Ohio Turnpike Commission

Noise Mitigation Study

Contract No. 71-08-02

Prepared For:

Ohio Turnpike Commission
682 Prospect Street
Berea, Ohio 44017

Prepared By:

TranSystems®

Ohio Turnpike Commission

November 2008

Noise Mitigation Study
Ohio Turnpike Commission
Contract No. 71-08-02

TABLE OF CONTENTS

TABLES

APPENDICES

Executive Summary

This report identifies sixty seven (67) sites along the Ohio Turnpike which are considered as noise sensitive areas (NSA). The NSAs predominantly consist of residential neighborhoods that may potentially be impacted by traffic noise and may be considered as a location for noise mitigation. The report also reviews numerous non-traditional noise abatement measures such as quiet pavement, noise insulation of receptor sites, land use planning and control, innovative noise barrier walls, acoustic panels, vegetation and other natural treatments.

Of the sixty seven (67) NSAs, TranSystems identified a short list of twenty (20) potential sites for further consideration and potential implementation of the pilot project. The short list of sites was developed by considering various criteria which meet the goals of the pilot project such as the size of the site and number of receptors which could benefit from the pilot project. For each of the short listed sites, an appropriate non-traditional noise abatement measure was chosen based on various criteria such as the physical site-specific characteristics, the physical characteristics of the noise abatement measure, its' expected performance, unit cost and total construction cost which would fall within the estimated project budget constraints.

Following a review of traditional and non-traditional noise mitigation measures, it was determined that the installation of absorptive acoustic panels on the center concrete median and the construction of a "T"-top noise barrier wall would be implemented as the noise mitigation measures.

NSA 47 was chosen as the site for the pilot program to implement the median-mounted acoustic panels and a grouping of homes on the east side of NSA 39 was chosen for the site of the pilot program to implement the "T"-top noise barrier wall. NSA 47 is located on the south side of the turnpike west of West 130th Street. NSA 39 is located on the south side of the turnpike just west of the Sprague Road overpass.

SECTION 1.0
INTRODUCTION

Section 1.0
Introduction

1.1 Project Description

In accordance with the requirements of Am. Sub. H.B. 67 of the 127th General Assembly, TranSystems was selected to perform a study of noise impact mitigation measures that may be used along the Ohio Turnpike. As part of this study, alternatives to the traditional concrete or timber noise barrier walls are to be evaluated, tested and recommended through a pilot program. The study, Project Number 71-08-02, examined the viability of alternative noise abatement measures to substantially reduce the existing noise levels along the Turnpike. The noise mitigation study followed by a pilot program will be conducted in accordance with the Code of Federal Regulations (CFR), Title 23, Part 772, and the U.S. Department of Transportation, Federal Highway Administration (FHWA), *Highway Traffic Noise Analysis and Abatement Policy and Guidance* (FHWA, 1995). The project was further conducted in accordance with the ODOT noise policy pertaining to *Standard Procedure for Analysis and Abatement of Highway Traffic Noise* Standard Procedures No. 417-001 (SP) effective August 14, 2008.

1.2 Study Objectives

The approach to this project is to investigate and evaluate any and all potentially feasible and reasonable mitigation alternatives while maintaining compliance with both the FHWA and the ODOT traffic noise analysis and abatement policy and guidance documents. The objectives of the study include: (1) identification of existing noise sensitive areas in the vicinity of the turnpike, (2) characterization of the existing ambient noise environment through field measurement and computer modeling and estimate the number of receptor sites currently impacted by traffic noise, (3) the identification of sites along the turnpike suitable for implementation of an innovative mitigation measure, (4) a review and evaluation of innovative noise mitigation measures used throughout the United States and the world, (5) design and construction of a selected innovative mitigation measure as a pilot project, and (6) monitoring the implemented mitigation measure compared to the existing ambient noise level to determine the relative effectiveness of the innovative measure to the traditional noise mitigation measure (noise barrier wall).

1.3 Noise Descriptors

Noise descriptors are used to describe the time varying nature of noise. In this report, noise levels will be described as hourly A weighted equivalent sound level in decibels, or dBA $L_{eq(h)}$. Noise is defined as unwanted sound, which is produced by the vibration of sound pressure waves. Sound pressure levels are used to measure the intensity of sound and are described in terms of decibels (dB). Decibels are a logarithmic unit, which expresses the ratio of sound pressure level to a standard reference scale. The decibel scale has a range of 0-120 and is used to show the amount of sound pressure at a given location from the general environment of specific sources. An increase or decrease of 10 dB is perceived as doubling or halving of the sound intensity since the decibel scale is logarithmic. In general, the average person cannot detect an increase or decrease in sound pressure level of less than 3 dB. A change in sound pressure level of 5 dB is readily perceptible by most people.

Sound is composed of various frequencies which are measured in cycles per second or Hertz (Hz). The human ear can detect a wide range of frequencies from 20 to 20,000 Hz, but is most sensitive to sounds over a frequency range of 200 to 5,000 Hz. The human ear does not respond in a uniform manner to different frequency sounds. A sound pressure level of 70 dB will be perceived as much louder at 1,000 Hz than at 100 Hz. To account for this, various weighting methods have been developed to reflect human sensitivity to noise. The purpose of a weighting method is to de-emphasize the frequency ranges in which the human ear is less sensitive. The most commonly used measure of noise level is the A-weighted sound level (dBA). The dBA sound level is widely used for transportation related noise measurements and specifications for community noise ordinances and standards. The dBA has been shown to be highly correlated to human response to noise.

In addition to noise fluctuating in frequency, environmental noise will fluctuate in intensity from moment to moment. Over a period of time there will be quiet moments and peak levels resulting from noisy, identifiable sources (trucks, aircraft, etc.). Because of these fluctuations, it is common practice to average these noise level fluctuations over a specified period of time. The equivalent sound level over a given period of interest, L_{eq}, is widely accepted as a valid measure of community noise. The L_{eq} is equal to the equivalent steady state noise level which, in a stated time period, would contain the same acoustical energy as the time varying noise levels that actually occurred during the same time period. The hourly value of L_{eq}, based upon the peak hour percentage of the annual average daily traffic, is referred to as $L_{eq(h)}$. Surveys have shown that L_{eq} properly predicts annoyance, and this descriptor is commonly used for noise measurement, prediction, and impact assessment.

1.4 Federal Highway Administration Noise Abatement Criteria

The first step in this study is the definition of the criteria for a traffic noise impact. With this definition established, the location of noise sensitive land uses in the vicinity of the Ohio Turnpike can be identified. The Ohio Turnpike Commission is not subject to the policies of the Federal Highway Administration. However, in order to establish a level at which receptor sites may experience a traffic-related noise impact, the federal criteria will be followed as a guideline only. According to the FHWA, a traffic noise impact occurs when the predicted levels "approach or exceed" the FHWA-established noise abatement criteria (NAC) or when a predicted traffic noise level substantially exceeds the existing noise level, even though the predicted levels may not exceed the NAC. This definition reflects the FHWA position that traffic noise impacts can occur under either of two separate conditions: (1) when noise levels are unacceptably high ("absolute level"); or (2) when a proposed highway project will substantially increase the existing noise environment ("substantial increase"). For the purpose of this study, only the "absolute level" will be used to identify noise impacts. "Substantial increase" is used to identify impacts associated with proposed projects and does not apply to this study. The FHWA noise regulations allow individual states to define what level "approaches" the NAC. ODOT has established a definition of "approach" that is 1dBA less than the applicable NAC. The NAC, shown in the following table, has five activity categories. Each activity category lists a Leq(h) that, when met, approached or exceeded, identifies a traffic noise impact. Activity Category A is used for areas such as an outdoor theatre or amphitheatre. Category B is used for most land uses where frequent outdoor use occurs. Category C is used for commercial areas. Category D is for undeveloped areas. Category D (interior) is used for municipal land uses or other land uses having no exterior use.

Table 1.
Noise Abatement Criteria (NAC): Hourly A-Weighted Sound Level in Decibels (dBA)

Activity Category	Leq(h)	L10(h)	Description of Activity Category
A	57 (Exterior)	60 (Exterior)	Lands on which serenity and quiet are of extraordinary significance and serve an important public need and where the preservation of those qualities is essential if the area is to continue to serve its intended purpose.
B	67 (Exterior)	70 (Exterior)	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals.
C	72 (Exterior)	75 (Exterior)	Developed lands, properties, or activities not included in Categories A or B above.
D	--	--	Undeveloped lands.
E	52 (Interior)	55 (Interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.

In developing the NAC, the FHWA attempted to strike a balance between that which is most desirable and that which is feasible. The decibel level upon which the NAC is based is related to interference with speech communication. A relaxed outdoor conversation can be held at decibel levels of less than 67 dBA. Therefore, when determining traffic noise impacts, primary consideration is to be given to exterior areas. Noise mitigation will be considered only where frequent exterior human use occurs and a lowered noise level would be of benefit. For this study, it is assumed that all noise sensitive receptors identified as part of this project fall into Activity Category B. Activity Category E (interior) is only used in rare situations where there are no exterior areas affected by traffic noise. This interior use applies generally to hospitals, libraries and other municipal uses where windows are kept closed almost every day of the year.

SECTION 2.0
NOISE MITIGATION STUDY

Section 2.0
Noise Mitigation Study

2.1 Noise Sensitive Areas (NSA)

The first objective of the mitigation study is to identify potential NSAs along the entire length of the Turnpike. NSAs were identified not only for the purpose of the selection of the pilot program location, but to further identify locations were noise mitigation may prove to be feasible for future noise abatement programs.

A noise sensitive area is described as an area of residential structures, schools, hospitals, or similar land use where increased traffic noise levels could interfere with the use of exterior space. Isolated residential structures and groups of three to four residential structures located at underpass/overpass locations along the turnpike are not considered NSAs. Though these structures may be impacted by traffic noise, it is not cost reasonable to mitigate impacts on single structures or structures separated by existing roadways. The Ohio Turnpike Commission's GIS website and other web-based aerial mapping sites were utilized to identify NSAs located along the turnpike. A total of 67 NSAs were identified, most being located in the vicinity of Toledo and in the suburbs south of Cleveland. Figure 1 shows the location of the 67 NSAs along the turnpike. Figures 2A-2C provides a more detailed location of each NSA including the aerial extent of each NSA, relative land use and numbers and location of receptors within each NSA. The table on the left side of Figure 1 provides additional detail on each NSA. The table indicates the approximate location of each NSA based on the turnpike mile post, the approximate length that each NSA extends along the turnpike (length is also indicative of the minimum length a mitigation measure would extend), the number of receptors located within 500 feet of the turnpike pavement, the relative elevation (at grade being a similar elevation, fill being where receptors are lower than turnpike, cut being where receptors are higher than turnpike) of receptors to the turnpike, and the distance between the turnpike pavement and the closest receptor within the NSA. All of the information was used in the recommendation of potential pilot program locations, which will be discussed further in the report. The consideration of noise mitigation for noise sensitive areas is limited to exterior areas of frequent human use.

2.2 Field Measured Noise Levels

The second objective of the mitigation study is to determine the existing noise levels at each NSA through computer modeling using the FHWA Transportation Noise Model (TNM) Version 2.5. To calibrate the noise model, noise levels were field measured at 12 locations along the turnpike. Noise measurements were recorded at representative locations during the worst hourly traffic noise condition. The worst hour condition occurs at a time when truck volumes are at their highest and vehicle speeds are the greatest, typically when traffic is free-flowing. Noise measurements were performed in accordance with the FHWA Report Number FHWA-PD-96-046, *Measurement of Highway Related Noise* (May, 1996). Measurements were taken at representative receptor sites for fifteen (15) minute intervals. The noise meter was tripod mounted with the microphone at a distance of approximately 4.9 feet above ground level and angled toward the dominate noise source. A foam windscreen was used for all noise measurements. Noise measurements were recorded with a Quest 2900 Type 2 Data Logging SLM. The noise meter continuously measures and records the ambient noise level and integrates these values into a L_{eq} for the duration of the reading. Statistical summaries computed and recorded by an internal microprocessor were printed out for each fifteen minute noise monitoring period. Ambient noise levels recorded at representative receptor sites are listed in the following table.

Table 2.
Field Noise Measurements

NSA	Approximate Mile Post	Location Description	Measured Noise Level L_{eq}
2	51	Next to Mobile Home Closest to Turnpike	77.1
5	57	North Edge of Country Creek Road	57.4
17	62	North End of Rosedale Street	69.5
23	70	East End of Lakeview Drive	61.1
24	140	South End of Lancer Drive, East of Plaza	74.8
28	147	South End of Vermont Road	74.8
40	158	Merrimak Drive Cul de Sac	63.9
49	166	East of Apartment Complex-Royal Park Drive	66.8
53	184	North Side of Glen Echo Drive	59.0
56	188	North Side of Navaho Trail	62.1
61	216	East End of Pike Drive	69.0
66	228	West End of Mercedes Place at Apartment Complex	69.9

Figures 2A-2C provides a more detailed location of each noise measurement location. During each of the ambient noise measurement periods, simultaneous data including traffic volume, speed, and vehicle composition were collected. These data were imputed into TNM V2.5 to calibrate the measured noise level with the modeled noise level at each representative site.

Noise Measurement along Turnpike at NSA 2

Field Measurement at Residential Neighborhood at NSA 23

2.3 Predicted Existing Condition Traffic Noise Levels and Noise Impacts

Traffic noise levels and potential noise impacts were evaluated at each NSA along the Turnpike through the use of the FHWA TNM Version 2.5. Traffic data used in the model was provided by the OTC and is reproduced in Appendix B. The data provided traffic volumes between turnpike exits and was further broken down into vehicle mix including automobiles, medium trucks and heavy trucks. A simple noise model was run for each section of Turnpike (between exits) to estimate the existing traffic noise levels at various distances from the roadway in at-grade, cut and fill scenarios. The model was refined to determine the distance from the Turnpike where the noise level would be 66 dB (the NAC Category B impact level) for all three elevation scenarios. Any receptor site located within the roadway and the 66 dB isoline was considered and impacted receptor site. As an example, NSA 1 is an at-grade residential neighborhood located near mile post 48. A noise analysis using the traffic volumes and vehicle mix between exits 39-58 was run and determined that the 66 dB isoline was located at a distance of 305 feet from the roadway. In NSA 1 there are a total of 68 individual receptors located within 305 feet of the roadway so it was assumed that 68 receptor sites could be experiencing traffic noise levels above the Category B NAC. This procedure was completed for each NSA along the length of the turnpike to estimate the potential number of impacts per NSA. The number of potentially impacted receptors located in each NSA is shown in Table 3 and will be discussed as part of the pilot program location in Section 3.0.

SECTION 3.0
REVIEW OF INNOVATIVE NOISE MITIGATION MEASURES

Section 3.0
Review of Innovative Noise Mitigation Measures

A literature review of noise mitigation materials and techniques was conducted to identify innovative noise mitigation designs that have been proven successful in the United States and in other countries. The comprehensive literature review included research reports, technical papers, journal articles, conference proceedings, and websites documenting mathematical calculations of noise reduction benefits, experimental field applications and practical use of innovative designs and materials for noise mitigation. Discussions were held with vendors representing innovative noise abatement measures. A discussion was also conducted with Mr. Elvin Pinckney, Noise and Air Quality Coordinator with the Ohio Department of Transportation to see what innovative mitigation methods have been used or are being considered for use in the state of Ohio and what limitations some innovative measures may have. When traffic noise impacts are identified the following noise mitigation measures are generally considered:

1. Traffic management measures;
2. Alteration of horizontal and vertical alignments;
3. Acquisition of real property to serve as a buffer zone to preempt development which could be adversely impacted by noise;
4. Noise insulation of public or nonprofit institutional structures; and,
5. Construction of traditional concrete noise barriers.

None of the above, traditional mitigation measures are realistic options for noise mitigation along the Ohio Turnpike. Traffic management measures such as limiting the hours of usage by truck traffic or reducing the existing speed limits is not a feasible or reasonable mitigation measure for a commercial interstate highway such as the turnpike and altering the physical alignment of an existing highway is not feasible. Most of the impacted sites along the turnpike consist of residential homes adjacent to the roadway where noise insulation is generally not considered. No land is available to serve as a buffer zone and noise insulation is generally not provided to privately owned property. Noise barriers, typically pre-fabricated concrete, have been used by the FHWA for over 30 years to reduce traffic noise levels for highway-adjacent residential areas. As traffic volumes and speeds have increased on highways, noise levels have raised prompting agencies to look at more innovative noise attenuation at a reasonable cost.

Noise abatement measures generally fall into three categories: 1) Noise control at the source – consisting of low noise pavement, traffic management measures, low noise tires and vehicles and driver behavior; 2) noise control at the receiver in the form of sound insulation and land use planning; and, 3) Noise control along the source/receiver pathway in the form of a noise barrier of some type. The following noise mitigation measures were evaluated as part of the project;

- Quiet Pavement Technology
- Noise Insulation and Land Use Planning
- Innovative noise barrier designs and treatments involving noise absorption technology and acoustical treatments such as curved and angled tops as well as T-top and Y-top treatments combined with noise absorption technology.
- Noise absorption treatments for the existing median concrete barrier
- Natural barriers including vegetation and soil mounds

3.1 Quiet Pavement Technology

The cause of traffic noise is generally the result of three main components: tires interacting with the pavement surface; engine (power train); and, engine exhaust. Research indicates that most highway noise is caused by the tire/pavement interaction as heard by the characteristic whine or high pitched hums. Depending on atmospheric conditions, tire noise can be heard for miles. According to the California Department of Transportation (CALTRANS), the average light vehicle at freeway cruise speed, tire/pavement noise accounts for 75 to 90 percent of the overall noise energy. What this means is that if the noise level at the pavement can be turned down, the overall traffic noise levels will also drop. Several pavement types may be utilized to reduce noise at the source (tire noise) as opposed to the traditional noise abatement measure of modifying the pathway of the noise via a noise barrier wall. It has been shown that modification of pavement surface type and/or texture can result in significant tire/pavement noise reductions. North American and European highway agencies have found that the proper selection of the pavement surface can be an appropriate stand alone noise abatement procedure. Specifically, they have identified that a low noise road surface can be built while at the same time considering safety, durability and cost using one of the following approaches:

- A surface with a smooth texture using small aggregate material.
- A porous surface, such as an open graded friction course (OGFC) with a high air void content.
- A pavement-wearing surface with an inherent low stiffness at the tire/pavement interface.

Pavement types can be classified as either rigid or flexible and both types' exhibit different audible effects resulting from the tire/roadway interface.

3.1.1 Rigid Pavements

Portland Cement Concrete (PCC). Rigid pavements are so named because the pavement structure deflects very little under loading. PCC has a very hard, dense surface that is highly reflective of roadway noise. All PCC pavements use purposefully placed discontinuities known as contraction or expansion joints which further increase tire noise. Worn PCC pavements with deteriorated joints make a clapping noise as vehicles pass by resulting in high levels of annoyance to nearby residents. Tining is the creation of shallow channels in a concrete roadway to enhance weather traction of an otherwise smooth surface. While tining is sometimes necessary for safe driving conditions in wet weather, it does affect roadway noise. Transversely tined PCC surfaces are grooved perpendicular to the direction of traffic movement. Transverse tined PCC pavements also tend to increase high frequency noise by nearly 50% compared to non-tined PCC and is generally considered one of the loudest pavement types. Two types of tining methods will often be used that have noise-reducing benefits. The Colorado Department of Transportation (CDOT) has conducted several studies that look at different ways of applying tining. The results show that some tining patterns, including longitudinal tining, can help produce lower levels of pavement noise. Through various studies, it has been demonstrated that longitudinal tining is quieter than transverse tining and is, thus, the standard tining pattern of choice. In CDOT's inventory of pavement type, it was discovered that noise levels in a concrete roadway with longitudinal tining only increased by one decibel over several years, which is below the level that the human ear can distinguish. Diamond grinding PCC pavements provides a very smooth pavement with less tire friction and noise. Diamond grinding PCC pavement with a longitudinally tined surface results in the quietest PCC roadway with generally a 3 dB reduction in noise levels compared to non-surface treated PCC.

Transverse tinned PCC

Longitudinally tinned PCC

3.1.2 Flexible Pavements

Densely-Graded Asphalt (DGA). The most common type of flexible pavement surfacing used in the U.S. is hot mix asphalt (HMA). HMA is known by many different names such as hot mix, asphalt concrete, asphalt, blacktop, or bitumen. HMA is distinguished by its design and production methods and includes traditional dense-graded mixes. DGA has a texture that is similar in all directions, is well graded and intended for general use. DGA pavements are semi-porous in nature due to the use of various grades of pebbles and sand in the mix. Void space is generally around 8% and the porous nature of the pavement reduces roadway noise. The sound absorption effect can be better understood if we assume that air pumping is the predominant cause of road/tire noise. Gaps in the tire tread allow some lateral air drainage that reduces air pumping. With a porous surface, vertical air drainage is also possible. This vertical air drainage into the pavement surface effectively prevents the occurrence of air pumping by the tire treads and results in reduced road noise. Generally, a higher percentage of pavement void space results in lower roadway noise. Typical DGA pavements with a void space of around 8% are 3 to 4 dB quieter than PCC pavements at the time of construction. Decibel levels of DGA pavements increase over time as the surface wears and the pore spaces become clogged with road debris.

Typical DGA surface

Stone Matrix Asphalt (SMA). A standard pavement type that the Colorado Department of Transportation (CDOT) often uses is SMA which is also known as stone mastic asphalt. SMA is a gap graded HMA originally developed in Europe to maximize rutting resistance and durability. The design goal of this pavement type was to create a stone-on-stone (aggregate) contact within the mixture. Since aggregates do not deform as much as the asphalt binder used under load, this contact reduces rutting. SMA is generally more expensive than a typical DGA because it requires more durable aggregates, higher asphalt content, modified asphalt binder and fibers. In the right situations it is cost-effective because of its increased rut resistance and improved durability. SMA, has been used for surface courses on U.S. interstates since about 1990. Other reported benefits include better drainage and wet weather friction due to its coarser surface texture, reductions in glare, less severe reflective cracking and lower tire noise than typical DGA mixes. In CDOT's pavement noise inventory, it was determined that SMA has a slightly lower initial noise level than DGA, but as the pavement aged, the noise levels did not increase as quickly.


Typical Stone Matrix Asphalt surface.


Stone Matrix Asphalt Lab Sample

Open Graded Asphalt (OGA). Open graded refers to a gradation that contains only a small percentage of aggregate particles in the small range. This results in more air voids because there are not enough small particles to fill in the voids between the larger particles. Unlike DGA and SMA, an OGA mixture is designed to be water permeable. The majority of quieter pavement designs use a "negative texture," and the most common of these is the open graded friction course. OGA is used for surface courses only. OGA reduces tire spray in wet weather and typically result in smoother surfaces than a DGA mixture. An OGA has a high percentage of small air voids in the pavement that provides a sound absorbing negative texture. The OGA pavement differs from traditional dense-grade asphalt by having much higher air voids. Typical dense-grade asphalt pavement has air voids that begin at eight percent and decrease over the life of the pavement to approximately four percent. OGA start with air voids from 10 to 22 percent and has little decrease over the life of the pavement. According to the National Asphalt Pavement Association, most modern OGA have air voids in from 15 to 22 percent.

Typical Open Graded Asphalt Friction Course Surface

In British Columbia, Canada, a 1.6 km stretch of Highway 19 was paved with OGA and monitored for traffic noise reduction. In the early stage of the study, newly laid pavement was found to reduce traffic noise by 4.1 dB based on before and after pavement measurements. The OGA was further found to reduce traffic noise by 4.9 dB when compared to the conventional dense graded asphalt pavement of a control site. After three years of service, the OGA continued to reduce traffic noise in the range of 3.5 and 4.0 dB. The study also found that there was no consistent trend toward decreasing pavement performance and there was no undue physical wear or deterioration of the pavement (rutting, raveling or reduction in surface porosity by dirt and sand) over the first three years of service. The study concluded that the durability of the OGA paved section of Highway 19 compared favorably with that of standard asphalt pavements.

The OGA pavement structure, due to the lack of "fines", is permeated with tiny interconnected voids so that, under most conditions, it is sufficiently porous to permit excess water to enter its surface and drain away to the sides of the road. With this characteristic, OGA has been used to promote surface drainage, eliminate hydroplaning, and improve skid resistance and overall driving safety. An adverse characteristic of OGA pavement is the difficulty of removing ice or hard-packed snow. OGA is more expensive per ton than dense-graded HMA, but the unit weight of the mix when in-place is lower, which partially offsets the higher per-ton cost. The open gradation creates pores in the mix, which are essential to the mix's proper function. Anything that tends to clog these pores, such as low-speed traffic, excessive dirt on the roadway can degrade performance.

A section of the Ohio Turnpike was resurfaced with OGA friction course in 1993. The section of turnpike from mile post 170.5 (just west of Broadview Road) to mile post 172.4 (just east of Brecksville Road). Though this section of turnpike did exhibit a general decrease in traffic noise level, it also presented a problem with ice and snow removal. An OGA friction course has greater surface area (due to the numerous voids) than traditional DGA and as a result will freeze quicker. There were a disproportionate number of ice-related accidents and vehicle slide offs along this section of turnpike compared to other sections of the turnpike. In addition to the icing problems, the OGA pavement was less durable having a tendency to ravel. The OGA section of pavement proved to be high maintenance and somewhat unsafe compared to other sections of the turnpike and the OGA friction course was removed and replaced with a DGA friction course only six years later in 1999.

<u>Porous Asphalt (PA)</u> Porous asphalt mixes made with hard aggregates, a modified asphalt binder and stabilizing fibers are widely used. The structure of a porous asphalt surface contains interconnected voids,

which can drain away rainwater during wet weather. The porous structure can also reduce tire/pavement noise by interfering with some noise generation mechanisms. Porous pavements have also proven to be durable, to possess good surface friction and to decrease splash and spray during rain events. PA mixes were found to be rut-resistant, skid-resistant and noise reducing. PA has a longer history in Europe and their experience is valuable in determining the benefit of quiet pavements as an alternative method in reducing highway noise. Single-layer porous asphalt has been implemented in the Netherlands, France and Germany. Though noise is a regulated property in these countries, pavement performance is a high priority and life-cycle costs determine the use of most noise abatement remedies. Single-layer porous asphalt consists of a 30 to 40 mm thick gap-graded mix with 20 to 30 percent air voids. It provides a 3 to 5 dBA noise reduction. The construction cost of single-layer porous asphalt is about 10 to 25 percent more than conventional dense-graded asphalt and typically lasts 8 to 10 years.

Two-layer porous asphalt has been implemented in Denmark, France and Italy and is in the developmental stage in the Netherlands. Two-layer porous asphalt in Denmark is designed to use about an inch of 1/8- or ¼-inch top size aggregate mix as a filter layer and about 1.75 inches of ½-inch top size aggregate in the lower layer for drainage. Noise reduction with two-layer porous asphalt is 8 or 9 dBA quieter than conventional asphalt mixes and 4 dBA quieter than single-layer porous asphalt. The mix for a two-layer porous asphalt system usually contains an average of 20 percent voids. The typical binder contents are 5.7 to 6.0 percent based on aggregate weight. Construction costs of a two-layer porous asphalt system are typically 25 to 35 percent higher than conventional costs. The second layer of the two-layer system should be placed while the first course is still warm and tack coats are essential. The pavement life of two-layer porous asphalt is 8 to 10 years.

Denmark has completed three case studies in which they compared the cost of PA, noise barriers, and sound insulation for various road categories including divided freeway. They concluded, “Compared to noise barriers and façade insulation, porous asphalt gives a much higher noise reduction per invested Euro.” However, they also added this disclaimer: “The test section is only 3 years old, and it therefore is still to be proven that the pavement can maintain the noise reduction throughout its entire lifetime.”

Examples of two-layer porous asphalt

In The Netherlands, a recent comparison test of dense asphalt concrete, single-layer PA, two-layer PA, and thin top layer (Microflex 0/6). The two-layer PA was 4 dB quieter at all speeds tested (20–80 mph) than the thin layer Microflex and the single-layer PA. At high speed (80 mph), the two-layer PA was 9 dB quieter than conventional dense graded asphalt. Therefore, the two-layer PA could be an excellent alternative to noise barrier walls on an interstate highway system where traffic speeds are higher and sound reduction the greatest. Even with the additional expense of a two-layer system, costs are about 50 percent less than that of noise barrier walls.

Eight roadway test sections of single and two- layer PA was completed in France. The test sections varied from ~4-7 dB in noise reduction compared to dense asphalt concrete. The average two-layer reduction was about 6 dB for both light and heavy vehicles. Listed are the pavement types evaluated and their corresponding reduction from the reference dense asphalt concrete:

1. single-layer porous, 3.5 dB,
2. two-layer 2-8mm top layer chipping, 5-6 dB,
3. two-layer 2-6mm top layer chipping, 6-7 dB, and
4. two-layer 4-8mm top layer chipping (normal 2-layer type), ~6 dB.

The French test sections were performed on pavement aged 1-5 years, with two sections aged 6 and 7 years. There was no appreciable decrease in noise levels due to the difference in pavement age. There was shown to be an increase in noise level of approximately 1 dB over 5 years. The noise levels for dense asphalt concrete did increase by approximately 3 dB over the course of 6 years; one data point at 7 years showed an additional 0.8 dB increase. The test indicated a need for additional research on noise levels in regard to pavement aging.

Single layer and two-layer PA has a similar characteristic to OGA in that the numerous void spaces in the friction course have a tendency to freeze very quickly. Winter weather driving can be somewhat more hazardous with this type of pavement if deicing agents are not applied quickly. PA has a higher level of winter maintenance compared to other asphalt surfaces as deicing agents must be applied prior to freezing and more frequently than on other pavements.

