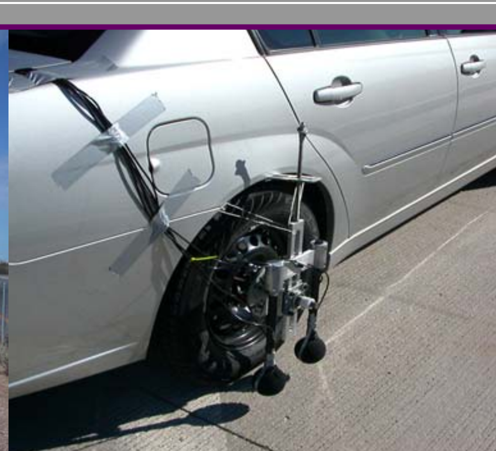
Quiet Pavement Pilot Program: Progress Report 3

Final Report 577
September 2012


Arizona Department of Transportation
Research Center

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September 2012

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16. Abstract
Since 2003, the Arizona Department of Transportation (ADOT) has been conducting a Quiet Pavement Pilot Program (QPPP) in cooperation with the Federal Highway Administration (FHWA). This report presents the noise findings of this research through 2007. The initial reduction in noise levels achieved by overlaying portland cement concrete pavement (PCCP) on freeways in the greater Phoenix area with asphalt rubber friction course (ARFC) were documented with three types of measurements: 1.) tire/pavement noise levels measured on-board a test vehicle near a test tire (Site 1), 2.) neighborhood noise levels measured at typical receiver locations in the vicinity of the freeways (Site 2), and 3.) wayside tire/pavement noise levels measured at five research grade sites (Site 3). The initial reductions ranged on average from 5.5 to 9 dB depending on the type of measurement and the specific location. In subsequent years, measurements were conducted to assess the noise reduction performance of the AFRC over time or the acoustic longevity of the pavement. For the Site 1 and 3 data, the noise reduction has dropped by about 2 dB on average over the four years since the overlay was installed while the Site 2 levels have shown less than a 1 dB reduction. The results of the Site 3 measurements were compared to the results calculated from the FWHA Traffic Noise Model (TNM) using TNM Average Pavement. Through 2007, the measured noise levels at the tire/pavement interface have been 4 dB or more lower than the TNM predictions for the 50 ft and 100 ft distant microphone locations except for the 50 ft position (only) at one of the Site 3 locations.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ABBREVIATIONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AC	asphalt concrete
ADOT	Arizona Department of Transportation
ARFC	asphalt rubber friction course
CFR	Code of Federal Regulations
CPX	close proximity
dB	decibel
dBA	A-weighted decibel
EFR	effective flow resistivity
FHWA	Federal Highway Administration
I	Interstate
L_{50}	sound level exceeded 50% of time
L_{eq}	energy mean noise level
LOS	level of service
NAC	noise abatement criteria
NCHRP	National Cooperative Highway Research Program
OBSI	on-board sound intensity
PCCP	portland cement concrete pavement
QPPP	Quiet Pavement Pilot Program
QPR	Quieter Pavement Research
REMEL	reference mean emission levels
SI	sound intensity
SR	state route
TNM	Traffic Noise Model

EXECUTIVE SUMMARY

Since 2003, the Arizona Department of Transportation (ADOT) has been conducting a Quiet Pavement Pilot Program (QPPP) in cooperation with the Federal Highway Administration (FHWA). This report presents an assessment of the longevity of noise reduction resulting from the program through 2007. Results reveal the program's effectiveness in reducing traffic noise over that time period.

The initial reduction in noise levels achieved by overlaying portland cement concrete pavement (PCCP) on freeways in the greater Phoenix area with asphalt rubber friction course (ARFC) was documented. Following that initial application of ARFC, noise reduction ranged on average from 5.5 to 9 decibels (dB), depending on the type of measurement and the specific location. In 2007, three types of measurements were made to assess the noise reduction performance of the AFRC over time:

- Site 1: noise produced by tires on pavement, measured on board a test vehicle near a test tire; measurements were taken at each milepost and direction of travel along 115 miles of freeway
- Site 2: noise levels in urban residential neighborhoods in the vicinity of freeways; measurements were taken at select locations for one hour during times of highest traffic noise
- Site 3: noise levels at distances farther from the freeway; measurements were taken at 95 to 250 feet

For Sites 1 and 3 data, noise reduction declined by an average of 2 dB over the four years after the overlay was installed, while the Site 2 levels showed less than a 1 dB reduction. The results of the Site 3 measurements were compared to the results calculated from the FWHA Traffic Noise Model (TNM). The comparison showed that during the four years following the installation of ARFC, the measured traffic noise levels have been 4 dB or more lower than the model's predictions for all but one of the Site 3 locations.

I. INTRODUCTION

Under FHWA noise abatement polices as documented in Title 23 Part 772 of the U.S. Code of Federal Regulations (23 CFR 772), federal funds can be used for noise abatement only if it falls into one or more of five types: traffic management, alteration of horizontal and vertical alignments, construction of noise barriers, creation of buffer zones, or insulation of public or nonprofit institutional structures. Given the limitations and costs of the other four measures, construction of noise barriers is very often the only one implemented by state and local transportation agencies. At times, however, noise barriers meet with resistance due to cost, visual impact, graffiti concerns, and other issues. In some circumstances, barriers are not physically viable or will not provide the necessary minimum 5 decibel (dB) noise reduction stated in the 23 CFR 772 FHWA Guidance Document[1]. As a result, several states have become interested in using quieter pavement to reduce traffic noise. In Arizona, the need for additional methods of noise abatement became apparent throughout the 1990s as citizen concerns over traffic noise led to ADOT adopt Noise Abatement Criteria (NAC) of 64 A-weighted decibels (dBA) instead of the 67 dBA NAC stated in the 23 CFR 772 Guidance Document. As a result, ADOT also became interested in pursuing quieter pavement for reducing traffic noise as an alternative or supplement to traditional noise barriers.

In the early 2000s, quieter pavement technology was rapidly advancing in Europe and Asia. This sparked interest from state highway agencies and the FHWA in evaluating the effectiveness of pavement types for reducing highway traffic noise levels. However, under 23 CFR 772 and FHWA policy, a pavement type cannot be considered as a noise abatement measure. One of the major concerns precipitating this position is the acoustical performance of quieter pavement over time, particularly in comparison to noise barriers, which maintain their effectiveness indefinitely. As a result of this interest on the part of ADOT and FHWA, the two agencies partnered to initiate a research program in April 2003 called the Arizona Quiet Pavement Pilot Program (QPPP).

The QPPP has two components: construction and research. The construction component consists of overlaying approximately 115 miles of existing urban freeways with asphalt rubber friction course (ARFC) in five separate phases (Figure 1). The status of overlay progression and planned dates for future overlays are presented in Figure 2. The research component evaluates the potential for using ARFC as a noise mitigation measure. This component consists of three separate technical studies designated as Site 1, Site 2, and Site 3. The studies at the three types of study sites, located on or adjacent to selected Maricopa County regional freeways, involve measuring traffic noise levels prior to applying ARFC (hereinafter referred to as pre-overlay) and measuring traffic noise levels at the same monitoring positions subsequent to the application of ARFC (hereinafter referred to as post-overlay). Site 1 examines freeway noise reduction at the tire pavement interface due to the application of ARFC. Site 2 examines noise reduction in urban residential neighborhoods associated with the application of ARFC to a nearby freeway segment. Site 3 evaluates noise reduction at adjacent properties and the longevity of the noise reduction benefit.

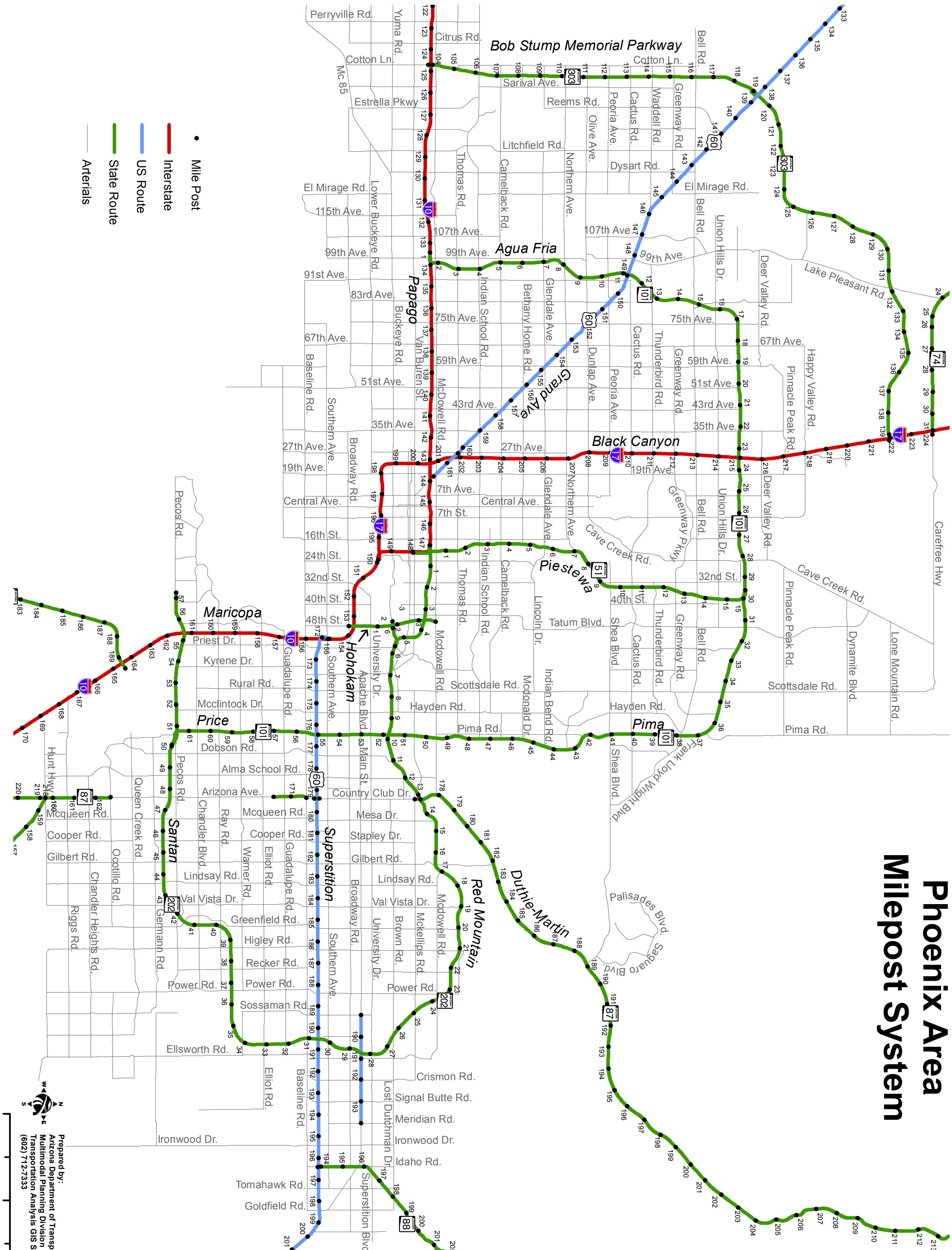

Figure 1: Area Diagram of QPPP Study Site

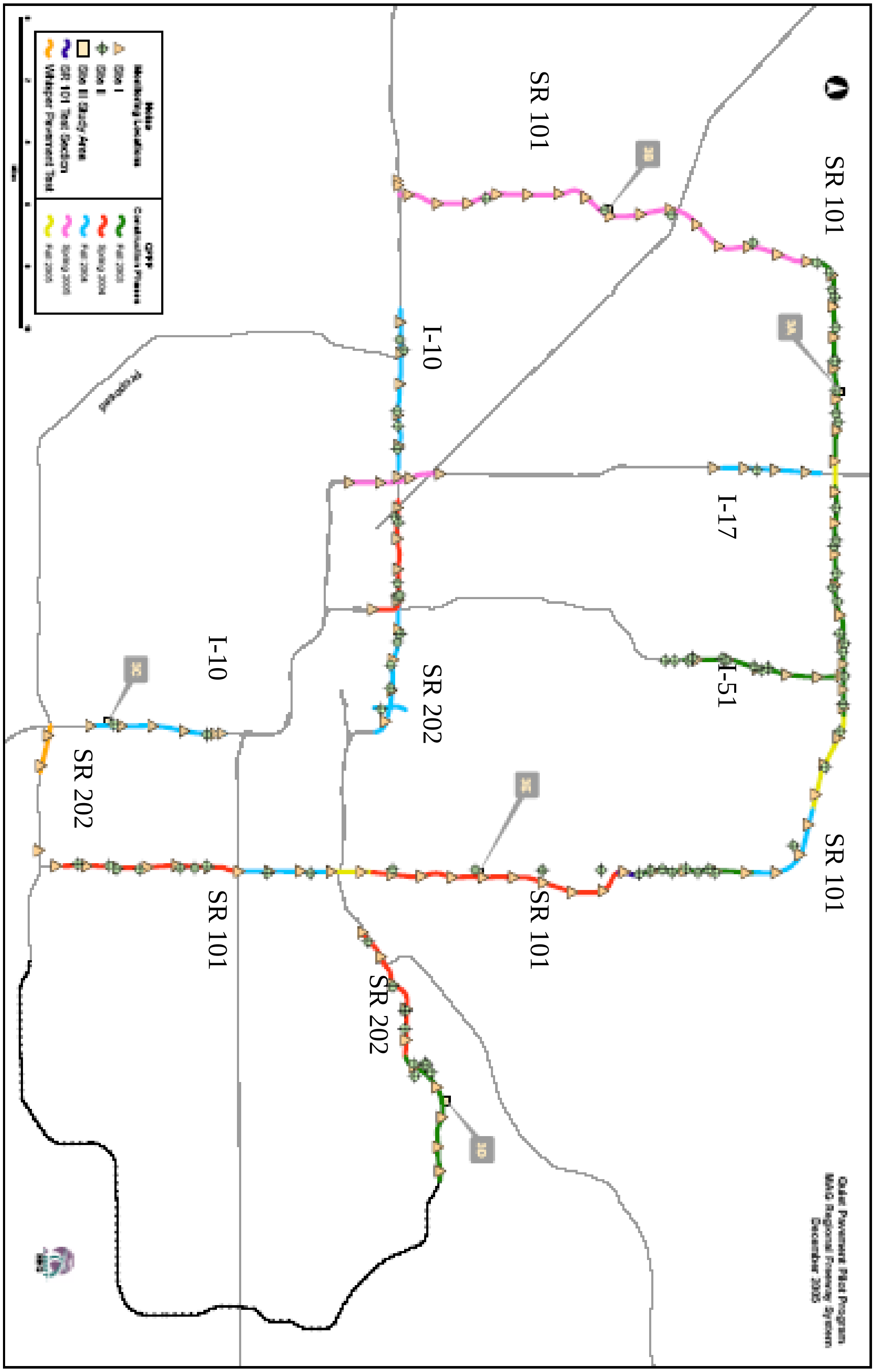

Figure 2: Timing of ARFC Overlays

This report summarizes the research activities performed in the QPPP through the end of 2007, presents the results of the noise measurements, and provides an overall status of the project. The results of this research have also been published in the proceedings of a number of technical conferences on noise[2,3,4,5,6,7] and in previous QPPP progress reports.

II. QPPP DESCRIPTION

Prior to the initiation of the QPPP, ADOT performed extensive research into quieter pavements, equivalent to what FHWA would today consider a Quieter Pavement Research program (QPR). This included the construction and noise evaluation of test sections constructed of a variety of asphalt concrete (AC) pavement designs to assess their potential for tire/pavement noise reduction. This investigation found that the ARFC pavement used in the QPPP produced the lowest noise levels of the four sample pavements. The QPR also included an evaluation of the noise performance of ARFC overlays of various ages as applied throughout the state highway system. This provided some information on the expected noise reduction potential of the ARFC over time.[8] Finally, research was conducted on alternative portland cement concrete pavement (PCCP) texturing methods including the then-ADOT standard of uniform-spaced 3/4 inch aggregate, transverse tining, random transverse tining, longitudinal tining, and diamond-ground textured pavements.[9] Although the diamond-ground PCCP performed significantly better than the other textures, it did not produce noise levels as low as the ARFC. However, this research led to ADOT's adoption of longitudinal tining as its standard texture for PCCP. With the completion of this research, an ARFC overlay was selected as the pavement to be used in the QPPP.

Although ADOT first used asphalt rubber in 1964, its continuous use of asphalt-rubber products began in 1968.[10] The development of an asphalt-rubber overlay system for PCCP began in 1973 with a two-layer system. The two-layer system was quickly replaced with a three-layer system in 1975 and the first non-experimental section was placed on Interstate 17 in Phoenix in 1985. The three-layer system was eventually replaced by a one-inch-thick ARFC. ADOT first used the one-inch overlay ARFC on Interstate 19 near Tucson in 1988, when it overlaid a one and one-half mile section of southbound I-19 with one inch of ARFC. Portions of this overlay are still in service today. The one-inch-thick ARFC surfacing used in Arizona consists of a 3/8 inch minus, open-graded aggregate. Typical asphalt-rubber binder contents range between 9 to 9.4 % of the total mix by weight. This overlay strategy has been used for most of the PCCP overlay placements since 1988. Appendix A has a more complete description of the ARFC overlay.

After completing the research described above, ADOT initiated the QPPP in April 2003 after receiving FHWA approval. In regard to noise, the program consists of two elements. The first is a noise reduction allowance or credit for the use of the quieter ARFC pavement and the second is the commitment to document the acoustic performance, public response, and policy application of the pavement over a 10-year period. Under the QPPP agreement, the pilot status allows ADOT to assume a 4 dB reduction due to pavement surface type when designing for noise mitigation. This allowance is applied to the result of the traffic noise level predicted by the FHWA Traffic Noise Model (TNM). Under current FHWA policy, only vehicle noise source levels, the Reference Mean Emission Levels (REMELs),[11] corresponding to average pavement are authorized in the use of the TNM. As a result, for purposes of predicting future traffic noise levels and assessing the performance of noise abatement options in the QPPP, such as barriers, the 4 dB reduction is applied to the result of the TNM calculation. When applied at the project design stage, this 4 dB allowance could result in lower heights for noise barriers along the freeway or even omitting barriers if the predicted levels fall below the ADOT threshold of 64 dBA.

In exchange for a 4 dB acoustic credit, ADOT agreed to monitor the noise performance of the pavement over time. This is being done using three different methods. The first is the measurement of tire/pavement noise levels at the source using on-board measurement techniques at each milepost and direction of travel for the 115-mile project (Site 1). The second type of measurement was short-term, time-averaged noise levels taken at select locations in neighborhoods surrounding various segments of the freeway (Site 2). These were typically one hour in duration at the time highest levels were produced by the traffic. These locations may or may not be on a direct line of sight to the freeway and may also be subject to noise from sources other than the freeway. The third type of measurement is time-averaged traffic noise made at "research grade" sites conforming to the site requirements specified in FHWA measurement procedures[12] at a 50 ft microphone location (Site 3). Site 3 measurements are also made at distances further from the freeway -- 95 to 250 feet depending on the site, under the circumstances described in Section V.

Five locations (see Figure 1) were selected with the expectation that they would not change acoustically over the duration of the study except for the effects of pavement aging. Depending on the specific site, noise was measured for one or two consecutive days over a period of two hours each day. The frequency of the Site 1, 2, and 3 measurements varied with the site type and the locations within the type. Generally, Site 1 measurements have been ongoing on a semiannual schedule and are intended to continue throughout the project period. Site 2 measurements were performed pre- and post-overlay and at one additional time at selected locations. Site 3 measurements were completed pre- and post-overlay at all locations with additional measurement one, three, and six years after the overlay at two sites, and more regular, semiannual measurement at two others, with the final location to be used as a back-up site.

The dates of the Site 1, 2, and 3 measurements through the end of 2007 are provided in Table 1. The measurements were performed by several different teams. ADOT took the Site 1 measurements up until March 2005, at which time they were made jointly with Illingworth & Rodkin, Inc. (I&R). I&R has made the Site 1 measurements since March 2006. HDR, Inc. took the Site 2 measurements. I&R took the measurements at Site 3A, 3D, and 3E; the Volpe Center of the U.S. Department of Transportation took those at Site 3B and 3C. The remainder of this report documents the results of the measurements at all three sites through 2007 made by all three of these teams.

Table 1: Matrix of the occurrence of QPPP noise measurements

	Site 1	Site 2	Site 3A	Site 3B	Site 3C	Site 3D	Site 3E
Pre Overlay	ADOT	Jul-03 Apr-04	Aug-03	Jun-04	Jun-04	Oct-03	Apr-04
Post Overlay							
2003		Oct-03					
2004	ADOT						
2004		Nov-04	Sep-04			Oct-04	Oct-04
2005	Mar-05		Apr-05		Jun-05	Mar-05	Apr-05
2005				Aug-05		Oct-05	Oct-05
2006	Mar-06		Mar-06	Jun-06	Jun-06	Mar-06	Mar-06
2006	Nov-06					Nov-06	Oct-06
2007	Mar-07	Apr-07				Mar-07	Mar-07
2007	Oct-07			Oct-07		Oct-07	

III. SITE 1 – TIRE/PAVEMENT NOISE SOURCE LEVELS

Measurement Methods and Description

Measurements of tire/pavement noise source levels have been taken at more than 108 mileposts on Interstates 17 and 10 (I-17 and I-10), State Route 51 (SR 51), and Loops 101 and 202 in the metropolitan Phoenix area, which are identified in Figure 1. The terrain is relatively flat throughout the study area. Site 1 field activities included the measurement of on-board tire/pavement noise sources using both the Close Proximity (CPX) and On-Board Sound Intensity (OBSI) testing methods. The PCCP's noise was measured prior to the ARFC overlay, primarily in 2003, to document baseline levels. Post-overlay conditions have been documented each year since 2004. ADOT used a CPX trailer to take measurements through March 2005. I&R assumed responsibility for measurement taking in March 2006. In this period, there was a transition to OBSI measurements that have been used consistently from November 2006 until the present. Due to the size of the pavement program, ARFC pavement overlays are being applied to sections of the Site 1 roadway network over a period of several years. Therefore, some sections of pavement measured during the period from 2004 through November 2006 have been used to document pre-overlay baseline conditions.

Noise measurements are typically made in the right through-travel lane. The test speed for both on-board measurements (CPX and OBSI) is 60 mph (97 km/h), and 5-second average time is used at each milepost. The test tire is a Goodyear Aquatred 3 P205/R7015, chosen to be common with that used by the California Department of Transportation (Caltrans) in its pavement research activities dating back to 2002. Measurements are typically made between about 9:00 am and 3:00 pm to avoid congested traffic conditions. Due to the extent of the project, only one measurement pass for each milepost in each direction was made. Under the on-board testing methods, data from the leading edge and trailing edge of the tire contact patch are obtained separately for the same section of pavement and then later averaged to determine the level of the sound propagating from the tire/pavement interface toward the "wayside" or community.

