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Arizona Quiet Pavement Pilot Program:
Comprehensive Report

Arizona Department of Transportation Research Center

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16. Abstract

The Quiet Pavement Pilot Program (QPPP) was developed in cooperation with the Federal Highway Administration to evaluate the noise benefit of asphalt rubber friction course (ARFC) on urban freeways in the Phoenix, Arizona, area. The research was conducted periodically over 10 years and involved the use of three types of testing methods to assess the potential of ARFC as a noise abatement measure: Type 1 examined tire/pavement noise at the source; Type 2 examined noise in residential neighborhoods near the freeways; and Type 3 evaluated noise using direct measures of traffic noise adjacent to the freeways. Sound absorption measurements were also made at specific sites at various times throughout the project. Type 1 measurements documented an average initial reduction of 8.7 dBA and an average increase of 0.5 dB/year afterward. The Type 2 measurements revealed an average initial reduction of 5.2 dBA, while the Type 3 measurements showed an average initial reduction of 9.1 dBA and an average increase of 0.5 dB/year.

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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 ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AADT .... annual average daily traffic

AASHTO................. American Association of State Highway and Transportation Officials

AC.......................... asphalt concrete

ACFC...................... asphalt concrete friction course (non-rubber)

ADOT...................... Arizona Department of Transportation

ANSI .... American National Standards Institute

ARFC...................... asphalt rubber friction course

CFR .... Code of Federal Regulations

cgs rayls................. centimeter gram second Rayleighs

CPX .... close-proximity

CTIM...................... continuous-flow time-integrated method

dB……………………….decibel

dBA........................ A-weighted decibel

DD .... doubling of distance

Δ .... delta (change)

DOT .... Department of Transportation

EFR .... effective flow resistance

°F........................... degrees Fahrenheit

FHWA .... Federal Highway Administration

ft............................ foot/feet

GLSS .... ground-level source strength

h .... hour

HOV....................... high-occupancy vehicle

Hz .... hertz

I-10 .... Interstate 10

I-17 .... Interstate 17

I&R .... Illingworth & Rodkin, Inc.

IL_{meas} .... measured sound intensity level

IL_{norm} .... normalized sound intensity level

ISO .... International Organization for Standardization

km .... kilometer

L_{eq} .... equivalent sound level

L_{50} .... median sound level

L_{max} .... maximum sound level

LOS .... level of service

m .... meter

mm .... millimeter

MPD .... mean profile depth

mph .... miles per hour

NAC .... Noise Abatement Criterion

NCHRP .... National Cooperative Highway Research Program

OBSI .... on-board sound intensity

OGAC .... open-graded asphalt concrete

P-ACFC .... porous asphalt concrete friction course

PCC .... portland cement concrete

PCCP .... portland cement concrete pavement

PEM .... porous European mix

QPPP .... Quiet Pavement Pilot Program

QPR .... Quiet Pavement Research

R^2 .... coefficient of determination

RAC(O) .... rubberized asphalt concrete open-grade

REMELs .... reference energy mean emission levels

RTA .... Real-Time Analyzer

SLM .... Sound Level Meter

SMA........................ stone mastic asphalt; stone matrix asphalt

SR .... State Route

SRTT .... Standard Reference Test Tire

Std Dev................... standard deviation

T_{meas}........................ measured temperature

TNM .... Traffic Noise Model

US........................... United States

EXECUTIVE SUMMARY

The Arizona Department of Transportation (ADOT) initiated the Arizona Quiet Pavement Pilot Program (QPPP) in April 2003 with approval from the Federal Highway Administration (FHWA). The QPPP consisted of two components: construction and research. The construction component consisted of overlaying approximately 330 miles of existing transversely tined portland cement concrete (PCC) on urban freeways in the Phoenix, Arizona, area with asphalt rubber friction course (ARFC). The research component evaluated the potential for using ARFC as a noise mitigation measure. The program consisted of two noise-related elements. The first was a noise reduction allowance, or credit, of 4 dB for the use of the quieter ARFC pavement, and the second was documentation of the initial and continuing acoustic performance of the pavement over a 10-year period. The acoustic performance was monitored with three different measurement types: Type 1 examined tire/pavement noise reduction at the source; Type 2 examined noise reduction in residential neighborhoods near the freeways; and Type 3 evaluated noise reduction using direct measures of traffic noise adjacent to the freeways. Data from these sites were collected for the pre-overlay period (2003-2004) and at various times for the post-overlay periods through 2015.

For the Type 1 measurements, the initial reductions in tire/pavement noise through the first year after the overlay were about 8.7 dBA, on average. By the final year of testing, in 2015 (which was about 12.5 years after pavement overlay) noise reductions averaged 3.2 dBA. The rate of noise level increase for Type 1 measurements averaged 0.5 dB/year. For the Type 2 neighborhood noise measurements, the initial reduction at 52 well-documented locations was about 5.2 dBA, with a great deal of scatter due to the nature of these types of measurements. These reductions were stable through the follow-up measurements conducted at 16 well-documented locations; in the final follow-up period, the noise reduction averaged 5.1 dBA. For the Type 3 measurements, the initial reduction in traffic noise averaged 9.1 dBA at the 50-ft microphone position at all five sites and averaged 7.3 dBA at the 100-ft microphone position. Due to roadway construction or other site-altering reasons, the final testing period for each of the Type 3 sites varied, but on average, noise reductions equaled 5.5 dBA at 50 ft 10 years after the overlay was constructed. Type 3 noise levels at the 50-ft microphone position increased at rates ranging from 0.22 to 0.61 dB/year at each of the sites with an average of 0.5 dB/year.

To assess the performance of the pavement relative to the 4-dB credit allowed by the QPPP, measured noise levels from the Type 3 data were compared with the predictions of the FHWA Traffic Noise Model (TNM). For this comparison, the predicted levels should have been at least 4 dB greater than the measured levels. This was achieved at all of the initial Type 3 locations at microphone locations 50 ft away from the freeway. At distances of 100 ft, the 4-dB difference was initially exceeded and lasted through three years of testing at Site 3B and through six years of testing at the other sites.

CHAPTER 1. INTRODUCTION

Under Federal Highway Administration (FHWA) noise abatement policies, as documented in Title 23, Part 772 of the US Code of Federal Regulations (23 CFR 772), federal funds can be used for noise abatement only if a project falls into any of five categories: traffic management, alteration of horizontal and vertical alignments, construction of noise barriers, creation of buffer zones, and 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 of these actually implemented by state and local transportation agencies. At times, however, noise barriers do meet with some resistance, due to cost, visual impact, graffiti concerns, and other issues. In some circumstances, barriers would not be physically viable, cost reasonable, or would not provide the necessary 5-dB noise reduction mandated in 23 CFR 772 in the early 2000s. As a result, several states became 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 the Arizona Department of Transportation (ADOT) to adopt a mitigation threshold of 64 dBA instead of 66 dBA, as required by 23 CFR 772. 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, FHWA also became interested in at least evaluating the effectiveness of pavement type in reducing traffic noise levels. Under FHWA policy at that time and at present, quieter pavement was explicitly not to be considered as noise abatement. One of the major concerns precipitating this position was the acoustical performance of quieter pavement over time, particularly in comparison to noise barriers that maintain a constant amount of noise reduction indefinitely. However, with the interest shown by state agencies and the apparent success of quieter pavements in Europe and Asia, FHWA became supportive of research into the potential use of pavement to produce lower levels of traffic noise. Therefore, in April 2003, ADOT initiated a Quiet Pavement Pilot Program (QPPP) research project in partnership with FHWA. The QPPP consisted of two components: construction and research. The construction component consisted of overlaying approximately 330 miles of existing urban freeways with asphalt rubber friction course (ARFC) in five separate phases. The research component evaluated the potential for using ARFC as a noise mitigation measure. This component consisted of three separate technical studies designated as Type 1, Type 2, and Type 3. The locations of the three types are shown in Figure 1 and are discussed in detail below:

- Type 1—On-Board Sound Intensity (OBSI), which measured the tire/pavement noise levels at the source. OBSI measurements averaged over a 5-sec period were taken at each milepost and in each travel direction.
- Type 2—Short-term, time-averaged noise levels measured at selected locations in neighborhoods surrounding various segments of the freeway. These were typically 1 hr in duration at the times when the highest noise levels were produced by the traffic flow. Some of these measurement locations may have been shielded by existing sound walls, fences, buildings, etc.

- Type 3—Time-averaged traffic noise made at "research-grade" sites that conformed to the site requirements specified in FHWA measurement procedures (Lee 1996) at the 50-ft microphone location.

Each measurement type, located at sites on or adjacent to selected Maricopa County regional freeways, involved measuring traffic noise levels prior to application of ARFC (hereinafter referred to as pre-overlay) and measuring traffic noise levels at the same sites after application of ARFC (hereinafter referred to as post-overlay).

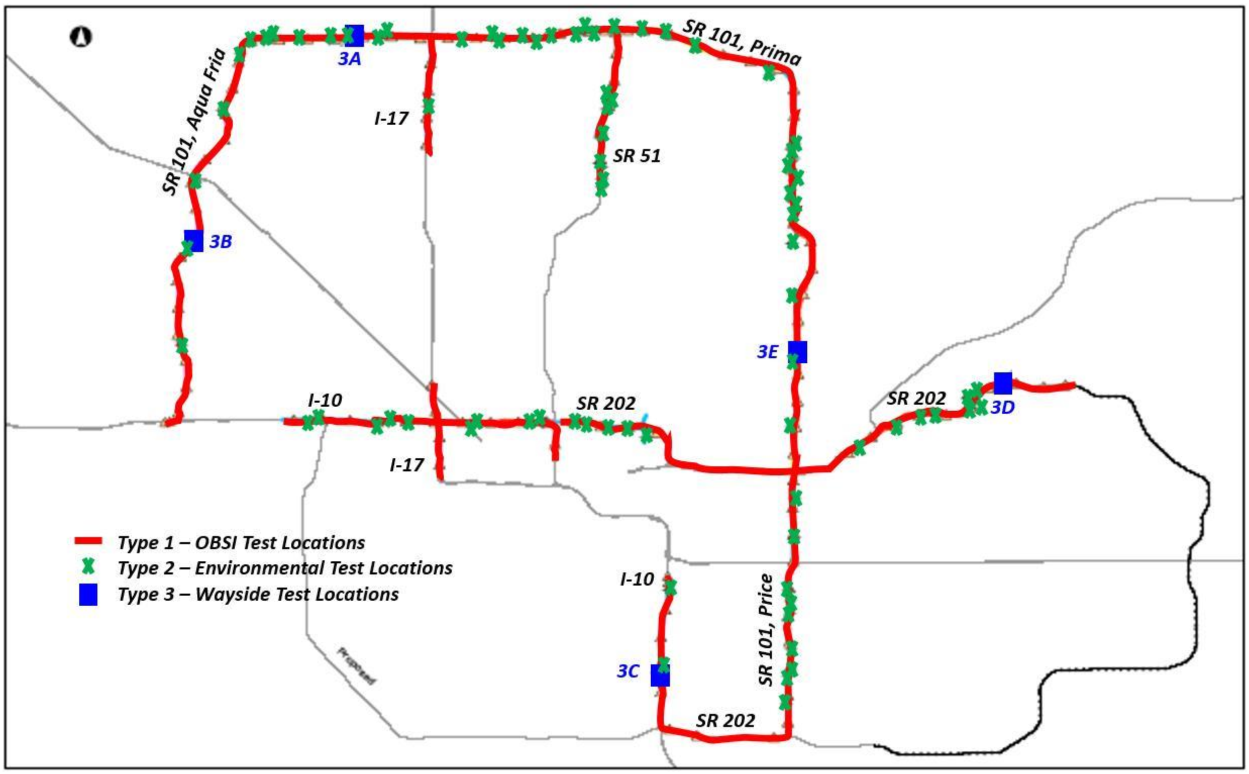

Figure 1. Measurement Locations for Types 1, 2, and 3 (Maricopa County, Arizona, Regional Freeway System)

This final project report summarizes the activities performed in the QPPP through the end of 2015, when the project concluded. Included in this report are the results of the noise measurements, comparison of the different measurement types, a summary of pavement measurements, and brief discussions of preliminary and additional research.

CHAPTER 2. QPPP PROGRAM DESCRIPTION

Before initiating the QPPP, ADOT performed extensive research into quieter pavements, equivalent to what would today be considered a Quieter Pavement Research (QPR) program by FHWA. This QPR consisted of the installation and noise evaluation of test sections constructed of according to various asphalt concrete (AC) pavement designs in order to assess the designs' potential for tire/pavement noise reduction. Of the pavements tested in the QPR program, the ARFC material later used in the QPPP was found to produce the lowest noise levels. The QPR also included an evaluation of the noise performance of ARFC overlays of various ages as applied throughout the state highway systems. This provided some information on the expected noise reduction potential of ARFC over time (Donavan and Scofield 2004). Finally, research was conducted on alternative portland cement concrete (PCC) texturing methods, including uniformly spaced (at 0.75 inch) transversely tined texture (which was then the ADOT standard); randomly spaced transversely tined texture; longitudinally tined pavement; and diamond-ground pavement (Donavan and Scofield 2003). Although the ground PCC performed significantly better than the other textures, it did not produce noise levels as low as those with ARFC. However, this research led to the adoption of longitudinally tined pavement as the new ADOT standard for PCC pavement texture. With the completion of this research, ARFC overlay was selected as the pavement to be used in the QPPP. All of these early studies are summarized in Chapter 5 of this report.

Although ADOT first used asphalt rubber in 1964, it did not begin regular use of asphalt rubber products until 1968 (Scofield 1989). The development of an asphalt rubber overlay system for portland cement concrete pavement (PCCP) began in 1973 with a two-layer system. The two-layer system was quickly replaced by a three-layer system in 1975, and the first nonexperimental section was placed on Interstate 17 (I-17) in Phoenix, Arizona, in 1985. The three-layer system was eventually replaced by 1-inch-thick ARFC. The first use of the ARFC strategy occurred on I-19 near Tucson, Arizona, in 1988, when a 1.5-mi section of southbound I-19 was overlaid with 1-inch-thick ARFC. The 1-inch-thick ARFC surfacing used in Arizona consists of a 0.375-inch-minus open-graded aggregate. Typical asphalt rubber binder contents range between 9.0 and 9.4 percent by total mix weight. This overlay strategy has been used for most of the PCCP overlay placements since 1988. A more complete description of the ARFC overlay is provided in Appendix A.

ADOT initiated the QPPP in April 2003 after FHWA approved it. The program consisted of two noise-related elements: (1) a noise reduction allowance, or credit, for the use of the quieter ARFC pavement; and (2) documentation of the pavement's acoustic performance over a 10-year period. Under the QPPP agreement, the program's pilot status allowed ADOT to assume a 4-dB reduction due to pavement surface type when designing noise mitigation. This allowance was applied to the final predicted traffic noise level using the FHWA Traffic Noise Model (TNM). Under FHWA policy, only vehicle noise source levels—or reference energy mean emission levels (REMELs) (Fleming et al. 1996)—corresponding to average pavement were authorized in the use of the TNM. As a result, to predict future traffic noise levels and assess the performance of noise abatement options, such as barriers in the QPPP, the 4-dB reduction was 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 the omission of barriers if the predicted noise levels fall below the ADOT threshold of 64 dBA.

In exchange for the 4-dB acoustic credit, ADOT agreed to monitor the noise performance of the pavement over time. ADOT used three different testing methods:

- Type 1—Measurement of tire/pavement noise levels at the source using on-board measurement techniques at each milepost and in each direction of travel for the 330-mile project
- Type 2—Measurement of short-term, time-averaged noise levels conducted at selected locations in neighborhoods surrounding various segments of the freeway
- Type 3—Measurements of time-averaged traffic noise made at "research-grade" sites conforming to the site requirements specified in FHWA measurement procedures (Lee 1996) at the 50-ft microphone location

The testing locations for each type of measurement are shown in Figure 1. The frequency of the Type 1, 2, and 3 measurements are shown in Table 1. The frequency varied with the site type and the locations within the type. Generally, Type 1 measurements were conducted semiannually through 2010 and then annually through 2015. Type 2 measurements were performed pre- and post-overlay, as well as during an additional follow-up period. Type 3 measurements were completed pre-overlay at all locations and post-overlay at all sites within six months. Additional post-overlay testing varied by location. At two sites (3B and 3C), testing was done typically every 2 to 3 years after the first year. For the other three sites (3A, 3D, and 3E), testing was planned to be done semiannually until the seventh year after the overlay and then annually afterwards. This was accomplished at one site (3D). For the other two sites (3A and 3E) this could not be accomplished due to construction at these locations. As a result, measurements at these two sites were less consistent. Each measurement type and its results during the project are described in Chapter 3 of this report.

The measurements were performed by several different teams. The Type 1 measurements were performed by ADOT until March 2005, at which time they were made jointly with Illingworth & Rodkin, Inc. (I&R). From March 2006 through 2015, the Type 1 measurements were made by I&R. The Type 2 measurements were performed by HDR. The measurements at Sites 3A, 3D, and 3E were performed by I&R, and those at Sites 3B and 3C by the Volpe Center of the US Department of Transportation. The remainder of this report provides details about each testing operation, the results of each type of measurement throughout the project, pavement measurements made at the Type 3 locations, and the findings of the early studies conducted by ADOT prior to the QPPP.

Table 1. Schedule of QPPP Noise Measurements

Timing	Type 1	Type 2	Type 3 Site 3A	Type 3 Site 3B	Type 3 Site 3C	Type 3 Site 3D	Type 3 Site 3E
Pre-Overlay	2003	Jul 03 Apr 04	Aug 03	Jun 04	Jun 04	Oct 03	Apr 04
Overlay Applied	2003-2004	2003-2004	Sep 03	Jun 05	Mar/Apr 05	Mar 04	May 04
Post-Overlay	2003-2004	Oct 03 Nov 04	Oct 03	Aug 05	Jun 05		
Year 0.5						Oct 04	Oct 04
Year 1	04		Sep 04	Jun 06	Jun 06	Mar 05	
Year 1.5			Apr 05			Oct 05	Oct 05
Year 2	Mar 05					Mar 06	Mar 06
Year 2.5			Mar 06	Oct 07		Nov 06	Oct 06
Year 3	Mar 06			Jun 08	Jun 08	Mar 07	Mar 07
Year 3.5	Nov 06					Oct 07	
Year 4	Mar 07	Apr 07				Mar 08	
Year 4.5	Oct 07					Oct 08	
Year 5	Mar 08					Mar 09	Mar 09
Year 5.5	Oct 08					Nov 09	Nov 09
Year 6	Mar 09			Jun 11	Jun 11	Mar 10	Mar 10
Year 6.5	Nov 09					Nov 10	Nov 10
Year 7	Mar 10		Nov 10				
Year 7.5	Nov 10					Oct/Nov 11	Oct 11
Year 8			Nov 11	Jun 13	Jun 13		
Year 8.5	Nov 11					Oct 12	Nov ’12
Year 9			Oct 12				
Year 9.5	Oct 12					Nov 13	Oct 13
Year 10			Oct 13	Jun 15	Jun 15		
Year 10.5	Oct 13					Oct 14	
Year 11			Oct 14				
Year 11.5	Oct 14						
Year 12			Oct 15				
Year 12.5	Oct 15						

CHAPTER 3. NOISE MEASUREMENTS

TYPE 1 – TIRE/PAVEMENT NOISE SOURCE LEVELS

Measurement Methods and Description

Measurements of tire/pavement noise source levels were conducted at more than 330 mileposts (identified in Figure 1) on Arizona I-17, State Route 51 (SR 51), SR 101, SR 202, and I-10 in the metropolitan Phoenix area. The terrain is relatively flat throughout the study area. Type 1 field activities included the measurement of on-board tire/pavement noise sources using both the Close Proximity (CPX) and the OBSI testing methods. Measurements of the PCC pavement were conducted prior to the ARFC overlay, primarily in 2003, to document baseline levels. Post-overlay conditions were documented in 2004 and every year thereafter through 2015. Measurements through March 2005 were conducted by ADOT using a CPX trailer. Starting in March 2006, testing was completed by I&R. In this period, there was a transition to OBSI measurements, which were used consistently from November 2006 through the remainder of the project. Due to the size of the pavement program, ARFC pavement overlays were applied to sections of the roadway network over a period of several years. Therefore, some sections of pavement measured from 2004 through November 2006 were used to document pre-overlay baseline conditions.

Description of Pavement

Prior to beginning the ARFC overlay program, most of the Phoenix metropolitan area highway network had been constructed with uniformly spaced (0.75-inch) transverse tine PCC. In 2001, ADOT began to use quieter, uniformly spaced (0.75-inch) longitudinal tine PCC. To achieve even further noise reduction, ADOT elected to place ARFC overlays on existing and new portions of the Phoenix area freeway system. The 1-inch-thick ARFC surfacing used in Arizona consists of a 0.375-inch-minus open-graded aggregate. Typical asphalt rubber binder contents range between 9.0 and 9.4 percent by total mix weight. Figure 2 shows the ADOT standard uniformly spaced transverse tine PCC with and without the ARFC overlay.

As of 2008, newly constructed PCC that was intended to receive an ARFC overlay was constructed with artificial-turf texturing, while non-overlaid PCC received uniform longitudinal tining. Each of the Type 3 measurement locations went through various reconstruction processes over the duration of the project, and details at each specific site are discussed in the corresponding chapters of this report.

Figure 2. ADOT Standard Uniformly-Spaced Transverse-Tined PCC With and Without the 1-Inch-Thick ARFC Overlay

Testing Methods

Noise measurements were typically made in the right through-travel lane. However, special circumstances, such as traffic congestion, roadway construction, and lane shifting, would occasionally force measurements to be made in other lanes. The vehicle speed for both types of on-board measurements was 60 mph (97 km/h), and the noise levels were averaged over 5-sec time periods. These 5-sec measurements were taken at each milepost throughout the Type 1 test area. Initially, the test tire was a Goodyear Aquatred 3™ P205/R7015, which was chosen to be common with that used by the California Department of Transportation (Caltrans) in its early pavement research activities dating back to 2002 (Donavan and Scofield 2003; Donavan and Rymer 2004). However, starting in the fall of 2012, the Uniroyal Standard Reference Test Tire (SRTT)™ was used for testing, per the American Association of State Highway and Transportation Officials (AASHTO) Standard Method of Test TP 76-10 (AASHTO 2010), which was based on the research completed in National Cooperative Highway Research Program (NCHRP) Project 1-44 (Donavan and Lodico 2009). Measurements were typically made between about 9:00 a.m. and 4:00 p.m., and at times after 7:00 p.m., to avoid congested traffic conditions. Due to the extent of the project, only one measurement pass for each milepost/direction was made in a given testing period. Under the on-board testing methods (CPX and OBSI), data from the leading edge and trailing edge of the tire contact patch were obtained separately for the same section of pavement and then later averaged together to determine the noise level of the sound propagating away from the tire/pavement interface toward the wayside and the community.

CPX Method Versus OBSI Method. Initially, tire/pavement noise source level measurements, which are used to differentiate tire/pavement noise measurements made close to the tire from those measured alongside the roadway or in the community, were done using the CPX testing method (ISO 2000). However, after a few years it was decided to replace CPX with the newer OBSI method for all future testing, a transition that was completed in 2006. The change was made because of maintenance/reliability issues with the ADOT CPX trailer, the ease of testing with the OBSI method, improved ability to compare results with other databases, and improved correlation to pass-by levels. To facilitate the migration from CPX to OBSI, investigators conducted simultaneous measurement of CPX sound pressure levels and sound intensity levels in March 2005 on the ADOT CPX trailer (Figure 3a). 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 the on-vehicle OBSI fixture on consecutive days. This transition was facilitated by the development of an on-vehicle, dual-probe OBSI configuration that allowed both the leading and the trailing tire-contact-patch positions to be measured at once (Donavan and Scofield 2003; Donavan and Rymer 2004), continuing the single-pass approach taken for data collection (Figure 3b). In the November 2006 measurements, one day of CPX measurements were 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 with the OBSI results for a different test tire of the same type. Using the results from both the March 2005 and the November 2006 comparisons, investigators determined that an offset of 3 dB should be applied by adding this amount to the CPX data to obtain OBSI equivalent levels. Data and discussion for the development of this correction are provided in Appendix B. This correction has been applied to all of the historical CPX data, allowing for direct comparison of the earlier on-board data with the data obtained more recently.

a) OBSI Dual-Probe Fixture Installed on ADOT CPX Trailer for Comparative Testing in March 2005

b) OBSI Dual-Probe Fixture Installed on Vehicle for Testing in November 2006

Figure 3. Comparative Test Rigs Used During the Transition Period

Test Setup and Acquisition Systems. To perform the CPX measurements, ADOT had the National Center for Asphalt Technology construct a trailer to meet the specifications in the ISO standard. The trailer was used to minimize the effect of wind noise on the measurement microphones; the trailer's interior was lined with convoluted foam to minimize internal reflections of the tire noise inside the trailer enclosure. Under the procedure, sound pressure level was measured at a distance of 7.9 inches (200 mm) from the center of the tire contact patch and 7.9 inches from the undeflected plane of the test tire sidewall at positions to the front and rear of the tire. The measurements were made using two GRAS 40AE™ 0.5-inch-diameter microphones and GRAS 26CA™ 0.5-inch-diameter preamplifiers whose signals were captured by an Oros™ data acquisition system linked to a laptop computer. Before the trailer was used for the QPPP, validation tests were conducted on the trailer and data system to verify that the requirements of the ISO CPX procedure were met. Photographs of the interior of the trailer and installation of the measurement microphones are shown in Figure 4.

a) CPX Trailer Interior with Closable Panel Opened Fully

b) CPX Trailer Closable Panel with Microphones Installed

Figure 4. Photographs of the ADOT CPX Trailer

For on-vehicle OBSI testing, a two-probe sound intensity fixture was attached to and supported by the test vehicle, as shown in Figure 5. Each probe consisted of two 0.5-inch GRAS 40AI™ phase-matched condenser microphones installed on 0.5-inch GRAS 26AK™ microphone preamplifiers. Each set of microphones was attached to plastic probe holders, which provided 0.63-inch (16-mm) spacing between each set of microphones in a side-by-side configuration, and the microphones were fitted with spherical windscreens. The two probes were then positioned 3.0 inches (75 mm) above the pavement surface and 3.9 inches (100 mm) from the face of the tire, at locations opposite the leading edge and the trailing edge of the tire's contact patch. The probes were oriented so that the sensitive axis was positioned toward the tire. Through the fall of 2011, signals from all four microphones were inputted directly into a Brüel & Kjaer PULSE™ five-channel front-end system and transmitted to a laptop computer configured with PULSE software. Starting in 2012 and continuing through 2015, National Instruments LabView™ was used for acquisition. The data were stored on the laptop for later use and analyzed in real time. The microphones were calibrated using a Larson Davis Model CAL200™ acoustic calibrator set for 94 dB at the beginning and end of each measurement day. The OBSI measurements generally conform to the AASHTO Provisional OBSI Standard Method of Test TP-76-11 (AASHTO 2010) with several exceptions. Prior to 2013, a Goodyear Aquatred 3 test tire was used. Further, only one measurement was made at each milepost, whereas the standard requires at least two with a range of no greater than 1.0 dB. With the use of only one measurement per milepost, the uncertainty is greater than the ±0.7 dB stated in the standard for repeatability and bias.

Figure 5. OBSI Measurement Equipment Setup

Air Temperature Correction. In addition to pavement aging, environmental conditions such as temperature may also affect noise level results. A recent study conducted for NCHRP has shown that OBSI levels decrease as the temperature increases at a rate of approximately 0.04 dB/^{o}F (Donavan and Lodico 2011). In the study, it was determined that this linear air temperature correction should be used to normalize the overall A-weighted OBSI levels to a standardized air temperature of 68^{o}F (20^{o}C). Based on this research, the following formula is specified in the 2016 full AASHTO OBSI T360-16 (AASHTO 2016) procedure to calculate the normalized levels:

$$IL_{norm} = IL_{meas} + 0.04\left(T_{meas} - 68^o F\right) \qquad \text{(Eq. 1)}$$

Where IL_{meas} = the sound intensity measured by the analyzer set to 68^{o}F

T_{meas} = the temperature at the time of testing (in ^{o}F)

IL_{norm} = the OBSI level to be reported as the corrected level

Note: The temperatures used to calculate the corrected OBSI levels were the average temperatures throughout each testing period. That is, the temperatures measured over multiple days and at various times throughout each day were averaged to yield one temperature value per testing period. The tire/pavement noise levels for all pre- and post-overlay measurements were corrected using this temperature normalization formula.

Results

Type 1 Milepost and Highway Corridor OBSI Measurement Results

Type 1 tire/pavement noise source levels were measured along the I-17, SR 101, SR 51, SR 202, and I-10 freeways in the Phoenix metropolitan area. Additionally, OBSI measurements were also made at the sites used for Type 3 wayside measurements; these measurements are discussed in this section and in later subsections of this report corresponding to each site. During the early testing periods, not all Type 1 pavement sections contained the ARFC overlay and were not included in the results. Similarly, any sections that had been repaved with the ARFC overlay or a different pavement altogether since the original ARFC had been installed were also discarded from the results, since they would not reflect the aging effects of the original overlay. Data were collected where possible, but heavy traffic conditions, lane shifting, and reduced speed limits did impede the overall testing process. The 5-sec measurement averages typically started at the milepost highway markers, unless the mileposts were located on a bridge. Also, some of the Type 1 mileposts were unmarked, mostly because of construction roadwork; the mile indicator on the test vehicle was used to estimate these locations. Prior to March 2006, complete Type 1 measurements were not made. For the pre-overlay condition, only 107 of the 330 mileposts were measured. For the post-overlay condition, only 95 were measured in 2004, and only 18 were measured in 2005. Beginning in 2006, an average of 211 mileposts were measured. For each testing period, data were typically collected between the hours of 9:00 a.m. and 4:00 p.m. and at times between 7:00 p.m. and 9:00 p.m. In addition to OBSI measurements, environmental data such as air temperature, humidity, air pressure, and wind speeds were collected during each testing period. The environmental data collected for each testing period are provided in Appendix B.

Figure 6 presents, for each freeway segment studied, a scatter plot of all the milepost measurements taken prior to the overlay, at 1-2 years post-overlay, and at 10.5 years post-overlay. The Figure also shows the average of the measurements for each time period. The data shown include adjustment factors for the pre-2006 CPX measurements and for temperature, but not for the SRTT tire. Previous studies have shown that for newer pavements, the Aquatred tire would result in overall OBSI levels approximately 1 dBA higher than those with the SRTT; however, these effects decrease to virtually 0 dBA with aged pavement. Since the SRTT was not used until later years, the pavement age would nullify any need for an adjustment factor due to the test tire, and the overall OBSI results do not include an adjustment factor for the tire.

Figure 6 shows that the average sound intensity level for all the pre-overlay pavements was 105.5 dBA. The maximum range of individual milepost OBSI readings was 8.8 dBA when the data points from all the freeway segments are considered. For the PCC pre-overlay measurement points, the texture was almost entirely uniformly spaced transverse tine of the same specification; the only exceptions were on SR 202 where experimental random transverse tine and longitudinal tine textures had been applied. Recent research in other states has shown, however, that considerable variation in the levels for transversely tined PCC is rather typical of this category of texturing, with variations of 6 dBA or more (Thornton et al. 2004) on specific highways and of over 10 dBA nationwide (Rasmussen et al. 2007). 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. The Year 1-2 individual post-overlay measurements, which averaged 97.4 dBA, had a range of almost 4 dBA from maximum level to minimum level, excluding the older I-17 ARFC. By Year 10.5, when the average level was 102.6 dBA, the range in sound intensity levels had increased to 9.4 dBA.

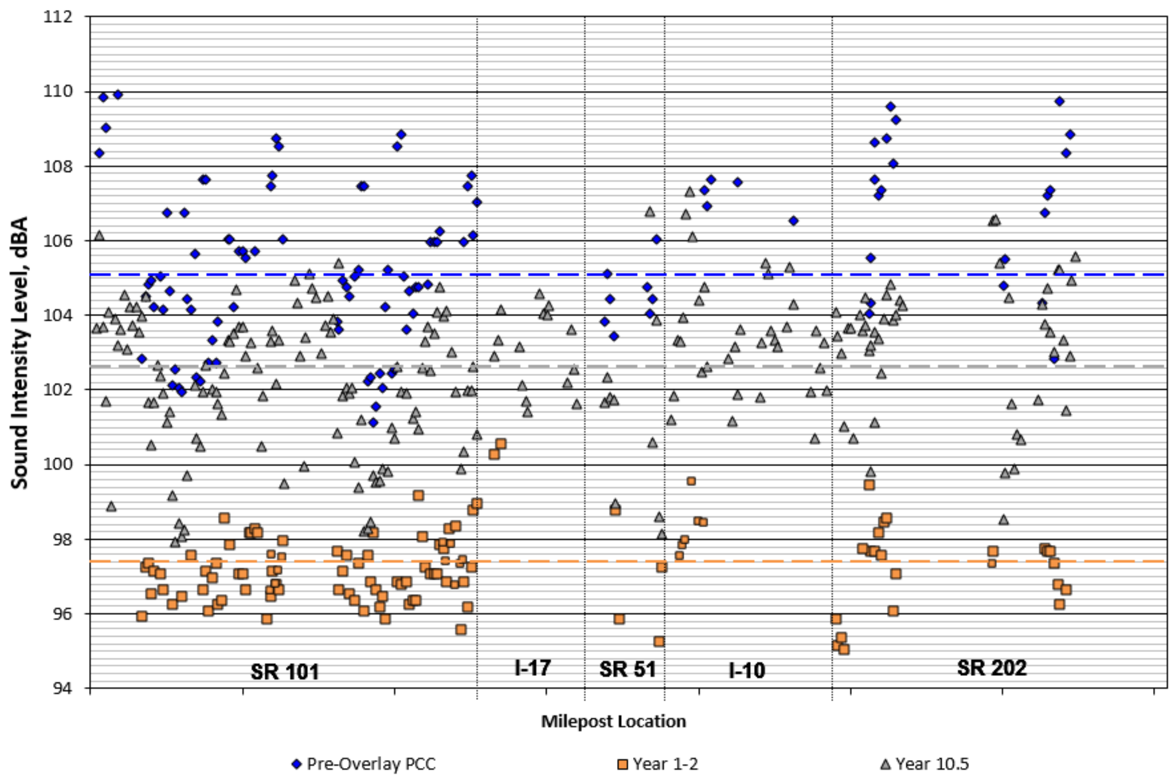

Figure 6. Individual Temperature-Corrected OBSI Levels for Freeway Segment for Pre-Overlay and Post-Overlay After 1-2 Years and at 10.5 Years

The OBSI levels for each milepost and each measurement period are tabulated in Appendix B. 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. Only about 50 percent of the pre-overlay milepost data and only about 44 percent of the initial post-overlay data are available. After the transition in 2006, 80 percent or more of the mileposts have been routinely measured. While gaps in the data sets taken after March 2006 can be found, these gaps would be due to ongoing construction or roadway rehabilitation projects in the Phoenix metropolitan area. It should also be noted that the certainty in any individual milepost measurement is on the order of 1 dBA or possibly even more, since single-pass measurements are associated with higher uncertainty than are multiple passes averaged together. This association was stipulated in the then-current AASHTO test procedure (AASHTO 2010). Other issues, such as uncertainty due to the ambiguity of lane designation in the vicinity of freeway interchanges, may also come into play. Based on these uncertainties, comparison of the corridor averages is likely to be more meaningful than is comparison of individual mileposts.

Table 2 summarizes the average temperature-corrected OBSI levels for each of the pre-overlay PCC pavements and post-overlay ARFC pavements. The table also provides the average for all the highway segments, along with the standard deviation of the average. Across the highway segments, the PCC averages span a range of 2.9 dB. Although the predominant texturing for these segments is ADOT uniform transverse tine, the age of the PCC varies as does the actual texturing. These variations contribute to the higher standard deviation for the pre-overlay PCC, compared those for the ARFC overlay in the initial years of the QPPP. In the initial periods after the overlay, some variation in OBSI levels is also seen between the freeway segments, with I-17 noticeably higher than the other segments. Although I-17 had relatively new ARFC, it was several years older, which likely accounts for the higher OBSI level.

Table 2. Temperature-Corrected OBSI Levels for All Testing Periods Through October 2015, dBA

Testing Period	SR 101, Agua Fria	SR 101, Pima	SR 101, Price	I-17	SR 51	I-10	SR 202	Average	Std Dev
PCC	105.7	104.4	107.3		104.5	107.1	106.8	**105.5**	**2.2**
2004 (Year 1)	97.0	97.1	97.2	100.4	96.8		97.2	**97.2**	**1.0**
Mar 2005 (Year 2)		97.6	97.2			98.3	97.3	**97.6**	**0.7**
Mar 2006 (Year 3)	99.2	98.5	98.7	100.3	98.5	99.7	98.7	**99.0**	**1.1**
Nov 2006 (Year 3.5)	99.4	99.0	99.1	100.0	98.3	99.7	99.5	**99.3**	**1.1**
Mar 2007 (Year 4)	99.4	99.0	99.2	100.5	98.8	100.2	99.6	**99.4**	**1.2**
Oct 2007 (Year 4.5)	100.1	99.2	99.1	101.4	98.2	100.7	99.5	**99.7**	**1.4**
Mar 2008 (Year 5)	99.9	99.2	99.3	100.7	98.8	100.4	99.5	**99.7**	**1.6**
Oct 2008 (Year 5.5)	99.7	99.5	99.4	100.3	98.8	100.7	99.4	**99.7**	**1.5**
Mar 2009 (Year 6)	100.4	100.0	99.7	100.4	99.7	100.2	100.0	**100.1**	**1.2**
Nov 2009 (Year 6.5)	101.6	101.1	100.4	101.7	100.3	101.8	100.7	**101.2**	**1.4**
Mar 2010 (Year 7)	101.5	101.1	101.4	101.7	100.8	101.7	101.3	**101.4**	**1.3**
Nov 2010 (Year 7.5)	101.0	100.5	101.0	102.0	99.9	101.3	100.8	**100.9**	**1.5**
Nov 2011 (Year 8.5)	102.5	101.3	100.6	102.2	100.3	102.8	102.3	**102.0**	**1.8**
Oct 2012 (Year 9.5)	102.5	101.8	101.6	102.9	100.8	103.3	102.8	**102.4**	**1.7**
Oct 2013 (Year 10.5)	103.1	101.3	101.6	103.2	101.2	103.5	103.2	**102.6**	**1.9**
Oct 2014 (Year 11.5)	102.9	101.2	101.1	102.9	100.1	103.0	103.6	**102.3**	**2.0**
Oct 2015 (Year 12.5)	103.2	102.0	101.6	103.6	101.2	103.5	104.9	**103.0**	**2.2**

Table 3 summarizes the noise level reductions calculated for each of the post-overlay periods for each roadway segment. Note, a pre-overlay measurement was not taken along I-17, and therefore, post-overlay noise reductions could not be calculated along this corridor. On average, the pre-overlay level was 105.5 dBA, while the initial post-overlay average in 2004 was 97.2 dBA, which was an average reduction of 8.3 dBA. Starting in March 2007 (Year 4) and continuing through March 2009 (Year 6), an average reduction of 6.0 to 6.6 dBA was measured. From November 2009 through November 2011 (Years 6.5 to 8.5), the average reduction ranged from 4.3 to 5.2 dBA, and for the remainder of the project (Years 9.5 to 12.5), the average reduction ranged from 3.2 to 4.0 dBA.

Table 3. Reductions in OBSI Levels Produced by ARFC Through October 2015, dBA

Testing Period	SR 101, Agua Fria	SR 101, Pima	SR 101, Price	I-17	SR 51	I-10	SR 202	Average
2004 (Year 1)	8.7	7.3	10.1	N/A	7.7		9.6	**8.7**
Mar 2005 (Year 2)		6.8	10.1			8.8	9.5	**8.8**
Mar 2006 (Year 3)	6.5	5.9	8.6		6.0	7.4	8.1	**7.1**
Nov 2006 (Year 3.5)	6.3	5.4	8.2		6.2	7.4	7.3	**6.8**
Mar 2007 (Year 4)	6.3	5.4	8.1		5.7	6.9	7.2	**6.6**
Oct 2007 (Year 4.5)	5.6	5.2	8.2		6.3	6.4	7.3	**6.5**
Mar 2008 (Year 5)	5.8	5.2	8.0		5.7	6.7	7.3	**6.5**
Oct 2008 (Year 5.5)	6.0	4.9	7.9		5.7	6.4	7.4	**6.4**
Mar 2009 (Year 6)	5.3	4.4	7.6		4.8	6.9	6.8	**6.0**
Nov 2009 (Year 6.5)	4.1	3.3	6.9		4.2	5.3	6.1	**5.0**
Mar 2010 (Year 7)	4.2	3.3	5.9		3.7	5.4	5.5	**4.7**
Nov 2010 (Year 7.5)	4.7	3.9	6.3		4.6	5.8	6.0	**5.2**
Nov 2011 (Year 8.5)	3.2	3.1	6.7		4.2	4.3	4.5	**4.3**
Oct 2012 (Year 9.5)	3.2	2.6	5.7		3.7	3.9	4.1	**3.9**
Oct 2013 (Year 10.5)	2.6	3.0	5.7		3.3	3.6	3.6	**3.6**
Oct 2014 (Year 11.5)	2.8	3.1	6.2		4.4	4.1	3.2	**4.0**
Oct 2015 (Year 12.5)	2.5	2.4	5.7		3.3	3.6	1.9	**3.2**

The overall temperature-corrected noise levels summarized in Table 2 are shown graphically in Figure 7. The pre-overlay PCC OBSI levels display a significant range (of 2.9 dBA) even when averaged over corridors. As a result, the reductions produced by the overlay vary for the different corridors, as shown in Table 3. The results for the newer overlays measured along SR 101, SR 51, and SR 202 are similar to each other at the same date of testing. The variation in reduction is then seen to be due almost entirely to the noise levels of the pre-overlay PCC. The steady increase in overall OBSI levels over time reflects a reduction in performance of about 0.5 dB per year, on average. The average rate of increase for each roadway corridor varies from 0.34 dB per year on I-17 (which can be attributed mostly to the high initial post-overlay measurements) to 0.64 dB per year on SR 202. Figure 8 shows the plot of the OBSI levels for each year versus the ARFC age. For the average trend line, the coefficient of determination (R^2) is about 0.94, which demonstrates good correlation. The range of R^2 is from 0.79 along SR 51 to 0.97 along SR 202.

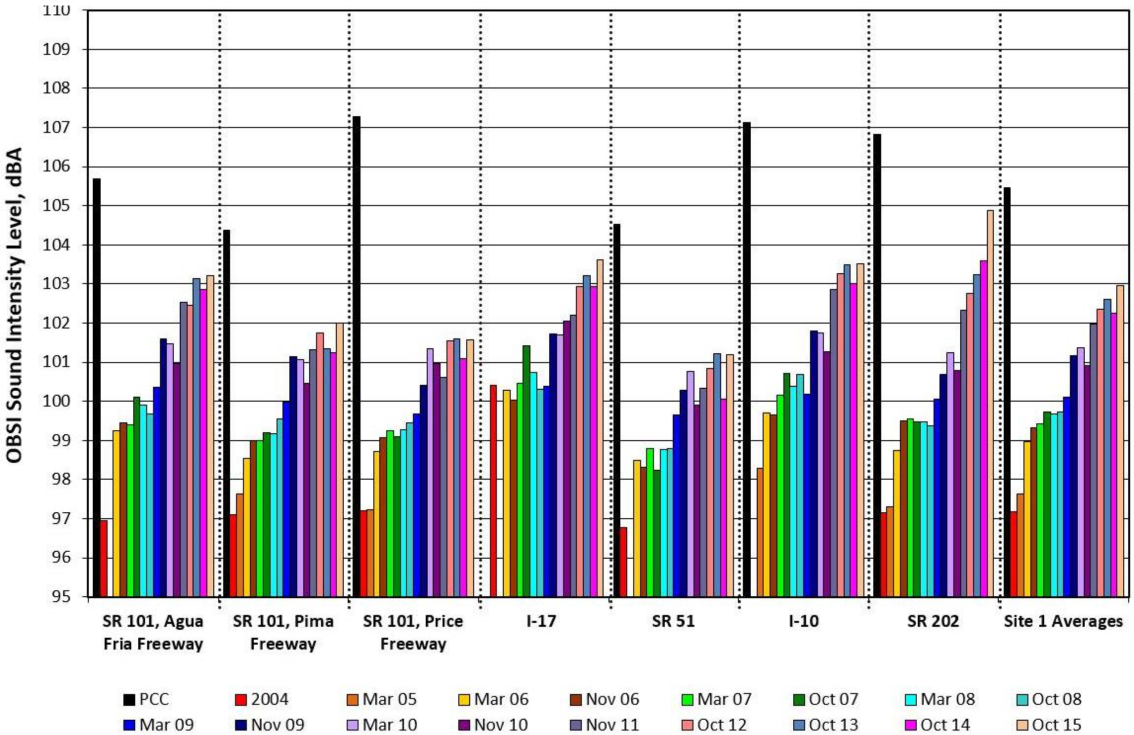

Figure 6. Milepost-Averaged OBSI Levels for Freeway Corridors Pre- and Post-ARFC Overlay

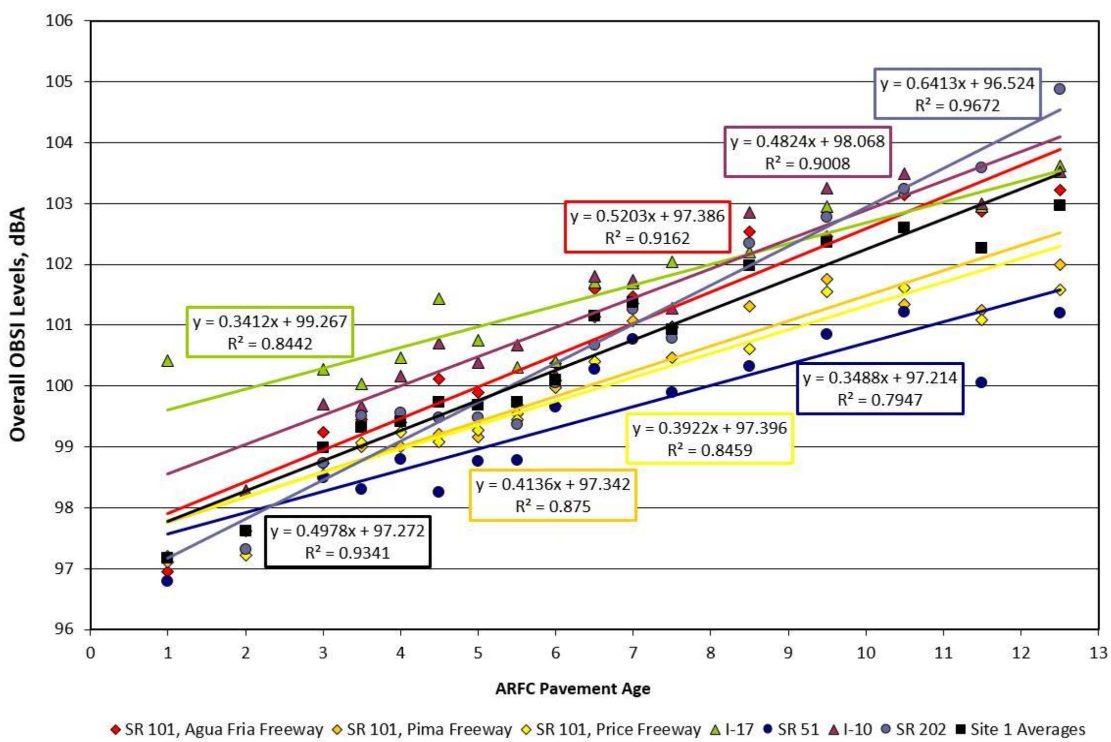

Figure 7. Overall OBSI Levels Versus Age, in Years, of ARFC Overlay

Spectral data were available for the OBSI data collected by I&R in November 2006 (Year 3.5) and from March 2008 (Year 5) to the final measurement period in October 2015. The spectra for each of these years are shown in Figure 9. The most obvious difference over time is the increase in levels at frequency bands below 1600 Hz. For frequency bands ranging from 400 to 800 Hz, noise levels measured from March 2008 (Year 5) through November 2010 (Year 7.5) were about 1 to 2 dBA higher than levels in November 2006 (Year 3.5); however, degradation occurred faster at the lower frequencies starting in November 2011 (Year 8.5). By October 2015 (Year 12.5), noise levels at frequencies from 400 to 800 Hz were approximately 5 dBA higher than the measurements from Year 3.5. This low frequency degradation indicates that the pavement was raveling. In the frequency range from 1000 to 1600 Hz, the noise levels through March 2009 (Year 6) were 1 dBA above those for Year 3.5, but starting in November 2009 (Year 6.5), noise levels in this range jumped to about 3 dBA above Year 3.5 measurements, and were 4 to 5 dBA higher than in Year 3.5 from November 2011 (Year 8.5) through October 2015 (Year 12.5). The range of levels for all measurements shown in Figure 9 in the frequency bands above 1600 Hz spans about 2 dBA, with levels even going down at the later years.