<u>Asphaltic Rubber Concrete (ARC).</u> Asphalt rubber concrete pavements include at least two types of flexible pavement surfacing made with asphalt rubber cement as the binder, stone mastic and open-graded mixtures. The asphalt rubber binder generally contains 15-25 percent recycled scrap tire rubber blended with standard paving grade asphalt cement. Asphalt rubber concrete pavements are applicable to virtually any flexible pavement surfacing requirement, providing such performance benefits as reduced temperature susceptibility, reduced low- temperature cracking potential, reduced high temperature deformation distress potential, reduced age-hardening potential, and reduced binder-aggregate stripping potential. ARC has been in use in the US since the mid 1980's and has proven to be an environmentally friendly alternative to conventional asphalt pavement. ARC has many reported benefits that distinguish it from conventional asphalt pavements including reduced roadway noise. Beginning in 2002 and carrying through 2006, several test roadways in Alberta, Canada were paved with ARC. ARC mix designs are based on a method-based specification used by the Arizona Department of Transportation. This specification requires the use of finely ground rubber crumb blended with asphalt cement and aggregate to produce the ARC mix. The

primary assumed mechanism behind lower road noise on ARC paved surfaces is the porous surface texture of the finished product.

As noted above, ARC has a very coarse and open appearing surface texture, similar to SMA mixes. This porous texture appears to absorb sound energy radiated from the engine, exhaust, and tires. Test cases have shown that the sound absorption co-efficient (α) is much greater for a porous textured pavement like ARC than for a conventional dense graded asphalt concrete. The amount of time that ARC will remain a source of noise reduction is dependent on several factors – the most important is clogging of the surface pores. The use of road salt and salt/sand mixtures for de-icing in winter can result in the clogging of the ARC surface pores. Tests have shown that a decrease in noise reduction of about 2 dBA can result from clogging. It is not yet clear if clogging has had a direct effect in the Alberta pavement test. The exact mechanisms and their quantifiable effect on reduced road noise have not yet been proven, although research is ongoing. Similarly, the length of time that ARC can effectively reduce road noise has also not been conclusively established. A road noise test at one of the Alberta locations was performed shortly before and after paving with ARC in 2002 and once per year since then.

Road Noise Reduction Data

Test Year	Noise Reduction (dB)
2002	6.9
2003	6.7
2004	4.9
2005	4.7

As can be seen, the dB reduction in 2005 of 4.7 dB is still readily perceptible to the average human ear. The noise reduction value for 2005 is roughly the equivalent of being twice as far away from the sound source. By comparison, conventional asphalt concrete pavement placed at the same time as the ARC had a noise reduction of only 2.4 dB, which is just barely perceptible to the human ear.

In addition to the questions regarding the effectiveness of asphalt rubber, other concerns include cost, placement temperature, safety, and long term noise abatement. The unit costs of asphalt rubber mixes can range from 60 to 80% higher than those of conventional dense graded hot mix, making ARC one of the most costly asphalt products.

3.1.3 Evaluating the Various Pavement Types

Pavement Life Pavement deterioration occurs at an accelerated rate over time. The four major components of pavement degradation (premature or otherwise) are sunlight and oxidation, water infiltration, deficient pavement thickness and/or subgrade strength and fuel and oils.

Typically, the useful life of a hot mix asphalt pavement system is between twelve (12) and fifteen (15) years. However, the actual useful life of a pavement system varies based upon many variables. Asphalt thickness, subgrade conditions, surface porosity and existing drainage conditions will dictate the economic useful life of a pavement system.

Construction Normal construction equipment and technology are used to construct all types of ridged and flexible pavements evaluated as part of this study. Construction of the 2-layer porous asphalt system should be placed "warm-on-warm" — not allowing cooling of the first layer and eliminating the tack coat.

Maintenance There are still minor but persistent disagreements about effective maintenance of open graded and porous pavements. Although some countries require pressure washing and vacuuming of the pavements at least twice each year, other countries contend that the practice may not only be useless, but perhaps even harmful. There was no reliable data identified that could be used to substantiate either claim. Winter maintenance is higher, especially on the highly porous pavements. Winter maintenance relies on advanced use of pre-wetted salt to fight formation of "black ice" on the highly porous pavements resulting in a winter maintenance cost increase of 25-50 percent. Friction materials such as sand and other grits are not used on PA or ARC. Some countries have discontinued using highly porous pavements in snow and ice regions and instead are using SMA-type pavements with small aggregate. The primary failure mode for porous mixes is raveling. Raveling has been associated with the gap grading, and 7–10 percent sand mortar is now used to resist raveling.

Studies performed by the National Center for Asphalt Technology tested approximately 244 pavement surfaces in ten states. The test included 43 portland cement concrete surfaces (PCC) and 201 Hot Mix Asphalt (HMA) surfaces. HMA materials were comprised of Open-Graded Friction Course (OGA), Novachip, Microsurfacing, Stone-Matrix Asphalt (SMA) and dense graded asphalt (DGA) surfaces. Using PCC as a baseline, the study determined tire/pavement noise reductions with the following HMA pavements:

- OGA is modified with crumb rubber of fine and coarse gradations.
  Fine gradation resulted in a noise reduction of 7 dB.
  Coarse gradation resulted in a noise reduction of 6 dB.
- The Novachip process places an ultra-thin, coarse aggregate with a polymer-modified asphalt binder over a special asphalt membrane.
  Novachip surface resulted in a 5 dB noise reduction.
- Micro-surfacing is a mixture of quick setting polymer-modified asphalt binder, aggregate, water and mineral filler mixed into a slurry and placed onto existing pavements.
  Micro-surfacing resulted in a 4.5 dB noise reduction.
- SMA is a gap-graded HMA designed in Europe to maximize rutting resistance and durability. The aggregates do not deform as much as the asphalt binder and the stone-on-stone contact provides a highly rut resistant mix.
  SMA resulted in a 5 dB noise reduction.
- Dense Graded Asphalt contains well-graded aggregates intended for general use applications.
  DGA with fine aggregate size resulted in 6 dB noise reduction.
  DGA with coarse aggregate size resulted in a 3dB noise reduction.

France has been using thin, gap-graded HMA pavements for several years. They can lower noise levels by 6 decibels as compared to dense-graded HMA pavement. France is also using single-layer porous HMA pavements, which can lower noise by 6 to 9 decibels as compared to dense-graded HMA pavements. Italy, meanwhile, has been using porous asphalt mixes since the late 1980s to reduce highway noise. Italy has found that a properly designed porous mix can achieve a life performance that is 80 to 90 percent of that achieved with a dense-graded mix. As the United States looks at using quieter pavements, cost is also a factor. Quiet pavements in Europe tend to cost about 10 to 25 percent more than traditional pavements.

Any of the above described quiet pavements may be installed as a wearing surface or friction coat over existing pavement.

3.2 Noise Insulation

In some situations, the overall effects of controlling noise at the source and/or limiting its propagation are not sufficient methods of noise control. Another mitigation measure, noise insulation, can reduce noise impacts within buildings. Sound insulation in buildings, in the form of replacing windows and doors, providing central ventilating systems, and adding insulation to attics, are only considered for public buildings and nonprofit institutional structures on a case-by-case basis. When the noise reduction is to be provided by the building enclosure it is essential that all possible paths for the transmission of sound are considered. However, there would still be lifestyle limitations to persons living at the site because sound insulation can only provide a satisfactory acoustic environment within the building, not outside. Patios, decks, swimming pools, and other areas of frequent outdoor use will still be subjected to noise. For example, windows cannot be opened to provide natural ventilation without reducing the sound insulation.

Federal and state noise policies have been established to provide noise abatement at exterior areas where frequent human activity occurs. As an example, ODOT will only use noise insulation for public use and nonprofit institutional structures when other forms of abatement (noise walls) are found to be not reasonable or feasible. It is ODOT’s policy to not spend state money on noise abatement for private residences outside of state right-of-way. Therefore, sound insulation of private residences is typically not an abatement option. Participation in the noise insulation of private residences is allowable only in extraordinary situations where severe traffic noise impacts exist or are expected, and normal abatement measures are physically infeasible or economically unreasonable. When considering extraordinary abatement measures, it must demonstrated that the affected activities experience traffic noise impacts to a far greater degree than other similar activities adjacent to highway facilities. None of the receptor sites located along the turnpike are expected to experience severe or extraordinary noise impact.

3.3 Land Use Planning and Controls

The Federal Government has essentially no authority to regulate land use planning or the land development process. However, the prevention of future impacts is one of the most important parts of noise control. The compatibility of a highway and its neighbors is essential for the continuing growth of local areas. Both development and highways can be compatible. But, local government officials need to know what noise levels to expect from a highway and what techniques they can use to prevent future impacts. States can help by providing this information to local governments; such information should be made available for disclosure in real estate transactions. Highway traffic noise should be reduced through a program of shared responsibility. Thus, the FHWA encourages State and local governments to practice compatible land use planning and control in the vicinity of highways. Local governments should use their power to regulate land development in such a way that noise-sensitive land uses are either prohibited from being located adjacent to a highway, or that the developments are planned, designed, and constructed in such a way that noise impacts are minimized.

Some State and local governments have enacted legislative statutes for land use planning and control. As an example, the City of San Antonio’s subdivision plats’ state “For residential development directly adjacent to State right of way, the Developer shall be responsible for adequate set-back and/or sound abatement measures for future noise mitigation." The City of Gilbert, Arizona places on their plat a note stating "This property could experience noise from the freeway." In Texas, noise analyses for proposed projects present noise contour lines that establish areas of noise impact based on design year noise levels. In the noise analysis, TxDOT states that any future development that is located within the impact area should expect traffic noise impact and that TxDOT will not be responsible for providing any future noise mitigation for any new development. Although other States and local governments have similar laws, the entire issue of land use is extremely complicated with a vast array of competing considerations entering into any actual land use control decisions. For this reason, it is nearly impossible to measure the progress of using land use to control the effects of noise.

3.4 Innovative Noise Barrier Walls

The 2006 FHWA report, *Summary of Noise Barriers Constructed by December 31, 2004*, shows that in terms of square feet constructed, use of concrete noise barriers far exceeds that of any other material. Concrete barriers are built primarily of precast concrete, although concrete block has also been used as a low cost alternative, particularly in California. Between these two types, 100 million square feet of noise barrier had been constructed in the United States as of the end of 2004. Another 14 million square feet of unspecified concrete barrier has also been constructed. The area of wood barriers built by 2004 is a distant second to concrete with only 13 million square feet, while unspecified metal barrier square footage was third with only 4 million. It is likely that some of the area of absorptive material used is of metal. Most state DOTs have banned the use of some material products including vegetation, shotcrete/gunite on chain link fence, and timber products. The materials with which states most frequently reported problems were timber (wood products), precast concrete, and proprietary materials. For timber products, the most frequently cited problems were warping, rotting, weathering, and ultraviolet (UV) degradation. Problems reported for proprietary materials were: lack of material replacement parts, weathering, rusting, warping, and spalling. In general noise barriers can largely be categorized as either reflective or absorptive.

The following table presents barrier wall costs based on an inquiry of 30 vendors presented in the document *Guidelines for Selection and Approval of Noise Barrier Products* National Cooperative Highway Research Program Project 25-25, Task 40 July 2008.

Table 3.
Noise Barrier Material Types

Material Type	Reflective/Absorptive	Generalized cost range per sq. ft.
Precast Concrete	Reflective	$16 to $19
Precast Concrete	Absorptive	$10 to $23
Machine Made Concrete Block	Reflective	$12
Metal	Reflective	$10 to $40
Metal	Absorptive	$10 to $40
Wood	N/A	No Products Used

To be considered absorptive, traditional absorptive concrete noise barriers must be designed so that the absorptive portion on the highway side has a minimum noise reduction coefficient of 0.70 when measured in accordance with the requirements of ASTM C423-08 (ASTM, 2008a). While barrier durability is important, so is the acoustical performance. To be effective, regardless of the barrier material, noise barriers should provide a transmission loss of at least 23 dB(A) when tested in accordance with the requirements of ASTM E90-04 (ASTM, 2004a) using the typical truck noise spectrum and should have vibration-free joints and fittings. To aid in preventing the transmission of noise through the barrier, the design should minimize or eliminate gaps or openings. Traffic noise barriers made of other than concrete components must meet the noise reduction coefficient and transmission loss of concrete noise barriers to be considered equally effective in reduction traffic generated noise.

3.4.1 Traditional Noise Barrier Walls

There are numerous manufacturers of traditional noise barrier walls and each manufacture has their own proprietary design for improved noise reduction. AcoustaCrete, a sound-absorptive concrete noise barrier from Faddis, is porous concrete with a noise reduction coefficient of 0.8 to 1.0. The wall resists damage from rapid freeze-thaw cycles and salt scaling due to its free-draining open-cell structure and wood-fiber reinforcement.


AcoustaCrete


Quietwall

Carsonite International's QuietWall is a fiberglass-reinforced polymer sound barrier system that reduces noise and light pollution along highways. The product's extremely light weight, only 7.5 pounds per square foot, makes it quick and easy to install, and easy for DOT maintenance crews to repair when panels are damaged by vehicle impacts. No heavy equipment is required. The lightweight system can also be placed on bridges and overpasses without additional structural support. The barrier withstands harsh weather and corrosive elements, is naturally fire resistant, is available in heights up to 28 feet, and comes in virtually any color or color combination.

The Whisper-Wall from Concrete Precast Systems is a sound-absorbing wall that cuts down on reflected sound. The wall is a blend of select aggregates, cement, recycled rubber tire chips, and additives. The sound-absorbing mixture is placed into formliners that create the brick, stone, or other design on the wall surface. The surface is then stained. The wall's durability and performance is not affected by prolonged exposure to moisture, according to the company.


WhisperWall


Quilite System

Quilite's noise barrier system is designed to reduce noise while maintaining light transparency. Corrugated on both sides, the panels merge noise-cutting with light-transmitting aesthetics. According to the company, lab and field tests on the barrier rated noise reduction at 60 to 80%, and light transmission at 80%. The barrier is a modular post and panel system, is easy to install, and requires virtually no maintenance.

3.4.2 Alternative or Innovative Noise Barrier Walls

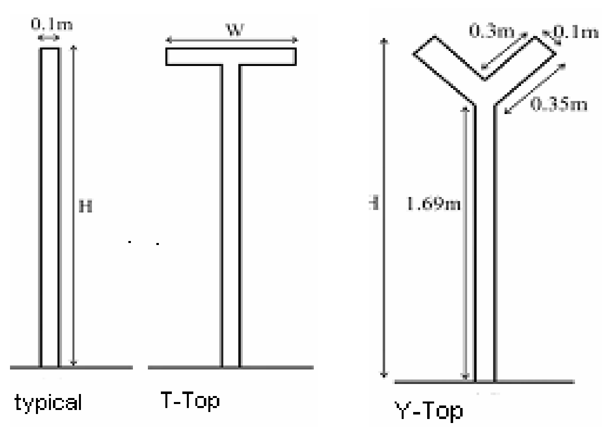
The effectiveness of a typical noise barrier wall of given height may be increased by bringing the diffracting edge nearer to the source of noise - thus increasing the path difference. Where a tall barrier is placed near a highway, tilting the upper section towards the source can provide additional benefit. Increasing the number of diffracting edges on the top of a noise barrier wall can also improve attenuation considerably. The following section discusses the trend in Japan to modify the typical flat top of a noise barrier, disrupting the transmission of noise across the top of the barrier thereby reducing the level of noise at receptor sites without raising and sometimes lowering the height of a traditional noise barrier.

<u>Innovative Top Treatments to Traditional Noise Barriers</u> As traffic volumes and speeds have increased on highways, noise levels have risen for nearby homes, prompting transportation agencies to look for ways to provide more effective noise attenuation at a reasonable cost. Much of the available research focuses on various treatments for the top edge of the barrier. The intent is to alter the hard linear edge that causes diffraction of sound toward receivers behind the barrier. Some of the earliest research on modified top noise barriers in Japan identified that a T-profile top edge noise barrier wall reduced noise levels in a residential area behind the barrier by 1.0 to 1.5 decibels (dBA), compared with a conventional vertical barrier of the same height. Later studies confirmed the benefits of a T-profile top edge in reducing noise levels, even when compared to variations such as Y-profile and arrow-profile barriers. More recent research into T-profile barriers in the Netherlands has shown that adding an absorptive material to the top horizontal section of the T-profile barrier further increases the noise reduction properties of the barrier. The research showed noise reductions of 2 to 3 dBA at a cost similar to raising the barrier by 3 feet, but did not have the implications for the wall foundation as raising the height of the wall.

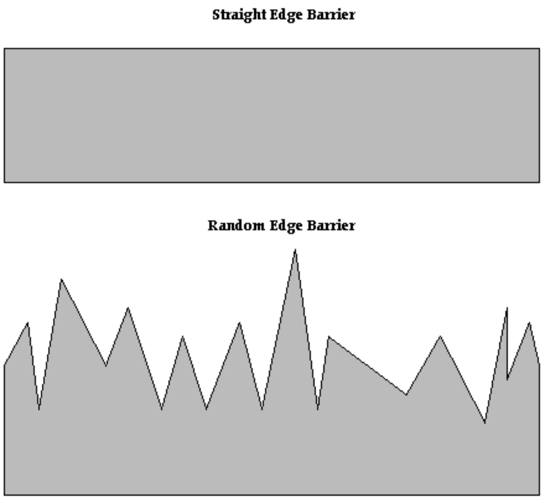
<u>T-Top and Y-Top Barriers</u> The Arizona Department of Transportation (ADOT) has performed an evaluation to identify innovative noise barrier top designs that had potential to be implemented in Arizona. Innovative noise barrier designs and treatments have been successfully implemented in other states and in other countries for a number of years. These innovative designs have allowed the initial construction of a noise wall to be lower in height than a conventional wall. Many of the barrier designs consisted of treatments to the top edge of the barrier to change or disrupt the diffraction pathway from the noise source to the

receiver. The results of the previous research studies were compiled into a matrix to assist in evaluating the various barrier designs and materials. The evaluation matrix was used to score the barrier designs based on their acoustic performance, as well as economic, constructability, maintenance, and aesthetic considerations. The scores were weighted based on the potential reduction in barrier height. The evaluation matrix revealed that the designs with the most potential were a T-top barrier design with absorptive material on the top and a barrier with absorptive material applied to the roadway side or face of the barrier. The T-top barrier design consists of a vertical barrier with a horizontal cap along the top edge of the barrier, creating a shape that resembles a "T." The horizontal portion of the barrier is approximately 2 to 3 feet wide and creates a double-diffraction pathway over the top of the barrier, thereby reducing noise levels compared to a vertical barrier of similar height. To increase the noise reduction potential of this barrier design, an absorptive material is applied to the top of the horizontal portion of the barrier. Research has shown that this barrier design reduces noise levels by about 2 to 3 decibels, which could reduce barrier heights by approximately 4 to 6 feet, or about 5 feet on average.

A Y-top barrier design consists of a vertical barrier with a horizontal cap along the top edge of the barrier, creating a shape that resembles a "Y." The horizontal portion of the barrier is approximately 1.5 to 2 feet wide and, similar to the "T" top design, creates a double-diffraction pathway over the top of the barrier, thereby reducing noise levels compared to a vertical barrier of similar height. Research conducted by the Arizona Department of Transportation has found that this barrier design has the potential to reduce barrier heights by about 2 to 5 feet, or about 3.5 feet on average. Noise barrier walls with the Y-top design were shown to reduce noise levels by about 1 to 3 decibels over a traditional flat-top noise wall design. The Y-top design has a tendency to accumulate debris within the Y section resulting in additional maintenance cost to clear the debris. The application of this barrier design may be most appropriate in locations with a parallel barrier situation, or when the noise barrier is located in close proximity to highway traffic. Based on the research and evaluation conducted for this study, a T-top design with absorptive material placed on the top of the horizontal portion of the barrier could reduce overall barrier heights by as much as 3 to 5 feet compared with a conventional noise barrier of concrete or masonry block construction. A diagram of a typical wall cross section, a T-Top wall section and a Y-Top wall section is shown below for comparison purposes.



Jagged Edge-Top Barrier In the late 1990s and early 2000s, several researchers examined the potential noise reduction created by replacing the linear top edge of a noise barrier with a jagged or irregular top edge. The results were mixed, with some researchers demonstrating as much as 6 dBA reduction in noise levels. However, two research teams identified that at lower frequencies, the jagged edge barrier design provided minimal benefit. The poor low frequency performance was unexplained and led one research team to conclude that there was no benefit in using the jagged top edge design for highway noise barriers. A diagram of a typical straight top edge barrier and a random edge of jagged edge-top barrier is shown below for comparison purposes.



Cylindrical Edge-Top Barrier The earliest research in this sub-area of innovative noise barrier designs occurred in Japan. Here, researchers examined acoustically hard and absorptive cylinders along the top edge of an existing noise barrier. Field tests of the two cylinder attachments showed that the absorptive cylinder provided 2 to 3 dBA more attenuation compared with a conventional noise barrier, which translated into about a 6.5 feet of comparable noise barrier wall height. Subsequent research in Japan compared the absorptive cylinder with an absorptive mushroom-type attachment. The mushroom-type design was constructed with absorptive materials and was applied as a retrofit application to the top edge of existing noise barriers. CALTRANS applied a similar mushroom-type design along a noise barrier wall near Los Angeles and showed the application, with an effective height of 1.5 feet, provided the same noise reduction as 2.0 to 3.5 feet of additional barrier height. In regards to differences in elevation, Japanese researchers conducted field applications along two expressways in Japan, resulting in negligible reductions along a depressed (cut) section of roadway, but found an approximate 1.8 to 2.3 dBA reductions along an elevated (fill) section of roadway.

3.5 Sound Absorptive Materials - Acoustic Panels

Noise Barriers reduce noise levels either by absorbing sound energy or by reflecting sound energy. Both methods work, however, sound absorption is more efficient and less likely to produce unexpected results. Sound absorbing barriers allow sound waves to enter a sound panel, as the sound waves travel through the sound absorbing material within the panel, they are forced to change direction and follow a longer pathway. Every change in direction results in a decrease in the sound waves' energy. After the sound wave completes its journey through the barrier, little, if any sound energy remains to re-enter the environment. An acoustic panel is typically made up of a perforated cover sheet enclosing noise absorptive material (mineral wool or fiberglass inside and wrapped up with polyester film). The performance of acoustical panels can be rated by its sound transmission loss and its noise reduction coefficient. For comparison purposes, concrete noise barriers typically have a sound transmission loss of around 39 and a noise reduction coefficient of 0.7 to 0.9.

Sound Transmission Loss- All materials permit sound energy to pass through, although in varying degrees depending on the material and the frequency of sound. The attenuation of sound passing through a material is referred to as Transmission Loss (TL). For a barrier to be fully effective the amount of sound energy passing through it must be significantly less than that passing over the top or around the edge. For acoustical purposes, any material may be used for a barrier between a noise source and a noise receiver as long as it has a TL of at least 10 dB(A) greater than the desired noise reduction. This ensures that the only noise path to be considered in the acoustical design of a noise barrier is the diffracted noise path, i.e. the path over (or around) the barrier. For example, if a noise barrier is designed to reduce the noise level at a receiver by 8 dB(A), the TL of the barrier must be at least 18 dB(A). The transmitted noise may then be ignored, because the diffracted noise is at least 10 dB(A) greater and hence the noise propagation path must be over the barrier. The following table shows the typical TL for various materials. Absorptive panels are shown to have the highest TL compared to other barrier materials. A materials TL is based on ASTM Test Method E 90-90 and E 413-87

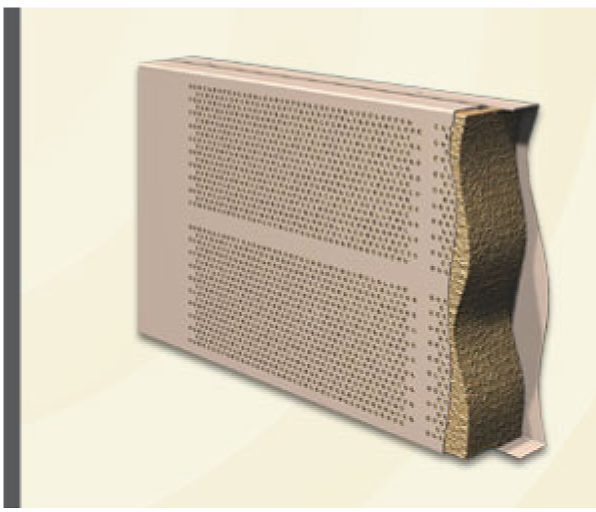
Table 4.
Comparison of Absorbent Materials

Material	Thickness	Transmission Loss dB
Concrete	6 inches	39
Steel	20 gauge	25
Aluminum	1/8”	25
Wood	1 inch	21
Polycarbonate/Acrylic	½”	32
Absorptive panels with polyester film	5”	47

All values assume no openings or gaps in the barrier

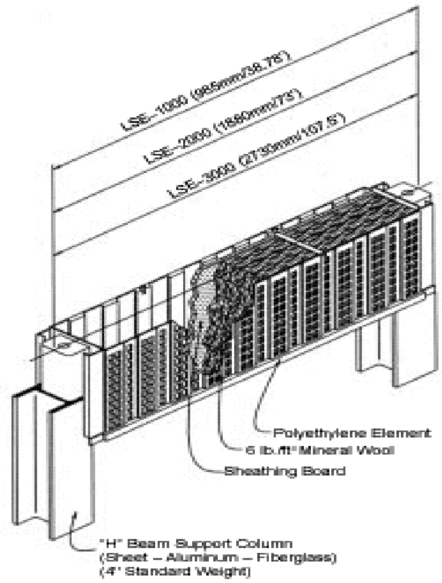
Noise Reduction Coefficient (NRC) The NRC is a scalar representation of the amount of sound energy that is absorbed upon striking a particular surface. An NRC of 0 indicates perfect reflection where an NRC of 1.0 indicates perfect absorption. Specifications for materials used in sound absorption commonly include an NRC for simplicity. Tests in a reverberation chamber will produce a frequency response curve. It is desirable for absorption coefficients to be better than 0.8 at frequencies which are significant in the traffic noise spectrum. In general, the peak traffic noise frequencies lie between 500 - 1500 Hz. In some cases, tests may indicate absorption coefficients larger than 1. Although theoretically impossible, this can occur with highly absorbent materials where the shape of the product differs markedly from the ideal of a flat sheet. Some products are strongly tuned to prevent reverberation of low frequencies (100 - 300Hz). These are unlikely to prove useful in connection with high speed roads, but may be appropriate in urban centers where heavy vehicles will be stationary at intersections and accelerating in low gear. A materials NRC is based on ASTM Test Method C 423-90a and E 795-92.

Acoustax Noise Panels - Acoustaxis a perforated aluminum sound absorptive system developed for industrial and commercial noise control as well as for highway structures. Acoustax is a stackable, lightweight noise barrier designed to remedy a broad range of community and transportation noise problems. Certified tests prove Acoustax absorbs a broad frequency spectrum and prevents noise transmission through the barrier, making it ideal for use as noise walls – absorbing twice as much noise as a traditional concrete noise barrier. The panels are available in either perforated aluminum (3 lbs/sf) or galvanized steel (7.5 lbs/sf) and the panels may be mounted either horizontally or vertically. Acoustax is five times lighter on average than concrete noise barriers (32 lbs/sf) making it easier and less expensive to install. The Acoustax system can be made available as a complete kit with support beams. Powder coated with chemical resistant, UV stable TGIC polyester or with graffiti-resistant super durable aliphatic urethane polyester in the color of your choice, with the option of having the front and back panels of different colors, Acoustax is made to withstand harsh weather environments. The Acoustax noise panels have been rated to have a TL of 38.4 and an NRC of 1.05.



Acoustax noise panel

Sound Fighter Systems-LSE Noise Barrier Wall System The LSE system was engineered and designed in Germany over 35 years ago specifically to mitigate road and traffic noise frequencies. The wall system is 100% noise absorptive with virtually no reflective noise. Barriers can be used in bridge, ground or existing barrier-mounted designs. The LSE System is considered a lightweight barrier system. As such, it can be readily used on new and existing bridge structures without the need to retrofit due to weight (as with concrete). The LSE system is constructed from a proprietary high density, UV and color-stabilized synthetic material that is water resistant, non-corrosive, non-conductive and graffiti resistant. An acoustic absorptive media is inserted into the wall panels to absorb noise by completely diffusing the sound waves. The panels also contain an acoustic sound board that eliminates sound penetration. The wall is competitively priced with other structures and has the unique feature of being completely salvable. Should conditions change; the nose barrier wall can be moved to a new location. The Sound Fighter LSE Noise Barrier Wall System is designed for easy installation. Because the panels are lightweight and modular, the LSE sound wall can be installed much cheaper than other noise barriers. Any construction company can easily erect the LSE wall system in just a few days without any special equipment. The LSE system noise panels have been rated to have a TL of 33 and an NRC of 1.05.



Sound Fighter System

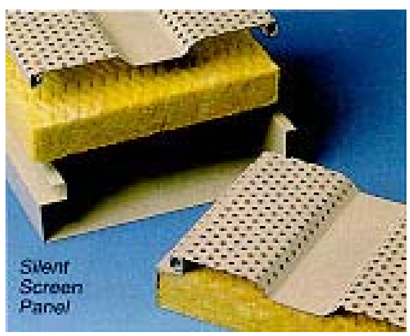
Rock Delta Green Noise Barrier RockDelta® Green Noise Barriers are high noise absorbing and noise insulating pre-fabricated walls. They have been tested at reputed European test institutes and they are placed in the highest absorption and insulation classes. It is a slim, flexible construction that fits in everywhere. The elements are easy to install and they have a high resistance to degradation. The noise barrier elements need practically no maintenance and they are 100% recyclable. The water absorbent stone wool core material in the barrier provides optimum noise abatement and promotes a rapid establishment of a variety of plant species that can be chosen to fit in with the surrounding environment. Through the use of a simple irrigation system situated along the top of the barrier, controlled, long-lasting plant growth can be ensured. The integrated capillary barriers in the façade elements ensure even and thorough water penetration, distribution and buffering throughout the entire height of the barrier. The stone wool structure stores the water much longer than other constructions. Plants are easily placed into the ground immediately in front of the barrier. The plants then grow up the face of the barrier, using it for support. Rainwater trickles through the water absorbent stone wool core, thus providing the optimum in noise insulation while at the same time providing the plants with a water reservoir during the summer. The "Extensive" RockDelta® Green Sound Barrier's water absorbent core allows rainwater to trickle down to the base of the structure. The hard external stone wool façade, combined with the overlaying polythene net, discourages vandalism and graffiti.