Initially, tire/pavement noise source level measurements were done using the CPX testing method. However, the newer OBSI testing method was chosen for later testing due to the ongoing maintenance/reliability issues with the ADOT CPX trailer, the ease of testing using the OBSI method, improved ability to compare to other databases, and improved correlation to pass-by levels. Transition to the OBSI method was completed in 2006. To facilitate the migration from CPX to OBSI, CPX sound pressure levels and sound intensity levels were simultaneously measured in March 2005 on the ADOT CPX trailer (Figure 3). In this testing, data of both types were collected for the same tire. To complete the transition to a totally vehicle-based system, measurements were made in November 2006 using both the CPX trailer and a test vehicle with OBSI measurements. This transition was facilitated by the development of an on-vehicle, dual OBSI probe configuration that allowed both the leading and trailing tire contact patch positions to be measured at once[13] continuing the single-pass approach taken for data collection (Figure 4). In the November 2006 measurements, one day of CPX measurements was completed at a majority of the mileposts followed by two days of OBSI data collection at all of the mileposts. The overlapping data were then used to compare the CPX results using the tire specific to the trailer to that obtained from the OBSI measurements with the same type of tire. The results from both the March 2005 and November 2006 comparisons were used to determine a 3.0 dB offset, which was added to the CPX data to obtain OBSI equivalent levels. Data and discussion for the development of this correction are provided in Appendix B.

Figure 3: Dual probe OBSI fixture installed on the ADOT CPX trailer for comparative testing in March 2005.

This correction has been applied to all of the historic CPX data, allowing direct comparison of the earlier on-board data to those obtained more recently.

Results

The results of all of the available Site 1 testing are presented in Figure 5 for each freeway segment included in the study area. This plot shows the considerable variation in the pre-overlay on-board noise levels. While the average of all the original PCCP is an overall A-weighted level of 105.0 dB, the standard deviation is 2.1 dB with an 8.8 dB range. Initially, the variation in the ARFC overlay pavements was less, typically 1.1 to 1.2 dB; however, both the standard deviation and range in the ARFC levels have increased in the Site 1 measurements of October 2007. As noted in Figure 5, some of this increased range (8.4 dB) can be attributed to higher levels on portions of I-17 and I-10 where older, poorer condition ARFC pavement is included in the data set. The PCCP pre-overlay texture was almost entirely uniform spaced, transverse tining. Recent research in other states has shown, however, that considerable variation in the levels for transverse tined PCCP is rather typical of this category of texturing, with variations of 6 dB or more[14] on specific highways and over 10 dB nationwide.[15] This variation, particularly in the performance of the pre-overlay pavement, leads to the conclusion that the localized noise reduction obtained with the overlay will also be quite variable.

Figure 4: Dual probe OBSI fixture installed on car test with ADOT test tire in November 2006

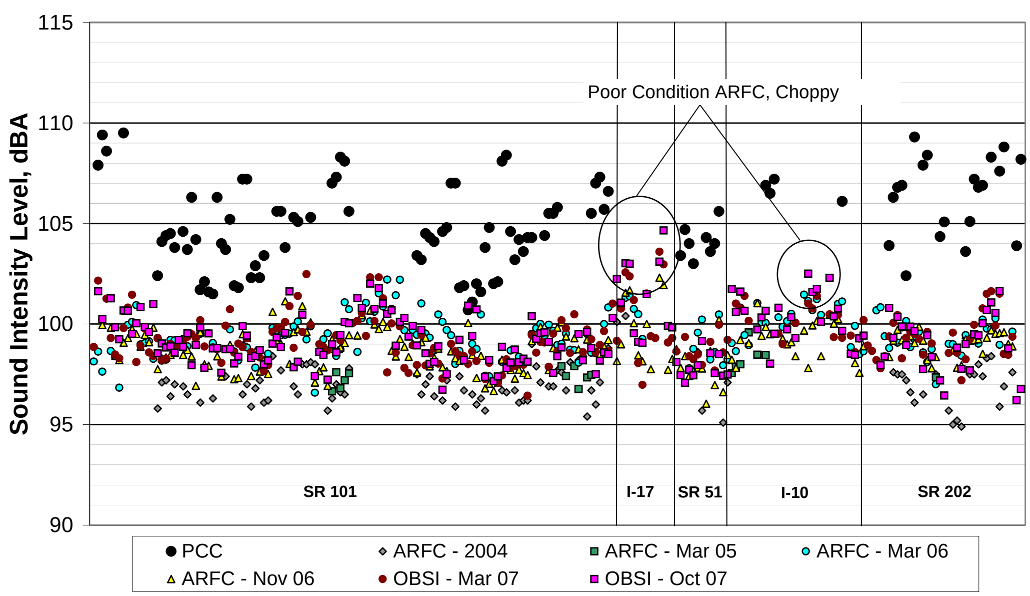

Figure 5: Sound intensity levels pre- and post-ARFC overlay on freeway corridors

For a number of reasons it is appropriate to compare the bulk of the pre- and post-overlay results and the pavement performance over time on a highway-corridor–wide average basis. This comparison is made in Figure 6 for the data through October 2007. As noted in regard to Figure 4, the pre-overlay PCCP OBSI levels display a significant range (2+ dB) in level even when averaged over corridors.

As a result, the reductions produced by the overlay vary for the different corridors. For the newer overlays (Loop 101, SR 51, and Loop 202), the ARFCs are quite similar to each other when compared for the same date of testing. The variation in reduction is then seen to be due almost entirely to the

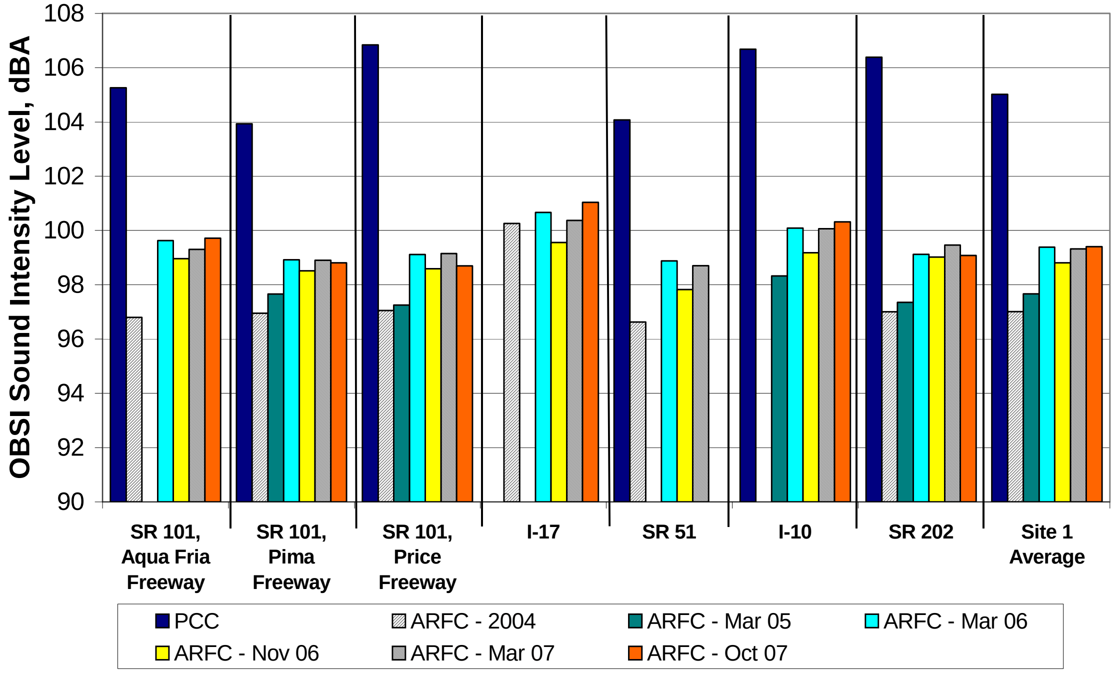

Figure 6: Milepost-averaged OBSI levels for freeway corridors pre-and post-ARFC Overlay

levels of the pre-overlay PCCP. These reductions are presented for each corridor in Table 2. No reductions are reported for I-17 due to the lack of any pre-overlay data.

Table 2: On-board sound intensity pavement tire/noise reductions averaged by freeway corridor

Road	2004	March 2005	March 2006	November 2006	March 2007	October 2007
SR 101, Aqua Fria Freeway	8.5		5.6	6.3	6.0	5.5
SR 101, Pima Freeway	7.0	6.3	5.0	5.4	5.0	5.1
SR 101, Price Freeway	9.8	9.6	7.7	8.3	7.7	8.1
SR 51	7.5		5.2	6.3	5.4	6.2
I-10		8.4	6.6	7.5	6.6	6.4
SR 202	9.4	9.0	7.3	7.4	6.9	7.3
Average	**8.0**	**7.4**	**5.6**	**6.2**	**5.7**	**5.7**

Also included in Figure 6 and Table 2 are the results for the average of all mileposts. These data show an average reduction of 8.0 dB between the initial pre- and post-overlay measurements with the reduction decreasing over time. In the period between the March 2005 and March 2006, the reduction dropped by about 2 dB and has remained rather constant since that time. Overall, this reflects a reduction in performance of about 0.5 to 0.6 dB per year. This rate is somewhat greater than the 0.3 dB per year trend reported for ARFC earlier;[2] however, if the reduction continues to plateau this trend may be re-established in the QPPP.

The OBSI levels for each milepost and each measurement period are tabulated in Appendix C. Review of these data reveals some of the benefits of averaging the results over the various freeway corridors. Prior to March 2006, the data are quite incomplete. At this time it is not known if the data were ever taken or were lost in transition from ADOT . Only about 50% of the pre-overlay milepost data and only about 44% of the initial post-overlay data are available. Sound at 80% to 89% of the mileposts has been routinely measured since the transition in 2006. Although it is unfortunate that complete data sets are not available for the pre- and initial post-overlay measurements, at this point in the program the primary issue is the acoustic longevity of the ARFC, as the initial performance is fairly well documented. Aside from the issue with the initial data, it will be noted from Appendix C that for any particular one of newer data sets, some gaps are present. Not all specific mileposts are captured in each test period due to construction, missing milepost markers, interference from traffic, etc. Because of these data gaps and the sheer bulk of the data acquired, the corridor averages were formed. It should also be noted that the certainty in any individual milepost measurement is on the order of 1 dB or possibly more. This is due to the higher uncertainty in single-pass measurements opposed to multiple-pass averages as stipulated in the current AASHTO test procedure,[16] and to other issues such as uncertainty arising from the ambiguity of lane designation in the vicinity of freeway interchanges. Due to these uncertainties, comparison of the corridor average data is likely to be more meaningful than those of individual mileposts.

Specific OBSI data corresponding to each Site 3 location is of interest. Full data sets are available for these locations except for the initial post-overlay data, which is available for Site 3E only. The levels for these locations are presented in Figure 7. Similar to the averages for all mileposts, these data

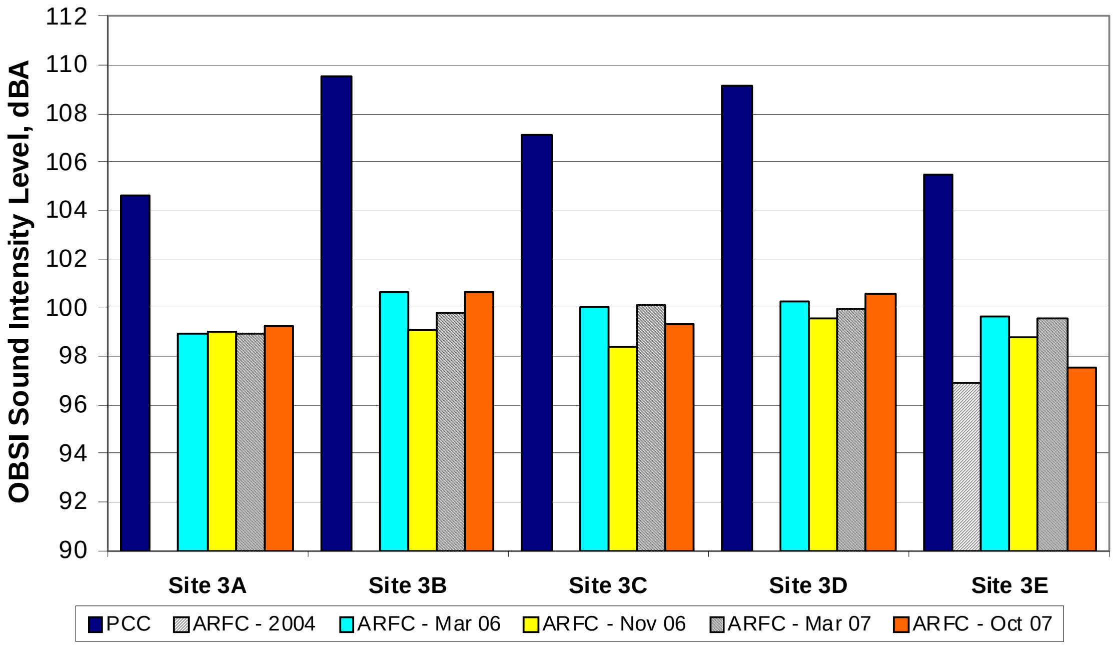

Figure 7: OBSI levels at each of the Site 3 Locations for pre- and post- overlay

indicate little degradation in acoustical performance over the last two years. Over that period, the noise reduction for all three sites has averaged 7.7 dB with Sites 3B and 3D achieving the greatest noise reduction due to higher pre-overlay PCCP levels (Table 3). Site 3A had the lowest noise reduction, also due to the PCCP levels that are lower than the others (Figure 7). One-third octave band spectra corresponding to the Site 3 locations are provided in Appendix C.

Table 3: On-board sound intensity tire/pavement noise reductions for each Site 3 wayside noise location

	March 2006	November 2006	March 2007	October 2007	Site Average
Site 3A	5.7	5.6	5.7	5.4	5.6
Site 3B	8.9	10.4	9.7	8.8	9.5
Site 3C	7.1	8.7	7.1	7.8	7.7
Site 3D	8.9	9.6	9.2	8.6	9.1
Site 3E	5.8	6.7	6.0	7.9	6.6
Average	7.3	8.2	7.5	7.7	7.7

IV. SITE 2 – RESIDENTIAL NEIGHBORHOOD NOISE MEASUREMENTS

Measurement Description

Site 2 data acquisition involves collecting pre-overlay, post-overlay, and follow-up noise measurements in residential neighborhoods adjacent to urban freeways overlaid with ARFC. Measurement positions were chosen to represent typical urban subdivisions because the purpose of the Site 2 study is to evaluate noise reductions in residential neighborhoods due to the application of ARFC overlays on the freeways. In addition, noise measurements were collected when freeway noise was anticipated to be loudest: Level of Service (LOS) C, defined as maximum traffic volume traveling at posted speeds, at the time of day when peak traffic volumes occur; on maximum traffic volume days (Tuesday, Wednesday, or Thursday), and during clear, calm weather.

Some selected measurement positions were modeled using the FHWA-approved Traffic Noise Model (TNM), Version 2.5, using program settings that represent existing conditions, including the presence or absence of noise barriers. The model was set to "Average Pavement" to represent paving conditions. Site 2 modeling results were compared to measured noise reductions as part of the process to assess wayside noise reductions adjacent to transverse tined PCCP pavement sections.

It was initially proposed that four noise measurements be collected at each position: one measurement prior to ARFC application; one measurement post-ARFC application; and two measurements completed in a calendar year (biannual measurements). The initial biannual noise measurements were to be collected in the spring and fall at least one year after the date of overlay; where possible, it was intended that Site 2 biannual noise measurements coincide with Site 1 and Site 3 measurements. The purpose of the biannual measurements was to help confirm the sustainability of noise reductions in residential neighborhoods over the life of the ARFC overlay. These initially planned biannual measurements were later reduced to a single follow-up measurement at selected sites due both to financial constraints and to the demonstrated continued noise reduction capabilities of the ARFC overlay following the first follow-up measurements.

Field Activities

Times of daily peak noise levels were determined for each freeway segment by continuously monitoring traffic noise levels for 24 hours, thus establishing peak noise levels for both the morning and evening. At least three 20-minute noise measurements were recorded at each neighborhood position during either the morning or evening peak traffic noise periods. The reported level was an average of three of these samples that differed by less than 3 dB. Traffic volumes for the measurement period were determined by simultaneously recording traffic on videotape, then subsequently counting vehicles by type. Traffic counts were obtained and utilized for the pre-overlay, post-overlay, and follow-up measurement periods. The post-overlay noise measurements were intended to be normalized to the corresponding pre-noise measurements using equivalent vehicle counts based on REMELs database and vehicle definitions in U.S. Department of Transportation Report No. DOT-VNTSC-FHWA-96-2.[11] Comparison of the very few limited normalized results[18] to those contained in this report indicated that those herein are not normalized.

Air temperature, humidity, wind speed, and wind direction were recorded simultaneously with the noise measurement using field meteorological instruments. The immediate vicinity of each measurement site was sketched on the field data form and digitally photographed. Pertinent characteristics of each site were also recorded on the field data form.

ADOT collected meteorological data to document conditions existing at the time of each noise measurement as part of the process to evaluate measurement positions, particularly those positions that exhibit noise level reductions significantly greater or less than the target noise level reduction of 4 dBA for residential subdivisions. Noise measurements were not collected when wind speeds exceeded 12 mph.

Results

As presented in Table 4 the noise-reduction capabilities of the ARFC remained effective three to four years later, with an average noise reduction of 5.1 dB from pre-overlay readings at the measured Site 2 locations. The noise reductions ranged from 0.1 dB to 9.4 dB, with noise reduction of under 4 dBA recorded at only 5 of 17 (29%) locations. The standard deviation of the difference between the pre- and post-overlay measurements was 2.3 dB; the standard deviation of the difference between the pre-overlay and follow-up readings was 2.3 dB. Appendix E presents the pertinent data for the pre, post, and follow-up measurements. This includes maximum, minimum, and time-average noise levels, the traffic data, the weather conditions, and the date and time.

Table 4 Summary of *Pre, Post,* and *Follow-up* neighborhood noise measurements

Noise Reduction Comparisons									
Route	Segment	HDR ID	Receiver	Before Leq	After Leq	Difference	Before Leq	Follow up Leq	Difference
L101	A	1	1	74.6	69.8	4.8	74.6	65.2	9.4
L101	A	2	2	64.3	55.5	8.8	64.3	59.4	4.9
L101	A	5	5	55.6	52.5	3.1	55.6	55.5	0.1
L101	A	6	6	59.3	57	2.3	59.3	57.3	2
L101	A	8	8	64.9	59.5	5.4	64.9	58.9	6
L101	A	9	9	73.1	69.6	3.5	73.1	70.3	2.8
L101	C	5	25	63.2	64.5	-1.3	63.2	57.9	5.3
L101	D	1	31	61.9	55.7	6.2	61.9	55.1	6.8
L101	D	2	32	58.8	53.5	5.3	58.8	54.3	4.5
L101	D	4	34	64	58.1	5.9	64	57.9	6.1
L101	F	4	48	68.7	63.9	4.8	68.7	61.5	7.2
L202	G	1	52	63.6	58.8	4.8	63.6	61	2.6
I-10	H	1	56	65.7	62	3.7	65.7	60.7	5
I-10	H	3	58	65.8	60	5.8	65.8	59.1	6.7
I-10	H	4	59	68.7	62.6	6.1	68.7	62.8	5.9
I-10	H	5	60	67.8	60.8	7	67.8	60.9	6.9
				Average Reduction		**4.76**	**Average Reduction**		**5.14**

It is likely that meteorological conditions and physical characteristics of Site 2 measurement positions influence the noise reduction attributed to ARFC overlay. These site characteristics include vertical or horizontal freeway alignment changes, the presence of noise barriers, the presence of existing buildings, the presence of other competing noise sources such as local traffic, and ground surface composition.

V. SITE 3 – WAYSIDE NOISE MEASUREMENTS

Measurement Description

Field activities included the measurements of wayside traffic noise levels near the freeway along with simultaneous measurements of traffic and meteorological conditions. The wayside measurements occurred before the ARFC overlay and afterward at the frequency shown in Table 1. As noted in Section II, the Site 3 measurements were made by two different research teams, Volpe and I&R. Although the measurement practices of both are similar, the details are provided below.

Illingworth & Rodkin, Inc. Measurements

At each measurement position, data were collected using Larson Davis Model 820 sound level meters with 1/2-inch diameter GRAS Model 40AQ prepolarized random incidence microphones. Noise levels were stored in 5-minute intervals. The interval data included the Energy Mean Noise Level (L_{eq}) and sound level exceeded 50% of the time (L_{50}).The output from each sound level meter was also fed into TDC-D100 Sony digital audio tape recorders for any necessary subsequent analysis. Simultaneous spectra measurements (one-third octave band center frequency) were made for some of the intervals using a Larson Davis Model 2900b or 3000 real-time analyzer. The systems were calibrated at the beginning and end of each test session with a Larson Davis Model CAL200 acoustic calibrator.

Vehicle volumes were determined by video tape recording of traffic during the noise measurements and subsequently counting the vehicles for the appropriate 15-minute intervals. Traffic counts were determined lane by lane for the near lanes and overall for the far lanes. For pre-overlay conditions, some vehicle volumes were determined from overall field counts for each direction only. Traffic speeds were estimated for each vehicle type from typical passing vehicles measured with a handheld radar gun. All traffic data were classified into five categories: light-duty vehicles, medium-duty trucks, heavy-duty trucks, buses, and motorcycles. Wind speed, direction, and air temperature were measured during noise measurements.

Volpe Center Measurements

Volpe Center staff also deployed Larson Davis Model 820 sound level meters. These were equipped with either Type 4155 Brüel & Kjaer 1/2-inch diameter free-field polarized microphones or Type 4189 1/2-inch diameter free-field pre-polarized microphones. The noise was sampled in 5-minute intervals and recorded also with TDC-D100 Sony digital audio tape recorders. Events were logged for potential noise contamination using an HP 200 LX Palmtop computer electronic log. The systems were calibrated using a Type 4231 Brüel & Kjaer sound calibrator.

Traffic data were obtained from video tapes on each side of the highway. Counts and average speed of each vehicle type were determined for each lane of travel in both directions. Counts were produced in 5-minute intervals. The data were acquired by manual and automatic methods where the automatic system detected speed for each vehicle and provided averages of vehicle counts by vehicle type, and speed in 5-minute periods. Wind speed, direction, and air temperature were measured during noise measurements.