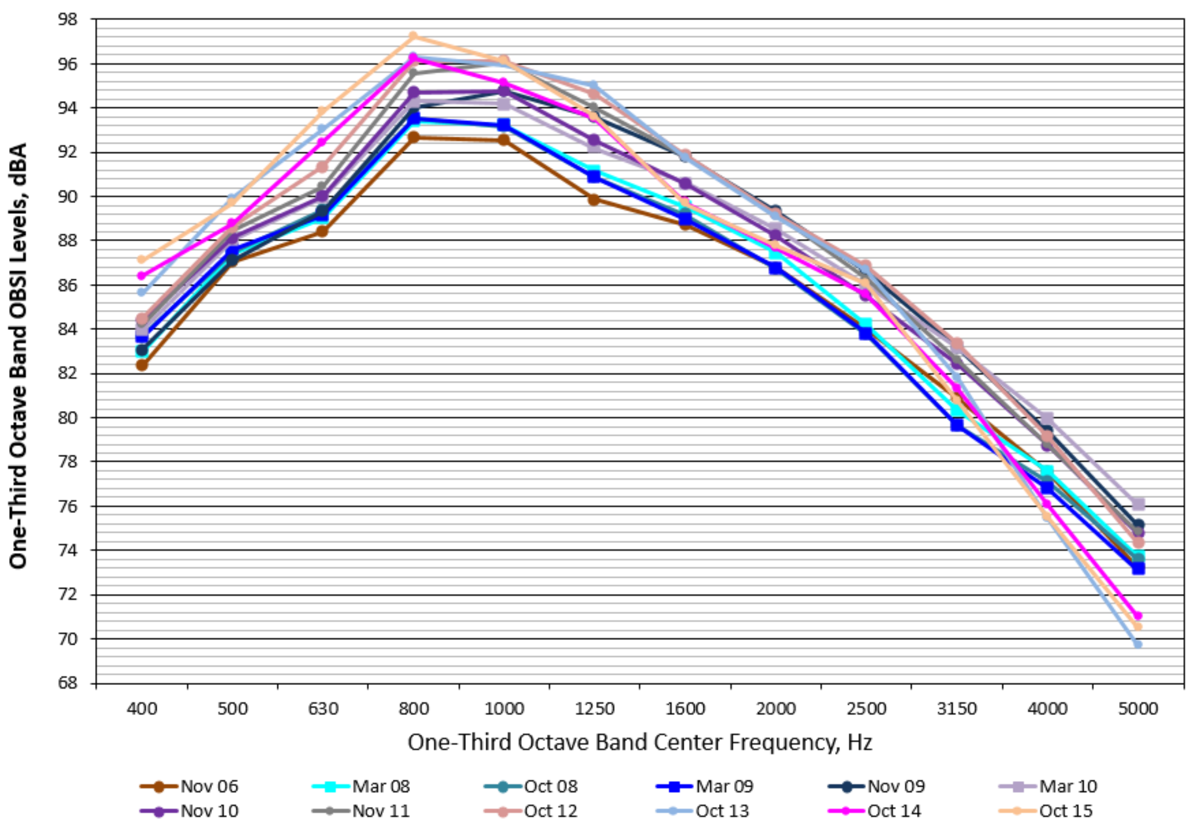

Figure 8. Average OBSI One-Third Octave Band Spectra for All Type 1 Mileposts for Post-Overlay Measurements After 3.5 Years

The overall levels shown in Figure 7, which would be dominated by noise levels in the frequency bands below 1600 Hz, indicate a 2 dBA increase from Year 1 in 2004 to Year 3.5 in November 2006; therefore, it could be assumed that levels in the lower bands of Figure 9 would be lower than the November 2006 spectra, especially at the peak levels in the 800 to 1000 Hz range, by approximately 2 dBA, and the degradation in noise levels at the peaks would be up to 6 dBA after 12.5 years.

OBSI Measurement Results at Type 3 Sites

In addition to the milepost and highway corridor OBSI measurements, single OBSI data were collected at each of the Type 3 sites. The overall OBSI levels for these locations are summarized in Table 4 and presented graphically in Figure 10. The only 2004 post-overlay OBSI measurement was taken at Site 3E, where a reduction of 8.8 dBA was measured. From March 2006 (Year 3) through March 2009 (Year 6), average noise level reductions of 7.5 to 8.2 dBA were measured. The degradation through March 2009 was less than what was observed for the average milepost OBSI data. From November 2009 (Year 6.5) through November 2011 (Year 8.5), noise level reductions ranged from 5.1 to 6.1 dBA, which indicated slightly less degradation than observed for the milepost averages. The noise level reduction measured over the last four measurement periods (Years 9.5 through 12.5) ranged from 3.9 to 4.6 dBA, which was similar to the average milepost degradation discussed above.

Sites 3A and 3E showed the lowest noise reductions in each measurement period, which may have been due to those sites having had the lowest pre-overlay PCC noise levels. Sites 3B and 3D showed the greatest initial noise reductions, which may have been due to their loud pre-overlay OBSI measurements. Over time, however, the degradation was more severe at Site 3D than at Site 3B. As will be discussed in a later subsection, prior to the ARFC application Site 3D had been paved with random transverse tined PCC while Site 3B had been paved with uniform transverse tined PCC. The noise reduction measured at each site during the later years may have been indicative of the type of pre-overlay pavement with which the site had been paved. Site 3C had been paved similarly to Site 3B, and as shown in Table 4, the degradation of noise reductions levels over time at Site 3C had less of a fall-off than at Site 3D.

OBSI levels for each of the Type 3 sites were plotted versus ARFC age to determine fall-off rates. Figure 11 shows the resulting trend lines for each site and the average for all the Type 3 locations. The fall-off rates range from 0.36 dB/year at Site 3C to 0.71 dB/year at Site 3D. The average trend line, which shows good correlation with an R^2 of 0.94, has a fall-off rate of 0.56 dB/year. This rate indicates a slightly steeper increase in OBSI level per year than is indicated by the average milepost fall-off rate, but in general, OBSI degradation averages about 0.5 dB/year.

Table 4. OBSI Levels and Noise Reductions (Δ) Measured at the Type 3 Sites, dB

Testing Period	Site 3A		Site 3B		Site 3C		Site 3D		Site 3E		Average	
	Level	Δ	Level	Δ	Level	Δ	Level	Δ	Level	Δ	Level	Δ
PCC	105.0	--	109.9	--	107.6	--	109.6	--	105.9	--	**107.6**	**--**
2004 (Year 1)	--	--	--	--	--	--	--	--	97.1	8.8	**97.1**	**8.8**
Mar 2006 (Year 3)	98.6	6.4	100.3	9.6	99.7	7.9	99.9	9.7	99.3	6.6	**99.5**	**8.1**
Nov 2006 (Year 3.5)	99.5	5.5	99.6	10.3	98.9	8.7	100.0	9.6	99.3	6.6	**99.4**	**8.2**
Mar 2007 (Year 4)	99.0	6.0	99.9	10.0	100.2	7.4	100.0	9.6	99.6	6.3	**99.8**	**7.8**
Oct 2007 (Year 4.5)	99.6	5.4	101.1	8.8	99.7	7.9	100.9	8.7	98.0	7.9	**99.9**	**7.7**
Mar 2008 (Year 5)	98.7	6.3	101.0	8.9	98.2	9.4	101.6	8.0	--	--	**99.9**	**7.7**
Oct 2008 (Year 5.5)	99.4	5.6	101.8	8.1	99.5	8.1	99.2	10.4	--	--	**100.0**	**7.6**
Mar 2009 (Year 6)	99.7	5.3	100.6	9.3	99.6	8.0	99.7	9.9	101.1	4.8	**100.1**	**7.5**
Nov 2009 (Year 6.5)	101.4	3.6	100.8	9.1	101.6	6.0	101.9	7.7	102.3	3.6	**101.6**	**6.0**
Mar 2010 (Year 7)	101.3	3.7	101.9	8.0	100.0	7.6	103.3	6.3	102.6	3.3	**101.8**	**5.8**
Nov 2010 (Year 7.5)	100.9	4.1	101.2	8.7	--	--	102.1	7.5	102.0	3.9	**101.5**	**6.1**
Nov 2011 (Yr 8.5)	102.2	2.8	102.4	7.5	101.1	6.5	103.2	6.4	103.5	2.4	**102.5**	**5.1**
Oct 2012 (Year 9.5)	101.9	3.1	103.5	6.4	102.6	5.0	104.4	5.2	102.6	3.3	**103.0**	**4.6**
Oct 2013 (Year 10.5)	102.8	2.2	103.3	6.6	101.7	5.9	104.6	5.0	103.8	2.1	**103.3**	**4.3**
Oct 2014 (Year 11.5)	102.1	2.9	--	--	--	--	104.9	4.7	--	--	**103.5**	**4.1**
Oct 2015 (Year 12.5)	103.1	1.9	104.1	5.8	102.0	5.6	106.6	3.0	102.9	3.0	**103.7**	**3.9**

Figure 12 shows one-third octave band spectra corresponding to the Type 3 locations from March 2008 (Year 5) through October 2015 (Year 12.5). Spectra for the previous years were not available for the Type 3 locations. As with the Type 1 OBSI spectra, the final three measurement periods showed levels rapidly dropping at frequencies of 3150 Hz and above. At frequencies of 800 Hz and below, the noise levels in October 2015 (Year 12.5) were about 5 to 6 dBA higher than the levels measured in March 2008 (Year 5). This degradation was about 1 dBA greater at the Type 3 locations than at the average Type 1 mileposts. In both Type 1 and Type 3 spectra after 12.5 years, the peak at 800 Hz was more predominant than in any other spectra in previous years. In fact, in the early measurement periods, the noise levels in the 800 and 1000 Hz frequency bands were relatively the same, but with age, the 800 Hz peak became more dominant.

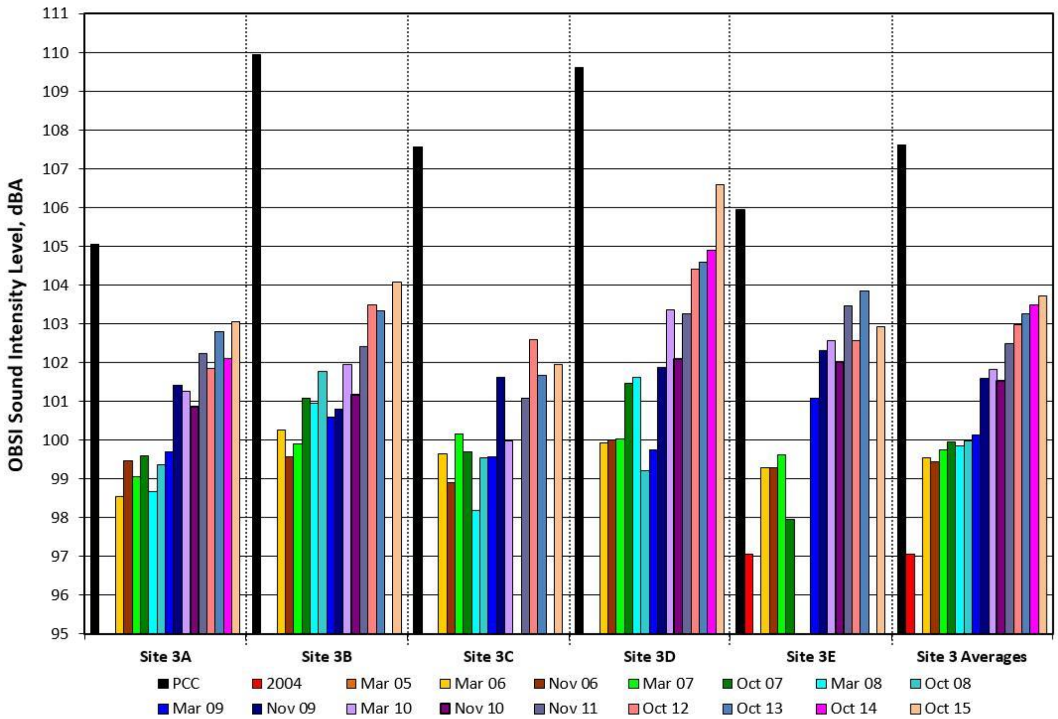

Figure 9. Overall OBSI Levels for Freeway Corridors Pre- and Post-ARFC Overlay

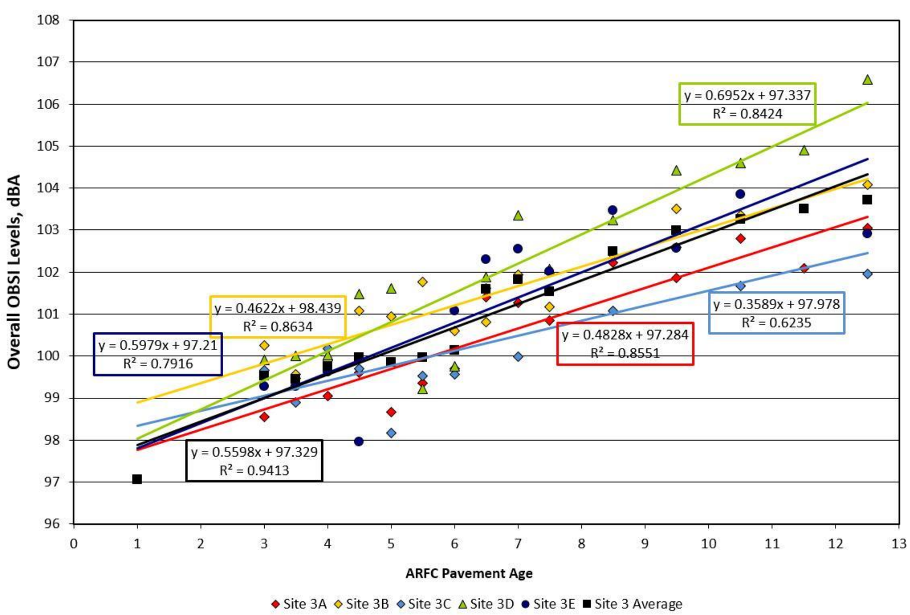

Figure 10. Overall OBSI Levels at Type 3 Sites Versus Age, in Years, of ARFC Overlay

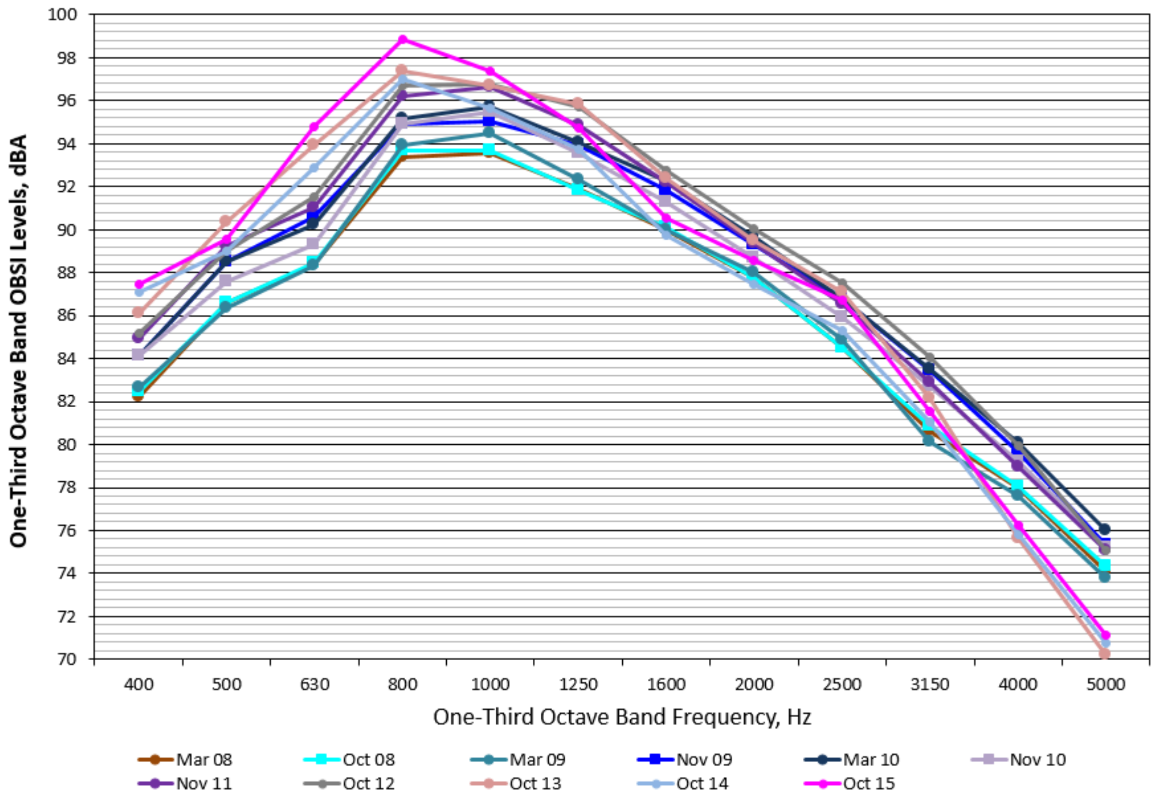

Figure 11. Average One-Third Octave Band OBSI Spectra for All Site 3 Locations for Post-Overlay Measurements After 5 Years

TYPE 2 – RESIDENTIAL NEIGHBORHOOD NOISE MEASUREMENTS

Measurement Description

Type 2 data acquisition involved collecting pre- and post-overlay and follow-up noise measurements in residential neighborhoods adjacent to the selected urban freeways. The purpose of the Type 2 study was to evaluate noise reductions in those neighborhoods that were due to the ARFC overlay. To accomplish this, measurement positions were chosen to represent typical urban subdivisions. In addition, noise measurements were collected when freeway noise was anticipated to be loudest: at Level of Service C, which is defined as maximum traffic volume traveling at posted speeds; at times of day when peak traffic volumes occur; on maximum traffic volume days (Tuesday, Wednesday, or Thursday); and during clear, calm weather conditions.

Some selected measurement positions were modeled with the FHWA-approved 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 pavement conditions. Type 2 modeling results were compared to measured noise reductions as part of the process to assess wayside noise reductions adjacent to transversely tined PCC 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 subsequent 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 Type 2 biannual noise measurements coincide with Type 1 and Type 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. This change was 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 freeway noise levels were determined for each freeway segment by continuously monitoring traffic noise levels for 24 hours, establishing peak noise levels in the morning and evening. Three 20-minute noise measurements were recorded at each neighborhood position during either the morning or the evening peak traffic noise periods. When three noise measurements differed by less than 3 dB, noise measuring was terminated, and the three measurements were averaged to provide a single noise level for the measurement position. Traffic volumes for the measurement period were determined by recording traffic on videotape, then counting vehicles by type. Traffic counts were obtained 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-overlay noise measurements using equivalent vehicle counts based on the REMELs database and vehicle definitions in FHWA-PD-96-008, DOT-VNTSC-FHWA-96-2 (Fleming et al. 1996). Comparison of the very few limited, normalized results (Donavan and Lodico 2011) to those contained in this report indicates 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. Data collected at the sites are provided in Appendix E.

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 exhibited 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.

Available Type 2 Information

Eighty-six locations were originally identified for the Type 2 measurements. In Progress Report No. 2 (Elters 2005), which provides the most complete documentation of Type 2 measurements, 88 locations were identified for pre-overlay measurements. For a variety of reasons, the post-overlay measurements and results covered a total of 78 locations. Limited documentation for 37 sites was provided in the first progress report. Neither the first (Higgins 2004) nor the second progress report provided any specific site information (e.g., distance from the freeway, location of structures, location of noise walls). However, photographs and sketches of each site were reportedly taken. Of the 78 locations, 52 were documented on aerial photographs that were available during later analysis. Investigators determined the measurement locations on these photographs by using Google Earth™. These aerial views were then used to determine approximate distances to the freeway, the location of structures and existing noise walls, and the elevation of the freeway relative to the measurement location. With the Google Street View™ tool, the sites were examined in more detail to determine the approximate height of existing noise walls, the freeway's recess or elevation, and any other site geometry nuance that might affect received noise levels.

Results

The data analysis was limited to the 52 points for which explicit site information was available. The average noise reduction for these points was 5.2 dBA, compared to 5.3 dBA for the complete 78 data points. The good correlation of these averages provided some assurance that analysis using the smaller data set was representative of the complete set. Table 5 shows the measurement points for the analysis as identified by their location number (see Appendix F), along with measurement values and noise level reductions during pre- and post-overlay testing periods.

In the QPPP correlation study (Appendix F), several parameters were examined to see whether they affected noise reductions. Among the parameters examined were the distance of the measurement from the center of the nearest through-lane of vehicle travel, barrier heights, and site geometry (i.e., recessed or elevated roadways).

As shown in Table 5, the noise reductions of the ARFC after three to four years averaged 5.1 dBA. This result demonstrates practically no degradation from the initial reductions recorded after the pre-overlay readings at the measured Type 2 locations. The noise reductions ranged from 0.1 to 9.4 dBA, with only four out of 16 total locations (25 percent) showing noise reductions of under 4.0 dBA. The standard deviation of the noise reductions measured during the post-overlay testing period was about 2.7 dBA for all 52 locations shown in Table 5; the standard deviation of the reductions measured during the follow-up period was 2.3 dBA for the 16 follow-up locations. The available pertinent data for all of the pre-overlay, post-overlay, and follow-up measurements are provided in QPPP Progress Report 3 (Donavan et al.) and the correlation study (Appendix F).

Meteorological conditions and physical characteristics of Type 2 measurement sites likely influenced the noise reductions attributed to the ARFC overlay. These site characteristics included vertical or horizontal freeway alignment changes, the presence of noise barriers and buildings, the presence of other competing noise sources such as local traffic, and ground surface composition. The effects some of these characteristics had on the noise reductions were investigated in the 2013 correlation study (Appendix F).

Table 5. Summary of Pre-Overlay, Post-Overlay, and Follow-Up Neighborhood Noise Measurements, dBA

Roadway	Site No.	Pre-Overlay L_{eq}	Post-Overlay L_{eq}	Reduction	Follow-Up L_{eq}	Reduction
SR 101, Pima	1	74.6	69.3	5.3	65.2	9.4
SR 101, Pima	2	64.3	55.7	8.6	59.4	4.9
SR 101, Pima	3	64.6	58.5	6.1		
SR 101, Pima	4	66.5	59.2	7.3		
SR 101, Pima	5	55.6	52.2	3.4	55.5	0.1
SR 101, Pima	6	59.3	56.1	3.2	57.3	2.0
SR 101, Pima	7	60.7	58.4	2.3		
SR 101, Pima	8	64.9	59.1	5.8	58.9	6.0
SR 101, Pima	9	73.1	69.6	3.5	70.3	2.8
SR 101, Pima	10	69.0	65.5	3.5		
SR 101, Pima	11	70.1	67.5	2.6		
SR 51, Piestewa	12	64.2	59.2	5.0		
SR 51, Piestewa	13	66.3	63.3	3.0		
SR 51, Piestewa	14	68.4	58.4	10.0		
SR 51, Piestewa	15	67.4	57.6	9.8		
SR 51, Piestewa	16	65.6	57.0	8.6		
SR 51, Piestewa	17	63.0	60.2	2.8		
SR 51, Piestewa	18	62.4	57.9	4.5		
SR 51, Piestewa	19	62.8	58.6	4.2		
SR 51, Piestewa	20	57.4	54.9	2.5		
SR 101, Agua	21	64.3	62.2	2.1		
SR 101, Agua	22	65.2	63.2	2.0		
SR 101, Agua	23	65.9	64.7	1.2		
SR 101, Agua	24	62.2	55.2	7.0		
SR 101, Agua	25	63.2	63.1	0.1	57.9	5.3
SR 101, Agua	26	58.5	56.7	1.8		
SR 101, Agua	27	67.7	60.6	7.1		
SR 101, Agua	28	72.4	67.2	5.2		
SR 101, Agua	29	69.6	69.1	0.5		
SR 101, Agua	30	73.9	73.0	0.9		
SR 101, Pima	31	61.9	55.8	6.1	55.1	6.8
SR 101, Pima	32	58.8	53.6	5.2	54.3	4.5
SR 101, Pima	33	64.7	58.8	5.9		
SR 101, Pima	34	64.0	58.5	5.5	57.9	6.1
SR 101, Pima	35	59.3	55.5	3.8		

Table 5 (Continued). Summary of Pre-Overlay, Post-Overlay, and Follow-Up Neighborhood Noise Measurements, dBA

Roadway	Site No.	Pre-Overlay L_{eq}	Post-Overlay L_{eq}	Reduction	Follow-Up L_{eq}	Reduction
SR 101, Pima	36	66.9	61.1	5.8		
SR 101, Pima	37	64.4	56.9	7.5		
SR 101, Pima	38	60.8	52.0	8.8		
SR 101, Price	45	63.3	59.6	3.7		
SR 101, Price	46	61.7	57.4	4.3		
SR 101, Price	47	64.1	60.4	3.7		
SR 101, Price	48	68.7	62.4	6.3	61.5	7.2
SR 101, Price	49	59.6	51.6	8.0		
SR 101, Price	50	62.1	58.0	4.1		
SR 101, Price	51	64.9	56.1	8.8		
SR 202, Red	52	63.6	56.7	6.9	61.0	2.6
SR 202, Red	53	62.8	50.5	12.3		
SR 202, Red	54	60.5	51.3	9.2		
I-10, Maricopa	56	65.7	62.0	3.7	60.7	5.0
I-10, Maricopa	58	65.8	59.9	5.9	59.1	6.7
I-10, Maricopa	59	68.7	62.5	6.2	62.8	5.9
I-10, Maricopa	60	67.8	60.5	7.3	60.9	6.9
			Average Reduction	**5.2**	**Average Reduction**	**5.1**

TYPE 3 – WAYSIDE NOISE MEASUREMENTS

Measurement Description

Field activities included the measurement of wayside traffic noise levels near the freeways, along with simultaneous measurements of traffic and meteorological conditions. Table 1 (in Chapter 2) showed the wayside measurements made during the pre-ARFC overlay and post-ARFC overlay testing periods. As noted in Chapter 2, the Type 3 measurements were made by two different research teams: Volpe and I&R. The measurement practices of both were similar; details are provided below.

Illingworth & Rodkin, Inc. Measurements

I&R began conducting pre-overlay wayside traffic noise measurements at two Type 3 locations (3A and 3D) in 2003 and at one Type 3 location (3E) in 2004. Thereafter, biannual noise measurements were made at some or all of these sites through 2010. Beginning in 2011, testing was conducted in the fall only. At each site and at each measurement position, data were collected using either a Larson Davis Model 820 Sound Level Meter™ (SLMs) or a Larson Davis Model 2900b or 3000 Real-Time Analyzer™ (RTA). Both setups were paired with 0.5-inch-diameter GRAS Model 40AQ random incidence microphones. Noise levels were stored in 5-min intervals. The interval data included equivalent sound level (L_{eq}) and median sound level (L_{50}) noise measurements. The output from either the SLM or the RTA was fed into TDC-D100 Sony Digital Audio™ Tape Recorders, Marantz Solid State Recorders Model PMD660™, or solid-state Roland R-05™ audio recorders in case any subsequent analysis would be necessary. Simultaneous spectra measurements (one-third octave band center frequency) were made for some of the intervals using the RTA devices. 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 making videotape recordings of the traffic during the noise measurements and subsequently counting vehicles by vehicle type during the corresponding 15-min intervals. Volumes from these counts were made lane-by-lane for the near lanes and overall for the far lanes. For pre-overlay counts, some vehicle volumes were determined from field counts made for all lanes each direction Traffic speeds were estimated for each vehicle type from typical passing vehicles measured with a handheld radar gun. All traffic data were broken down by five vehicle categories: light-duty vehicles, medium-duty trucks, heavy-duty trucks, buses, and motorcycles. Measurements of wind speed, wind direction and air temperature were made during noise measurements.

Although developed after the methodology of the Type 3 testing, the measurement methods follow those set forth in the AASHTO Continuous-Flow Time-Integrated Method (CTIM) Provisional Standard Method of Test (AASHTO 2011). For the Type 3 measurements, optional microphone locations located farther from the roadway were adopted, depending upon the geometry of the specific site; these locations are described in the discussion of each of the sites. To relate to historical data, a microphone also was added at a height of 5 ft above the surface of the roadway at a distance of 50 ft from the centerline of the nearest through-lane.

Volpe Center Measurements

The US Department of Transportation's Volpe Center tested Sites 3B and 3C for this study (Hastings et al. 2016). In addition to the noise measurements, other field activities for Type 3 site locations included traffic counting, traffic speed monitoring, and surveying of meteorological conditions. Volpe measurements were also made using Larson Davis Model 820 Sound Level Meters. These were equipped with either Type 4155 Brüel & Kjaer™ 0.5-inch-diameter free-field microphones or Type 4189™ 0.5-inch-diameter free field microphones. The noise was sampled in 5-min intervals and recorded 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 videotapes of each side of the highway. Counts and average speeds for each vehicle type were determined for each lane of travel in both directions. Counts were produced in 5-min intervals. The data were acquired with manual and automatic methods; the automatic system detected speeds for each vehicle and provided average results for vehicle counts, vehicle type, and speed in 5-min periods. Measurements of wind speed, wind direction and air temperature were made during noise measurements.

Traffic Noise Modeling

Both research teams performed TNM modeling and traffic normalization as well as noise measurements. Both teams used TNM Version 2.5, and both developed model geometry from site survey data provided by ADOT. It was determined that “hard soil” was the most appropriate TNM ground type to use for these sites. It was found that the predicted noise fall-off rates, which measure the decrease in noise level with increasing distance, were always less than the measured rates; however, the use of softer ground type could not be justified physically. The TNM results were used only to normalize measured traffic noise levels for variations in traffic conditions so that pre- and post-overlay measurements could be compared. As a result, it was not necessary to resolve the fall-off issues. The modeling results were also used to compare the performance of the ARFC overlay to that of the TNM average pavement. Therefore, calibrating the models was not feasible and was not an objective of the modeling process. Site-specific details of the individual TNM models are given in the description of each site.

In general, the I&R modeling was done lane-by-lane in the direction of travel for the lanes nearest the microphones and by lane average for the far lanes. For the pre-overlay measurements, the I&R modeling was done using averages in both directions of travel. This simplification was subsequently evaluated 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 lower at 100 ft, and 0.6 dB lower at 250 ft. Volpe modeling was performed lane-by-lane for both directions of travel. Volpe modeled the traffic in 5-min intervals and used these results to normalize the measured data for traffic conditions. I&R modeled on a 15-min basis and performed traffic normalization at this interval. TNM results and normalized L_{eq} were averaged over the periods of measurement to produce single-average values for each measurement event.

Test Site Description and Results of Measurements and Modeling

The Type 3 wayside measurements reflect five different measurement locations: Sites 3A, 3B, 3C, 3D, and 3E. Locations are shown in Figure 1. A description of each site follows.

Site 3A

Site Description. Site 3A is located north of SR 101 (or the Agua Fria Freeway), which primarily runs in an east-west direction, between mileposts 20 and 21. Originally, this section of SR 101 consisted of three travel lanes in each direction, with terrain features that included a roadside ditch, a two-lane frontage road (West Beardsley Road) whose edge was approximately 55 ft from the center of the SR 101 near travel lane, and a concrete channel approximately 145 ft from SR 101. Aside from West Beardsley Road and the concrete channel, the ground at the site consisted of naturally compacted earth with some limited vegetation. No permanent reflecting surfaces, such as signboards or buildings, were located at or close to the site. North of the site, the terrain was hilly, and there was an unobstructed view of the freeway in both directions for an arc of more than 150 degrees. The pre-overlay PCC at Site 3A consisted of the standard ADOT uniform transverse tine texture (Donavan 2005) with joints between slabs diagonal to the direction of travel. The overlay consisted of 1-inch-thick ARFC.

The pre-overlay surfaces at this site were measured in August 2003. In 2005, construction of new auxiliary lanes began at Site 3A. In addition to adding another lane of intermittent vehicle travel in each direction, the construction also resulted in some significant geometrical changes to the site, particularly near the 50 ft position (Donavan et al. 2009). To retain this site for future measurements, wayside noise data were collected in the spring of 2005 after the PCC pavement of the auxiliary lanes had been completed and prior to opening the auxiliary lane to traffic and the ARFC overlay. The purpose of these measurements was to isolate the acoustic effect of the new geometry. Noise measurements with the new auxiliary lanes open and the ARFC pavement overlay in place were conducted in the spring of 2006. During the early measurements, West Beardsley Road traffic was diverted so that measured levels would not be influenced by local traffic along this roadway.

Because of the additional lanes, the geometrical changes, and ongoing problems with traffic on the frontage road crossing between the microphones at 50 ft and 100 ft, testing at Site 3A was not conducted after the spring of 2006 through the spring of 2010; testing recommenced in November 2010. The roadway geometry in November 2010 was the same as in the 2006 testing period, and there were no further changes to the frontage road or the concrete channel during the testing hiatus. However, the ground surrounding the site became more overgrown with vegetation than it had been during the previous testing periods. Photos taken in August 2003, April 2005, and October 2015 are included in Appendix C to show the changes that occurred at Site 3A over time. Starting in November 2011, traffic along West Beardsley Road was not diverted during testing, and therefore noise levels measured at Site 3A from 2011 through 2015 did include the effects of traffic along the frontage roadway as well as on SR 101.

Noise Measurements. Pre-overlay measurements were conducted at Site 3A in August 2003, and the overlay was completed in September 2003. Post-overlay measurements were then performed in October 2003, September 2004, April 2005, and March 2006. Due to the site changes between September 2004 and March 2006, testing was suspended and emphasis was switched to Site 3E, the back-up site. In November 2010, measurements resumed and continued every year through 2015 (Donavan et al. 2011). The recorded environmental conditions for each measurement period are summarized in Appendix C. Wayside noise measurements during the majority of the original testing periods, as well as in the October 2015 testing period, were conducted for two continuous hours on two consecutive days; however, during the testing periods in October 2003, April 2005, November 2010, and October 2012, testing was conducted on a single day for two to four continuous hours. Four microphones were positioned as follows:

- 50 ft from the center of the near travel lane at 12 ft above the ground and the road surface (50ft/12ft)
- 50 ft from the center of the near travel lane at 5 ft above the ground and the road surface (50ft/5ft)
- 100 ft from the center of the near travel lane at 5 ft above the ground (100ft/5ft)
- 175 ft from the center of the near travel lane at 5 ft above the ground (175ft/5ft)

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. The average measured L_{eq} and the correlating average modeled L_{eq} are presented in Table 6. Table 7 summarizes the average measured L_{eq} (normalized based on the TNM traffic input) and the change in levels caused by the pavement alone. The level of noise reduction influenced by the pavement alone is calculated by subtracting the difference between the modeled and measured levels for each post-overlay measurement period from the difference between the modeled and measured levels for the pre-overlay period. This calculation accounts for any differences in noise due to differing traffic conditions as determined by TNM. Table 8 provides these differences for each post-overlay measurement period.

As Table 7 shows, the initial change in noise level after the ARFC overlay application in September 2003 was approximately 9.2 dBA at the 50ft/12ft microphone and 9.3 dBA at the 50ft/5ft microphone. After 2.5 years and prior to the lane-widening construction project in March 2005, the post-overlay noise reductions were 6.7 dBA and 6.6 dBA at the 50ft/12ft and 50ft/5ft microphones, respectively. This shows a degradation in noise reduction of at least 2.5 dBA over the 2.5 years. The 100ft/5ft microphone measurements were not collected in October 2003, immediately following the overlay application. After one year, however, the noise level reduction caused exclusively by the ARFC pavement was 5.2 dBA at the 100 ft measurement location. After 2.5 years, the pavement noise level reduction was 4.6 dBA at 100 ft, which was a degradation of less than 1 dBA. In the 3.5-year span from March 2006 to November 2010, the pavement noise level reductions worsened by 0.8 at the 100ft/5ft microphone location to 2.2 dBA at the 50ft/5ft location. This indicates that the aging ARFC overlay pavement made a fairly significant impact at 50ft/5ft location at Site 3A in that 3.5-year span. In November 2011, noise level reductions increased by 0.2 to 1.1 dBA compared to the year before. However, the frontage road traffic noise and/or the additional auxiliary lane may have influenced the November 2010 and 2011 levels. After 12 years, the reductions measured at both 50 ft locations were approximately 3 to 3.5 dBA, while the reductions measured at 100 ft was approximately 2 dBA.

Table 8 shows the difference between the measured and the modeled levels for each microphone location. One-third octave band spectra for the pre- and post-overlay conditions are shown in Figure 13 for the 50ft/5ft microphone position. Spectra for other microphone locations are provided in Appendix C. Each of the spectra shown in the figure are within 3 dBA of each other in the frequencies from 40 to 500 Hz. Between 800 and 1600 Hz, the 2004 post-overlay spectrum shows a reduction in levels that is not observed during the other later testing periods. The reduction measured in 2004 from the PCC pre-overlay spectrum ranges from about 8 to 11 dBA. The PCC pre-overlay spectrum is approximately 2 to 10 dBA higher than each of the post-overlay spectra measured after 2010 in the frequency bands from 1000 to 8000 Hz. At the 10,000-Hz band, levels measured during the pre-overlay period and the post-overlay period in 2004 show a small spike that was not measured in the post-overlay periods between 2010 and 2015.

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

Testing Period	Average Measured L_{eq}, dBA				Average Modeled L_{eq}, dBA			
	Microphone Position (Distance/Height)				Microphone Position (Distance/Height)			
	50ft/ 12ft	50ft/5ft	100ft/ 5ft	175ft/ 5ft	50ft/ 12ft	50ft/5ft	100ft/ 5ft	175ft/ 5ft
Pre-Overlay (Aug 03)	82.5	82.3	76.7	--	79.8	79.9	77.5	74.7
Post-Overlay (Oct 03)	74.6	74.2	--	--	81.1	81.1	--	--
1-Yr (Sep 04)	74.8	75.1	71.3	66.9	79.5	79.5	77.3	74.6
1.5-Yr (Apr 05)	75.1	75.0	70.4	65.1	79.2	79.2	76.9	74.1
2.5-Yr (Mar 06)	75.8	75.7	72.1	67.6	79.8	79.8	77.4	74.6
7-Yr (Nov 10)	76.9	77.2	72.1	67.0	79.2	79.2	76.7	73.9
8-Yr (Nov 11)	77.0	76.9	71.2	65.2	79.4	79.5	77.0	74.1
9-Yr (Oct 12)	77.5	77.6	72.3	66.3	79.7	79.7	77.3	74.4
Testing Period	**Average Measured L_{eq}, dBA**				**Average Measured L_{eq}, dBA**			
	Microphone Position (Distance/Height)				**Microphone Position (Distance/Height)**			
	50ft/ 12ft	**50ft/5ft**	**100ft/ 5ft**	**175ft/ 5ft**	**50ft/5ft**		**50ft/ 12ft**	**50ft/5ft**
10-Yr (Oct 13)	77.9	77.9	73.1	67.3	79.0	79.1	76.6	73.8
11-Yr (Oct 14)	78.2	77.9	73.0	66.9	79.2	79.3	76.8	73.9
12-Yr (Oct 15)	78.4	78.4	74.0	68.1	79.2	79.2	76.9	74.0

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

Testing Period	Normalized L_{eq}, dBA				Change in Level, dBA			
	Microphone Position (Distance/Height)				Microphone Position (Distance/Height)			
	50ft/ 12ft	50ft/5ft	100ft/ 5ft	175ft/ 5ft	50ft/ 12ft	50ft/5ft	100ft/ 5ft	175ft/ 5ft
Pre-Overlay (Aug 03)	82.5	82.3	76.7	--	N/A	N/A	N/A	N/A
Post-Overlay (Oct 03)	73.3	73.0	--	--	9.2	9.3	--	--
1-Yr (Sep 04)	75.1	75.5	71.5	67.1	7.4	6.8	5.2	--
1.5-Yr (Apr 05)	75.7	75.7	71.0	65.7	6.8	6.6	5.7	--
2.5-Yr (Mar 06)	75.8	75.8	72.2	67.7	6.7	6.6	4.6	--
7-Yr (Nov 10)	77.5	77.9	72.9	67.8	5.0	4.4	3.8	--
8-Yr (Nov 11)	77.3	77.3	71.8	65.8	5.2	5.0	4.9	--
9-Yr (Oct 12)	77.6	77.8	72.6	66.5	4.9	4.5	4.1	--
10-Yr (Oct 13)	78.7	78.8	74.0	68.2	3.8	3.5	2.7	--
11-Yr (Oct 14)	78.8	78.5	73.7	67.6	3.8	3.8	3.1	--
12-Yr (Oct 15)	79.0	79.1	74.6	68.7	3.5	3.2	2.2	--

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

Testing Period	Microphone Position (Distance/Height)			
	50ft/12ft, dBA	50ft/5ft, dBA	100ft/5ft, dBA	175ft/5ft, dBA
Pre-Overlay (Aug 03)	-2.7	-2.4	0.8	--
Post-Overlay (Oct 03)	6.5	6.9	--	--
1-Yr (Sep 04)	4.7	4.4	6.0	7.7
1.5-Yr (Apr 05)	4.1	4.2	6.5	9.0
2.5-Yr (Mar 06)	4.0	4.2	5.3	7.1
7-Yr (Nov 10)	2.3	2.0	4.6	6.9
8-Yr (Nov 11)	2.5	2.6	5.7	10.5
9-Yr (Oct 12)	2.2	2.1	4.9	8.2
10-Yr (Oct 13)	1.1	1.1	3.5	6.5
11-Yr (Oct 14)	1.1	1.4	3.9	7.0
12-Yr (Oct 15)	0.8	0.8	3.0	5.9

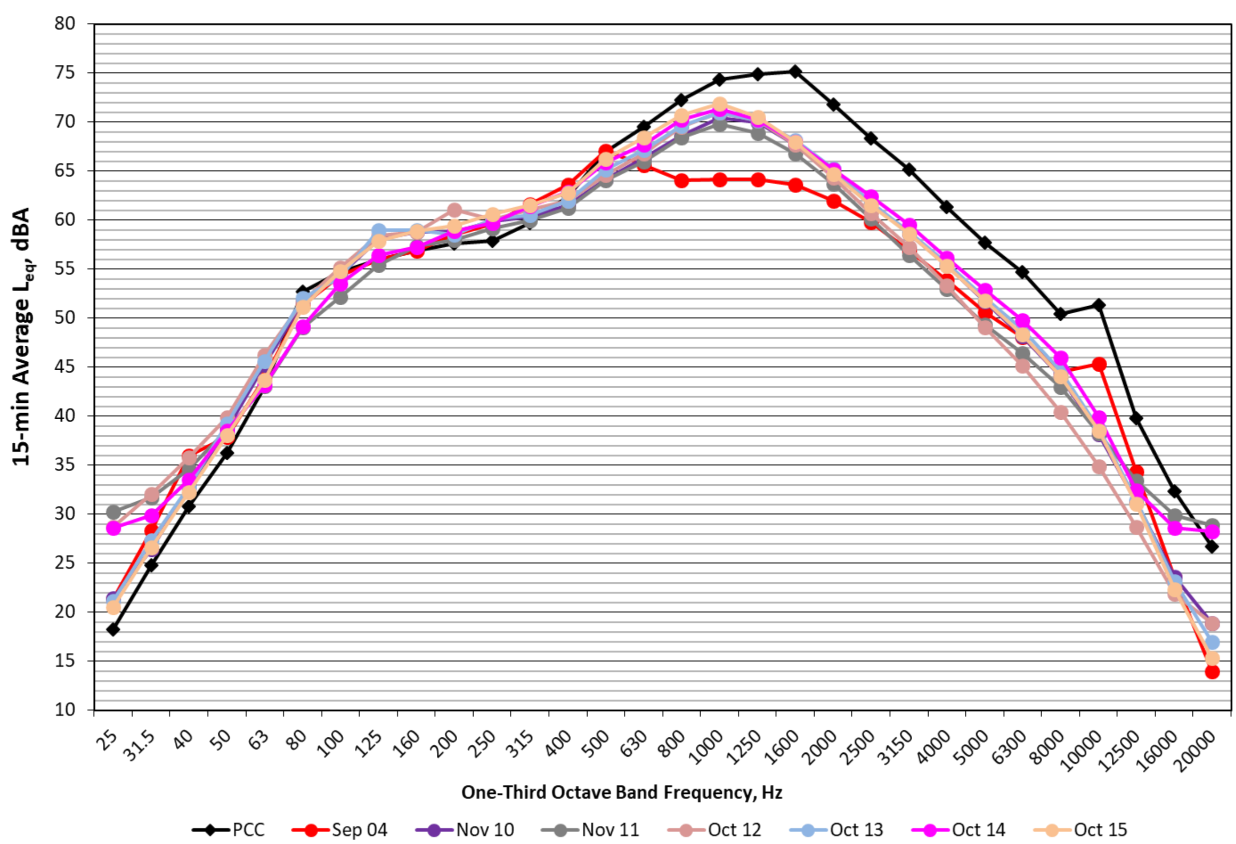

Figure 12. One-Third Octave Band Spectra for Measured Noise Levels at Site 3A at 50ft/5ft Microphone for PCC Pre-Overlay and Post-Overlay in 2004 and 2010 Through 2015

Site 3B

Site Description. Site 3B is located west of SR 101 (or the Agua Fria Freeway), which primarily runs in a north-south direction, between mileposts 8 and 9. This site is adjacent to and includes the Sun Valley Elementary School. Originally, this section of SR 101 consisted of three travel lanes in each direction. The ground at the site consisted of hard-packed dirt in the right-of-way and mowed lawn within the school property. The one-story elementary school was relatively close to the wayside measurement locations but would have resulted in minimal reflecting surfaces. Billboards and other permanent reflecting surfaces were not located at or close to the site during early testing periods. The terrain was relatively flat in the area surrounding Site 3B, and in the early testing periods, there was an unobstructed view of the freeway in both directions for more than an arc of 150 degrees. The pre-overlay PCC at Site 3B consisted of the standard ADOT uniform transverse tine texture (Donavan 2005). The entire length of roadway near the site did not include expansion joints, which was unusual. The overlay consisted of 1-inch-thick ARFC.