RockDelta Stone Wool Material

RockDelta After Six Months

Silent Screen Absorption Panels Silent Screen absorption panels are designed to provide both sound absorption and sound transmission loss. These panels consist of individual sections, each 12 inches wide, mounted horizontally on top of one another, or vertically, side by side. Each section consists of a 2 3/4 inch deep, 16 to 22-gauge tray. Typically, the tray is filled with six-pound density mineral wool, and covered with a perforated 22-gauge face panel. Some of the incident sound striking the perforated side will pass through the perforations and be absorbed by the acoustical material, and some will be reflected back in the direction of the noise source. The "remaining" sound, which is transmitted through the barrier, will be substantially reduced. The panels have a Noise Reduction Coefficient (NRC) of 1.05. The panels also have a TL of 26 for 22 gauge steel and TL of 35 for 16 gauge steel. TL's as high as 46 are available. The M-90 panel is designed for wall-mounting indoor and outdoor applications. The panel widths are 24 inches wide. The panel thickness is 2 5/8 inches and lengths vary up to 12 feet. The absorptive material is a six-pound density mineral rock wool. The M-90 panel has a sound absorption value of NRC 1.1.

Silent Screen Panel



Section of Silent Screen Panel

Acoustical Blankets Baffle Seam Design Acoustical blankets are manufactured using a patented "Baffle/Seam" design. This design is used for both blocking and absorbing unwanted noise. Fabricated from poly-vinyl-chloride coated outer shells with a noise absorption inner construction, blankets have been laboratory and field tested to achieve optimum performance for noise mitigation. They have proven extremely effective for withstanding the elements of nature and extensive handling. The acoustical

blankets come with brass grommets on 12" centers along all sides of the blanket to allow for ease of attachment.
Noise Reduction Coefficient=1.00
Sound Transmission Loss 23


Acoustical Blanket used along Highway in California

Median and Shoulder Acoustic Panels Calm-Tracks & Routes, Germany constructs single or dual absorption extruded aluminum panels. Panels have a 15 to 17 dB absorption value and come in heights of 6, 8, and 12 feet. Supporting steel columns can be mounted on Jersey-type barriers in the highway median, along the highway shoulder, or bridge mounted.

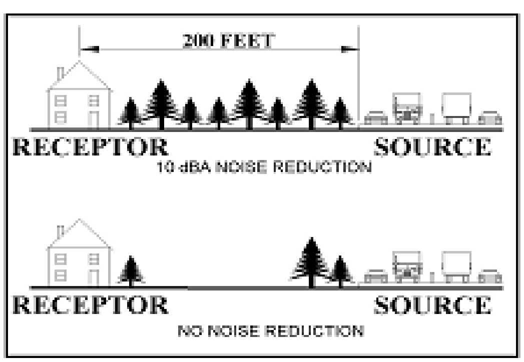

Calm Tracks mounted on Jersey Barrier


Dual High Absorption Aluminum Panels

3.6 Vegetation and Natural Treatments

Vegetation Vegetation is the most controversial form of noise mitigation – ranging from being the most effective mitigation measure to being completely ineffective. Vegetation affects what residents see as well as what they hear. It appears as though perception is everything when considering vegetation as a mitigation measure. Research has shown that the visual and acoustic aspects of vegetation may interact to alter the perception and evaluation of sound in residential settings. For example, people sometimes report that traffic noise is reduced by thin planting strips and even hedges that are simply too sparse to have any physical impact on sound transmission. Psychological factors, having to do with how we perceive our environment, must explain why a narrow planting strip or hedge is prized as a screen against noise, when it actually has little or no humanly detectable effect on sound transmission. A noise study in California showed that if a sound source was completely screened from view, its noise was described as *louder* than when the source was either partially or completely visible. An explanation of this paradox lays in the fact that people's past experience and expectations affect their perception of current information. People learn that the intensity of a sound is reduced by obstacles, and by distance away from the sound source. When a screen blocks the observer's view of the sound source, the observer expects the sound to be of lower intensity. This expected drop in intensity could be due to a possible increase in distance of the source behind the screen, or to the obstacle of the screen itself. What happens if the screened source is just as loud as the unscreened source? The observer may then report that the screened source is *louder,* as it would have to be if the source were further away or if the screens involved were truly effective in reducing noise levels. Sometimes people experience noise "reduction" from vegetative screens that have little detectable influence on actual sound intensity. Here the listeners may be responding to their expectation that the screen is effective, and so attribute noise reduction to the screen when it is really due only to distance. On many occasions, people will complain that noise levels have actually increased following the construction of a noise barrier adjacent to their property. Though the noise meter may indicate that noise levels have decreased following construction, the resident's perception is that the new barrier wall has resulted in an increase in noise level. While some researchers continue to study the effects of trees and shrubs on sound transmission, others have addressed the effects of vegetation on human response to and perception of sound. The psychology of noise abatement will always be fundamental to the study of noise impact and mitigation, because it is people who decide what sound levels and types constitute noise.

However, it has been demonstrated that wide planting strips near the sound source are necessary to effectively abate traffic noise. Abatement is achieved by a combination of vegetative elements. First, a soft forest floor reduces the intensity of low frequency sound by absorbing its energy and the leaves and stems help to reduce noise levels by scattering high frequency sound waves. Acoustic researchers emphasize, however, that substantially more than a single row of street trees is needed to significantly reduce traffic noise. According to the FHWA, vegetation that has sufficient height, depth and density of plant materials that blocks the view of a highway can also decrease traffic noise. Studies have shown that a 200 feet depth of dense vegetation can reduce noise levels by 10 dBA. It is often impractical to plant this quantity of vegetation to achieve such reductions. However, it does demonstrate the potential utility of retaining a vegetative buffer area between developed areas and highways. Other studies have shown that trees and shrubs planted in dense stands as little as 16 feet wide can appreciably affect the transmission of sound. The high cost of conventional highway noise abatement methodology (noise walls) has made mitigation of many impacted sites economically infeasible. A solution that may prove more economically reasonable for those sites is the use of strategically planted evergreen vegetation to form a dense barrier between the highway and impacted area. Field measurements have been made on vegetative barriers planted only for visual screening purposes.



The results of these measurements indicate that a 2 to 3 dB decrease in noise levels is possible with a narrow 30 feet belt of vegetation. Though thin vegetative plantings do not provide a substantial level of noise reduction, vegetative screening, when coupled with the non-quantifiable psychological effects of blocking the highway from view, may have the potential for solving uneconomical abatement problems.

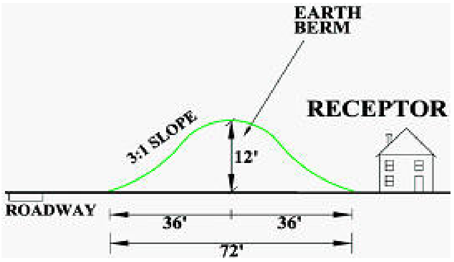
Acoustic Green Barrier ETS Ltd, Scotland, supplies an innovative, attractive and environmentally friendly range of absorptive solutions, called the acoustic Green Barrier™. The acoustic Green Barrier is formed by combining a modern sound absorptive core with living willow hedging or woven (dead) willow screening. The choice of hedge or screen may be determined by the space available, soil conditions and the type of effect desired to be created. As the barrier is absorptive it reduces overall noise levels by absorbing the sound energy. The result is a more efficient and effective way to reducing noise pollution. The Green Barrier is manufactured from natural materials and is attractive and environmentally positive. The Green Barrier in living willow changes color and appearance with the seasons and is environmentally friendly. Its leaves help to reduce carbon dioxide levels by absorption, and return oxygen to the atmosphere. The living willow during the growing season will draw water from the soil, reducing run-off from the site, also absorbing any nutrient or contaminant run off. The Green Barrier can even be engineered to utilize grey water. The Green Barrier in woven (dead) willow, being rustic and attractive, combines with climbers and evergreens to form an effective natural screen.

Green Barrier Under Construction

Three Months After Planting

The Green Barrier is much less likely to attract vandalism and is graffiti resistant. Maintenance is simple and inexpensive. The living willow option requires a water supply, and comes with a drip irrigation system, switches on in the spring and off in autumn. It is trimmed in winter. The woven option requires minimal attention. The expected lifetime of the acoustic Green Barrier is a minimum of twenty five years. ETS have recently installed two barriers in Scotland, where development is taking place next to a major highway (M73). The main problem was excessive noise levels from the highway which needed to be dealt with. After visiting an existing acoustic Green Barrier, this being the only product which in the client's view gave significant reduction in the noise levels; a natural look of the foliage worked very well creating a much better effect than a concrete or other such barrier would have had on the surrounding environment.

Earth Berms Earthen berms require more right-of-way than walls and are usually constructed with a 3-to-1 slope. Using this requirement, a berm 8 feet tall would slope 24 feet in each direction, for a total width of 48 feet. For most highway projects, berms are not feasible because of the additional right-of-way requirement. Earth berms are more effective in reducing traffic noise levels than noise walls due to the longer pathway created by the noise berm. The longer pathway and vegetative surface has a higher attenuation rate than a traditional noise wall and results in less reflected noise. Similar to noise walls, berns must be high enough to break the line-of-sight between the noise source and the receiver and also be long enough to prevent significant flanking of noise around the ends of the berm. However, the use of berms depends on the space available.



Typical Berm Construction


Low Roadside Soil Berm

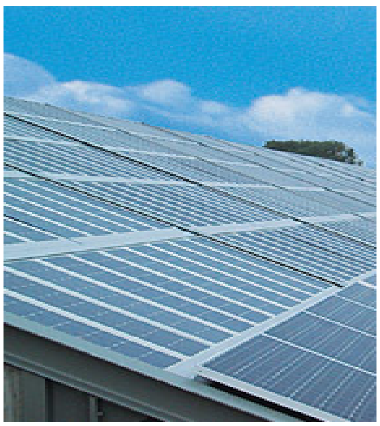
Gabion Stone Baskets Gabion baskets are generally used for erosion protection and in the construction of retaining walls, bank stabilization, and stream channel protection. Gabion Baskets have been used as a natural material use in sound control. The basket walls are free-standing without foundations can be easily moved reused or extended in height or length. The walls are environmentally friendly, water permeable, economical, frost and weather resistant. The walls can use local rock materials or sound-absorbing material such as dolomite to further enhance their noise reduction properties


Sileno–Plus Noise Barrier Wall

3.7 Other Innovative Mitigation Methods

Active Noise Control Active noise control, also known as noise cancellation, involves an electronic device that is mounted to a noise barrier or hung from poles along a highway. The device continually samples the ambient noise spectrum and produces an opposite sound wave 180 degrees out of phase to essentially cancel the noise emitted by the highway. This is an emerging area of noise research in recent years. Among the first practical research in the area of active noise control consisted of a theoretical concept by researchers in Japan that showed, in simulations, attenuation of 3 to 5 dBA more than an absorptive top edge treatment. Researchers in Australia conducted a comparison of various barrier designs, identifying active control as one of three warranting further consideration. ODOT investigated this method of noise mitigation and found that the technology is not developed in the United States and has only been proven to work in very small scaled models. ODOT does not consider it to be a viable mitigation measure at this time.

Photovoltaic Noise-Protective Walls The integration of photovoltaic in existing or planned noise protection walls represents a new challenge. They offer the double uses of noise protection in conjunction with ecologically compatible generation of energy. In order to devise the most technically up-to-date solutions, a German company Kohlhauer GmbH, worked in close co-operation with experienced partners from the photovoltaic industry and business. Among others, items have been successfully achieved jointly in Freising and in Zürich. At the southern end of the Clemenssänger industrial district, the world's largest combined photovoltaic noise-protective wall was constructed at a total length of 1200 m and a top performance of 620 Kilowatts. On a piled up noise-protection wall of earth material along the Autobahn, a noise-protective wall and a pillar construction have been erected for a 6,000 square meter solar modules. The modules are aligned with their active surfaces so that solar radiation can be optimally used for the creation of energy and at the same time the noise emissions of highway traffic can be strongly reduced.



The world's first photovoltaic system, consisting of bifacial modules facing from east to west, was commissioned in December 1997 in Aubrugg near Zurich. The generator was installed as a replacement for an existing wall on a bridge. The photovoltaic noise protection wall, consisting of 50 prototype modules and 10 dummy assemblies, is semi-transparent and has a total length of 120 metres. It is sound absorbing and reflecting.

SECTION 4.0
EVALUATION OF POTENTIAL
PILOT PROGRAM LOCATIONS

Section 4.0
Evaluation of Potential Pilot Program Locations

In the technical approach section of the proposal for this project, it was stated that TranSystems would identify several potential locations for the construction of the pilot program. The initial site selection criteria to be used in determining optimal locations for the program included the following:

- A generally level location with receptor sites having a full view of the turnpike;
- No adjacent secondary noise sources such as a railroad or rail crossing where trains can be heard, commercial or industrial land uses;
- A tight grouping or receptor sites where a noise mitigation program would benefit the greatest number of receptors;
- For cost consideration, an area where the pilot program could be implemented and tested over a section of turnpike of approximately 800 feet in length;

As the project developed, additional criteria were brought into consideration for selecting a pilot program location. The first additional criterion was how many individual receptor sites could be benefitted by a noise mitigation measure.

4.1 Benefitted Receptor Sites

According to the ODOT noise policy, an abatement measure should be designed with the goal of obtaining an 8 dB noise reduction for the front row receptor sites along a highway. However, an individual receptor site is considered to be "benefitted" if a mitigation measure provides a minimum 5 dB noise reduction for a first row receptor. Other sites, located in the second or third row of receptors, which would receive 3 dB or more reduction in noise level are also considered a "benefitted" receptor. To estimate the number of potentially benefitted receptors in each NSA, the noise models that were run to determine existing noise levels at each NSA (discussed in Section 2.0) were modified and re-run with the insertion of a noise barrier wall.

Though a noise barrier wall may not be the selected noise mitigation measure for this study, the use of a noise barrier wall was chosen as a means to estimate the number of potentially benefitted receptors. Levels of potential noise reduction can easily be modeled using TNM V2.5. The relative cost of providing mitigation for each NSA can also be estimated using this method. Whether the selected mitigation measure is a noise barrier wall or quiet pavement, the relative cost can be estimated based on the cost of a noise wall that takes into consideration the length of the mitigation measure and the site-specific location of each NSA to the Turnpike. Additionally, one of the goals of the mitigation study is to evaluate the effectiveness of an alternative noise mitigation measure as compared to a traditional noise barrier wall.

Using a method similar to the one used to determine the distance of 66 dB from the roadway (Section 2.0), noise barriers of various heights were inserted into the model to estimate the distance from the roadway that a certain height barrier could provide a 3 dB or greater noise reduction. As an example, NSA 1 is an at-grade residential neighborhood. A 12-foot high noise barrier could provide a minimum 5 dB reduction to front row receptors and could also provide a 3 dB to a distance of approximately 310 feet from the roadway. A mitigation measure at this NSA could possibly benefit approximately 75 individual receptor sites.

In general, it was determined, depending on traffic volume and site-specific conditions, that a 12-foot high noise wall could provide a 3 dB reduction in noise level to a distance of 310 feet in an at-grade scenario. An 11-foot high noise wall could provide a 3 dB reduction in noise level to a distance of 350 feet in a cut roadway scenario, and a 14-foot high noise wall would be necessary to provide a 3dB reduction in noise level at a distance of 300 feet where the Turnpike is in a fill roadway scenario.

Please keep in mind that the above generated numbers are all based on a very simplified noise model analysis and are only general values used to estimate the potential number of impacted receptors and the potential number of receptors that could be benefitted with a baseline mitigation measure such as a typical noise barrier wall. Also, the estimated cost of mitigation for each NSA (based on an ODOT recommended cost of $25 ft^2 for noise barrier construction) is used only for comparison purposes so that a relative cost at one NSA could be compared to a relative cost at another NSA to determine which NSA could experience the highest levels of noise reduction to the most receptor sites at the least cost. The estimates were used to develop a benefit to cost analysis for each NSA which can be further used in determining which NSAs warrant further consideration for the pilot program.

Table 5.
Comparison Table for Potential Noise Mitigation

Noise Sensitive Area[1]	Impacted Receptors[2]	Comparison Mitigation Cost[3]	Benefitted Receptors[4]	Cost Per Benefitted Receptors[5]
1	70	$1,162,500	52	$22,356
2	68	$1,006,000	10	$100,600
3	50	$212,500	5	$42,500
4	Residential development has a soil barrier in place - assume no noise impacts.			
5	8	$300,000	8	$37,500
6	19	$335,000	8	$41,875
7	64	$862,500	60	$14,375
8	24	$321,000	22	$14,591
9	52	$661,000	50	$13,220
10	40	$412,500	5	$82,500
11	Park	$375,000	0	- - -
12	35	$630,000	19	$33,158
13	12	$145,000	3	$48,333
14	42	$953,800	35	$27,251
15	63	$975,000	45	$21,667
16	41	$575,000	25	$23,000
17	39	$980,000	81	$12,099
18	18	$301,000	16	$18,812
19	16	$537,500	6	$89,583
20	7	$300,000	4	$75,000
21	12	$700,000	7	$100,000
22	19	$400,000	16	$25,000
23	30	$316,250	18	$17,569
24	11	$300,000	12	$25,000

Table 5. Comparison Table for Potential Noise Mitigation				
Noise Sensitive Area[1]	Impacted Receptors[2]	Comparison Mitigation Cost[3]	Benefitted Receptors[4]	Cost Per Benefitted Receptors[5]
25	61	$517,500	50	$10,350
26	28	$337,000	32	$10,531
27	9	$591,000	8	$73,875
28	82	$1,067,500	55	$19,409
29	16	$320,750	5	$64,150
30	27	$412,500	7	$58,929
31	26	$372,500	16	$23,281
32	13	$384,000	18	$21,333
33	90	$586,000	25	$23,440
34	14	$400,000	16	$25,000
35	31	$675,000	31	$21,774
36	55	$643,750	46	$13,995
37	13	$227,000	19	$11,947
38	11	$260,000	8	$32,500
39	81	$1,486,750	57	$26,083
40	85	$1,623,750	121	$13,419
41	18	$217,500	8	$27,188
42	38	$662,500	27	$24,537
43	10	$316,000	10	$31,600
44	40	$408,750	9	$10,219
45	12	$260,000	5	$52,000
46	9	$347,500	10	$34,750
47	13	$491,250	10	$49,125
48	70	$627,500	21	$29,881
49	35	$913,750	19	$48,092
50	20	$982,750	11	$89,341
51	15	$400,000	11	$36,364
52	18	$815,000	17	$47,941
53	14	$691,250	10	$69,125
54	10	$432,500	10	$43,250
55	39	$1,065,000	30	$35,500
56	28	$690,500	19	$36,342
57	72	$1,277,500	46	$27,772
58	61	$387,500	61	$6,352
59	26	$306,250	36	$8,507
60	37	$677,500	59	$11,483
61	33	$1,050,000	66	$15,909
62	10	$275,000	8	$34,375
63	13	$266,250	12	$22,188

Table 5. Comparison Table for Potential Noise Mitigation				
Noise Sensitive Area[1]	Impacted Receptors[2]	Comparison Mitigation Cost[3]	Benefitted Receptors[4]	Cost Per Benefitted Receptors[5]
64	18	$642,500	17	$37,794
65	38	$435,000	27	$16,111
66	30	$881,250	16	$55,078
67	34	$783,750	25	$31,350

[1] Noise Sensitive areas are shown on Figures 2A through 2C.
[2] The estimated number of receptors within each NSA that were predicted to currently experience noise levels above the FHWA NAC Category B of 66 dBA.
[3] Cost of mitigation is based on the ODOT figure of $25 ft^2 for noise barrier wall construction.
[4] The estimated number of receptor sites that could potentially be benefitted by a noise mitigation measure based on the TNM V2.5 noise model.
[5] According to the ODOT noise policy, if the average cost per benefitted receptor is less than $35,000, noise mitigation would be considered cost reasonable.

4.2 Pilot Program Matrix Evaluation

A matrix was prepared to rank the 67 NSAs in determining which locations would be best suited for implementation of a pilot program. In the matrix, seven variables were evaluated and assigned a value of one to three with one being the highest. All variables were weighted the same. The seven variables evaluated are as follows:

- Length of the NSA along the Turnpike – This variable is related to cost. Limited funds are available to implement the pilot program and it is thought that the maximum length along the Turnpike for the pilot program would be less than 1,000 feet. An NSA with a length of less than 1,000’ was assigned a score of 1. An NSA between 1,000 and 1,500’ scored a 2, an NSA between 1,500’ 2,000’ scored a 3, an NSA between 2,000’ and 2,500 scored a 4 and any NSA longer than 2,500 feet scored a 5.
- Site Specific Elevation – This variable relates to the relative elevation of the Turnpike to the NSA receptors. NSAs having receptor sites located at a similar elevation as the Turnpike were considered at-grade and scored a 1. NSAs at a higher elevation than the Turnpike were considered a cut elevation and scored a 2. NSAs at a lower elevation than the Turnpike were considered a fill elevation and scored a 4 as mitigation is much more difficult to achieve in highway fill conditions.
- Distance of the nearest receptor from the Turnpike – Receptor sites located close to the a highway facility generally receive higher levels of noise reduction than receptor sites located at a farther distance. An NSA with receptors located 300 feet away from the Turnpike would likely receive relatively low levels of noise reduction and should not be considered in a pilot program. NSAs with receptors less than 50 feet from the Turnpike scored a 1. NSAs with the nearest receptor site located between 50 and 100 feet from the Turnpike scored a 2, NSAs with the nearest receptor site located between 100 and 150 feet from the Turnpike scored a 3, NSAs with the nearest receptor site located between 150 and 200 feet from the Turnpike scored a 4 and NSAs with the closest receptor located over 200 feet from the Turnpike scored a 5.

- Secondary Sources of Noise – If an NSA is affected by noise from a different noise source other than the Turnpike, it would be less likely that a substantial reduction in noise levels could be achieved. Secondary noise sources would include major cross roads such as US routes, interstate routes and state routes abutting an NSA, a major railroad line or adjacent retail and commercial land use. The pilot program should be considered for implemented at a location where an NSA is not affected by other noise sources or would have minor affect from secondary noise. NSAs with no adjacent secondary noise sources scored a 1. Those NSAs located adjacent to local roadways scored a 2. NSAs located adjacent to multiple local roadways or state routes scored a 3. NSAs located next to multiple state routes or US routes scored a 4 and those NSAs located near an interstate route scored a 5.
- Impacted Receptor Sites - This variable relates to the number of sites that are currently impacted by traffic noise from the Turnpike. Impacted receptor sites are those sites predicted to currently experience noise levels approaching or exceeding the FHWA NAC Activity Category B of 66 dB. The pilot program should be considered for implemented at a location where traffic noise is affecting the most people. NSAs having impact at more than 50 receptor sites scored a 1. NSAs with impacted receptor sites ranging from 40 to 50 scored a 2, NSAs with impacted receptor sites from 20 to 40 scored a 3, NSAs with impacted receptor sites ranging from 10 to 20 scored 4 and those NSAs with less than 10 impacted receptor sites scored a 5.
- Benefitted Receptor Sites – This variable relates to the number of receptors that could be benefitted by a substantial reduction in traffic noise with implementation of a noise mitigation measure. A substantial reduction in noise level cannot be achieved at all sites. An NSA may have many impacted receptor sites but only a few sites where a substantial noise reduction can be achieved due to variables such a distance from the highway and secondary noise sources. The pilot program should be considered for implemented at a location where a substantial noise reduction may be obtained for the greatest number of people. NSAs where a substantial noise reduction would benefit more than 50 receptor sites scored a 1. NSAs where 40 to 50 receptors could be benefitted scored a 2, NSAs where 20 to 40 receptors could be benefitted scored a 3, NSAs where 10 to 20 receptors could be benefitted scored a 4 and sites where less than 10 receptors could be benefitted scored a 5.
- Cost per Benefitted Receptor – This is a benefit to cost variable. The pilot program should be considered for implemented at a location where the greatest number of receptors can be benefitted at the lowest cost. NSAs where the cost per benefitted receptor was estimated to be less than $10,000 scored a 1, NSAs with an estimated cost of between $10,000 and $15,000 scored a 2, NSAs with an estimated cost of between $15,000 and $25,000 scored a 3, NSAs with an estimated cost of between $25,000 and $35,000 scored a 4. According to the ODOT noise policy, if the cost per benefitted receptor exceeds $35,000, then noise mitigation is considered to be not cost reasonable and is not implemented. Those NSAs with a cost per benefitted receptor of more than $35,000 scored a 5.

The scores for each NSA were totaled and divided by 7 to obtain an average score. Four NSAs had average scores of equal to or less than 2.0. The pilot program location matrix is shown in Table 6.

Table 6. Pilot Program Location Matrix									
NSA	Mile Post	Length of NSA along Turnpike	Site Specific Elevation	Distance of Receptors	Secondary Sources of Noise	Impacted Receptor Sites	Benefitted Receptors Sites	Cost per Benefitted Receptor	Score
1	48	5	1	2	2	1	1	3	2.1
2	51	5	4	2	1	1	4	5	3.1
3	56	2	4	2	2	1	5	5	3.0
4	57	3	1	5	1	5	5	5	3.6
5	57	2	1	5	1	5	5	5	3.4
6	58	3	2	5	2	2	5	5	3.4
7	58	5	1	1	3	1	1	2	2.0
8	59	3	2	2	2	3	3	2	2.4
9	59	5	1	2	2	1	1	2	3.3
10	60	3	4	3	1	2	5	5	3.3
11	60	2	1	3	1	5	5	5	3.1
12	61	5	1	2	3	2	4	4	3.0
13	61	1	1	2	2	4	5	5	2.8
14	61	5	4	3	2	2	3	4	3.3
15	62	5	1	2	3	1	2	3	2.4
16	61	4	4	4	2	2	3	3	3.1
17	62	5	1	2	3	3	1	2	2.4
18	63	2	2	3	2	4	4	3	2.8
19	63	4	4	2	4	4	5	5	4.0
20	63	2	4	5	4	5	5	5	4.3
21	64	5	1	2	3	4	5	5	3.6
22	67	2	1	2	2	4	4	3	2.6
23	70	2	4	3	1	3	4	3	2.8
24	140	2	1	2	2	4	4	3	2.6
25	145	4	4	3	3	1	1	2	2.6
26	146	3	2	3	2	3	3	2	2.6
27	146	4	2	3	2	5	5	5	3.7
28	147	5	2	2	2	1	1	3	2.3
29	147	2	4	5	5	4	5	5	4.2
30	147	3	4	5	5	3	5	5	4.3
31	148	2	4	2	3	3	4	3	3.0
32	148	3	4	2	1	4	4	3	3.0
33	153	4	1	3	1	1	3	3	2.3
34	155	3	1	3	1	4	4	3	2.7
35	156	5	1	2	2	3	3	3	2.7
36	157	5	1	2	1	1	2	2	2.0
37	157	2	2	4	1	4	4	2	3.0
38	158	2	4	5	2	4	5	4	3.7
39	158	5	4	1	1	1	1	3	2.3

Table 6. Pilot Program Location Matrix									
NSA	Mile Post	Length of NSA along Turnpike	Site Specific Elevation	Distance of Receptors	Secondary Sources of Noise	Impacted Receptor Sites	Benefitted Receptors Sites	Cost per Benefitted Receptor	Score
40	158	5	1	2	1	1	1	2	1.8
41	159	1	1	2	3	4	5	3	2.7
42	160	5	1	2	2	3	3	3	2.7
43	160	3	2	4	1	5	5	4	3.4
44	161	3	1	3	3	2	5	2	2.7
45	162	2	2	4	5	4	5	5	3.9
46	163	2	1	3	2	5	4	4	3.0
47	164	3	1	2	2	4	4	5	3.0
48	164	5	1	2	2	1	3	4	2.6
49	166	5	4	4	3	3	4	4	3.9
50	171	4	4	3	1	4	4	4	3.4
51	183	3	2	4	1	4	4	4	3.1
52	184	5	2	5	2	4	4	4	3.7
53	184	5	2	5	2	4	5	4	3.9
54	187	3	2	5	2	5	5	4	3.7
55	188	5	4	4	2	3	3	4	3.6
56	188	5	4	2	2	3	4	4	3.4
57	189	5	2	3	2	1	2	3	2.6
58	193	3	4	2	1	1	1	1	1.8
59	194	2	4	2	2	3	3	1	3.9
60	204	5	2	3	2	3	1	2	2.6
61	216	5	1	3	2	3	1	3	2.6
62	222	2	2	5	1	5	5	4	3.4
63	225	2	2	4	3	4	4	3	3.1
64	226	5	2	4	2	4	4	5	3.7
65	227	3	4	2	2	3	3	3	2.8
66	228	5	1	4	2	3	4	5	3.4
67	229	5	1	4	1	3	3	4	3.0

The matrix presents a starting point for the evaluation and determination of a pilot program location. Since all variables were weighted evenly, the lowest scoring site doesn't mean it is the best site to implement the program. Sites scoring less than two may be better sites to implement a program. However, sites scoring over 3.5 probably have more than one important reason for not being selected as the pilot program site. Another consideration in the selection of the pilot program location may include the relative location to the OTC office to reduce the cost of supervising, constructing and monitoring the selected site.