Traffic Noise Modeling

As in the case of the noise measurements, traffic noise modeling and traffic normalization were performed by both measurement teams following similar methods with somewhat different approaches. In both cases, TNM Version 2.5 was used and model geometry was developed from site survey data provided by ADOT. The TNM results were used to normalize measured traffic noise levels for variations in traffic conditions so that pre- and post-overlay conditions could be compared. The model results were also used as a point of comparison of the performance of the ARFC overlay to TNM average pavement. Site-specific details of the individual TNM models are given in the description of each site.

In general, the I&R modeling was performed lane by lane in the direction of travel nearest the microphones and by lane average in the far lanes. For the pre-overlay measurements, the I&R modeling was done based on averages in both directions of travel. Subsequent evaluation of this simplification was done for post-overlay measurements with the finding that the lane-by-lane analysis produced levels that were 0.2 to 0.3 dB lower at 50 ft, 0.4 dB at 100 ft, and 0.6 dB at 250 ft. Volpe modeling was performed lane by lane for both directions of travel. Volpe modeled the traffic in 5-minute intervals and used these to normalize the measured data for traffic conditions. I&R modeled on a 15-minute basis and performed traffic normalization at this interval. TNM results and normalized L_{eq} levels were averaged over the period of measurements to produce single average values for each measurement event.

Test Site Description and Results of Measurements and Modeling

The Site 3 wayside measurements are comprised of five different measurement locations, Sites 3A-3E. Locations are shown in Figure 1. A description of each site is as follows. At each site, it was attempted to locate microphone positions at distances of 50, 100, 250 ft from the center of the near lane of vehicle travel. For the 100 and 250 ft locations, alternative, but similar, distances were used based on the local geometry and constraints of the site. In some case, it was not possible to measure at the furthest distance.

Site 3A

Site Description

Traffic on Site 3A, located on Loop 101, travels primarily east-west and consists of three travel lanes in each direction. Wayside noise levels were measured on the north side of the freeway. The primary site terrain features located north of the freeway are a roadside ditch, West Beardsley Road (a frontage road), and a concrete channel. Aside from West Beardsley Road and the concrete channel, the ground at the site consists of naturally compacted earth with some limited vegetation. There are no permanent large reflecting surfaces such as signboards or buildings. The terrain becomes hilly proceeding north of the measurement sites. The view at the site is unobstructed in both directions for an arc of more than 150 degrees at the freeway. West Beardsley Road traffic was diverted during the noise measurements so that measured levels would not be influenced by local traffic. Photographs and an aerial diagram of the site are in Appendix F. For the TNM, the ground between the highway shoulder and the microphones was taken to be hard ground with the geometry as specified in the ADOT site survey.

Construction of new auxiliary lanes at this site began in 2005. In addition to adding another lane of intermittent vehicle travel, the new lane also resulted in some significant geometry changes to the site, particularly near the 50 ft position (see Appendix E). In an attempt to retain this site for future measurement, wayside noise data were collected in the spring of 2005, prior to the opening of a newly completed lane. This surface was subsequently overlaid with ARFC before being opened to vehicle travel; measurements were conducted in the spring of 2006. The initial plan was for Sites 3A and 3D to be the primary locations for regular testing with occasional backup testing at Site 3E. However, because of the additional lane, geometry changes, and ongoing traffic problems with the frontage road that crosses the microphone line between the 50 ft and 100 ft positions, it was decided to relegate 3A to standby status and to make Site 3E a primary location for continued regular testing.

This site's pre-overlay PCCP had uniform-spaced transverse tining with joints between slabs cut on diagonal to the direction of travel. The overlay consisted of one-inch-thick ARFC. Photographs of the two surfaces are in Appendix E. As noted in Section IV, the noise performance of the pre-overlay PCCP was quite variable even though all of the PCCP along this section of Loop 101 had the standard ADOT uniform spaced transverse tining. This particular location generated tire/pavement noise source levels about .5 dB lower than the average on the pre-overlay PCCP included in the QPPP (compare Figures 6 and 7).

Noise Measurements

Pre-overlay measurements were conducted at Site 3A in August 2003. The overlay was completed by September 2003. Post-overlay measurements were then performed in October 2003, September 2004, April 2005, and March 2006. Wayside noise measurements were conducted for two continuous hours for two days each time. TNM predictions have not been made since 2006 when this site was relegated to standby status. If valid measurements are deemed to be feasible in the future, the modeling will be updated to reflect the newest measurement conditions.

Traffic noise measurements were made at four positions in a line normal to the westbound Loop 101 travel lanes. The positions are as follows:

1. 50 feet from the center of the near travel lane at 12 feet above the ground and the road surface (50 ft/12 ft)
2. 50 feet from the center of the near travel lane at 5 feet above the ground and the road surface (50 ft/5 ft)
3. 100 feet from the center of the near travel lane at 5 feet above the ground (100 ft/5 ft)
4. 175 feet from the center of the near travel lane at 5 feet above the ground (175 ft/5 ft)

Results of Noise Measurements and Modeling

The pre-overlay and post-overlay noise measurement data and noise modeling results were compared to assess the noise reduction provided by the ARFC. A comparison of the average measured and modeled L_{eq} levels for each microphone location is presented in Table 5. Table 6 shows the normalized L_{eq} levels and the reduction in normalized noise levels between the pre-overlay PCCP and the post-overlay ARFC; Table 7 shows the differences between normalized noise levels and modeled noise level predictions. One-third octave band spectra for the pre- and post-overlay condition are shown in Figure 8 for the microphone position 50 ft distant and 5 ft above the roadway for similar traffic conditions. Spectra for other microphone locations are provided in Appendix E.

Table 5: Comparison of Average Measured and Modeled Site 3A Wayside Traffic Noise Levels

Measurement Position	Average Measured L_{eq}					Average Modeled L_{eq}				
	Pre-Overlay	New ARFC	1-Year ARFC	1½-Year ARFC[1]	2½-Year ARFC[1]	Pre-Overlay	New ARFC	1-Year ARFC	1½-Year ARFC	2½-Year ARFC
50 ft/12 ft	82.5	74.6	74.8	75.1	75.8	79.8	81.1	79.5	--	--
50 ft/5 ft	82.3	74.2	75.1	75	75.7	79.9	81.1	79.5	--	--
100 ft/5 ft	76.7	--	71.3	70.4	72.1	77.5	N/A	77.3	--	--
175 ft/5 ft	--	--	66.9	65.1	67.6	--	N/A	74.6	--	--

[1] Includes Construction of new auxiliary lane

Table 6: Normalized L_{eq} and Reduction of Normalized L_{eq} for Site 3A Traffic Noise Levels Between Pre-Overlay PCCP and Post-Overlay ARFC

Measurement Position	Normalized L_{eq}					Change in Level			
	Pre-Overlay	New ARFC	1-Year ARFC	1½-Year ARFC	2½-Year ARFC	New ARFC	1-Year ARFC	1½-Year ARFC	2½-Year ARFC
50 ft/12 ft	82.5	73.0	74.6	--	--	9.5	7.9	--	--
50 ft/5 ft	82.3	73.2	75.1	--	--	9.1	7.6	--	--
100 ft/5 ft	76.7	--	71.3	--	--	--	5.6	--	--
175 ft/5 ft	--	--	66.9	--	--	--	--	--	--

Table 7: Differences Between Site 3A Measured and Modeled Noise Levels

Measurement Position	Measured vs. Modeled Differences				
	Pre-Overlay	New ARFC	1-Year ARFC	1½-Year ARFC	2½-Year ARFC
50 ft/12 ft	-2.7	6.5	4.7	--	--
50 ft/5 ft	-2.4	6.9	4.4	--	--
100 ft/5 ft	0.8	--	6.0	--	--
175 ft/5 ft	--	--	7.7	--	--

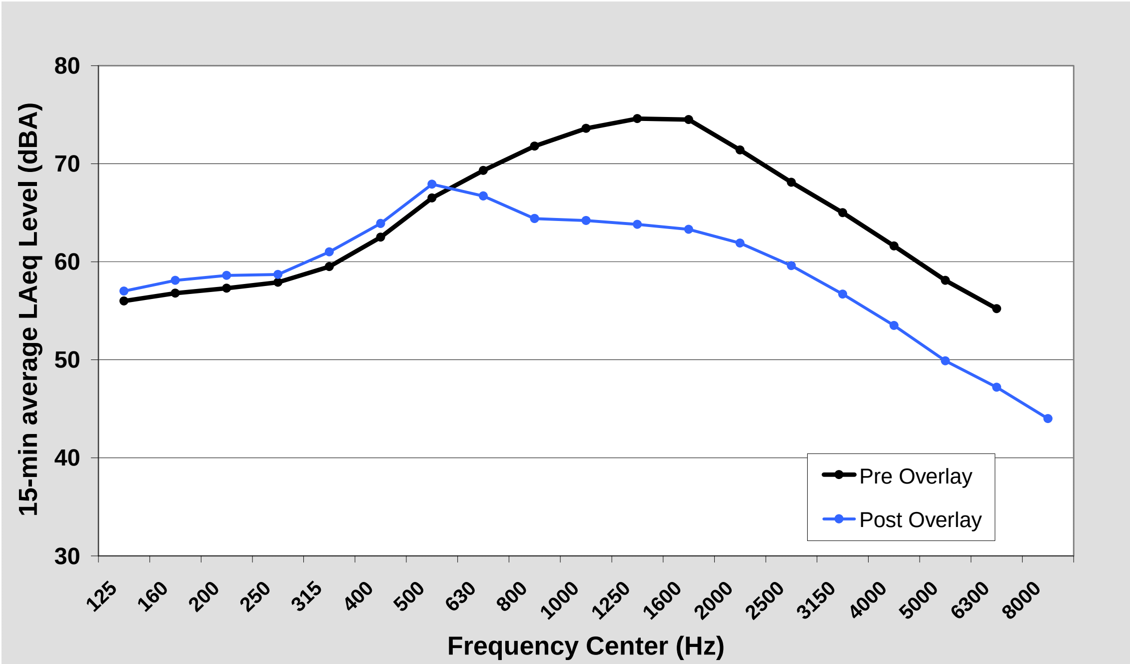

Figure 8: Wayside 1/3 octave band spectra measured at Site 3A at 50 ft from and 5 ft above the roadway pre- & post-overlay for similar traffic conditions

Site 3B

Site Description

Site 3B is located on Loop 101 between mileposts 8 and 9 on the southbound side adjacent to and including the Sun Valley Elementary School. At this location Loop 101 consists of three travel lanes in both the northbound and southbound directions. The terrain is relatively flat and unobstructed on both sides of the freeway. Photographs and an aerial diagram of the site are in Appendix F. The ground at the site is hard-packed dirt in the right-of-way and mowed lawn within the school property. The site provides an unobstructed view of the freeway in both directions for an arc of more than 150 degrees. There were no apparent noise sources in the measurement area. For the TNM, the area between the highway shoulder and closest two microphone locations (50 ft and 95 ft) was taken to be hard soil, while most of the ground type beyond the 95 ft microphone location to the 246 ft location was taken as lawn.

The pre-overlay PCCP had uniform-spaced, transverse tining with respect to the direction of traffic flow, and contained joints between slabs diagonal to the direction of travel. The overlay consisted of one-inch-thick ARFC. As noted in Section IV, the noise performance of the pre-overlay PCCP was quite variable, even though all the PCCP along this section of Loop 101 had the ADOT standard uniform-spaced transverse tining. This particular location generated tire/pavement noise source levels about 4 dB higher than the average for the Agua Fria portion of Loop 101 (compare Figures 6 and 7).

Noise Measurements

Pre-overlay noise levels were measured at Site 3B in June 2004. The overlay was scheduled for completion prior to the summer of 2005. Post-overlay measurements were conducted in August 2005, June 2006, and October 2007. The third set of post-overlay measurements was not available at the time of this report. The future of Site 3B is uncertain at this time due to construction of both a frontage road and a noise barrier along Loop 101 between Olive Avenue and Northern Avenue.

Traffic noise measurements were made at three positions in a line normal to the westbound Loop 101 travel lanes. The positions were:

1. 50 feet from the center of the near travel lane at 10 feet above the ground and 5 feet above the roadway elevation (50 ft/5 ft)
2. 95 feet from the center of the near travel lane at 5 feet above the ground (95 ft/5 ft)
3. 246 feet from the center of the near travel lane at 5 feet above the ground (246 ft/5 ft)

Results of Noise Measurements and Modeling

The pre- and post-overlay noise measurement data and noise modeling results were compared to assess the noise reduction provided by the ARFC. A comparison of the average measured and modeled L_{eq} levels for each site is presented in Table 8. Table 9 shows the L_{eq} levels normalized for traffic and reduction in normalized noise levels between the pre-overlay PCCP and the post-overlay ARFC. Table 10 shows the differences between normalized noise levels and modeled noise level predictions. Normalized one-third octave band spectra for the pre- and post-overlay condition are shown in Figure 9 for the microphone position 50 ft from and 5 ft above the roadway surface. Spectra for other microphone locations are provided in Appendix E.

Table 8: Comparison of Average Measured and Modeled Site 3B Wayside Traffic Noise Levels

Measurement Position	Average Measured L_{eq}			Average Modeled L_{eq}		
	Pre-Overlay	New ARFC	1-Year ARFC	Pre-Overlay	New ARFC	1-Year ARFC
50 ft/5 ft	82.9	74.1	74.9	79.4	80.1	79.8
95 ft/5 ft	77	70.2	70.7	76.1	76.8	76.6
246 ft/5 ft	70.3	62	63.6	71.3	72.1	71.8

Table 9: Normalized L_{eq} and Reduction of Normalized L_{eq} for Site 3B Traffic Noise Levels Between Pre-Overlay PCCP and Post-Overlay ARFC

Measurement Position	Normalized L_{eq}			Change in Level	
	Pre-Overlay	New ARFC	1-Year ARFC	New ARFC	1-Year ARFC
50 ft/5 ft	82.8	73.6	74.6	9.2	8.2
95 ft/5 ft	77.1	69.8	70.5	7.3	6.6
246 ft/5 ft	70.3	61.4	63.2	8.9	7.0

Table 10: Differences Between Site 3B Measured and Modeled Noise Levels

Measurement Position	Measured vs. Modeled Differences		
	Pre-Overlay	New ARFC	1-Year ARFC
50 ft/5 ft	-3.5	6	4.9
95 ft/5 ft	-0.9	6.6	5.9
246 ft/5 ft	1.0	10.1	8.2

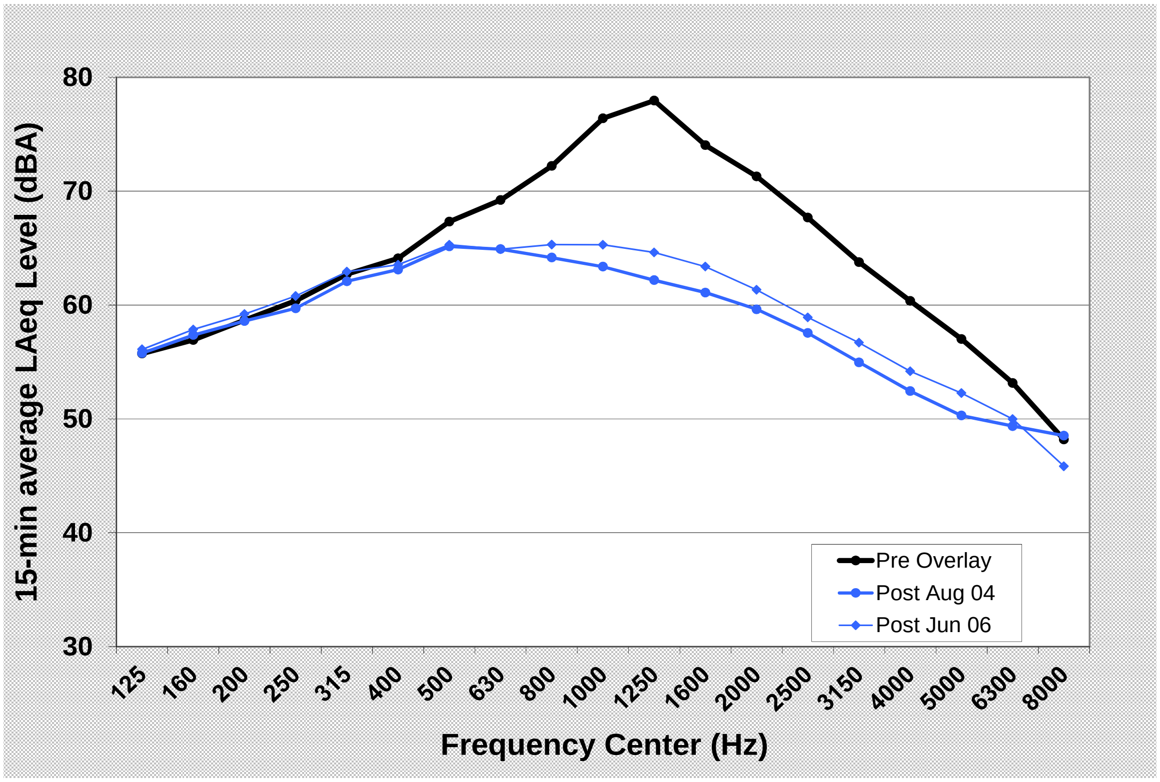

Figure 9: Wayside 1/3 octave band spectra normalized for traffic measured at Site 3A at 50- ft from and 5- ft above the roadway pre- and post-overlay for similar traffic conditions

Site 3C

Site Description

Site 3C is located on I-10 between mileposts 159 and 160 on the southbound side adjacent to and including Mountain Vista Park. At this location I-10 consists of four lanes in both the eastbound and westbound directions, with an exit lane in the eastbound direction. The freeway and its surrounding terrain are relatively flat and unobstructed on both sides. Photographs and an aerial diagram of the site are presented in Appendix F. The ground at the site consists of large gravel within the right-of-way and mowed lawn throughout the park. The ground between the road shoulder and the 50 ft microphone location was noted as gravel for the TNM and considered fairly absorptive (similar to lawn), while from 50 ft to the 141 ft microphone location, the ground varied from gravel to lawn and finally sand (custom EFR value of 240 rayls in the centimeter-gram-second system, where one rayl equals 1dyne-second per centimeter cubed).

There is an existing noise barrier north of the microphone location (see Appendix E) that partially obscures the 141 ft location from the required unobstructed view of 150 degrees. The barrier obstructs the left-most 15 degrees of the complete 150 degree angle and would add less than 0.1 dB to the measured levels so that no adjustments were needed. The 50 ft location provided an unobstructed view of the freeway in both directions for an arc of more than 150 degrees. The measurement area had no apparent noise sources.

The pre-overlay PCCP had uniform-spaced transverse tining, with joints between the dowelled slabs ,perpendicular to the direction of travel. The overlay consisted of 1-inch ARFC. As noted in Section IV, the noise performance of the pre-overlay PCCP was quite variable even though all the PCCP along this section of I-10 had the ADOT standard uniform-spaced, transverse tining. This particular location generated tire/pavement noise source levels about .5 dB higher than the average on the pre-overlay PCCP on I-10 and about 2 dB higher than the average of the PCCP included in the QPPP (compare Figures 6 and 7).

Noise Measurements

Pre-overlay measurements were taken at Site 3C in June of 2004; the overlay was completed in the fall of 2004. Post-overlay measurements were made in June 2005 and June 2006. Traffic noise measurements were made at two positions in a line normal to the westbound I-10 travel lanes. The positions are as follows:

1. 50 feet from the center of the near travel lane at 9.5 feet above the ground and 5 feet above the roadway (50 ft/5 ft)

2. 141 feet from the center of the near travel lane at 5 feet above the ground (141 ft/5 ft)

Results of Noise Measurements and Modeling

The pre-overlay and post-overlay noise measurement data and noise modeling results were compared to assess the noise reduction provided by the ARFC. A comparison of the average measured and modeled L_{eq} levels for each microphone location is presented in Table 11. Table 12 shows the normalized L_{eq} and the reduction in normalized noise levels between the pre-overlay PCCP and the post-overlay ARFC, and Table 13 shows the differences between normalized noise levels and modeled noise level predictions. One-third octave band spectra normalized for traffic conditions for the pre- and post-overlay conditions are shown in Figure 10 for the microphone position 50 ft distant and 5 ft above the roadway. Spectra for other microphone locations are provided in Appendix E.