The pre-overlay surfaces at this site were measured in June 2004, and the overlay was installed in June 2005. Initial post-overlay measurements were made in August 2005. Starting in 2011, roadway construction altered the characteristics of the site. A fourth travel lane was constructed along SR 101, as was a roadside sound wall. While the distant measurement was still collected from behind the sound wall, the 50-ft measurement was moved to an alternate location. This alternate site (Site 3B alt) had pavement of the same construction and age as the original Site 3B. Site 3B alt was located north of Site 3B, between mileposts 10 and 11, on the southbound side of SR 101. Photos taken in June 2004 and August 2005 are shown in Appendix C to represent the site before and after overlay application.

Noise Measurements. Pre-overlay measurements were conducted at Site 3B in June 2004. The overlay was completed in June 2005. Post-overlay measurements were conducted in August 2005, June 2006, October 2007, June 2008, June 2011, June 2013, and June 2015. Prior to roadway construction in 2010, traffic noise measurements were made at three microphone positions in a line normal to the westbound SR 101 travel lanes. Following the site alterations, the 50 ft measurement position was relocated to the Site 3B alt location, the 95 ft position was not measured, and the 246 ft position was measured from behind the newly-erected barrier. The environmental conditions are summarized for each measurement period in Appendix C. The three microphones were positioned as follows:

- 50 ft from the center of the near travel lane at 10 ft above the ground and 5 ft above the roadway elevation (50ft/5ft)
- 95 ft from the center of the near travel lane at 5 ft above the ground (95ft/5ft)
- 246 ft from the center of the near travel lane at 5 ft above the ground (246ft/5ft)

Following the site alterations, the 50-ft measurement position was relocated to the Site 3B alt location, the 95-ft position was not measured, and the 246-ft position was measured from behind the newly erected barrier. The environmental conditions are summarized for each measurement period in Appendix C.

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. Table 9 presents a comparison of the average measured and modeled L_{eq} for each measurement position. Table 10 shows the L_{eq} normalized for the traffic and the reductions in normalized noise levels between the pre-overlay PCC and the post-overlay ARFC. Table 11 shows the differences between measured noise levels and modeled noise levels. Normalized one-third octave band spectra for the pre-overlay condition and post-overlay conditions from each measurement period are shown in Figure 14 for the 50ft/5ft microphone position. Spectra for other microphone locations are provided in Appendix C.

Results in Table 10 show a substantial decrease in sound level upon application of the ARFC overlay on the transversely tined PCC (about 7 to 9 dBA at all measurement locations). As the pavement aged over the initial 3-year period, the noise benefit deteriorated (with the reduction from the pre-overlay noise levels ranging from 6 to 7 dBA at each location). This was followed by a period of little to no deterioration over the remaining monitoring period (a reduction of about 5.5 to 6.5 dBA, not including the distant measurement location behind the barrier). It should be noted that factors other than the influence of pavement (e.g., shielding and reflections) can noticeably affect sound levels at receivers beyond 50 ft.

When the spectra for the transversely tined PCC and the ARFC were compared, there was a noticeable difference from 630 Hz and up, with some very small effects down to 200 Hz. The largest effect from the pavement was seen in the frequency range of 630 to 2000 Hz, an important range for reducing the overall A-weighted sound level and speech interference. After a year, the sound levels in that range started to increase over time up to Year 3, similar to the overall A-weighted results. Between Years 6 and 10, only small increases in sound level occurred in this frequency range. Above 5000 Hz, there were small decreases in sound level over time. At farther distances, which are shown in Appendix C, the overall effect from the pavement was less, since noise levels measured at those distances were dominated by lower-frequency noise, and low frequencies are not greatly affected by pavement type.

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

Testing Period	Average Measured L_{eq}, dBA			Average Modeled L_{eq}, dBA		
	Microphone Position (Distance/Height)			Microphone Position (Distance/Height)		
	50ft/5ft	95ft/ 5ft	246ft/ 5ft	50ft/5ft	95ft/ 5ft	246ft/ 5ft
Pre-Overlay (Jun 04)	82.9	77.0	70.3	79.4	76.1	71.3
Post-Overlay (Aug 05)	74.1	70.2	62.0	80.1	76.8	72.1
1-Yr (Jun 06)	74.9	70.7	63.6	79.8	76.6	71.8
2.5-Yr (Oct 07)	75.9	71.5	64.3	79.5	76.3	71.8
3-Yr (Jun 08)	75.6	70.8	63.4	79.4	76.1	71.6
6-Yr (Jun 11)	74.6[a]	--	63.6	78.1	--	70.6
8-Yr (Jun 13)	74.6[a]	--	58.0[b]	78.4	--	69.6
10-Yr (Jun 15)	74.3[a]	--	60.0[b]	78.4	--	70.0

[a] Measured from the Site 3B alt location.
[b] Measured behind a newly erected noise barrier.

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

Testing Period	Normalized L_{eq}, dBA			Change in Level, dBA		
	Microphone Position (Distance/Height)			Microphone Position (Distance/Height)		
	50ft/5ft	95ft/ 5ft	246ft/ 5ft	50ft/5ft	95ft/ 5ft	246ft/ 5ft
Pre-Overlay (Jun 04)	82.8	77.1	70.3	N/A	N/A	N/A
Post-Overlay (Aug 05)	73.6	69.8	61.4	9.2	7.3	8.9
1-Yr (Jun 06)	74.6	70.5	63.2	8.2	6.6	7.0
2.5-Yr (Oct 07)	75.9	71.5	65.0	6.9	5.5	5.2
3-Yr (Jun 08)	75.7	71.0	63.3	7.1	6.1	6.9
6-Yr (Jun 11)	76.6[a]	--	64.8	6.2[a]	--	5.4
8-Yr (Jun 13)	76.4[a]	--	60.6[b]	6.4[a]	--	9.7[b]
10-Yr (Jun 15)	76.0[a]	--	62.1[b]	6.8[a]	--	8.2[b]

[a] Measured from the Site 3B alt location.
[b] Measured behind a newly erected noise barrier.

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

Testing Period	Microphone Position (Distance/Height)		
	50ft/5ft, dBA	95ft/5ft, dBA	246ft/5ft, dBA
Pre-Overlay (Jun 04)	-3.5	-0.9	1.0
Post-Overlay (Aug 05)	6.0	6.6	10.1
1-Yr (Jun 06)	4.9	5.9	8.2
2.5-Yr (Oct 07)	3.6	4.8	7.5
3-Yr (Jun 08)	3.7	5.3	8.2
6-Yr (Jun 11)	3.5[a]	--	7.0
8-Yr (Jun 13)	3.8[a]	--	11.6[b]
10-Yr (Jun 15)	4.1[a]	--	10.0[b]

[a] Measured from the Site 3B alt location.

[b] Measured behind a newly erected noise barrier.

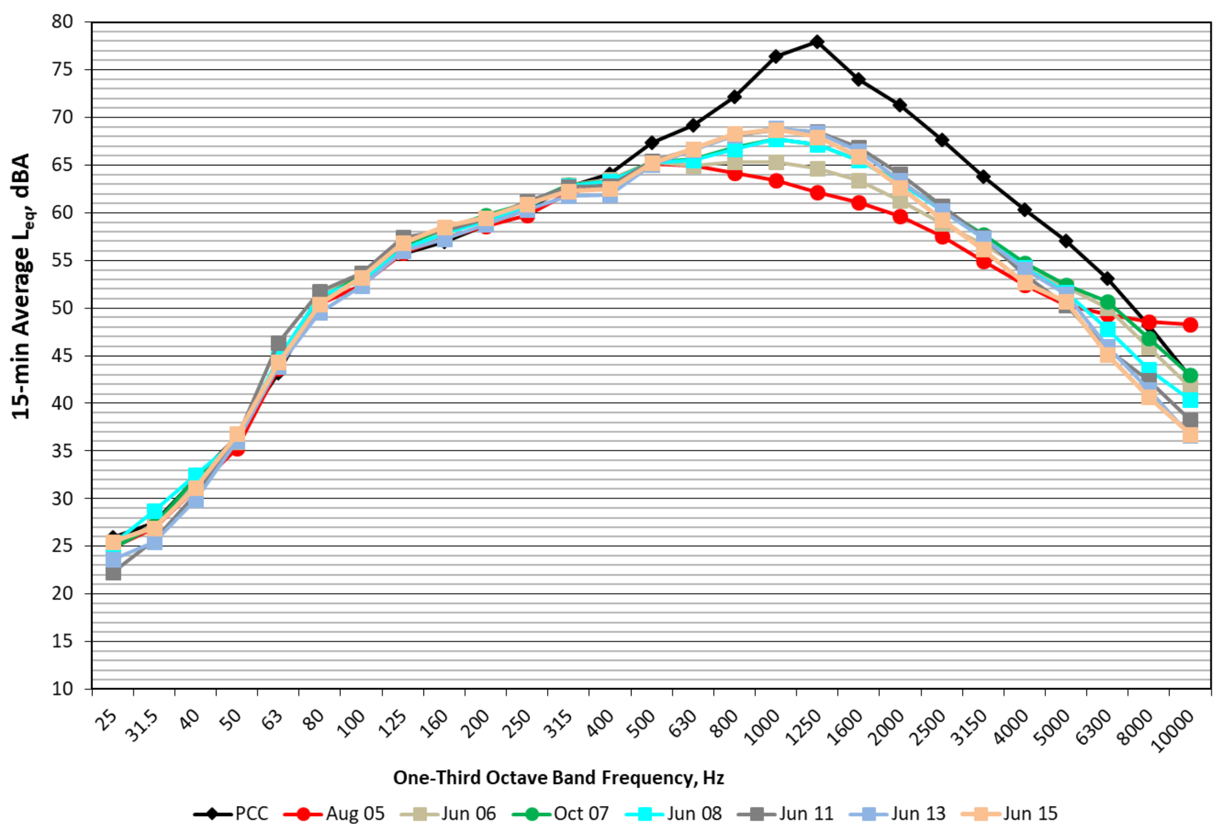

Figure 13. One-Third Octave Band Spectra for Measured Noise Levels at Site 3B at 50ft/5ft Microphone for PCC Pre-Overlay and Post-Overlay in 2005 Through 2015

Site 3C

Site Description. Site 3C is located on I-10 between mileposts 159 and 160 on the eastbound side adjacent to and including Mountain Vista Park. At this location, I-10 consists of four through-travel lanes in both the eastbound and the westbound directions, with an exit lane in the eastbound direction. At the 50-ft measurement location, an unobstructed view of the freeway was obtained in both directions for more than an arc of 150 degrees. There is an existing noise barrier north of that microphone location (see Appendix C) that does have some effect on the distant microphone location. There were no apparent noise sources in the measurement area. At the wayside, the ground consisted of gravel in the right of way and mowed lawn and sand within the park grounds. The pre-overlay PCC at Site 3C consisted of the standard ADOT uniform transverse tine texture (Donavan 2005) and contained joints between the dowelled slabs that were perpendicular to the direction of travel. The overlay consisted of 1-inch-thick ARFC.

The pre-overlay surfaces at this site were measured in June 2004, and the overlay was installed in March/April 2005. Initial post-overlay measurements were made in June 2005. Appendix C shows photos taken in June 2004 and June 2005 to represent before- and after-overlay applications.

Noise Measurements. Besides June 2005, post-overlay measurements were made in June 2006, June 2008, June 2011, June 2013, and June 2015. The environmental conditions are summarized for each measurement period in Appendix C. The two microphones were positioned as follows:

- 50 ft from the center of the near travel lane at 9.5 ft above the ground and 5 ft above the roadway elevation (50ft/5ft)
- 141 ft from the center of the near travel lane at 5 ft above the ground (141ft/5ft)

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. Table 12 presents a comparison of the average measured and modeled L_{eq} for each microphone location. Table 13 shows the normalized L_{eq} and the reduction in normalized noise levels between the pre-overlay PCC and the post-overlay ARFC, and Table 14 shows the differences between normalized and modeled noise levels. One-third octave band spectra normalized for traffic conditions for the pre- and post-overlay conditions are shown in Figure 15 for the 50ft/5ft microphone position. Spectra for other microphone locations are provided in Appendix C.

As Table 13 shows, the initial noise reduction due to the ARFC application was 8.8 dBA at the 50-ft location and 6.6 dBA at the distant 141-ft location. Through Year 3, the measured noise reduction was about 7.6 dBA at 50 ft and about 5.7 dBA at 141 ft. However, from Years 3 to 6, there was substantial degradation. The measured noise reduction in Year 6 was 5.6 dBA at 50 ft and 4.6 dBA at 141 ft. By Year 10, the measured noise reduction from the pre-overlay PCC was 6.3 dBA at 50 ft and 5.9 dBA at 141 ft.

The spectra at Site 3C show behavior similar to that of the spectra at Site 3B. At both sites, the largest effect from the pavement was seen in the frequency range of 630 to 2000 Hz. At Site 3C, the initial reduction at these frequency bands ranged from about 9 to 16 dBA in 2005. By Year 3, the reduction from PCC in this range was about 8 to 10 dBA, and after 10 years, the reduction was about 6 to 9 dBA. Above 5000 Hz, there were small decreases in sound level over time.

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

Testing Period	Average Measured L_{eq}, dBA		Average Modeled L_{eq}, dBA	
	Microphone Position (Distance/Height)		Microphone Position (Distance/Height)	
	50ft/5ft	141ft/5ft	50ft/5ft	141ft/5ft
Pre-Overlay (Jun 04)	82.9	72.4	79.8	74.8
Post-Overlay (Jun 05)	75.2	66.9	80.9	75.9
1-Yr (Jun 06)	75.3	67.3	80.1	75.1
3-Yr (Jun 08)	75.7	66.7	80.0	74.9
6-Yr (Jun 11)	76.3	67.0	78.7	73.7
8-Yr (Jun 13)	76.8	67.6	80.2	75.0
10-Yr (Jun 15)	77.2	67.4	80.4	75.5

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

Testing Period	Normalized L_{eq}, dBA		Change in Level, dBA	
	Microphone Position (Distance/Height)		Microphone Position (Distance/Height)	
	50ft/5ft	141ft/5ft	50ft/5ft	141ft/5ft
Pre-Overlay (Jun 04)	83.2	72.6	N/A	N/A
Post-Overlay (Jun 05)	74.4	66.0	8.8	6.6
1-Yr (Jun 06)	75.2	67.0	8.1	5.6
3-Yr (Jun 08)	75.7	66.6	7.6	5.7
6-Yr (Jun 11)	77.7	68.0	5.6	4.6
8-Yr (Jun 13)	76.7	67.5	6.5	5.1
10-Yr (Jun 15)	76.9	66.7	6.3	5.9

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

Testing Period	Microphone Position (Distance/Height)	
	50ft/5ft, dBA	141ft/5ft, dBA
Pre-Overlay (Jun 04)	-3.1	2.4
Post-Overlay (Jun 05)	5.7	9.0
1-Yr (Jun 06)	4.8	7.8
3-Yr (Jun 08)	4.3	8.1
6-Yr (Jun 11)	2.4	6.8
8-Yr (Jun 13)	3.4	7.4
10-Yr (Jun 15)	3.2	8.1

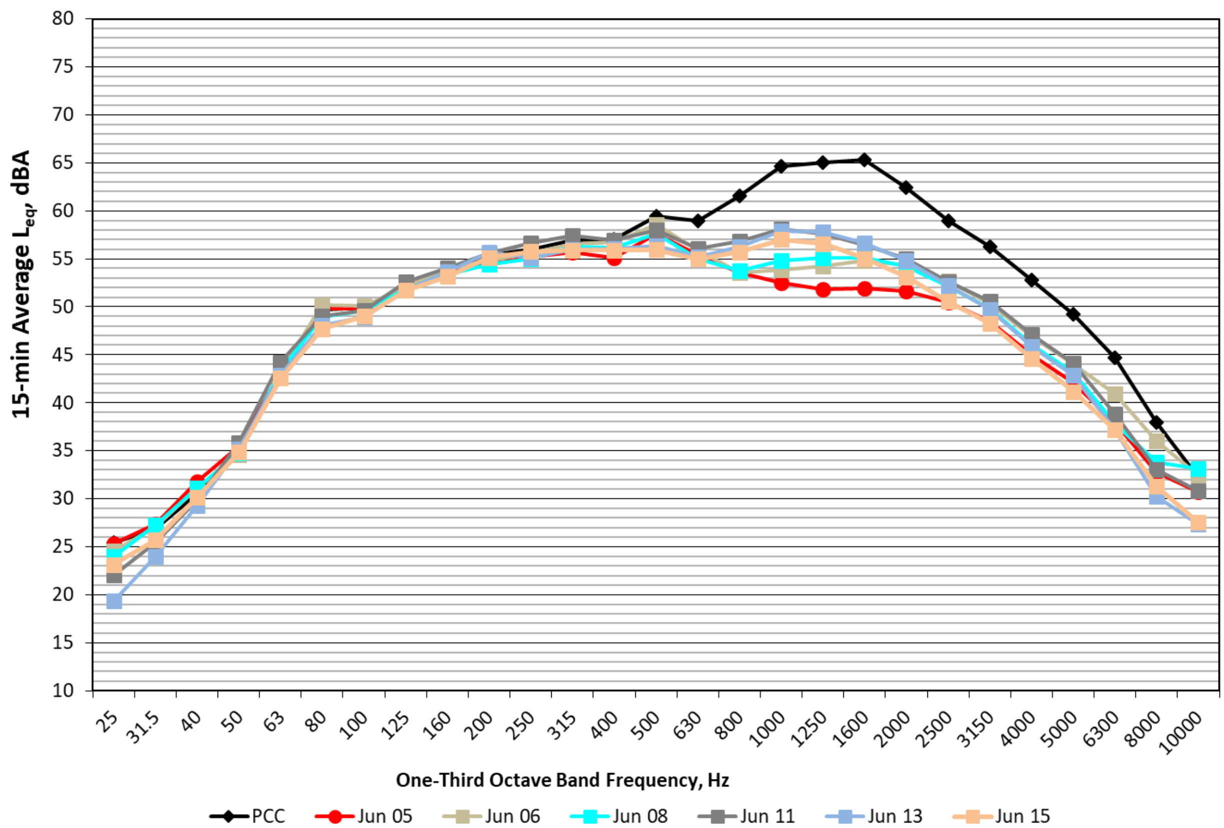

Figure 14. One-Third Octave Band Spectra for Measured Noise Levels at Site 3C at 50ft/5ft Microphone for PCC Pre-Overlay and Post-Overlays in 2005 Through 2015

Site 3D

Site Description. Site 3D is located along the north side of SR 202 between the exits for East McDowell Road (exit 18) and North Val Vista Drive (exit 19). At this location, SR 202 consists of three travel lanes in both the westbound and the eastbound directions. The westbound entrance ramp from North Val Vista Drive begins to merge with the near travel lane at Site 3D, causing the near lane to be twice as wide as a typical lane (i.e., approximately 24 ft wide). The surrounding terrain is relatively flat and consists of naturally compacted earth with minimal vegetation. The site is free of any permanent, large reflecting surfaces, such as signboards, buildings, and hillsides, and provides an unobstructed view of the freeway in both directions for more than a 150-degree arc at each microphone position.

Photographs showing Site 3D as it existed during the October 2003, October 2004, and (final) October 2014 testing periods can be found in Appendix C. There were no apparent noise sources in the measurement area other than the occasional aircraft overhead. As of the fall of 2015, SR 202 construction was underway to widen the freeway. Because of construction activity at and near Site 3D, measurements at the site were not feasible, and data was collected only through the fall of 2014.

The pre-overlay PCC pavement at Site 3D was random transverse tined PCC and contained joints between slabs diagonal to the direction of travel. This site had been the location of experimental textures applied in previous research projects (Donavan et al. 2011), which is why the pre-overlay pavement differed from the ADOT standard. The overlay consisted of 1-inch-thick ARFC.

Noise Measurements. Pre-overlay testing was conducted in October 2003. The overlay was applied in March 2004 and was followed up with post-overlay testing in October 2004, March and October 2005, March and November 2006, March and October 2007, March and October 2008, March and November 2009, March and November 2010, November 2011, October 2012, November 2013, and October 2014. The data through October 2007 were presented in Progress Report 3 (Donavan et al. 2009), and data from March 2008 through November 2010 were reported in Progress Report 4 (Donavan et al. 2011). Subsequent technical memorandum reports discussed the data through 2014. The environmental conditions for each testing period through October 2014 are shown in Appendix C. The wayside noise measurements were conducted for two continuous hours on two days. Four microphones were positioned as follows:

- 50 ft from the center of the near travel lane at 12 ft above the ground and roadway (50ft/12ft)
- 50 ft from the center of the near travel lane at 5 ft above the ground and roadway (50ft/5ft)
- 100 ft from the center of the near travel lane at 5 ft above the ground (100ft/5ft)
- 250 ft from the center of the near travel lane at 5 ft above the ground (250ft/5ft)

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. Table 15 presents the average measured L_{eq} and the correlating average modeled L_{eq}. The modeled results in Table 15 are different from those reported previously (Donavan et al. 2009, 2011). The original land survey of Site 3D, upon which the previous model had been based, did not accurately portray the testing site, so an updated model was developed. Table 16 summarizes the normalized L_{eq}

and the change in the average measured L_{eq} due to the pavement alone. Table 17 presents the calculated differences between the measured and modeled L_{eq} results. Figure 16 shows, for the 50ft/5ft microphone position, the one-third octave band spectra for pre-and post-overlay conditions. Spectra for other microphone locations are provided in Appendix C.

Table 14. Comparison of Average Measured and Modeled Site 3D Wayside Traffic Noise Levels

Testing Period	Average Measured L_{eq}, dBA Microphone Position (Distance/Height)				Average Modeled L_{eq}, dBA Microphone Position (Distance/Height)			
	50ft/12ft	50ft/5ft	100ft/5ft	250ft/5ft	50ft/12ft	50ft/5ft	100ft/5ft	250ft/5ft
Pre-Overlay (Oct 03)	84.3	83.2	76.8	68.9	76.1	76.2	73.3	68.3
0.5-Yr (Oct 04)	70.9	70.9	65.6	59.7	75.2	75.2	72.4	67.4
1-Yr (Mar 05)	72.2	72.0	67.5	61.4	75.3	75.5	72.7	67.5
1.5-Yr (Oct 05)	73.3	73.4	67.4	61.6	75.2	75.3	72.4	67.3
2-Yr (Mar 06)	73.3	72.8	65.8	60.4	76.2	76.4	73.6	68.4
2.5-Yr (Nov 06)	74.9	75.2	66.8	60.1	76.5	76.6	73.8	68.8
3-Yr (Mar 07)	74.2	74.2	66.6	60.4	76.3	76.4	73.7	68.6
3.5-Yr (Oct 07)	74.5	74.2	66.8	60.3	76.0	76.1	73.2	68.2
4-Yr (Mar 08)	75.2	75.1	67.4	61.1	76.6	76.7	73.8	68.9
4.5-Yr (Oct 08)	74.9	74.7	67.0	60.3	76.1	76.2	73.3	68.3
5-Yr (Mar 09)	75.5	75.4	67.2	60.1	76.6	76.7	74.0	68.9
5.5-Yr (Nov 09)	75.5	75.2	67.5	60.1	75.7	75.8	73.0	67.9
6-Yr (Mar 10)	75.7	75.3	67.9	60.3	76.3	76.4	73.5	68.4
6.5-Yr (Nov 10)	75.0	75.2	67.9	60.1	75.8	75.9	73.1	67.9
7.5-Yr (Nov 11)	75.5	74.2	68.6	60.8	75.5	75.7	72.8	67.8
8.5-Yr (Oct 12)	75.6	75.5	69.2	61.3	75.3	75.4	72.6	67.5
9.5-Yr (Nov 13)	77.0	76.6	69.6	60.7	74.9	75.0	72.2	67.1
10.5-Yr (Oct 14)	77.2	77.8	70.5	61.6	76.1	75.6	73.4	68.3

As Table 16 shows, the ARFC overlay provided a noise improvement of approximately 11.4 to 12.4 dBA at the 50-ft microphones, 10.2 dBA at 100 ft, and 8.2 dBA at 250 ft. For October 2014, the noise level reductions from pre-overlay conditions were 7.0 dBA at the 50ft/12ft microphone, 4.8 dBA at 50ft/5ft, 6.3 dBA at 100ft/5ft, and 7.3 dBA at 250ft/5ft. Therefore, aging effects after 10 years produced a degradation of approximately 5.4 to 6.6 dBA at 50 ft, 3.9 dBA at 100 ft, and 0.9 dBA at 250 ft. While degradation occurred nearly every year, after Year 8, it amounted to approximately 0.4 dBA per year on average.

As Table 17 shows, the modeled results from the pre-overlay testing period were significantly lower than the measured levels. These predictions, which were lower than the measured levels by as much as 8.2 dBA, are in contrast to the differences between the model predictions and measured levels at Sites 3A and 3E. In the pre-overlay testing period for Sites 3A and 3E, the predicted levels were up to approximately 2.7 and 4.0 dBA, respectively, lower than the measured levels. The great contrast at Site 3D between measured and modeled results may indicate the effect of pavement characteristics, since Site 3D had a different PCC base pavement than the other two sites.

Table 15. Normalized L_{eq} and Reduction of Normalized L_{eq} for Site 3D Traffic Noise Levels Between Pre-Overlay PCC and Post-Overlay ARFC

Testing Period	Normalized L_{eq}, dBA				Change in Level, dBA			
	Microphone Position (Distance/Height)				Microphone Position (Distance/Height)			
	50ft/12ft	50ft/5ft	100ft/5ft	250ft/5ft	50ft/12ft	50ft/5ft	100ft/5ft	250ft/5ft
Pre-Overlay (Oct 03)	84.3	83.2	76.8	68.9	N/A	N/A	N/A	N/A
0.5-Yr (Oct 04)	71.9	71.8	66.6	60.7	12.4	11.4	10.2	8.2
1-Yr (Mar 05)	73.0	72.7	68.2	62.2	11.3	10.5	8.6	6.7
1.5-Yr (Oct 05)	74.2	74.3	68.3	62.6	10.0	8.8	8.5	6.3
2-Yr (Mar 06)	73.2	72.6	65.6	60.3	11.1	10.6	11.2	8.6
2.5-Yr (Nov 06)	74.5	74.7	66.4	59.6	9.7	8.4	10.4	9.3
3-Yr (Mar 07)	74.1	74.1	66.2	60.1	10.2	9.1	10.6	8.8
3.5-Yr (Oct 07)	74.6	74.3	67.0	60.5	9.6	8.8	9.8	8.4
4-Yr (Mar 08)	74.7	74.6	67.0	60.6	9.6	8.6	9.8	8.4
4.5-Yr (Oct 08)	74.9	74.7	67.1	60.3	9.4	8.5	9.7	8.6
5-Yr (Mar 09)	75.0	74.8	66.5	59.5	9.3	8.3	10.3	9.4

Table 16 (Continued). Normalized L_{eq} and Reduction of Normalized L_{eq} for Site 3D Traffic Noise Levels Between Pre-Overlay PCC and Post-Overlay ARFC

Testing Period	Normalized L_{eq}, dBA				Change in Level, dBA			
	Microphone Position (Distance/Height)				Microphone Position (Distance/Height)			
	50ft/12ft	50ft/5ft	100ft/5ft	250ft/5ft	50ft/12ft	50ft/5ft	100ft/5ft	250ft/5ft
5.5-Yr (Nov 09)	75.9	75.6	67.9	60.5	8.4	7.6	8.9	8.4
6-Yr (Mar 10)	75.6	75.1	67.7	60.2	8.7	8.1	9.1	8.7
6.5-Yr (Nov 10)	75.4	75.5	68.1	60.5	8.9	7.6	8.7	8.5
7.5-Yr (Nov 11)	76.1	74.7	69.1	61.3	8.2	8.4	7.7	7.6
8.5-Yr (Oct 12)	76.4	76.3	69.9	62.1	7.9	6.9	6.9	6.8
9.5-Yr (Nov 13)	78.3	77.8	70.8	62.0	6.0	5.4	6.0	7.0
10.5-Yr (Oct 14)	77.2	78.4	70.5	61.6	7.0	4.8	6.3	7.3

Table 16. Difference Between Site 3D Measured and Modeled Noise Levels

Testing Period	Microphone Position (Distance/Height)			
	50ft/12ft, dBA	50ft/5ft, dBA	100ft/5ft, dBA	250ft/5ft, dBA
Pre-Overlay (Oct 03)	-8.2	-7.0	-3.5	-0.6
0.5-Yr (Oct 04)	4.3	4.3	6.7	7.7
1-Yr (Mar 05)	3.2	3.5	5.2	6.1
1.5-Yr (Oct 05)	1.9	1.9	5.1	5.7
2-Yr (Mar 06)	2.9	3.6	7.8	8.0
2.5-Yr (Nov 06)	1.6	1.4	7.0	8.7
3-Yr (Mar 07)	2.0	2.1	7.1	8.2
3.5-Yr (Oct 07)	1.5	1.8	6.4	7.8
4-Yr (Mar 08)	1.5	1.6	6.4	7.7
4.5-Yr (Oct 08)	1.3	1.5	6.3	8.0
5-Yr (Mar 09)	1.1	1.3	6.8	8.8
5.5-Yr (Nov 09)	0.2	0.6	5.5	7.8
6-Yr (Mar 10)	0.5	1.1	5.6	8.1
6.5-Yr (Nov 10)	0.8	0.6	5.2	7.9
7.5-Yr (Nov 11)	0.0	1.4	4.2	7.0
8.5-Yr (Oct 12)	-0.3	-0.1	3.4	6.2
9.5-Yr (Nov 13)	-2.2	-1.6	2.5	6.3
10.5-Yr (Oct 14)	-1.1	-2.2	2.9	6.7

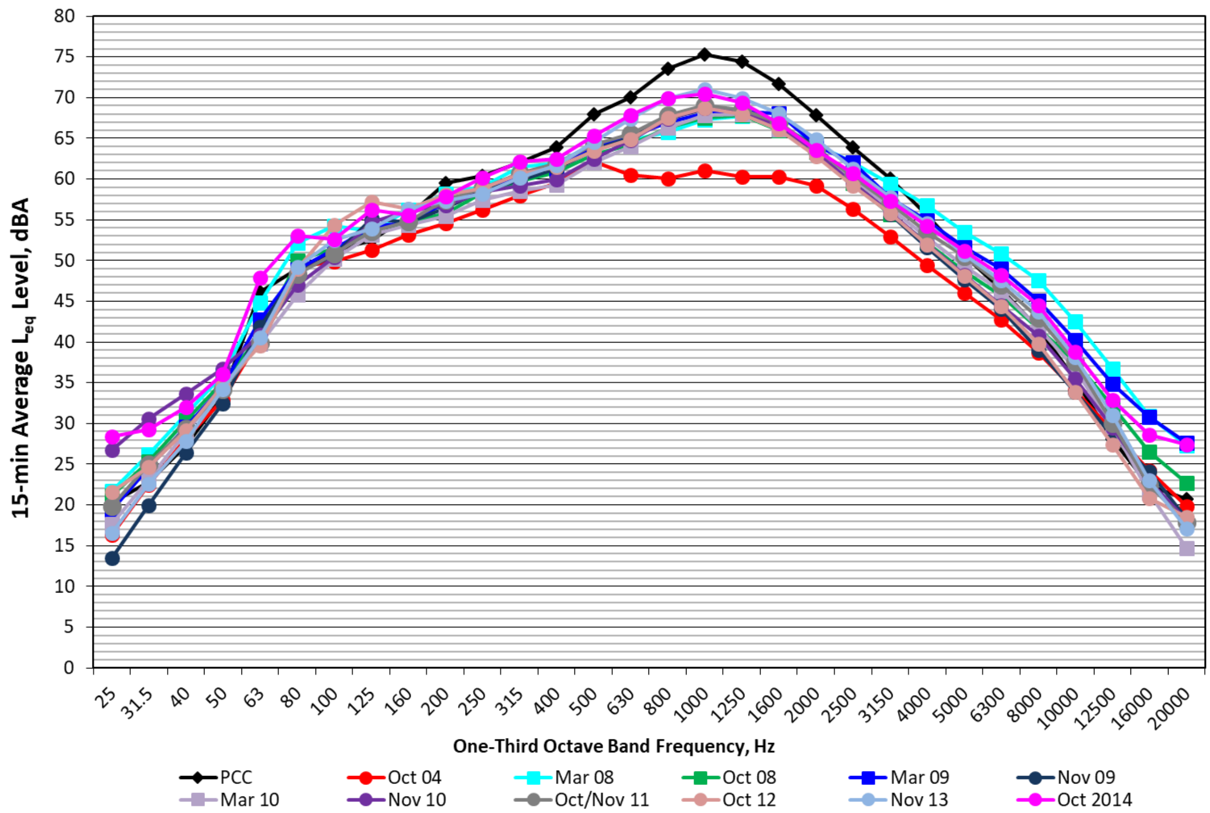

Figure 15. One-Third Octave Band Spectra for Measured Noise Levels at Site 3D at 50ft/5ft Microphone for PCC Pre-Overlay and Post-Overlay in 2004 and 2008 Through 2014

Site 3E

Site Description. Site 3E is located west of SR 101 midway between the exits for Chaparral Road (exit 46) and Indian School Road (exit 47) in Scottsdale, Arizona. At this location, SR 101 consisted of three through-travel lanes, along with an outside auxiliary lane in both southbound and northbound directions. As of 2009, an additional High Occupancy Vehicle (HOV) lane was also included in both directions of this segment of SR 101. The freeway is relatively flat but is on a slight embankment. The ground at the site is naturally compacted earth with minimal vegetation, features that were consistent throughout the project. The packed-earth ground at the site was modeled in TNM using a hard-ground type. During the original measurements, the site was free of any permanent large reflecting surfaces, such as signboards, buildings, and hillsides; however, the top of the small embankment did provide some shielding. The site originally had an unobstructed view of the freeway in both directions for more than an arc of 150 degrees, with no other apparent noise sources in the area. The southbound auxiliary lane was located about 40 ft from the closest measurement positions.

Starting in the fall of 2007, construction was done along SR 101 to add an HOV lane in both travel directions. Additionally, a 5-ft-high K-rail divider was erected in the median. Because of the embankment, the K-rail obstructs the view of the northbound traffic, providing at least partial barrier effects to Site 3E. During the roadway construction, testing was suspended at Site 3E and resumed in the spring of 2009.

Starting in the fall of 2014, a major lane-widening project began near Site 3E. Because of the embankment on the roadside shoulder of this stretch of SR 101, the widening project included major shoulder work. The monument that identified Site 3E was removed, and the landscape of the site was altered beyond recognition. These changes to the site and the widening and repaving of the roadway made testing at this site impractical after the fall of 2013. Photographs in Appendix C show Site 3E during the pre-overlay measurement period in April 2004 and during the post-overlay measurement periods in October 2004 and October 2013 (the final measurement period).

The pre-overlay pavement at Site 3E conformed to the ADOT standard: It was uniform transversely tined PCC with respect to the direction of traffic flow, and contained joints between slabs diagonal to the direction of travel. The overlay consisted of 1-inch-thick ARFC.

Noise Measurements. Pre-overlay testing was conducted at Site 3E in April 2004. The overlay was applied in May 2004 and followed up with post-overlay testing in October 2004, October 2005, March and October 2006, March 2007, March and November 2009, March and November 2010, October 2011, November 2012, and October 2013. Originally, Site 3E was to be tested only on occasion and was intended to be a backup site; Site 3A was supposed to be a primary test site, along with Site 3D. Because of the additional auxiliary lane, the geometrical changes, and the ongoing traffic problems with the frontage road running through Site 3A, Site 3E became a primary location for continued regular testing.

Construction near Site 3E resulted in an additional HOV lane in both southbound and northbound directions and took place between March 2007 and March 2009. During construction, no data were collected. The noise results through March 2007 were presented in Progress Report 3 (Donavan et al. 2009). The results for the testing periods in 2009 and 2010 were presented in Progress Report 4 (Donavan et al. 2011). Environmental conditions for each of the testing periods are summarized in Appendix C. The wayside noise measurements were conducted for two continuous hours on two consecutive days. Only three microphones were used to collect data since Site 3E is adjacent to private property, which is located to the west of the site. The three microphone positions were as follows:

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

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. Table 18 presents the average measured L_{eq} and the correlating average modeled L_{eq} levels. The measured levels at the 50ft/1.3ft microphone were an average 2.3 dBA lower than the levels measured at the 50ft/5ft microphone, probably because the shoulder of the embankment acted like a barrier to shield the 1.3 ft high microphone from the nearby traffic along SR 101. Table 19 summarizes the normalized L_{eq} results and the reduction from pre-overlay measurements due to traffic alone. The post-overlay L_{eq} measured in October 2004, immediately following the overlay application, showed an improvement from the pre-overlay measurements by approximately 9.1 and 8.3 dBA at the 50ft/5ft and 50ft/1.3ft microphones, respectively, and approximately 8.9 dBA at the 100ft/5ft microphone. At each measurement period from Year 1.5 through Year 3, the reduction in L_{eq} due to the pavement ranged from 8.1 to 8.8 dBA at the 50ft/5ft microphone, from 7.4 to 8.3 dBA at the 50ft/1.3ft microphone, and from 7.3 to 10.4 dBA at the 100ft/5ft microphone. In March 2009, the construction of the additional HOV lane and K-rail median divider was completed and testing resumed. By the final testing period in Year 9.5 (October 2013), the reductions in L_{eq} from the pre-overlay PCC pavement were 4.2 dBA at the 50ft/5ft microphone, 4.5 dBA at the 50ft/1.3ft microphone, and 4.3 dBA at the 100ft/5ft microphone.

Table 20 shows the differences between the measured and modeled levels for each testing period. One-third octave band spectra for the pre-and post-overlay conditions are shown in Figure 17 for the 50ft/5ft microphone position. Spectra for other microphone locations are provided in Appendix C.

Table 17. Comparison of Average Measured and Modeled Site 3E Wayside Traffic Noise Levels

Testing Period	Average Measured L_{eq}, dBA			Averaged Modeled L_{eq}, dBA		
	Microphone Position (Distance/Height)			Microphone Position (Distance/Height)		
	50ft/5ft	50ft/1.3ft	100ft/5ft	50ft/5ft	50ft/1.3ft	100ft/5ft
Pre-Overlay (Apr 04)	84.2	81.6	78.7	80.2	80.0	76.9
0.5-Yr (Oct 04)	74.9	73.2	69.8	80.1	79.9	76.9
1.5-Yr (Oct 05)	75.1	72.8	69.9	79.9	79.4	76.8
2-Yr (Mar 06)	75.3	72.5	68.9	80.0	79.0	77.5
2.5-Yr (Oct 06)	75.7	72.9	69.9	80.0	79.4	77.1
3-Yr (Mar 07)	76.0	74.1	71.3	80.1	79.8	76.8
5-Yr (Mar 09)	75.7	74.0	70.5	78.3	78.5	75.4
5.5-Yr (Nov 09)	76.5	74.2	71.6	78.6	78.7	75.6
6-Yr (Mar 10)	76.4	74.4	70.6	78.6	78.7	75.5
6.5-Yr (Nov 10)	76.7	74.2	71.4	78.1	78.2	75.0
7.5-Yr (Oct 11)	77.4	74.9	71.4	78.2	78.3	75.2
8.5-Yr (Nov 12)	77.9	75.6	72.4	78.4	78.5	75.4
9.5-Yr (Oct 13)	78.4	75.8	73.0	78.5	78.6	75.5

Table 18. Normalized L_{eq} and Reduction of Normalized L_{eq} for Site 3E Traffic Noise Levels Between Pre-Overlay PCC and Post-Overlay ARFC

Testing Period	Normalized L_{eq}, dBA			Change in Level, dBA		
	Microphone Position (Distance/Height)			Microphone Position (Distance/Height)		
	50ft/5ft	50ft/1.3ft	100ft/5ft	50ft/5ft	50ft/1.3ft	100ft/5ft
Pre-Overlay (Apr 04)	84.2	81.6	78.7	N/A	N/A	N/A
0.5-Yr (Oct 04)	75.1	73.3	69.8	9.1	8.3	8.9
1.5-Yr (Oct 05)	75.4	73.3	69.9	8.8	8.3	8.8
2-Yr (Mar 06)	75.5	73.4	68.3	8.7	8.2	10.4
2.5-Yr (Oct 06)	75.9	73.5	69.7	8.3	8.2	9.0
3-Yr (Mar 07)	76.1	74.2	71.4	8.1	7.4	7.3
5-Yr (Mar 09)	77.6	75.4	72.0	6.6	6.2	6.7
5.5-Yr (Nov 09)	78.0	75.5	72.8	6.2	6.1	5.8
6-Yr (Mar 10)	78.0	75.7	72.0	6.2	5.9	6.7
6.5-Yr (Nov 10)	78.8	76.0	73.3	5.4	5.7	5.4
7.5-Yr (Oct 11)	79.4	76.5	73.1	4.8	5.1	5.6
8.5-Yr (Nov 12)	79.6	77.0	73.8	4.6	4.6	4.8
9.5-Yr (Oct 13)	80.0	77.1	74.4	4.2	4.5	4.3

Table 19. Differences Between Site 3E Measured and Modeled Noise Levels

Testing Period	Microphone Position (Distance/Height)		
	50ft/5ft, dBA	50ft/1.3ft, dBA	100ft/5ft, dBA
Pre-Overlay (Apr 04)	-4.0	-1.7	-1.8
0.5-Yr (Oct 04)	5.1	6.6	7.1
1.5-Yr (Oct 05)	4.8	6.7	7.0
2-Yr (Mar 06)	4.7	6.6	8.6
2.5-Yr (Oct 06)	4.3	6.5	7.2
3-Yr (Mar 07)	4.1	5.8	5.4
5-Yr (Mar 09)	2.6	4.5	4.9
5.5-Yr (Nov 09)	2.2	4.5	4.0
6-Yr (Mar 10)	2.2	4.3	4.9
6.5-Yr (Nov 10)	1.4	4.0	3.6
7.5-Yr (Oct 11)	0.8	3.5	3.8
8.5-Yr (Nov 12)	0.6	2.9	3.0
9.5-Yr (Oct 13)	0.2	2.9	2.5

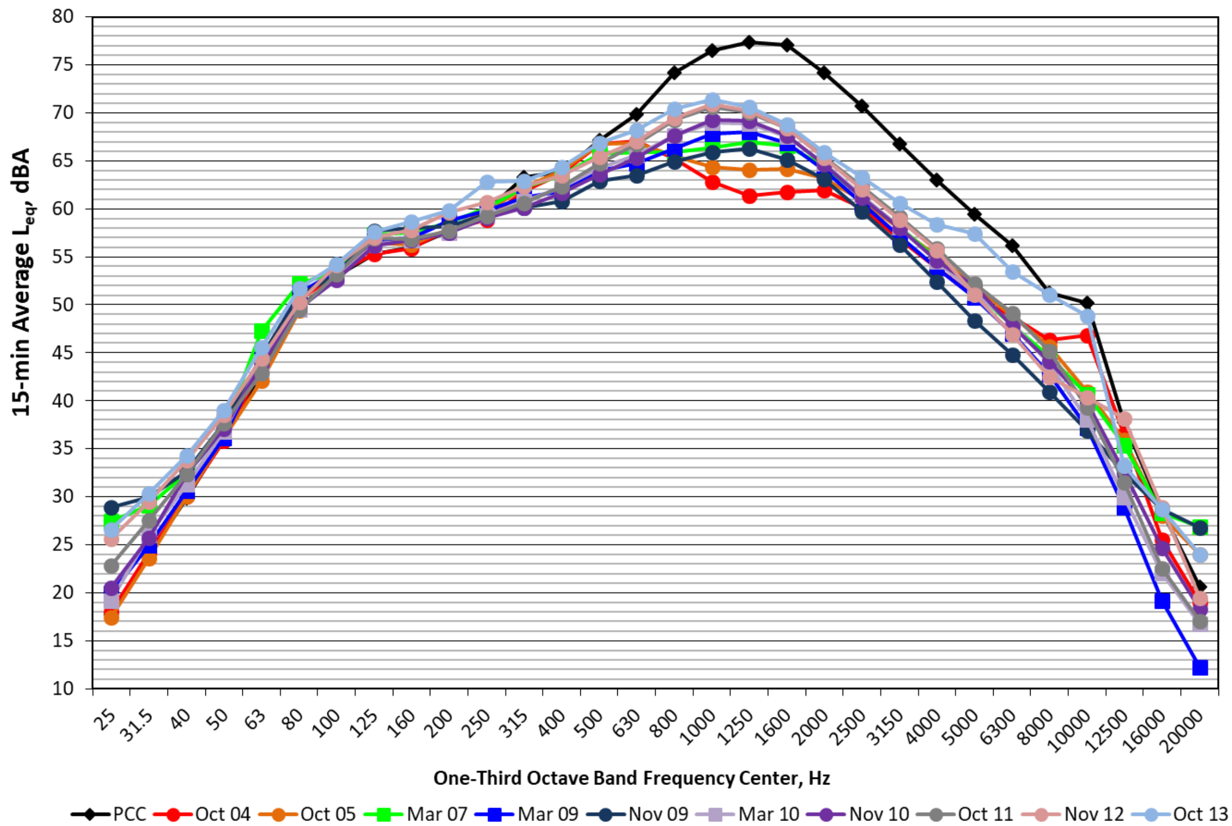

Figure 16. One-Third Octave Band Spectra for Measured Noise Levels at Site 3E at 50ft/5ft Microphone for PCC Pre-Overlay and Post-Overlays in 2004 and 2009 Through 2013

SUMMARY AND ANALYSIS

Normalized Wayside Levels

To summarize the Type 3 results, tables comparing results for similar microphone positions were developed. The first of these, Table 21, compares the reductions in normalized noise levels across sites with the microphone at the 50ft/5ft location. Prior to the first year of the overlay (i.e., measurements shown in the table as new ARFC and 0.5-year ARFC), the average reduction for all five of the sites was 9.5 dBA. Starting in Year 1, the measured reductions shown in the table vary by site. Site 3A had the smallest measured reductions, of 6.6 to 6.8 dBA, in the first three years. Sites 3B and 3C saw reductions of about 8 dBA at Year 1, but in Year 2.5, the effect of the overlay had degraded by about 1 dBA. These two sites showed reductions ranging from 5.6 to 7.6 dBA through Years 3 through 10. Site 3E showed gradual degradation over time. Reductions ranged from 8.1 to 8.8 dBA in Years 1.5 to 3; from 5.4 to 6.6 dBA in Years 5 through 6.5; and from 4.2 to 4.8 dBA in Years 7.5 to 9.5. Site 3D saw the greatest reductions throughout the life of the pavement overlay. This was expected, as Site 3D was the only site with a pre-overlay PCC consisting of random transverse tining, which was found to produce higher noise levels than the ADOT standard uniform transverse tining (Donavan and Scofield 2003). Reductions of 7.6 to 10.5 dBA were measured at Site 3D in Years 1 through 7, while reductions of 4.8 to 6.9 dBA were measured from Years 8.5 to 10.5.