SECTION 5.0
EVALUATION SUMMARY

Section 5.0
Evaluation Summary

5.1 Mitigation Measures

Innovative mitigation measures were grouped into seven types for evaluation. The types include: quiet pavement; noise insulation of receptor sites; land use planning and control; innovative noise barrier walls; acoustic panels; vegetation and other natural treatments; and, other mitigation. A matrix was prepared to compare and evaluate the various mitigation measures. Criteria used for evaluation included their acoustic performance, relative cost, service life, maintenance costs and other limitations.

Pavement Table 7 is a summary of the pavement types evaluated as part of the project. In the table the various pavement types are compared to DGA as a baseline since DGA has such common use. Table 8 assigns a number rating to each of the different pavement types for ranking purposes. The table shows that stone mastic asphalt has a similar rating to DGA but offers very little noise reduction compared to DGA. For noise reduction, asphaltic rubber concrete and double layer porous asphalt offer the greatest reduction in noise levels but have limitations when compared to DGA for durability and cost. If a pavement type were to be selected as a mitigation measure, it appears that Asphaltic rubber concrete may provide the greatest noise reduction compared to service life and cost compared to double layer porous asphalt.

Noise Insulation Noise insulation can reduce noise impacts within buildings and can be a less expensive mitigation measure per benefitted receptor than building noise barrier wall. However, there would still be lifestyle limitations to persons living at the site because sound insulation can only provide a satisfactory acoustic environment within the building, not outside. Patios, decks, swimming pools, and other areas of frequent outdoor use will still be subjected to noise. For example, windows cannot be opened to provide natural ventilation without reducing the sound insulation. ODOT uses noise insulation for public use and nonprofit institutional structures when other forms of abatement (noise walls) are found to be not reasonable or feasible. FHWA participation in the noise insulation of private residences is allowable only in situations where severe traffic noise impacts exist. Most state DOTs do not spend state money on noise abatement for private residences outside of state right-of-way. Noise insulation may be an option for mitigation however considering noise reduction would only occur inside a residence with the windows and doors closed, it may not be a desirable mitigation measure for residents.

Land Use Planning and Controls Proper land use planning may play a role in the prevention of future noise impact. People and local governments need to be informed that noise impacts exist within several hundred feet of the highway pavement. The compatibility of a highway and its neighbors is essential for the continuing growth of local areas. Local governments should use their power to regulate land development in such a way that noise-sensitive land uses are either prohibited from being located adjacent to a highway, or that the developments are planned, designed, and constructed in such a way that noise impacts are minimized. The OTC can share the information provided in this report to local governments so that they can plan future land use near the turnpike and let developers know that future noise mitigation will not be provided to future incompatible land use adjacent to the turnpike. Thus, the FHWA encourages State and local governments to practice compatible land use planning and control in the vicinity of highways.

Table 7
Evaluation of Quiet Pavement Types

Pavement Type	Noise Reduction [1]	Average Service Life[2]	Approximate Cost[3]	Construction Methods[4]	Surface Course Durability	Maintenance Issues	Benefits	Limitations
Dense Graded Asphalt (DGA)	Baseline	15 years	Baseline	Normal methods.	Very High.			
Portland Cement Concrete (PCC)	2.5 dBA more than DGA	>20 years	Generally More than DGA	Normal methods.	Very High.			
Open graded Asphalt (OGA)	3 dBA less than DGA	10- 12 years	10% higher than DGA	Normal methods.	High.	Higher Snow Removal/Winter Maintenance	Spray reduction. Skid resistant.	Subject to raveling
Asphaltic Rubber Concrete (ARC)	4.5 dBA less than DGA	12-15 years	40% higher than DGA	Normal methods.	High.	Higher Snow Removal/Winter Maintenance	Resistant to reflective cracking and rutting.	Tendency for pores to clog over time. Noise reduction decreases with time High placement temperature
Single Layer Porous Asphalt	4 dBA less than DGA	10-12 years	10-25% higher than DGA	Normal methods.	Medium.	Higher Snow Removal/Winter Maintenance	Spray reduction. Skid resistant. Rut resistant. Stormwater infiltration.	Tendency for pores to clog over time. High placement temperature Subject to raveling
Double Layer Porous Asphalt	6 dBA less than DGA	8-10 years	25-35% higher than DGA	Normal methods. Warm-on-warm layers.	Medium.	Higher Snow Removal/Winter Maintenance	Spray reduction. Skid resistant. Rut resistant. Stormwater infiltration.	Tendency for pores to clog over time. High placement temperature Subject to raveling
Stone Mastic (Matrix) Asphalt	1 dBA less than DGA	15 years	Similar to DGA	Normal methods.	Very High.		Rut resistant Crack resistant Skid resistant	

Table 8. Quiet Pavement Types Matrix								
Pavement Type	Noise Reduction [1]	Average Service Life[2]	Cost[3]	Surface Course Durability	Maintenance Issues	Benefits	Limitations	Rating
Dense Graded Asphalt (DGA)	4	2	1	1	2	3	2	2.1
Portland Cement Concrete (PCC)	5	1	2	1	3	3	2	2.4
Open graded Asphalt (OGA)	3	3	3	3	4	2	3 (subject to raveling)	3
Asphaltic Rubber Concrete (ARC)	1	2	4	3	4	1	3 (pores clog and noise reduction over time)	2.6
Single Layer Porous Asphalt	2	3	3	3	4	1	4 (pores clog over time and subject to raveling)	2.8
Double Layer Porous Asphalt	1	4	4	4	4	1	5 (pores clog over time, high placement temperature and subject to raveling	3.8
Stone Mastic (Matrix) Asphalt	4	2	2	2	2	1	2	2.1

[1] *Comparative Measurements of Tire/Pavement Noise in Europe, California and Arizona.*
[2] *Danish Road Institute, European Design of Low-Noise Pavements – Quiet Asphalts 2005 Symposium. The actual service life of a pavement system will vary based upon many variables: Asphalt thickness, subgrade conditions, surface porosity and existing drainage conditions will dictate the economic useful life of a pavement system.*
[3] *Relative costs were based on the FHWA Scanning Tour of Europe, 2007 where all pavement types have been historically used.*
[4] *Benefits of the roadway wearing course compared to DGA or PCC. OGA was given a rating of 2 is for improved skid resistance and spray reduction. ARC and MSA were given a rating of 2 for improved resistance to reflective cracking, rutting and skid resistance. The porous asphalts were given a rating of 1 for improved skid resistance and spray reduction* as well as potential for storm water infiltration.

Innovative Noise Barrier Walls The FHWA and state DOTs have used traditional concrete noise barrier wall for noise mitigation for the past thirty years. A problem with traditional noise barrier wall is that they only provide a reduction in noise levels to those properties located within 300 to 4000 from the roadway As traffic volumes and speeds have increased on highways, noise levels have risen for nearby homes, prompting transportation agencies to look for ways to provide more effective noise attenuation at a reasonable cost. Various treatments for the top edge of traditional noise barrier walls have been investigated. The intent is to alter the hard linear edge that causes diffraction of sound toward receivers behind the barrier thereby reducing the height and cost for noise barrier walls while achieving the same level of noise reduction. Table 9 evaluates the use of various top edge designs for noise barrier walls. If the mitigation measure were to consider noise barriers with innovative top edge design, the T-top design with absorptive material provides the greatest reduction in noise level of decrease in wall height at a moderate cost.

Absorbent Acoustic Panels An acoustic panel is typically made up of a perforated cover sheet enclosing noise absorptive material (mineral wool or fiberglass inside and wrapped up with polyester film). Sound absorbing barriers allow sound waves to enter a sound panel, as the sound waves travel through the sound absorbing material within the panel, they are forced to change direction and follow a longer pathway thereby reducing sound energy. Acoustic panels can be installed similar to noise barrier walls or may be placed on a center concrete median to reduce noise levels along the roadway. Table 10 is a summary of absorbent acoustic panels evaluated as part of the study. Most acoustic panels perform the same in reducing the transmission of noise. If absorbent acoustic panels are considered for noise mitigation, it appears that the light weight synthetic Sound Fighter panels seem to be more suited to placement on top of an existing concrete median. The panels would cost in the neighborhood of $25 per ft^2 and can be installed by a local maintenance staff.

Vegetation and other Natural Materials The effectiveness of vegetative screening used for noise mitigation purposes is hard to gauge. Some individual's perception is that a thin screening of vegetation does reduce noise levels when a noise meter indicates little or no reduction. The FHWA and state DOTs only consider vegetation an appropriate abatement measure when at least 100 feet of dense is available. A distance of 100 feet of dense vegetation may provide a substantial noise reduction of 5 dB. There is no where along the turnpike that a swath of vegetation 100 feet thick could be planted with vegetation to provide a substantial noise reduction. It would be hard to monitor the effectiveness of a pilot program until the vegetation has grown to full height and density. This mitigation measure may not be a good selection for the pilot program. Soil berms were also evaluated under natural materials. Soil berms have proven to be more effective than noise barrier walls in reducing traffic noise levels. However a wide footprint is necessary to construct soil berms of adequate height. A soil berm 12 feet in height would require a base width of 72 feet. There are no locations along the turnpike with adequate space to construct a soil berm as a mitigation measure.

Other Mitigation Measures This type of mitigation measure included experimental devices such as noise control/noise cancellation and the use of photovoltaic noise walls. Noise cancellation has yet to be proven to provide a feasible noise reduction of at least 5 dB on a large scale project. Photovoltaic noise walls provide the benefit of electricity generation and noise mitigation. The technology has been used in Europe with favorable results. Being predominantly an east/west highway, the Turnpike is well suited for optimal placement of solar panels facing south. However, the technology is very expensive and construction of a photovoltaic noise wall as a pilot program would not be cost reasonable.

Table 9
Evaluation of Edge-Modified Barrier Top Treatments

Barrier Type	Additional Noise Reduction	Potential Reduced Height (Range)	Potential Reduced Height (Average)	Relative Cost (per sq.ft.)	Comments
T-Top Barrier Design	1-1.5 dBA	2 – 3 feet	2.5 feet	$27-$29	Minor increase in cost compared to traditional noise barrier
T-Top Barrier Design with Absorptive Material	2-3 dBA	4 - 6 feet	5 feet	$28-$30	Moderate increase in cost compared to traditional noise barrier.
Y-Top Barrier Design	0.5 – 1 dBA	1 – 2 feet	1.5 feet	$30-$35	Moderate increase in cost compared to traditional noise barrier.
Jagged Top Barrier Design	0 – 6 dBA	0 – 3 feet	1.5 feet	$25-$28	Minor increase in cost compared to traditional noise barrier
Cylindrical Top Treatment	2 – 3 dBA	3 – 4 feet	3.5 feet	$40	Substantial increase in cost compared to traditional noise barrier. Proprietary noise abatement technology.
Mushroom-Shaped Top Treatment	0.5 – 1 dBA	1 – 2 feet	1.5 feet	$40	Substantial increase in cost compared to traditional noise barrier. Proprietary noise abatement technology.

Table 10. Absorbent Acoustic Panels					
PanelType	Noise Reduction Coeffieient	Sound Transmission Loss	Material	Relative Cost Per sq. ft.	Comments
Acoustax Noise Panels	1.05	38.4	Aluminum or Galvenized steel	$30-$40	Perforated Aluminum -3lbs/sf Galvanized Steel - 7.5 lbs/sf Can be placed back-to-back 20% more expensive than concrete noise barrier wall Made in USA – readily available
Sound Fighter System-LSE	1.05	33	Proprietary Synthetic	$22-$25	Synthetic Material -4.5 lbs/sf Panels can be moved if conditions change Can be mounted on Jersey-type barrier Similar in cost to concrete noise barrier wall Made in USA – readily available
Rock Delta Green Noise Barrier System	1.0	28	Aluminum/stone wool core	$35-$50	Water absorbent - no maintenance Plants grow up the front of the wall Expensive European – may not be available locally
Silent Screen Absorption Panels	1.1	26-46	Various thicknesses of steel	$25	Powder coated 22 to 16 gauge steel Mineral wool noise absorptive material 10% more expensive than concrete noise barrier wall Made in USA – readily available
Baffle Seam Acoustic blanket	1.0	23	PVC	$20-$25	UV and rust resistant Less expensive than concrete noise barrier wall Made in USA – readily available
Calm Tracks Absorptive Panels	N/A	N/A	Aluminum	Not Known Expensive	17 db noise absorption value Can be mounted on Jersey-type barrier Little data available - No price available Made in Germany – may not be available locally
Sileno – Plus Gabion Stone Basket	0.8	39	Dolomite Stone	$25-$30	Free standing – no foundation required Easily moved, re-used or extended in height and width Made in USA – readily available

Based on the literature review of data for potential innovative noise mitigation measures, it appears that installation of an asphaltic rubber concrete surface coat, installation of T-top edge noise barrier walls or installation of absorptive noise panels along the turnpike concrete median could be suitable for a pilot program.

5.2 Pilot Program Location

Several criteria were considered in the recommendation of sites for the pilot program. The criteria are shown in Table 6 and discussed in detail in Section 4.2. The matrix is a comparison of NSAs based on cost of a traditional pre-cast concrete noise barrier wall that would be completed for a typical FHWA or ODOT noise abatement analysis. The cost of the traditional concrete noise barrier is not a consideration in the matrix. The site recommendation is based solely on the other measurement criteria shown on the column headings. The rating criteria used to develop the matrix for traditional noise barriers can also be used to rate other innovative noise mitigation measures.

When mitigation is found to be reasonable and feasible in a typical FHWA or ODOT noise study, the total cost of the abatement is not an issue if the mitigation is found to be warranted. Funding is limited for this pilot program making cost consideration possibly the most important factor in selecting a site. Another consideration is that the location of the pilot program should be in close proximity to the Cleveland area to limit the total construction, supervision and monitoring costs. Further, the selection of a pilot program location is not an independent issue. It is highly dependent on the selected mitigation measure chosen for the pilot program. Pilot program locations will be recommended based on the cost of the selected mitigation measure.

A conservative estimate is that there will be $350,000 available for the construction of the innovative noise mitigation measure for the pilot program. The figure does not include the cost of evaluating potential mitigation measures and pilot program site, design and monitoring of the pilot program. A conservative number has been estimated because it is understood that project funding will not exceed $500,000. Using $350,000 as a starting point, pilot program locations (NSAs) can be recommended for various mitigation measures. Unit costs per 100 linear feet have been estimated for selected mitigation measures. This cost will be used to determine which NSAs would be best suited for implementation of selected mitigation measures while within the project budget. Table 11 presents a comparison of selected mitigation measures and which NSAs would be best suited for potential implementation of that particular measure. The final column of Table 11 provides a benefit to cost ratio for mitigation measures at various NSA. Below is an example of how the Cost Benefit Ratio was derived.

Cost of mitigation measure at NSA	$100,000	$100,000	$100,000
Number of benefitted receptors at NSA	100	100	100
Expected dB reduction for mitigation measure	1	2.5	5
Cost Benefit Ratio = Cost/benefitted receptor/dB reduction	$ 1,000	$ 400	$ 200

Table 11
Mitigation Measure/Pilot Program Location

Mitigation Measure	Cost of Mitigation Measure	Estimated Cost per 100 linear feet	Estimated Length of Mitigation Measure	Suitable NSAs and Estimated Construction Costs					
				NSA	Total Cost	Benefitted Receptors	Cost per Benefitted Receptor	Noise Reduction	Cost Benefit Ratio[1]
Traditional Pre-Cast Concrete Noise Barrier (for comparison)	Assume average 12' height at $25 ft^2$	$30,000	1,150 feet	7	$1,020,000	60	$17,000	5 dB	$3,400
				36	$ 771,000	46	$16,700	5 dB	$3,350
				39	$1,620,000	57	$28,400	5 dB	$5,600
				40	$1,947,000	121	$16,000	5 dB	$3,200
				58	$ 465,000	61	$ 7,600	5 dB	$1,500
Quiet Pavement Asphaltic Rubber Concrete	Assume $2 yd^2 to Scarify Assume $65 yd^2 installed	$7,300	4,800 feet	7	$252,000	54	$4,700	4.5 dB	$1,040
				17	$ 286,000	73	$3,900	4.5 dB	$ 870
				28	$312,000	50	$6,200	4.5 dB	$1,380
				36	$190,000	41	$4,600	4.5 dB	$1,020
				61	$307,000	59	$ 5,200	4.5 dB	$1,160
Alternative Noise Barrier T-Top Edge	Assume average 8' height at $29 ft^2$	$23,200	1,500 feet	18	$348,000	16	$21,750	5 dB	$4,350
				24	$278,000	12	$23,200	5 dB	$4,630
				37	$262,000	19	$13,800	5 dB	$2,760
				41	$202,000	8	$25,200	5 dB	$5,050
				63	$247,000	12	$ 20,583	5 dB	$4,100
Acoustic Panel Sound Fighter System	Assume average height of 5' attached to center median facing toward NSA at $28 ft^2$	$14,000	2,500 feet	26	$236,000	32	$7,300	3 dB	$2,400
				35	$221,000	29	$7,620	3 dB	$2,540
				36	$360,000	46	$7,800	3 dB	$2,600
				37	$159,000	19	$8,300	3 dB	$2,800
				58	$217,000	47	$4,600	3 dB	$1,500
Systems could also be used in combination. Example: Quiet pavement combined with acoustic panel	Assume $2 yd^2 to Scarify Assume $65 yd^2 installed Assume average height of 5' attached to center median facing toward NSA at $29 ft^2$	$21,300	1,650 feet	32	$327,000	22	$14,800	6.8 dB[2]	$2,185
				34	$347,000	20	$17,350	6.8 dB	$2,550
				37	$242,000	23	$10,500	6.8 dB	$1,550
				38	$222,000	10	$22,000	6.8 dB	$3,200
				43	$337,000	15	$22,400	6.8 dB	$3,300

[1] Cost Benefit Ratio = total cost/benefitted receptor /expected dB noise reduction
[2] decibels added logarithmically

SECTION 6.0
CONCLUSION AND RECOMMENDATION

Section 6.0
Conclusion and Recommendation

6.1 Mitigation Measures

Based on the general evaluation of the seven mitigation measure types, three measures were selected for final evaluation and selection of the preferred measure for implementation in the pilot program. The three measures included: quiet pavement (open graded asphalt); absorbent acoustic panels for placement in the turnpike median (Sound Fighter System); and, innovative "T"-top noise wall (Whisper Wall systeb). Criteria used in the final evaluation included the measure's acoustic performance, relative cost, service life, maintenance costs and other limitations.

Quiet Pavement

As mentioned previously in this report, a section of the Ohio Turnpike was resurfaced with OGA friction course in 1993. The section of turnpike from mile post 170.5 (just west of Broadview Road) to mile post 172.4 (just east of Brecksville Road). Though this section of turnpike did exhibit a general decrease in traffic noise level, it also presented a problem with ice and snow removal. An OGA friction course has greater surface area (due to the numerous voids) than traditional DGA and as a result will freeze quicker. There were a disproportionate number of ice-related accidents and vehicle slide offs along this section of turnpike compared to other sections of the turnpike. In addition to the icing problems, the OGA pavement was less durable having a tendency to ravel. The OGA section of pavement proved to be high maintenance and somewhat unsafe compared to other sections of the turnpike and the OGA friction course was removed and replaced with a DGA friction course only six years later in 1999. Though it has been over ten years since the since the section of turnpike was paved with OGA, today's technology in regards to OGA is essentially the same. The benefit of a somewhat quieter pavement is outweighed by the potential safety hazards and maintenance problems posed by using OGA. For these reasons, OGA is not recommended as a mitigation measure.

Median-mounted acoustic panels and "T"-top noise wall

Both the median-mounted acoustic panels and the "T"-top noise wall are considered to be innovative noise mitigation measures that would be suitable for use on the Ohio Turnpike. Either mitigation measure could be used at a length of approximately 2,400 feet at one NSA along the turnpike or both measures could be used at two different NSAs at approximate lengths of 1,200 feet. Since the goal of the project is to evaluate the potential noise reduction benefits of innovative noise mitigation measures, it was determined that both measures could be adequately evaluated at shorter lengths. Results of the measures could then be compared to determine whether either measure could be used for future mitigation. Therefore, it was determined that both measures be implemented and evaluated at separate locations along the turnpike.

6.2 Pilot Program Locations

The final selection of the locations for the pilot programs were based primarily on the amount of funds available to implement the two mitigation measures which is now estimated at $450,000. The $450,000 budget was further broken down to an estimate of $220,000 for implementing the median-mounted acoustic panels and $230,000 for implementing the "T"-top noise barrier wall.

Sound Fighter median-mounted acoustic panels

Assumptions used in selecting the location of the pilot program for the median-mounted acoustic panels:

- The pilot program location should be somewhat level with noise receptors situated at the same relative elevation as the turnpike.

- There should be few or no noise sensitive sites located opposite the pilot program location to limit the potential for reflected noise impacts from the back side of the acoustic panels.
- There should be a tight grouping of receptor sites within a distance of 200' of the turnpike pavement.
- The minimum length of installed acoustic panels should be at least 900' to adequately monitor the effectiveness of the mitigation measure.

The Sound Fighter acoustic panels are approximately 14" in height. It was originally proposed that the acoustic panels be installed on the center median to a height of 5' above the median (a total height of 10'). According to the manufacturer, the acoustic panels could be installed at heights of either 4'-8" or 5'-9" on top of the center median. At a cost of approximately $25 ft^2, an installed price at a height of 5'-9" and a length of 1,000' would cost $220,000. This is about the maximum available funding for absorbent panels. An installed price with an acoustic panel height of 4'8" and a length of 1,200' would be $221,500 and within the range of the maximum allowable cost. The NSAs along the turnpike were re-evaluated to find suitable locations with lengths somewhere between a 900' minimum length and a 1,200' maximum length. Three suitable locations met the above criteria.

- <u>NSA 35</u> is located on the north side of the turnpike west of Usher Road. At this location, a 1,200-foot long median panel barrier could be constructed at a height of 4'-8". This is a good potential site for the pilot program having 14 homes located approximately 150' off the turnpike pavement. The cost of the median-mounted acoustic panels at this location would be approximately $221,500.

- <u>NSA 40 (east)</u> is located on the north side of the turnpike just west of the Sprague Road overpass. At this location, a 1,100-foot long median panel barrier could be constructed at a height of 5'-9". This site meets the location criteria and has 13 receptor sites located within 150' off the turnpike pavement. The cost of the median-mounted acoustic panels at this location would be approximately $239,900. NSA 40 (east) is a good location for the pilot program but not an ideal location considering there are three homes located opposite the NSA. The total cost at a height of 5'-9" would likely exceed the budget for the project but the cost could be reduced by lowering the panel height along certain sections of the median.

- <u>NSA 47</u> is located on the south side of the turnpike and west of West 130th Street. NSA 47 is a smaller, more compact NSA where a shorter section of median-mounted acoustic panels could be evaluated. At this location, a 900-foot long median barrier could be constructed at a height of 5'-9". The cost of the median panels at this location would be approximately $191,500. The total cost of implementing the median-mounted acoustic panels at this location would cost approximately $30,000 less than the other NSAs considered for the pilot program. One consideration in selecting this site for the pilot program is the savings of approximately $30,000 that could be used to construct a higher or longer "T"-top noise barrier.

<u>Whisper Wall "T"-top concrete noise barrier</u>
Assumptions used in selecting the location of the pilot program for the "T"-top noise barrier wall:

- The "T"-top noise barrier would be constructed approximately 2 feet within the turnpike right-of-way line. However, locating a noise barrier along the right-of-way line will likely result in a higher installation cost as opposed to construction along the edge of shoulder and may impact existing vegetation along the right-of-way.

- An underground fiber optic communication line is located along the north right-of-way line. The selection of a pilot program location along the north right-of-way line could result in additional project cost if the line were to be relocated. Therefore, the optimum location for the "T"-top noise barrier would be along the south right-of-way line.
- The pilot program location should be somewhat level with noise receptors situated at the same relative elevation as the turnpike.
- The side of the noise barrier facing the turnpike will be constructed of noise absorptive material having a noise reduction coefficient of approximately 1.0. Reflected noise should not be a problem and the noise barrier could be located opposite other noise sensitive receptors without the concern of reflected noise.
- There should be a tight grouping of receptor sites within a distance of 200' of the turnpike pavement.
- The minimum length of the "T"-top noise wall should be at least 900' to adequately monitor the effectiveness of the mitigation measure.

The "T"-top barrier will be approximately 9' in height. The "T", or top section of the wall, will extend a minimum horizontal distance of one foot on both sides of the wall and the top surface of the "T" will be comprised of absorptive material. According to the manufacturer and their recommended installer, the cost of installed "T"-top barrier along the turnpike right-of-way fence would cost approximately \$24 ft^2. At this cost, an installed price at a height of 9' and a length of 1,100' would cost about \$237,000. This is about the maximum available funding for the "T"-top noise barrier. The NSAs along the turnpike were re-evaluated to find suitable locations with lengths somewhere between the 900' minimum length and a 1,100' maximum length. Three suitable locations met the above criteria.

- <u>NSA 35</u> is located on the north side of the turnpike west of Usher Road. At this location, a 1,200-foot long noise barrier could be constructed at a cost of \$259,000. This is an excellent site for the pilot program having 14 homes located approximately 150' off the turnpike pavement. However, there is potential for conflict with the underground fiber optic line. It would also cost about \$30,000 more than the suggested maximum cost, but is still worth considering as sections of noise barrier could be reduced in height to get closer to the maximum allowable budget.

- <u>NSA 39 (west)</u> is located on the south side of the turnpike west of the Sprague Road overpass. The potential pilot location would be located in the west area of NSA 39 in what appears to be a group of condominiums or large homes having eight structures located within 250' of the turnpike pavement. This pilot location could utilize a shorter section of noise barrier of approximately 900' in length at an approximate cost of \$195,400. Having an estimated cost of about \$35,000 less than the expected budget for the "T"-top noise wall, the additional funds could be used in combination with a longer median-mounted acoustic panel location.

- <u>NSA 39 (east)</u> is located on the south side of the turnpike west of the Sprague Road overpass. The pilot program would be located in the east area of NSA 39 which consists of a residential development having approximately 21 homes located within 250' of the turnpike pavement. A noise barrier at this location would require a length of approximately 1,200' at a cost of about \$259,000. Similar to NSA 35, NSA 39 (east) would cost about \$30,000 more than the suggested maximum budget. However, it is still worth considering as sections of noise barrier could be reduced in height to get closer to the maximum allowable budget.

Recommendation

For the Sound Fighter acoustic panels, it is recommended that NSA 47 be selected for the pilot program. The site meets all the selection criteria for the median-mounted acoustic panels. There are eight homes within 200 feet of the turnpike pavement and it is believed that this site would work well to accurately evaluate the median-mounted acoustic panels. A major consideration in the selection of this site for the pilot program is the overall cost. It is estimated that a 900' section of acoustic panels could be installed at a cost of approximately $191,500 at a panel height of 5'-9" (total height 10'-9"). This represents an implementation cost of approximately $30,000 less that the other suitable sites for acoustic panels. The additional funds may be used in implementing the "T"-top noise wall which is a relatively more expensive measure to implement on a lineal foot basis.

For the Whisper Wall "T"-top noise wall, it is recommended that NSA 39 (east) be selected for the pilot program. The site meets all the selection criteria and, similar to the absorbent panels, it is believed that a longer test section would work best to accurately evaluate the "T"-top barrier. It is estimated that the noise wall could be installed at a cost of approximately $259,000 for a nine-foot high wall.

The combination of the Sound Fighter acoustic panels implemented at NSA 47 at an estimated cost of $191,500 and the Whisper Wall "T"-top noise wall implemented at NSA 39 (east) at an estimated cost of $259,000 would total $450,500. The recommended locations for each mitigation measure will fit the total estimated budget of $450,000.

SECTION 7.0
REFERENCES

Section 7.0
References

<u>General</u>

Federal Highway Administration. *Highway Traffic Noise Analysis and Abatement – Policy and Guidance*. June 1995.

Ohio Department of Transportation. *Standard Procedure for Analysis and Abatement of Highway Traffic Noise*. Standard Procedure No. 417-001 (SP). August 4, 2008

Queensland Department of Roads, Tugun Bypass Environmental Impact Statement. Technical Paper 10 – Noise and Vibration. 1999.

<u>Pavements</u>

CALTRANS, *Sound Engineering – Innovations in Pavement*. California Transportation Journal Volume 3, Issue 4, January 2003.

Cohn, L.F., Harris, R.A. Department of Civil Engineering University of Louisville, KY. *Special Noise Barrier Applications Phase III,* Final Technical Report, Washington State Department of Transportation,1996.

Engle, E., Mujeeb, M., Gansen E. Evaluation of Recycled Rubber in Asphalt Cement Concrete – Field Testing. Iowa Department of Transportation, Materials Research Division. October 2002.

Hall, S.M., Lane, D.A. Evaluation of Rubberized Hot Mix Asphalt for use on Tennessee Roadways. Tennessee Department of Transportation Division of Material and Tests. March 2001.

Hanson, James and Waller. Pavement/Tire Noise Study for the Arkansas Asphalt Pavement Alliance (APA). National Center for Asphalt Technology, Auburn University, Auburn, Alabama. January 2005.

McDaniel R. S. *Field Evaluation of Porous Asphalt Pavement* Final Report SQDH 2004-3 The Institute for Safe, Quiet and Durable Highways. May 2004.

Muench, S. T. Hawaii Department of Transportation Hawaii Asphalt Pavement Industry (HAPI) *Asphalt Pavement Guide.* 2003

Ministry of Transportation & Highways of British Columbia. *Assessment of Traffic Noise Reduction Performance of Open Graded Asphalt or "Quiet Pavement" Phase 4/End of Project Report.* Victoria, British Columbia, 1999.