Table 11: Comparison of Average Measured and Modeled Site 3C Wayside Traffic Noise Levels

Measurement Position	Average Measured L_{eq}			Average Modeled L_{eq}		
	Pre-Overlay	½-Year ARFC	1½-Year ARFC	Pre-Overlay	½-Year ARFC	1½-Year ARFC
50 ft/5 ft	82.9	75.2	75.3	79.8	80.9	80.1
141 ft/5 ft	72.4	66.9	67.3	74.8	75.9	75.1

Table 12: Normalized L_{eq} and Reduction of Normalized L_{eq} for Site 3C Traffic Noise Levels Between Pre-Overlay PCCP and Post-Overlay ARFC

Measurement Position	Normalized L_{eq}			Change in Level	
	Pre-Overlay	½-Year ARFC	1½-Year ARFC	½-Year ARFC	1½-Year ARFC
50 ft/5 ft	83.2	74.4	75.2	8.8	8.1
141 ft/5 ft	72.6	66.0	67.0	6.6	5.6

Table 13: Differences Between Site 3C Measured and Modeled Noise Levels

Measurement Position	Measured vs. Modeled Differences		
	Pre-Overlay	½-Year ARFC	1½-Year ARFC
50 ft/5 ft	-3.1	5.7	4.8
141 ft/5 ft	2.4	9	7.8

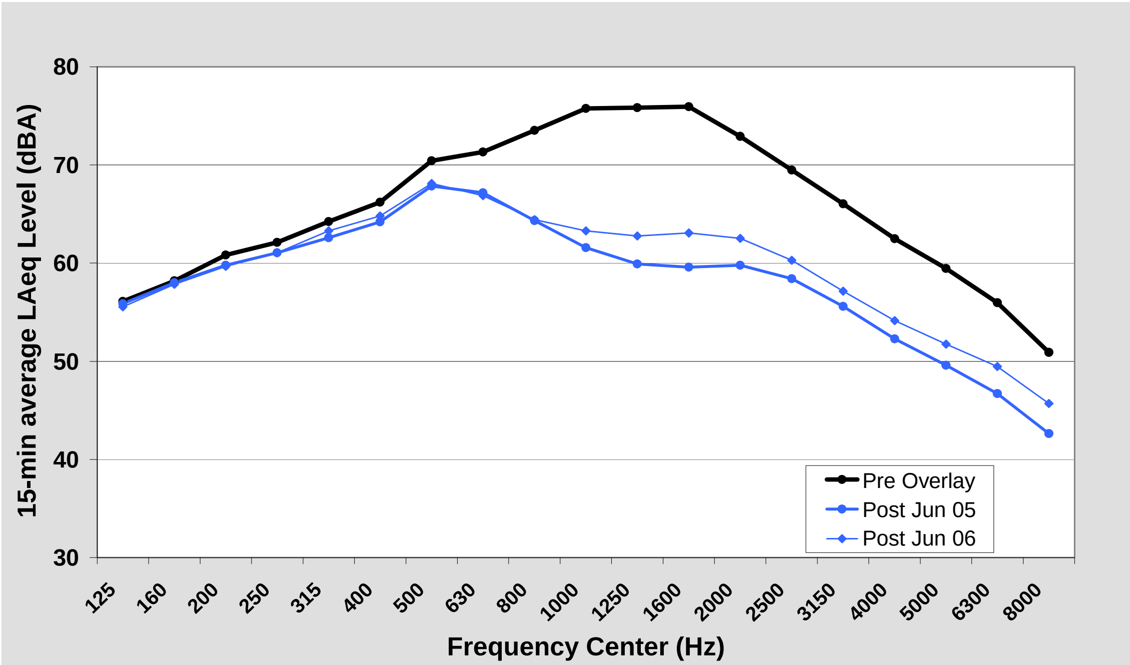

Figure 10: Wayside 1/3 octave band spectra normalized for traffic measured at Site 3C at 50 ft from and 5 ft above the roadway pre- and post-overlay

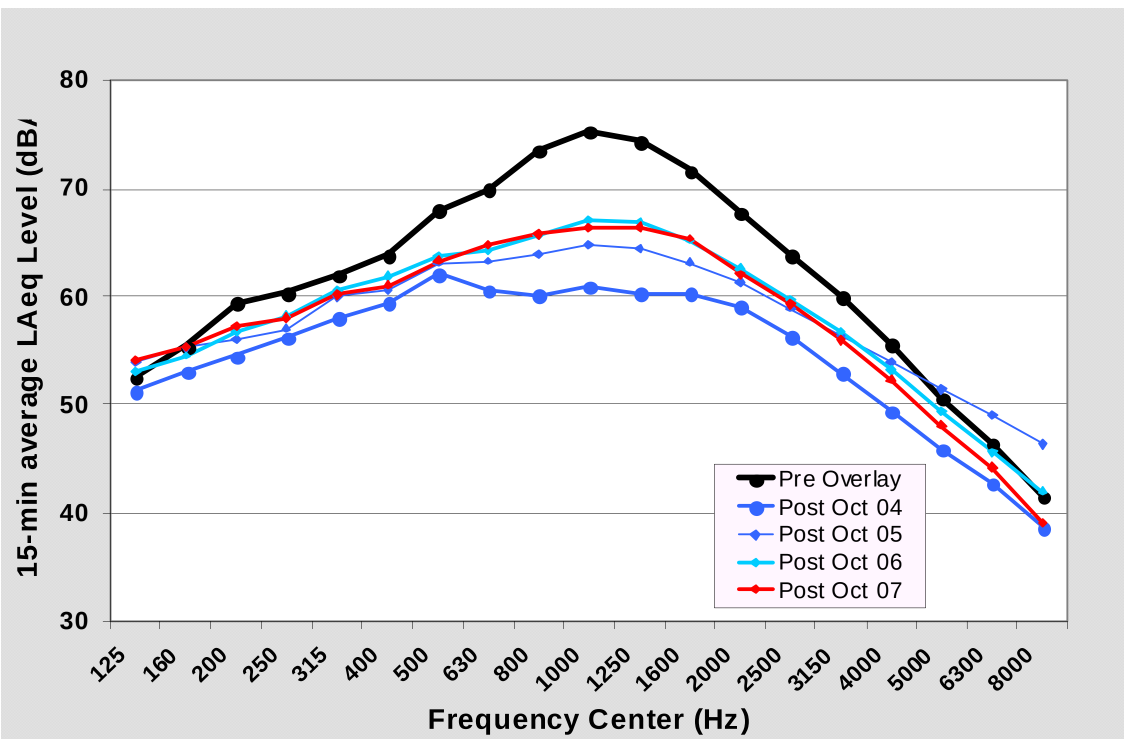

Figure 11: Wayside 1/3 octave band spectra measured at Site 3A at 50 ft from and 5 ft above the roadway pre & post overlay for similar traffic conditions

Site 3D

Site Description

Site 3D is located on Loop 202 between mileposts 18 and 19, between the East McDowell Road and North Val Vista Drive exits. At this location Loop 202 consists of three travel lanes in both the westbound and eastbound directions. The surrounding terrain is relatively flat and unobstructed to the north of the freeway. The packed earth at the site was modeled in TNM using a hard ground type.

Photographs of the site are in Appendix F. The ground at the site is naturally compacted earth with minimal vegetation. The site is free of any permanent large reflecting surfaces such as signboards, buildings, or hillsides. The site provides an unobstructed view of the freeway in both directions for an arc of more than 150 degrees for all microphone locations. There were no apparent noise sources in the measurement area other than occasional aircraft overflights.

The pre-overlay PCCP had random-spaced, transverse tining with joints between slabs diagonal to the direction of travel. The overlay consisted of one-inch-thick ARFC. Photographs and an aerial diagram of the site and photographs of the two surfaces are in Appendix E. As previously noted, most of the pre-overlay PCCP included in the QPPP had ADOT standard uniform–spaced, transverse tining. The location of Site 3D coincided with the area where experimental textures had been applied in previous research.[9] This particular location had random-spaced, transverse tining PCCP that produced levels generally higher than the uniform-spaced transverse tining. In this case, the levels were about 4 dB higher than average PCCP levels throughout the QPPP area and about 2.5 dB higher than the average of the other Site 3 PCCP. Within the experimental sections, this random-spaced, transverse tined pavement was about 2 dB higher than the uniform-spaced, transverse tined pavement and about 4 to 5 dB higher than longitudinal tined PCCP.

Noise Measurements

Pre-overlay measurements were conducted at Site 3D in October of 2003. The overlay was placed in March of 2004 and followed up by post-overlay measurements in October 2004, March and October 2005, April and November 2006, and March and October 2007. Wayside noise measurements were conducted for two continuous hours on two days each time.

Traffic noise measurements were made at four positions in a line normal to the westbound Loop 202 travel lanes. The positions are as follows:

1. 50 feet from the center of the near travel lane at 12 feet above the ground (50 ft/12 ft)
2. 50 feet from the center of the near travel lane at 5 feet above the ground and roadway (50 ft/5 ft)
3. 100 feet from the center of the near travel lane at 5 feet above the ground (100 ft/5 ft)
4. 250 feet from the center of the near travel lane at 5 feet above the ground (175 ft/5 ft)

Results of Noise Measurements and Modeling

The pre-overlay and post-overlay noise measurement data and noise modeling results were compared to assess the noise reduction provided by the ARFC. A comparison of the average measured and modeled L_{eq} levels for each microphone location is presented in Tables 14 and 15. Table 16 shows the normalized L_{eq} levels for pre-overlay PCCP and the post-overlay ARFC and Table 17 shows reduction in normalized levels. The differences between normalized noise levels and modeled noise level predictions are shown in Table 18. It is important to note the ARFC differences between measured noise levels and modeled noise level predictions.

Table 14: Comparison of Average Measured Site 3D Wayside Traffic Noise Levels

Measurement Position	Average Measured L_{eq}							
	Pre-Overlay	½-Year ARFC	1-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC	3½-Year ARFC
50 ft/12 ft	84.3	70.9	72.2	73.3	73.3	74.9	74.2	74.5
50 ft/5 ft	83.2	70.9	72.0	73.4	72.8	75.2	74.2	74.2
100 ft/5 ft	76.8	65.6	67.5	67.4	65.8	66.8	66.6	66.8
250 ft/5 ft	68.9	59.7	61.4	61.6	60.4	60.1	60.4	60.3

Table 15: Comparison of Average Modeled Site 3D Wayside Traffic Noise Levels

Measurement Position	Average Modeled L_{eq}							
	Pre-Overlay	½-Year ARFC	1-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC	3½-Year ARFC
50 ft/12 ft	75.0	74.1	74.4	74.1	75.3	75.5	75.4	74.8
50 ft/5 ft	75.1	74.1	74.4	74.1	75.3	75.5	75.4	74.9
100 ft/5 ft	72.6	71.6	71.9	71.7	72.8	73.0	72.9	72.4
250 ft/5 ft	67.6	66.6	66.9	66.6	67.7	68.1	67.9	67.4

Table 16: Normalized Leq for Site 3A Traffic Noise Levels Between Pre-Overlay PCCP and Post-Overlay ARFC

Measurement Position	Normalized L_{eq}							
	Pre-Overlay	½-Year ARFC	1-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC	3½-Year ARFC
50 ft/12 ft	84.3	70.4	71.4	72.8	71.6	73.1	72.5	73.3
50 ft/5 ft	83.2	70.6	71.4	73.1	71.3	73.5	72.6	73.2
100 ft/5 ft	76.8	65.4	66.9	67.1	64.4	65.1	65.0	65.8
250 ft/5 ft	68.9	59.5	60.9	61.4	59.2	58.4	58.9	59.3

Table 17: Reduction in Site 3D Normalized Levels Between Pre-Overlay PCCP and Post-Overlay ARFC

Measurement Position	Change in Level						
	½-Year ARFC	1-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC	3½-Year ARFC
50 ft/12 ft	12.4	11.4	10.0	11.2	9.7	10.3	9.5
50 ft/5 ft	11.1	10.3	8.6	10.4	8.2	9.0	8.5
100 ft/5 ft	10.0	8.5	8.4	11.0	10.3	10.4	9.6
250 ft/5 ft	8.1	6.7	6.2	8.5	9.2	8.7	8.3

Table 18: Differences Between Site 3D Measured and Modeled Noise Levels

Measurement Position	Measured vs. Modeled Differences							
	Pre-Overlay	½-Year ARFC	1-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC	3½-Year ARFC
50 ft/12 ft	-9.3	3.2	2.2	0.8	2.0	0.5	1.1	0.3
50 ft/5 ft	-8.0	3.2	2.5	0.7	2.5	0.3	1.2	0.6
100 ft/5 ft	-4.2	5.9	4.4	4.3	7.0	6.2	6.4	5.6
250 ft/5 ft	-1.3	6.8	5.5	5.0	7.2	8.0	7.5	7.1

It should be to noted that the ARFC overlay had already been placed on the far lanes (eastbound direction) when pre-overlay measurements were conducted. As a result, the pre-overlay data are suspected to be slightly lower (less than 1 dB) than they would have been if the far lanes were the original PCCP, however, it is not possible to account for this in the TNM normalization. One-third octave band spectra for the pre- and post-overlay condition are shown in Figure 11 for the 50 ft distant, 5 ft above the roadway microphone position for similar traffic conditions. Spectra for other microphone locations are provided in Appendix E.

Site 3E

Site Description

Site 3E is at milepost 47 on Loop 101 about midway between its intersections with Chaparral Road and Indian School Road in Scottsdale. At this location Loop 101 consists of three through-travel lanes for the southbound and northbound directions along with an outside auxiliary lane in each direction. The freeway is relatively flat, but is on a slight embankment. Photographs of the site are in Appendix F. The packed earth at the site was modeled in TNM using a hard ground type.

The ground at the site is naturally compacted earth with minimal vegetation for the both the pre- and post-measurement conditions. The site is free of any permanent large reflecting surfaces such as signboards, buildings, or hillsides. The top of the small embankment provides some shielding. The site provides an unobstructed view of the freeway with an arc of more than 150 degrees in both directions. There were no apparent noise sources in the measurement area. The southbound auxiliary lane is about 40 feet from the closest measurement positions.

The pre-overlay PCCP had uniform-spaced transverse tining with joints between slabs diagonal to the direction of travel. The overlay consisted of 1-inch-thick ARFC. The PCCP along this section of Loop 101 had the standard ADOT uniform-spaced transverse tining. This particular location generated tire/pavement noise source levels about .5 dB higher than the average of the pre-overlay PCCP included in the QPPP (compare Figures 6 and 7).

Noise Measurements

Pre-overlay measurements were conducted at Site 3E in April 2004. The overlay was placed in May 2004; post-overlay measurements were conducted in October 2004, October 2005, March and October 2006, and March 2007. Wayside noise measurements were made for two continuous hours on two days each time.

Traffic noise measurements were made at three positions in a line normal to the westbound Loop 101 travel lanes. The positions are as follows:

1. 50 feet from the center of the near travel lane at 8.7 feet above the ground which was 5 feet above the pavement surface (50 ft/5 ft)
2. 50 feet from the center of the near travel lane at 5 feet above the ground, 1.3 ft above the pavement surface (50 ft/1.3 ft)
3. 100 feet from the center of the near travel lane at 5 feet above the ground (100 ft/5 ft)

Results of Noise Measurements and Modeling

The pre-overlay and post-overlay noise measurement data and noise modeling results were compared to assess the noise reduction provided by the ARFC. A comparison of the average measured and modeled L_{eq} levels for each site is presented in Tables 19 and 20. Table 21 shows the normalized noise levels and Table 22 the difference between the normalized pre-overlay PCCP and post-overlay ARFC levels. Table 23 shows the differences between normalized noise levels and modeled noise level predictions. One-third octave band spectra for the pre- and post-overlay condition are shown in Figure 12 for the 50 ft distant, 5 ft above the roadway microphone position. Spectra for other microphone locations are provided in Appendix E.

Table 19: Comparison of Average Measured Site 3E Wayside Traffic Noise Levels

Measurement Position	Average Measured L_{eq}					
	Pre-Overlay	½-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC
50 ft/5 ft	84.2	74.9	75.1	75.3	75.7	76
50 ft/1.3 ft	81.6	73.2	72.8	72.5	72.9	74.1
100 ft/5 ft	78.7	69.8	69.9	68.9	69.9	71.3

Table 20: Comparison of Average Modeled Site 3E Wayside Traffic Noise levels

Measurement Position	Average Modeled L_{eq}					
	Pre-Overlay	½-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC
50 ft/5 ft	80.2	80.1	79.9	80	80	80.1
50 ft/1.3 ft	80	79.9	79.4	79	79.4	79.8
100 ft/5 ft	76.9	76.9	76.8	77.5	77.1	76.8

Table 21: Comparison of Average Normalized Site 3E Wayside Traffic Noise Levels

Measurement Position	Normalized L_{eq}					
	Pre-Overlay	½-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC
50 ft/5 ft	84.2	75.0	75.4	75.5	75.9	76.1
50 ft/1.3 ft	81.6	73.3	73.4	73.5	73.5	74.3
100 ft/5 ft	78.7	69.8	70.0	68.3	69.7	71.4

Table 22: Reduction in Site 3E Normalized Levels Between Pre-Overlay PCCP and Post-Overlay ARFC

Measurement Position	Change in Level				
	½-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC
50 ft/5 ft	9.1	8.7	8.6	8.2	8.0
50 ft/1.3 ft	8.3	8.2	8.1	8.2	7.3
100 ft/5 ft	8.9	8.7	10.4	9.0	7.3

Table 23: Differences Between Site 3E Measured and Modeled Noise Levels

Measurement Position	Measured vs. Modeled Differences					
	Pre-Overlay	½-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC
50 ft/5 ft	-4.0	5.2	4.8	4.7	4.3	4.1
50 ft/1.3 ft	-1.7	6.7	6.6	6.5	6.5	5.7
100 ft/5 ft	-1.8	7.1	6.9	8.6	7.2	5.5

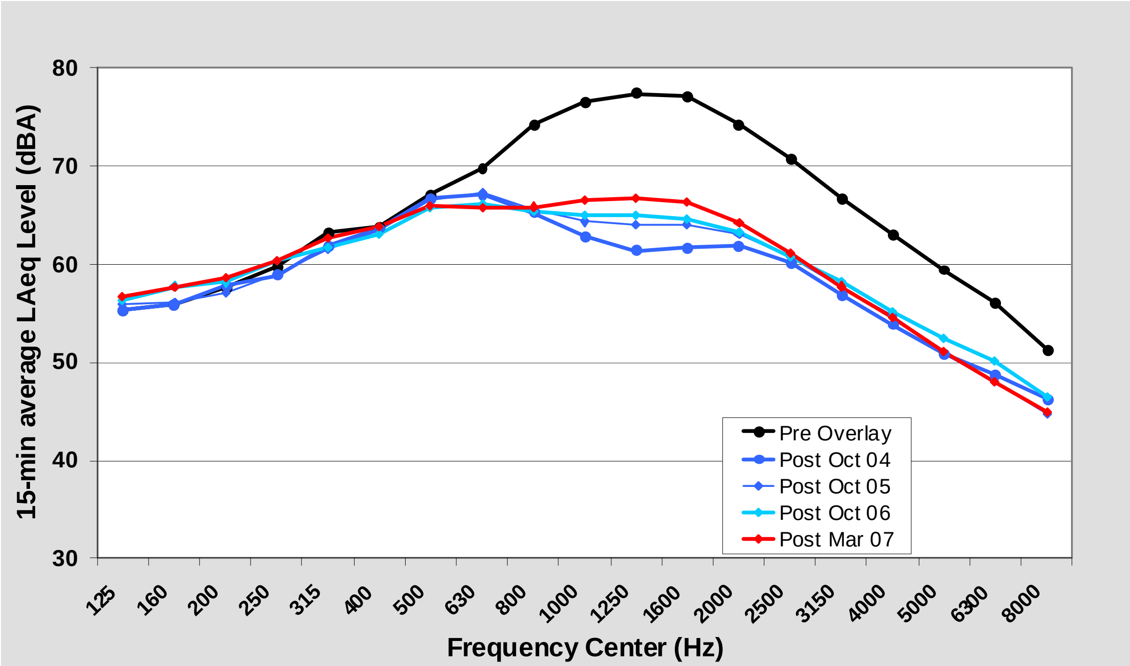

Figure 12: Wayside 1/3 octave band spectra measured at Site 3E at 50 ft from and 5 ft above the roadway pre and post overlay for similar traffic conditions

VI. SUMMARIES

Normalized Wayside Levels

As a summary of the Site 3 results, tables comparing results for similar microphone positions were developed. The first of these, Table 24, compares the reductions in normalized noise level for each site

Table 24: Comparison of Wayside Traffic Noise Reductions for Each of the Five Site 3 Locations for 50 ft Microphone Locations

50 ft/5 ft Measurement Position	Change in Level							
	New ARFC	½-Year ARFC	1-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC	3½-Year ARFC
3A	9.1		7.6					
3B	9.2		8.2					
3C		8.8		6.6				
3D		11.1	10.3	8.6	10.4	8.2	9.0	8.5
3E		9.1		8.7	8.6	8.2	8.0	

at the microphone location 50 ft away from the center of the near lane of travel and a height 5 ft above the roadway. Prior to the first year (new ARFC and 1/2-year ARFC) of the overlay, the average reduction for all five of the sites was 9.5 dB. The average reduction for the first year was 8.3 dB for all five sites, while for the second year, the reduction was 8.9 dB, but measurements were taken at sites 3D and 3E only. For the third year, these sites had an average reduction of 8.5 dB. Site 3D had reductions equal to or greater than any of the other sites at 50 ft. This is expected as this is the only site in which the pre-overlay PCCP had the random-spaced transverse tining that produced higher noise levels than ADOT's standard uniform-spaced transverse tining.[9] The reductions in normalized level for the microphones located 95 and 100 ft away from the center of the near lane are given in Table 25. For these positions, results prior to the end of the first year of the overlay are sparse and the

Table 25: Comparison of Wayside Traffic Noise Reductions for Each of the Five Site 3 Locations for 100 ft Microphone Locations

95-100 ft/5 ft Measurement Position	Change in Level							
	New ARFC	½-Year ARFC	1-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC	3½-Year ARFC
3A			5.6					
3B	7.3		6.6					
3C								
3D		10.0	8.5	8.4	11.0	10.3	10.4	9.6
3E		8.9		8.7	10.4	9.0	7.3	

average reduction was 8.7 dB. The one-year and 1.5 year measurements showed an average reduction at the four sites of 7.6 dB. the reduction at the two sites where measurements were taken two and three years later averaged 10.2 dB, while three and four years later the average reduction sites was 9.1 dB. Tables 24 and 25, show that prior to the end of the first year the reductions at all sites were greater at the 50 ft microphone locations than at 95/100 ft locations. Beginning in the second year, the reductions at the more distant microphone locations are typically greater.

Wayside Comparisons to TNM

Table 26 shows the differences between the measured wayside noise levels and those predicted by TNM for the 50 ft microphone locations. These indicate how much additional noise abatement the pavement is providing relative to the TNM predicted levels. They also indicate how the pavement is performing relative to the average pavement used in TNM. These values relate directly to the 4 dB credit allowed in the QPPP and as such should be 4 dB or greater. The data in Table 26 indicate that Sites 3A, 3B, 3C, and 3E all behave similarly: the TNM average pavement predicted levels are 2.4 to 4 dB lower than the measured levels of the original PCCP. For Site 3D, the predicted levels are 8 dB lower than the measured.

Table 26: Difference Between Measured and Modeled Noise Levels for Each of the Five Site 3 Locations for 50 ft Microphone Distance

50 ft/5 ft Measurement Position	Measured v Modeled Differences								
	Pre-Overlay	New ARFC	½-Year ARFC	1-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC	3½-Year ARFC
3A	-2.4	6.9		4.4					
3B	-3.5	6.0		4.9					
3C	-3.1		5.7		4.8				
3D	-8.0		3.2	2.5	0.7	2.5	0.3	1.2	0.6
3E	-4.0		5.2		4.8	4.7	4.3	4.1	

After the overlay, within the first six months, the TNM predicted levels for 3A, 3B, 3C, and 3E were 5.2 to 6.9 dB greater than the measured levels, however, for 3D, they were only 3.2 dB greater than that of the overlay. Site 3D is a definite anomaly with the predicted levels being 8 dB lower than the measured levels for the PCCP, while the post-overlay predicted levels were only 3.2 greater than the measured levels. From comparison to TNM, this implies that the pavement at Site 3D is 4 to 5 dB noisier than the others. However, from Figure 7, the OBSI levels for all of the other Site 3 overlays were within 1 dB of those of Site 3D. Further, the measured reduction in noise with the overlay was actually greater at 3D than the other sites, implying that the pavement at 3D was performing as well as it was at the other sites. From research done on PCCP texturing conducted on the Loop 202 near Site 3D, the random-spaced, transverse tined pavement was found to be about 2 to 2.5 dB louder than the typical ADOT uniform-spaced, transverse tined PCCP as measured with OBSI, controlled pass-by, and pseudo statistical methods.[9] This is consistent with the higher wayside measured noise reductions for 3D. These observations lead to conjecture that there may be a calibration offset in the TNM predictions for Site 3D and that the predicted levels should actually be about 2 to 3 dB higher than indicated. At this time, the atypical results at 3D cannot be confirmed to be due to an offset and this will be the subject of further investigation.