Table 20. Comparison of Wayside Traffic Noise Reductions for Each of the Five Type 3 Site Locations for 50 ft/5ft Microphone Positions

Age	Site 3A	Site 3B	Site 3C	Site 3D	Site 3E
New ARFC	9.3	9.2	8.8		
0.5-Year ARFC				11.4	9.1
1-Year ARFC	6.8	8.2	8.1	10.5	
1.5-Year ARFC	6.6			8.8	8.8
2-Year ARFC				10.6	8.7
2.5-Year ARFC	6.6	6.9		8.4	8.3
3-Year ARFC		7.1	7.6	9.1	8.1
3.5-Year ARFC				8.8	
4-Year ARFC				8.6	
4.5-Year ARFC				8.5	
5-Year ARFC				8.3	6.6
5.5-Year ARFC				7.6	6.2
6-Year ARFC		6.2[a]	5.6	8.1	6.2
6.5-Year ARFC				7.6	5.4
7-Year ARFC	4.4				
7.5-Year ARFC				8.4	4.8
8-Year ARFC	5.0	6.4[a]	6.5		
8.5-Year ARFC				6.9	4.6
9-Year ARFC	4.5				
9.5-Year ARFC				5.4	4.2
10-Year ARFC	3.5	6.8[a]	6.3		
10.5-Year ARFC				4.8	
11-Year ARFC	3.5				
12-Year ARFC	3.2				

[a] Measured from the Site 3B alt location.

Table 22 shows the normalized noise reductions for the microphone positioned at 95 and 100 ft from the center of the near lane. (Site 3C did not have a measurement at this distance and therefore is not included in this discussion.) For these positions, results prior to the first year of the overlay were sparse, and the average reduction was 8.6 dBA. For Years 1 through 3, Site 3A reductions ranged from 4.6 to 5.7 dBA, while Site 3B reductions ranged from 5.5 to 6.6 dBA and Site 3E reductions ranged from 7.4 to 8.3 dBA. For Site 3A, reductions at the 100-ft position showed the greatest degradation over time, as they had at the 50-ft position. From Years 4 through 9, Site 3A had reductions ranging from 3.8 to 4.9 dBA, and from Years 10 through 12, reductions ranging from 2.2 to 2.7 dBA. The 100-ft position at Site 3B was discontinued after Year 3 so no further comparisons are possible. At Site 3E, reductions ranged from 5.7 to 6.2 dBA in Years 5 through 6.5 and from 4.5 to 5.1 dBA in Years 7.5 through 9.5. Site 3D again showed the greatest reductions from the PCC pre-overlay measurement. From Years 1 through 6.5, reductions at Site 3D ranged from 8.5 to 11.2 dBA, and from Years 7.5 through 10.5, from 6.0 to 7.7 dBA.

Table 21. Comparison of Wayside Traffic Noise Reductions for Each of the Five Type 3 Site Locations for 95 and 100 ft Microphone Positions

Age	Site 3A	Site 3B	Site 3C	Site 3D	Site 3E
New ARFC		7.3			
0.5-Year ARFC				10.2	8.3
1-Year ARFC	5.2	6.6		8.6	
1.5-Year ARFC	5.7			8.5	8.3
2-Year ARFC				11.2	8.2
2.5-Year ARFC	4.6	5.5		10.4	8.2
3-Year ARFC		6.1		10.6	7.4
3.5-Year ARFC				9.8	
4-Year ARFC				9.8	
4.5-Year ARFC				9.7	
5-Year ARFC				10.3	6.2
5.5-Year ARFC				8.9	6.1
6-Year ARFC				9.1	5.9
6.5-Year ARFC				8.7	5.7
7-Year ARFC	3.8				
7.5-Year ARFC				7.7	5.1
8-Year ARFC	4.9				
8.5-Year ARFC				6.9	4.6
9-Year ARFC	4.1				
9.5-Year ARFC				6.0	4.5
10-Year ARFC	2.7				
10.5-Year ARFC				6.3	
11-Year ARFC	2.5				
12-Year ARFC	2.2				

Wayside Comparisons to TNM

Table 23 shows the difference between the measured wayside noise levels and those predicted by TNM for all Type 3 microphone locations over the entire QPPP. Site 3B is excluded from this table because of the changes in this site prior to the completion of QPPP monitoring. The values in Table 23 indicate how much additional noise abatement the overlay 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 therefore should be 4 dB or greater. At the beginning of the QPPP, the overlay produced an average difference of 6.6 dB. As the pavement aged, the difference declined to 3.2 dB, producing a net difference of 3.4 dB. There was some rank order change over the course of the QPPP. At the beginning of the project, Site 3C produced the biggest difference between the measured and modeled values, and was still doing so at the end of the project. The change in the change in average reduction between measured and modeled levels was only 1.7 dB for Site 3C compared with the overall average of 3.4 dB for all sites. Site 3E had the lowest difference of all the sites at both the beginning and the end; however, the change was 4.7 dB. Relative to TNM, this implies that the overlay deteriorated faster at 3E than at the other sites, which is shown by the trends in Figure 18. Compared with all the other Type 3 microphone locations, the 50-ft location at Site 3D displays some anomalous behavior. This position had the smallest difference between the measured and modeled results at the start of the monitoring; however, it had the loudest pavement (see Table 4). The differences at Site 3D beyond 50 ft were more like those at the other Type 3 locations. At the end of the QPPP, Site 3D again had the lowest difference at the 50-ft microphone, one that actually indicated the pavement was noisier than the TNM average. The Site 3D differences beyond 50 ft were in line with those for the other sites. Removing this one datum increases the average difference between the measured and the modeled levels to 3.7 dB, which is in line with the goal set for the project.

Table 22. Differences Between TNM Modeled and Measured Levels for Type 3 Microphone Locations

Site	**Beginning of QPPP**				**End of QPPP**			
	50ft	100ft	>100ft	Average	50ft	100ft	>100ft	Average
3A	6.9	6	7.7	6.9	0.8	3	5.9	3.2
3C	5.7		9.0	7.4	3.2		8.1	5.7
3D	4.3	6.7	7.7	6.2	-2.2	2.9	6.7	2.5
3E	5.1	7.1	1.4	6.1	0.2	2.5		1.4
Overall				**6.6**	**Overall**			**3.2**

Table 24 shows the corresponding differences between measured results at the beginning and end of the QPPP. Average differences (measured noise reductions) between the measured results are greater than the TNM-to-measured differences.

In Table 24, the results for Site 3D at 50 ft are again anomalous. Unlike Table 23, Table 24 shows that this location saw the largest reduction at the beginning of monitoring, not the smallest. This is consistent with the research done on PCC texturing conducted on SR 202 near Site 3D. The random transverse tine pavement was found to be about 2.0 to 2.5 dBA noisier than the typical ADOT uniform transverse tine PCC, as measured with OBSI, controlled pass-by, and pseudo-statistical methods (Donavan and Scofield 2003). With respect to the predicted levels prior to the overlay, Site 3D at 50 ft was also an apparent anomaly, with predicted levels (Table 23) for the PCC being 7.1 dBA lower than the measured (Table 24) The other sites averaged 2.4 with a maximum of 4.0 dB lower for the predicted levels. Based on the pre-overlay results, the tire/pavement noise levels of the PCC pavement at Site 3D would have to have been 3.0 to 4.6 dBA higher than at the other sites—instead of 2.0 to 2.5 dB—to produce the results indicated by the modeled-to-measured comparison.

Table 23. Differences Between Levels at the Beginning and End of QPPP Noise Monitoring for Type 3 Microphone Locations

Site	Beginning of QPPP				End of QPPP			
	50ft	100ft	>100ft	Average	50ft	100ft	>100ft	Average
3A	6.8	5.2		6.0	3.2	2.2		2.7
3C	8.8		6.6	7.7	6.3		5.9	6.1
3D	11.4	10.2	8.2	9.9	4.8	6.3	7.3	6.1
3E	9.1	8.9		9.0	4.2	4.3		4.3
Overall				**8.2**	**Overall**			**4.8**

From the Type 1 testing done at the Type 3 locations (see Table 4 and Figure 10), Site 3D was found to be consistently higher in noise levels than Sites 3A, 3C, and 3E through Year 5, but virtually equal to Site 3B. The OBSI measurements around Years 6 and 6.5 showed levels of 100 to 102 dBA at all five sites, but from Years 7 through 10.5, results at Site 3D were consistently 1 to 2 dBA greater than at Sites 3A and 3C, while being practically equal to those at Sites 3B and 3E.

Acoustic Longevity – Type 1 and Type 3

The age of the overlay differs for each freeway since the overlay was initially applied at different times. Figure 18 shows the average overall degradation at Type 1 sites and the degradation at each of the Type 3 sites measured at the 50ft/5ft microphone position. The trend lines of overall noise levels at each of the Type 3 locations rise at rates ranging from 0.22 dB/year at Site 3B to 0.61 dB/year at Site 3E. The two sites with the worst correlation to the trend line, with R^2 values of 0.56 and 0.69, respectively, are Sites 3B and 3C, which also show the slowest degradation over the life of the overlay. This could be due to the limited number of measurements made at these locations. Also, the locations of the measurements at Site 3B changed halfway through the project, which would affect the accuracy of the degradation results. Sites 3A and 3D both had good R^2 values: 0.87 and 0.83, respectively. The rates of noise level increase were 0.40 dB/year at Site 3A and 0.51 dB/year at Site 3D. The location which resulted in the best trend line correlation was Site 3E, with an R^2 of 0.99. The rate of degradation at the 50ft/5ft position over the life of the overlay at Site 3E was 0.61 dB/year. The rates of degradation at Sites 3A, 3D, and 3E were similar to the rate measured at Type 1, which was 0.50 dB/year.

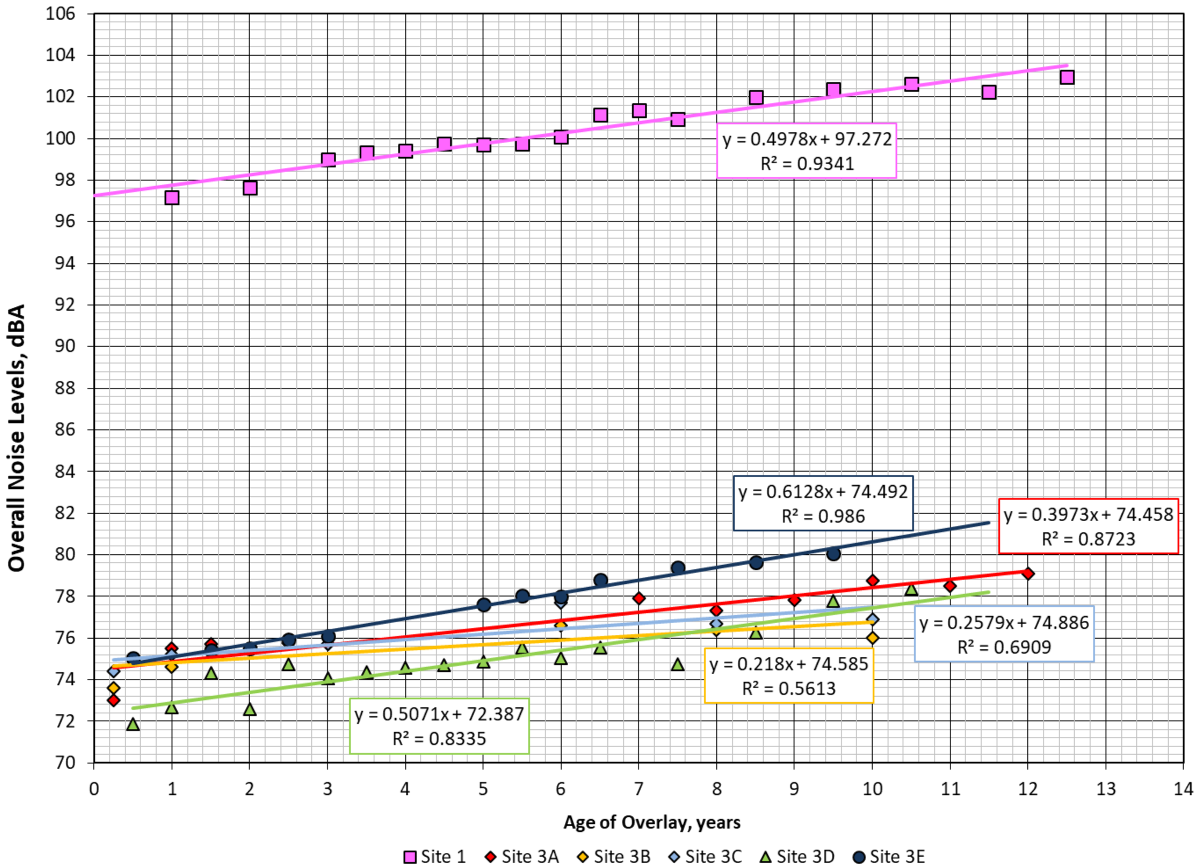

Figure 17. Overall Noise Levels Versus Age of the Overlay for Both Type 1 and Type 3 Measurements at the 50ft/5ft Position

Starting after Year 1, the average noise reductions at Type 1 sites, which are shown in Table 3, and the average reductions at each of the Type 3 sites at 50ft/5ft, which are shown in Table 21, were subtracted from reductions measured in Year 1 to show the relative increase over time using the OBSI and wayside methods. The pink squares in Figure 19 represent the average increases in OBSI levels after one year, and the blue circles represent the average wayside increases at the 50ft/5ft position after one year. While the OBSI levels were consistently higher than the average wayside measurements at 50 ft, the data for both testing methods were combined for an overall trend line. An exponential fit resulted in an R^2 of 0.78, while the linear fit shown in Figure 19 resulted in an R^2 of 0.77. With virtually the same correlation, the linear trend line in the figure shows an increase of about 0.51 dB/year, which is similar to the increases in Type 1 and Site 3D trend lines in Figure 18. This may be expected since more measurements were taken at these sites than at any others, somewhat influencing the data in Figure 19.

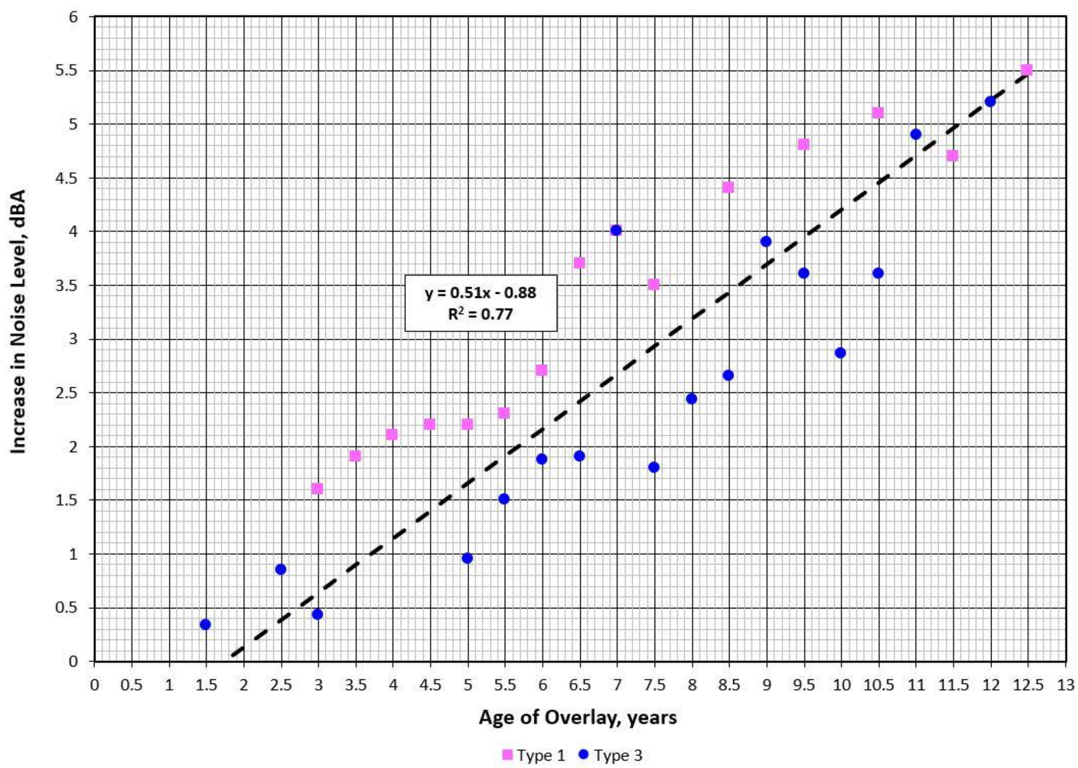

Figure 18. Increase in Type 1 and Type 3 Noise Levels Versus Time from Year 1 with Trend Line Including Both Data Types

The frequency spectra for all Type 3 sites (Figures 13 through 17) show substantial noise reductions in the frequency bands above 630 Hz. The amount of reduction appears to be associated with the characteristics of the original PCC pavement. The signature of the new ARFC overlay appears to be fairly consistent from site to site. The variations in the new ARFC overlay spectra shapes 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 and 3C (Figures 14 and 15) showed an increase of 2 to 3 dBA in the frequency bands ranging from 630 to 2000 Hz in the first year of the overlay life, from Years 1 to 3, and from Years 3 to 6. At both sites, there appeared to be little degradation after Year 6. At Year 10 at Sites 3B and 3C, there was a total increase of 6 to 8 dBA. Site 3A saw a 6-dBA increase from Year 1 to Year 7 and only an additional 2-dBA increase through Year 12. The total increase from Year 1 to Year 12 was about 8 dBA. At Site 3D, an increase of about 8 dBA was measured in the frequency range of 630 to 2000 Hz from Year 0.5 to Year 4, and only an additional increase of 1 to 2 dBA by Year 10.5. The total increase from Year 0.5 to Year 10.5 was about 9 dBA at Site 3D. There was a more gradual increase at Site 3E over time in this frequency range. From Year 0.5 to Year 1.5, there was a 3-dBA increase, and after 5.5 years, an additional increase of about 2 dBA. The total increase at Site 3E from Year 0.5 to Year 9.5 was about 10 dBA.

Correlation of Type 1, 2, and 3 Results

During the first several years after the ARFC overlay, the reductions measured at the Type 2 neighborhood locations were clearly lower than those at the Type 1 and 3 locations. The neighborhood locations were supposed to be representative of where residents would hear the noise in their yards; however, these locations apparently were not experiencing the full benefit of the reduced OBSI tire-pavement noise levels or receiving the reduced wayside levels that were measured in the open settings of the Type 3 sites. Given the apparent discrepancy between the Type 2 results and those for Types 1 and 3, an investigation of the "correlation" between the three types of measurements was initiated. This analysis concentrates on the first four years of the program, the only period during which Type 2 measurements were conducted. The results of this investigation are discussion in this section.

Initial Comparison of Results

Direct comparisons are somewhat problematic because the Type 1, 2, and 3 measurements were not coordinated and were made at different times relative to the initial overlay. Many pairs of pre- and post-overlay measurements are missing, especially for the Type 1 and 2 sites. Further, there were lag times between measurement types: Type 3 measurements lagged the initial Type 2 measurements by about three to 15 months, and Type 1 measurements lagged Type 2 by 10 to 12 months. Even during these relatively short times, the noise reduction performance of the ARFC was found to degrade. To develop a comparison of averages, noise reductions for 71 Type 1 mileposts from 2004 were used, along with 78 noise reductions from Type 2 sites. For the Type 3 locations, the initial reductions from all five sites were averaged (including all microphone locations), providing a total of 12 data points. From these data, the average noise reductions were 8.3 dBA for the Type 1 milepost measurements, 5.3 dBA for the Type 2 neighborhood measurements, and 9.1 dBA for the Type 3 roadside measurements.

The noise reductions indicated by the Type 1 and Type 2 results can be compared more directly by pairing the Type 1 site at each milepost with the nearest location of a Type 2 site. This resulted in 63 pairs of data points being identified. In Figure 20, the Type 2 reductions are plotted against the Type 1 results. This plot, with an R^2 of 0.05, displays virtually no correlation between the noise reductions. The average reduction is 7.8 dBA for the Type 1 results and 4.7 dBA for the Type 2 results, a difference of about 3 dBA. There is considerable scatter and range in the noise reductions for both the Type 1 and the Type 2 sites.

Another approach is to compare the Type 1 and Type 2 results with those for each Type 3 location. Type 2 measurements were conducted close to all five sites of the Type 3 measurements. For three of the Type 3 sites, true OBSI measurements were completed in the fall of 2004. The noise reductions are shown graphically in Figure 21. For the Type 3 sites, there are some differences in noise reduction depending on microphone distance at each site, with the reductions at 50 ft being the greatest. For the Type 2 measurements, the distances are unknown except for Location 29 at 135 ft. The Type 1 OBSI results are within about 1 dBA or less of the Type 3 at 50 ft. The rank ordering of the reductions - is consistent between these two data types. For the Type 2 locations, the reductions are always lower than those seen in the Type 1 and 3 data, regardless of microphone distance at the Type 3 sites. In some cases, the differences between the Type 2 and Type 3 noise reductions are quite large. The results of Figure 21, along with the average reductions cited above, indicate that the Type 1 and Type 3 measurements typically show similar noise reductions, while the Type 2 noise reductions were regularly less.

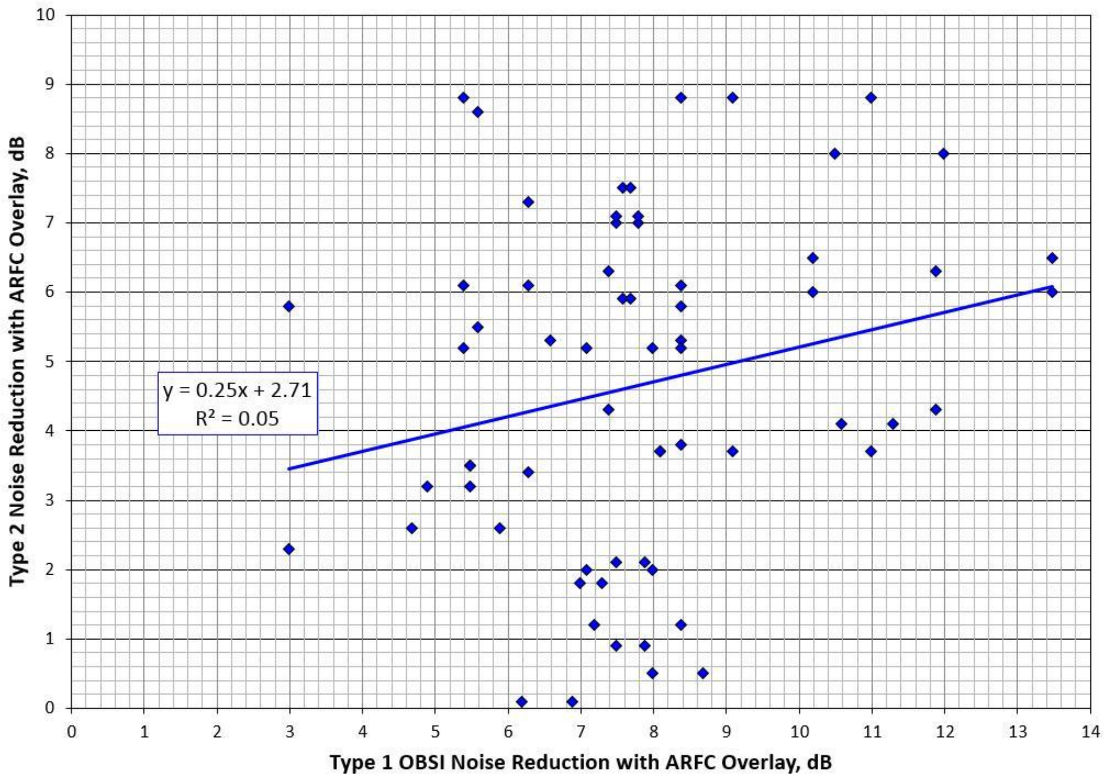

Figure 19. Linear Regression of Type 2 Noise Reductions Versus Type 1 Noise Reductions

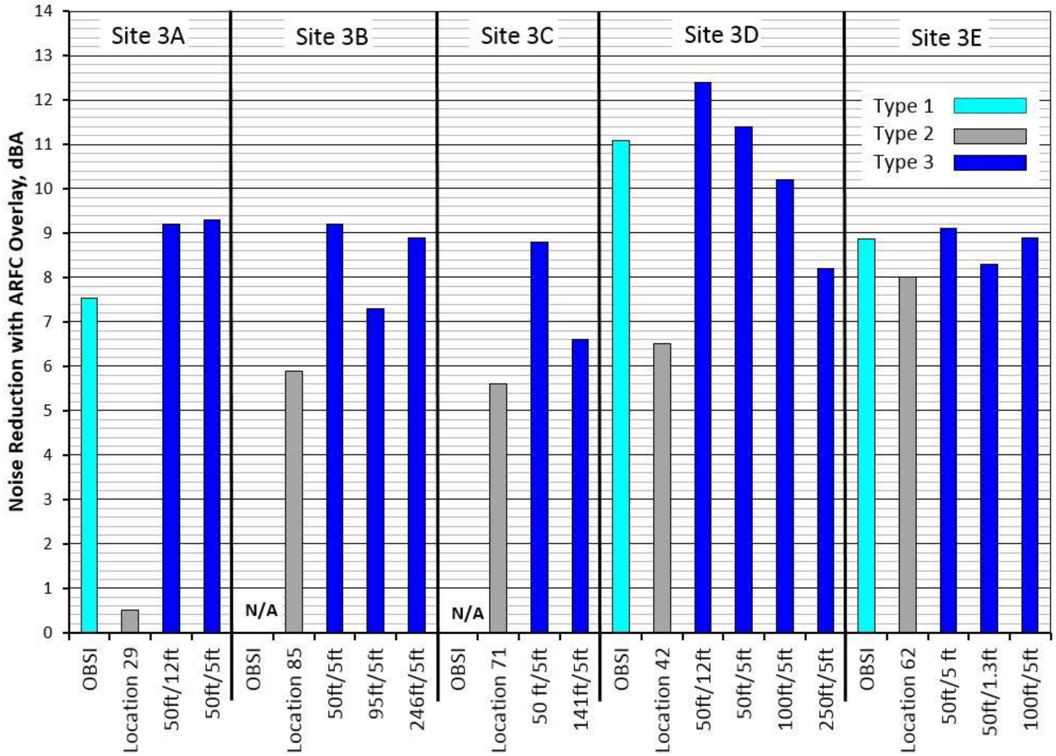

Figure 20. Comparison of Pre- and Post-Overlay Noise Reductions for Types 1, 2, and 3 Measurements

Evaluation of the Type 2 Neighborhood Measurements

Examination of Site and Environmental Variables. Type 2 measurement locations were identified using photographs of 52 documented Type 2 sites in conjunction with Google Earth. This tool was used to determine approximate distances to the freeway, the location of structures and existing noise walls, and the elevation of the freeway relative to the measurement location. The sites were examined virtually to determine the approximate height of existing noise walls, freeway recess or elevation, and any other site geometry nuances that might affect received noise levels. In this manner, the sites were characterized by:

- Open or obstructed view of the freeway
- Flat, elevated, or recessed geometry between the freeway and the measurement location
- Presence of single or multiple barriers and earth berms and approximate height
- Distances from the near lane of vehicle travel to the receiver location and to any intervening barriers or features
- Presence of any nearby potentially high-traffic-volume streets or of other noise sources, such as intervening frontage roads
- General notes about each site

The average noise reduction for the 52 locations was 5.2 dBA compared with 5.3 dBA for all 78 data points. This provided some assurance that the analysis of the smaller number of points would be representative of the complete set. Several of the site variables were analyzed to determine if they had a relationship with the reported noise reductions. One hypothesis was that the sites with the higher pre-overlay noise levels would be highly dominated by freeway traffic and hence should record the largest noise reductions with the overlay. Conversely, sites with low initial noise levels might have other contributing sources and hence would produce only small noise reductions. Regressing noise reduction against pre-overlay levels demonstrated that no such correlation existed. A related hypothesis was that the noise reduction would be less with increasing distance from the highway, as indicated by some of the Type 3 measurements. This trend was not found in the Type 2 measurements.

The data from the 52 sites were also used to examine the influence of frontage roads and arterial streets on noise reductions. Frontage roads between the freeway and the measurement locations were found for 21 sites. On average, these sites produced noise reductions of 4.3 dBA. The 31 sites without frontage roads averaged reductions of 5.8 dBA. This suggests that background noise from the frontage roads resulted in lower noise reductions for these locations. Only three sites out of the 52 had arterial streets nearby, and at these sites the noise reductions were actually slightly higher than the Type 2 average noise reduction, rather than lower.

Another factor that could affect results is the presence of a barrier or a recessed freeway, which could diminish the reductions attributable to quieter pavement (Rochat 2006). Using the data from the Type 2 sites, noise reductions were regressed as a function of barrier height and freeway recess. These regressions again showed very little correlation between the noise reductions with the overlay and barrier height or recess depth. However, the results were contradictory: Increased barrier height showed a slight trend of decreased noise reduction, but increased recess depth showed increased noise reduction with the quieter pavement.

Another aspect of the pre- and post-overlay Type 2 measurements was the range in air temperature at the time the data were taken. Most of the pre-overlay measurements were taken in conditions that were hotter by as much as 30° to 40° F. Noise reduction versus the difference in temperature between the pre- and post-overlay measurements was also regressed and demonstrated poor correlation. There was only a very slight trend for noise reductions being smaller with greater temperature differences.

Comparison to Type 3 Noise Reductions. Assuming relatively equivalent traffic conditions, the noise reduction from the Type 3 pre- and post-overlay measurements should provide an upper bound of reduction versus distance for comparison to the Type 2 results. The noise levels from the five Type 3 locations were averaged together for similar distances, and results of the pre- and post-overlay measurements were fitted with logarithmic regressions of level versus distance. The trends for both were quite good, with R2 values of 0.97 and 1.00 for the pre- and post-overlay conditions, respectively. The pre-overlay regressions provided a fall-off rate of about 5.7 dBA per doubling of distance (DD), and the post-overlay fall-off was only slightly less at 5.3 dBA/DD. Noise reduction versus distance is determined by the difference between these two curves and is shown in Figure 22, along with individual noise reductions for the Type 2 sites. The Type 2 results display considerable scatter, ranging from 3.9

dBA higher than the Type 3 curve to about 8 dBA below. In principle, the Type 2 reductions should be at or below the noise reduction curve of the Type 3 data; however, six sites lie above it, with five being within 1 to 2 dBA above the Type 3 curve. Thirty of the data points lie 2 dBA or more below the Type 3 curve. The single data point with a reduction slightly greater than 12 dBA appears to be errant after closer review.

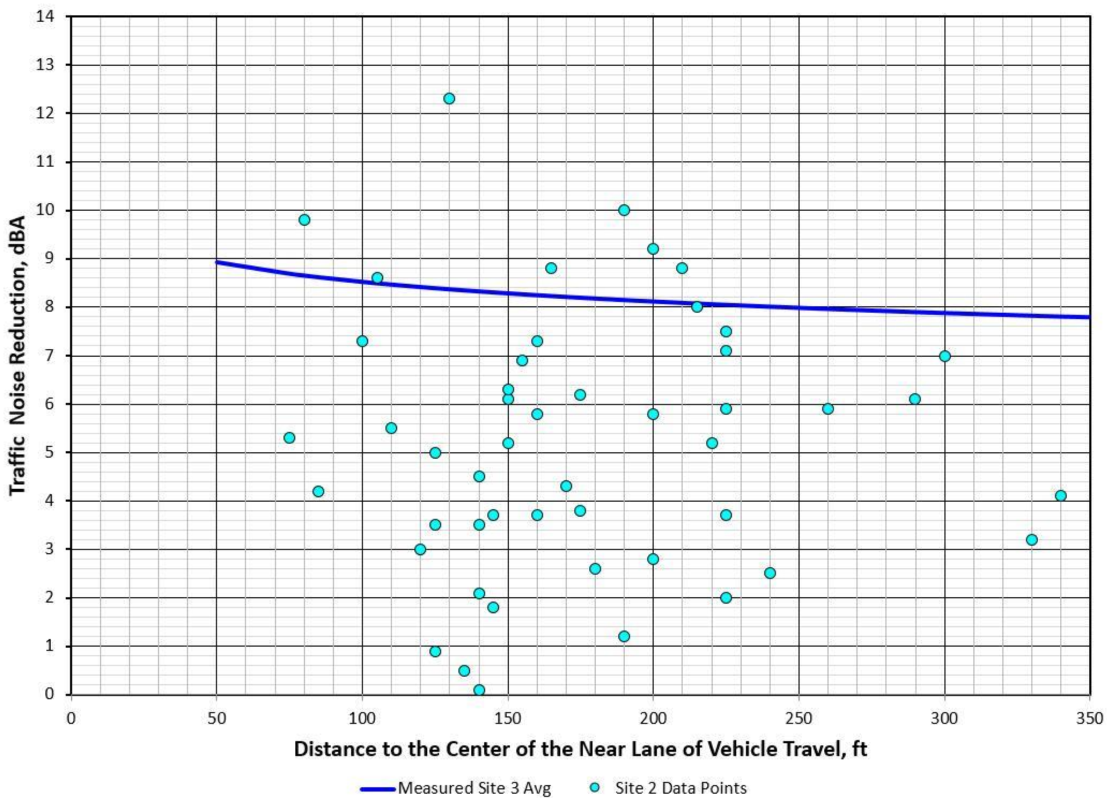

Figure 21. Type 2 Noise Reductions Compared to Type 3 Average Noise Reductions as a Function of Distance from the Roadway

Analysis Using TNM

Development of Case Models. To assess the effects that site geometries may have had on the reported Type 2 reductions, generic TNM models were constructed to represent different groupings of the sites. Based on the virtual reconnaissance, these geometries fell into three groupings: flat terrain, recessed highway, and elevated highway. Most of the measurement locations were near recessed roadways. Within this grouping, the amount of recess was split into two subgroupings: 6 ft and 12 ft. The 6-ft-recess grouping was split into two further subgroups: no barriers and barriers 12 ft high. The 12-ft-recess grouping was subdivided into three subgroups: no barriers, barriers 8 ft high, and barriers 12 ft high. For each barrier height, several distances between the barrier and the edge of the roadway were selected based on the ranges in the site data. Groupings were also developed for the flat terrain and elevated roadway cases. All the groupings are presented in Table 25.

Table 24. Groupings, Features, and Parameters for TNM Analysis of Type 2 Results

Site Configuration	Feature Depth/Height	Barrier Geometry	
		Height	**Distance from Near Lane**
Flat	0 ft	0 ft	--
		12 ft	40, 110, and 180 ft
		3 ft K-Rail	20 ft
Recessed	6 ft	0 ft	--
		12 ft	53, 100, and 160 ft
	12 ft	0 ft	--
		8 ft	70 and 120 ft
		12 ft	70, 110, and 150 ft
Elevated	4 ft	0 ft	--
		3 ft K-Rail	20 ft

For each case in Table 25, receiver locations were analyzed at distances of 75 to 425 ft from the center of the near lane of travel, in 50-ft increments. From TNM, each calculation point generates a level with and without a barrier. For the recessed cases, there was also a noise reduction due to the barrier effect of the recess, aside from the reduction produced by an installed noise barrier. This site effect noise reduction could be determined by subtracting the TNM predictions for the flat, open geometries from those for the recessed geometries. At the time of the Type 2 measurements, the freeways were typically three lanes in each direction, with a large median in between. Aerial photographs showed that the typical roadway geometry consisted of three 12-ft-wide lanes in each direction separated by a 48-ft-wide median and with 20-ft-wide shoulder/clear areas in either direction adjacent to the outside lanes. Based on the traffic data from the Type 2 measurements, a typical traffic condition was developed with 8,000 vehicles per hour at 65 mph, 3 percent medium trucks, and 2 percent heavy trucks. The intent of this model was not to accurately reproduce the measured levels but rather to evaluate the differences in predicted levels between flat, open sites (Type 3 locations) and groupings of the Type 2 geometries. Since the same roadway geometry, traffic conditions, and distributions were used in all cases, the relative differences between the sites were not expected to be very dependent on the traffic parameters.

To evaluate the additional noise reduction produced by the ARFC overlay, a research version of TNM was used that was developed by the US Department of Transportation Volpe Center as part of the FHWA Pavement Effects Implementation Study (Rochat, Donavan, et al. 2012). In this version of TNM, the ground level source strength (GLSS) was scaled by using measured OBSI data so that the effects of pavement on vehicle emissions could be taken into account in the predicted traffic noise levels. For application to the QPPP, representative OBSI spectra were selected for new ARFC and pre-overlay uniform transverse tine PCC. These data correspond to a reduction of 9.8 dBA, which is slightly higher than the 8.9 dBA average from the Type 1 data (see Figure 21 for Site 3E).

Results of Modeling. Using OBSI data and the research version of TNM, traffic noise levels were predicted for the site geometries of Table 25. Predicted noise levels for a 12-ft recessed freeway with a 12-ft noise barrier located 70 ft from the roadway are shown in Figure 23 as an example. The highest predicted levels occur for an open site with the pre-overlay PCC corresponding to the pre-overlay levels of the Type 3 sites. The next highest levels (still with PCC) show the effects of the recess. The recess provides virtually no reduction near the roadway, as there was unobstructed line-of-sight to the traffic. Noise reduction increases at more distant receiver locations, since the recess obscures the roadway. When the noise barrier is added to the site, the next lowest levels are produced. In this case, the noise barrier provides substantial reduction near the freeway, as the line-of-sight is totally blocked. Finally, when the effects of the ARFC overlay are included, additional noise reductions of about 3 dBA are seen with the new pavement. For a Type 2 location corresponding to this recessed geometry with a 12-ft barrier, the application of ARFC would provide only a 3-dBA reduction from the noise level of the original PCC pavement.

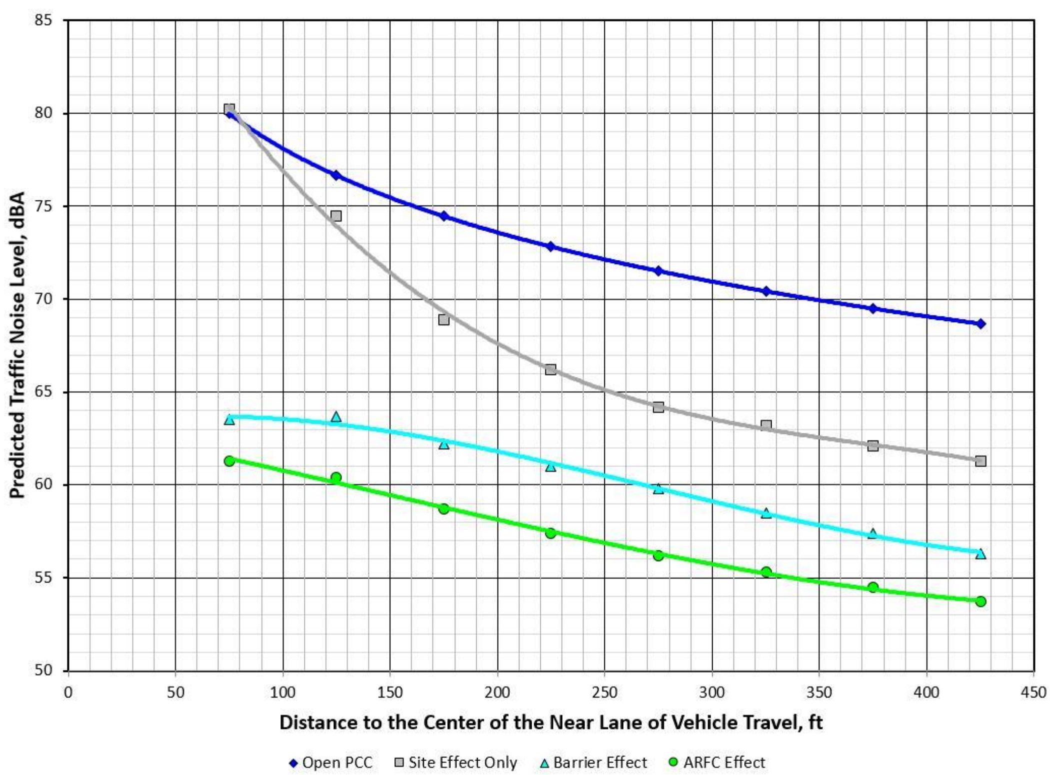

Figure 22. Example of TNM Predictions for a Roadway Recessed 12 ft (Side Effect), with an Added 12-ft Barrier, 70 ft from the Roadway (Barrier Effect), and with ARFC Added (ARFC Effect)

The predicted levels for a flat site with a 12-ft-high barrier 110 ft from the roadway are shown in Figure 24. In this case, the site effect is small, essentially equal to the open case. Just behind the barrier at 125 ft from the roadway, the reduction is large, about 13 dBA. At farther distances from the freeway (250 to 425 ft), the reduction is smaller, amounting to about 7 to 8 dBA. When the ARFC is applied, the levels drop another 5 dBA. The example of a 4-ft elevated roadway with a 3-ft K-rail at the edge of the roadway is shown in Figure 25. The K-rail provides a fairly constant 5- to-6-dBA reduction with distance. When the ARFC is applied in this case, an additional reduction of 5 to 6 dBA occurs.

Figure 26 shows the noise reductions predicted to occur with the ARFC overlay for each of the 52 Type 2 locations used in this analysis, along with a logarithmic curve fit through the data points. Also shown are the average reductions, as a function of receiver distance, measured for the Type 3 locations. Based on this analysis, the Type 2 reductions should fall below those for the flat, open Type 3 locations, which receive reductions only through the application of the ARFC and not through other noise-reducing features. Of the 52 Type 2 locations, only four correspond to the flat, open Type 3 locations without barriers. In Figure 26, the noise reductions at these four sites are 7 dBA or greater. The three noise reductions produced by the ARFC that fall between 6 and 7 dBA in Figure 26 had K-rails near the roadway, and the roadway was either elevated or a flat site. These cases were represented in Figure 25 by those reductions falling into a range of 4.4 to 6.9 dBA. All the other noise reductions in Figure 25 corresponded to measurement locations where there were existing barriers. Of these, 32 had recessed roadways for which the noise reduction produced by the ARFC ranges from 3.7 to 5.5 dBA. The remaining 16 locations were either flat terrain or elevated roadway with barriers for which the predicted reductions with the ARFC range from about 4.4 to 5.7 dBA. The curve through the predicted Type 2 reductions parallels the Type 3 curve with an offset of 3.1 to 3.2 dBA. Adding this offset to the Type 2 average brings the reductions for all three measurement types within less than 1 dBA of each other.