National Asphalt Pavement Association (NAPA) guide for Hot Mix Asphalt Pavement

U.S. Department of Transportation, Federal Highway Administration. Highway Traffic Noise-Guidance on Quiet Pavement Pilot Programs and Tire/Pavement Noise Research

U.S. Department of Transportation, Federal Highway Administration. Quiet Pavements – A Scanning Tour of Denmark, The Netherlands, France, Italy and The United Kingdom. 2007

Washington State Department of Transportation (WSDOT). *Quieter Pavements: Options & Challenges for Washington State*. WSDOT, 2005.

http://www.dot.state.co.us/publications/Brochures/PavementTypeBrocureFinalJuly.pdf

http://www.asphaltmagazine.com/singlenews.asp?item_ID=988&comm=0&list_code_int=MAG01-INT

Innovative Noise Barriers

Chang, W.F., Lee, Y.Y., Cheng, G.F. The Application of a New Roadside Barrier to Traffic Noise Mitigation. Hong Kong Polytechnic Institute. 2003.

Egan, C.A., Chilekwa, V. and Oldham, D. J., *An Investigation of the Use of Top Edge Treatments to Enhance the Performance of a Noise Barrier Using the Boundary Element Method*. Acoustic Research Unit, University of Liverpool UK, 2006.

European Commission Directorate-General Environment Policy area: Noise. Inventory of Noise Mitigation Measures. July 2002.

Morgan, P.A., Dutch Innovation Programme (IPG) *Review of Japanese Noise Barrier Research*, DWW-2004-081. December 2004.

Padmos, C.J., de Roo, F. How to Predict the Far Field Effect of Barrier Tops From Diffraction Test Results. International Congress on Acoustics, 2007.

Watson, Dustin, HDR Engineering, Inc. Evaluation of Benefits and Opportunities for Innovative Noise Barrier Designs. Final report 572. Arizona Department of Transportaion. 2006.

Acoustic Panels

Sonic Stop Noise Abatement Panels
http://www.sonicstopcorp.com/noise_solution.html

Acoustax Noise Barrier Panels
http://www.acoustax.com/

Sound Fighter Systems
http://www.soundfighter.com/

RockDelta Green
http://www.kohlhauer.com/englisch/produkte-opakter-laermschutz-rockdelta-green.php

Silent Screen Panels
http://www.empireacoustical.com/Acoustical_Panels/Index.htm

Acoustical sound Blankets

http://www.environmental-noise-control.com/blankets.html
Calm Tracks and Routes
http://www.calmtracks.com/home/index.php

Vegetation

Anderson, L.M., Mulligan, B.E., Goodman, L.S. Effects of Vegetation on Human Response to Sound. Jpurnal of Arboriculture, February 1984, pp. 45-49.

Aylor, D.E., and L.E. Marks. 1976. *Perception of noise transmitted through barriers.* J. Acoustical Society of America 59: 397-400.

Cook, D.I. 1980. Trees, solid barriers, and combinations: Alternatives for noise control. In: Proceedings, National Urban Forestry Conference, November 13-16, 1978, Washington DC. Syracuse, NY: State University of New York, College of Environmental Science and Forestry, ESF Publication 80-003; pp. 330-339.

Harris, R.A. Assoc. Member, ASCE, (Assoc. Prof., Dept. of Civ. Engrg., Univ. of Louisville, Louisville, Ky. 40292) and Cohn, L.F., Member, ASCE, (Prof. and Chmn., Dept. of Civ. Engrg., Univ. of Louisville, Louisville, Ky. 40292) *Use of Vegetation for Abatement of Highway Traffic Noise Journal of Urban Planning and Development*, Vol. 111, No. 1, November 1985, pp. 34-48

Mulligan, B.E., L.S. Goodman, M. Faupel, S. Lewis, and L.M. Anderson. 1982. Interactive effects of outdoor noise and visible aspects of vegetation on behaviour. In: Proceedings, Southeastern Recreation Researchers Conference, February 18-19, 1981, Asheville, NC, pp. 265-279.

APPENDIX A

Figure 1 – Noise Sensitive areas (NSA) Location Map
Figure 2A, 2B and 2C – NSA Detail Maps
Figure 3A and 3B Mitigation Measure Locations

Noise Sensitive Area (NSA) Locations

NSA	Approx MP	MP Range	Length	Receptors	Elevation	Distance	LEQ (dB)
1	48	39-52	4650	85	At Grade	100	
2	51	39-52	4025	90	Fill	90	77.1
3	56	52-59	850	60	Fill	75	
4	57	52-59	1685	30	At Grade	250	
5	57	52-59	1200	8	At Grade	230	57.4
6	58	52-59	1675	20	Cut	240	
7	58	52-59	3450	70	At Grade	50	
8	59	52-59	1605	50	Cut	90	
9	59	52-59	2645	55	At Grade	100	
10	60	59-64	1650	50	Fill	130	
11	60	59-64	1500	Park	At Grade	0	
12	61	59-64	2520	50	At Grade	100	
13	61	59-64	580	24	At Grade	60	
14	61	59-64	3815	40	Fill	130	
15	62	59-64	3900	65	At Grade	100	
16	61	59-64	2300	40	Fill	180	
17	62	59-64	3920	100	At Grade	70	69.5
18	63	59-64	1505	15	Cut	130	
19	63	59-64	2125	15	Fill	100	
20	63	59-64	1200	7	Fill	250	
21	64	59-64	2800	25	At Grade	80	
22	67	64-71	1600	25	At Grade	70	
23	70	64-71	1265	30	Fill	140	61.1
24	140	135-140	1200	15	At Grade	60	74.8
25	145	142-145	2070	50	Fill	110	
26	146	145-151	1685	50	Cut	125	
27	146	145-151	2240	10	Cut	130	
28	147	145-151	4270	80	Cut	75	74.8
29	147	145-151	1180	20	Fill	260	
30	147	145-151	1650	28	Fill	260	
31	148	145-151	1490	30	Fill	100	
32	148	145-151	1535	25	Fill	100	
33	153	152-161	2085	20	At Grade	140	
34	155	152-161	1630	20	At Grade	150	
35	156	152-161	2700	35	At Grade	100	
36	157	152-161	2575	70	At Grade	70	
37	157	152-161	1135	25	Cut	180	
38	158	152-161	1040	10	Fill	230	
39	158	152-161	5405	100	Fill	40	
40	158	152-161	6495	160	At Grade	100	63.9
41	159	152-161	870	15	At Grade	85	
42	160	152-161	2650	50	At Grade	60	
43	160	152-161	1580	15	Cut	200	
44	161	152-161	1635	55	At Grade	125	
45	162	161-173	1040	12	Cut	160	
46	163	161-173	1390	15	At Grade	110	
47	164	161-173	1965	25	At Grade	60	
48	164	161-173	2510	42	At Grade	80	
49	166	161-173	3655	25	Fill	190	66.8
50	171	161-173	3931	20	Fill	140	
51	183	180-187	1995	10	Cut	160	
52	184	180-187	3260	20	Cut	270	
53	184	180-187	2765	18	Cut	220	59.0
54	187	180-187	1730	10	Cut	235	
55	188	187-193	4260	50	Fill	170	
56	188	187-193	2750	35	Fill	90	62.1
57	189	187-193	5110	75	all 3	110	
58	193	187-193	1550	100	Fill	80	
59	194	193-209	1225	35	Fill	85	
60	204	193-209	2710	60	Cut	120	
61	216	215-216	4200	50	At Grade	150	69.0
62	222	218-232	1110	10	Cut	210	
63	225	218-232	1065	13	Cut	150	
64	226	218-232	2570	20	Cut	150	
65	227	218-232	1740	48	Fill	90	
66	228	218-232	3525	56	At Grade	130	69.9
67	229	218-232	3135	40	Fill	150	

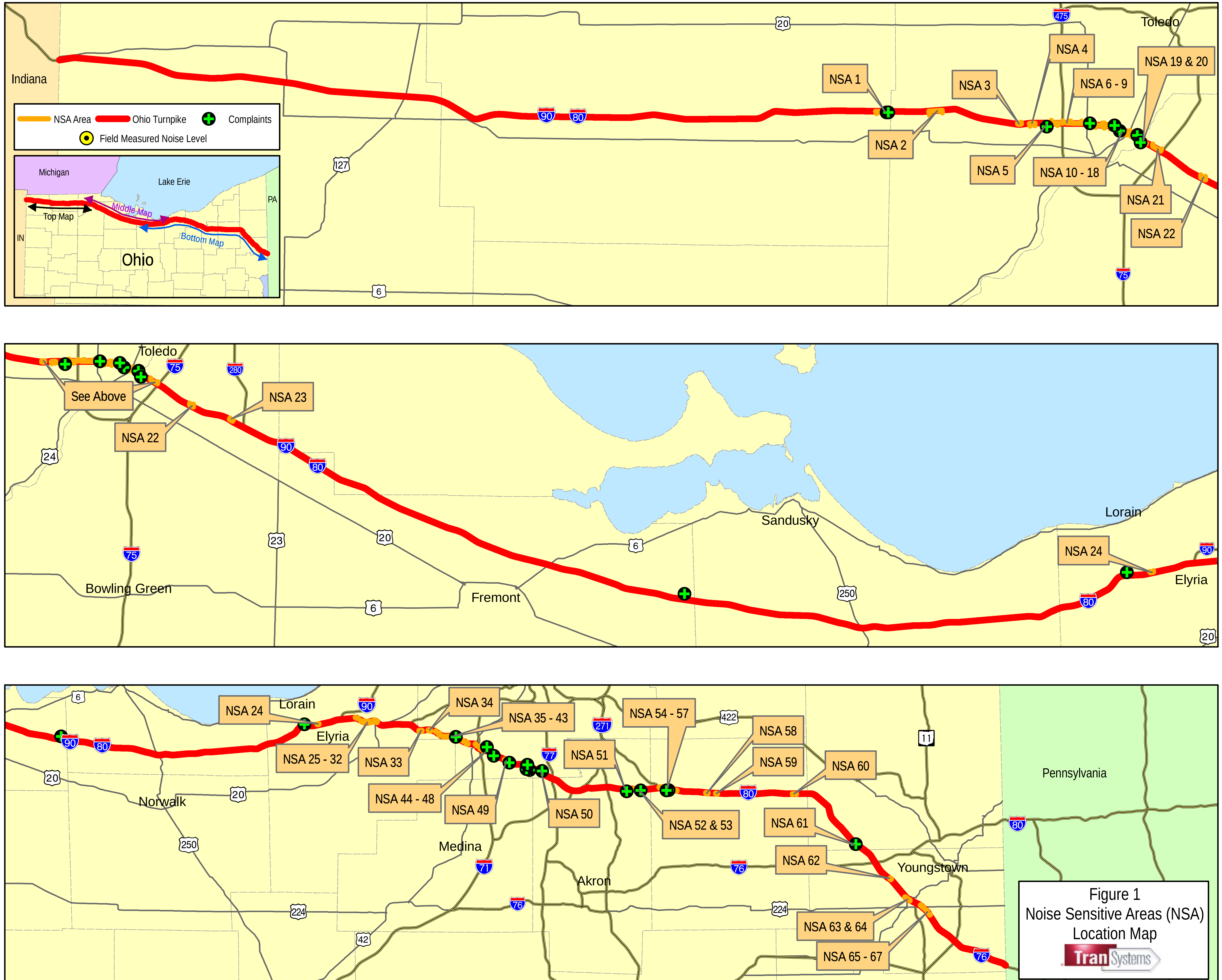


Figure 1
Noise Sensitive Areas (NSA)
Location Map

TranSystems

Figure 2A
NSA Detail Map

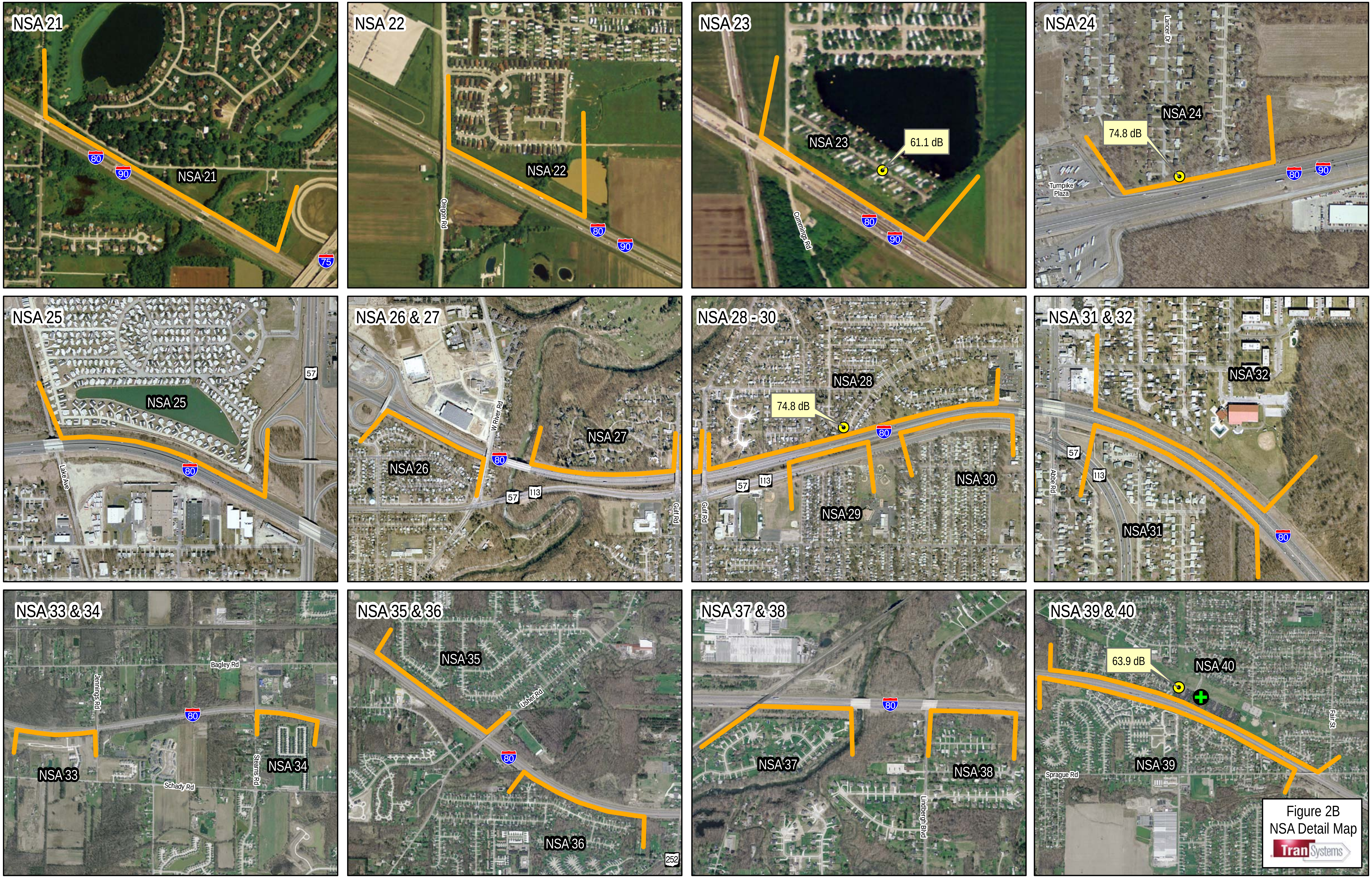


Figure 2B
NSA Detail Map

Figure 2C
NSA Detail Map

Figure 3A - NSA 47
Acoustic Panel Location

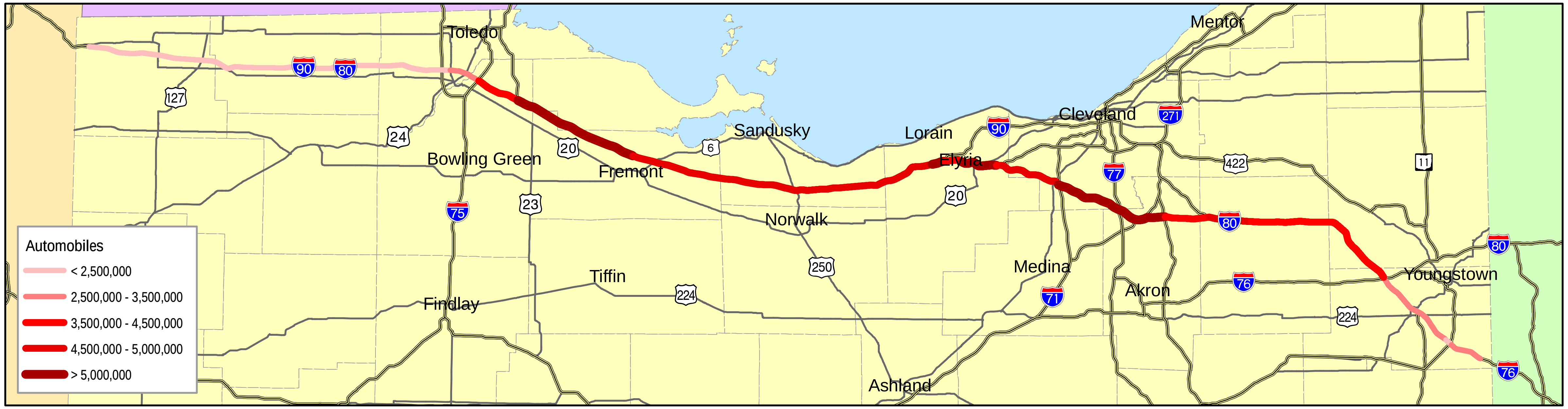
Figure 3B - NSA 39
"T"-Top Noise Barrier
Location
NSA 39 (east)
Ohio Turnpike (Tollroad)
Sonora
Canter Circle
Shetland Circle
Bridle Ln
Trotter Ln
Yearling Dr
Starlite Dr
Sprague Rd
80
Potential "T" Top Noise Barrier
1,200' Along Right-of-Way
© 2008 Tele Atlas
579 ft
17 T 426990.80 m E 4578255.73 m N
elev 797 ft
Jun 2007
Eye alt 2802 ft
Google
N

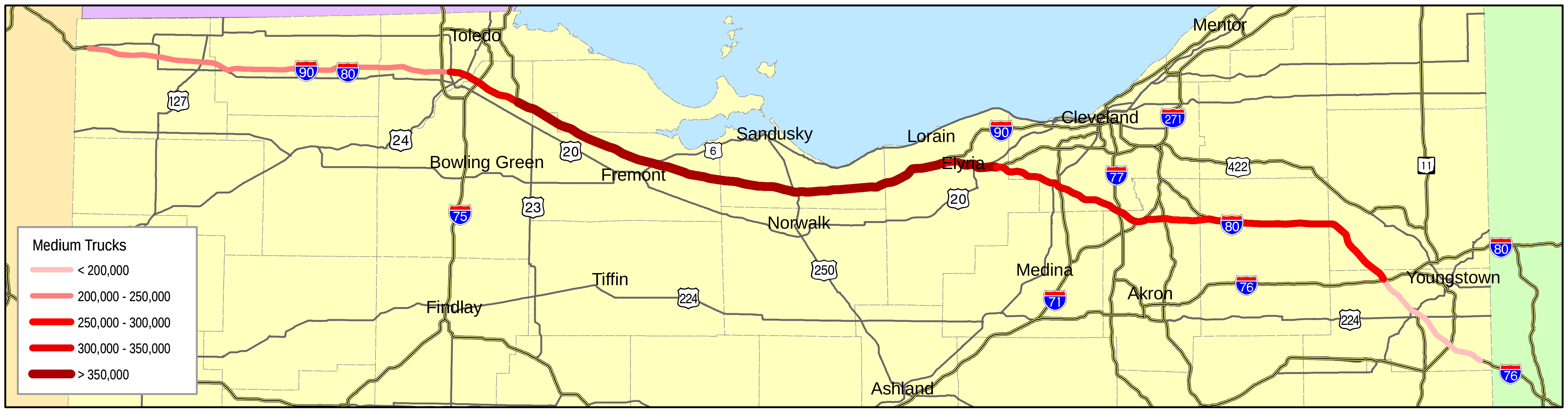
APPENDIX B
Traffic Data

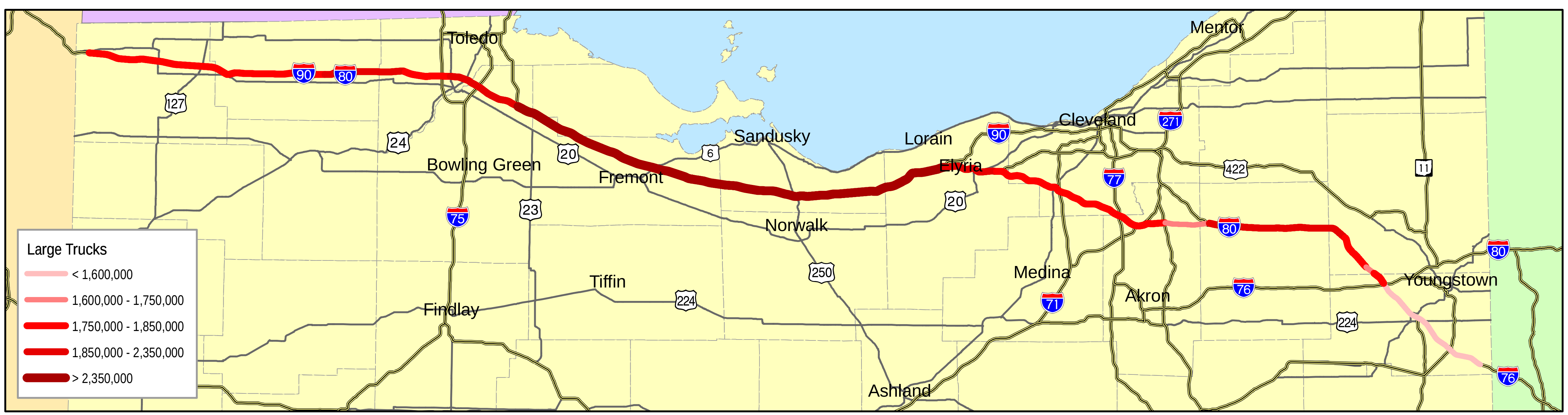
Ohio Turnpike
East Bound Traffic

December Year to Date, 2007

Miles	Automobiles	Medium Trucks	Large Trucks
2-13	1,940,704	237,248	1,794,341
13-25	2,092,916	245,178	1,809,416
25-34	2,193,294	249,393	1,816,451
34-39	2,365,214	257,301	1,830,263
39-52	2,455,573	261,239	1,855,099
52-59	2,489,026	260,033	1,833,488
59-64	3,377,068	311,344	1,882,553
64-71	3,885,545	325,347	1,892,449
71-81	5,258,063	400,945	2,408,877
81-91	5,098,446	396,543	2,406,564
91-110	4,890,327	388,292	2,433,963
110-118	4,573,505	371,830	2,399,871
118-135	4,538,556	362,066	2,359,862
135-140	4,682,531	369,023	2,357,285
140-142	5,092,420	380,157	2,358,695
142-145	4,011,752	307,893	2,010,144
145-151	6,371,980	376,035	2,126,858
151-152	4,126,065	293,729	1,778,681
152-161	4,639,144	308,294	1,799,699
161-173	5,453,709	326,258	1,821,383
173-180	5,379,125	304,253	1,772,475
180-187	3,916,501	273,140	1,673,688
187-193	4,820,852	314,376	1,880,199
193-209	4,498,196	301,289	1,867,821
209-215	4,101,357	288,811	1,806,379
215-216	3,938,454	274,766	1,740,658
216-218	4,049,646	279,210	1,770,328
218-232	2,534,181	175,880	840,141
232-234	2,416,664	165,532	803,551
234-239	2,877,464	193,923	898,398



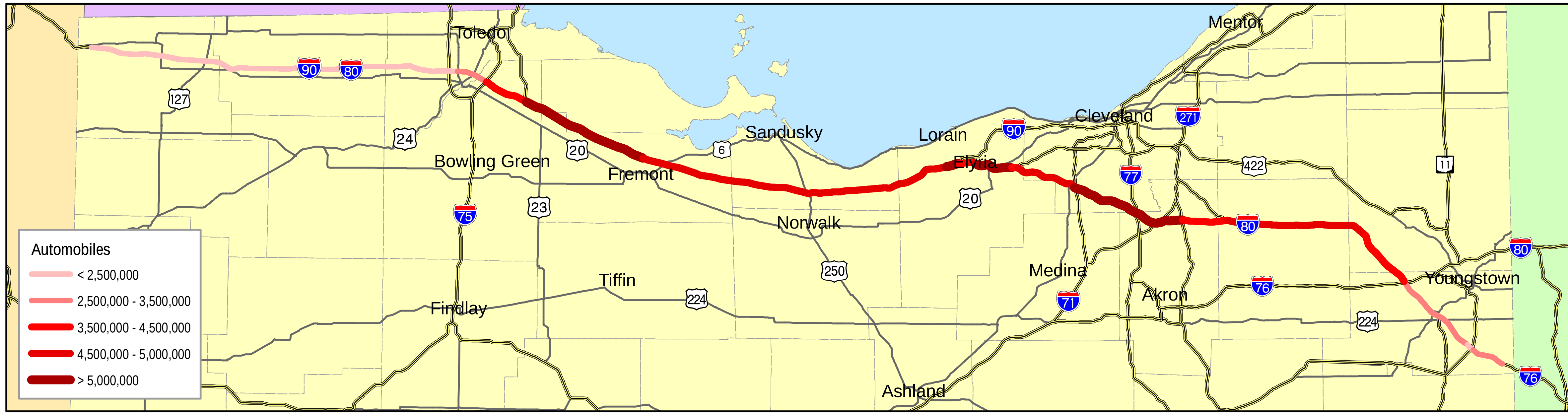


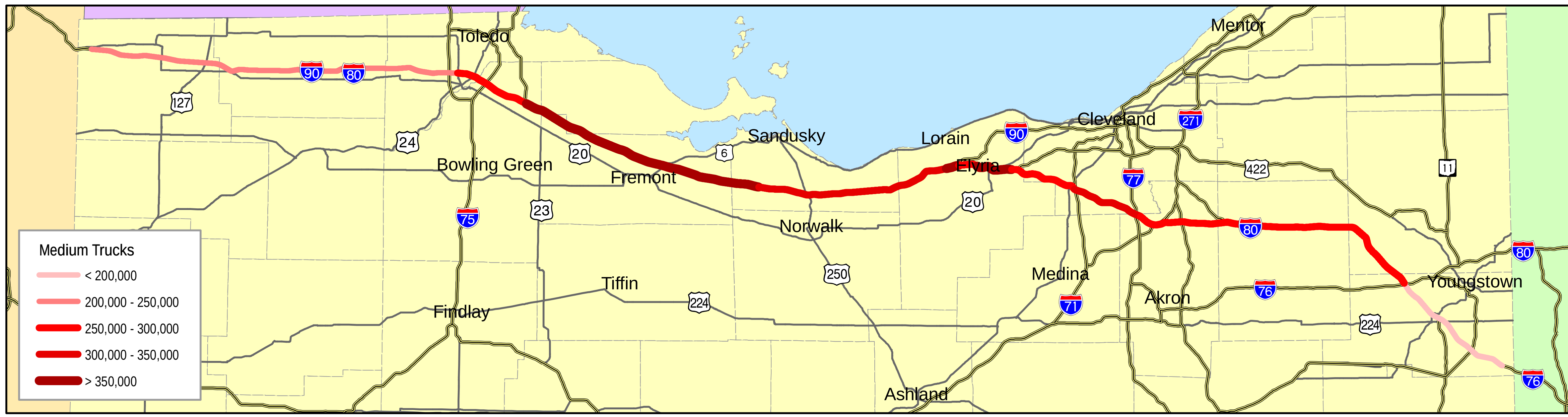


Ohio Turnpike
West Bound Traffic

December Year to Date, 2007

Miles	Automobiles	Medium Trucks	Large Trucks
2-13	1,974,738	208,551	1,744,791
13-25	2,121,478	218,044	1,762,591
25-34	2,221,979	223,536	1,773,855
34-39	2,372,875	229,828	1,785,058
39-52	2,451,115	233,164	1,805,677
52-59	2,492,004	232,540	1,788,590
59-64	3,337,451	272,814	1,827,548
64-71	3,945,221	288,886	1,874,409
71-81	5,232,490	366,833	2,392,570
81-91	5,035,892	361,526	2,386,565
91-110	4,845,623	356,430	2,413,256
110-118	4,641,433	344,752	2,365,555
118-135	4,594,657	338,233	2,336,033
135-140	4,779,775	346,647	2,337,066
140-142	5,221,270	357,007	2,340,359
142-145	4,038,110	283,013	1,952,851
145-151	6,419,755	355,844	2,077,942
151-152	4,187,058	274,589	1,744,474
152-161	4,695,341	291,463	1,771,106
161-173	5,468,762	308,215	1,805,018
173-180	5,439,426	286,072	1,747,864
180-187	3,943,336	252,113	1,661,218
187-193	4,869,406	295,443	1,886,461
193-209	4,544,262	285,048	1,878,609
209-215	4,117,215	272,070	1,766,179
215-216	3,964,504	257,515	1,702,784
216-218	4,108,537	262,820	1,734,133
218-232	2,532,707	163,646	897,335
232-234	2,479,431	157,935	871,503
234-239	2,984,409	185,959	994,572





APPENDIX C
Field Noise Measurement Data

QuestSuite Professional-OTC.sdat

2900 Integrating/Logging Sound Level Meter

FW Version: 02.4

Serial Number: CDE060039

Name:

Company:

Work Area:

Description:

Comments:

Group 1 Test 1

Test Started: 9/4/2008 9:30:52AM

Test Ended: 9/4/2008 9:51:51AM

Run Time: 00:20:58

Measuring Parameters

Range: 60 - 120 dB	Weighting: A	Time Constant: Fast
Threshold: Off	Exchange Rate: 3 dB	Peak Weighting: C