Although not the primary focus of comparison between TNM and measured results, the differences between the modeled and normalized L_{eq} levels are shown in Table 27 for the four sites where 95/100 ft microphone locations were measured.

Table 27: Difference Between Measured and Modeled Noise Levels for Each of the Five Site 3 Locations for 100 ft Microphone Distance

95-100 ft/5 ft Measurement Position	Measured v Modeled Differences								
	Pre-Overlay	New ARFC	½-Year ARFC	1-Year ARFC	1½-Year ARFC	2-Year ARFC	2½-Year ARFC	3-Year ARFC	3½-Year ARFC
3A	0.8			6.0	6.5				
3B	-0.9	6.6		5.9					
3C									
3D	-4.2		5.9	4.4	4.3	7.0	6.2	6.4	5.6
3E	-1.8		7.1		6.9	8.6	7.2	5.5	

In these cases, the differences for 3A, 3B, and 3E are again similar for the pre-overlay conditions with differences ranging from -1.8 to 0.8 dB. Again, 3D stands out, as the difference between the predicted and measured PCCP is 2.4 to 5 dB more than that at the other sites. For the post-overlay cases, however, the difference between predicted and measured levels is more consistent among the sites and the differences remain greater than 4 dB in all cases.

Acoustic Longevity

Conclusions regarding the acoustic longevity of the ARFC overlay may be premature at this point in the project. Depending on which freeway is considered, the overlay ranges between two to three and a half years old by the end of 2007. In the cases where the results span three to three and one-half years, the noise reduction performance has degraded by 2.6 and 1.1 dB respectively for the 3D and 3E wayside data (Table 24) and 2.3 dB for the Site 1 on-board data (Table 2). The performance fell rapidly for both types of data in the first year to one and one-half years of the overlay but has appeared to maintain a consistent level of performance after one and one-half to two years. Starting in year one and one-half, the wayside data for Site 3D appears to show some variation in the pavement's performance with time starting in year one and a half. From this point, the reduction cycles with the data taken in the half years (springtime) being typically greater than the surrounding full years (fall). For Site 3E, the noise reduction performance remains fairly consistent after the first year which is also the case for the Site 1 averages (Table 2). Combining the trends from the Site 1 and 3D and 3E results, the decline in noise reduction performance has been about 0.7 dB per year overall.

To utilize more of the Site 3 data, the data of Table 24 can be processed further by using the average of the increments in noise reduction measured at 50 ft across all sites and plotting them versus time. The changes in the Site 1 OBSI results for each freeway can be averaged in the same manner. The results are plotted in Figure 13. Examining the wayside and OBSI changes, it appears that trends are similar and as a result, the data were merged and curve-fitted. Figure 13 shows an exponential fit through the points. This type of curve fit produced a higher R^2 value than either a linear or logarithmic fit. However, this trend line reaches a maximum at about four years and then drops in an unrealistic manner. A linear fit starting at one year (ignoring the zero/zero data point) gives a slope of about 0.6 dB per year similar to that discussed above for Site 1, 3D, and 3E results alone. At this time the data is

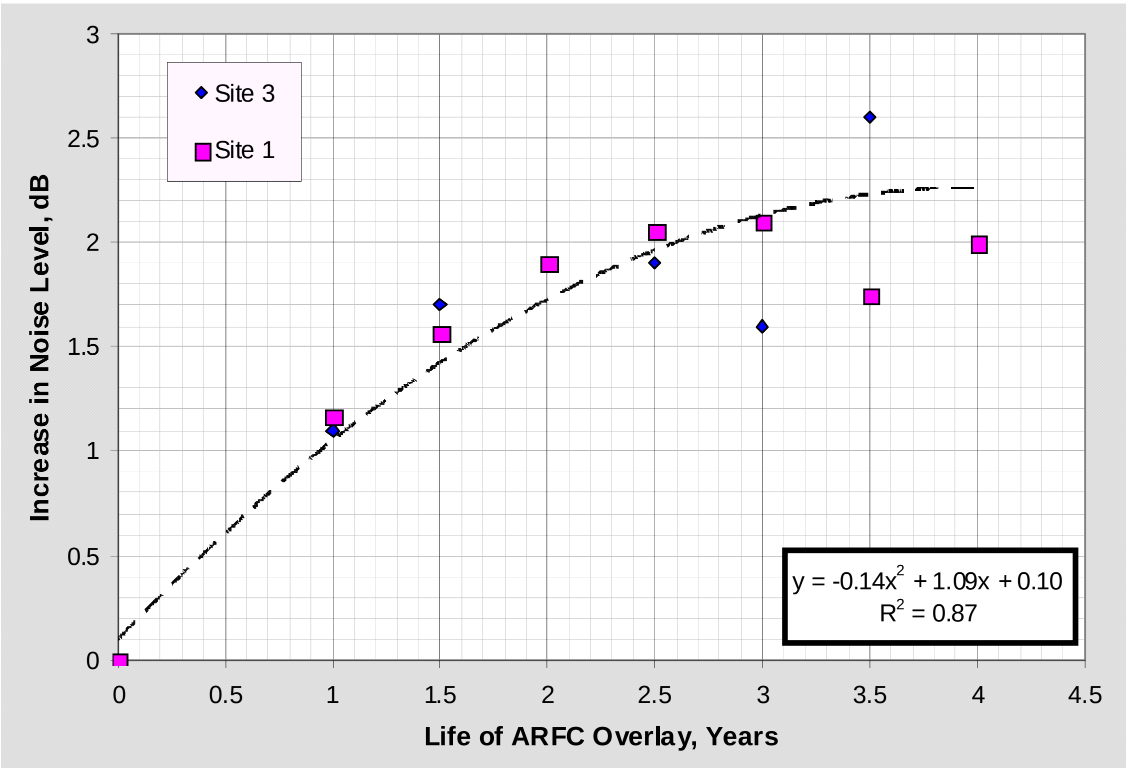

Figure 13: Increase in Site 1 & Site 3 noise levels versus time from initial overlay

insufficient to be certain of a long-term trend and to extrapolate with any confidence.

The frequency spectra for all sites (Figures 8 through 12) show substantial noise reductions above 630 Hz. The amount of reduction appears to be associated with the characteristics of the original PCCP. The signature of the new ARFC overlay appears to be fairly consistent from site to site. The variations of the new ARFC overlay's spectra shape from site to site may have to do with the differences in age when each of the sites was first tested. In regard to acoustic longevity, Sites 3B, 3C, and 3D show similar spectral trends. In these cases (Figures 9 through 11), Sites 3B and 3C showed about 1 dB less reduction from year one to year two. The reduction changed by less than 1 dB at the more distant positions. At year two, the reduction was about 8 dB at the 50 ft positions. The frequency spectra in Figures 9 and 10 show that noise levels are increasing with age in the 800 to 2000 Hz range. For Site 3E (Figure 12), the increases are also in the higher frequencies, but limited in range from 1000 to 2500 Hz.

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APPENDIX A

DESCRIPTION OF ADOT ARFC OVERLAY

Because ADOT has been using ARFC surfaces for more than 30 years, its recent use as a quiet pavement was based on considerable performance history. Typically, a one-half-inch thick ARFC is used over hot mix asphalt surfaces on interstate or high volume pavements in Arizona. ARFC pavements first evolved as a durable surface, eliminating the raveling problems experienced with conventional friction courses.

ARFC surfaces were first placed on concrete pavements in the late 1980s as a rehabilitation strategy. When ARFC is placed on PCCP it is placed one inch thick instead of one-half-inch thick as on flexible pavements. The increase in thickness is used to prevent formation of reflective cracking at the contraction joints of the PCCP. These joints are spaced 13 to 17 ft apart, with an average of 15 ft spacing. Until recently, the use of ARFC over PCCP has not been common. It was originally planned as the rehabilitation strategy for the freeway system when it became old (e.g., 34 years after construction). However, since the early 1990s ADOT has been aware of the noise benefits of ARFC pavements. When the public became concerned with freeway noise, the use of ARFC changed from a rehab strategy to that of a noise mitigation surface. However, the mixture design was not modified for noise considerations. Instead, the normal mixture, developed for durability, was used.

The ARFC is a 3/8 inch top size mixture typically produced between 9.1% to 9.6% total binder content and constructed one inch thick. The gradation requirements are shown in Table 1A.

Table 1A ARFC Gradation

Sieve Size	Typical Gradation Without Admixture (% Passing)	Specification Band (% Passing)
3/8	100	100
# 4	38	30-45
# 8	6	4-8
#16	4	
#40	2	
#200	0.8	0-2.5

One percent lime or cement is used as an admixture. Typical bulk densities are 114-115 pcf.

Two to four stockpiles are used to produce aggregate gradations that consist of 95% 9.5mm chips and 5% fine aggregate. Typical aggregate properties range between 94-100 % double crushed faces (minimum of 85 % required). Flakiness index typically ranges between 13 and 22 (30 maximum).

Asphalt rubber is produced by combining 18-22% crumb rubber particles (CRA-1, Type B) with neat asphalt cement (PG 64-16) in a process commonly referred to as the wet process. The crumb rubber is reacted with the neat asphalt for approximately one hour at a temperature between 350 to 375 degrees Fahrenheit. Upon completion of the reaction process the asphalt rubber binder is introduced into the hot plant through conventional means. The binder is added at a rate of 9.1 to 9.6 % by total weight of mixture. The high binder content makes the product very durable with good resistance to reflective crack formation. Although void contents are typically 20-21%, these mixtures do not exhibit the significant splash spray reductions often experienced with conventional open graded mixes. This could be the result of the smaller aggregate sizing or the higher binder contents or both. Field permeability testing conducted on these mixtures using the National Center for Asphalt Testing (NCAT) infiltration test resulted in flow rates of 15 m (49.2 ft)/day.

APPENDIX B

Transition from CPX Data to OBSI SITE 1 Levels

In 2006 it became clear that a transition from the original CPX method of collecting the Site 1 milepost tire/pavement noise source levels would be necessary. This was actually anticipated as early as 2003 after some cooperative testing was completed with Caltrans in 2002. This very early testing included CPX and OBSI measurements on the ADOT trailer using the older, single OBSI probe methodology to examine the acoustic longevity performance of the existing ARFC on the Interstate system.[8] With this single probe system, however, two passes over the same pavement was necessary. Given the extent of the milepost measurement program, doubling the amount of testing was not practical. In 2005 measurements were made again on the ADOT trailer using simultaneous CPX and OBSI data. In this case, a two-probe OBSI fixture was used. From these tests, extensive correlation data were obtained. It was intended at that time to not only continue the trailer measurements, but to actually collect OBSI data using this dual probe approach. In the transition within ADOT at that time, this concept was shelved and in March 2006 a regular measurement program relying on CPX data and the ADOT trailer was re-established. During the March 2006 testing, a number of operational and maintenance issues arose with the trailer and in the absence of an "owner" within ADOT to address these, plans were made to make the transition to a test car that would not require special attention to maintenance. During this time the OBSI became standardized with a number of researchers within the United States. Additionally, in 2006 it was found that the dual probe design developed for trailer use could also be used in open air mounted on a test car[13] facilitating the one-pass concept needed for the Site 1 measurements. In November 2006 additional comparative testing was completed with CPX data on the trailer and OBSI data on a test car. Using the results of this and previous comparisons, the relationships to estimate OBSI level from the CPX data were established as documented in this Appendix. It should also be noted that the recently completed NCHRP 1-44 project identified the OBSI method as preferred to the CPX, supporting ADOT's migration to this approach.[18]

March 2005 CPX vs. OBSI on the ADOT CPX trailer

Simultaneous measurement of CPX sound pressure levels and sound intensity on the ADOT CPX trailer was conducted in March 2005. Testing was made at 193 locations, including 23 Site 1 mileage posts, additional ARFC pavement type locations along SR 51, Loops 101 and 202, I-17, I-10, and several pavement test sections along I-8. Prior to the road measurements, testing in a lab setting indicated that the presence of the two-probe fixture increased the CPX microphone levels by 0.3 dB for both the front and rear locations. The levels measured by the SI probes were not affected by the presence of CPX enclosure or microphones. The results of the on-road comparison between overall A-weighted levels (500 to 5000 Hz) for CPX and SI are provided in Figure 1B. These results indicate a linear offset between the data in which the SI data is 3.3 dB higher than the CPX with a standard deviation of 0.6 dB, similar to that reported from previous investigations[1].

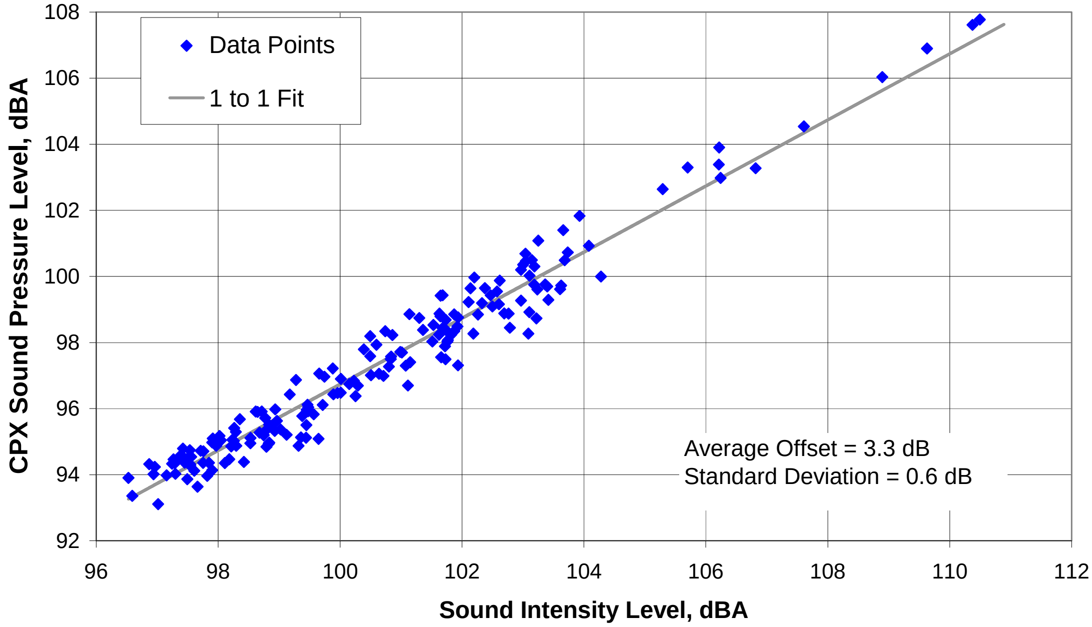


Figure 1B: Comparison of overall A-weighted CPX and OBSI levels obtained simultaneously on the ADOT CPX trailer in March 2005

November 2006 CPX vs. OBSI FIX FONT

CPX and on-vehicle OBSI measurements were conducted on the Site 1 mileage post sites and additional sites in the vicinity of Site 1 in November 2006. The CPX measurements were made on November 8 and the OBSI measurements were made on November 9 and 10. CPX testing was conducted at 177 locations and OBSI testing was conducted at 233 locations. Only locations that were common between both sets of data were used in this comparison. The results of the on-road comparison between overall A-weighted levels (500 to 5000 Hz) for CPX and OBSI are provided in Figure 2B. These results indicate a linear offset between the data in which the SI data is 2.6 dB higher than the CPX with a standard deviation of 0.7 dB.

To further assess the difference between the results of the OBSI and CPX data, the spectral properties of each measurement set can be compared. The OBSI and CPX sound pressure one-third octave band spectra are shown in Figure 3B, averaged over all Site 1 ARFC pavement sections for each testing method. The spectral trend indicated in Figure 3B is consistent with that found in the March 2005 data. For 1600 Hz and above, the OBSI and CPX levels are similar. However, there is a drop in the CPX noise levels in the frequencies below 1250 Hz, by as much as 6 dBA. This is consistent with previous testing assessing both loudspeaker and tire/pavement noise sources. The relative reduction in the CPX data is likely due to standing wave effects in the enclosure, as documented in European literature as well as in the NCHRP 1-44 report.

APPENDIX C

SITE 1 – ON BOARD MEASUREMENT RESULTS BY MILEPOST

This appendix includes the on-board, tire/pavement noise source levels for each milepost included in the QPPP for which data is available. The levels are overall A-weighted decibels (dBA). As necessary, the earlier data taken with the CPX method and the ADOT trailer have been converted to equivalent OBSI levels based on the analysis of Appendix B. Not all specific mileposts are captured in each test period due to construction, missing milepost markers, inference from traffic, etc. For results prior to 2006, it is not known if the data were ever taken or were lost in ADOT transition.

Road	Direction	Milepost	SR 101						
			Pre-Overlay PCC	ARFC 2004	ARFC Mar 2005	ARFC Mar 2006	ARFC Nov 2006	ARFC Mar 2007	ARFC Oct 2007
101	SB	2				98.1		98.9	
101	SB	3	107.9			98.6		102.2	101.6
101	SB	4	109.4			97.6	100.0	100.2	100.2
101	SB	5	108.6					101.3	
101	SB	6				98.7	99.8	99.3	101.3
101	SB	7				98.4	98.4	98.5	99.8
101	SB	8				96.8	98.2	98.3	99.2
101	SB	*Site 3B*	109.5			100.6	99.1	99.8	100.7
101	SB	9				100.0	99.3	100.8	100.7
101	SB	10				100.1	99.8	101.5	99.5
101	SB	11				100.9	99.5	98.1	100.0
101	SB	12				99.0	98.9	98.9	100.8
101	SB	13				99.1	99.5	99.8	99.8
101	SB	14				99.1	99.1	98.6	99.6
101	SB	15				98.3	99.8	98.4	101.0
101	SB	16	102.4	95.8		99.3	97.8	99.3	98.5
101	WB/SB	17	104.1	97.1		98.2	98.3	98.2	99.0
101	WB/SB	18	104.4	97.2		98.2	98.3	98.3	98.8
101	WB/SB	19	104.5	96.4		99.2	98.5	99.0	98.9
101	WB/SB	20	103.8	97		99.2	98.6	98.9	98.6
101	WB/SB	*Site 3A*				98.9	99.0	98.9	99.2
101	WB/SB	21	104.6	96.9		99.3	98.5	99.1	98.9
101	WB/SB	22	103.7	96.5		98.9	98.7	99.4	99.5
101	NB/WB	23	106.3				98.4	99.5	97.9
101	NB/WB	24	104.2				96.9	99.3	99.0
101	NB/WB	25	101.7	96.1		99.5	99.6	100.2	99.8
101	NB/WB	26	102.1			97.9	98.0	98.9	97.8
101	NB/WB	27	101.6				97.9	99.5	99.5
101	NB/WB	28	101.5	96.3		99.1	98.9	98.8	98.8
101	NB/WB	29	106.3				98.4	98.7	98.8
101	NB/WB	30	104.0				97.4	98.1	97.6
101	NB/WB	31	103.7	97.4			98.8	99.9	98.7
101	NB/WB	32	105.2			99.7	99.0	100.7	98.8
101	NB/WB	33	101.9			98.6	97.3	98.6	98.0
101	NB/WB	34	101.8			98.2	97.3	99.0	98.4
101	NB/WB	35	107.2	96.5		98.9	99.5	98.8	99.9
101	NB/WB	36	107.2	97.0		98.8	99.3	99.3	99.4
101	NB	37	102.3	95.9		98.4	97.4	98.6	98.3
101	NB	38	102.9	96.8		97.8	98.6	98.4	98.4
101	NB	39	102.3	97.2			97.6	98.3	98.7
101	NB	40	103.4	96.1		98.1	98.2	97.7	98.0
101	NB	41		96.2		98.5	97.5	97.9	98.2
101	NB	42		98.4		99.8	100.6	99.6	99.0
101	NB	43	105.6			99.5	99.2	99.8	99.3
101	NB	44	105.6	97.7		99.4	99.0	99.8	98.9
101	NB	45	103.8			99.5	101.1	100.1	99.6
101	NB	46				99.5	98.0	100.9	101.6
101	NB	*47 Site 3E*	105.3	96.9		99.9	99.6	98.8	97.8
101	NB	48	105.1	96.5		100.1	99.7	101.4	98.1
101	NB	49		98.0			100.9	99.6	100.5
101	NB	50		98.0		99.2	99.6	102.5	

Road	Direction	Milepost	SR 101						
			Pre-Overlay PCC	ARFC 2004	ARFC Mar 2005	ARFC Mar 2006	ARFC Nov 2006	ARFC Mar 2007	ARFC Oct 2007
101	NB	51	105.3	98.1		99.9	100.1	100.0	
101	NB	52		98		96.6	97.1		97.4
101	NB	53				98.6	97.7	99.0	98.6
101	NB	54				99.2	97.8	98.9	98.5
101	NB	55		95.7		99.5	96.9	98.7	97.2
101	NB	56	107.0	96.3	96.7	98.8	99.2	98.9	99.0
101	NB	57	107.3	97.0	97.6	98.4	98.6	99.5	98.6
101	NB	58	108.3	96.6	96.8	98.7	98.8	99.2	99.5
101	NB	59	108.1	96.5	97.2	101.1	99.1		100.1
101	NB	60	105.6	97.8	97.6	100.7	99.4		100.0
101	NB	2						100.1	
101	NB	3				98.6	99.4	100.2	101.3
101	NB	4				100.3	100.4	100.5	100.8
101	NB	5				101.1		99.4	
101	NB	6				100.1	100.7	102.3	102.0
101	NB	7				100.6	100.0	100.2	100.8
101	NB	8				101.5	99.7	102.3	101.8
101	NB	*Site 3B*				100.9	100.1	101.3	101.0
101	NB	9				102.2	99.9	97.6	100.5
101	NB	10				100.8	98.7	100.0	100.7
101	NB	11				101.4	98.4	98.6	98.9
101	NB	12				102.2	99.3	99.9	100.1
101	NB	13				99.7	98.9	97.8	100.3
101	NB	14					98.4	97.6	99.4
101	NB	15				99.7	99.0	98.9	99.9
101	NB	16	103.4	97.5		99.5	97.6	98.0	98.9
101	NB	17	103.2	96.5		101.0	99.1	99.5	99.7
101	NB/EB	18	104.5	97		99.5	99.3	97.9	98.5
101	NB/EB	19	104.3	97.4		99.3	97.9	98.5	98.0
101	NB/EB	20	104.1	96.4		98.7	98.3	98.8	98.1
101	NB/EB	*Site 3A*				100.5	98.8	98.0	98.9
101	NB/EB	21	104.6	96.2		100.1	97.8	97.3	96.7
101	NB/EB	22	104.8	97.2		99.7	97.7	97.5	97.5
101	SB/EB	23	107			99.4	98.6	99.0	
101	SB/EB	24	107	95.9		98.0	98.3	98.6	
101	SB/EB	25	101.8	97.4		98.7	98.2	98.4	99.2
101	SB/EB	26	101.9	96.7			98.4	98.4	98.2
101	SB/EB	27	100.7	98			100.0	98.0	100.9
101	SB/EB	28	101.1	96.5		99.0	98.5	98.6	99.4
101	SB/EB	29	102	96		98.8	97.3	98.2	100.7
101	SB/EB	30	101.6	96.3		100.5	98.4		
101	SB/EB	31	103.8	95.7		97.4	96.8	97.3	97.4
101	SB/EB	32	104.8			97.4	97.0	98.1	98.2
101	SB/EB	33	102				96.7		97.2
101	SB/EB	34	102.1			97.1	97.1	97.1	97.4
101	SB/EB	35	108.1	96.7		98.1	98.2	97.4	98.9
101	SB/EB	36	108.4	96.6		98.0	98.2	98.2	97.8
101	SB	37	104.6			98.7	97.7	97.8	98.1
101	SB	38	103.2	96.7		98.0	97.3	97.9	98.7
101	SB	39	104.2	96.1		98.4	97.7	98.0	98.1
101	SB	40	103.6	96.2		98.1	97.6	98.0	98.3