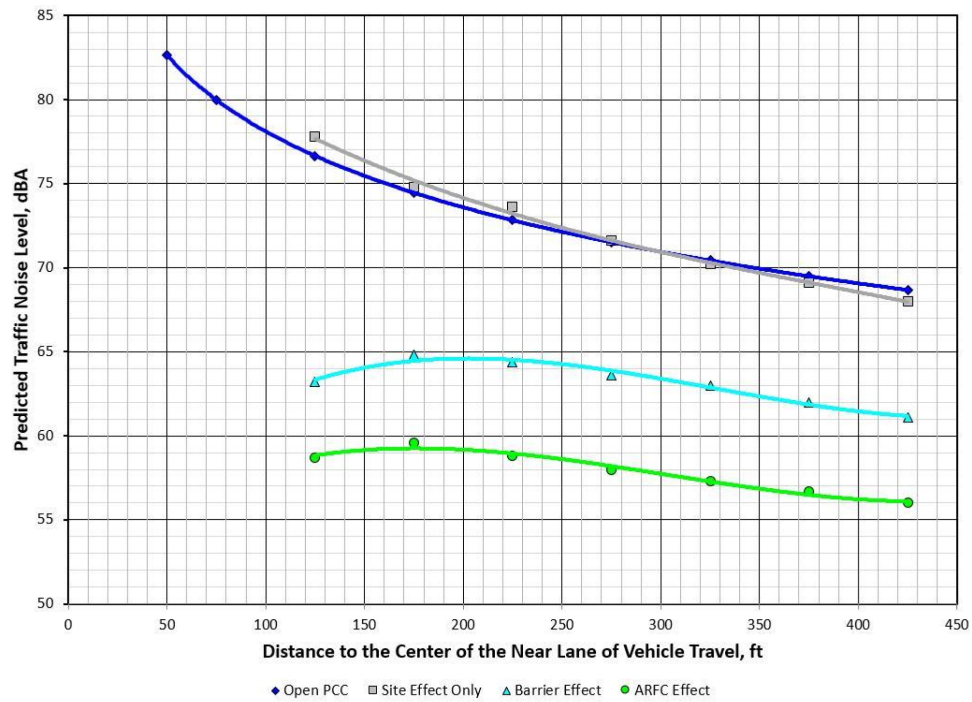

Figure 23. Example of TNM Predictions for a Flat, Unobstructed Site (Site Effect), with an Added 12-ft Barrier, 110 ft from the Roadway (Barrier Effect), and with ARFC Added (ARFC Effect)

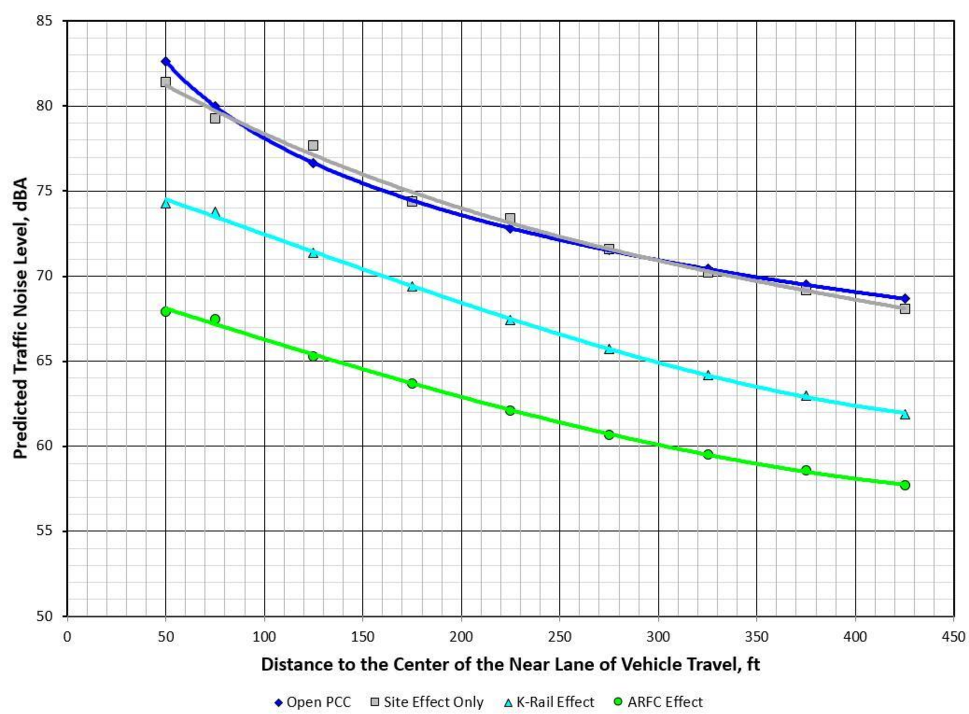

Figure 24. Example of TNM Predictions for a 4-ft Elevated Roadway (Site Effect), with an Added 3-ft K-Rail at the Edge of the Roadway (Barrier Effect), and with ARFC Added (ARFC Effect)

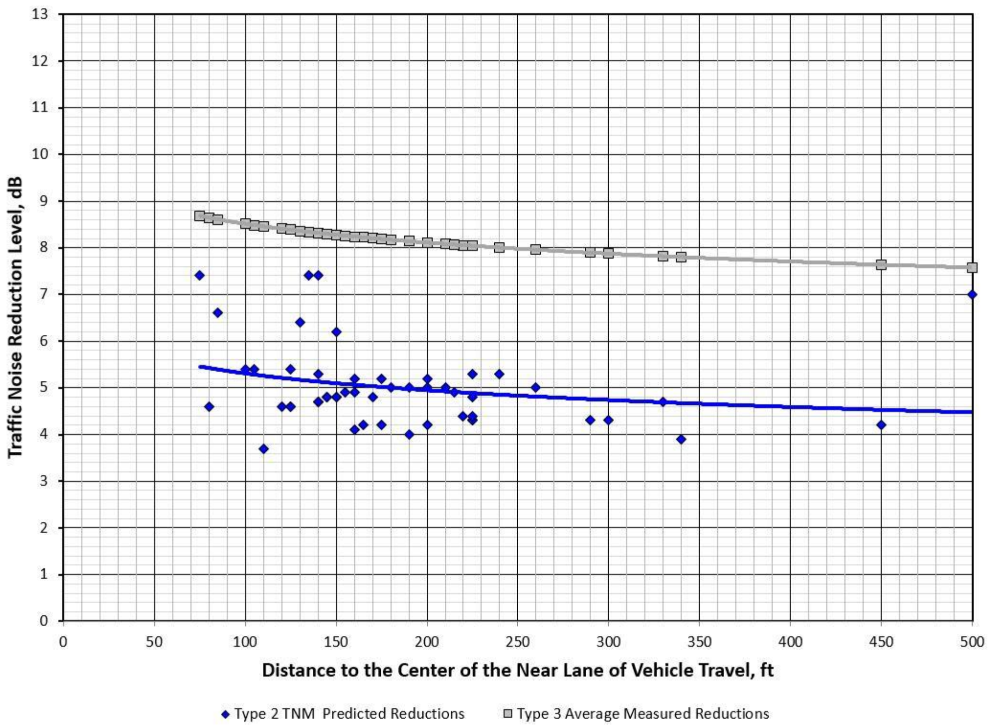

Figure 25. Predicted Noise Reductions for the Type 2 Sites with Logarithmic Regression Compared to the Average of Noise Reductions from Type 3 Measurements

Uncertainty in Type 2 Noise Reductions. The results in Figure 26 provide a reasonable basis for the Type 2 measurements' yielding a lower average noise reduction than the Type 1 and Type 3 measurements. However, the TNM results did not account for variance in individual points or the large scatter in the measured Type 2 reductions. In Figure 27, the measured Type 2 reductions are plotted versus distance, along with the logarithmic regression curve defined by these data points. Although there was large scatter in the measured reductions, the average, as represented by the logarithmic curve fit, was almost identical (within 0.4 dBA) to that of the TNM-predicted noise reductions of Figure 26. However, for the measured Type 2 reductions, the average deviation from their regression curve was 2.2 dBA, while the average deviation for the predicted reductions of Figure 26 is only 0.6 dBA. The measured reductions of Figure 27 display a range of 0.1 to 12.3 dBA, compared with 3.7 to 7.4 dBA for the TNM-predicted reductions.

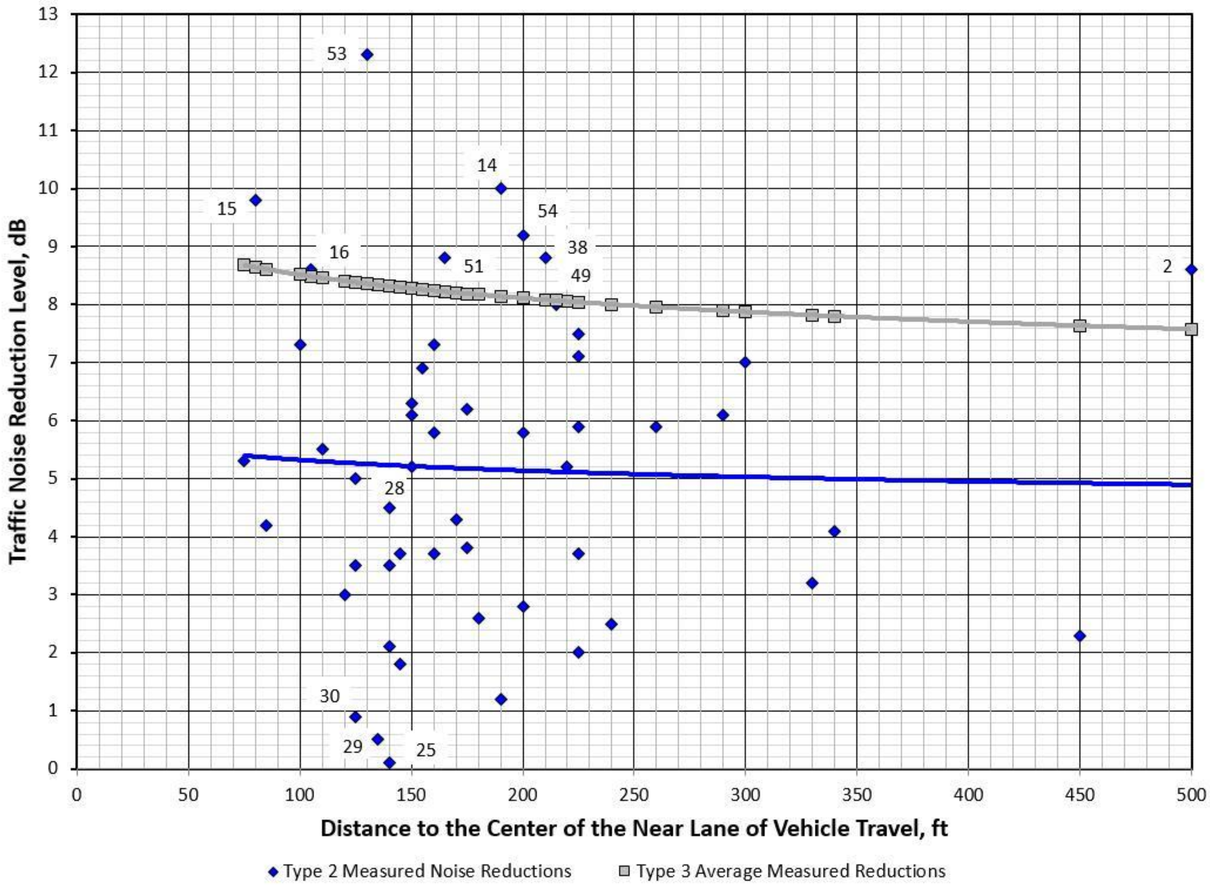

Figure 26. Measured Noise Reductions for the Type 2 Sites with Logarithmic Regression Compared to the Average of Noise Reductions from the Type 3 Measurements

To understand the scatter, some of the outlier points in Figure 27 were examined in more detail. Nine data points, identified as sites 2, 14, 15, 16, 38, 49, 51, 53, and 54, exceeded the Type 3 average post-overlay curve. In Figure 28, the curve fit for the post-overlay levels at the Site 3 locations is shown arbitrarily lowered from the actual average by 9 dB in order to identify data points that are particularly low compared to the expected level. Of the 7 data points below -9 dB curve, 6 correspond to the 9 sites identified in Figure 27 with high noise reductions and one (site 51) is on the -9 dB curve. The pre-overlay levels were typical of the average of the other sites. This implies that these sites had unusually low post-overlay noise levels, contributing to their high noise reductions. The site information for these locations did not show any consistent factors to indicate why these post-overlay levels were so low. Of the remaining three points above the Type 3 average reduction shown in Figure 27, two points (2 and 14) had pre-overlay levels that were among the highest. One of these sites was flat and open with no barrier, and the other was recessed with a barrier.

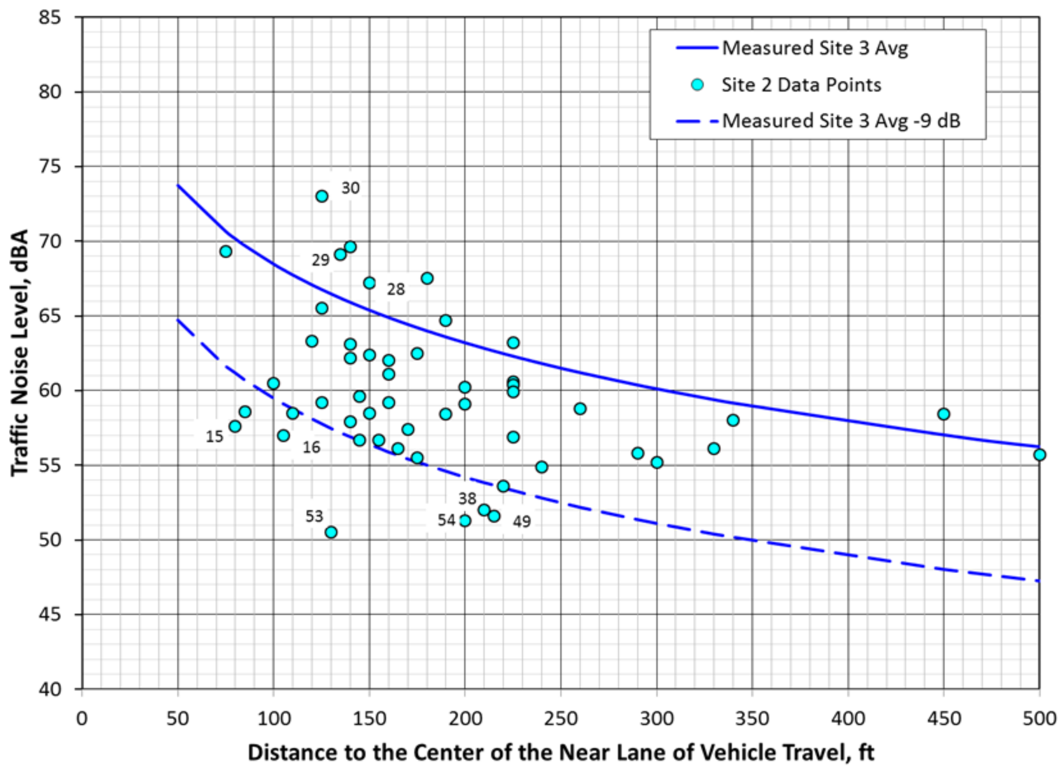

Figure 28. Site 2 Post-Overlay Noise Levels Compared to the Measured Site 3 Averages and to the Site 3 Averages Offset 9 dB Lower

The excessively low noise reduction data points (e.g. 25, 29, and 30 in Figure 27) were also examined in more detail. These data points were 3 of the 8 data points with levels above the measured Site 3 average (see Figure 28). As with the high noise reduction sites, these had no consistent characteristics or attributes that could explain the low noise reductions. Additional analysis of the outlier data points is provided in Appendix F.

Conclusions and Observations

The differences in the noise reductions produced by quieter ARFC, as determined in neighborhood traffic noise measurements from Type 1 and Type 3 sites, were found to be due not to a lack of "correlation" for the effects of quieter pavement, but rather to the nature of the measurement types. Type 1 and Type 3 measurements were designed to isolate the performance of pavements from other noises and obstacles to sound propagation. The Type 2 measurements were intended to measure community noise under any circumstance of the site. By taking into account the geometries and parameters of the Type 2 sites, it was found that the lower noise reductions in the Type 2 measurements were to be expected at these sites, based on the use of a research version of TNM that accounts for differences in tire/pavement noise source levels. Many of the Type 2 sites had features that provided noise reduction even prior to the overlay. The application of the overlay did produce reductions in the neighborhoods consistent with the reductions predicted with TNM using the measured OBSI levels. In this sense, the effectiveness of the overlay was correlated between the different measurement types.

The Type 2 measurements also demonstrated the effectiveness of using a quieter pavement even when there were other noise-reducing measures in place. On average, the pavement change produced a reduction of more than 5 dBA, which would be considered to be a “feasible” reduction under the FHWA 23 CFR 772 and ADOT policies. Additionally, of the 52 Type 2 locations, 30 would be defined as noise-impacted using the ADOT Noise Abatement Criterion (NAC) of 64 dBA, even with barriers in place and with reductions due to recessed roadways. After the overlay, the number of impacted receptor locations was reduced to seven. Further, 28 of the 52 locations would be classified as “benefited” receptors under ADOT policy, as reductions of 5 dBA or more were provided by the overlay. Of these 28 locations, 14 achieved a reduction of 7 dBA or more, meeting the ADOT reasonableness design goal of at least half of the benefited receptors receiving this level of reduction.

CHAPTER 4. PAVEMENT MEASUREMENTS

Along with wayside noise and tire/pavement source levels, pavement properties were measured to assess how they changed over time and in sound level. These properties included sound absorption and pavement surface characteristics.

PAVEMENT SOUND ABSORPTION

Porous pavements have been demonstrated to provide sound absorption, since air can penetrate the pavement surface. Energy is dissipated in the pavement due to the flow resistance provided by air movement through interconnected voids. Sound absorption has two effects on tire/pavement noise. It can reduce the strength of the noise, since the surface that the tire operates on does not reflect sound to the degree that a nonreflective pavement does, and also can relieve air pumped out of the tread voids. Sound absorption reduces the noise at distances away from the tire since acoustic energy is removed as the sound propagates over the absorptive surface. For the QPPP, sound absorption was evaluated by two different methods: effective flow resistance (EFR) and impedance tube. The EFR method is an indirect method in which reflection of sound is measured and results are analyzed relative to expected reflection interference. The impedance tube method determines sound absorption by evaluating the standing wave pattern produced in a closed volume where one end is the test sample.

EFR Measurements

Description

EFR is a measure of flow resistivity, which includes the influence of material characteristics such as tortuosity, porosity, and shape of ground surface. EFR is the sound absorption parameter used in TNM's sound propagation/reflection algorithms. In EFR, low values represent a very sound-absorbent material, and high values represent a very sound-reflective material. In the FHWA TNM version 2.5, a single EFR value of 20,000 cgs rayls is applied to pavements. Studies have shown that pavement EFR values can range from about 2000 to 30,000 cgs rayls, depending on pavement type and age (Rochat, Hastings, et al. 2012; Rochat and Donavan 2012). A range of values from 7200 to 30,000 cgs rayls have been measured previously on a number of mostly nonporous pavements (Rochat, Hastings, et al. 2012). More-porous pavements have been reported in the literature from about 1400 to 2000 cgs rayls (Hűbelt et al. 2002; Embleton et al. 1983; Bérengier et al. 1997). EFR is considered on a nonlinear scale in the sense that, for example, a difference of 1000 cgs rayls in the low range (0 to 1000 cgs rayls) can represent the significant difference between very sound absorbent powder snow and roadside dirt, whereas in a higher range (10,000 to 30,000 cgs rayls), a 1000-cgs rayls difference can represent slight differences in, for example, the EFR of dense-graded asphalt pavements.

Since the sound-absorbing properties of a pavement can affect the noise propagating into communities (Rochat, Donavan, et al. 2012), in 2010 ADOT determined the need to collect data to determine the pavement EFR values at the QPPP Type 3 sites as the pavement aged. As part of TNM Pavement Effects Implementation Study (Rochat, Hastings, et al. 2012), EFR measurements were taken at Site 3B in 2007, and related information from that study will be included in this report.

Data were collected in conformance with American National Standards Institute (ANSI) S1.18, Template Method for Ground Impedance, using "Geometry A" (ANSI 2010). The instrumentation setup consists of an acoustic point-source (compression driver with tube) and two microphones set a distance away and at two different heights above the ground. A signal generator is used to transmit tones at one-third octave band center frequencies between 250 and 4000 Hz, and the difference in sound level between the two microphones is noted for each frequency. Photographs of the EFR instrumentation are shown in Figure 29.

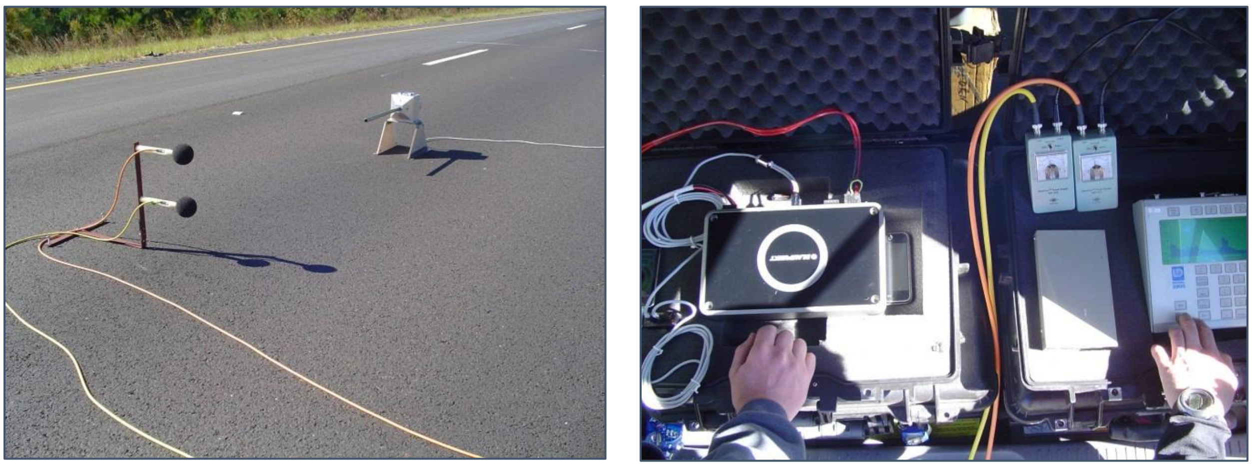

Figure 29. EFR Data-Collection Instrumentation (Rochat, Hastings, et al. 2012)

Typically, for each pavement type, four samples were collected with the point-source tube pointing in different directions for each sample. For each of the one-third octave bands, data on roadways were collected with the point-source tube pointing in the direction of travel and at 90, 180, and 270 degrees from the direction of travel.

Data analysis was conducted in partial conformance with the ANSI S1.18 standard. There are limitations in using ANSI S1.18 when trying to extract EFR values from the measured data in the range of 2000 to 30,000 cgs rayls, which is the important range when trying to obtain useful sound-absorption information for pavements. The process seems to be appropriate for identifying general ground types (e.g., lawn or pavement) but is inadequate for identifying sensitivities within a general ground type. Therefore, a different analysis process more sensitive to EFR values in the pavement range was developed and used for the QPPP (Rochat, Hastings, et al. 2012).

Table 26 shows the EFR data collection dates for the QPPP Type 3 sites with multiple years of measurement. In addition, EFR data were collected on new (less than one-year-old) ARFC pavement at a location just south of Site 3C in 2015. Site 3B is not shown in the table since it was only measured in 2007 in a separate effort, and was not part of the EFR project.

Table 25. Dates of EFR Data Collection and Pavement Age

Collection Date		Pavement Age, years			
Year	Month	Site 3A	Site 3C	Site 3D	Site 3E
2010	October	7.0	5.5	6.5	6.5
2011	October	8.0	6.5	7.5	7.5
2012	October	9.0	7.5	8.5	8.5
2013	October	10.0	8.5	9.5	9.5
2015	October	12.0	10.5	N/A[a]	N/A[a]

[a] Due to highway construction, measurements could not be conducted for this site/year.

Results

Table 27 presents EFR values for the various measurement dates and sites. All the Type 3 sites had the same nominal pavement (ARFC), yet there were differences in the EFR values, which were possibly related to pavement porosity or other pavement parameters.

Table 26. EFR Values for the Pavements at the Type 3 Sites

Collection Date		Site 3A		Site 3B		Site 3C		Site 3D		Site 3E	
Year	Month	Age, years	EFR, cgs rayls	Age, years	EFR, cgs rayls	Age, years	EFR, cgs rayls	Age, years	EFR, cgs rayls	Age, years	EFR, cgs rayls
2007	October			2.5	7,600						
2010	October	7.0	12,000			5.5	13,200	6.5	24,000	6.5	11,700
2011	June					6.0	10,300				
2011	October	8.0	13,100			6.5	10,000	7.5	10,000	7.5	12,000
2012	October	9.0	13,800			7.5	16,000	8.5	30,000	8.5	18,700
2013	October	10.0	24,000			8.5	20,000	9.5	28,000	9.5	30,000
2015	October	12.0	15,200			10.5	11,800				
2015	October					1.0	900[a]				

[a] Site 3C South (alternative Site 3C) was tested in October 2015 as well, when this newly paved surface was less than 1 year old.

The EFR values from Table 27 are plotted in Figure 30 versus the pavement age, along with an exponential trend line through the data points. For the newest pavements—Site 3B aged 2.5 years and Site 3C aged less than 1 year—the EFR values were in the lower range for nonporous pavements. Within the pavement age range of 5.5 to 7.5 years, the pavement EFR values generally ranged between 10,000 and 15,000 cgs rayls. After 6.5 years, however, Site 3D had a pavement EFR value of 24,000 cgs rayls. It should be noted that data collection personnel qualitatively observed, as vehicles drove by, that tire/pavement noise at Site 3D sounded louder than at the other Type 3 sites. In the years from 8 to 10, results are somewhat inconclusive. Data collected in 2012 and 2013 showed that most EFR values were in the range of 15,000 to 30,000 cgs rayls, while data collected in 2015 showed EFR values in the range of 10,000 to 15,000 cgs rayls, similar to the values in the years between 5.5 to 7.5. The trend line indicates an upward movement in EFR values with time; however, there is considerable scatter in the data around this line, which has an R^2 of 0.29. As stated above, EFR is considered on a nonlinear scale, and differences in values at the higher end of the range may represent only slight differences in pavements. However, none of the EFR values fall within the range (1400 to 2000 cgs rayls) that indicates a porous pavement.

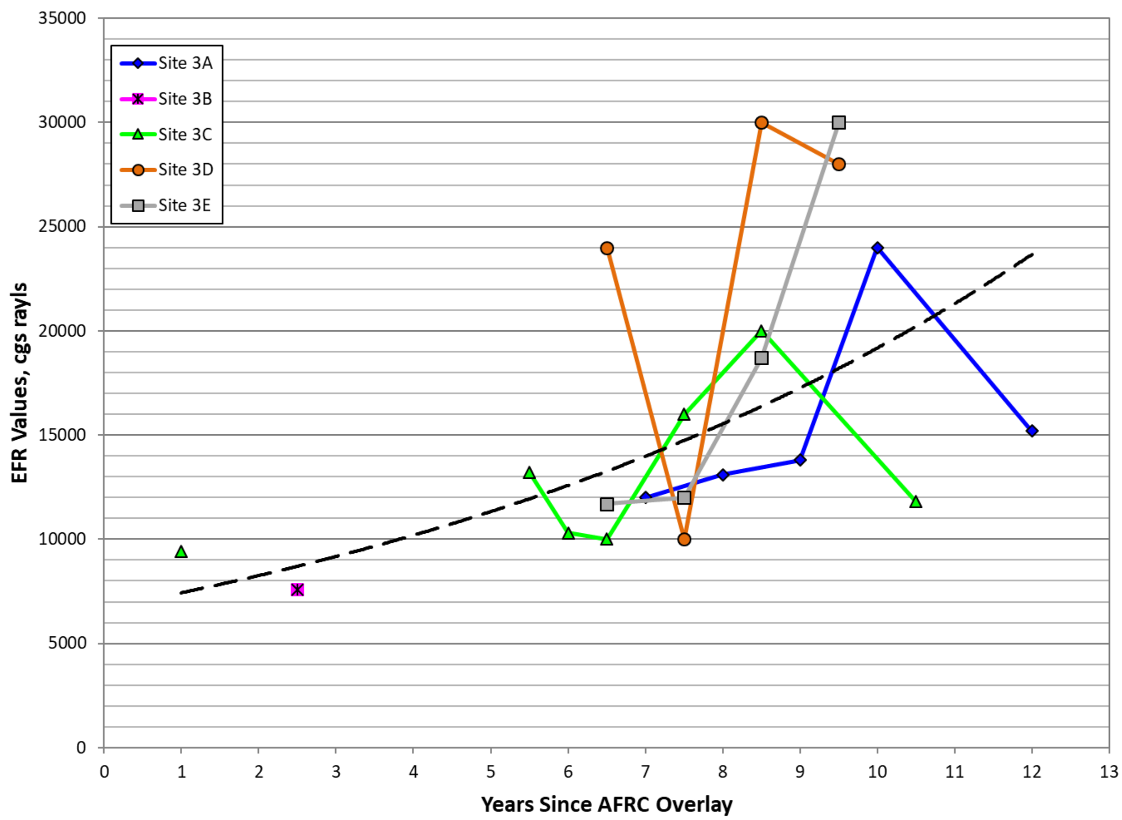

Figure 30. EFR Values for Type 3 Sites Versus Pavement Age

Impedance Tube Measurements

Description

The sound absorptions of the ARFC pavement at Type 3 Sites 3A, 3C, 3D, and 3E were quantified using the ISO 13472-2 impedance tube method (ISO 2010). Under this method, an impedance tube is placed vertically on, and sealed to, the pavement. The other end of the tube is terminated with an acoustic driver (speaker), which broadcasts wide-band noise into the tube. The transfer function between two microphones inserted into the side of the tube is measured. If the microphones are not phase-matched, they can be switched to compensate for phase differences. From the transfer function, the sound absorption coefficient can be calculated. Leakage and parasitic losses are determined from measurements with a steel plate inserted between the pavement and the tube, as is shown in Figure 31. The sound absorption measurements reported here for the Type 3 sites were made each year from 2010 through 2014 by personnel from the National Center for Asphalt Technology. The dates and locations are given in Table 28. At each of the four Type 3 sites, impedance measurements were made at three spots, and three samples were taken at each spot. The data were obtained in one-third octave bands from 315 to 1600 Hz.

Figure 31. Impedance Tube Installed on Pavement (Left), Sealing Ring Installed on the Pavement (Top Right), and Steel Plate Inserted Between Pavement and Impedance Tube (Lower Right) (Seybert and Martinus 2009)

Table 27. Location and Dates of Impedance Tube Sound Absorption Measurements

Site	Location	Test Dates
Site 3A	SR 101 WB Between Milepost 20 and 21	October 12, 2010 October 20, 2011 October 16, 2012 October 15, 2013 October 14, 2014
Site 3C	I-10 EB Between Milepost 159 and 160	October 13, 2010 October 19, 2011 October 17, 2012 October 16, 2013 October 15, 2014[a]
Site 3D	SR 202 WB Between Milepost 18 and 19	October 13, 2010 October 18, 2011 October 17, 2012 October 16, 2013 October 15, 2014
Site 3E	SR 101 SB Near Milepost 47	October 14, 2010 October 19, 2011 October 18, 2012 October 17, 2013 Canceled[b]

[a] The exact location that was previously tested had been repaved. At the direction of ADOT, the tests were run on the shoulder, which represented a similarly aged pavement.

[b] This roadway section was under construction. ADOT canceled sound absorption testing at this location.

Results

Figure 32 plots the average sound absorption percentage for each of the measured Type 3 sites versus the year of the measurement. Unlike the EFR data in Figure 30, the sound absorption data show very little change with time. The percentages of sound absorption are quite low, averaging about 8 percent. With a sound absorption value of 10 percent, the reflected sound would be only about 0.5 dBA lower than the sound coming directly from the tire. For a surface with an absorptive value of 90 percent, the reflected sound would be reduced by 10 dBA. In research sponsored by Caltrans, a number of different pavements included in their Quieter Pavement Research Projects were measured for sound absorption percentage also using impedance tube methods (Ongel et al. 2007). It was found that open-graded asphalt concrete (OGAC) mixes provided sound absorption percentages of 20 percent, on average, while gap- and dense-graded mixes typically provided absorption of 4 percent. It was also found that not all OGAC pavements produce higher sound absorption percentages. The ADOT ARFC is an open-graded mix; however, it has not been found to be porous (see Appendix A). This finding has been attributed to smaller aggregate size and/or higher binder content than is seen in other OGAC mixes.

The conclusion that the ARFC used for QPPP is not porous is also supported by the measured one-third octave sound absorption percentages. Figure 33 shows the sound absorption results for the porous open-graded pavements measured in the Caltrans research. These pavements typically reach a maximum absorption percentage of 60 percent or more in frequency bands above 800 Hz. Figure 34 shows absorption percentages for pavements that were concluded to be nonporous. Two of these, ES05 RAC(O) and QP29 OGAC, are open-graded, with somewhat higher absorption percentages, and the other three are not open-graded, with typically lower percentages of about 11 percent or less. The average absorption percentages of the porous and nonporous pavements are shown in Figure 35. In Figure 36, these are compared with the average absorption at each of the Type 3 Sites. This comparison also indicates that the ARFC at these sites is not porous.

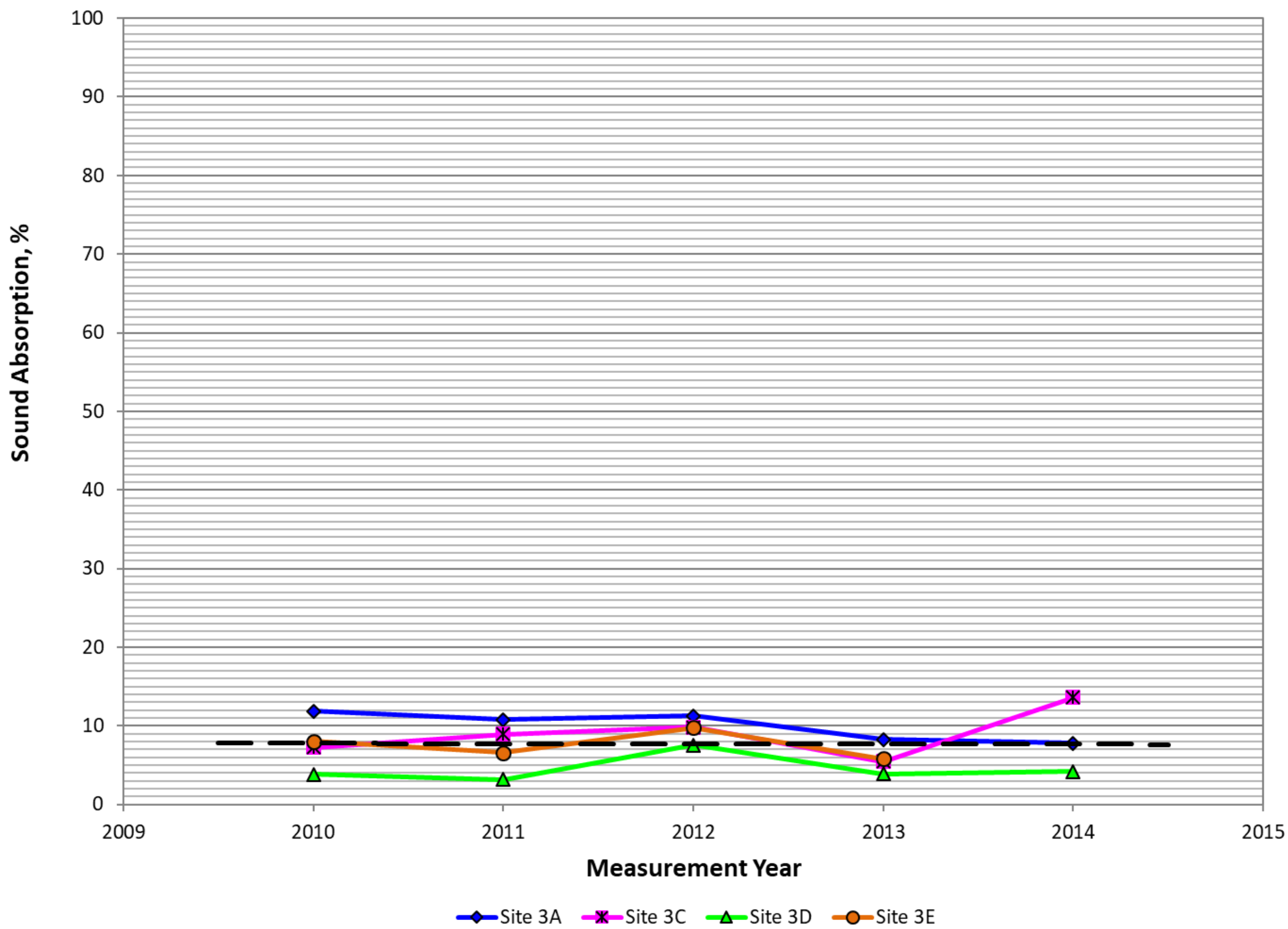

Figure 32. Overall Average Sound Absorption Percentage for Type 3 Sites for Five Measurement Years

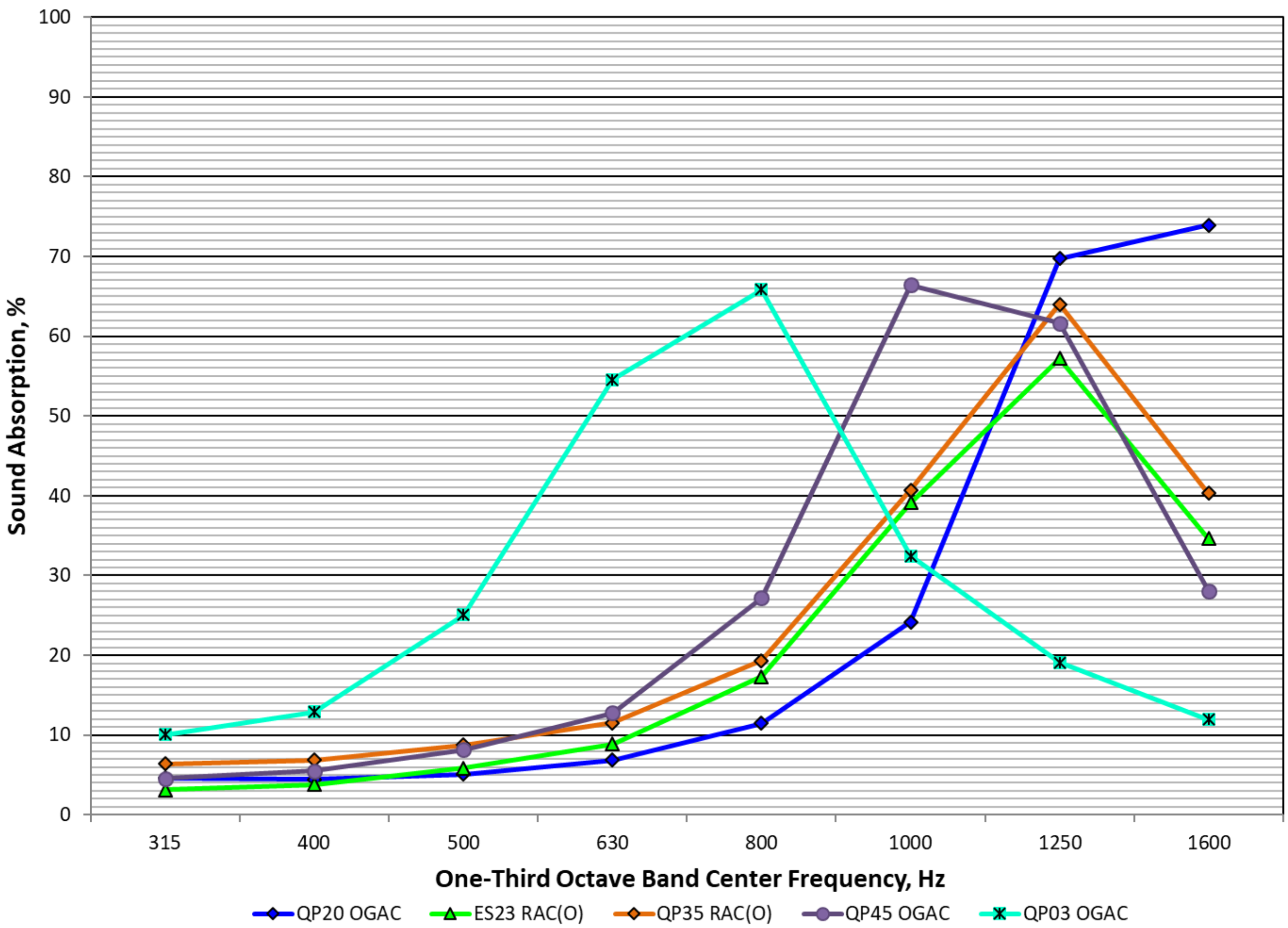

Figure 33. Sound Absorption Percentages for Porous, OGAC Pavements in California (Ongel et al. 2007)

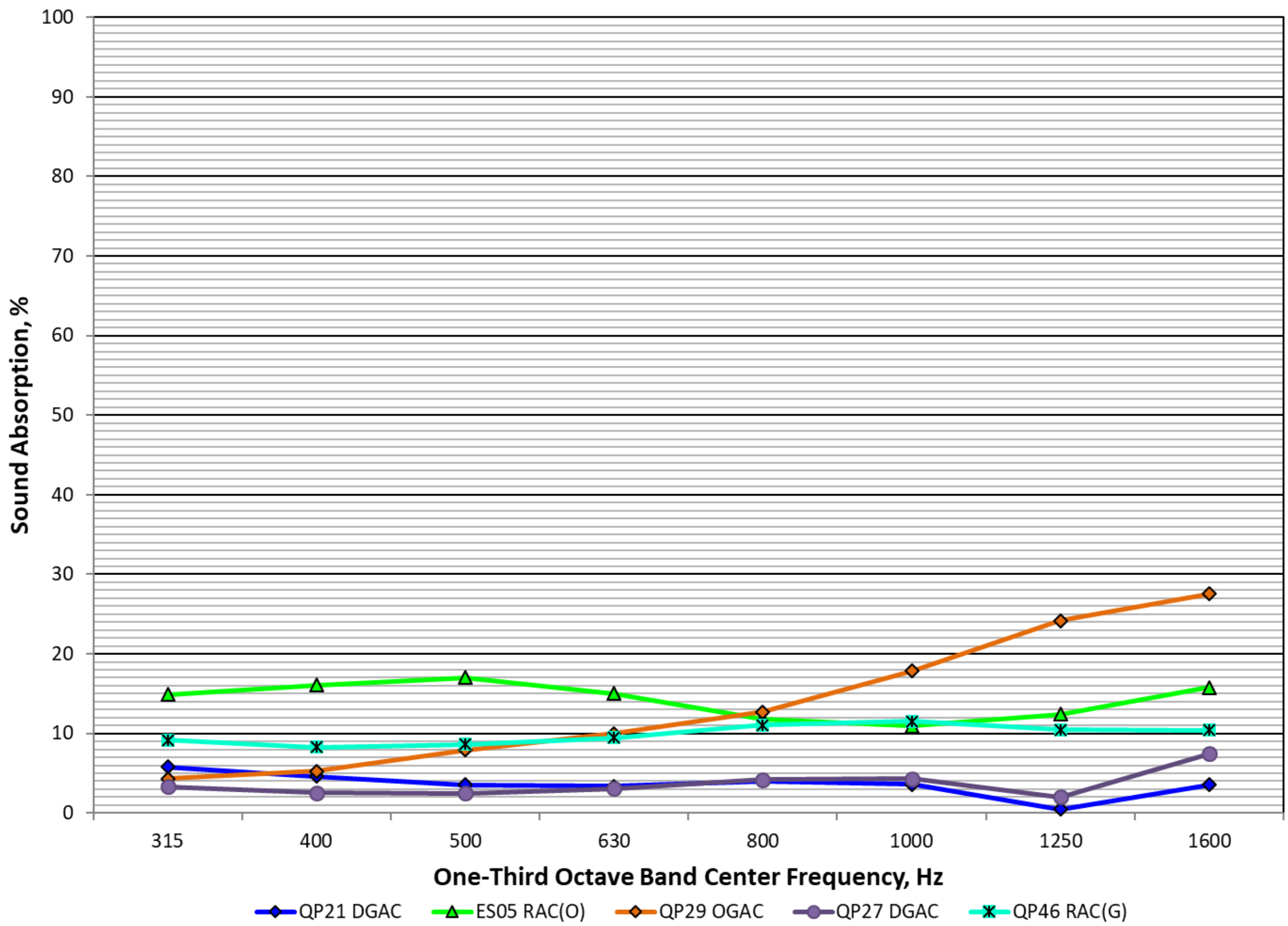

Figure 34. Sound Absorption Percentages for Nonporous Pavements in California (Ongel et al. 2007)

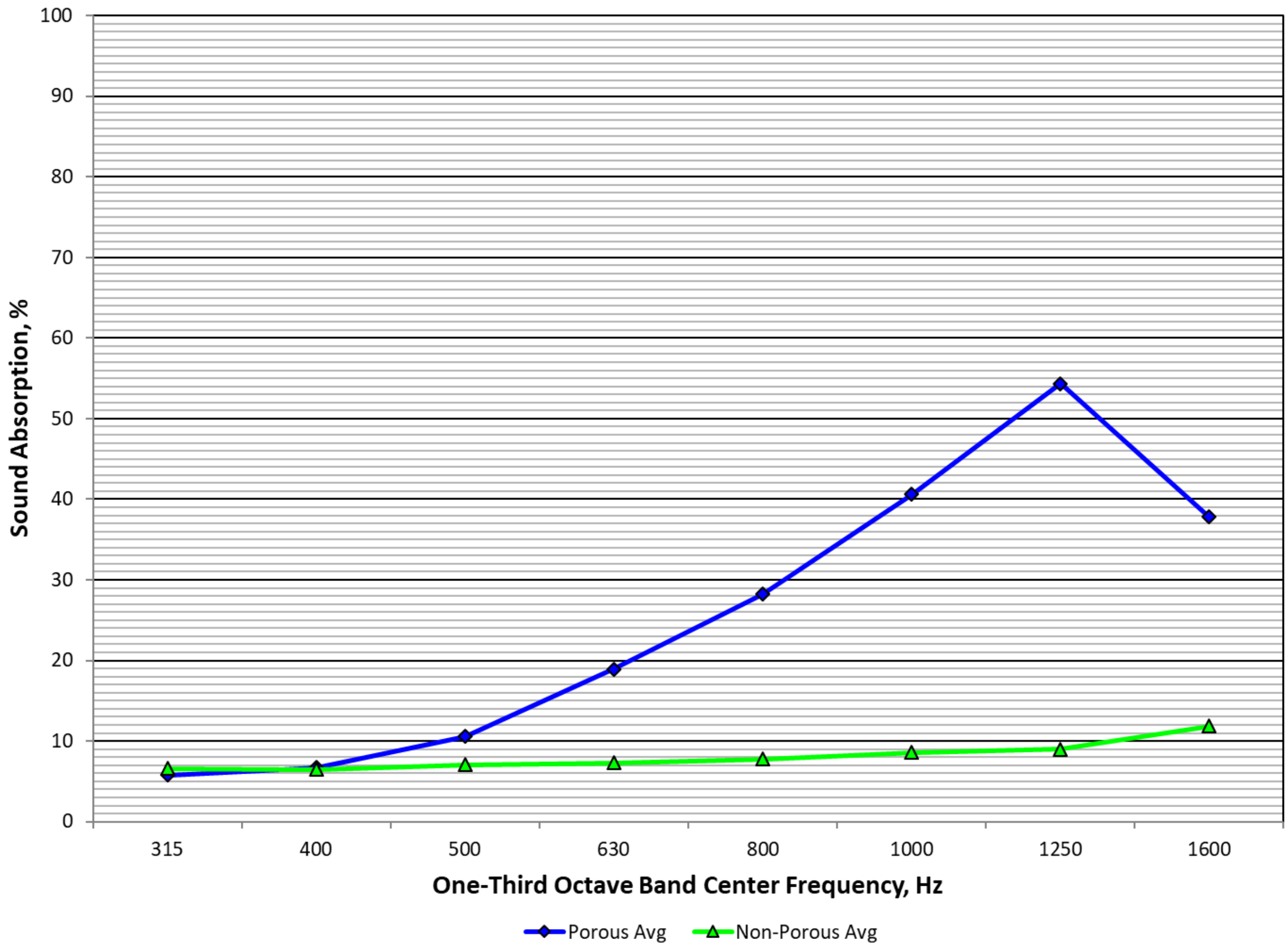

Figure 35. Average Sound Absorption Percentages for Porous and Nonporous Pavements in California

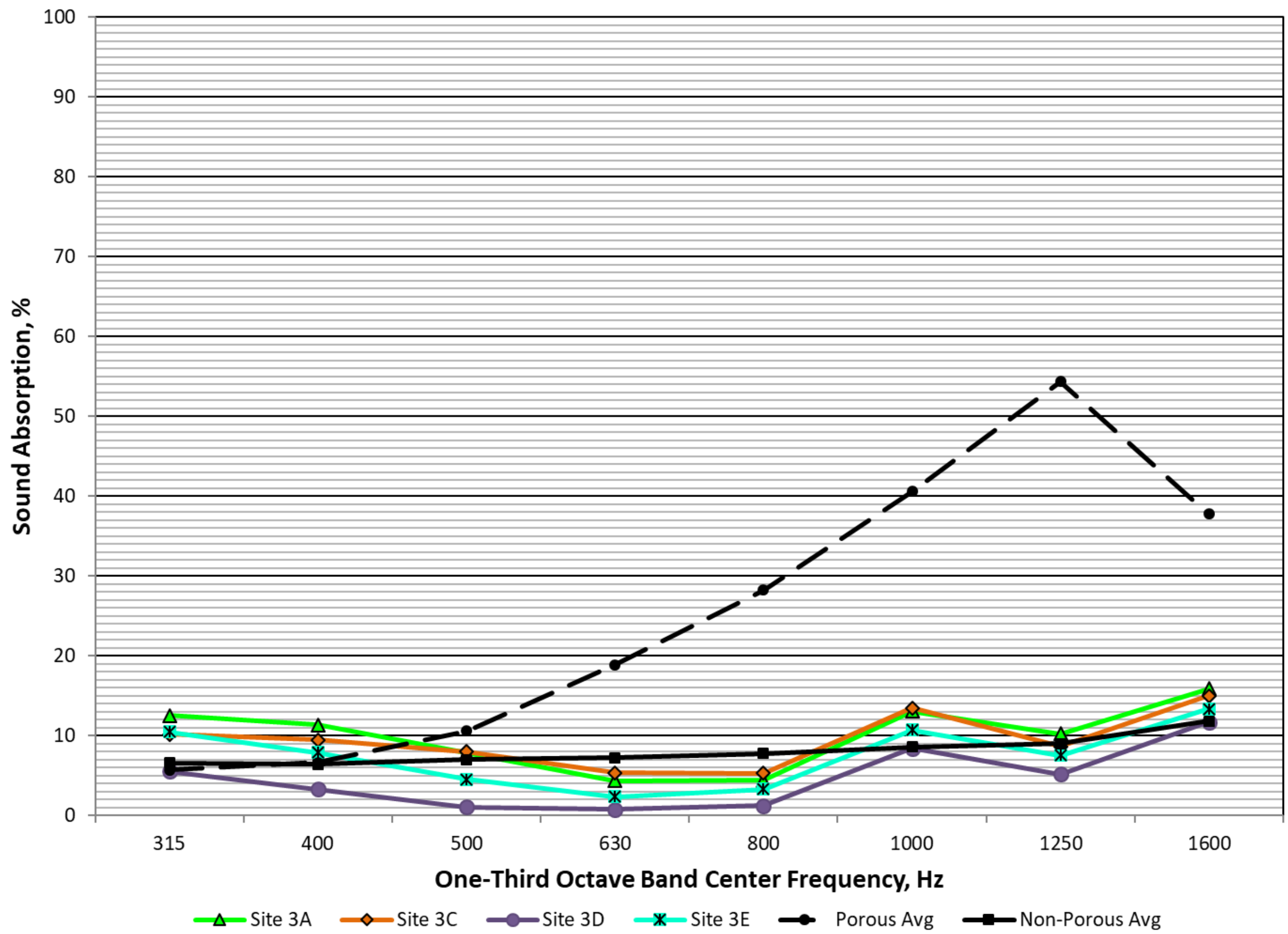

Figure 36. QPPP Type 3 Site Averages Compared to California Average Porous and Nonporous Pavement Sound Absorption Percentages

PAVEMENT SURFACE CHARACTERISTICS

Mean Profile Depth

Mean profile depth (MPD) was determined from measurements made with an outflow meter. These measurements were made regularly at Sites 3A, 3C, 3D, and 3E between 2010 and 2015. For nonporous pavement, the outflow from the meter was an indication of the MPD. MPD relates to tire/pavement noise, since increases in MPD typically imply increases in surface roughness. In the lower frequencies (below about 1000 Hz), the roughness generates increased noise through increased tire vibration (Sandberg and Ejsmont 2002). In the higher frequencies, roughness could cause a noise increase through increased air displacement between the rougher surface and the tire tread (Sandberg and Ejsmont 2002). However, the noise increase in the higher frequencies could also be caused by surface polishing, which creates less friction and more tire noise through less scrubbing of the tire tread on the surface (Rymer et al. 2010).