Summary

Peak Level: 108.4 dB, 9/4/2008 9:45:57AM

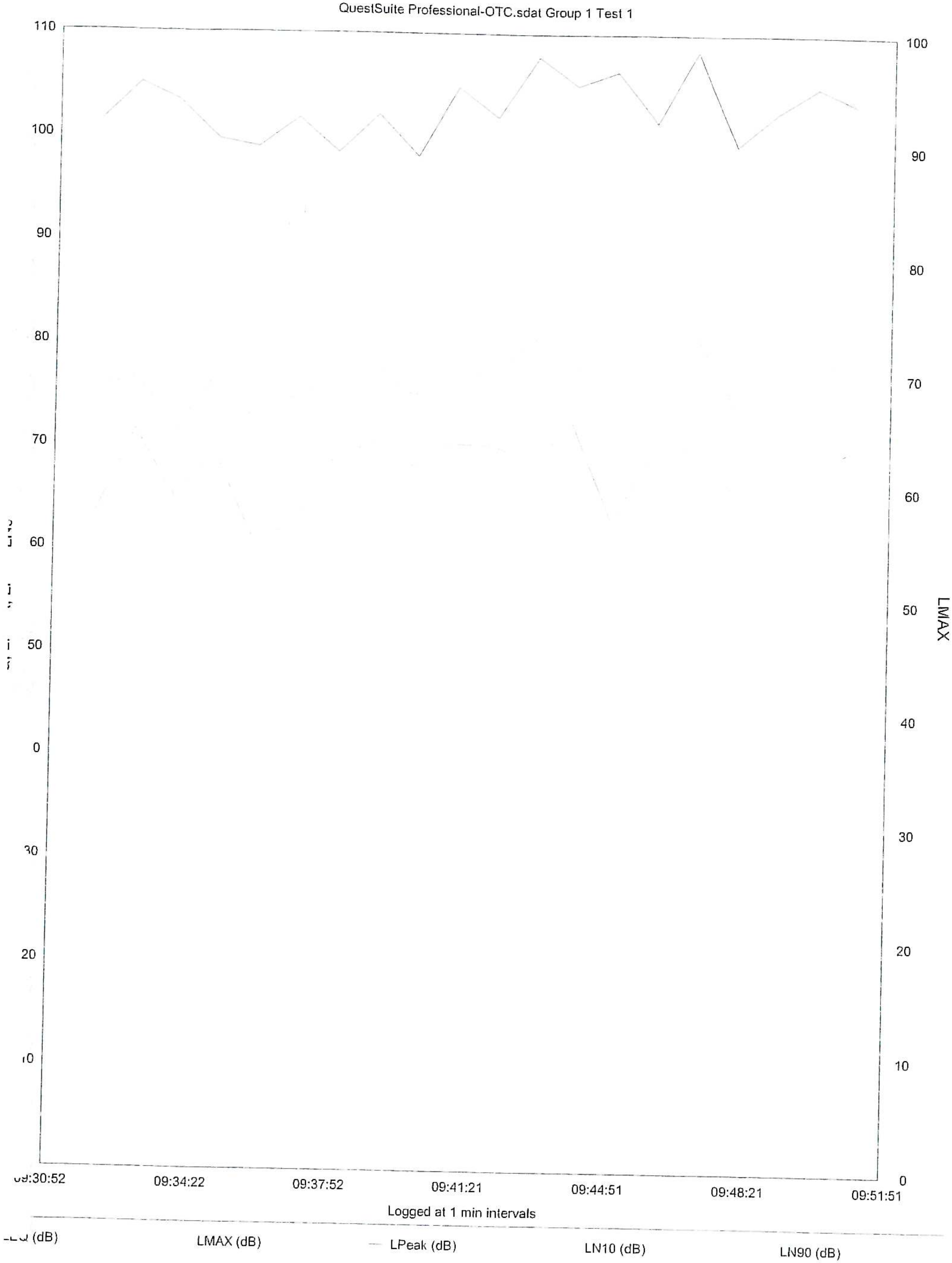
Max Level: 95.3 dB, 9/4/2008 9:45:56AM

Min Level: 59.7 dB, 9/4/2008 9:35:18AM

Overload: 0.00%

LEQ:	77.1 dB	SEL(3):	108.0 dB	TWA:	63.5 dB	TAKM5:	81.3 dB
LDN:	77.1 dB	CNEL:	77.1 dB	Pa2Sec:	25.3		
L5:	81.8 dB	L10:	80.4 dB	L50:	73.9 dB	L90:	66.8 dB

Comments:

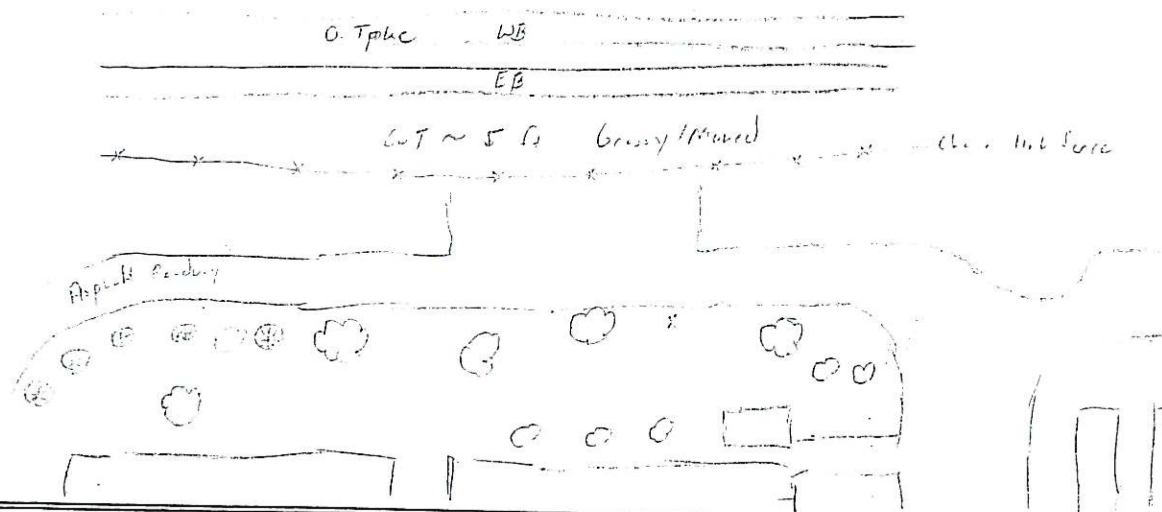

QuestSuite Professional-OTC.sdat Group 1 Test 1
110
100
90
80
70
60
50
0
30
20
10
100
90
80
70
60
50
40
30
20
10
0
LMAX
09:34:22
09:37:52
09:41:21
09:44:51
09:48:21
09:51:51
Logged at 1 min intervals
LMAX (dB)
LPeak (dB)
LN10 (dB)
LN90 (dB)

SOUND LEVEL DATA COLLECTION SHEET

DATE / TIME: 9-4-08	LOCATION: Ohio Turnpike
PROJECT NO.: 140050060	PERSONNEL: J.R. A/O
SITE: NSA - 2	WIND SPEED: 2.9 mph WIND DIR: NW
REL. HUMIDITY: 73.5	TEMP: Dry Bulb 69.9 °F Wet Bulb

EQUIPMENT MODEL: Quest 2900	SERIAL NO.:
CALIBRATION: Initial 112.2 Final 114.0	PROBLEMS: NA
DESCRIPTOR: LEQ	INTEGRATION RATE:
WEIGHTING: A	SAMPLE RATE: F

SITE DESCRIPTION / DRAWING:



SOUND LEVEL 1: 76.0 dBA	SOUND LEVEL 2: 77.2 dBA

NOTES:

- Train whistle @ 9:40 AM
- Tractor front loader on asphalt drive 2 x's

UCF, A great school

QuestSuite Professional-OTC.sdat

2900 Integrating/Logging Sound Level Meter

FW Version: 02.4

Serial Number: CDE060039

Name:

Company:

Work Area:

Description:

Comments:

Group 1 Test 2

Test Started: 9/4/2008 11:07:04AM
Test Ended: 9/4/2008 11:27:52AM
Run Time: 00:20:48

Measuring Parameters

Range:	60 - 120 dB	Weighting:	A	Time Constant:	Fast
Threshold:	Off	Exchange Rate:	3 dB	Peak Weighting:	C

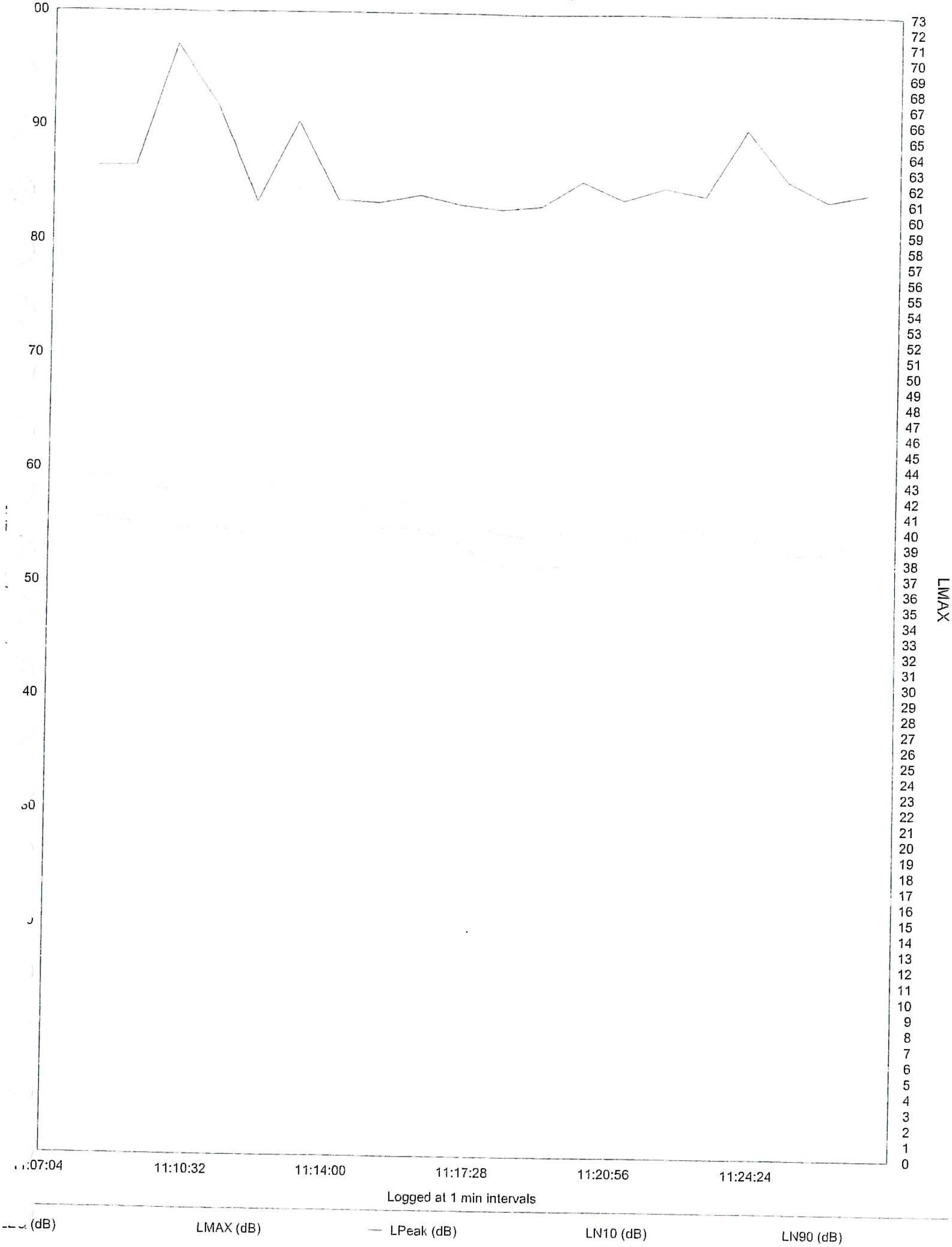
Summary

Peak Level: 97.1 dB, 9/4/2008 11:09:06AM
Max Level: 72.4 dB, 9/4/2008 11:12:47AM
Min Level: 51.6 dB, 9/4/2008 11:11:31AM
Overload: 0.00%

LEQ:	57.4 dB	SEL(3):	88.3 dB	TWA:	43.8 dB	TAKM5:	61.5 dB
LDN:	57.4 dB	CNEL:	57.4 dB	Pa2Sec:	0.3		
L5:	60.7 dB	L10:	59.4 dB	L50:	56.5 dB	L90:	53.3 dB

Comments:

QuestSuite Professional-OTC.sdat Group 1 Test 2

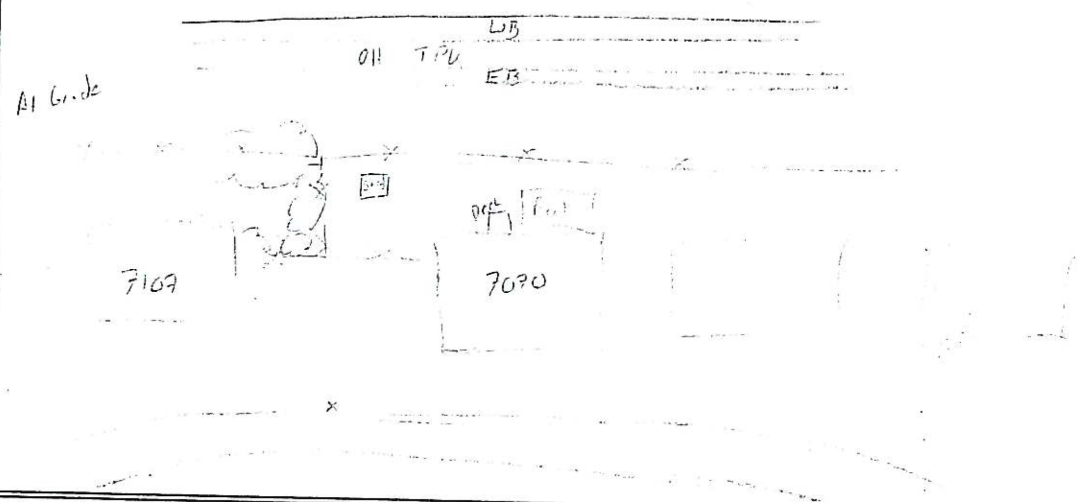


SOUND LEVEL DATA COLLECTION SHEET

DATE / TIME: 9-4-08	LOCATION: Country Club Rd MM 57 + 58 South
PROJECT NO.: P402060060	PERSONNEL: J. R. Alp
SITE: NJA-5	WIND SPEED: 1.5 MPH WIND DIR: NW
REL. HUMIDITY: 69.6	TEMP: Dry Bulb 73.4 °F Wet Bulb

EQUIPMENT MODEL: Quest 2900	SERIAL NO.:
CALIBRATION: Initial 114.0 Final	PROBLEMS: —
DESCRIPTOR: LEQ	INTEGRATION RATE: F
WEIGHTING: A	SAMPLE RATE:

SITE DESCRIPTION / DRAWING:



SOUND LEVEL 1: 59.4 LEQ	SOUND LEVEL 2: 57.5

NOTES:

- Dogs barking
- Can't see autos.
- shielded from the building (7090)

L max = 77.4
L min = 51.6

QuestSuite Professional-OTC.sdat

2900 Integrating/Logging Sound Level Meter

FW Version: 02.4

Serial Number: CDE060039

Name:

Company:

Work Area:

Description:

Comments:

Group 1 Test 3

Test Started: 9/4/2008 12:52:28PM
Test Ended: 9/4/2008 1:13:17PM
Run Time: 00:20:49

Measuring Parameters

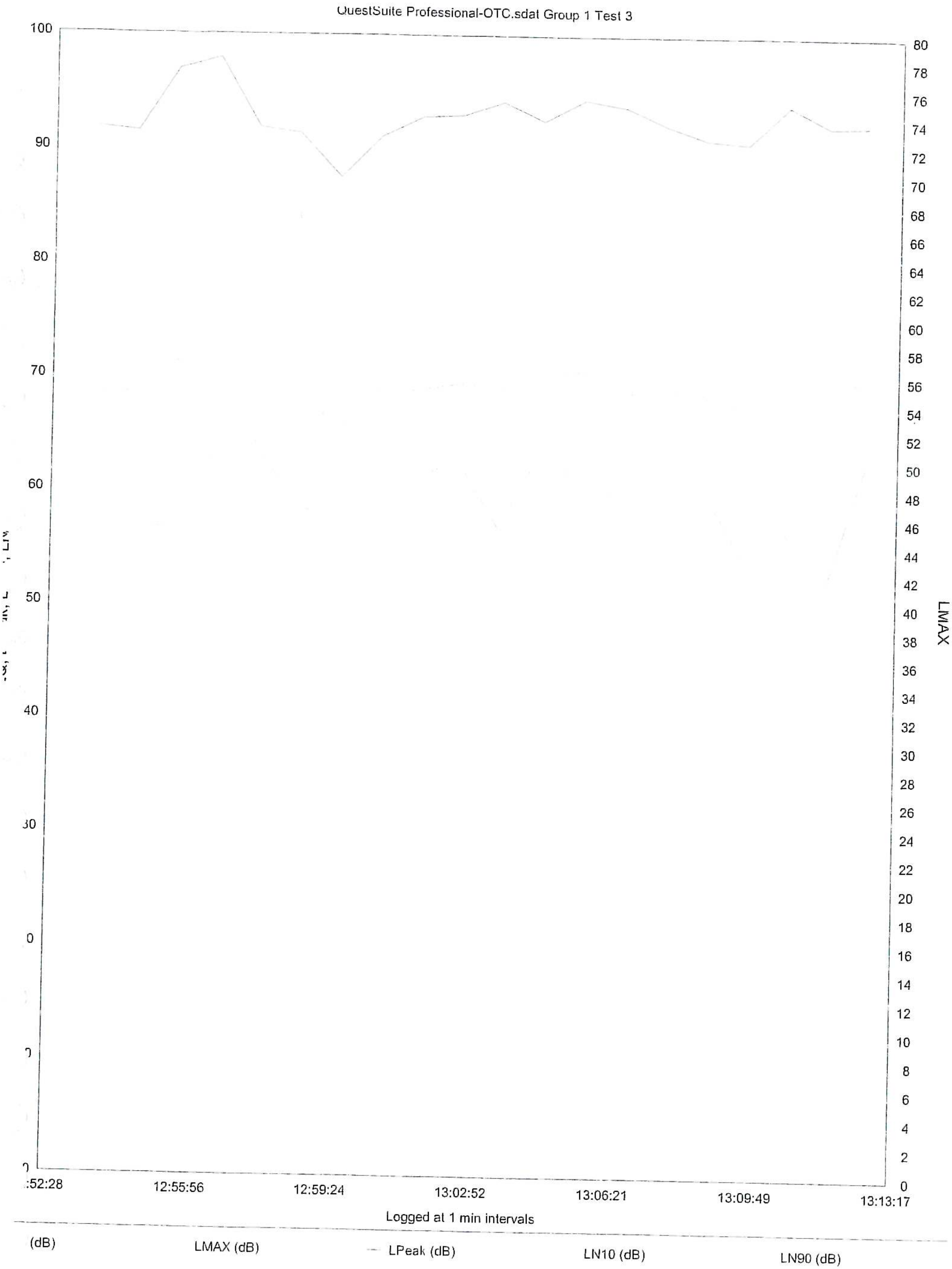
Range:	60 - 120 dB	Weighting:	A	Time Constant:	Fast
Threshold:	Off	Exchange Rate:	3 dB	Peak Weighting:	C

Summary

Peak Level: 97.9 dB, 9/4/2008 12:55:29PM
Max Level: 78.9 dB, 9/4/2008 1:04:51PM
Min Level: 51.6 dB, 9/4/2008 12:55:00PM
Overload: 0.00%

LEQ:	69.5 dB	SEL(3):	100.4 dB	TWA:	55.9 dB	TAKM5:	73.0 dB
LDN:	69.5 dB	CNEL:	69.5 dB	Pa2Sec:	4.4		
L5:	74.7 dB	L10:	73.4 dB	L50:	67.6 dB	L90:	59.1 dB

Comments:


QuestSuite Professional-OTC.sdat Group 1 Test 3
100
90
80
70
60
50
40
80
78
76
74
72
70
68
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
LMAX
:52:28
12:55:56
12:59:24
13:02:52
13:06:21
13:09:49
13:13:17
Logged at 1 min intervals
(dB)
LMAX (dB)
LPeak (dB)
LN10 (dB)
LN90 (dB)

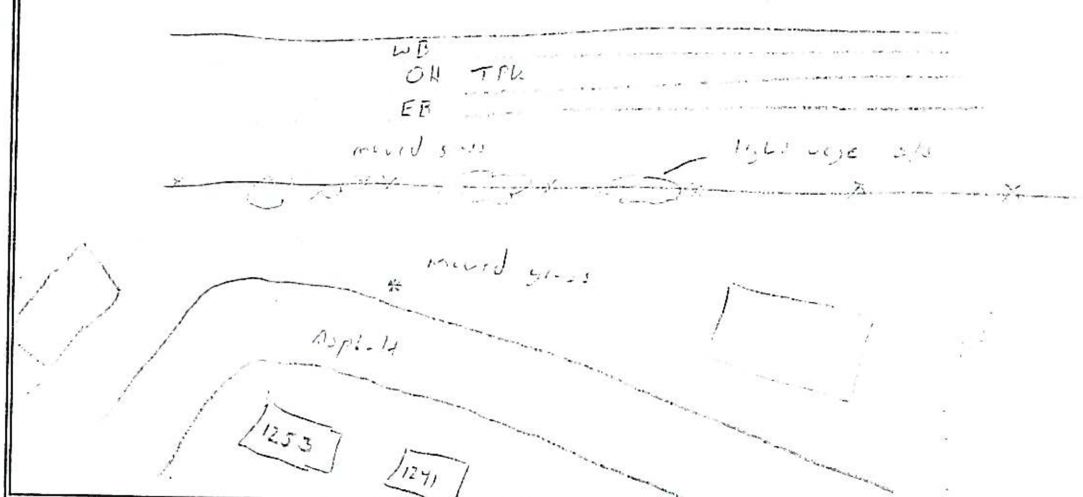
NSA-17

SOUND LEVEL DATA COLLECTION SHEET

DATE / TIME: 9-4-07	LOCATION: Toledo 1253 Riverdale / May Mm
PROJECT NO.: P402060060	PERSONNEL: J R. Arp
SITE: NSA 17	WIND SPEED: 2.2 mph WIND DIR: NW
REL. HUMIDITY: 66.3 %	TEMP: Dry Bulb 80.6 °F Wet Bulb

EQUIPMENT MODEL:	SERIAL NO.:
CALIBRATION: Initial 114 Final	PROBLEMS:
DESCRIPTOR: Leq	INTEGRATION RATE:
WEIGHTING: A	SAMPLE RATE: F

SITE DESCRIPTION / DRAWING:



SOUND LEVEL 1: 69.3 Leq	SOUND LEVEL 2: 68.6 Leq

NOTES:

Lmax = 74.9

Lmin = 51.6

QuestSuite Professional-OTC.sdat

2900 Integrating/Logging Sound Level Meter

FW Version: 02.4

Serial Number: CDE060039

Name:

Company:

Work Area:

Description:

Comments:

Group 1 Test 4

Test Started: 9/4/2008 1:58:16PM

Test Ended: 9/4/2008 2:20:19PM

Run Time: 00:22:02

Measuring Parameters

Range: 60 - 120 dB	Weighting: A	Time Constant: Fast
Threshold: Off	Exchange Rate: 3 dB	Peak Weighting: C

Summary

Peak Level: 96.2 dB, 9/4/2008 1:58:49PM

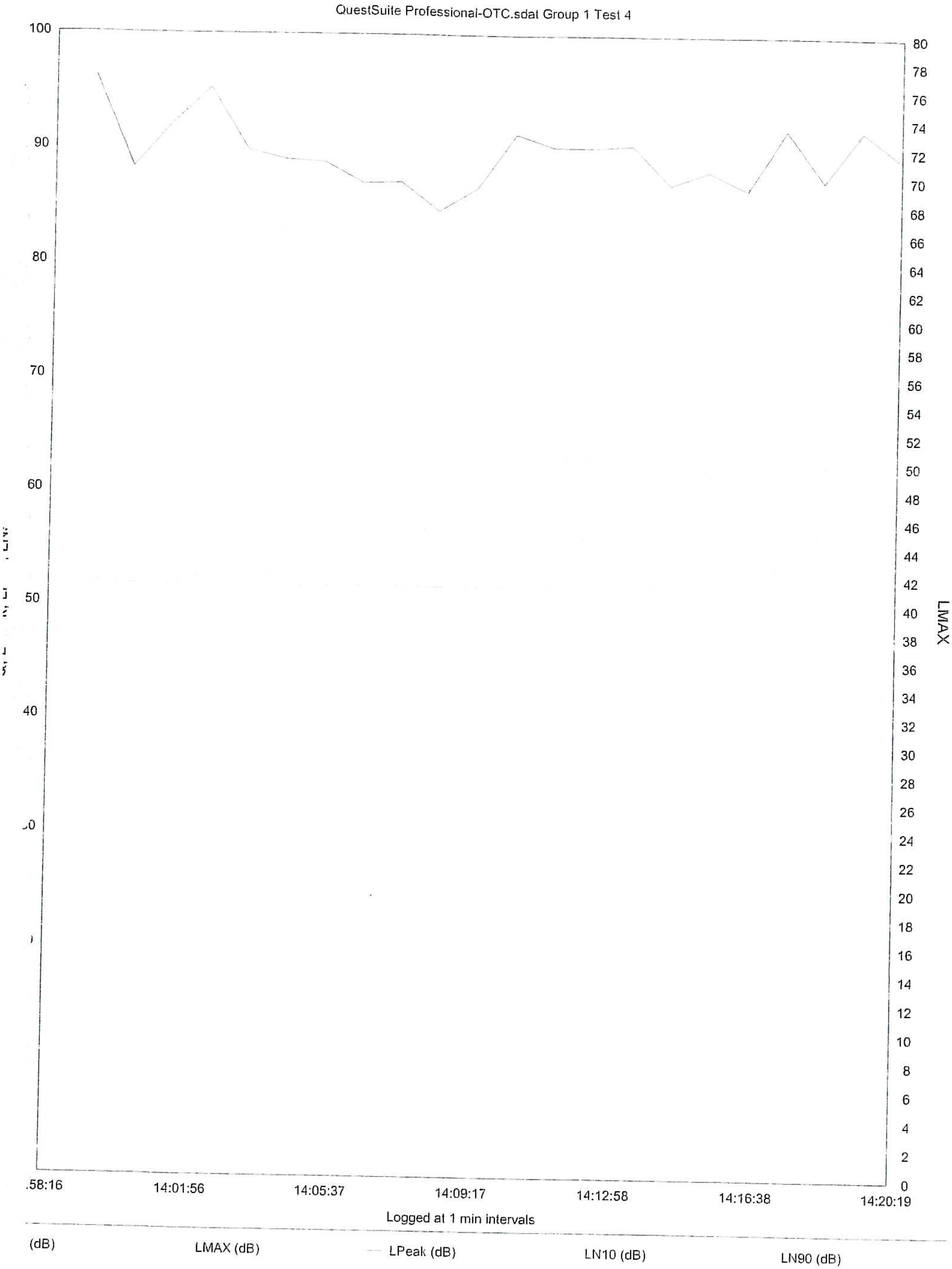
Max Level: 76.9 dB, 9/4/2008 2:10:53PM

Min Level: 51.6 dB, 9/4/2008 1:58:23PM

Overload: 0.00%

LEQ:	61.1 dB	SEL(3):	92.2 dB	TWA:	47.8 dB	TAKM5:	65.4 dB
LDN:	61.1 dB	CNEL:	61.1 dB	Pa2Sec:	0.7		
L5:	66.8 dB	L10:	65.4 dB	L50:	56.9 dB	L90:	51.6 dB

Comments:



QuestSuite Professional-OTC.sdat Group 1 Test 4
100
90
80
70
60
50
40
80
78
76
74
72
70
68
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
LMAX
.58:16
14:01:56
14:05:37
14:09:17
14:12:58
14:16:38
14:20:19
Logged at 1 min intervals
(dB)
LMAX (dB)
LPeak (dB)
LN10 (dB)
LN90 (dB)

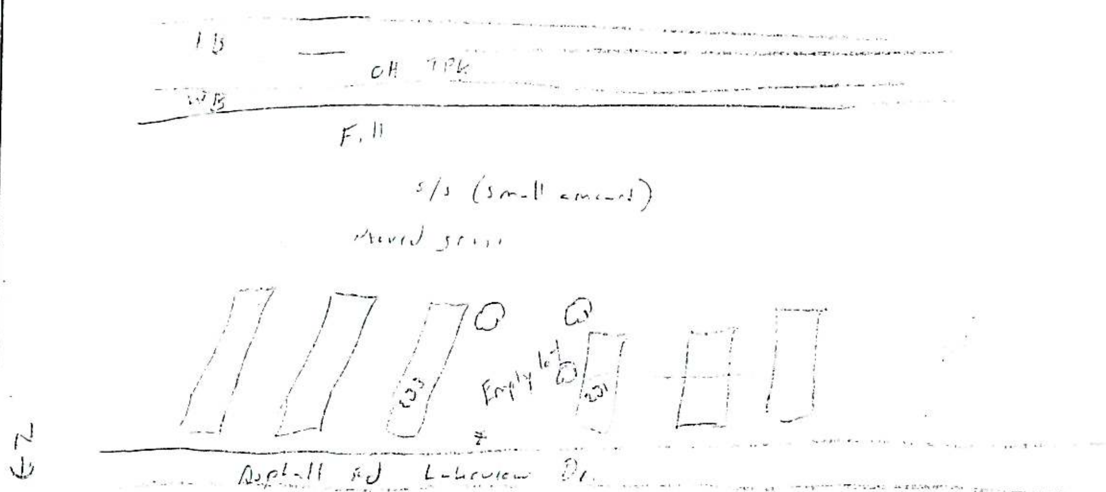
NSA-23

SOUND LEVEL DATA COLLECTION SHEET

DATE / TIME: 9-4-08	LOCATION: MM 70-71 North
PROJECT NO.: P402060060	PERSONNEL: J.R. ARP
SITE: NSA-23	WIND SPEED: 1.0 mph WIND DIR: NW
REL. HUMIDITY: 51.8 %	TEMP: Dry Bulb 91.9°F Wet Bulb