Road	Direction	Milepost	SR 101 Pre-Overlay PCC	ARFC 2004	ARFC Mar 2005	ARFC Mar 2006	ARFC Nov 2006	ARFC Mar 2007	ARFC Oct 2007
101	SB	41	104.3	96.2			97.5	96.4	98.1
101	SB	42	104.3	99		99.5	99.2	99.4	100.4
101	SB	43		97.9		99.8		98.6	99.3
101	SB	44		97.1		100.0	99.9	99.1	99.5
101	SB	45	104.4			99.4		99.1	99.6
101	SB	46	105.5	96.9		100.0	97.7	97.9	99.1
101	SB	*47 Site 3E*	105.5	96.9		99.7	98.8	99.5	97.6
101	SB	48	105.8	97.7		99.0	99.8	98.6	98.4
101	SB	49		97.6	97.9	99.0	100.1	100.2	98.8
101	SB	50		96.7	97.4	99.5	99.4	99.8	
101	SB	51		98.1		98.7		98.6	
101	SB	52			97.9	98.7	99.3	100.5	
101	SB	53		98.2	96.8	98.1	98.7		99.5
101	SB	54					98.6	98.6	98.2
101	SB	55		95.4	97.3	99.5	99.2	99.7	99.6
101	SB	56	105.5	96.7	97.5	98.6	98.8	99.2	98.8
101	SB	57	107	96		98.5	98.6	98.6	97.5
101	SB	58	107.3	97.1		99.0	98.5	99.0	98.2
101	SB	59	105.7	98.6		100.0	98.9	99.6	98.6
101	SB	60	106.6	98.8		100.8	99.2	98.7	98.5

Road	Direction	Milepost	I-17 Pre-Overlay PCC	ARFC 2004	ARFC Mar 2005	ARFC Mar 2006	ARFC Nov 2006	ARFC Mar 2007	ARFC Oct 2007
17	NB	199						101.0	100.3
17	NB	200		100.1			98.2	99.2	102.2
17	NB	201				100.8	99.0	100.8	101.1
17	NB	202		100.4		101.3	101.6	102.6	103.0
17	NB	211				101.37667	101.7	102.4	103.0
17	NB	212				100.7	100.0	101.2	99.5
17	NB	213				100.5	98.4	98.1	99.1
17	NB	214				99.3	98.1	97.0	99.1
17	SB	199					100.0	101.5	101.5
17	SB	200					97.8	99.4	
17	SB	201						99.3	
17	SB	202					102.3	103.6	103.1
17	SB	211					101.9	103.0	104.7
17	SB	212					97.7	99.1	99.9
17	SB	213					98.3	99.3	99.8
17	SB	214					98.8	98.6	98.1

Road	Direction	Milepost	SR 51 Pre-Overlay PCC	ARFC 2004	ARFC Mar 2005	ARFC Mar 2006	ARFC Nov 2006	ARFC Mar 2007	ARFC Oct 2007
51	NB	10	103.4				97.8		97.5
51	NB	11	104.7				98.4	99.4	97.1
51	NB	12	104			97.8	97.4	98.4	97.7
51	NB	13	103			98.8	97.7	98.3	97.5
51	NB	14		98.6		99.6	97.8	98.5	98.0
51	NB	15		95.7		100.2	97.8	98.0	99.2
51	SB	10	104.3				96.0		
51	SB	11	103.6			98.2	98.7	99.1	98.5
51	SB	12	104			98.6	97.0	97.7	97.6
51	SB	13	105.6			100.5	100.2	100.0	98.5
51	SB	14		95.1		97.9	96.6	98.6	97.4
51	SB	15		97.1		98.2	98.5	99.2	97.5

Road	Direction	Milepost	I-10						
			Pre-Overlay PCC	ARFC 2004	ARFC Mar 2005	ARFC Mar 2006	ARFC Nov 2006	ARFC Mar 2007	ARFC Oct 2007
I-10	EB	138			97.6	99.1	98.2		101.7
I-10	EB	139			97.9	98.7	97.8	101.0	100.6
I-10	EB	140			98.0	100.8	99.2	100.8	101.6
I-10	EB	141				99.4		101.4	100.7
I-10	EB	142			99.6	99.0	99.0	100.2	
I-10	EB	143							
I-10	EB	144			98.5	101.0	101.0		99.7
I-10	EB	145				100.1	99.4		100.3
I-10	EB	146	106.9		98.5	100.1	99.9		100.7
I-10	EB	147	106.5				99.5		98.0
I-10	EB	148	107.2						99.5
I-10	EB	156				100.3		99.5	100.8
I-10	EB	157				99.9	99.3	99.0	
I-10	EB	158				100.1	99.0	99.8	99.7
I-10	EB	159				100.5	99.1	100.3	100.3
I-10	EB	*Site 3C*	107.1			100.0	98.4	100.1	99.3
I-10	EB	160							
I-10	WB	138				101.5	99.7		
I-10	WB	139				101.1	97.8	101.0	102.5
I-10	WB	140				100.7	99.9	100.8	101.6
I-10	WB	141				101.2	100.2	101.4	101.7
I-10	WB	142				100.5	98.4	100.2	100.1
I-10	WB	143							
I-10	WB	144					100.5	100.5	102.3
I-10	WB	145					100.0	99.4	100.4
I-10	WB	146				101.0	100.3	100.5	100.8
I-10	WB	147	106.1			101.1		99.3	99.7
I-10	WB	148							
I-10	WB	156				98.8		99.4	98.5
I-10	WB	157				99.9	98.1	98.6	98.5
I-10	WB	158				98.5	97.6	99.3	99.3
I-10	WB	159				98.6	98.9	100.2	99.4
I-10	WB	160						98.9	

Road	Direction	Milepost	SR 202 Pre-Overlay PCC	ARFC 2004	ARFC Mar 2005	ARFC Mar 2006	ARFC Nov 2006	ARFC Mar 2007	ARFC Oct 2007
202	EB	1						98.7	
202	EB	2				100.7		98.2	
202	EB	3				100.8		97.8	98.0
202	EB	4				99.4		98.4	98.4
202	EB	12	103.9			98.8	98.4	99.4	100.8
202	EB	13	106.3	97.6			99.2	100.1	99.3
202	EB	14	106.8	97.5		99.1	99.7	100.4	100.3
202	EB	15	106.9	97.5		99.8	99.2	98.3	99.9
202	EB	16	102.4	97.2		100.2	99.9	99.3	99.0
202	EB	17		96.6		98.8	99.4	99.6	99.9
202	EB	18	109.3	96.1		99.2	99.1	99.5	99.7
202	EB	*Site 3D*				99.6	99.9	99.3	
202	EB	19	107.9	96.5		98.6	99.2	98.5	97.8
202	EB	20	108.4			98.1	98.2	99.6	99.4
202	EB	21				98.8	97.8	99.0	98.4
202	EB	52		97.5	97.3	97.0	98.4		
202	EB	55	104.4						97.2
202	EB	56	105.1						96.4
202	WB	1		95.7		99.0		98.6	
202	WB	2		95		99.0	98.7	99.6	
202	WB	3		95.2		98.7	97.8	98.6	98.8
202	WB	4		94.9		98.4	97.9	97.2	97.8
202	WB	12	103.6	99.3		99.4	99.2	98.2	99.0
202	WB	13	105.1	97.5		99.3	99.2	99.2	97.7
202	WB	14	107.2	97.5		99.4	99.2	100.0	99.5
202	WB	15	106.8	98		99.0	99.2	99.4	99.4
202	WB	16	106.9	97.4		100.2	98.5	100.8	100.0
202	WB	17		98.3		99.8	99.3	101.5	100.7
202	WB	18	108.3	98.4		99.7	99.7	101.6	101.1
202	WB	*Site 3D*	109.2			100.3	99.5	99.9	100.5
202	WB	19	107.6	95.9		99.0	99.5	101.5	101.6
202	WB	20	108.8	96.9		98.5	99.6	98.5	
202	WB	21				98.9	99.0	98.5	98.8
202	WB	52		97.6		99.6	98.9	99.4	
202	WB	55	103.9						96.2
202	WB	56	108.2						96.8

APPENDIX D

SITE 2 – *BEFORE, AFTER,* AND *FOLLOW-UP* DATA

The detailed data from the Site 2 *before*, *after,* and *follow-up* measurements of neighborhood noise levels and accompanying weather and traffic data are reported in this appendix.

Table D1: Data from ‘*Before*’ Site 2 Measurements

Before Readings																		
Site						Weather Conditions				Traffic Data						Noise Readings		
Route	Segment	HDR ID	Receiver	Date	Time	Temp (^{0}F)	Wind (mph)	Direction	Humidity (%)	Speed	Autos	Med Trucks	Hvy Trucks	Motorcycles	Buses	Lmin	Lmax	Leq
L101	A	1	1	7/30/2003	11:45am - 12:45pm	94.0	1.1	Variable	38	67	6652	241	166			62.7	81.5	74.6
L101	A	2	2	7/30/2003	11:45am - 12:45pm	92.0	1.4	Variable	41	65	6652	241	166			60.0	72.2	64.3
L101	A	3	3	7/30/2003	10:17am - 11:17am	92.9	1.2	Northeast	37	65	5226	302	96			59.0	72.4	64.6
L101	A	4	4	7/30/2003	10:15am - 11:15am	92.2	2.2	Variable	39	65	5226	302	96			61.2	76.8	66.5
L101	A	5	5	8/5/2003	9:30am - 10:30am	96.0	2.8	Variable	20	65	6383	215	233			50.3	69.9	55.6
L101	A	6	6	7/29/2003	11:00am - 12:00pm	90.5	3.2	Variable	34	65	6164	313	108			52.6	70.1	59.3
L101	A	7	7	8/5/2003	11:00am - 12:00pm	99.8	1.6	Southwest	16	65	7086	255	224			51.1	75.9	60.7
L101	A	8	8	7/29/2003	11:05am - 12:05pm	97.7	2.0	Variable	32	65	6164	313	108			56.7	78.6	64.9
L101	A	9	9	7/29/2003	9:30am - 10:30am	92.2	2.1	Variable	37	65	6788	349	148			63.3	84.0	73.1
L101	A	10	10	7/29/2003	9:30am - 10:30am	94.6	1.6	Variable	37	65	6788	349	148			63.2	79.9	69
L101	A	11	11	7/29/2003	9:30am - 10:30am	90.7	2.3	Variable	36	65	9279	315	257			63.5	81.0	70.1
SR51	B	1	12	8/7/2003	4:00pm - 5:00pm	108.4	2.1	Variable	16	65	9747	115	38			59.8	71.7	64.2
SR51	B	2	13	8/7/2003	4:00pm - 5:00pm	108.4	2.1	Variable	16	65	9747	115	38			60.7	76.9	66.3
SR51	B	3	14	8/12/2003	4:00pm - 5:00pm	108.5	3.3	Northwest	17	65	8274	160	36			63.9	73.1	68.4
SR51	B	4	15	8/13/2003	4:00pm - 5:00pm	111.0	1.1	Variable	15	65	5703	75	17			62.6	76.7	67.4
SR51	B	5	16	8/13/2003	5:30pm - 6:30pm	106.7	1.8	Variable	20	65	5009	31	8			60.8	70.9	65.6
SR51	B	6	17	8/12/2003	5:30pm - 6:30pm	104.4	1.3	West	19	65	6449	73	12			56.9	73.8	63
SR51	B	7	18	8/12/2003	5:30pm - 6:30pm	101.1	0.8	Variable	19	65	6449	73	12			57.5	68.0	62.4
SR51	B	8	19	8/12/2003	4:00pm - 5:00pm	106.4	3.5	Variable	18	65	8274	160	36			56.9	69.6	62.8
SR51	B	9	20	8/12/2003	4:00pm - 5:00pm	106.2	1.1	Variable	17	65	8274	160	36			52.0	71.6	57.4
L101	C	1	21	8/20/2003	6:40am - 7:40am	84.1	0.9	Southwest	58	65	8761	170	246			60.2	72.6	64.3
L101	C	2	22	8/20/2003	8:00am - 9:00am	87.4	0.7	East	52	65	8761	170	246			58.8	76.4	65.2
L101	C	3	23	8/28/2003	8:04am - 9:04am	85.0	0.9	Variable	61	65	6226	181	208			60.2	75.8	65.9
L101	C	4	24	8/21/2003	6:36am - 7:36am	86.4	1.3	West	55	65	7607	142	246			57.7	66.2	62.2
L101	C	5	25	8/21/2003	7:55am - 8:55am	88.5	1.1	Variable	15	65	5201	163	243			58.6	69.6	63.2
L101	C	6	26	8/21/2003	7:55am - 8:55am	86.4	1.8	West	56	65	5201	163	243			52.9	71.2	58.5
L101	C	7	27	8/21/2003	6:37am - 7:37am	93.5	1.3	Variable	63	65	7607	142	246			61.4	76.0	67.7
L101	C	8	28	9/4/2003	6:30am - 7:30am	86.0	1.3	Variable	56	65	8926	222	214			57.7	85.0	72.4
L101	C	9	29	9/4/2003	7:50am - 8:50am	91.3	2.0	Variable	44	65	8120	240	260			64.2	77.7	69.6
L101	C	10	30	8/20/2003	6:40am - 7:40am	84.5	1.1	Variable	57	65	6840	131	208			67.5	83.3	73.9
L101	D	1	31	9/30/2003	6:00am - 7:00am	72.3	Calm	Calm	51	65	8555	323	192			58.5	68.5	61.9
L101	D	2	32	9/30/2003	6:00am - 7:00am	73.4	Calm	Calm	39	65	8555	323	192			55.2	65.0	58.8

Before Readings																		
Site						Weather Conditions				Traffic Data						Noise Readings		
Route	Segment	HDR ID	Receiver	Date	Time	Temp (^{0}F)	Wind (mph)	Direction	Humidity (%)	Speed	Autos	Med Trucks	Hvy Trucks	Motorcycles	Buses	Lmin	Lmax	Leq
L101	D	3	33	10/2/2003	6:10am - 7:10am	74.6	Calm	Calm	49	65	8384	276	168			61.8	69.9	64.7
L101	D	4	34	10/1/2003	6:02am - 7:02am	73.0	0.2	East	39	65	9835	323	160			60.5	67.4	64
L101	D	5	35	10/8/2003	6:05am - 7:05am	64.1	Calm	Calm	71	65	8047	345	121			55.1	75.7	59.3
L101	D	6	36	10/7/2003	6:10am - 7:10am	74.7	Calm	Calm	38	65	8794	312	113			62.1	70.8	66.9
L101	D	7	37	10/7/2003	6:07am - 7:07am	75.3	Calm	Calm	43	65	7920	244	170			58.9	71.8	64.4
L101	D	8	38	10/8/2003	6:00am - 7:00am	67.7	0.2	West	68	65	7761	210	158			54.2	67.9	60.8
L202	E	1	39	10/9/2003	8:51am - 9:51am	84.3	4.4	Variable	29	65	2200	89	99			56.6	69.1	63.1
L202	E	2	40	10/9/2003	10:23am - 11:23am	92.3	2.1	Variable	25	65	1830	74	73			49.4	70.1	58
L202	E	3	41	10/9/2003	10:20am - 11:20am	92.3	2.1	Variable	25	65	1830	74	73			50.2	69.0	57.9
L202	E	4	42	10/8/2003	2:08pm - 3:08pm	92.3	1.5	South	28	65	2764	80	71			50.6	66.5	58.8
L202	E	5	43	10/9/2003	8:50am - 9:50am	84.3	4.4	Variable	29	65	2200	89	99			53.2	72.6	60.5
L202	E	6	44	10/9/2003	8:52am - 9:52am	84.3	4.4	Variable	29	65	2200	89	99			53.3	71.5	60.4
L101	F	1	45	2/11/2004	2:00pm - 3:00pm	65.1	1.3	Variable	16	65	9579	333	76			58.2	74.2	63.3
L101	F	2	46	2/11/2004	3:30pm - 4:30pm	64.4	1.3	Variable	18	65	7459	166	52			58.1	67.9	61.7
L101	F	3	47	2/10/2004	3:46pm - 4:46pm	66.3	0.8	Northeast	21	65	7403	160	56			56.7	73.5	64.1
L101	F	4	48	2/11/2004	3:39pm - 4:29pm	64.4	1.3	Variable	18	65	7459	166	52			65.0	77.5	68.7
L101	F	5	49	2/10/2004	2:17pm - 3:17pm	71.6	1.1	South	7	65	9828	276	60			55.3	65.4	59.6
L101	F	6	50	2/12/2004	1:57pm - 2:57pm	70.0	0.8	Variable	11	65	10147	327	59			56.9	69.6	62.1
L101	F	7	51	2/11/2004	1:59pm - 2:59pm	65.1	1.3	Variable	16	65	9579	333	76			59.8	72.8	64.9
L202	G	1	52	3/9/2004	7:55pm - 8:55pm	76.7	0.6	South	28	70	3304	60	13			58.0	70.9	63.6
L202	G	2	53	3/9/2004	9:16pm - 10:16pm	73.2	1.6	Variable	29	70	1712	47	11			57.0	69.8	62.8
L202	G	3	54	3/18/2004	8:55pm - 9:55pm	70.9	0.3	South	33	70	2190	42	5			54.5	66.3	60.5
L202	G	4	55	3/8/2004	7:00am - 7:30am					70	3126	55	41			66.7	73.4	70.7
I-10	H	1	56	3/23/2004	10:03am - 11:03am	86.4	3.8	North	24	65	14148	699	468			62.2	72.3	65.73
I-10	H	2	57	3/24/2004	1:37pm - 2:37pm	93.2	0.7	Variable	14	65	17680	689	461			66.8	75.6	70.3
I-10	H	3	58	3/25/2004	9:57am - 10:57am	83.3	1.1	Variable	20	65	12816	556	575			62.5	73.1	65.8
I-10	H	4	59	3/23/2004	1:11pm - 2:11pm	89.9	1.0	Variable	18	65	14604	829	436			66.0	73.1	68.7
I-10	H	5	60	3/34/2004	9:21am - 10:21am	80.1	1.3	West	27	65	14305	544	518			65.4	72.9	67.8
L101	J	1	61	4/29/2004	4:58am - 5:58am	71.7	3.5	Southwest	40	65	6510	232	158			56.9	67.0	60.3
L101	J	2	62	4/27/2004	5:05am - 6:05am	77.4	0.8	Northwest	24	65	6779	214	217			60.3	67.8	63.9
L101	J	3	63	4/27/2004	5:05am - 6:05am	80.1	2.6	ESE	12	65						56.3	67.3	60.3
L101	J	4	64	4/30/2004	5:00am - 6:00am	62.1	0.8	South	34	65	5359	182	115			48.2	67.5	56.8

Table D2. Data from '*After*' Site 2 Measurements

After Readings																		
Site						Weather Conditions				Traffic Data						Noise Readings		
Route	**Segment**	**HDR ID**	**Receiver**	**Date**	**Time**	**Temp (0F)**	**Wind (mph)**	**Direction**	**Humidity (%)**	**Speed**	**Autos**	**Med Trucks**	**Hvy Trucks**	**Buses**	**Motorcycles**	**Lmin**	**Lmax**	**Leq**
L101	A	1	1	11/6/2003	11:30am - 12:30pm	75.9	0.4	Northeast	15	65	6944	227	253			60.2	81.0	69.8
L101	A	2	2	1/29/2004	10:18am - 11:18am	59.7	1.0	Northeast	25	65	6322	321	126			49.7	68.4	55.5
L101	A	3	3	11/6/2003	10:00am - 11:00am	74.1	1.0	Northeast	18	65	6431	207	249			52.1	69.5	59.7
L101	A	4	4	1/27/2004	10:13am - 11:13am					65	7125	486	122			53.8	77.7	60.6
L101	A	5	5	1/28/2004	9:42am - 10:42am	59.8	1.7	Northeast	24	65	7231	399	152			47.7	59.7	52.5
L101	A	6	6	1/28/2004	11:07am - 12:07pm	71.9	1.3	Southeast	16	65	7368	431	127			49.1	72.4	57
L101	A	7	7	10/29/2003	11:02am - 12:02pm	79.7	1.2	Southeast	18	65	6348	298	194			47.5	76.7	58
L101	A	8	8	10/29/2003	11:00am - 12:00pm	83.3	4.1	Southeast	20	65	6348	298	194			51.2	73.3	59.5
L101	A	9	9	10/29/2003	9:30am - 10:30am	76.1	5.4	Variable	22	65	6260	312	221			59.5	83.3	69.6
L101	A	10	10	10/29/2003	9:33am - 10:33am	76.7	3.1	Variable	21	65	6260	312	221			58.4	78.6	65.5
L101	A	11	11	2/10/2004	10:27am - 11:27am	66.6	1.0	East	11	65	7545	448	151			58.4	80.6	66.7
SR51	B	1	12															
SR51	B	2	13															
SR51	B	3	14															
SR51	B	4	15	10/28/2003	5:15pm - 6:15pm	71.0	N/A	N/A	24	65	9746	115	17			54.1	69.3	59.9
SR51	B	5	16	10/28/2003	3:52pm - 4:52pm	85.0	1.2	Variable	12	65	8067	180	38			53.7	70.2	59.4
SR51	B	6	17	11/6/2003	4:41pm - 5:41pm	83.0	N/A	N/A	19	65	7328	86	14			53.3	71.7	60.8
SR51	B	7	18	9/18/2003	5:15pm - 6:15pm	94.9	1.8	West	10	65	8044	77	13			52.5	78.9	58.8
SR51	B	8	19	9/18/2003	3:45pm - 4:45pm	98.6	2.7	Variable	8	65	8225	168	32			51.6	69.5	58.6
SR51	B	9	20															
L101	C	1	21	11/18/2003	6:44am - 7:44am	54.0	N/A	N/A	62	63	9417	226	232			57.2	72.4	62.5
L101	C	2	22	5/13/2004	8:06am - 9:06am	70.0	0.2	North	34	65	8715	301	254			53.5	75.0	63.4
L101	C	3	23	5/13/2004	8:03am - 9:03am	65.3	0.2	Variable	25	65	8001	317	233			55.3	74.9	64.7
L101	C	4	24	5/13/2004	6:24am - 7:24am	54.8	0.3	North	35	65	8385	198	302			50.7	63.8	55.8
L101	C	5	25	11/19/2003	6:35am - 7:35am	65.6	1.5	Variable	29	65	7269	233	311			57.7	72.6	64.5
L101	C	6	26	11/20/2003	7:58am - 8:58am	63.5	N/A	N/A	37	65	6289	184	209			49.7	68.0	57.1
L101	C	7	27	11/19/2003	7:51am - 8:51am	59.5	1.1	Variable	36	63	7091	221	255			55.7	70.3	60.5