Figure 37 shows the MPD determined by the outflow meter for the four Type 3 sites for each of the measurement years. Each data point represents the average of the right and left wheel paths and the center of the lane. The measurements were conducted in the auxiliary lanes at all sites except Site 3D, where the outside lane was used. Averaging the results for each year produces an upward trend line in which MPD increases with each year. These data display some scatter, since in some cases MPD goes down from one year to the next. However, overall, there is a clear upward trend. To put the sites in rank order, the data for each year were averaged site-by-site. This indicated that Site 3A had the greatest average MPD, with Sites 3D having the lowest. Sites 3C and 3E fell about midway in the ranking.

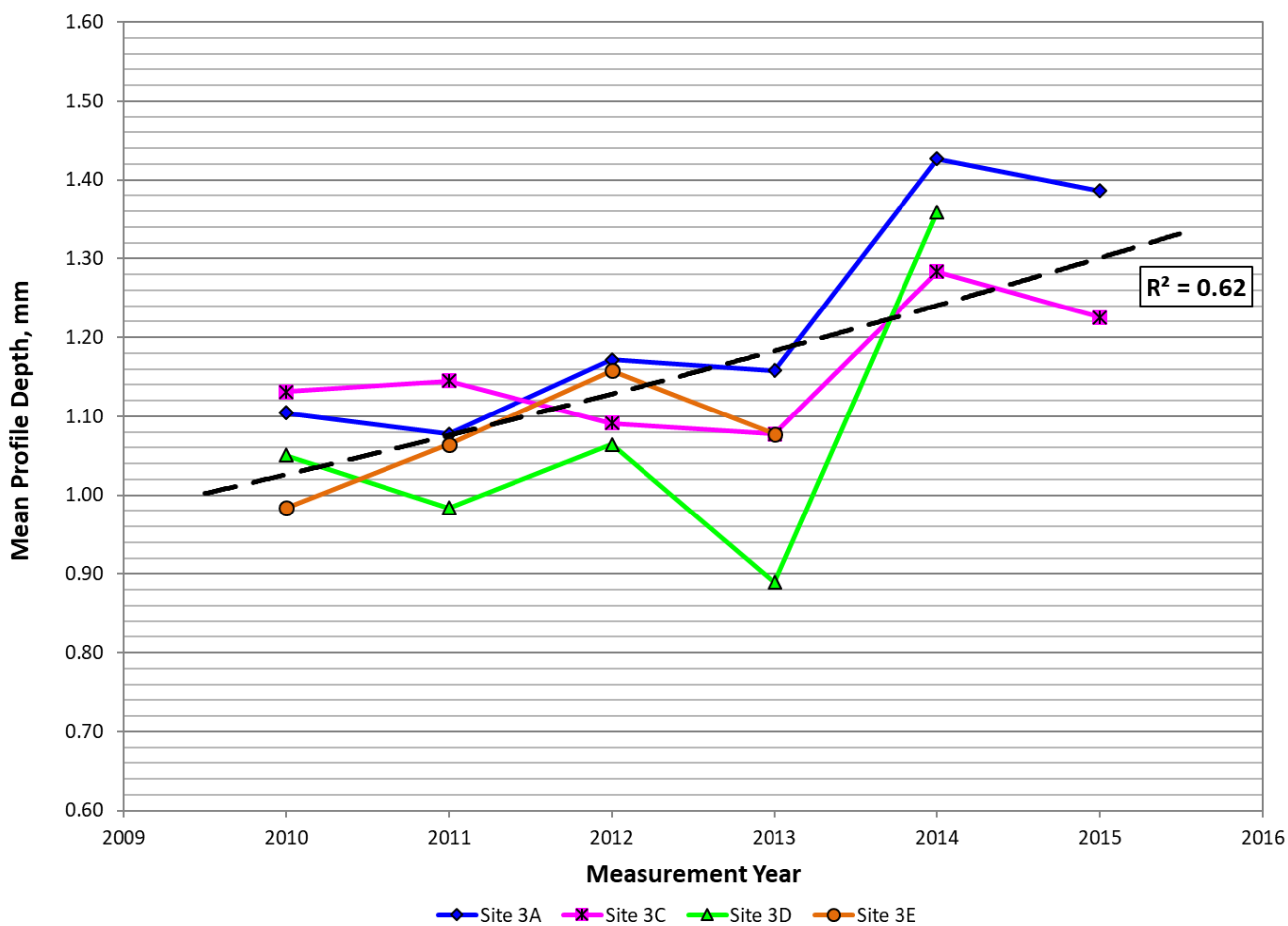

Figure 37. Mean Profile Depth for Sites 3A, 3C, 3D, and 3E from 2010 to 2015

COMPARISON OF PAVEMENT MEASUREMENTS

To compare the different types of pavement data, the averages for each site were calculated for the years in which the different types of data were collected. Although the numbers of data points were limited to just four, the resultant averages were plotted against one another to reveal any possible trends. As may be expected, there was a consistent relationship between the EFR data and sound absorption, as shown in Figure 38. Also, the higher EFR values corresponded to lower sound absorption percentages. In the comparison of sound absorption with MPD (Figure 39), there was a relationship between these values in which sound absorption increased as MPD increased. There was also a relationship between EFR and MPD, as is shown in Figure 40, but the relationship was weaker than those portrayed in Figures 38 and 39.

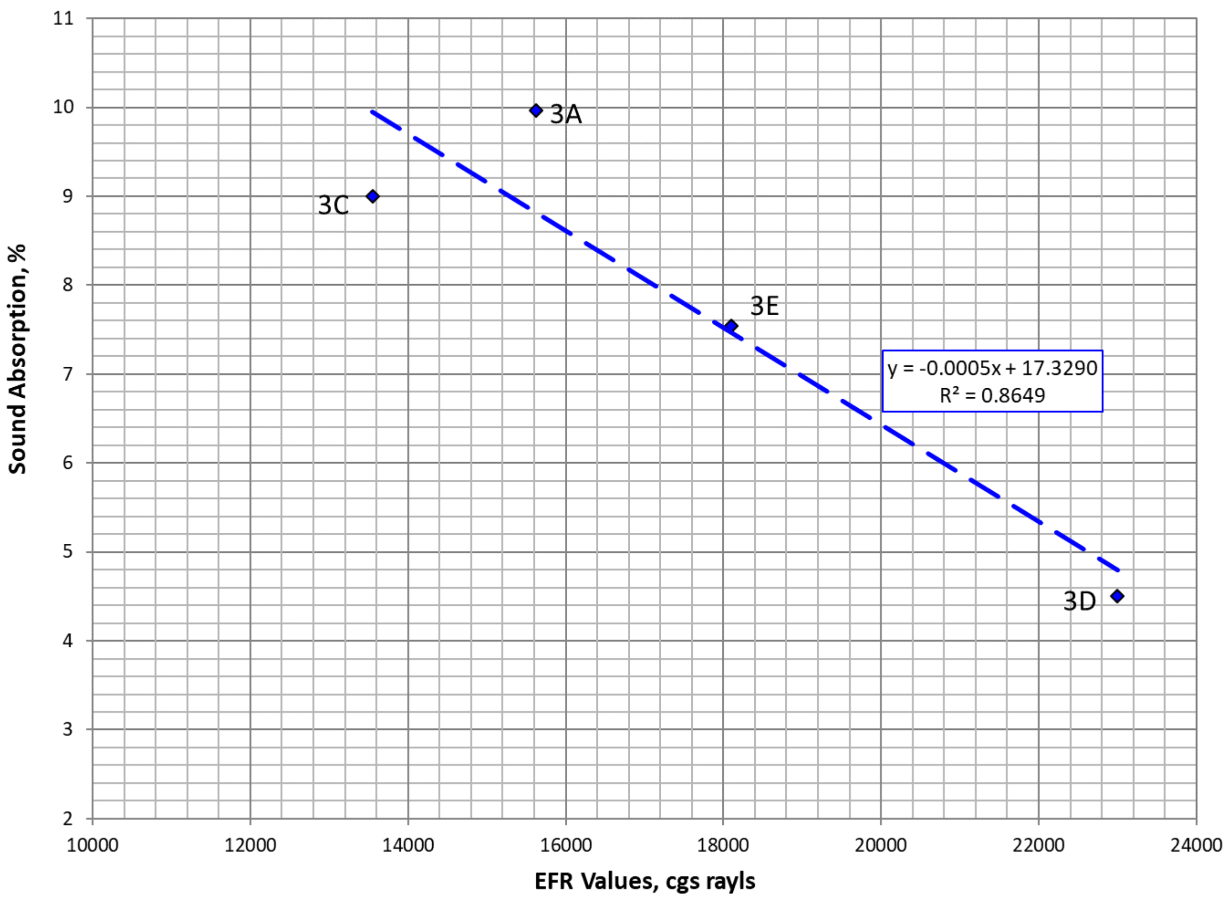

Figure 38. Sound Absorption and EFR Average Values for Sites 3A, 3C, 3D, and 3E

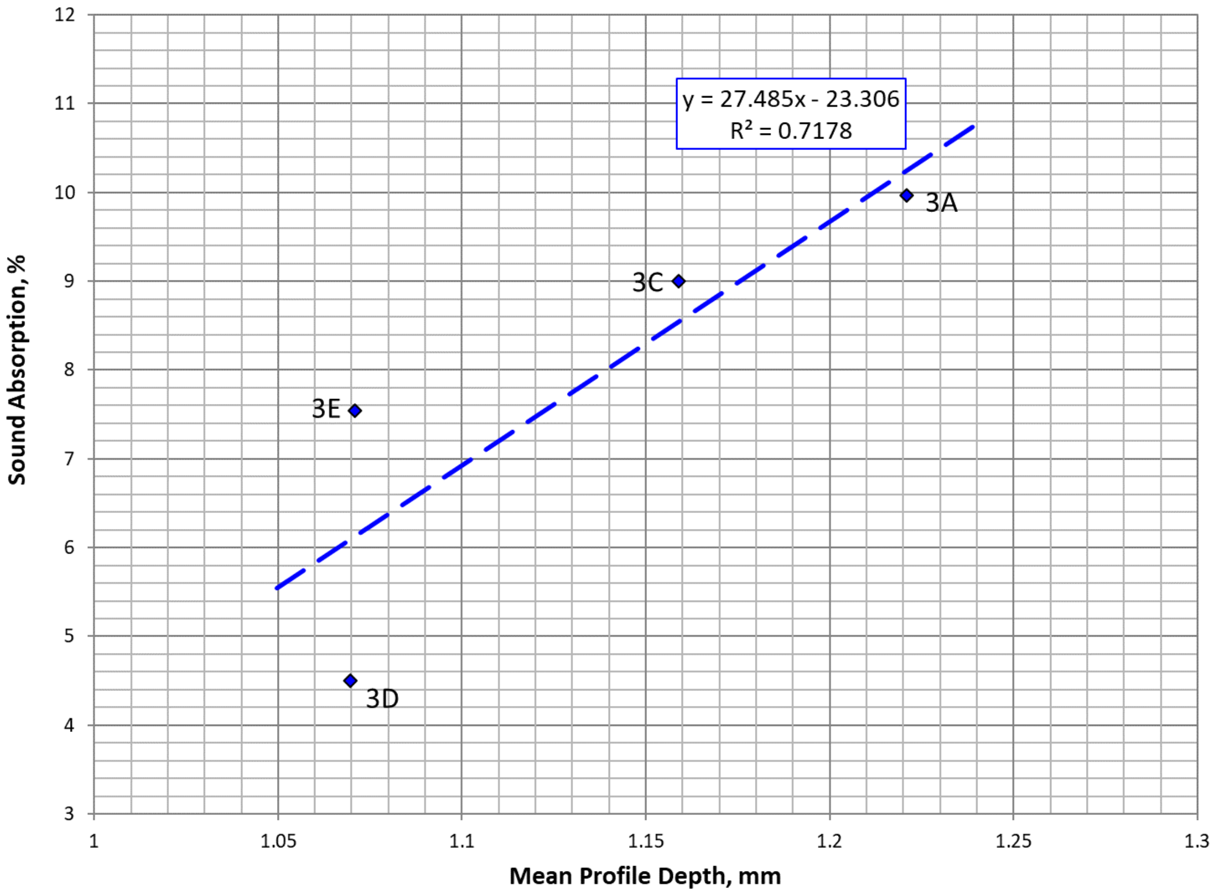

Figure 39. Sound Absorption and MPD Average Values for Sites 3A, 3C, 3D, and 3E

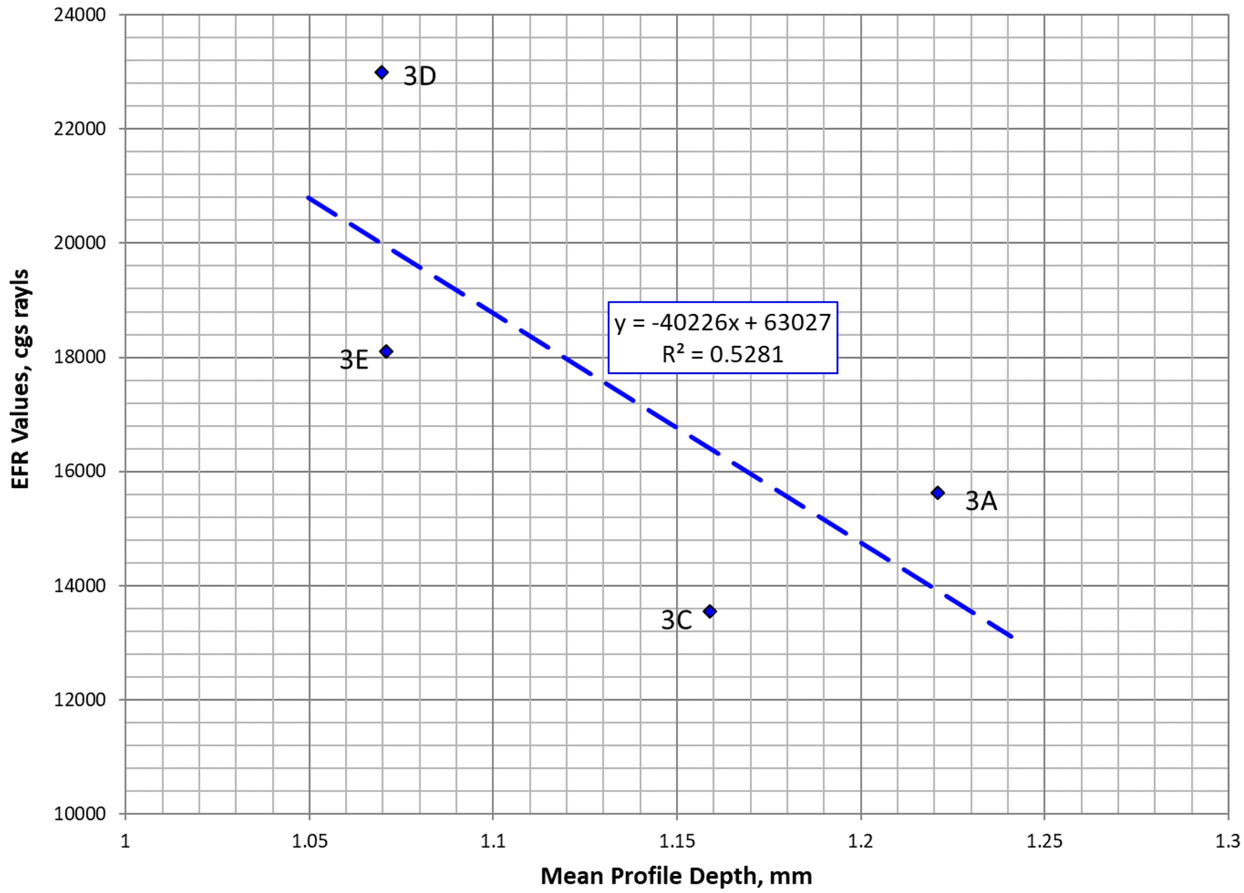

Figure 40. EFR and MPD Average Values for Sites 3A, 3C, 3D, and 3E

CHAPTER 5. PRELIMINARY STUDIES AND ADDITIONAL RESEARCH

Prior to the start of the QPPP, several preliminary studies were performed that led to the selection of ARFC pavement as the choice for the pilot project. These studies included a survey of in-service ARFC pavement throughout Arizona, the construction and testing of asphalt test sections in Casa Grande, Arizona, and the construction and testing of PCC sections with different textures. During the QPPP, an elevated PCC section of the SR 202 freeway at the eastern intersection of I-10 was ground with different methods, and testing was initially conducted in 2003 and periodically through 2007. The Casa Grande sections were first tested in 2002 and periodically tested through 2010.

STATEWIDE ARFC SURVEY, 2002

Before FHWA approval for the QPPP was received, a research effort was completed to determine the change in ARFC acoustic properties with time. Since the use of ARFC overlays on portland cement concrete pavement (PCCP) had been very limited, it was not possible to directly conduct the research with that material. However, since 12.5-mm-thick ARFC over flexible pavements has been used for many years, it was possible to evaluate the change in acoustic properties for that type of construction. Accordingly, 18 pavement projects using ARFC in similar environments were identified on the Arizona Interstate network on I-10, I-8, and I-19. The dates of construction of these pavements ranged from 1988 to 1999, yielding an age range of 3 to 17 years. The pavements were tested using both the OBSI method and the CPX method initially employed by ADOT. Both methods used Goodyear Aquatred P205/R15 test tires and a test speed of 60 mph.

Figure 41 presents the results of this study. The data indicate some scatter in both the OBSI and the CPX results. For pavements of nearly the same age, the difference in noise levels between the two test methods can be as much as about 3 dBA . The R^2 values for the linear trend lines in Figure 41 are low: 0.42 for the OBSI data and 0.64 for the CPX. The standard deviations about the trend lines are 1.8 dBA for the OBSI and 1.3 dBA for the CPX. However, the trends are parallel with an offset of 2.7 dBA. Despite the scatter in the results, there was some tendency of increased noise with pavement age. Prior to the QPPP, the PCCP to be overlaid produced overall A-weighted OBSI levels from about 107 to 109 dBA and CPX levels from about 104 to 106 dBA. As a result, ARFC overlays were expected to provide an improvement of at least 5 dBA over the pre-overlay PCCP levels regardless of pavement age up to 12 years. With proper pavement specification and quality control, it was expected that initial tire/pavement noise reductions of 8 dBA or greater would be achieved. These data helped to support the use of a 4 dBA “credit” in the QPPP for quieter pavement . These initial projections were somewhat supported by Table 3, which shows an initial average reduction with the ARFC of 8.7 dBA and an average reduction of 3.2 dBA after 12.5 years. A portion of this discrepancy is due to the finding that the average PCCP noise levels prior to the overlay were actually about 1.5 to 3.5 dBA lower than expected.

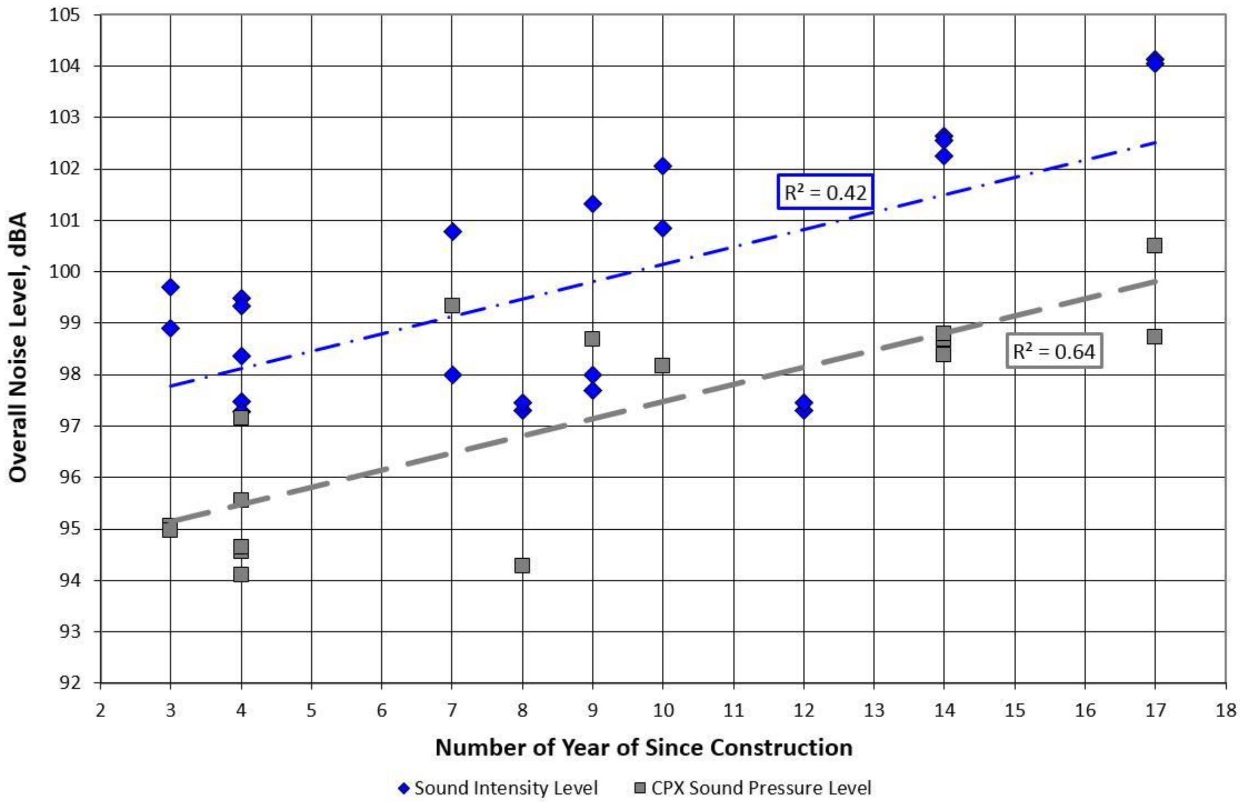

Figure 41. OBSI and CPX Tire/Pavement Noise Levels for Existing ARFC Pavements of Different Construction Years

CASA GRANDE AC PAVEMENT TEST SECTIONS

In 2000, ADOT had built a series of asphalt concrete (AC) test sections at rural locations on the interstate highway system. The purpose of these sections was to collect consistent noise data on various pavements that were expected to be quieter. The test pavements were an asphalt rubber asphalt concrete friction course (ARFC), a non-rubber asphalt concrete friction course (ACFC), a stone mastic or matrix asphalt (SMA), a porous ACFC (P-ACFC), and a porous European mix (PEM). Six samples of each pavement were installed in a randomized driving order along I-10 near Casa Grande, Arizona. All of these pavements had a maximum aggregate of 19 mm, except for the PEM, which was 32 mm. The initial OBSI measurements were made in 2002. By that time, the sections had been exposed to mixed interstate vehicular traffic for about two years.

Figure 42 shows the overall noise levels measured in May 2002 for 27 sections (four pavements with six sections each and one pavement of three sections). Except for the ACFC and the P-ACFC, the other pavements show variations of 2 to 2.5 dBA over the samples in their sample sets. The lowest measured level was from Sample 3 of the ARFC pavement (96.6 dBA), and the greatest level was measured at Sample 6 of the PEM pavement (102.5 dBA), which is a total range of about 6 dBA. The average for the samples of each pavement type (Figure 43) show that ARFC produced noise levels 2.6 dBA lower than the second-quietest pavement (ACFC) and 4.1 dBA lower than the loudest pavement (PEM).

Similar to the results from California's QPR, the one-third octave band spectra indicate that it is in the lower to middle frequencies, below 1250 Hz, where the ARFC pavement produced consistently lower noise levels (Figure 44). It may be noted that this frequency region is often controlled by surface roughness and hence aggregate size; however, in this case, the aggregate size was common to all pavements except the PEM. However, the gradations of the aggregate sizes were not necessarily the same. Further, the binder content was high for the ARFC. Both of these factors could contribute to the lower noise levels of the ARFC in the frequencies below 1250 Hz. As expected, the larger-aggregate PEM produces higher noise levels in the lower frequencies of 500 and 630 Hz. Above 1600 Hz, the effect of the porosity of the P-ACFC and PEM pavements is apparent from the lower levels produced by these pavements.

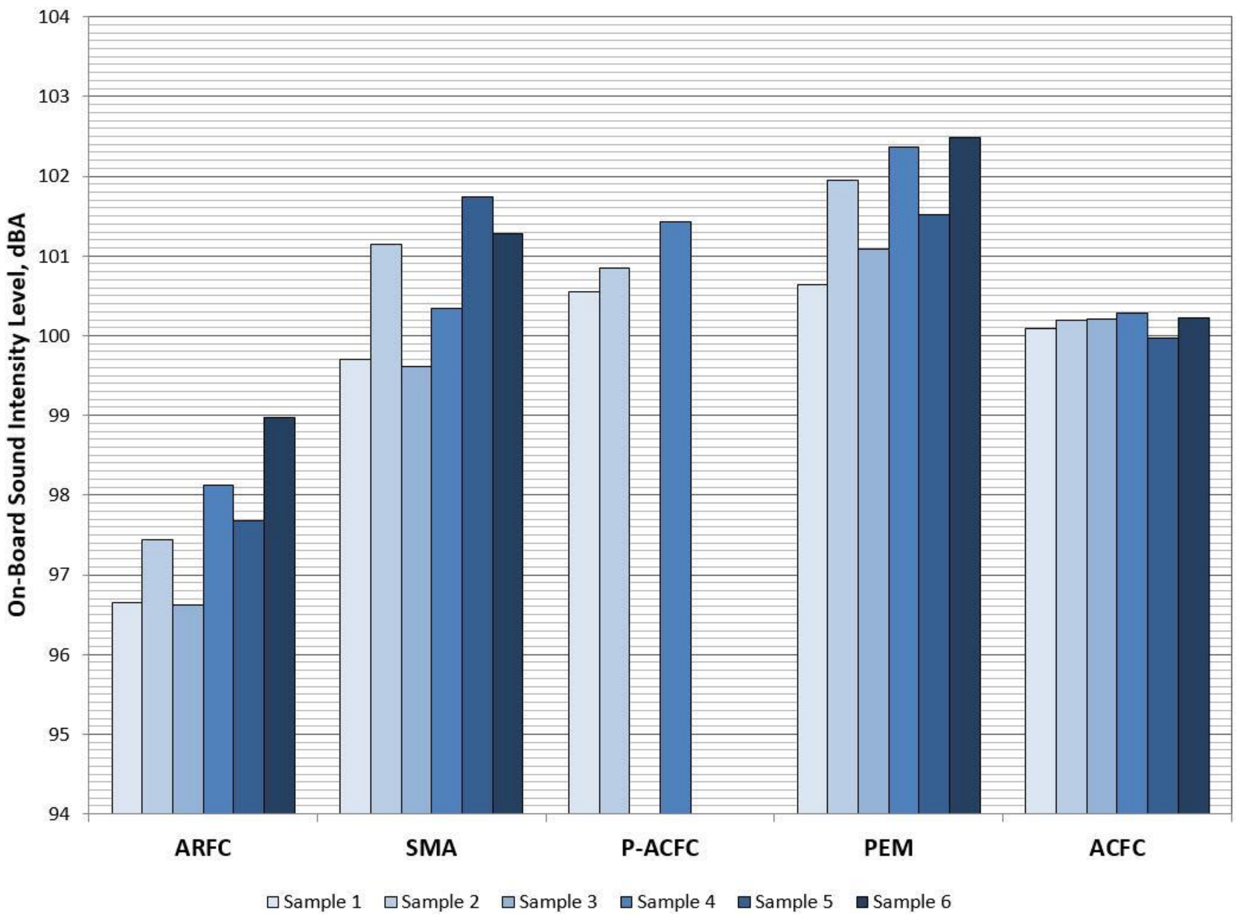

Figure 42. Overall OBSI Noise Levels for the Initial 2002 Casa Grande Measurement Period

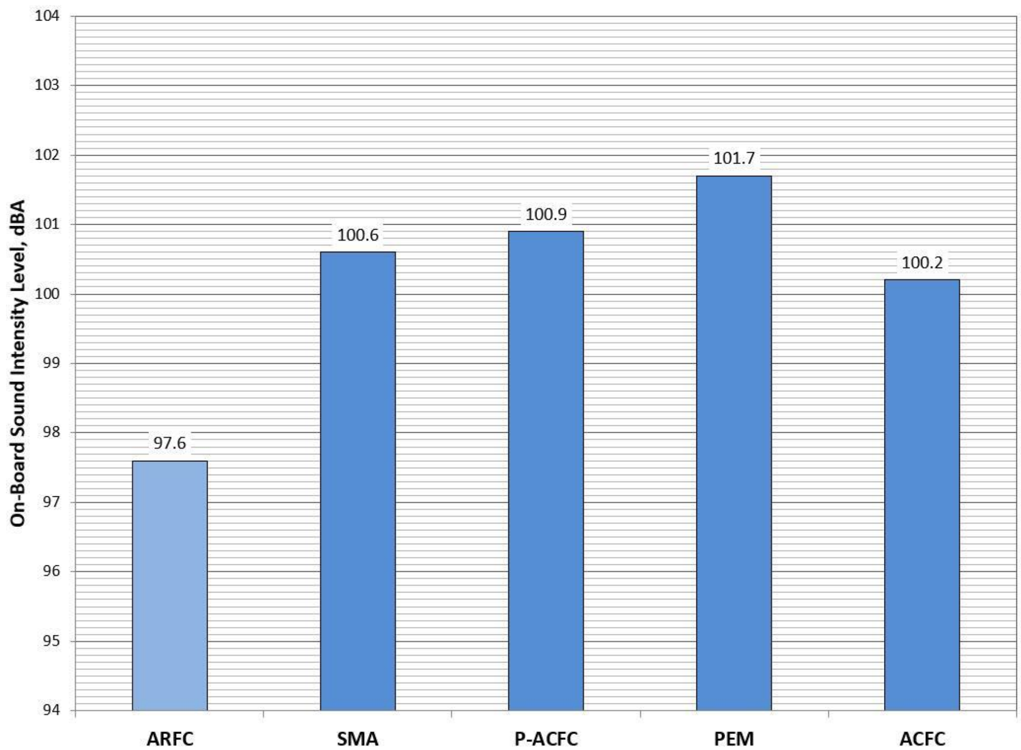

Figure 43. Average Overall Noise Levels for the Initial 2002 Casa Grande Measurement Period

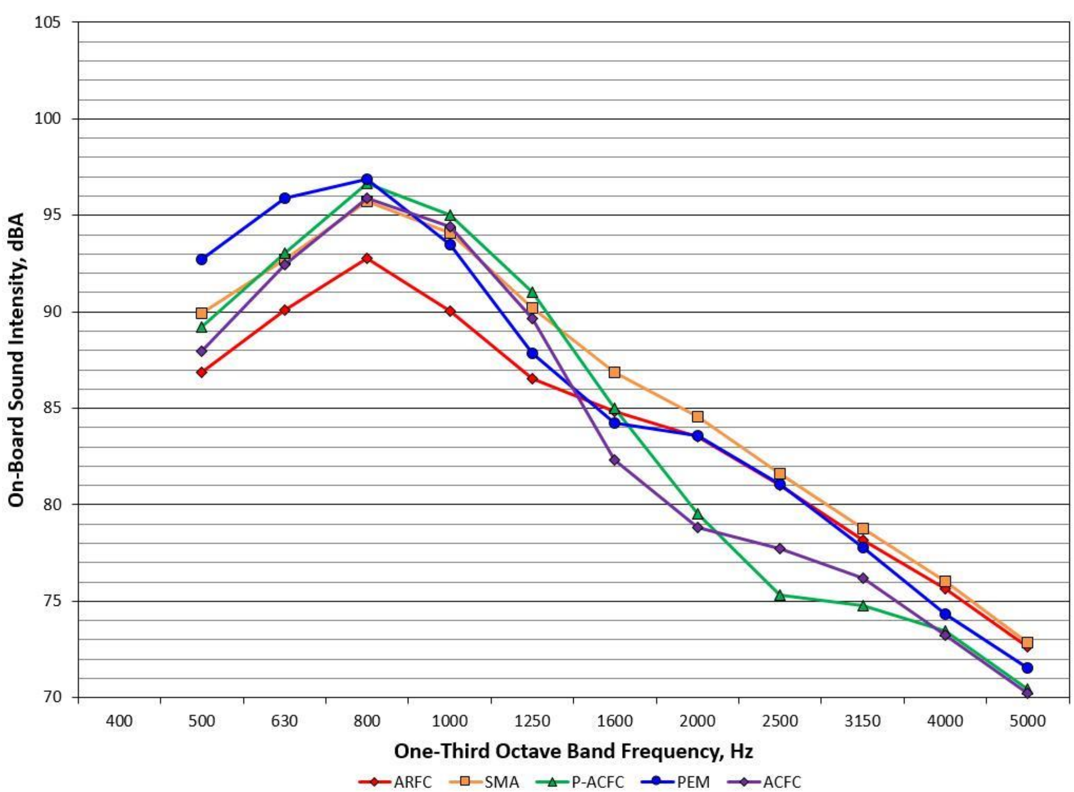

Figure 44. One-Third Octave Band Spectra for the Casa Grande Sections in May 2002

In addition to the initial 2002 tests, measurements were made at these Casa Grande sites in March 2005, March 2007, October 2008, November 2009, and November 2010. Figure 45 shows the overall noise levels measured at the sites during each measurement period. The ARFC pavement consistently resulted in the lowest overall levels. Typically, the ARFC pavement had levels about 4 to 6 dBA lower than the loudest pavement. While the PEM resulted in the highest initial levels in 2002, in all other years, the pavement that resulted in the highest overall noise levels was the P-ACFC. By November 2010, the overall level at the P-ACFC pavement was an average of 106.8 dBA, which was 1 to 4 dBA higher than the levels at the other pavements.

To examine the longevity of the Casa Grande pavements, the overall noise levels from Figure 43 were plotted against the age of the pavements in each corresponding measurement period. The overall OBSI levels versus pavement age are shown in Figure 46. The ARFC, SMA, and ACFC pavements increase at relatively similar rates: 0.48 to 0.65 dBA/year. The P-ACFC pavement shows a slightly steeper rate of increase, 0.71 dBA/year. This greater rate of increase could be due to the deterioration of performance in the lower frequency ranges of the spectra, likely reflecting the raveling of the pavement. The trend line for the PEM pavement shows the greatest difference from the others. While this pavement resulted in the highest initial OBSI level at Year 2, the rate of increase was only 0.39 dBA/year. However, the R^2 for the PEM pavement was the worst of the five sites at 0.66. Overall, the R^2 values were fairly good for the other four sites, ranging from 0.85 to 0.96.

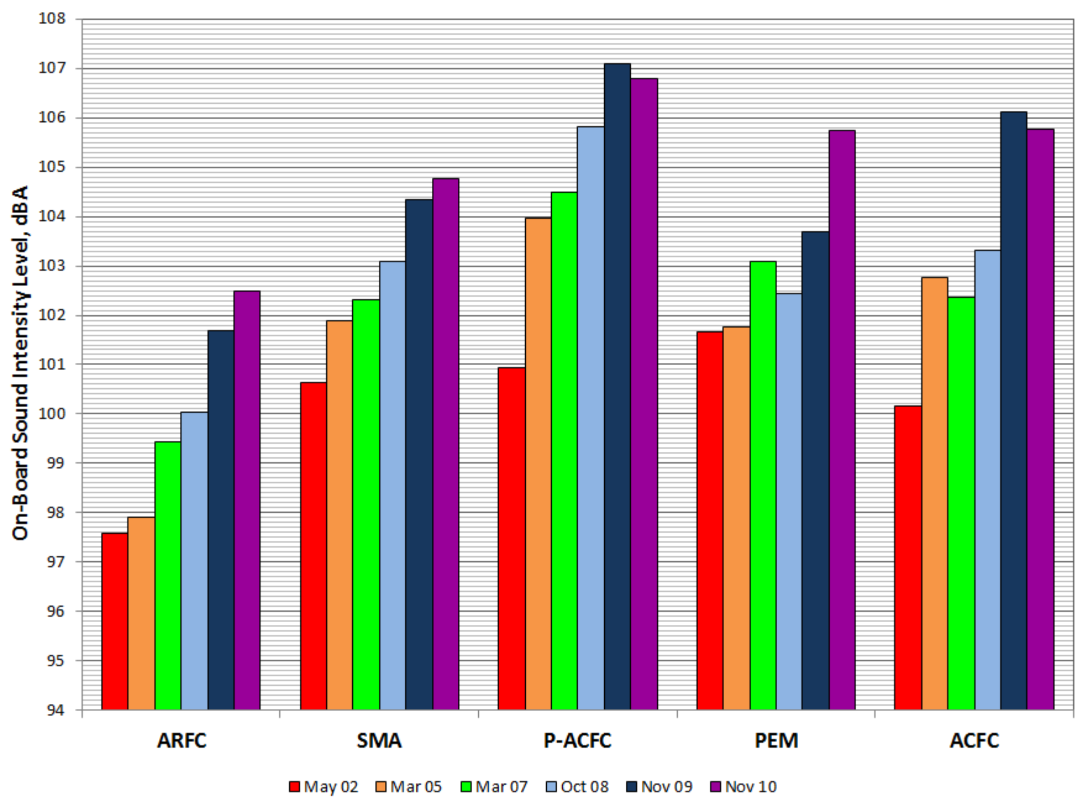

Figure 45. Overall Averaged OBSI Levels for Each of the Casa Grande Test Sites During Each Testing Period

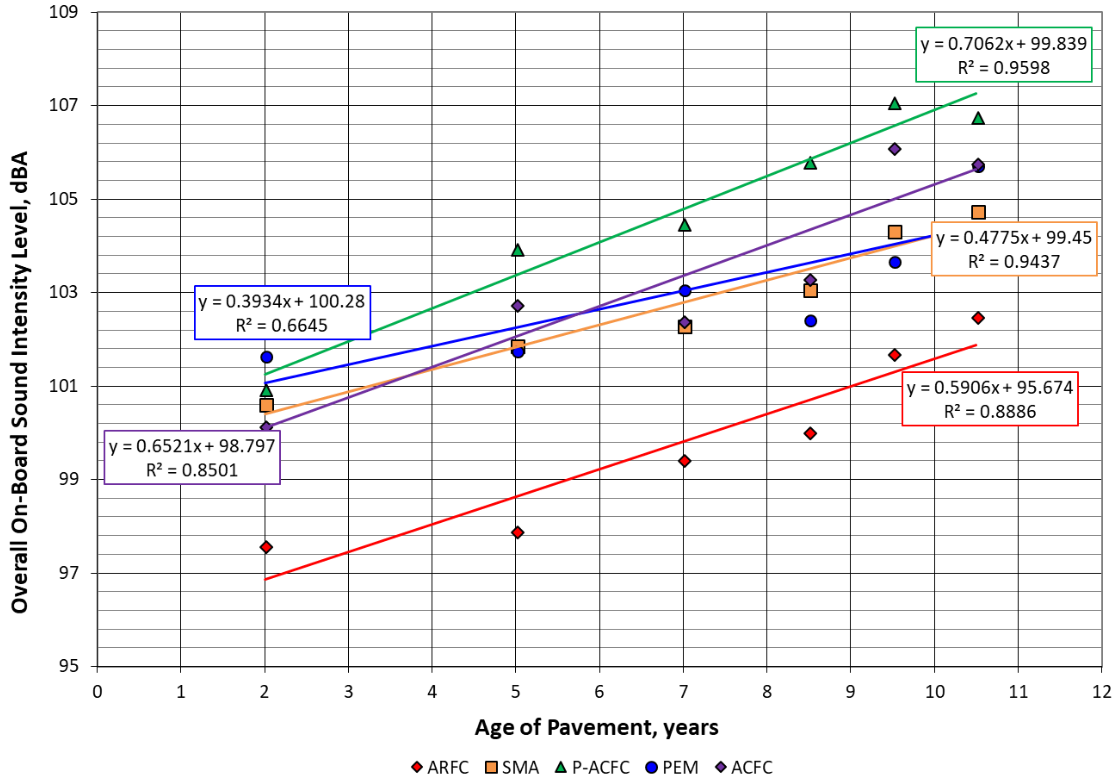

Figure 46. Overall OBSI Levels Versus Age, in Years, of the Casa Grande Test Sites

Figures 47 through 51 show the spectra for the five pavement types from the initial 2002 measurements through the November 2010 measurements. At each pavement type, the general shape of the spectrum measured in 2002 remained fairly consistent throughout the life of the test sections.