EQUIPMENT MODEL: Quest 290C	SERIAL NO.:
CALIBRATION: Initial Final	PROBLEMS:
DESCRIPTOR: LEQ	INTEGRATION RATE:
WEIGHTING: A	SAMPLE RATE: F

SITE DESCRIPTION / DRAWING:



SOUND LEVEL 1: 60.6 Leq	SOUND LEVEL 2: 61.1 Leq

NOTES:

Lmax = 76.9

Lmin = 51.6

UCF, A great school

QuestSuite Professional-OTC.sdat

2900 Integrating/Logging Sound Level Meter

FW Version: 02.4

Serial Number: CDE060039

Name:

Company:

Work Area:

Description:

Comments:

Group 1 Test 5

Test Started: 9/4/2008 4:10:40PM
Test Ended: 9/4/2008 4:31:05PM
Run Time: 00:20:25

Measuring Parameters

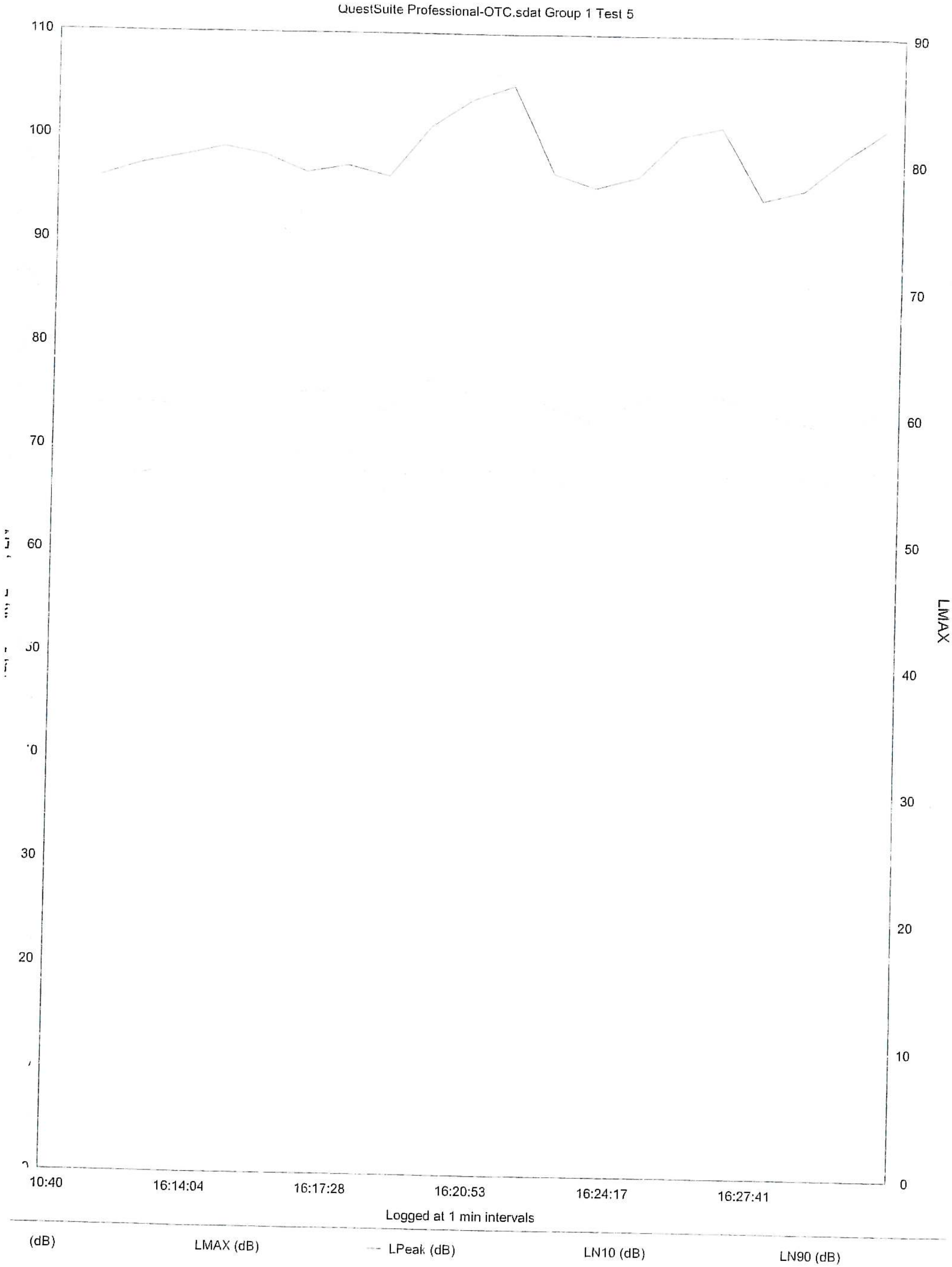
Range: 60 - 120 dB	Weighting: A	Time Constant: Fast
Threshold: Off	Exchange Rate: 3 dB	Peak Weighting: C

Summary

Peak Level: 105.0 dB, 9/4/2008 4:20:41PM
Max Level: 89.1 dB, 9/4/2008 4:20:40PM
Min Level: 60.4 dB, 9/4/2008 4:11:15PM
Overload: 0.00%

LEQ:	74.8 dB	SEL(3):	105.6 dB	TWA:	61.1 dB	TAKM5:	78.3 dB
LDN:	74.8 dB	CNEL:	74.8 dB	Pa2Sec:	14.4		
L5:	79.4 dB	L10:	78.3 dB	L50:	72.9 dB	L90:	67.4 dB

Comments:



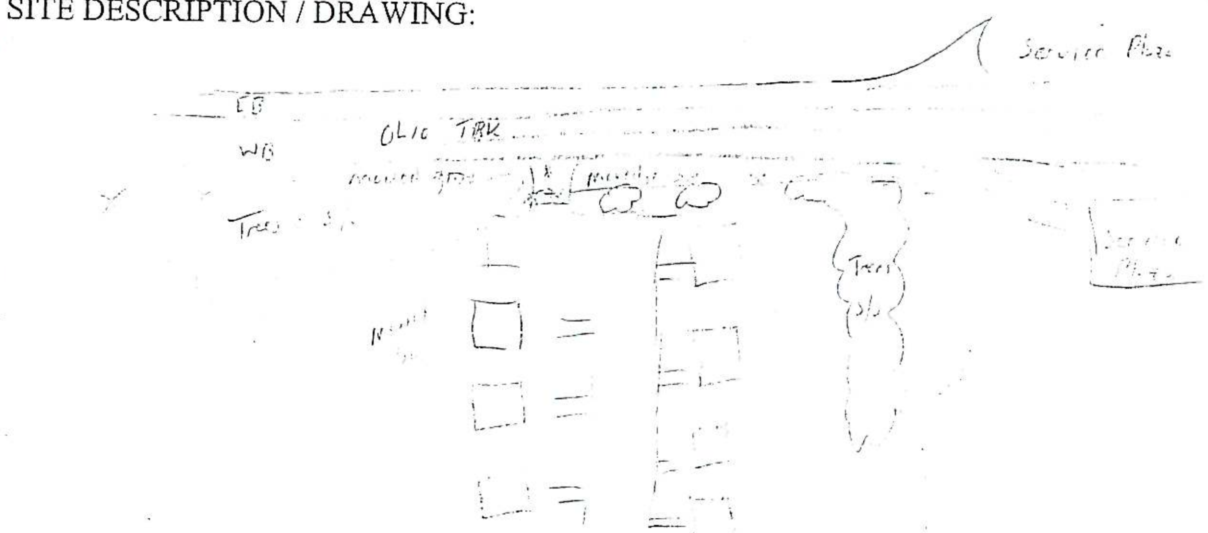
QuestSuite Professional-OTC.sdat Group 1 Test 5
110
100
90
80
70
60
30
20
90
80
70
60
50
40
30
20
10
0
LMAX
10:40
16:14:04
16:17:28
16:20:53
16:24:17
16:27:41
Logged at 1 min intervals
(dB)
LMAX (dB)
LPeak (dB)
LN10 (dB)
LN90 (dB)

SOUND LEVEL DATA COLLECTION SHEET

DATE / TIME: 9-4-08	LOCATION: Lancer Dr Amherst
PROJECT NO.: P402060060	PERSONNEL: J.R ARP
SITE: NSA-24	WIND SPEED: 1.2 mph WIND DIR: NW
REL. HUMIDITY: 41.2 %	TEMP: Dry Bulb 88.2 °F Wet Bulb

EQUIPMENT MODEL: Quest 2900	SERIAL NO.:
CALIBRATION: Initial Final	PROBLEMS:
DESCRIPTOR: Leq	INTEGRATION RATE:
WEIGHTING: A	SAMPLE RATE: F

SITE DESCRIPTION / DRAWING:



SOUND LEVEL 1: 74.4 Leq	SOUND LEVEL 2: 74.9 Leq

NOTES:

Lmax = 89.1

Lmin = 60.4

* located @ WB + EB service plazas

QuestSuite Professional-OTC.sdat

2900 Integrating/Logging Sound Level Meter

FW Version: 02.4

Serial Number: CDE060039

Name:

Company:

Work Area:

Description:

Comments:

Group 1 Test 6

Test Started: 9/4/2008 5:07:04PM
Test Ended: 9/4/2008 5:27:20PM
Run Time: 00:20:15

Measuring Parameters

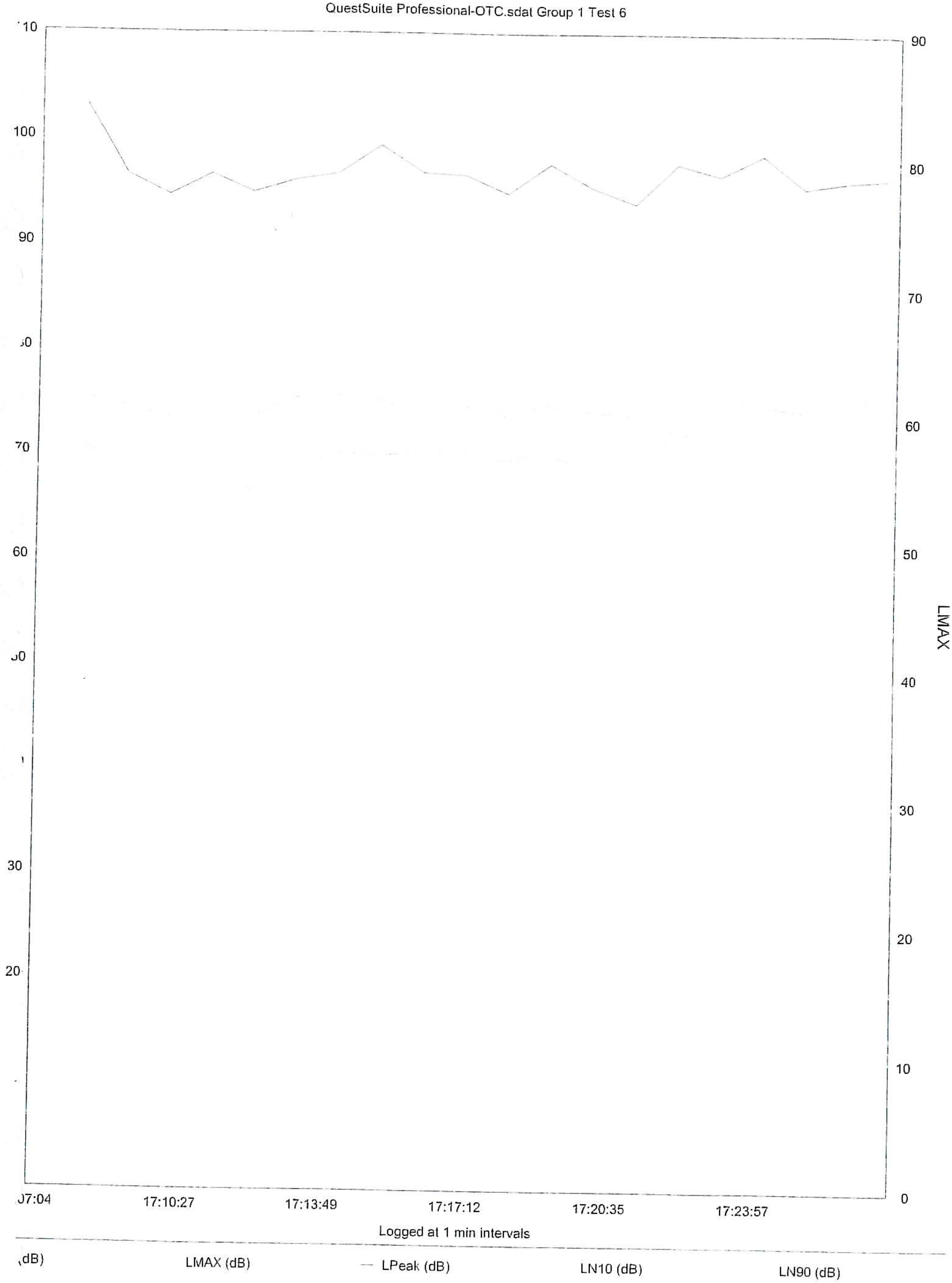
Range: 60 - 120 dB	Weighting: A	Time Constant: Fast
Threshold: Off	Exchange Rate: 3 dB	Peak Weighting: C

Summary

Peak Level: 103.2 dB, 9/4/2008 5:07:43PM
Max Level: 84.1 dB, 9/4/2008 5:22:58PM
Min Level: 61.3 dB, 9/4/2008 5:20:06PM
Overload: 0.00%

LEQ:	74.8 dB	SEL(3):	105.6 dB	TWA:	61.1 dB	TAKM5:	78.2 dB
LDN:	74.8 dB	CNEL:	74.8 dB	Pa2Sec:	14.4		
L5:	79.3 dB	L10:	78.1 dB	L50:	73.6 dB	L90:	69.1 dB

Comments:



QuestSuite Professional-OTC.sdat Group 1 Test 6
10
100
90
ɔ0
70
60
ɔ0
30
20
90
80
70
60
50
40
30
20
10
0
LMAX
07:04
17:10:27
17:13:49
17:17:12
17:20:35
17:23:57
Logged at 1 min intervals
(dB)
LMAX (dB)
LPeak (dB)
LN10 (dB)
LN90 (dB)

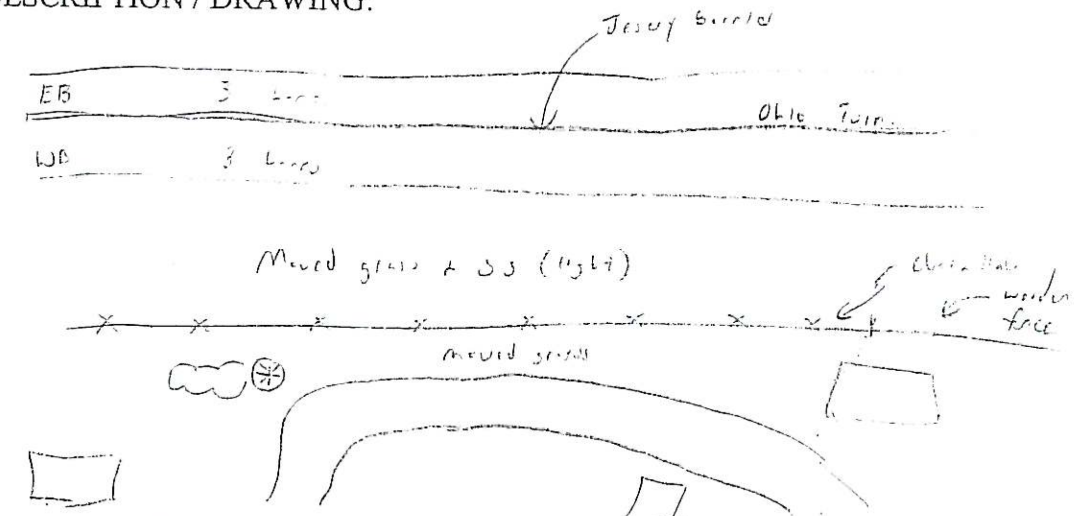
NSA-28

SOUND LEVEL DATA COLLECTION SHEET

DATE / TIME: 9-4-08	LOCATION: Elyria V
PROJECT NO.: P402060960	PERSONNEL: J.R. AIO
SITE: NSA 28	WIND SPEED: 1.8 mph WIND DIR: NW
REL. HUMIDITY: 39.2 %	TEMP: Dry Bulb 88.5 Wet Bulb

EQUIPMENT MODEL: Quest 2900	SERIAL NO.:
CALIBRATION: Initial Final	PROBLEMS:
DESCRIPTOR: Leq	INTEGRATION RATE:
WEIGHTING: A	SAMPLE RATE: F

SITE DESCRIPTION / DRAWING:



SOUND LEVEL 1: 74.6 Leq	SOUND LEVEL 2: 74.9 Leq

NOTES:

Lmax = 84.1

Lmin = 61.3

UCF, A great school

QuestSuite Professional-OTC.sdat

2900 Integrating/Logging Sound Level Meter

FW Version: 02.4

Serial Number: CDE060039

Name:

Company:

Work Area:

Description:

Comments:

Group 1 Test 7

Test Started: 9/5/2008 9:22:59AM
Test Ended: 9/5/2008 9:43:04AM
Run Time: 00:20:04

Measuring Parameters

Range:	60 - 120 dB	Weighting:	A	Time Constant:	Fast
Threshold:	Off	Exchange Rate:	3 dB	Peak Weighting:	C

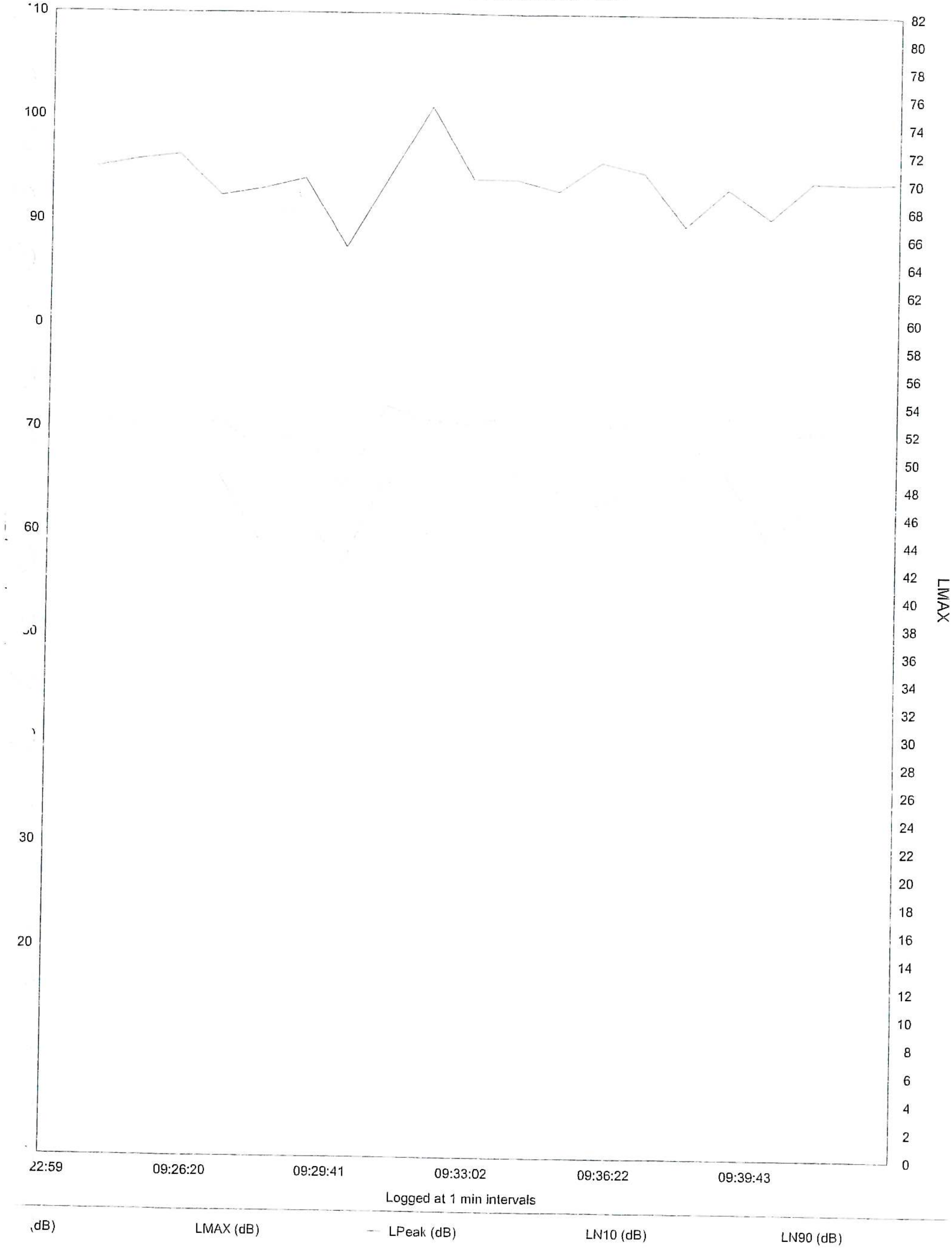
Summary

Peak Level: 101.0 dB, 9/5/2008 9:31:16AM
Max Level: 81.7 dB, 9/5/2008 9:23:52AM
Min Level: 54.4 dB, 9/5/2008 9:29:17AM
Overload: 0.00%

LEQ:	69.9 dB	SEL(3):	100.6 dB	TWA:	56.1 dB	TAKM5:	73.1 dB
LDN:	69.9 dB	CNEL:	69.9 dB	Pa2Sec:	4.6		
L5:	75.6 dB	L10:	74.0 dB	L50:	67.4 dB	L90:	61.3 dB

Comments:

QuestSuite Professional-OTC.sdat Group 1 Test 7

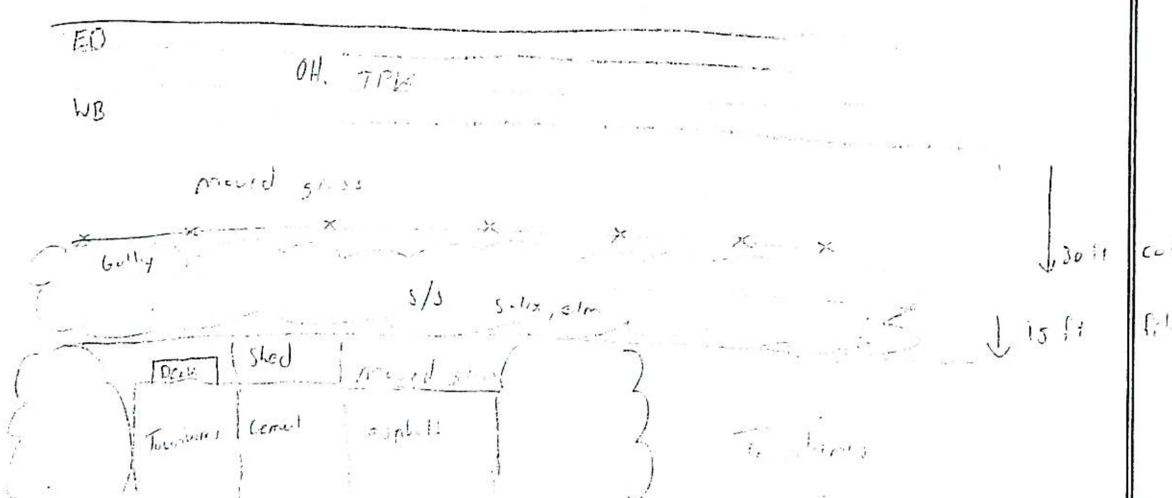


SOUND LEVEL DATA COLLECTION SHEET

DATE / TIME: 9-5-08	LOCATION: Canfield - Mercedes Dr.
PROJECT NO.: P402060060	PERSONNEL: J.R. ARP
SITE: NSA 66	WIND SPEED: 2.2 mph WIND DIR: W
REL. HUMIDITY: 54.5 %	TEMP: Dry Bulb 77.4 °F Wet Bulb —

EQUIPMENT MODEL: Quest 2900	SERIAL NO.:
CALIBRATION: Initial Final	PROBLEMS:
DESCRIPTOR:	INTEGRATION RATE:
WEIGHTING: A	SAMPLE RATE: F

SITE DESCRIPTION / DRAWING:



SOUND LEVEL 1: 71.4 Leq	SOUND LEVEL 2: 69.9 Leq

NOTES:

L max = 91.7

L min = 54.4

QuestSuite Professional-OTC.sdat

2900 Integrating/Logging Sound Level Meter

FW Version: 02.4

Serial Number: CDE060039

Name:

Company:

Work Area:

Description:

Comments:

Group 1 Test 8

Test Started: 9/5/2008 10:33:01AM
Test Ended: 9/5/2008 10:53:13AM
Run Time: 00:20:11

Measuring Parameters

Range: 60 - 120 dB
Threshold: Off

Weighting: A
Exchange Rate: 3 dB

Time Constant: Fast
Peak Weighting: C

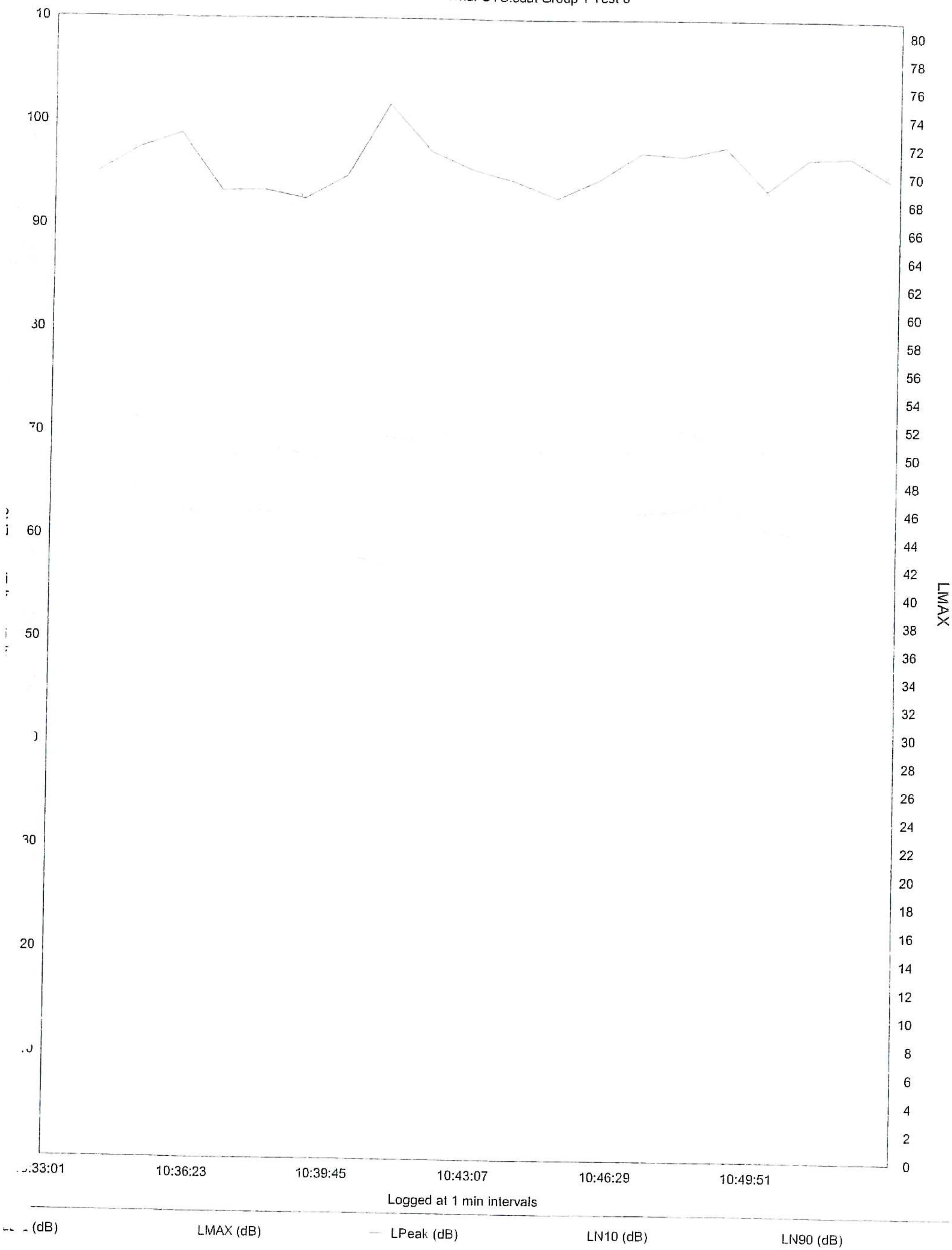
Summary

Peak Level: 101.7 dB, 9/5/2008 10:40:51AM
Max Level: 80.5 dB, 9/5/2008 10:40:49AM
Min Level: 55.8 dB, 9/5/2008 10:40:10AM
Overload: 0.00%

LEQ:	69.0 dB	SEL(3):	99.7 dB	TWA:	55.3 dB	TAKM5:	72.9 dB
LDN:	69.0 dB	CNEL:	69.0 dB	Pa2Sec:	3.7		
L5:	74.8 dB	L10:	73.3 dB	L50:	66.2 dB	L90:	61.7 dB

Comments:

QuestSuite Professional-OTC.sdat Group 1 Test 8

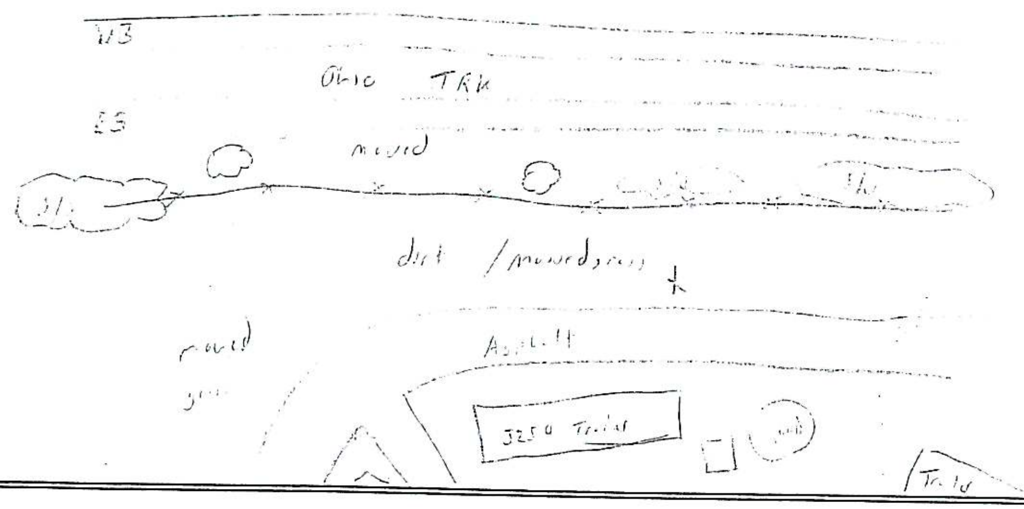


SOUND LEVEL DATA COLLECTION SHEET

DATE / TIME: 9-5-08	LOCATION: Lordstown MM 215-216 South
PROJECT NO.: P4020600 60	PERSONNEL: J.R. ARP
SITE: NSA-61	WIND SPEED: 2.1 mph WIND DIR: NW
REL. HUMIDITY: 52 %	TEMP: Dry Bulb 79.4 °F Wet Bulb

EQUIPMENT MODEL: Quest 2900	SERIAL NO.:
CALIBRATION: Initial Final	PROBLEMS:
DESCRIPTOR: Leq	INTEGRATION RATE:
WEIGHTING: A	SAMPLE RATE: F

SITE DESCRIPTION / DRAWING:



SOUND LEVEL 1: 70.4 leq	SOUND LEVEL 2: 69.0 leq

NOTES:
Lmax = 80.5
Lmin = 55.8

QuestSuite Professional-OTC.sdat

2900 Integrating/Logging Sound Level Meter

FW Version: 02.4 | Serial Number: CDE060039

Name:

Company:

Work Area:

Description:

Comments:

Group 1 Test 9

Test Started: 9/5/2008 12:34:07PM
Test Ended: 9/5/2008 12:54:17PM
Run Time: 00:20:09

Measuring Parameters

Range:	60 - 120 dB	Weighting:	A	Time Constant:	Fast
Threshold:	Off	Exchange Rate:	3 dB	Peak Weighting:	C

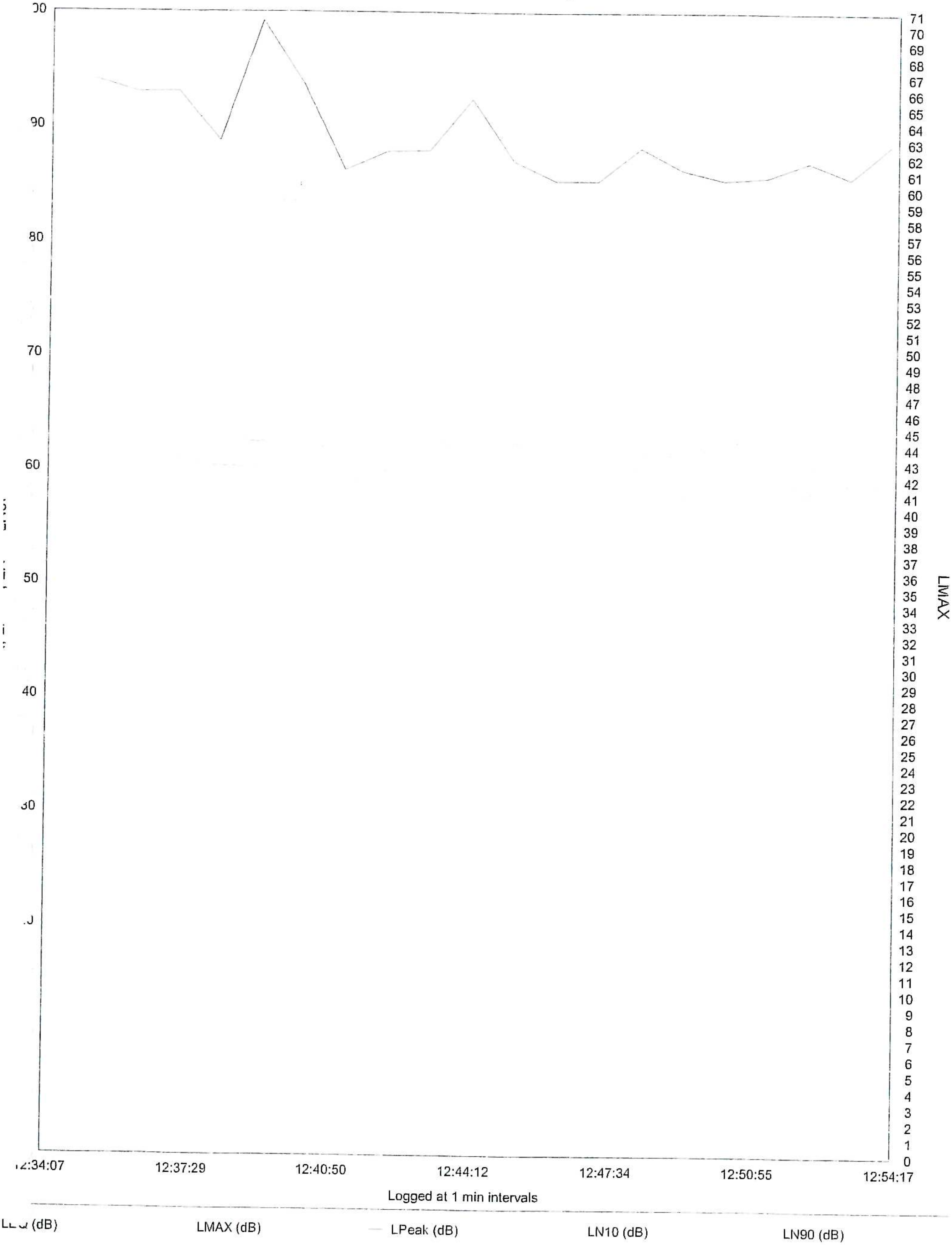
Summary

Peak Level: 99.2 dB, 9/5/2008 12:39:05PM
Max Level: 70.5 dB, 9/5/2008 12:36:11PM
Min Level: 56.1 dB, 9/5/2008 12:48:20PM
Overload: 0.00%

LEQ:	62.1 dB	SEL(3):	92.8 dB	TWA:	48.4 dB	TAKM5:	64.0 dB
LDN:	62.1 dB	CNEL:	62.1 dB	Pa2Sec:	0.8		
L5:	64.8 dB	L10:	64.1 dB	L50:	61.8 dB	L90:	59.2 dB

Comments:

QuestSuite Professional-OTC.sdat Group 1 Test 9



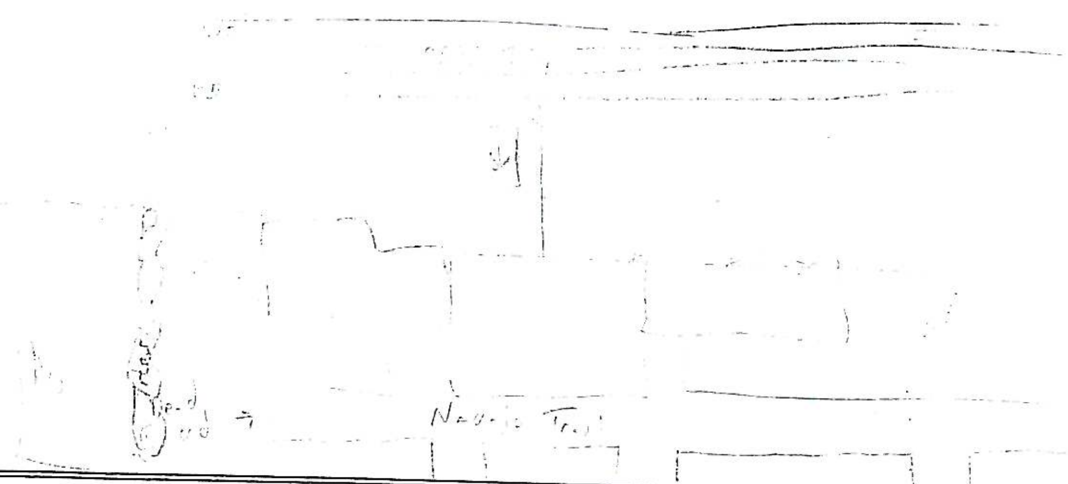
NSA-36

SOUND LEVEL DATA COLLECTION SHEET

DATE / TIME: 9-5-08	LOCATION: MM 187-188
PROJECT NO.:	PERSONNEL:
SITE: NSA-36	WIND SPEED: WIND DIR:
REL. HUMIDITY:	TEMP: Dry Bulb 70.0 °F Wet Bulb —

EQUIPMENT MODEL:	SERIAL NO.:
CALIBRATION: Initial Final	PROBLEMS:
DESCRIPTOR:	INTEGRATION RATE:
WEIGHTING:	SAMPLE RATE:

SITE DESCRIPTION / DRAWING:



SOUND LEVEL 1:	SOUND LEVEL 2: 62.1 Leq

NOTES:

Road mostly, steady

Lmax = 70.5

Lmin = 56.1

UCF, A great school

QuestSuite Professional-OTC.sdat

2900 Integrating/Logging Sound Level Meter

FW Version: 02.4

Serial Number: CDE060039

Name:

Company:

Work Area:

Description:

Comments:

Group 1 Test 10

Test Started: 9/5/2008 1:26:24PM
Test Ended: 9/5/2008 1:47:22PM
Run Time: 00:20:57

Measuring Parameters

Range: 60 - 120 dB	Weighting: A	Time Constant: Fast
Threshold: Off	Exchange Rate: 3 dB	Peak Weighting: C

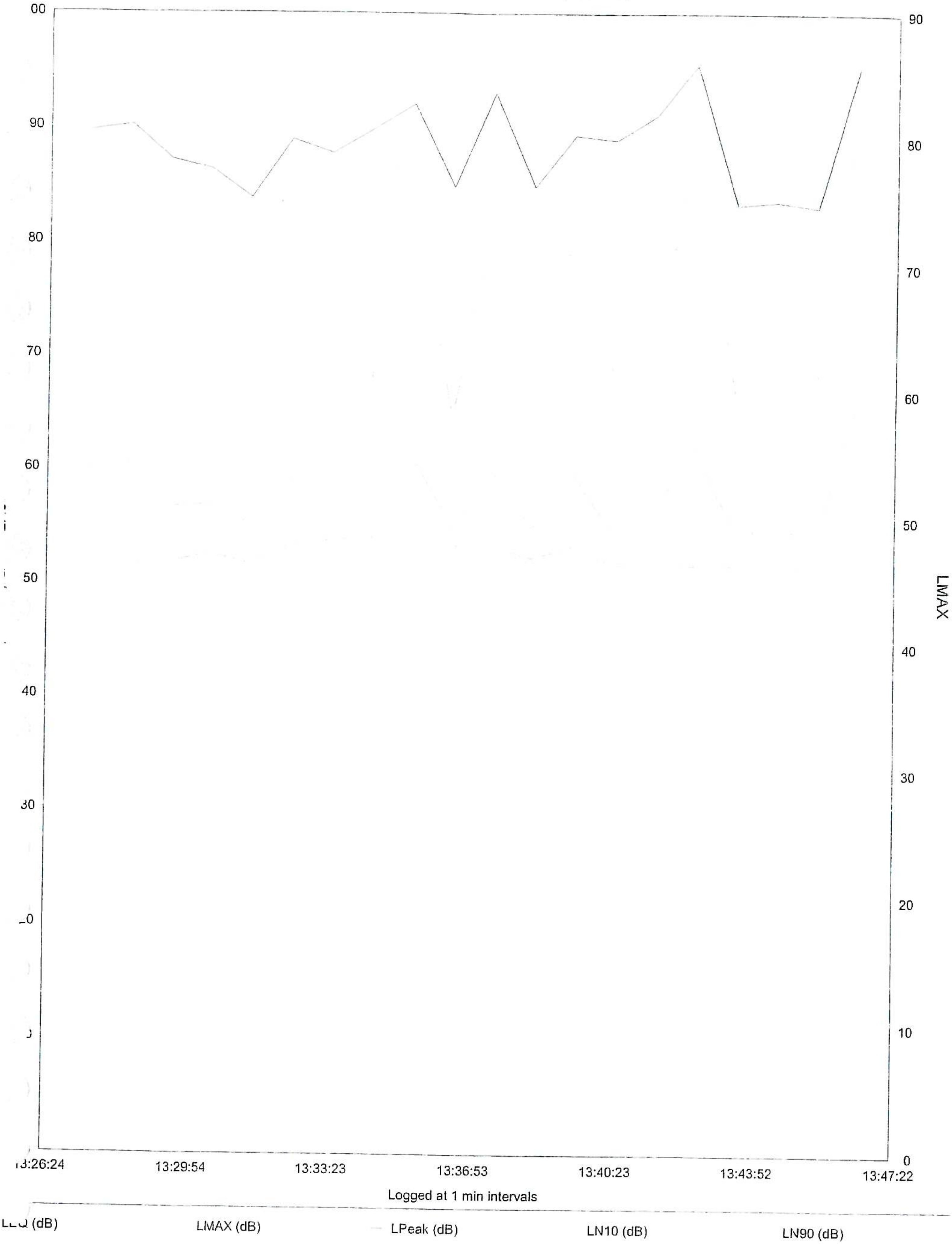
Summary

Peak Level: 95.5 dB, 9/5/2008 1:41:34PM
Max Level: 82.7 dB, 9/5/2008 1:45:46PM
Min Level: 51.6 dB, 9/5/2008 1:28:01PM
Overload: 0.00%

LEQ:	59.0 dB	SEL(3):	89.9 dB	TWA:	45.5 dB	TAKM5:	64.5 dB
LDN:	59.0 dB	CNEL:	59.0 dB	Pa2Sec:	0.4		
L5:	62.5 dB	L10:	60.5 dB	L50:	55.1 dB	L90:	52.0 dB

Comments:

QuestSuite Professional-OTC.sdat Group 1 Test 10

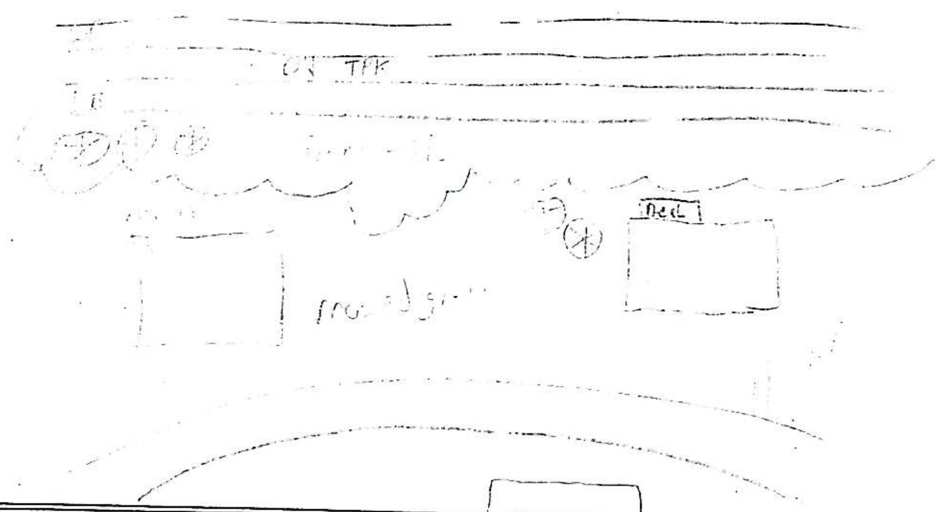


SOUND LEVEL DATA COLLECTION SHEET

DATE / TIME: 9-5-05	LOCATION: Hudson
PROJECT NO.:	PERSONNEL: J.R. A.P.
SITE: NSA 53	WIND SPEED: 3.4 mph WIND DIR: [illegible]
REL. HUMIDITY: 77.5	TEMP: Dry Bulb 72.5 °F Wet Bulb

EQUIPMENT MODEL: Quest 2900	SERIAL NO.:
CALIBRATION: Initial Final	PROBLEMS: —
DESCRIPTOR:	INTEGRATION RATE:
WEIGHTING:	SAMPLE RATE:

SITE DESCRIPTION / DRAWING:



SOUND LEVEL 1: 59.5 leq	SOUND LEVEL 2: 59.0

NOTES: Lmax = 82.7
Lmin = 51.6
* local road is the greatest noise source

QuestSuite Professional-OTC.sdat

2900 Integrating/Logging Sound Level Meter

FW Version: 02.4

Serial Number: CDE060039

Name:

Company:

Work Area:

Description:

Comments:

Group 1 Test 11

Test Started: 9/5/2008 3:46:38PM
Test Ended: 9/5/2008 4:07:03PM
Run Time: 00:20:24

Measuring Parameters

Range:	60 - 120 dB	Weighting:	A	Time Constant:	Fast
Threshold:	Off	Exchange Rate:	3 dB	Peak Weighting:	C

Summary

Peak Level: 96.3 dB, 9/5/2008 3:55:02PM
Max Level: 77.4 dB, 9/5/2008 3:49:20PM
Min Level: 56.4 dB, 9/5/2008 3:57:45PM
Overload: 0.00%

LEQ:	66.8 dB	SEL(3):	97.5 dB	TWA:	53.1 dB	TAKM5:	69.3 dB
LDN:	66.8 dB	CNEL:	66.8 dB	Pa2Sec:	2.3		
L5:	71.1 dB	L10:	70.2 dB	L50:	65.1 dB	L90:	60.9 dB

Comments:

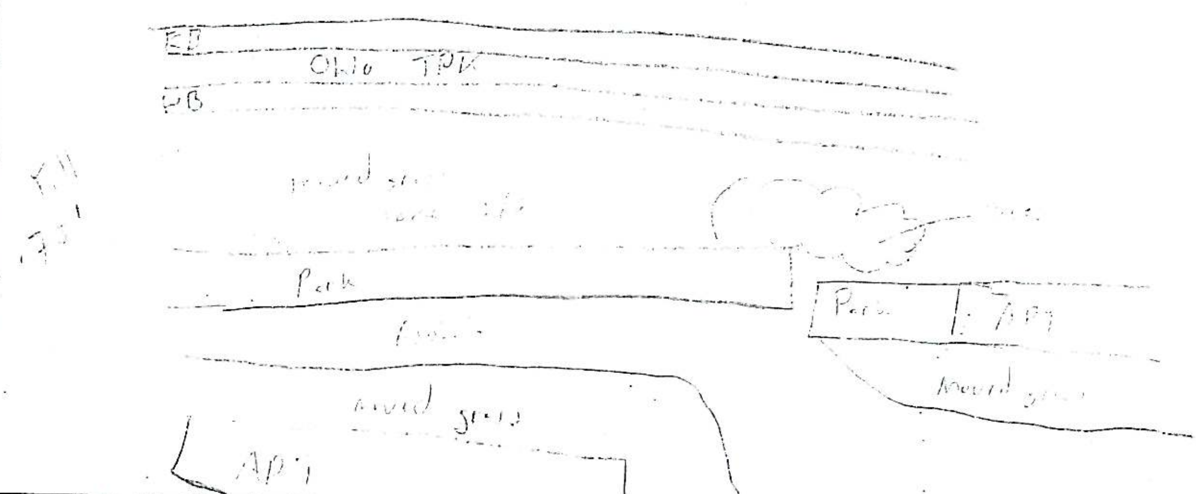
NJA-49

SOUND LEVEL DATA COLLECTION SHEET

DATE / TIME: 9-5-08/3:41	LOCATION: Apt.
PROJECT NO.: P402060060	PERSONNEL: J.R., ARF
SITE: NJA-42	WIND SPEED: 0.9 mph WIND DIR: W
REL. HUMIDITY: 90.1 %	TEMP: Dry Bulb 72.2 °F Wet Bulb

EQUIPMENT MODEL:	SERIAL NO.:
CALIBRATION: Initial Final	PROBLEMS:
DESCRIPTOR: Leq	INTEGRATION RATE:
WEIGHTING: A	SAMPLE RATE: F

SITE DESCRIPTION / DRAWING:



SOUND LEVEL 1: 66.6 Leq	SOUND LEVEL 2:

NOTES:

Lmax = 77.4

Lmin = 56.4

rained recently / pavement wet

UCF, A great school

QuestSuite Professional-OTC.sdat

2900 Integrating/Logging Sound Level Meter

FW Version: 02.4

Serial Number: CDE060039

Name:

Company:

Work Area:

Description:

Comments:

Group 1 Test 12

Test Started: 9/5/2008 4:57:51PM
Test Ended: 9/5/2008 5:18:53PM
Run Time: 00:21:02

Measuring Parameters

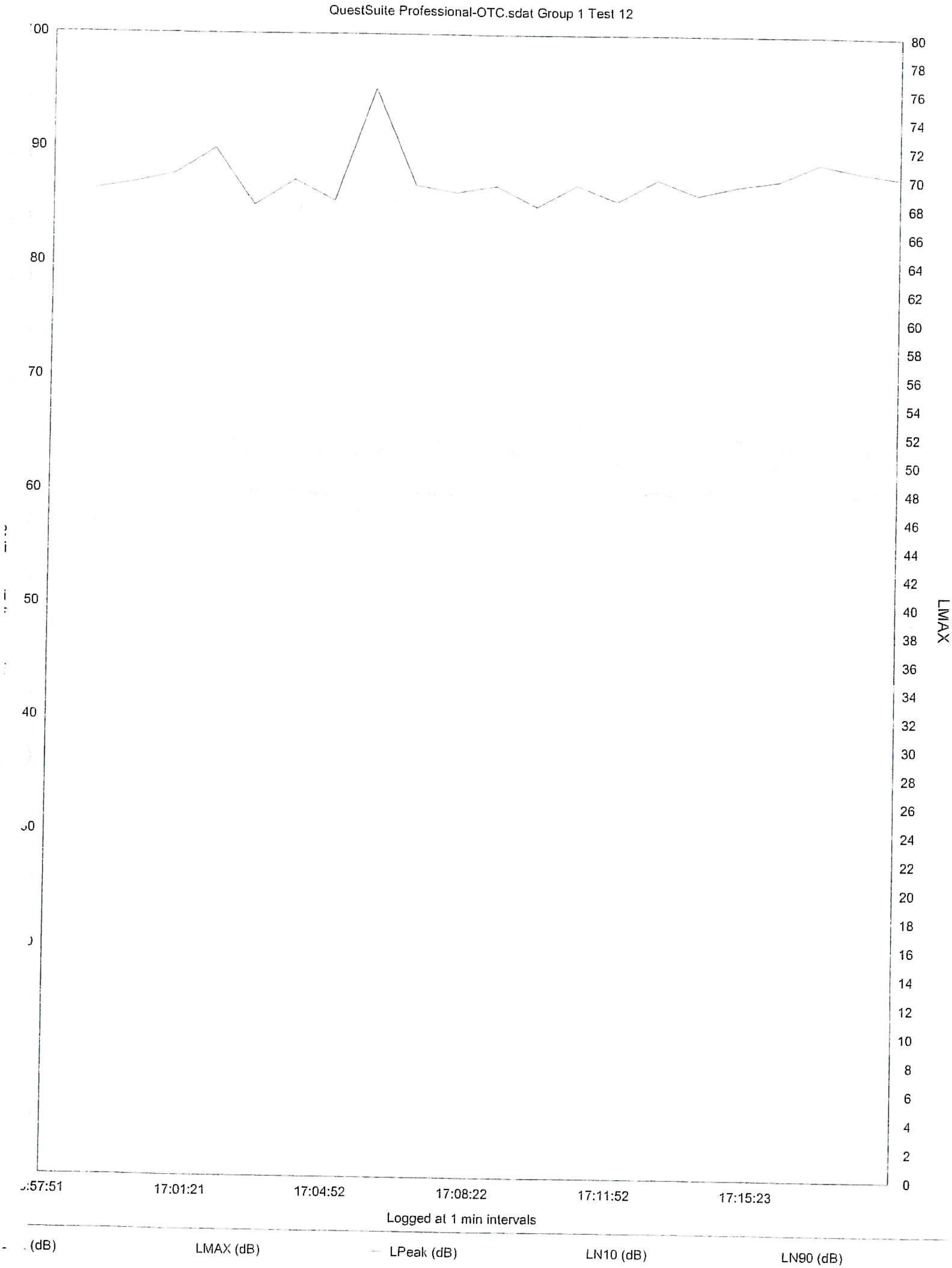
Range:	60 - 120 dB	Weighting:	A	Time Constant:	Fast
Threshold:	Off	Exchange Rate:	3 dB	Peak Weighting:	C

Summary

Peak Level: 95.2 dB, 9/5/2008 5:05:17PM
Max Level: 73.9 dB, 9/5/2008 5:01:42PM
Min Level: 54.5 dB, 9/5/2008 4:58:24PM
Overload: 0.00%

LEQ:	63.9 dB	SEL(3):	94.8 dB	TWA:	50.3 dB	TAKM5:	66.4 dB
LDN:	63.9 dB	CNEL:	63.9 dB	Pa2Sec:	1.2		
L5:	67.1 dB	L10:	66.2 dB	L50:	63.3 dB	L90:	59.9 dB

Comments:



QuestSuite Professional-OTC.sdat Group 1 Test 12
'00
90
80
70
60
50
40
ꞁ0
)
80
78
76
74
72
70
68
66
64
62
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
LMAX
ː57:51
17:01:21
17:04:52
17:08:22
17:11:52
17:15:23
Logged at 1 min intervals
(dB)
LMAX (dB)
LPeak (dB)
LN10 (dB)
LN90 (dB)

NSA-40

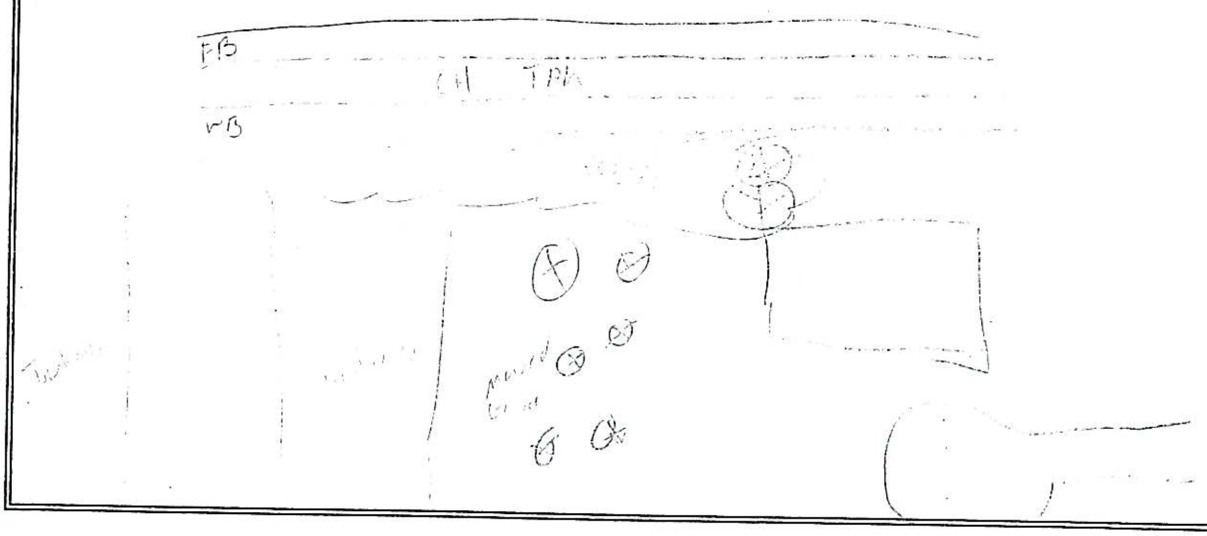
Nc, Hotels [illegible]

SOUND LEVEL DATA COLLECTION SHEET

DATE / TIME: 9-5-08 / 1153	LOCATION:
PROJECT NO.: P402060060	PERSONNEL: J. R. ARP
SITE: NSA 40	WIND SPEED: 0.6 mph WIND DIR: W
REL. HUMIDITY: 77.2 %	TEMP: Dry Bulb 73.4 °F Wet Bulb —

EQUIPMENT MODEL:	SERIAL NO.:
CALIBRATION: Initial Final	PROBLEMS:
DESCRIPTOR: Leq	INTEGRATION RATE:
WEIGHTING: A	SAMPLE RATE: F

SITE DESCRIPTION / DRAWING:



SOUND LEVEL 1: 63.8 Leq	SOUND LEVEL 2: 63.9 Leq

NOTES:

- Train whistles
- Birds [illegible]

Lmax = 73.9

Lmin = 54.5

Ohio Turnpike Commission

TranSystems

Noise Mitigation Study

Ohio Turnpike Commission

Contract No. 71-08-02

55 Public Square, Suite 1900

Cleveland, OH 44113-1901

216-861-1780