theory and review background behind some of the methods currently used in the computer noise prediction models. It also points out the key variables that must be considered during insertion loss predictions: site geometrics, barrier heights, ground conditions, and frequency.

Although not discussed, meteorological effects can have a significant effect on barrier performance as well. The speed of sound changes slightly with temperature. Temperature can also change the source levels since the tires and pavement become more pliable with increased

**Table T2. Computer Models Approaches Evaluated**

Computer model	Diffraction Approach	comments
STAMINA2.0/2.1, UCF Community Noise Model, ISO 9613:2	Kurze and Anderson based on Keller geometric diffraction	easy to use
FHWA TNM model	DeJong method based on Pierce and Jonasson asymp. Solutions	provides for impedance discontinuity, accuracy unknown other than DeJong tests

temperature, reducing the source level. Most importantly, temperature and wind gradients can cause refraction, changing the propagation direction.

To be complete, this project measured and/or reported these variables.

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