After Readings																		
Site						Weather Conditions				Traffic Data						Noise Readings		
Route	Segment	HDR ID	Receiver	Date	Time	Temp (0F)	Wind (mph)	Direction	Humidity (%)	Speed	Autos	Med Trucks	Hvy Trucks	Buses	Motorcycles	Lmin	Lmax	Leq
L101	C	8	28	11/20/2003	6:32am - 7:32am	53.4	N/A	N/A	57	58	7071	135	155			59.2	76.3	66.1
L101	C	9	29	11/25/2003	7:58am - 8:58am	55.8	1.6	Northwest	25	65	8428	218	220			61.9	77.1	69.1
L101	C	10	30	11/26/2003	6:28am - 7:28am	44.8	0.4	Southwest	40	63	5590	176	235			60.8	82.5	72.6
L101	D	1	31	1/28/2004	6:03am - 7:03am	42.1	0.3	West	84	65	9102	343	83			50.5	66.7	55.7
L101	D	2	32	1/28/2004	6:02am - 7:02am	42.1	0.3	West	84	65	9102	343	83			48.8	64.8	53.5
L101	D	3	33	1/1/2704	6:27am - 7:27am	34.3	Calm	Calm	88	65	9128	391	106			55.5	64.7	59
L101	D	4	34	2/11/2004	6:00am - 7:00am	38.8	Calm	Calm	60	65	9319	359	71			55.0	64.0	58.1
L101	D	5	35	2/11/2004	6:02am - 7:02am	38.8	Calm	Calm	60	65	9319	359	71			52.3	60.3	55.9
L101	D	6	36	1/27/2004	6:24am - 7:24am	34.3	Calm	Calm	88	65	9128	391	106			56.7	65.4	61.3
L101	D	7	37	1/28/2004	6:05am - 7:05am	42.1	0.3	West	84	65	9102	343	83			52.3	70.6	57.2
L101	D	8	38	1/28/2004	6:02am - 7:02am	42.1	0.3	West	84	65	9102	343	83			47.0	63.3	52.5
L202	E	1	39	12/3/2003	9:11am - 10:11am	60.0	0.7	East	28	65	2097	75	91			46.8	66.2	54.2
L202	E	2	40	12/4/2003	9:47am - 10:47am	65.9	3.7	Northeast	19	65	1908	62	75			42.8	65.2	52.7
L202	E	3	41	12/4/2003	9:45am - 10:45am	65.9	3.7	Northeast	19	65	1908	62	75			43.1	63.6	51.4
L202	E	4	42	10/29/2003	1:46pm - 2:46pm	88.3	1.6	Variable	13	65	2659	140	70			46.1	65.6	52.4
L202	E	5	43	12/3/2003	9:10am - 10:10am	60.0	0.7	East	28	65	2097	75	91			43.6	74.3	57
L202	E	6	44	12/3/2003	9:10am - 10:10am	60.0	0.7	East	28	65	2097	75	91			48.1	62.2	52.7
L101	F	1	45	11/10/2004	2:00pm - 3:00pm					65	10336	312	212			50.7	73.0	60.3
L101	F	2	46	11/10/2004	3:30pm - 4:30pm					65	10307	277	96			51.5	74.2	58.9
L101	F	3	47	11/4/2004	3:16pm - 4:16pm	81.3	0.9	West	14	65	7101	170	44	2	33.0	54.3	71.7	60.3
L101	F	4	48	11/10/2004	3:31pm - 4:31pm					65	10307	277	96			57.0	76.1	63.9
L101	F	5	49	11/4/2004	2:03pm - 3:03pm	82.6	1.7	Variable	12	65	8122	264	88	11	36.0	46.2	60.9	51.1
L101	F	6	50	11/2/2004	2:35pm - 3:35pm	81.1	1.9	South	11	65	12245	382	75	5	35.0	53.1	67.8	58.9
L101	F	7	51	11/16/2004	2:00pm - 3:00pm					65	10056	327	214			49.2	69.5	56.7
L202	G	1	52	11/17/2004	8:00pm - 9:00pm	61.0	0.0	N/A	59	65	5029	73	63			52.7	69.9	58.8
L202	G	2	53	11/18/2004	9:10pm - 10:10pm	57.8	0.0	N/A	64	65	1905	24	7					
L202	G	3	54	11/18/2004	8:00pm - 9:00pm	61.5	0.0	N/A	56	65	2744	28	6			44.8	63.9	52.2
L202	G	4	55															
I-10	H	1	56	11/17/2004	10:03am - 11:03am	76.0	0.9	NW	29	65	12795	627	632	14	28.0	58.6	67.1	62
I-10	H	2	57															

After Readings																		
Site						Weather Conditions				Traffic Data						Noise Readings		
Route	Segment	HDR ID	Receiver	Date	Time	Temp (0F)	Wind (mph)	Direction	Humidity (%)	Speed	Autos	Med Trucks	Hvy Trucks	Buses	Motorcycles	Lmin	Lmax	Leq
I-10	H	3	58	11/18/2004	10:06am - 11:06am	78.8	1.0	SE	33	65	12811	614	610	16	37.0	55.3	70.1	60
I-10	H	4	59	11/17/2004	1:30pm - 2:30pm	85.0	1.5	SE	24	65	14698	742	485	14	86.0	58.0	68.6	62.6
I-10	H	5	60	11/2/2004	9:49am-10:49am	74.5	0.7	N	13	65	15198	368	631	36	31.0	56.4	69.0	60.8
L101	J	1	61	8/10/2004	5:05am - 6:05am	86.1	0.9	South	36	65	5628	287	124	10	19.0	53.5	66.5	57.3
L101	J	2	62	7/27/2004	5:09am - 6:09am	85.1	0.0	South	47	65	5666	327	113	10	22.0	49.3	62.9	55.1
L101	J	3	63							65	4285	206	153			44.6	61.0	49.8
L101	J	4	64	8/11/2004	5:10am - 6:10am	86.2	0.0	N/A	38	65	4857	234	103	6	20.0	44.8	65.3	55.2

Table D3. Data from '*Follow-up*' Site 2 Measurements

Follow Up Readings																	
Site					Weather Conditions				Traffic Data						Noise Readings		
Route	Segment	Receiver	Date	Time	Average Temp. (0F)	Average Relative Humidity (%)	Average Wind Speed (mph)	Wind Direction	Avg. Speed	Autos	Med. Trucks	Hvy Trucks	Motor-cycles	Buses	Lmin	Lmax	Leq
L101	A	1	4/25/2007	3:05pm - 4:05pm	88.5	13.1	2.3	Variable	65	10,741	238	126	75	28	64.5	65.5	65.2
L101	A	2	5/3/2007	1:15pm - 2:15pm	85.0	14.6	3.2	East	65	6,740	187	195	39	7	59.1	59.7	59.4
L101	A	5	5/9/2007	12:15pm - 1:15pm	93.3	13.9	1.7	Variable	65						54.6	56.0	55.5
L101	A	6	5/9/2007	1:58pm - 2:58pm	93.2	14.7	1.0	Variable	65						56.5	58.7	57.3
L101	A	8	5/15/2007	2:00pm - 3:00pm	101.2	12.7	6.8	Variable	65						58.6	59.1	58.9
L101	A	9	5/15/2007	12:24pm - 1:24pm	96.6	14.6	1.1	Variable	65						70.2	70.5	70.3
L101	C	5	5/8/2007	1:48pm - 2:48pm	92.7	14.0	0.8	Variable	70						57.1	59.0	57.9
L101	D	1	5/1/2007	11:04am - 12:04pm	86.8	20.6	0.2	North	65	8,493	297	273	46	9	54.6	55.4	55.1
L101	D	2	5/1/2007	9:55am - 10:55am	86.9	20.7	0.5	West	65	8,327	290	316	27	7	53.4	55.5	54.3
L101	D	4	5/2/2007	10:09am - 11:09am	83.8	20.9	1.5	North	70	7,865	329	280	31	16	57.4	58.5	57.9
L101	F	4	5/2/2007	3:23pm - 4:23pm	92.0	14.4	2.1	North	60	9,927	226	122	67	9	60.8	61.9	61.5
L202	G	1	5/9/2007	8:57am - 9:57am	86.0	20.3	1.4	West	70						60.2	61.9	61.0
I10	H	1	4/19/2007	9:47am - 10:47am	73.7	11.6	0.9	Variable	65						59.6	62.6	60.7
I10	H	3	4/19/2007	11:14am - 12:14pm	76.0	9.9	1.0	North	65						58.8	59.3	59.1
I10	H	4	4/19/2007	12:22pm - 1:22pm	80.8	8.7	1.2	Variable	65						62.6	62.9	62.8
I10	H	5	4/26/2007	9:35am - 10:35am	82.3	18.0	0.8	Variable	65						60.7	61.2	60.9
I10	K	4	4/24/2007	11:35am - 12:35pm	83.7	16.1	0.6	South	65						64.0	65.6	64.9
I10	K	5	4/24/2007	10:15am - 11:15am	79.5	17.9	0.4	South	65						59.0	59.4	59.2
I17	M	1	5/8/2007	12:07pm - 1:07pm	91.9	15.1	1.8	Variable	65						56.9	59.0	58.1
L101	N	1	4/25/2007	12:01pm - 1:01pm	85.5	17.1	2.0	Variable	65	6,673	210	234	33	4	51.6	54.5	53.3
L101	O	2	4/19/2007	2:42pm - 3:42pm	80.7	8.4	1.4	Variable	65						55.7	58.0	56.5
L101	R	1	5/9/2007	3:26pm - 4:26pm	93.4	13.3	1.9	Variable	70						54.9	56.9	55.7
L101	S	1	4/25/2007	1:47pm - 2:47pm	86.6	14.6	1.2	Variable	65	9,088	264	170	56	16	61.8	63.1	62.4
L101	S	2	5/2/2007	1:12pm - 2:12pm	89.1	18.4	2.4	Variable	65						65.3	65.5	65.4

APPENDIX E

SITE 3 – DESCRIPTION OF SITES AND ADDITIONAL SPECTRAL DATA

Included in this appendix are photographs of the five Site 3 measurement locations. For Sites 3A, 3D, and 3E, photographs of the pavement are also provided. Photographs documenting the physical changes to Site 3A are also included. One-third octave spectra of wayside L_{eq} beyond those provided in Figures 7 through 11 in the main body of the report.

a. View from 175 ft/5 ft Microphone toward Freeway

b. View to the North away from Freeway

Figure E:1 View toward and from Freeway along Microphone Line at Suite 3A

a. Original PCCP

b. New ARFC Overlay

Figure E2: Pavement Surface Pre- and Post-overlay at Site 3A

Figure E3: Site 3A Geometry Changes relative to Microphone Locations after Addition of Auxilliary Lane

a. View from the Microphones

Figure E5: View toward Freeway along Microphone line at Site 3B

a. View Along Line of Microphones

Figure E6: View toward Freeway along Microphone Line at Site 3C

a. View Along Line of Microphones East

b. View Toward the East

Figure E7: View Microphone Line toward Freeway and from the Side for Site 3D

a. Original PCCP

b. New ARFC Overlay

Figure E8: Pavement Surface Pre- and Post-overlay at Site 3D

a. View from 100 ft/5 ft Microphone

b. View to the North

Figure E9: View Microphone Line toward Freeway and from the Side for Site 3E

a. Original PCCP

b. New ARFC overlay

Figure E10: Pavement Surfaces Pre-and Post-overlay at Site 3E

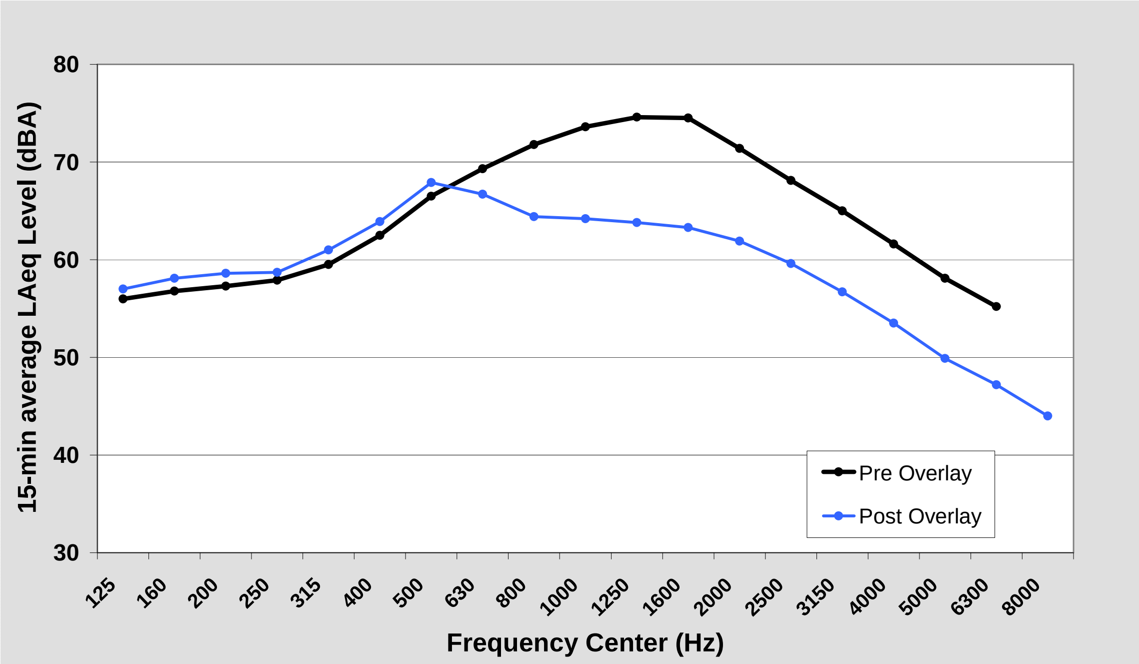


Figure E11: One-third octave band spectra for wayside noise measured at Site 3A at 50 ft distant and 5 ft high pre- and post-overlay

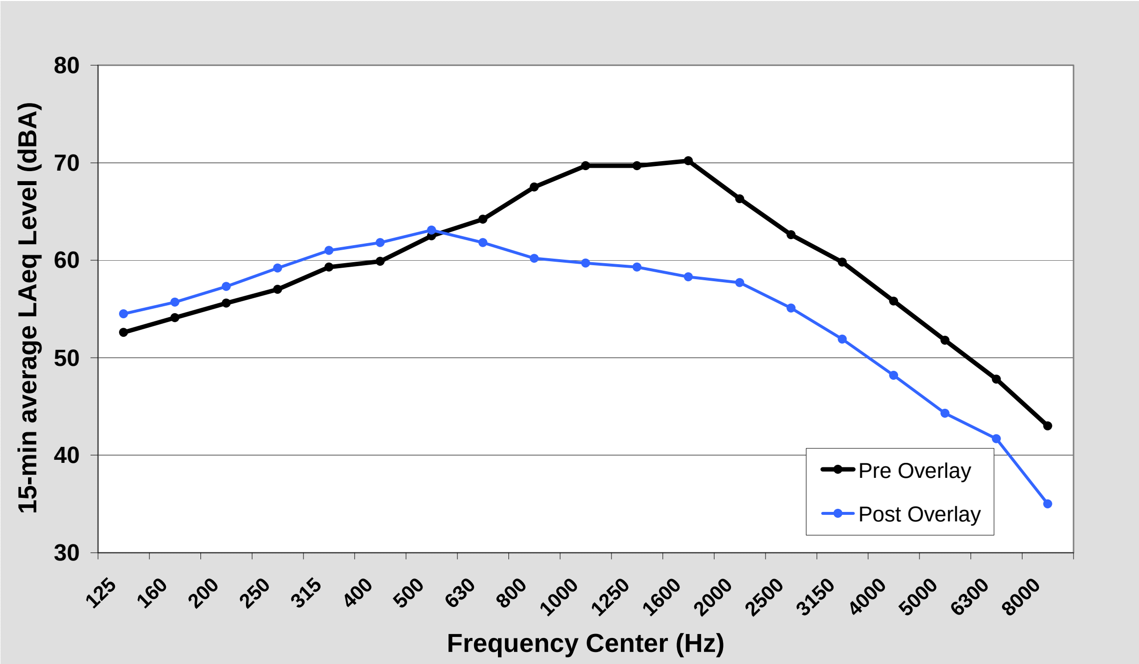


Figure E11: One-third octave band spectra for wayside noise measured at Site 3A at 100 ft distant and 5 ft high pre- and post-overlay

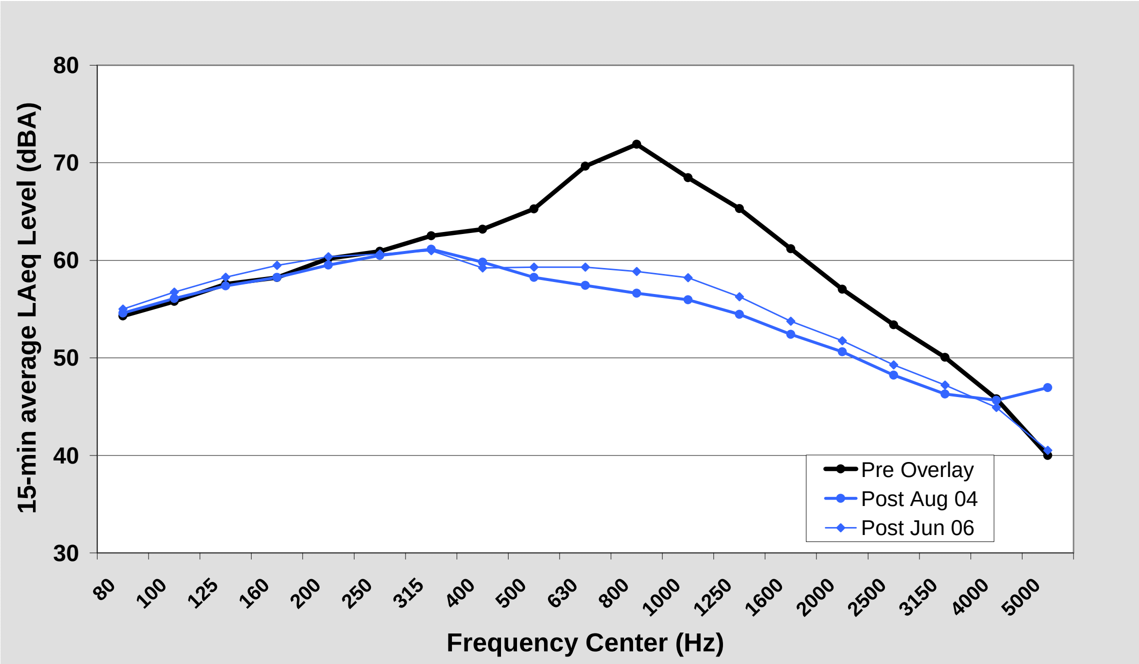


Figure E13: One-third octave band spectra for wayside noise measured at Site 3B at 95 ft distant and 5 ft high pre- and post-overlay

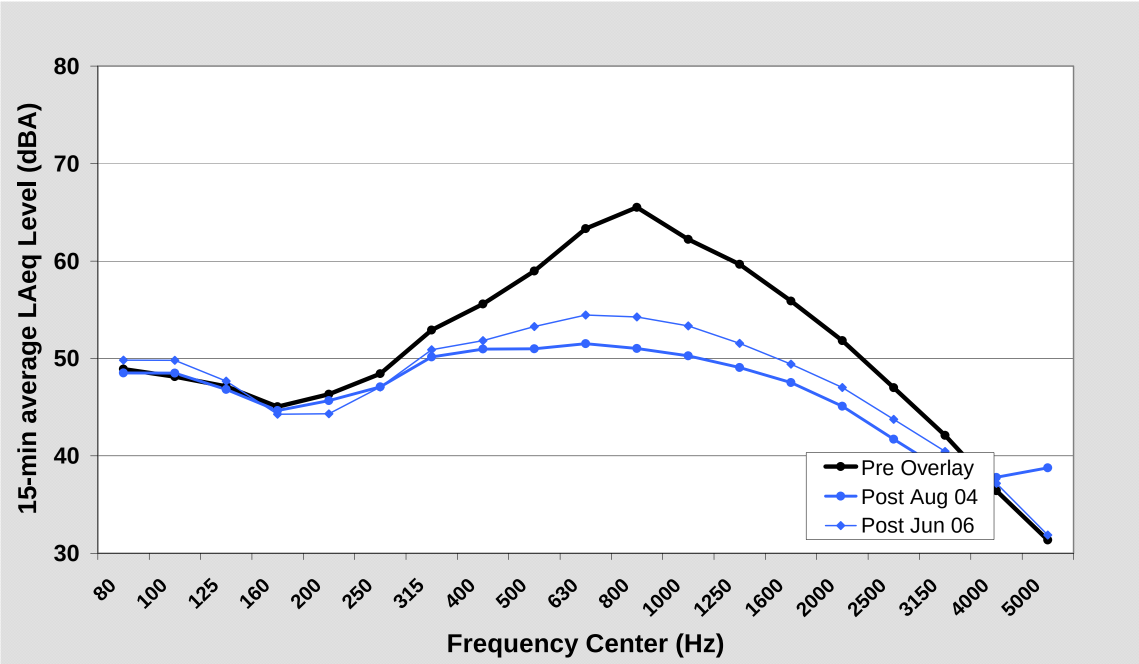


Figure E14: One-third octave band spectra for wayside noise measured at Site 3B at ball field locations 5 ft high pre- and post-overlay