As Figure 47 shows, a steady increase of 1 to 3 dBA throughout the frequency range typically occurred over time at the ARFC sites, except at the March 2005 testing period. From 2002 to 2010, an increase of about 4 to 5.5 dBA was measured at frequencies of 1250 Hz and below, while an increase of about 2.5 to 4.5 dBA was measured in the frequency bands above 1250 Hz. In the March 2005 testing period, the levels in the 630 and 800 Hz bands were slightly (1.5 dBA) below those in the original 2002 testing period. At frequencies above about 1000 Hz, the March 2005 spectrum was about 1 to 3 dBA higher than the 2002 spectrum and similar to the spectrum shape of the subsequent years. In Figure 48, the average March 2005 spectrum at the SMA sites showed similar behavior. For the bands below 800, noise levels were about equal to those of the 2002 spectrum. At 1000 Hz and above, the levels increased substantially, by 2 to 4 dBA, above those of the 2002 spectrum. This portion of the March 2005 spectrum was actually equal to or higher than the spectra for years through 2008. Overall, there was a 2.5 to 5 dBA increase from 2002 to 2010 measured at all frequency bands on the SMA pavement.

For the remaining three pavement types, the March 2005 spectra displayed trends similar to those of the ARFC and SMA pavements in the higher frequencies. For the spectra shown in Figure 49 for the P-ACFC pavement, the greatest increases were measured at frequencies below 1000 Hz and at frequencies between 1600 and 3150 Hz. From 2002 to 2010, the levels in the lower frequency range increased by 6 to 7 dBA, while at the higher frequencies, levels increased by 5.5 to 8 dBA. For the PEM pavement, the increase from 2002 to October 2008 was less than 2 dBA at frequencies of 1250 Hz and below, while an increase of 1.5 to 3 dBA was measured at frequencies above 1250 Hz. By 2010, an increase of 3 to 5 dBA was measured at every frequency band except 5000 Hz, where an increase of 2 dBA was measured. The aging ACFC spectra show similar behavior to those of the P-ACFC, which could be expected since the only difference would be the porosity of the P-ACFC. At frequencies below 1000 Hz, levels increased by 5.8 to 7 dBA from 2002 to 2010, and at frequencies between 1600 and 3150 Hz, levels increased by 4 to 6 dBA.

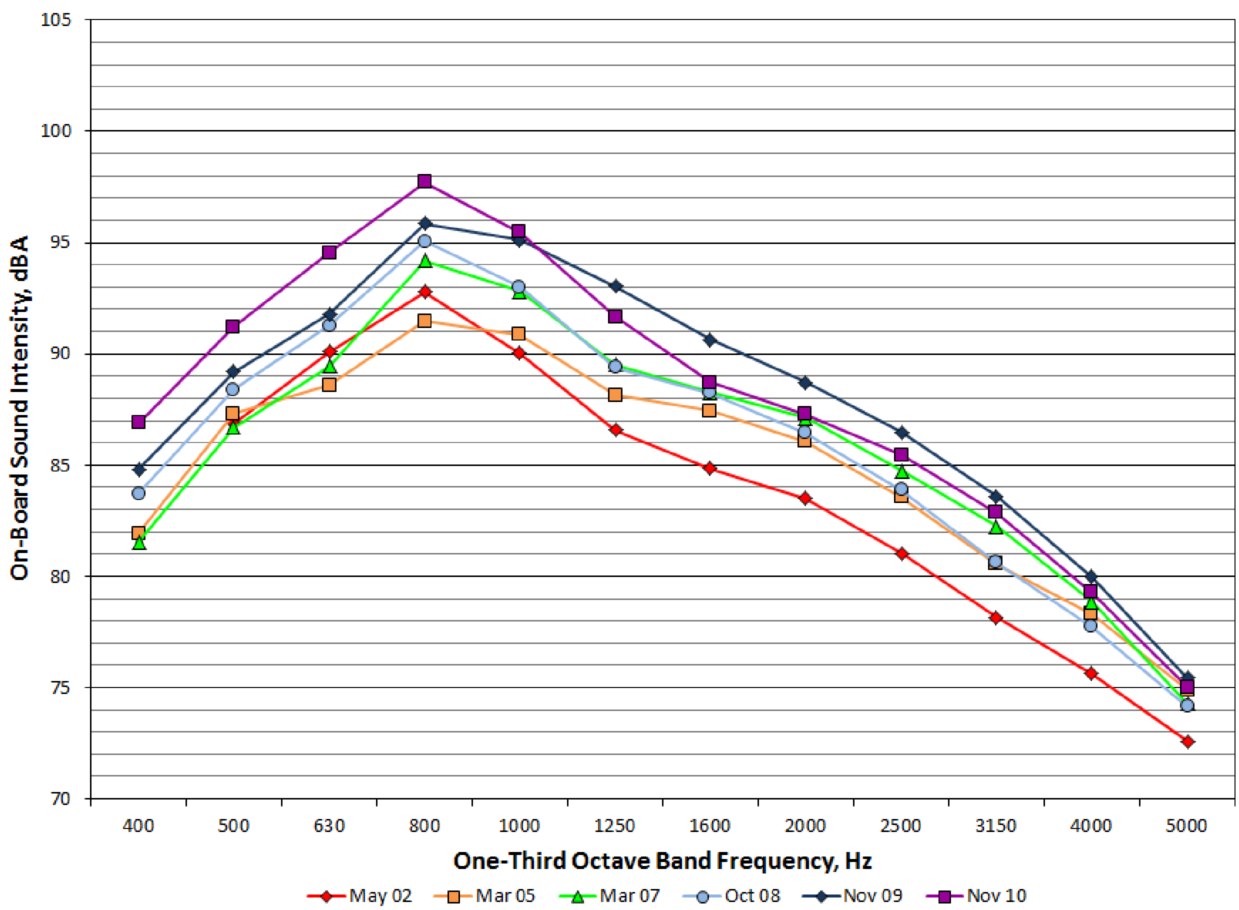

Figure 47. One-Third Octave Band Spectra for the Casa Grande ARFC Section from May 2002 to November 2010

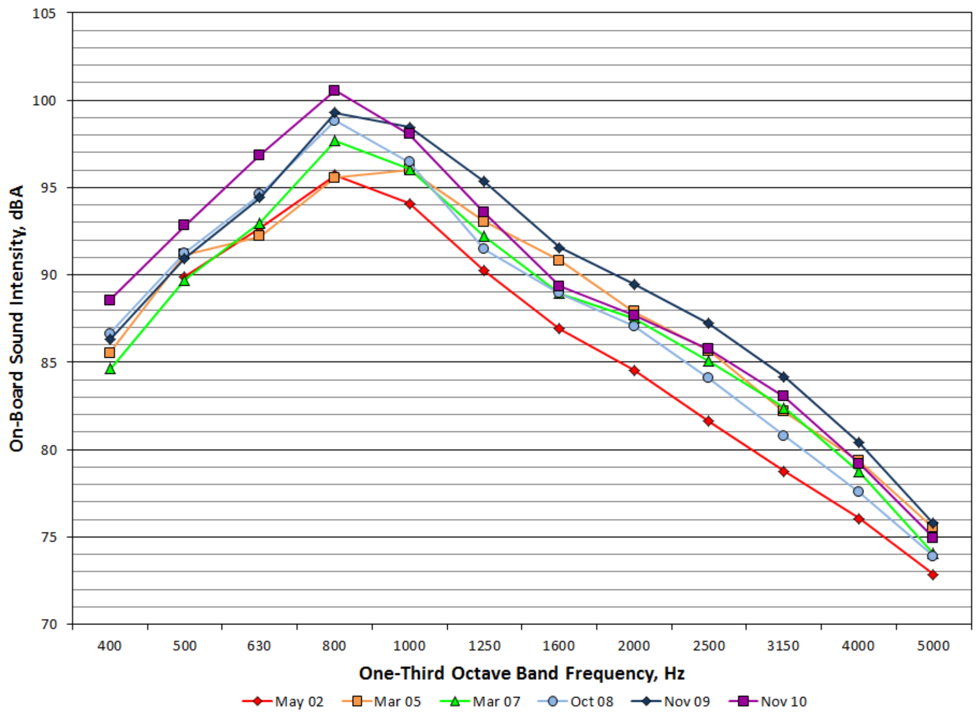

Figure 48. One-Third Octave Band Spectra for the Casa Grande SMA Section from May 2002 to November 2010

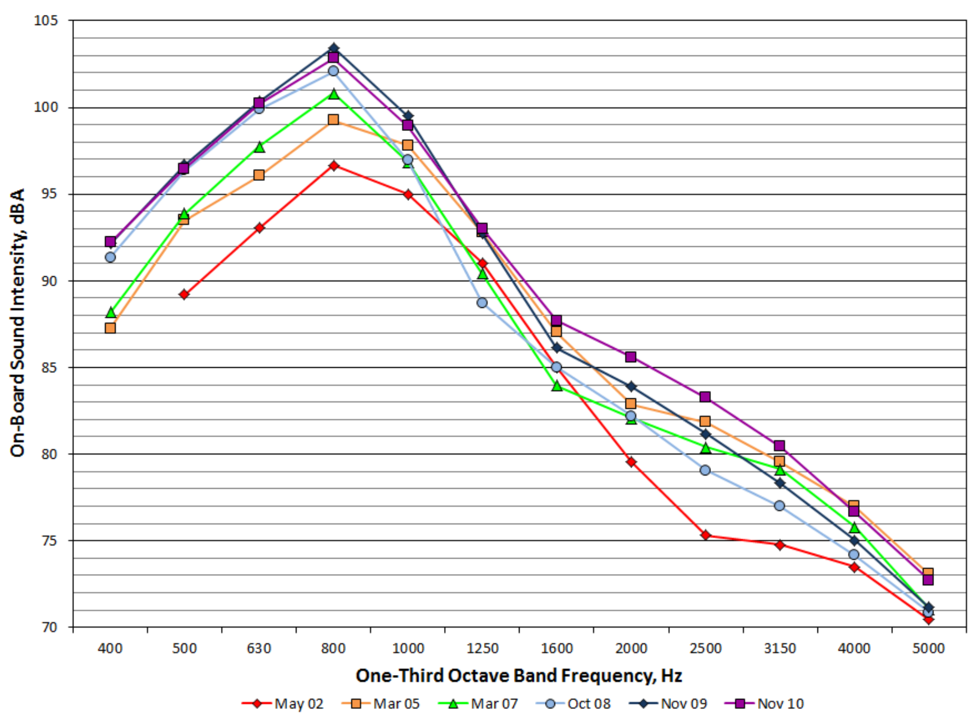

Figure 49. One-Third Octave Band Spectra for the Casa Grande P-ACFC Section from May 2002 to November 2010

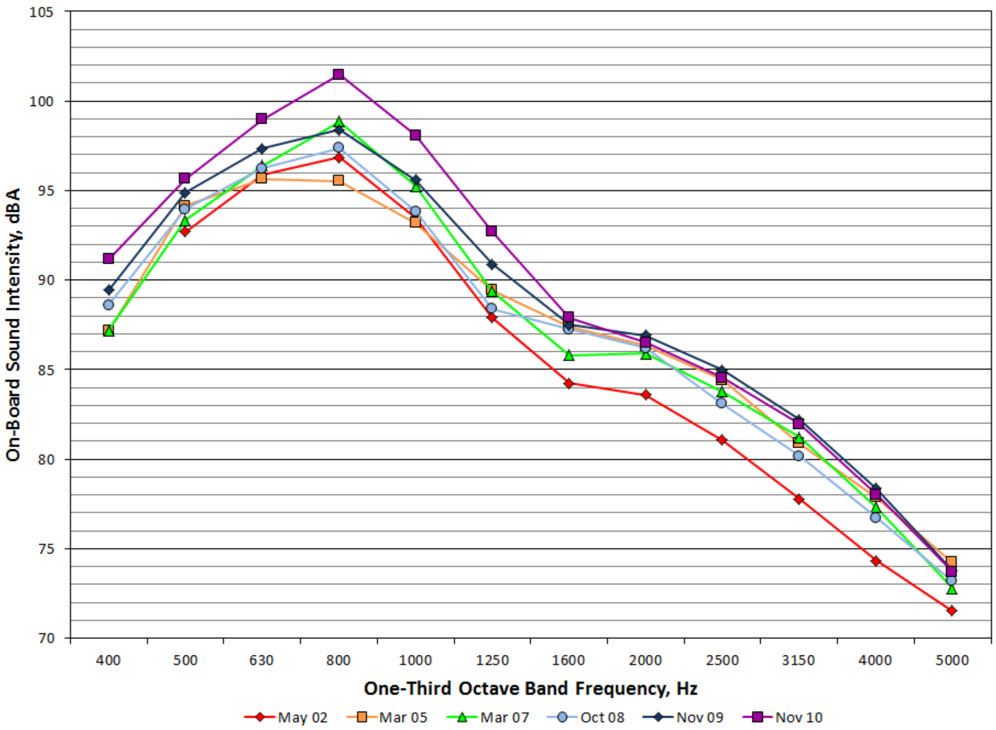

Figure 50. One-Third Octave Band Spectra for the Casa Grande PEM Section from May 2002 to November 2010

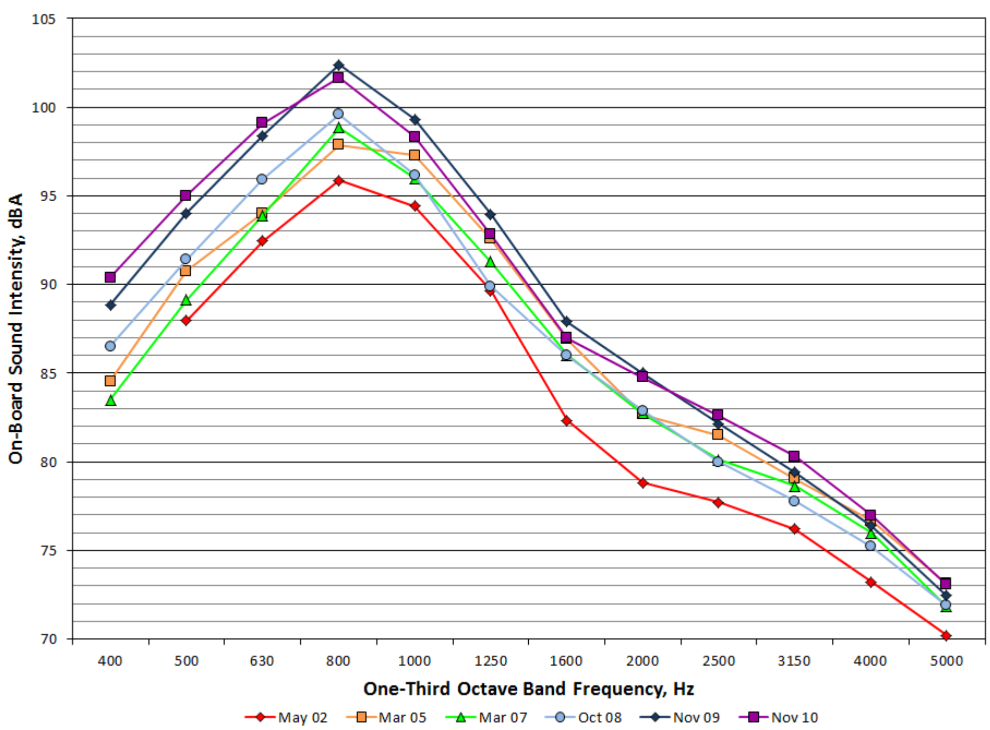

Figure 51. One-Third Octave Band Spectra for the Casa Grande ACFC Section from May 2002 to November 2010

PCC PAVEMENT TEXTURE AND NOISE

Prior to the QPPP, alternative types of tining on PCC pavement were applied to sections of the Red Mountain Freeway (SR 202) in the Phoenix, Arizona, area to investigate their effectiveness in reducing noise levels. The alternatives, which were all studied in 2002, included the standard ADOT uniform transverse tining, random transverse tining, and longitudinal tining. The standard ADOT surface was produced with texture grooves nominally 0.125-inch in width and 0.094- to 0.219-inch in depth, and spaced 1 inch apart. The random transverse tining, which used the Wisconsin DOT specification, had grooves of the same width and depth as the standard ADOT specification but with spacing varying from 0.375 to 2.25 inch. The longitudinal tining used 1-inch uniformly spaced longitudinal grooves. Each of these pavements was tested using controlled pass-by, a quasi-statistical pass-by, and sound intensity. The controlled pass-bys used a Subaru test vehicle with two different sets of the tires (Goodyear Aquatred 3 and Michelin Rainforce MX4™), and the quasi-statistical pass-by used a fleet of 30 light vehicles and trucks assembled and driven through the test sections at nominal speeds of 60 and 70 mph. Wayside measurements were made at 25 and 50 ft from the center of the lane of travel and at a height of 5 ft above the ground. An additional 100-ft wayside measurement was made at the random transverse tine site.

A total of 41 pass-bys were used at each site. Of these, 22 were nominally at 60 mph and 19 were at 70 mph. Initially, the pass-by data were processed to obtain the maximum overall A-weighted sound level for each individual pass-by at each site and microphone position. Figures 52 and 53 show the maximum overall A-weighted sound levels measured at 25 and 50 ft, respectively, during the pass-by events. Due to the tire variations, the resultant maximum levels for light vehicles showed scatter of about 4 or 5 dBA. For the controlled pass-bys, the typical range of run-to-run variation with the Subaru test vehicle was 1 dBA or less. As shown in the figures, some scatter in vehicle speed was also apparent, even though the drivers of the pass-by fleet were instructed to drive at 60 and 70 mph. At 60 mph, the speed scatter was about what would be expected based on speedometer tolerance, while at 70 mph, the scatter was greater. In general, the longitudinal tined pavement had the lowest noise levels of the three sites, followed by the uniform transverse tining and then the random transverse tining.

All data were categorized according to vehicle class, and the differences in measurements between the uniform and random transverse tining and the longitudinal tining were averaged by vehicle type. The vehicle classes were passenger cars, pickup or light trucks, medium trucks, heavy trucks, and the control Subaru vehicle. Sufficient pass-bys existed for the light-vehicle classes (cars and pickups/light trucks) for each category to have meaningful averages produced. For the other two truck categories, the data were limited. For the medium-duty truck, only the data on the random transverse and longitudinal tined surfaces were clean at 60 mph. At 70 mph, the pass-bys were judged clean, but, contrary to all the other data, the noise levels on the longitudinal tined surface were higher than on the other surfaces. For the heavy-duty trucks, two clean samples are available at 60 mph; however, only one sample was judged clean at 70 mph. The average pass-by results, where available, are presented in Table 29.

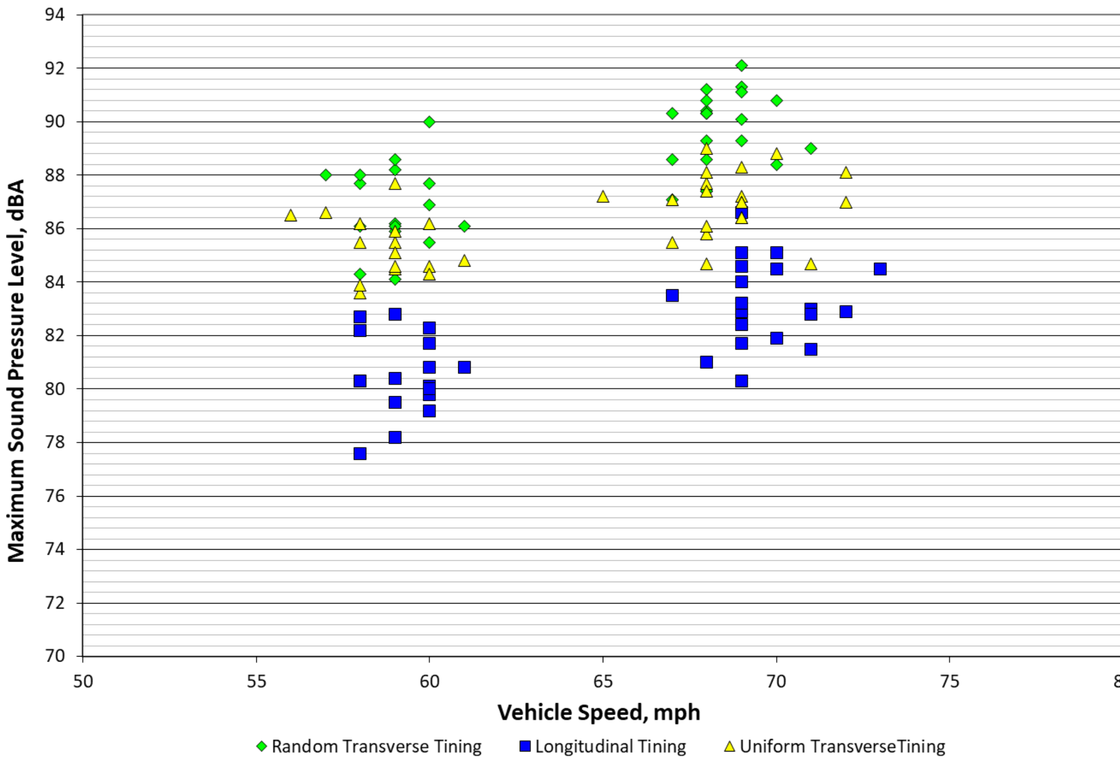

Figure 52. Maximum Pass-by Sound Level for the Average of Light Vehicles Traveling at 60 and 70 mph, as Measured at 25 ft

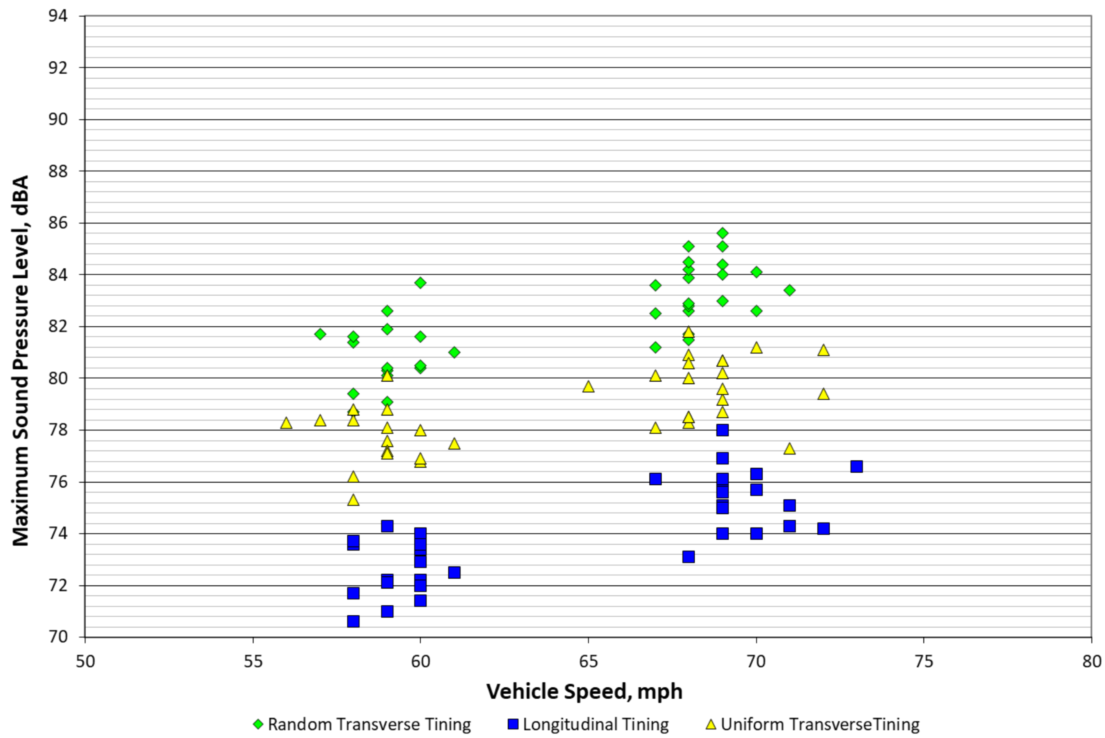

Figure 53. Maximum Pass-by Sound Level for the Average of Light Vehicles Traveling at 60 and 70 mph, as Measured at 50 ft

For the light vehicles, Figures 52 and 53 and Table 29 show that the uniform transverse tining produced lower noise levels than the random. For the random transverse tining, the increase over longitudinal tining shows little dependence on test speed, but for uniform transverse tining, the increases tended to be lower at 70 mph than at 60 mph. Also, for the random transverse tining, the increase measured at the 50-ft location was consistently higher than at the 25-ft location (by about 2 dBA). For the uniform transverse tining, the two microphone locations recorded about the same increase.

The increase in sound intensity measured on the random transverse tining fell within the range of increases measured at the two microphones, while the increase measured on the uniform transverse tining showed good correlation to the pass-by data.

Table 28. Summary of the Average Noise Level Increases of the Uniform and Random Transverse Tined Pavements Over the Longitudinal Tined

Description	60 mph		70 mph	
	Random Transverse Tining	Uniform Transverse Tining	Random Transverse Tining	Uniform Transverse Tining
Passenger Cars at 25 ft Passenger Cars at 50 ft	6.5 dBA 8.4 dBA	5.2 dBA 5.2 dBA	6.4 dBA 8.0 dBA	3.9 dBA 4.7 dBA
Pickup Trucks at 25 ft Pickup Trucks at 50 ft	6.0 dBA 8.1 dBA	4.1 dBA 4.9 dBA	6.6 dBA 8.2 dBA	3.7 dBA 4.1 dBA
All Light Vehicles at 25 ft All Light Vehicles at 50 ft	6.3 dBA 8.3 dBA	4.9 dBA 5.1 dBA	6.5 dBA 8.1 dBA	3.8 dBA 4.4 dBA
Subaru GDY Tires at 25 ft Subaru GDY Tires at 50 ft	7.2 dBA 7.8 dBA	5.9 dBA 5.2 dBA	6.1 dBA 8.1 dBA	4.1 dBA 4.4 dBA
Subaru Mich Tires at 25 ft Subaru Mich Tires at 50 ft	6.7 dBA 8.3 dBA	5.4 dBA 5.3 dBA	6.4 dBA 9.5 dBA	3.7 dBA 5.4 dBA
Sound Intensity – GDY Sound Intensity – Mich	7.2 dBA 7.5 dBA	5.1 dBA 5.4 dBA	--	--
Medium Truck at 25 ft Medium Truck at 50 ft	4.5 dBA 6.4 dBA	--	-0.7 dBA 0.2 dBA	-2.9 dBA -2.8 dBA
Heavy Trucks at 25 ft Heavy Trucks at 50 ft	3.0 dBA 4.7 dBA	1.6 dBA 3.2 dBA	9.9 dBA 10.8 dBA	8.1 dBA 10.0 dBA

The data for each type of test method were averaged to better rate the relative performance of the pavements. These data included all the light-vehicle pass-by data at both speeds and both microphone distances for the quasi-statistical pass-bys; both tire types, speeds, and distances for the controlled pass-bys; and both tire types for the sound intensity. The resultant values are given in Figure 54. Because of the limited number of runs measured for the medium and heavy trucks, the data for those two vehicle classes were excluded from these averages. As shown in the figure, the averaging yielded quite consistent performance results. For the random transverse tined PCC, the increase in noise levels over the longitudinal tined surface was 7.3 to 7.5 dBA consistently for all testing methods. The increase for the uniform transverse tining ranged from 4.6 to 5.2 dBA, which is still fairly consistent.

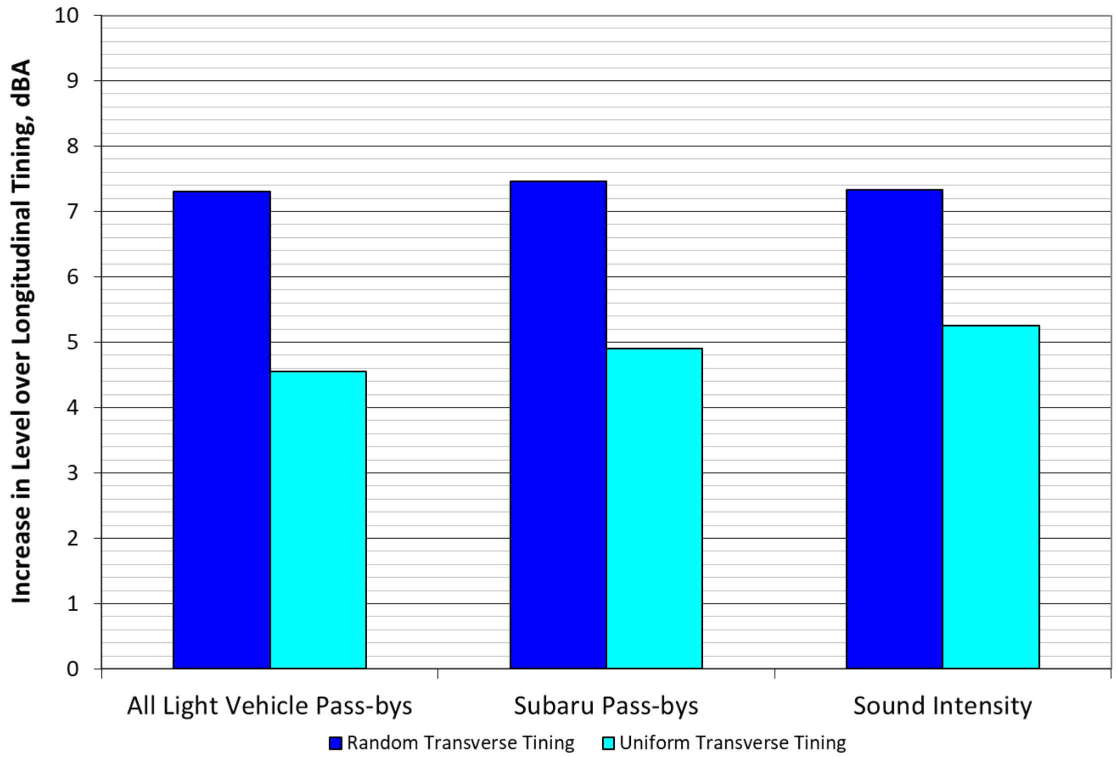

Figure 54. Average Increase in Noise Level for Random and Uniform Transverse Tining Over Longitudinal Tining for Each Test Method

The pass-by data from the Subaru test vehicle were reduced into one-third octave bands, corresponding to the instant that the maximum overall A-weighted sound pressure level was recorded. This was done for both sets of test tires and all microphone locations. Sound intensity data were also stored in one-third octave bands; however, because of low-frequency turbulence on the microphones, data below 400 Hz were not typically reported for sound intensity, and therefore are not shown for this test method. Additionally, due to finite difference error, the data above 5000 Hz were also not used. The resultant frequency range still captures most of the energy, which contributes to the overall A-weighted sound pressure level of a vehicle pass-by. To determine the overall A-weighted sound intensity level, only the energy in the frequency range from 500 to 5000 Hz was used. One-third octave band data for the Subaru pass-bys and sound intensity tests are plotted in Figures 55 through 58 for the two sets of tires and two microphone distances of 25 ft and 50 ft for the 60-mph test speed.

The relative trends of the spectra measured by using the sound intensity and pass-by methods seem to correspond well. In all cases, the greatest difference between both transverse tined pavements and the longitudinal tined pavement was found in the frequency range of 800 to 2000 Hz. Further, the random transverse tined spectra showed higher noise levels than were measured on both of the other surfaces at frequencies between 400 and 800 Hz. For the uniform transverse tined spectra, the pass-by levels display a more well define peak at 1000 Hz for the 50-ft microphone distance than for the 25-ft distance when comparing the 1000 Hz level to the adjacent band levels at 800 and 1250 Hz. This was true for both the Goodyear and the Michelin test tires. With both tire types, the difference between the longitudinal and random transverse tining was greater at the 50-ft microphone than at the 25-ft microphone. In comparing the test tires, the spectra were found to be quite similar for both the sound intensity and the pass-by data. Based on the information from this research (which is not directly related to the QPPP), ADOT has now adopted longitudinal tining as its standard PCCP texture.

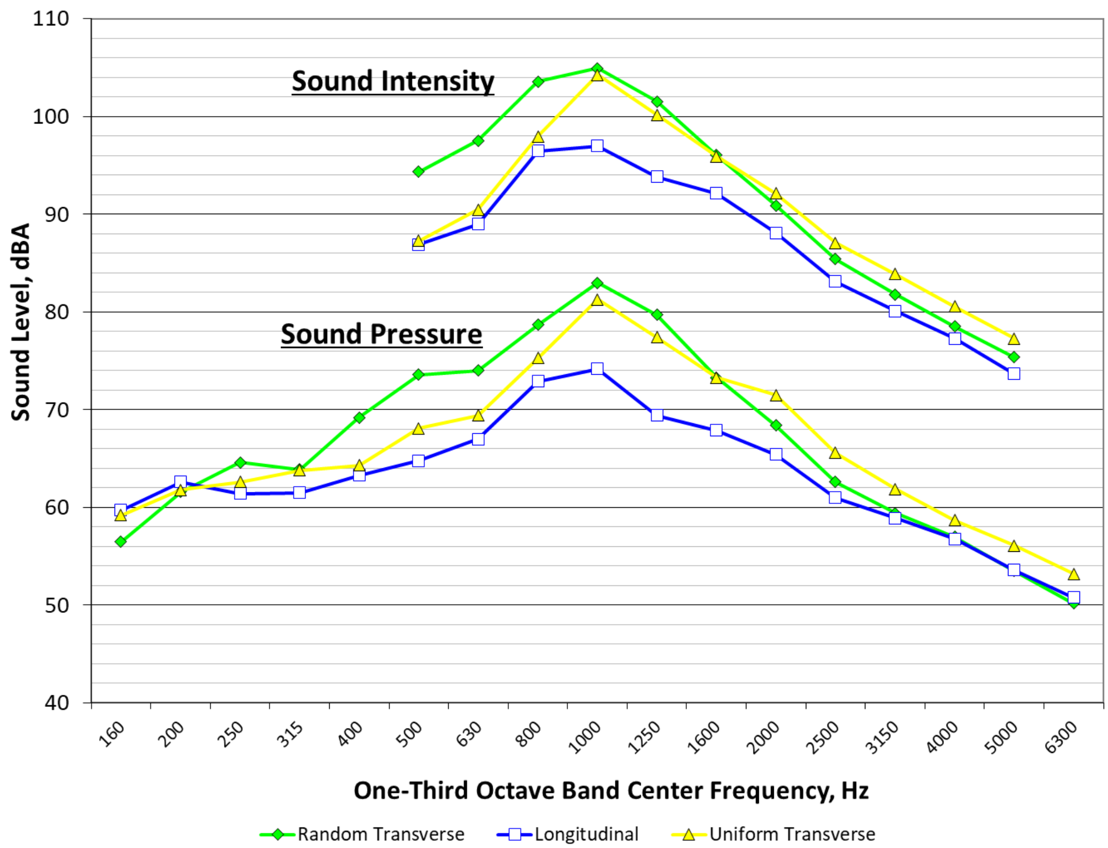

Figure 55. Sound Intensity and 25-ft Pass-By Spectra Measured with the Goodyear Aquatred 3 Test Tire Traveling at 60 mph on All Three Test PCC Pavements

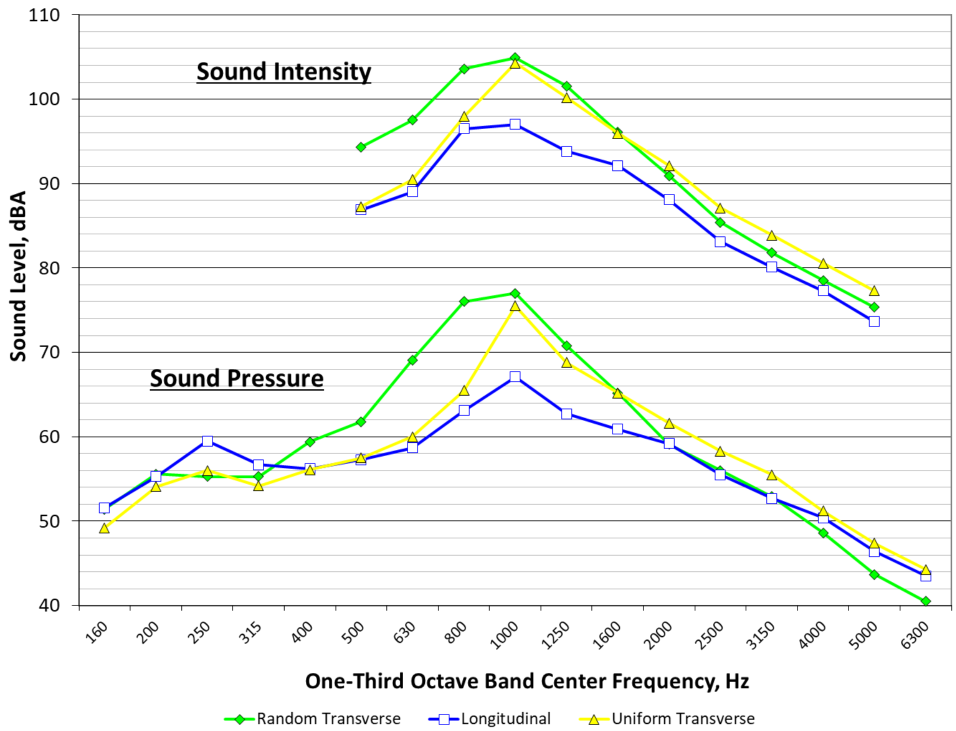

Figure 56. Sound Intensity and 50-ft Pass-By Spectra Measured with the Goodyear Aquatred 3 Test Tire Traveling at 60 mph on All Three Test PCC Pavements

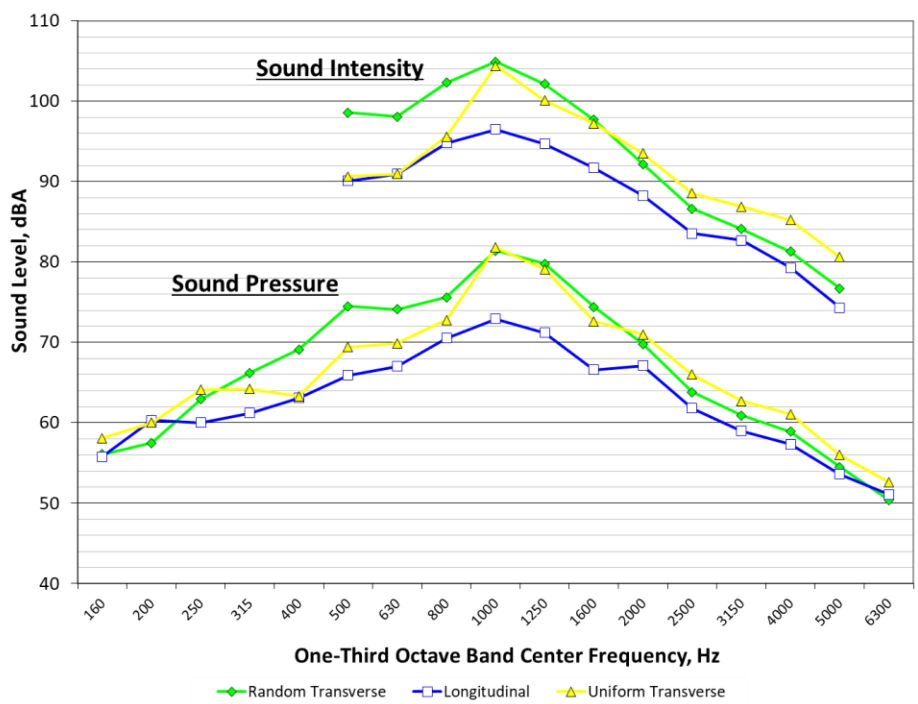

Figure 57. Sound Intensity and 25-ft Pass-By Spectra Measured with the Michelin Rainforce MX4 Test Tire Traveling at 60 mph on All Three Test PCC Pavements

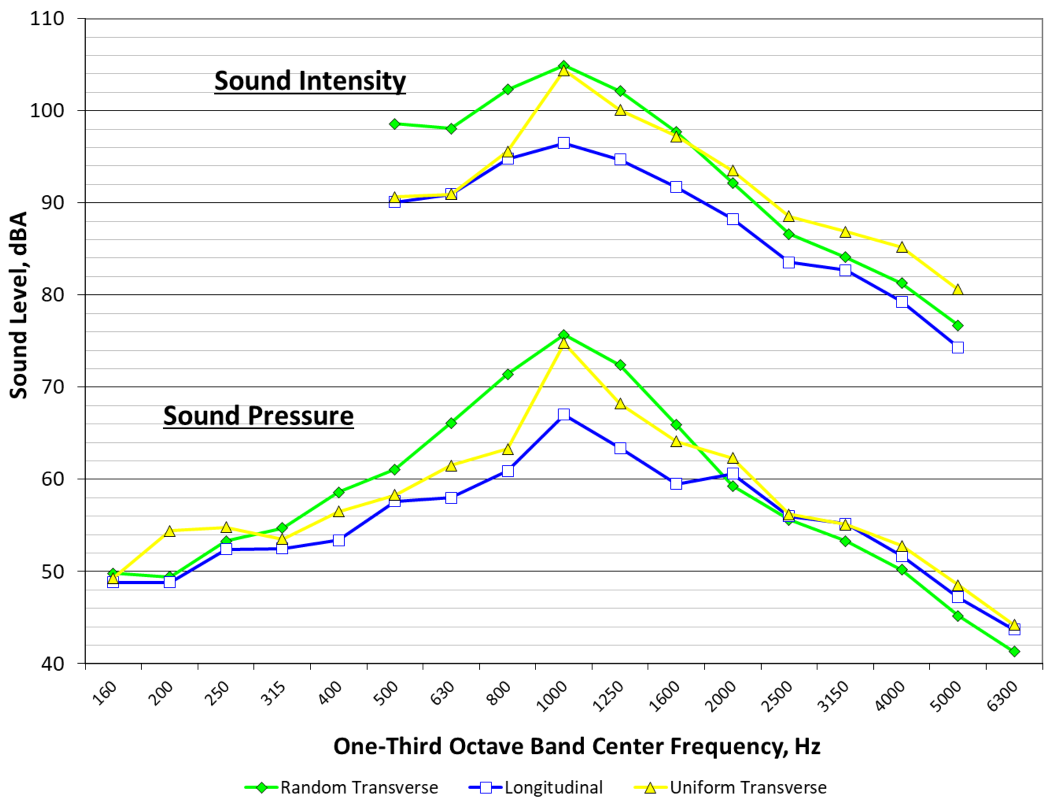

Figure 58. Sound Intensity and 50-ft Pass-By Spectra Measured with the Michelin Rainforce MX4 Test Tire Traveling at 60 mph on All Three Test PCC Pavements

WHISPER GRIND TEST SECTIONS

The longitudinal tining produced noise levels that were 5 and 7 dBA lower than those produced by the uniform and random transverse tining, respectively (Donavan and Scofield 2003). To demonstrate the potential for even lower levels of tire/pavement noise on PCCP, the International Grooving and Grinding Association, the American Concrete Pavement Association, and the Arizona Cement Association offered to diamond-grind four sections of longitudinal tined pavement on SR 202 at its southern intersection with I-10. These sections were designated as the "Whisper Grind" test sections. To enable evaluation of these sections, their acoustic performance was documented for four years after the grinding was completed (Scofield 2003).

After the grinding was completed in June 2003, acoustic measurements were performed on the sections at various times through March 2007, when the Whisper Grind test sections were overlaid with ARFC consistent with the rest of the QPPP project area. The profile grind of Test Area 1 was produced with 0.125-inch blades spaced 0.110 inches apart. The technique used allowed the grinding depth to vary somewhat based on the existing roadway profile; in this case, it varied from 0.125-inch to 0.25-inch. Test Area 2 was ground with the same head configuration as Test Area 1; however, instead of performing normal profile grinding, jacks were used to shorten the effective equipment wheelbase, and reduced head pressure was applied. For Test Area 3, the 0.125-inch blades were spaced 0.120 inches apart with the same equipment as in Test Area 1 (i.e., no jacks). With the wider blade spacing, this grind produced “fins,” or raised lines of material formed between the grooves cut by the blades. To simulate the breaking off of the fins that occurs once a surface is exposed to normal traffic, a motor grader was used to break off some of the fins. Test Area 4 was also ground with 0.120-inch blade spacing using jacks to shorten the wheelbase, but unlike Test Area 2, the grinding head was left in a floating position, resulting in a shallower depth of cut. Photographs of each of the Whisper Grind test sections are provided in the final project report (Scofield 2003; Donavan 2013).

Initial CPX Results

The first complete set of CPX measurements extended over a period from June to September 2003 (Scofield 2003). A complete set of results was published in December 2003 (Scofield and Donavan 2003) and later in 2005 (Scofield and Donavan 2005). After the 2003 measurements, a series of trailer validation tests and refinements were carried out, which are reflected in the 16-month results, conducted in October 2004, and in results from the March 2005 testing. Figure 59 shows the overall noise levels for the CPX testing completed through March 2005 on the Whisper Grind sections and on longitudinal tined PCCP. (Note that Test Areas 1 and 3 were tested in travel lanes 1 and 2.) These data indicate a consistent increase in noise level for all sections, including the longitudinal tined PCCP, between the 2003 results and the 2004/2005 results. The cause of this offset is unknown; however, the results of the October 2004 and March 2005 testing were more consistent with the results obtained once OBSI measurements were used. Despite the offset, the initial data and later data show similar trends, in terms of rank ordering of the various surfaces. Generally, the ground sections producing the highest noise levels were Test Areas 2 and 3. The sections with the lowest levels were Test Areas 1 and 4, although, some lane-to-lane variation occurs for Test Areas 1 and 3. The levels for the longitudinal tined PCCP ranged from 2.1 to 3.8 dBA higher than the levels for the ground sections. As for the grind parameters, it was difficult to draw conclusions. For blade spacing, the noise levels of Test Area 1 (with 0.110-inch spacing) were generally lower than those of Test Area 3 (0.120-inch). However, the levels of Test Area 2 (0.110-inch) were consistently higher than those of Test Area 4 (0.110-inch); but there was another parameter—that of head pressure—that may have affected the Test Area 2-versus-4 comparison. For jacks versus no jacks, Test Area 1 (without jacks) showed lower noise levels than Test Area 2 (with jacks); however, Test Area 3 (without jacks) had higher levels than Test Area 4 (with jacks).