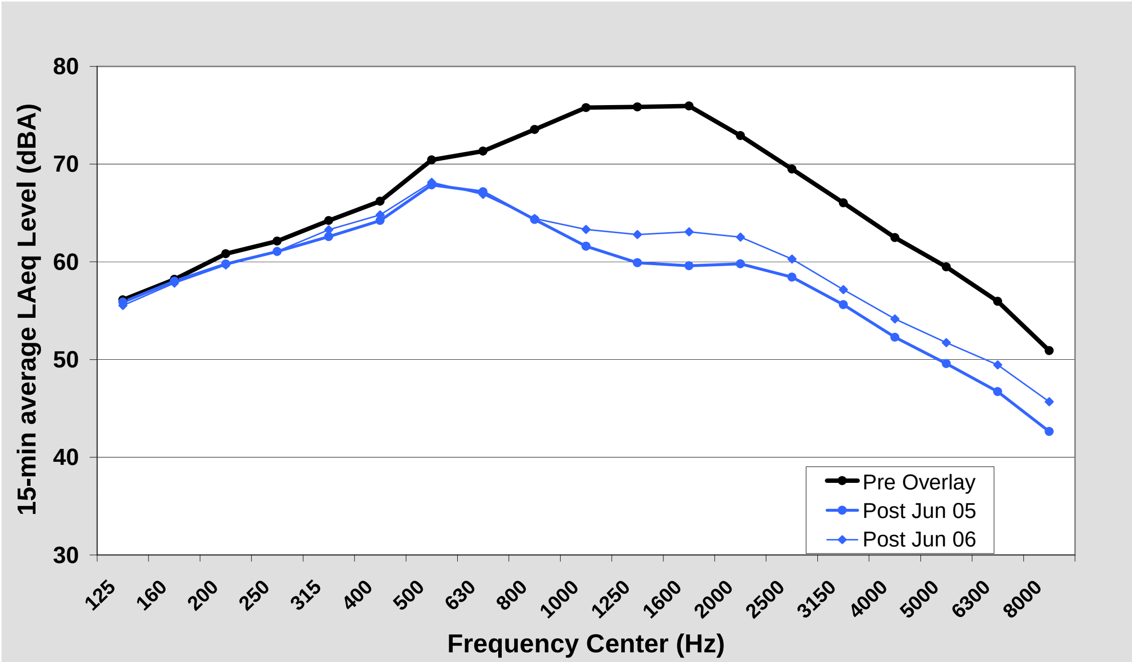


Figure E15: One-third octave band spectra for wayside noise measured at the volleyball court location 5 ft high pre- and post-overlay

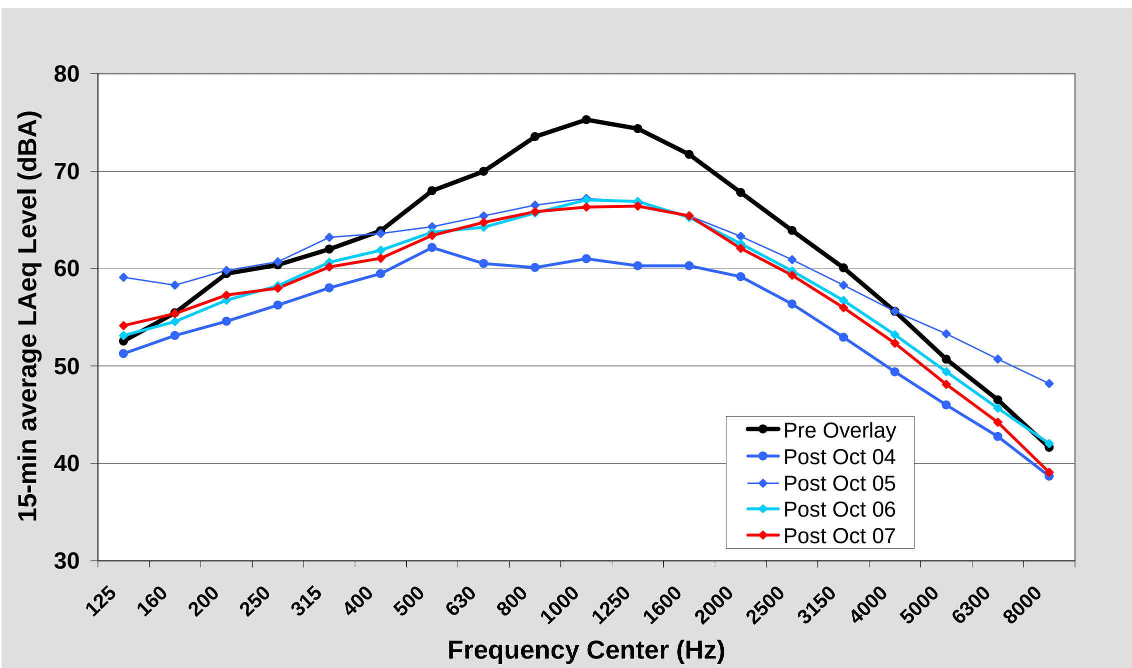


Figure E16: One-third octave band spectra for wayside noise measured at Site 3D at 50 ft distant and 5 ft high pre- and post-overlay

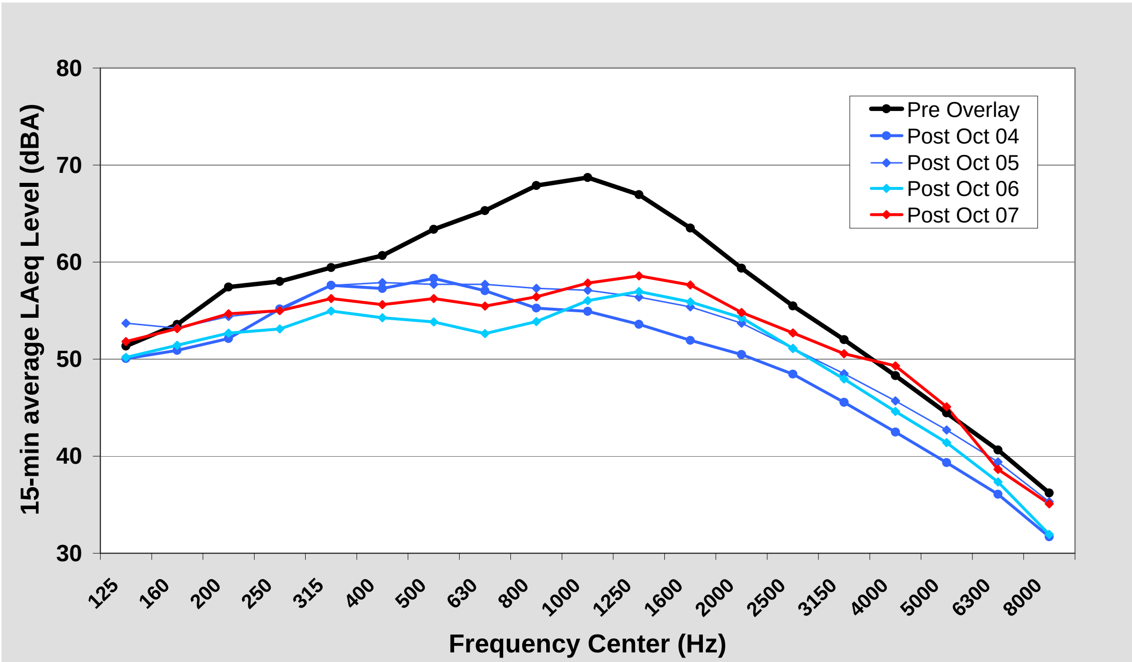


Figure E17: One-third octave band spectra for wayside noise measured at Site 3D at 100 ft distant and 5 ft high pre- and post-overlay

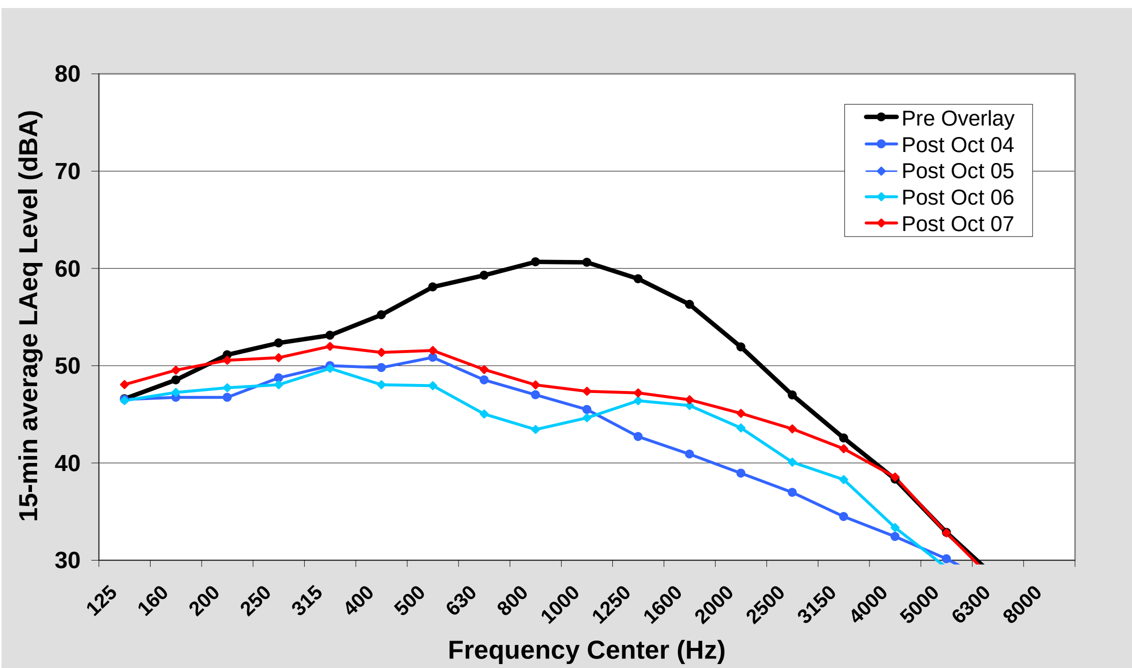


Figure E18: One-third octave band spectra for wayside noise measured at Site 3D at 250 ft distant and 5 ft high pre- and post-overlay

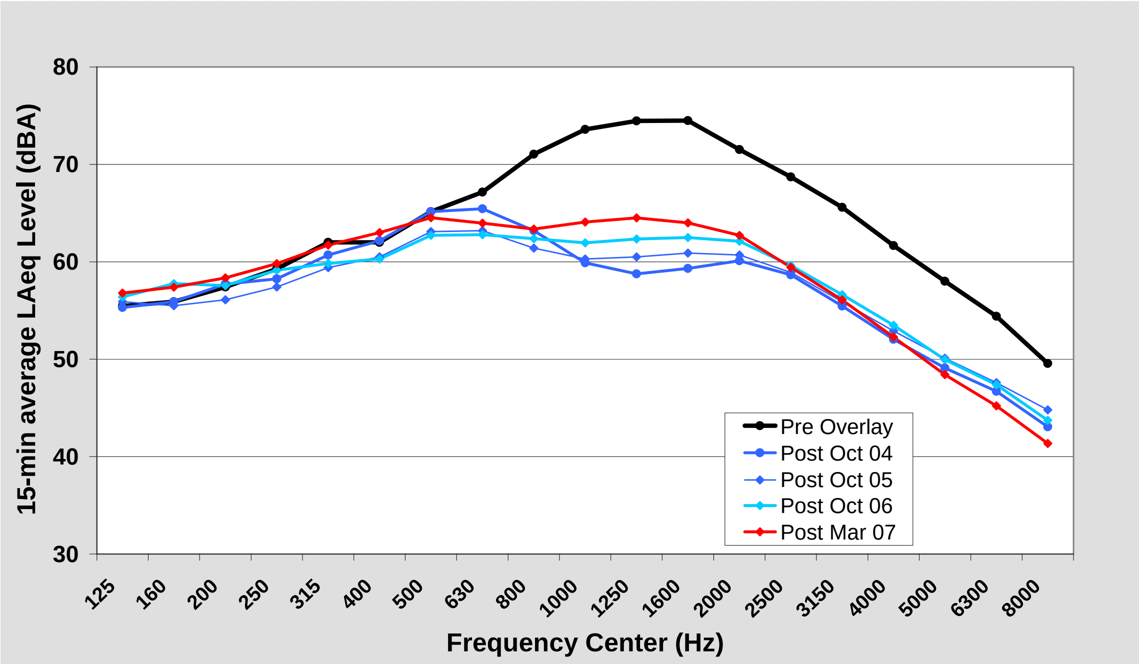


Figure E19: One-third octave band spectra for wayside noise measured at Site 3E at 50 ft distant and 5 ft high pre- and post-overlay

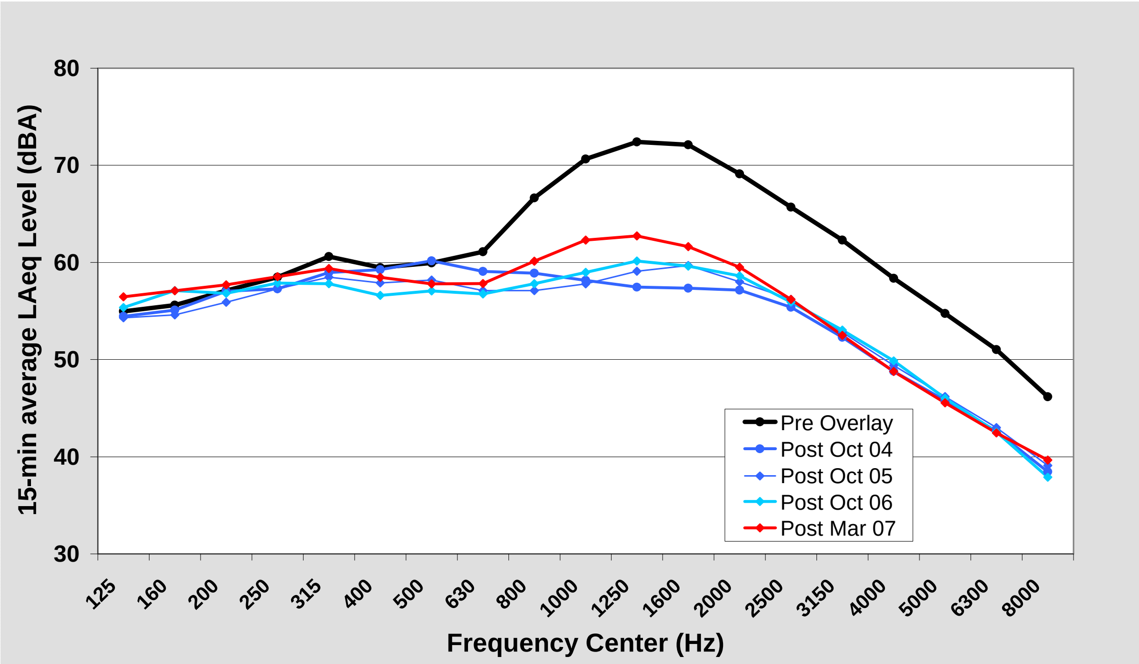
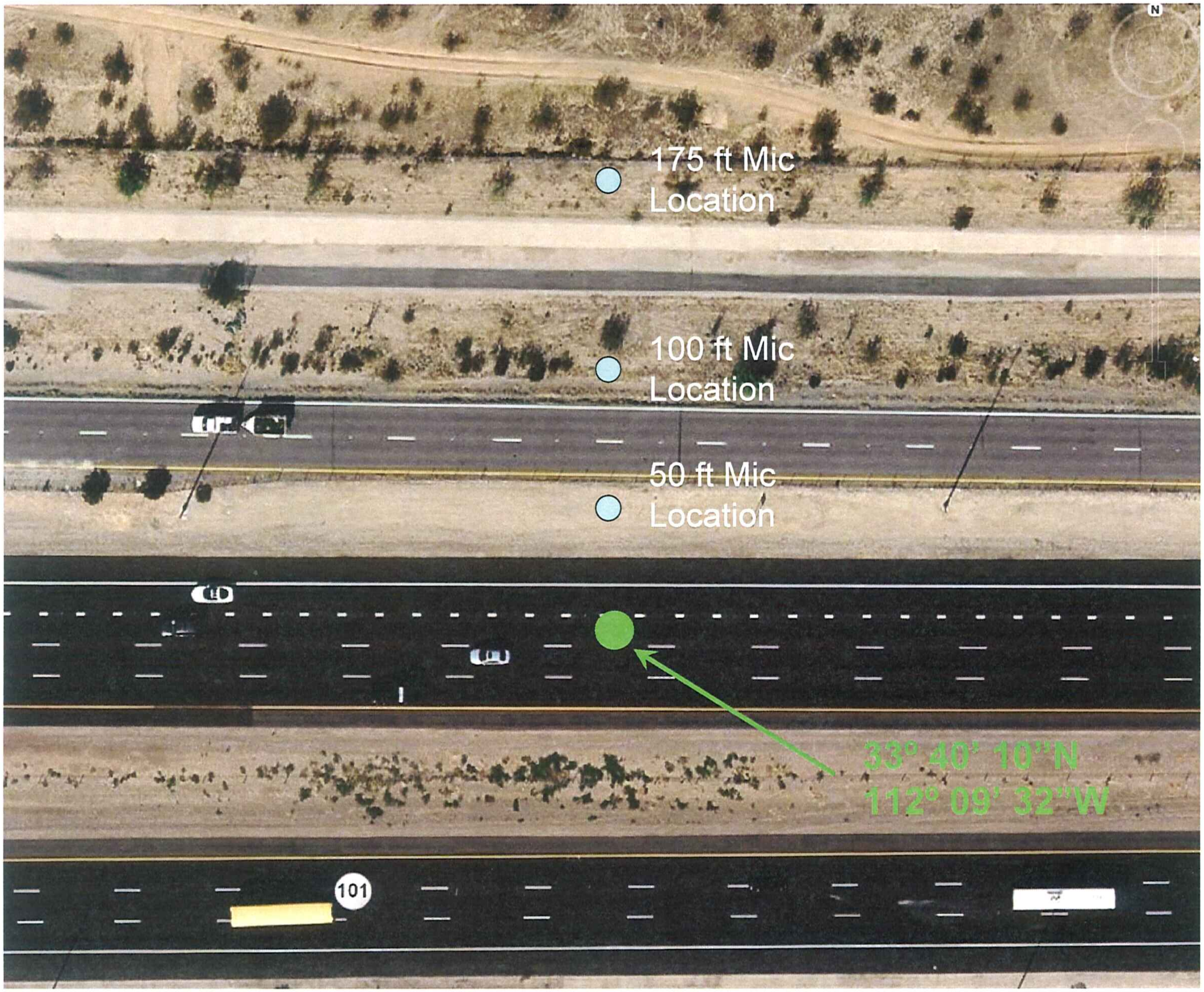


Figure E20: One-third octave band spectra for wayside noise measured at Site 3E at 100 ft distant and 5 ft high pre- and post-overlay

APPENDIX F

AERIAL VIEW OF SITES

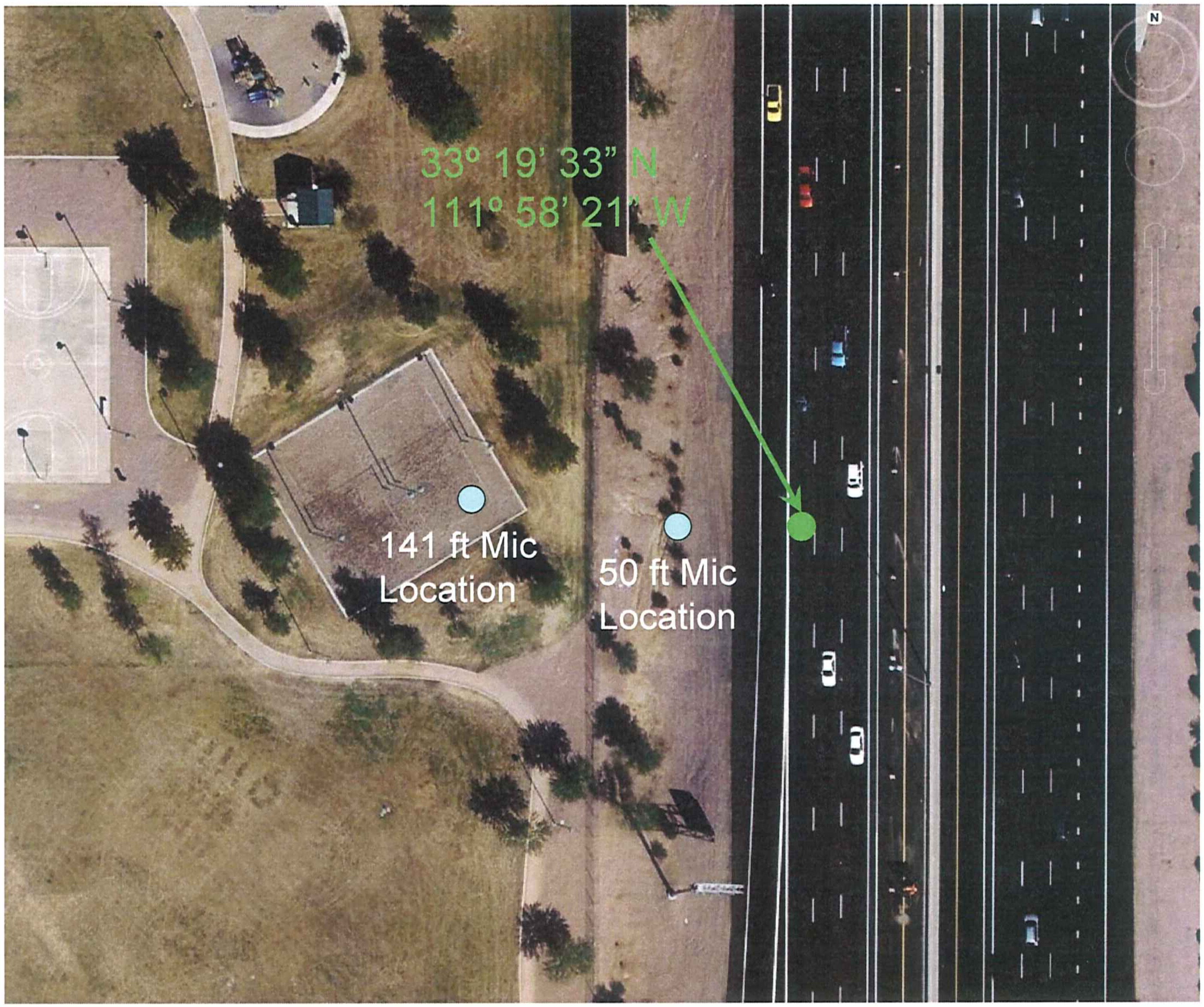
SITE 3A – SR 101 Aqua Fria Freeway between Milepost 20 & 21



SITE 3B – SR 101 Aqua Fria Freeway between Milepost 8 & 9

SITE 3B – SR 101 Aqua Fria Freeway between Milepost 8 & 9

SITE 3C – I-10 Maricopa Freeway between Milepost 159 & 160



SITE 3D – SR 202 Red Mountain Freeway between Milepost 18 & 19

SITE 3E – SR 101 Pima Freeway at Milepost 47