In March 2005, OBSI measurements were made at the same time as the CPX measurements, and the rank ordering of the test areas and lanes was the same as shown in Figure 59 for the CPX results. A consistent offset of 3.1 dBA (within ±0.3 dBA) was measured between the CPX and OBSI levels for each test section.

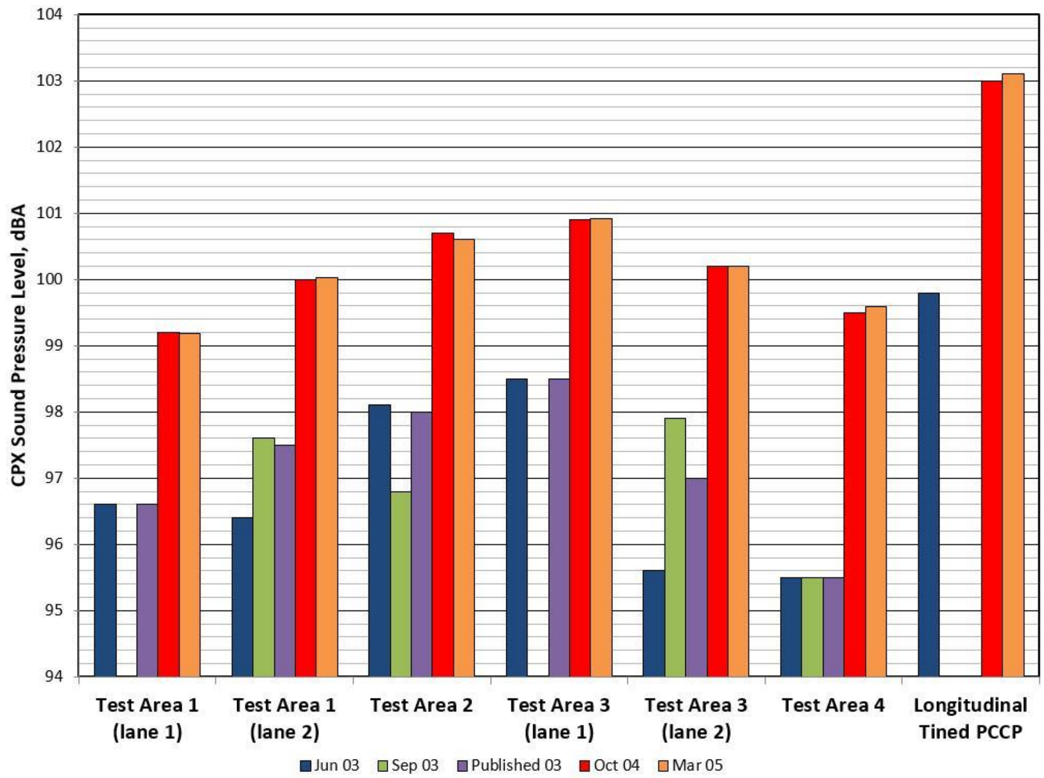

Figure 59. Overall A-Weighted CPX Noise Levels for the Whisper Grind Sections and Longitudinal Tined PCCP at Various Times through March 2005

Using the data taken in March 2005, Figure 60 shows the one-third octave band spectra for the six ground sections and the longitudinal tined section (lane 3). Across all the sections, the range in noise level for any band varied from about 3 to 5 dBA, with the largest variation between sections occurring below 800 Hz. In general, these frequencies are controlled by surface roughness, with rougher textures producing higher noise levels. Of the six test sections, Test Area 4 produced the lowest levels at these frequency bands, while Test Area 2 (with the smaller blade spacing) and Test Area 3 (lane 1) produced the highest levels. The remaining three sections fall in between these other levels. As noted in the ADOT Construction Report, with the shortened wheelbase and the floating head used at Test Area 4, the texture was shallower than in the other sections. This may have created less positive texture due to the fins, resulting in the lower noise levels at the low frequencies. It was observed that Test Area 2 had higher fins than Test Area 4 even though the blade spacing was slightly smaller, which may have created the higher low-frequency noise levels. For Test Area 3, as noted in the Construction Report, the fins were still pronounced even after scraping and may have been responsible for the higher levels in lane 1. In the higher-frequency bands (1000 Hz and above), the noise level differences were typically 3 dBA or less. For Test Area 4, the levels actually increased with frequency from 1250 to 1600 Hz, and relatively elevated levels were also seen in the 2000-Hz band. Increases in these same frequencies had been noted for the Caltrans Mojave Bypass PCCP texture research sections and were attributed to pavement polishing with traffic (Donavan and Rymer 2011). From Figure 60, it is also seen that the noise levels for the longitudinal tined PCCP are equal to or greater than the highest levels for the ground sections.

Because of uncertainty about some of the early CPX data for the Whisper Grind sections, it is problematic to make absolute comparisons among the ground pavements; however, relative comparisons for the longitudinal tined PCCP surfaces can be made. In the June 2003 data, the noise level for the longitudinal tined PCCP surface of lane 1 was measured at 99.8 dBA. On average, this was 3 dBA (with a range from 1.3 to 4.3 dBA) higher than the levels for the ground sections. In the March 2005 data, the noise level of the longitudinal tined PCCP of lane 3 was 103 dBA. This compares with an average for the ground sections that was 2.9 dBA (with a range from 2.1 to 3.8 dBA) quieter. These comparisons yield an offset between longitudinal tined PCCP and the ground PCCP of about 3 dBA.

Similar trends were observed from the OBSI spectra measured in March 2005. By way of relative comparison, the longitudinal tined PCCP section of lane 3 produced a noise level of 106.5 dBA, for an average difference from the ground sections of 3.4 dBA, which was slightly higher than that seen with the CPX data.

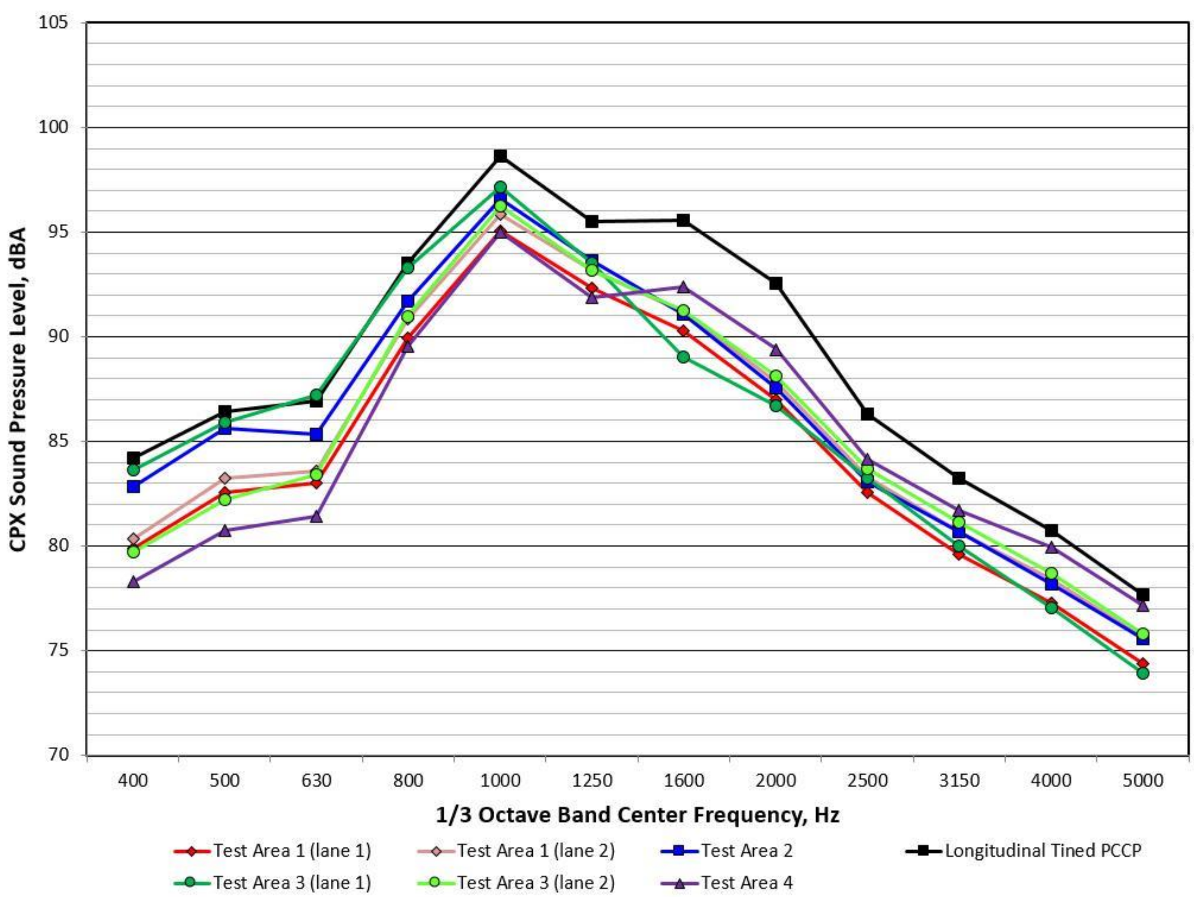

Figure 60. One-Third Octave Band CPX Noise Levels for the Whisper Grind Sections and Longitudinal Tined PCCP in March 2005

Acoustic Longevity

For the Whisper Grind sections, the period of time available to investigate the acoustic longevity of their surfaces was limited by the length of time between construction and overlay, which was approximately four years. During this time, the measurements included a mixture of CPX and OBSI data, and not all six sections were measured for each test event. The CPX data include three full sets of measurements: the initial levels measured in September 2003, the 16-month data taken in October 2004, and the data from March 2005. Test Areas 2 and 4 were also measured in March 2006 and November 2006. The initial levels from 2003 are irreconcilably low, and when they are used with the later data, they yield acoustic longevity rates ranging from 0.89 to 2.29 dB/year. If the initial data are ignored, the measurements of the sections in Test Areas 1 and 3 are separated by just six months (October 2004 to March 2005), which is an insufficient time period for determining acoustic longevity rates. For Test Areas 2 and 4, however, four sets of measurements were made from October 2004 to November 2006, slightly more than two years. Although this is still a short period over which to consider acoustic longevity, the results are somewhat more consistent with the OBSI longevity results from sites studied in California (Donavan and Rymer 2011). The California PCCP QPR pavements produced longevity rates ranging from 0.04 to 0.20 dBA/year on State Route 58 near Mojave where the AADT was about 34,000. Other PCCP highways with higher AADT of just over 200,000 produced rates of 0.25 dBA/year and 0.34 dBA/year (Paul Donavan and Carrie Janello, Illingworth & Rodkin, Inc. engineers, unpublished memo to Bruce Rymer, Caltrans, June 27, 2011). The results for ADOT Whisper Grind sections, shown in Figure 61, indicate a linear slope of 0.25 dBA/year for Test Area 2 and 0.54 dBA/year for Test Area 4.

The OBSI measurements include three full sets of data on all six Whisper Grind sections: from March 2005, June 2006, and March 2007. Data for Test Areas 2 and 4 are also available for November 2006. All of these data are shown in Figure 62, along with the corresponding linear regressions, which range from 0.05 dBA/year to 0.48 dBA/year. Given the low R^2 values and the scatter about the regressions, the confidence in these results is poor. Averaging the rates gives a value of 0.24 dBA/year, which is at least consistent with the California longevity results. The annual average daily traffic (AADT) for SR 202 in this area was 50,000, which falls within the range of AADT volumes counted on the corridors in California on which OBSI measurements were made.

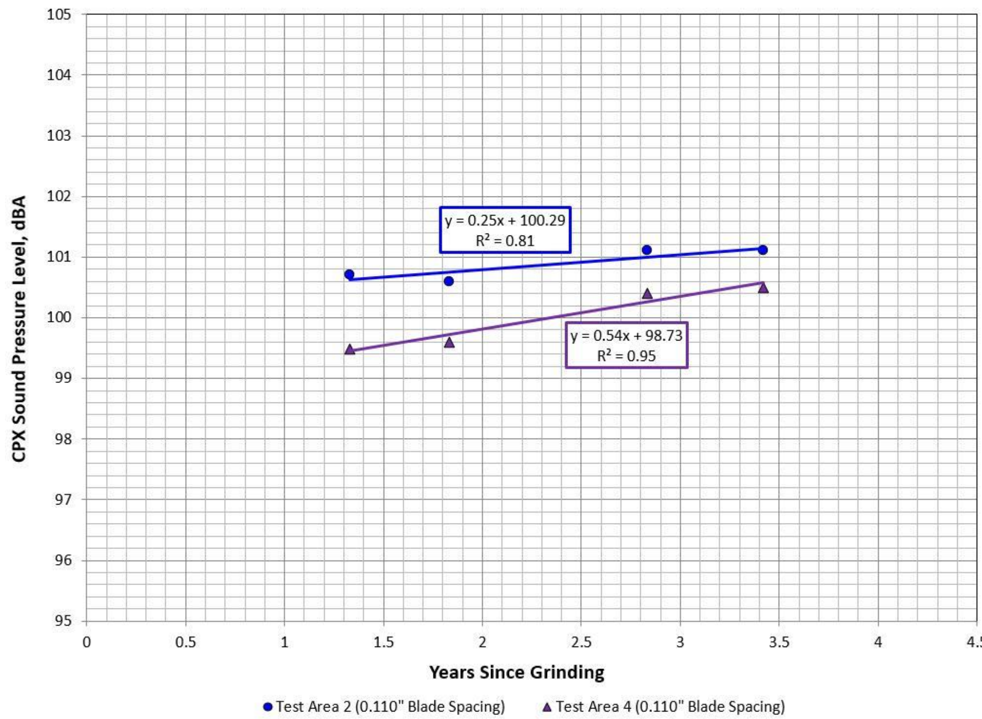

Figure 61. Overall A-Weighted CPX Noise Level Versus Years Since Construction for the Whisper Grind Sections

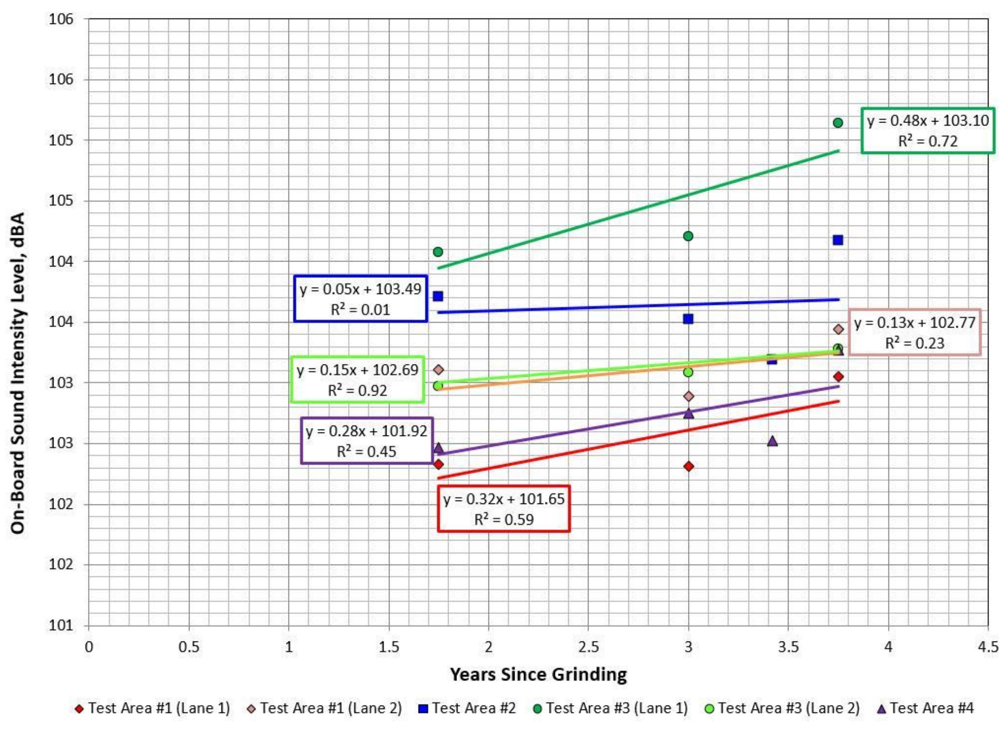

Figure 62. Overall A-Weighted OBSI Noise Level Versus Years Since Construction for the Whisper Grind Sections

CHAPTER 6. SUMMARY

SUMMARY OF PROJECT RESULTS

The QPPP was initiated to determine the noise benefit of the ARFC overlay using three different noise measurement methods. The noise reductions measured during the first post-overlay testing period were substantial, and after 10 years or more, noise levels continued to be lower than the pre-overlay PCC levels. Table 30 summarizes the initial noise reductions, the final post-overlay noise reductions, and the rate of noise level increase calculated for each type of measurement method. The averages shown in the table for the Type 3 sites are based on measurements at the 50ft/5ft microphone location of each site.

Table 29. Summary of the Initial and Final Measurement Results at 50ft

	Type 1	Type 2	Type 3					
			Site 3A	Site 3B	Site 3C	Site 3D	Site 3E	Avg
Initial Noise Reduction	8.7 dB	5.2 dB	9.3 dB	9.2 dB	8.8 dB	11.4 dB	9.1 dB	9.6 dB
Final Noise Reduction	3.2 dB at 12.5 years	5.1 dB at 4 years	3.2 dB at 12 years	6.8 dB at 10 years	6.3 dB at 10 years	4.8 dB at 10.5 years	4.2 dB at 9.5 years	5.1 dB
Rate of Noise Level Increase	0.50 dB/year	N/A	0.40 dB/year	0.22 dB/year	0.26 dB/year	0.51 dB/year	0.61 dB/year	0.04 dB/year

For each of the Type 3 measurement locations, TNM predictions were calculated and compared with the measured results, as shown in Table 31. For Sites 3A, 3B, 3C, and 3E, the TNM average pavement initially resulted in predicted noise levels about 6.0 to 7.4 dB higher than those with the ARFC pavement. Site 3D stands out, with the initial difference being 8.2 dB lower than the predicted level for the TNM average pavement. After 12 years, Site 3A resulted in levels 0.8 dB lower than those predicted with TNM, while Sites 3B, 3C, and 3E had levels 4.1, 3.2, and 0.2 dB lower than the predicted levels after about 10 years. The final measurement at Site 3D resulted in noise levels that were 2.2 dBA higher than the predicted levels after 10.5 years since the overlay application. The reasons for this anomalous measured-versus-predicted behavior of Site 3D relative to the other Type 3 sites are not known.

For the average of all the microphone distances at each site, the predicted levels were 6.6 dB greater than the measured levels (Table 23). All the positions met the 4-dB-credit criteria at distance of 100 feet or less. For the final measurements, the predicted levels were 1.4 to 5.7 dB greater than the measured levels, with an average of 3.2 dB, slightly less than the credit.

The sound absorption, or EFR, data indicated an upward trend in noise values as the pavement aged; however, the data showed considerable scatter. Using the impedance method, the sound absorption did not show any change with time. The percentages of sound absorption are quite low for all Type 3 locations, averaging about 8 percent, indicating that the pavement is not porous.

Table 30. Summary of Differences Between Initial and Final Measurement Results at 50 ft Compared to TNM

	Type 3					
	Site 3A	Site 3B	Site 3C	Site 3D	Site 3E	Avg
Initial Difference	6.9 dB	6.0 dB	7.4 dB	8.2 dB	6.1 dB	6.5 dB
Final Difference	0.8 dB at 12 years	4.1 dB at 10 years	3.2 dB at 10 years	-2.2 dB at 10.5 years	0.2 dB at 9.5 years	1.2 dB

CONCLUSIONS OF QPPP RESEARCH

At the end of the QPPP, the ARFC overlay was still successful, providing an average noise benefit of 4.8 dB to locations where residents would potentially be living near the freeways. With an average reduction of 8.2 dB, the overlay produced significant noise benefits throughout the life of the project. The original pavement produced levels that were higher than those for TNM's average pavement, and as a result, the measured levels at the end of monitoring were still lower (by 3.2 dB) than those predicted by TNM. If residential receptors were located at the Type 3 sites, all those within 175 ft would fall above the Noise Abatement Criterion (NAC) of 64 or 66 dBA, and abatement would be considered both before and after the overlay. Any residential receptors beyond 246 ft would be above the NAC before the overlay and below the NAC afterward for the duration of monitoring. The pavement overlay would have provided lasting noise abatement for these more distant locations.

The ARFC overlay is capable of producing significant reductions in noise at the wayside of the freeways, in places where people live near the freeway, and in tire/pavement noise. Where neighborhood noise-reducing features, such as sound walls and recessed roadways, are already in place, the reduction is less than at open research-grade sites. On average, noise levels at these Type 2, neighborhood locations were reduced by more than 5 dB, which is considered to be a "substantial" amount of noise reduction under FHWA guidance. Approximately 52 percent of the neighborhood sites would have exceeded the ADOT Noise Abatement Criterion of 64 dBA prior to the overlay. After the overlay, the proportion was reduced to 12 percent. After 3 to 4 years, none of the locations re-measured had changed to the point of exceeding the NAC.

The noise reductions produced by the ARFC overlay did diminish with time, as demonstrated by both the Type 1 OBSI and the Type 3 wayside data. The correlation between these data is sufficiently strong that OBSI measurements alone could be used to monitor pavement over time, as in previous research (Donavan et al. 2013; Janello and Donavan 2015).

Even if pavement is not used as noise abatement, it is important to account for it in highway noise assessment. If pavement is not accounted for properly, significant other adjustment or calibration factors may be introduced that do not properly account for pavement acoustic longevity.

RECOMMENDATIONS FOR FURTHER RESEARCH

The QPPP generated a lot of data, which proved valuable in evaluating the ARFC overlay. To enhance the results of this project, the following topics are suggested for further research:

- The deterioration of the pavement overlay was measurably different at different sections. To determine possible reasons for these differences, correlation of traffic mixture, traffic volumes, area development, etc., to noise degradation should be investigated. Areas where excessive raveling occurred should be reviewed by ADOT pavement engineers to determine causes that may be due to variation in the ARFC mixture or other factors.
- Statistically isolated pass-by (SIP) measurements should be taken along the wayside of the freeways to develop a REMELs database for aging ARFC pavements. Data would be collected at new ARFC pavement locations, as well as locations with older ARFC. This study should include heavy and medium trucks, as well as light vehicles.
- The methods developed in NCHRP Project 10-76 and documented in NCHRP Report 738 should be applied to new ADOT Type 1 projects using the data developed in the QPPP. This NCHRP project is titled “Evaluating Pavement Strategies and Barriers for Noise Mitigation.” It presents a life-cycle cost analysis methodology that considers the initial cost of sound walls and the ongoing cost of pavement maintenance for noise performance. It also provides methods for using barriers together to achieve lower cost and reduced noise impact. This NCHRP research was performed by the noise monitoring team of the QPPP based on their experiences in the ADOT program.
- For the Type 3 measurements, TNM used a ground type that physically appeared to be the most appropriate, but was found not to match the actual data. This issue should be examined further to determine if there is a unique ground type that should be used for desert ground. The existing Type 3 results and other ADOT experience could be drawn upon for an initial analysis and followed up with actual, new field measurements at several ideal sites.

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APPENDIX A:
DESCRIPTION OF ADOT ARFC OVERLAY

ADOT has been using ARFC surfaces for almost 30 years so 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 randomly spaced between 13 to 17 ft with an average spacing of 15 ft. 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 rehabilitation 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 9.5-mm top size mixture typically produced between 9.1 to 9.6 percent total binder content and constructed 25-mm thick. The gradation requirements are shown in Table A1.

Table A1. ARFC Gradation

Sieve Size	Typical Gradation Without Admixture (% Passing)	Specification Band (% Passing)
3/8	100	100
#4	38	30 to 45
#8	6	4 to 8
#16	4	--
#40	2	--
#200	0.8	0 to 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 percent 9.5-mm chips and 5 percent fine aggregate. Typical aggregate properties range between 94 to 100 percent double crushed faces (minimum of 85 percent required). Flakiness index typically ranges between 13 to 22 (30 max required).

Asphalt rubber is produced by combining 18 to 22 percent 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 percent 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 to 21 percent, 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 NCAT infiltration test resulted in flow rates of 15 m/day.

APPENDIX B:
TYPE 1 CPX AND OBSI CONDITIONS AND RESULTS

This appendix includes the CPX versus OBSI testing method comparison, a summary of the environmental conditions observed during each Type 1 testing period, and the overall 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). Not all specific mileposts are captured in each testing period due to construction, missing milepost markers, inference from traffic, etc. For results prior to 2006, it is not known if the data was ever taken or lost in ADOT transition.

TRANSITION FROM CPX TO OBSI TYPE 1 LEVELS

Transition from CPX Data to OBSI Type 1 Levels

In 2006, it became clear that a transition from the original CPX method of collecting the Type 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 state interstate system (Donavan and Scofield 2004). 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 of simultaneous CPX and OBSI data. In this case, a two-probe OBSI fixture was used. From these tests, extensive correlation data were obtained, and it was intended at that time to continue the trailer measurements but to actually collect OBSI data using this dual probe approach.

Due to a transition of personnel within ADOT at that time, this concept was shelved, and in March 2006, a regular measurement program was re-established relying on CPX data and the ADOT trailer. During the March 2006 testing, a number of operational/maintenance issues arose with the trailer and in the absence of an “owner” within ADOT to address these problems, plans were made to make the transition to a test car that would not require special attention to maintain. Also at this time, the OBSI became standardized with a number of researchers within the U.S. 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 (Donavan 2006) facilitating the one pass concept needed for the Type 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 and is documented in this Appendix. It should also be noted that the NCHRP 1-44 project completed in 2008 identified the OBSI method as preferred to the CPX supporting ADOT’s migration to this approach (Donavan and Lodico 2009).

March 2005 CPX Versus OBSI on the ADOT CPX Trailer

Simultaneous measurement of CPX sound pressure levels and sound intensity (SI) on the ADOT CPX trailer was conducted in March 2005. Testing was made at 193 locations, including 23 Type 1 mileage posts, additional ARFC pavement type locations along Arizona SR 17, SR 51, 101, 202, and 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 B1. 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, which is similar to that reported from previous investigations (Donavan and Scofield 2004).

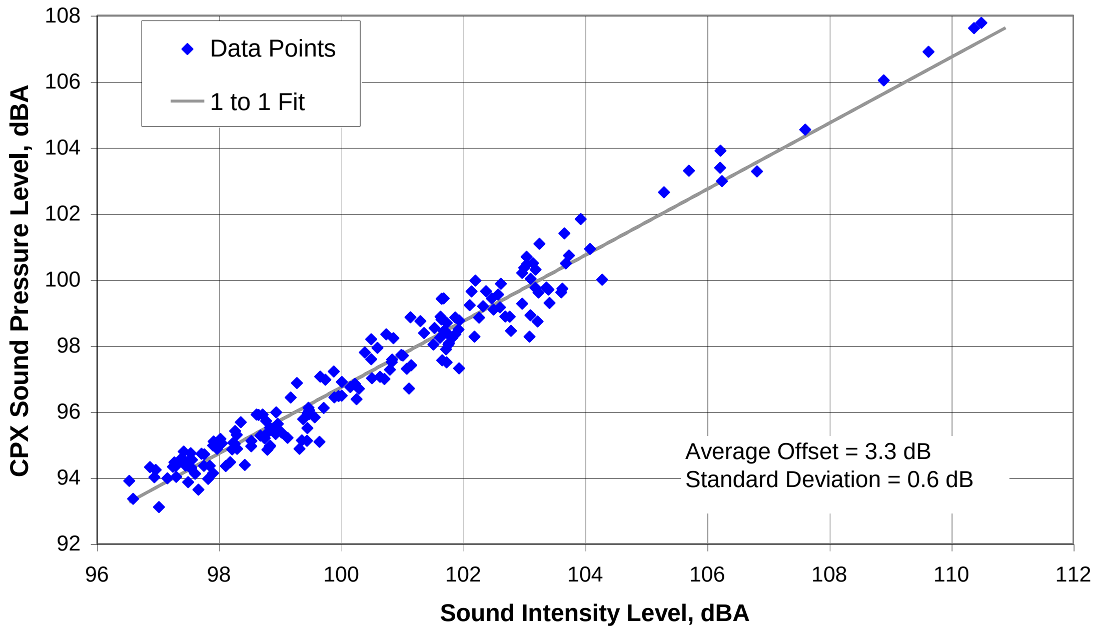


Figure B1. Comparison of Overall A-Weighted CPX and OBSI Levels Obtained Simultaneously on the ADOT CPX Trailer in March 2005

November 2006: CPX Versus OBSI

CPX and on-vehicle OBSI measurements were conducted on the Type 1 mileage post-sites and additional sites in the vicinity of Type 1 in November 2006. The CPX measurements were made on November 8, 2006, and the OBSI measurements were made on November 9 and 10, 2006. 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 B2. 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 B3, averaged over all Type 1 ARFC pavement sections for each testing method. The spectral trend indicated in Figure B3 is consistent with that found in the March 2005 data. For 1,600 Hz and above, the OBSI and CPX levels were similar. However, there is a drop in the CPX noise levels in the frequencies below 1,250 Hz, by as much as 6 dB. This is consistent with previous testing, assessing both loudspeaker and tire-pavement noise sources. The relative reduction in the CPX data was likely due to standing wave effects in the enclosure, as documented in European literature as well as in the NCHRP 1-44 report (Donavan and Lodico 2009).

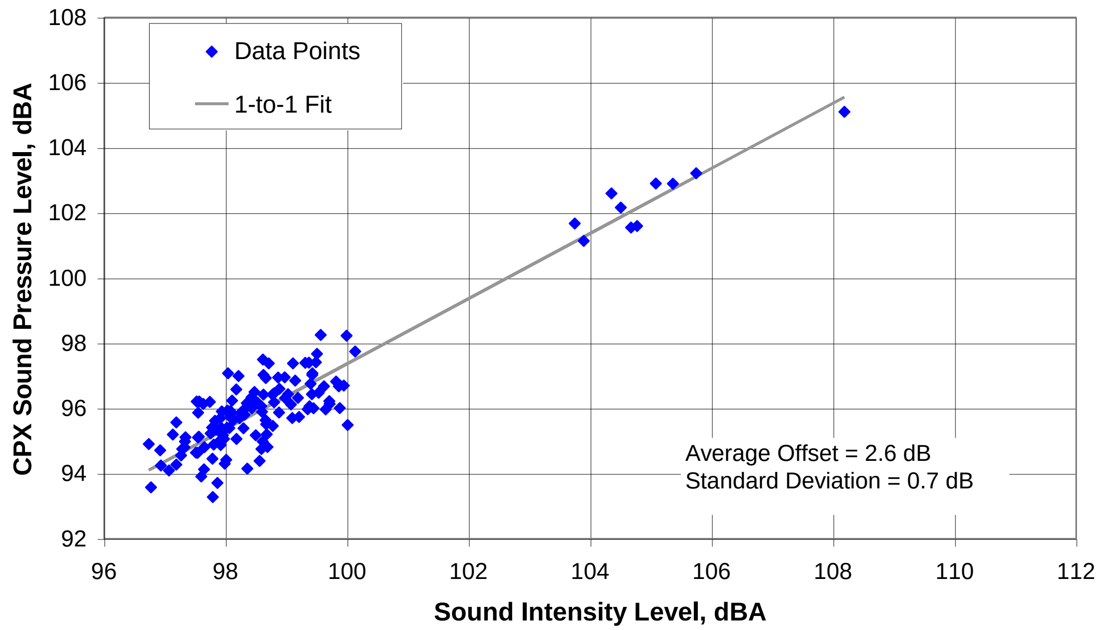


Figure B2. Comparison of Overall A-Weighted CPX Measured on the ADOT CPX Trailer and OBSI Levels Obtained Separately on a Test Car Using a Second ADOT Tire in November 2006

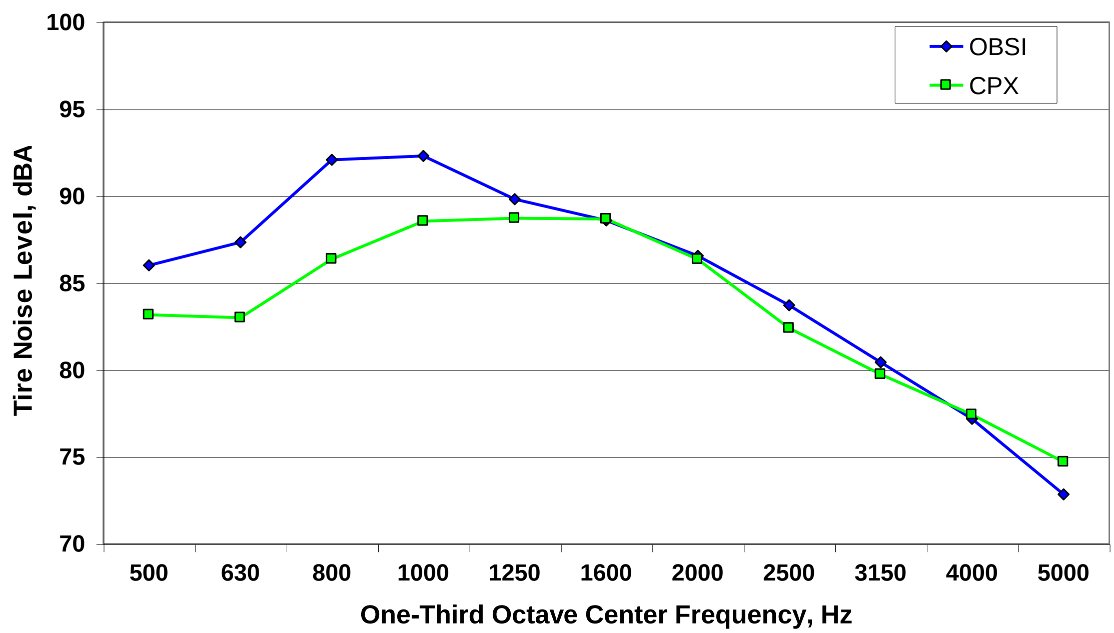


Figure B3. Comparison of Average One-Third Octave Band Levels of CPX and OBSI Data Taken on the ADOT CPX Trailer and a Test Car Separately in November 2006

Estimation of OBSI Levels from CPX Data

From the results of Figures B1 and B2, some difference (0.7 dB) in the relationship between the OBSI and CPX measurements taken on ADOT trailer and the on-vehicle OBSI and ADOT trailer CPX measurements were seen. One potential difference was the tire used for the trailer measurements versus that of the on-car measurements. The trailer had been in use for some time (approximately four years at the time of the 2006 comparison), while the tire for the on-car measurements was essentially new. Another potential difference was the sound field inside the trailer enclosure versus that in open space outside of the car. A third source of difference was the analyzer used to acquire and process the data. These were from two different instrument manufacturers, and other testing has indicated that there was a small (0.3 dB) bias between them.

In terms of the data sets themselves, both had strengths and weaknesses. The OBSI and CPX data from the trailer clearly were taken on exactly the same pavement at the same time, likely leading to the lower standard deviation in the data set. The trailer CPX to car OBSI data set indicated more variability, with a standard deviation of 0.7 dB that may have been due to uncertainty in the exact measurement location for the CPX and OBSI data that were taken on different days. As a data set, the 2006 results were biased to lower tire-pavement noise levels due to the absence of PCC on the freeway by that time. As result, the slope of the fit was determined by significantly fewer data points than was the 2005 data.

To avoid any undue bias in the CPX to OBSI comparison, it was decided to merge the 2005 and 2006 data sets to develop a composite offset between the data. The resultant plot is presented in Figure B4. For this composite set, the offset was now 3 dB, with a standard deviation of 0.7 dB. This offset has been applied to all of the CPX provided in this report to afford direct comparison of the early QPPP data with the more recent. In reviewing specific milestone data that includes both the earlier and later data, this amount of uncertainty should be kept in mind. Relying more on the corridor average results would improve the confidence in making comparisons over time.

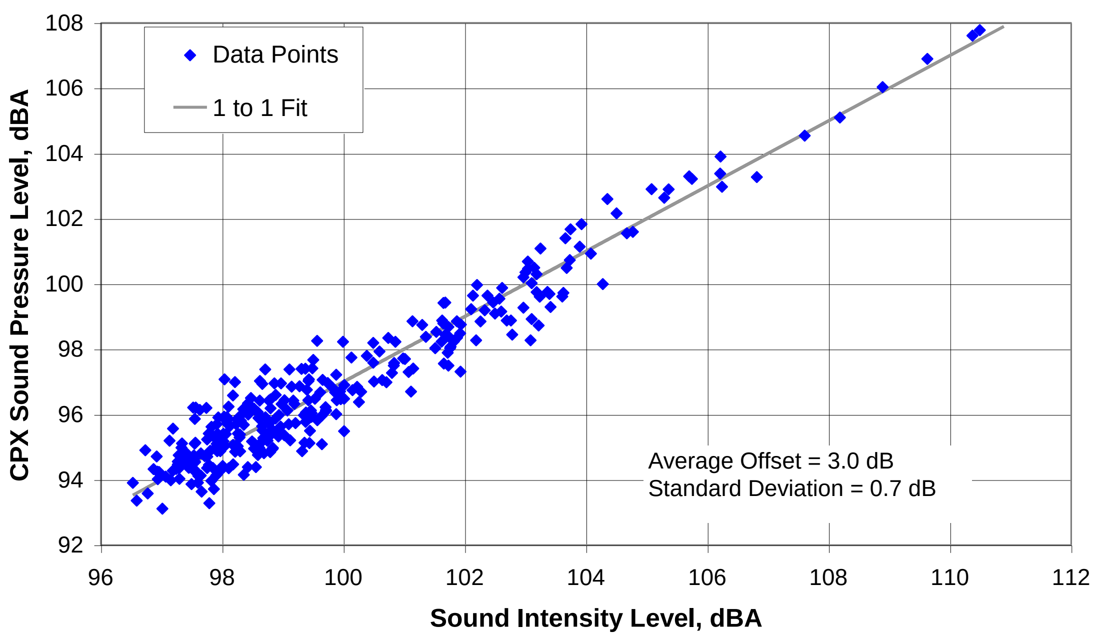


Figure B4. Comparison of All Overall A-Weighted CPX Levels Measured on the ADOT Trailer and OBSI Levels from March 2005 and November 2006

TYPE 1 ENVIRONMENTAL CONDITIONS

Table B1. Summary of Environmental Conditions at Type 1 During the *Pre*-Overlay Testing Periods in May 2002 and August 2003 and *Post*-Overlay Testing Periods from April 2004 through October 2015

Test Periods	Testing Times	Temperature		Relative Humidity	Barometric Pressure	Wind Speed
		Range	Average			
May 22, 2002	9:00-15:00	71-82°F (22-28°C)	78°F (26°C)	9-16%	1008-1013 hPa	2-5 m/s (N,NNE,WNW,W, variable)
May 23, 2002	9:00-12:00	75-84°F (24-29°C)	81°F (27°C)	12-16%	1008-1011 hPa	2-4 m/s (E,NNW, variable)
Aug 7, 2003	10:36-16:02	99-107°F (37-42°C)	104°F (37°C)	17-25%	1010-1012 hPa	2-5 m/s (W,WNW,SW, variable)
Aug 8, 2003	9:39-12:06	96-104°F (36-40°C)	99°F (37°C)	21-29%	1010-1012 hPa	2-4 m/s (NNW,NW)
Apr 6, 2004	9:19-10:50	68-73°F (20-23°C)	70°F (21°C)	42-55%	1015 hPa	3-4 m/s (E)
Apr 7, 2004	8:20-11:00	66-78°F (19-26°C)	73°F (23°C)	28-56%	1011-1012 hPa	3-5 m/s (ESE,SSE,SE)
Mar 16, 2005	14:49-17:31	65-71°F (18-22°C)	69°F (20°C)	10-15%	1015-1017 hPa	2-5 m/s (W,SW,SWS, variable)
Mar 17, 2005	8:04-11:57	52-67°F (11-19°C)	60°F (16°C)	21-43%	1010-1012 hPa	2-5 m/s (E,ESE,ENE, variable)
Mar 17, 2005	14:23-19:23	71-73°F (22-23°C)	72°F (22°C)	15-17%	1010-1012 hPa	4-5 m/s (W,WSW,WNW)
Mar 21, 2006	8:54-14:00	55-64°F (13-18°C)	61°F (16°C)	34-57%	1011-1014 hPa	5-7 m/s (ESE,SE,S,SSW,WSW)
Mar 22, 2006	8:44-12:08	46-63°F (8-17°C)	55°F (13°C)	24-52%	1020-1022 hPa	Calm-3 m/s (SW,N,SE,SS)
Nov 8, 2006	9:40-14:34	69-88°F (21-31°C)	80°F (27°C)	15-32%	1006-1010 hPa	2-3 m/s (SW,NE,E,SE,ESE)
Nov 9, 2006	12:11-15:05	81-84°F (27-29°C)	83°F (28°C)	15-18%	1007-1008 hPa	2-4 m/s (S,N,WNW)
Nov 10, 2006	9:51-14:02	71-83°F (22-28°C)	78°F (26°C)	11-28%	1015-1017 hPa	Calm-4 m/s (E, variable)
Mar 6, 2007	10:29-15:48	64-75°F (18-24°C)	71°F (22°C)	6-12%	1019-1021 hPa	Calm-5 m/s (N,NNE,E,SE)
Mar 5, 2007	9:34-11:56	63-76°F (17-24°C)	70°F (21°C)	8-16%	1019-1021 hPa	2-5 m/s (ESE,E,NE, variable)
Oct 17, 2007	10:29-15:14	72-81°F (22-27°C)	78°F (25°C)	19-33%	1006-1009 hPa	2-7 m/s (W,WSW)
Oct 18, 2007	10:30-	74-81°F	78°F	20-30%	1012-1014	Calm-3 m/s

Test Periods	Testing Times	Temperature		Relative Humidity	Barometric Pressure	Wind Speed
		Range	Average			
	12:59	(23-27°C)	(25°C)		hPa	(ESE,W, variable)
Mar 25, 2008	10:45-15:30	79-88°F (26-31°C)	84°F (29°C)	8-17%	1011-1015 hPa	Calm-4 m/s
Mar 26, 2008	11:15-14:15	76-86°F (24-30°C)	82°F (28°C)	5-11%	1012-1017 hPa	Calm-3 m/s
Oct 9, 2008	9:00-15:00 & 19:30-21:30	78-96°F (26-36°C)	88°F (31°C)	13-28%	1002-1008 hPa	2-5 m/s
Mar 19, 2009	10:20-16:35	74-87°F (23-31°C)	84°F (29°C)	8-16%	1009-1014 hPa	Calm-3 m/s
Mar 20, 2009	10:35-13:10	74-84°F (23-29°C)	79°F (26°C)	11-18%	1009-1010 hPa	2-4 m/s
Nov 19, 2009	8:15-14:15	50-76°F (10-24°C)	65°F (18°C)	10-38%	1013-1017 hPa	Calm-3 m/s
Mar 24, 2010	9:35-14:50	61-72°F (16-22°C)	67°F (20°C)	21-64%	1015-1018 hPa	Calm-3 m/s
Mar 25, 2010	9:40-12:30	63-75°F (17-24°C)	69°F (21°C)	22-37%	1015-1018 hPa	Calm-4 m/s
Nov 10, 2010	10:00-14:30	62-70°F (17-21°C)	66°F (19°C)	13-26%	1010-1014 hPa	Calm-3 m/s
Nov 11, 2010	10:30-15:00	62-72°F (17-22°C)	68°F (20°C)	12-23%	1017-1018 hPa	Calm-5 m/s
Nov 1, 2011	12:30-16:00	82-86°F (28-30°C)	84°F (29°C)	11-15%	1008-1010 hPa	Calm-3 m/s (N, E, W)
Nov 2, 2011	9:30-12:30	68-73°F (20-23°C)	71°F (21°C)	6-8%	1019-1020 hPa	Calm-3 m/s (variable direction)
Oct 23, 2012	12:30-15:40	79-84°F (26-29°C)	82°F (28°C)	31-40%	1008-1011 hPa	Calm-3 m/s (NW, W, WSW)
Oct 24, 2012	12:00-14:30	79-82°F (26-28°C)	81°F (27°C)	14-25%	1009-1011 hPa	3-7 m/s (W, WNW)
Oct 28, 2013	13:14-16:10	83-86°F (28-30°C)	85°F (29°C)	16-21%	1006-1007 hPa	5-8 m/s (SW, WSW)
Oct 29, 2013	12:47-15:40	74-75°F (23-24°C)	75°F (24°C)	27-33%	1009 hPa	4-9 m/s (W, WSW)
Oct 30, 2013	11:59-12:24	71°F (22°C)	71°F (22°C)	26-27%	1013-1014 hPa	3-4 m/s (W, WNW)
Oct 21, 2014	12:50-16:35	87-89°F (31-32°C)	88°F (31°C)	25-28%	1007-1008 hPa	Calm-5 m/s (SSE, WSW, variable)
Oct 22, 2014	12:20-15:55	85-91°F (29-33°C)	89°F (32°C)	21-31%	1010-1012 hPa	Calm-3 m/s (S, NNW, variable)
Oct 23, 2014	10:25-12:10	80-90°F (27-32°C)	86°F (30°C)	24-35%	1013-1016 hPa	Calm-4 m/s (E, SE, ESE)
Oct 13, 2015	9:00-	87-100°F	94°F	21-39%	1012-1017	Calm-5.1 m/s

Test Periods	Testing Times	Temperature		Relative Humidity	Barometric Pressure	Wind Speed
		Range	Average			
	16:35	(31-38°C)	(35°C)		hPa	(SE, W, WNW)
Oct 14, 2015	9:00-12:00	89-92°F (32-33°C)	90°F (32°C)	26-37%	1013-1014 hPa	1.6-4.1 m/s (ESE)

EFFECTS OF METEORLOGICAL CONDITIONS

In addition to the effect of temperature on OBSI measurements, studies have been conducted to implement a correction factor based on changing air density. However, recent studies (Donavan and Lodico 2011) have shown that correcting for air density increases the deviation in OBSI data and, therefore, has not been incorporated in this study.

Figure B5 shows the measured levels versus the ARFC pavement age (in years). The data show more scatter than the corrected data points provided in the main report. On average, coefficients of determination for the trend line of the measured data is approximately 0.82, while the average coefficient of determination for the corrected levels is about 0.93 (an improvement of approximately 0.11). Such improvements along each roadway test section range from 0.04 to 0.24. Table B2 summarizes the measured and corrected coefficients of determination for each roadway corridor. Scatter improvements were also determined in the NCHRP report (Donavan and Lodico 2009) and further confirm the proposed temperature correction calculation.

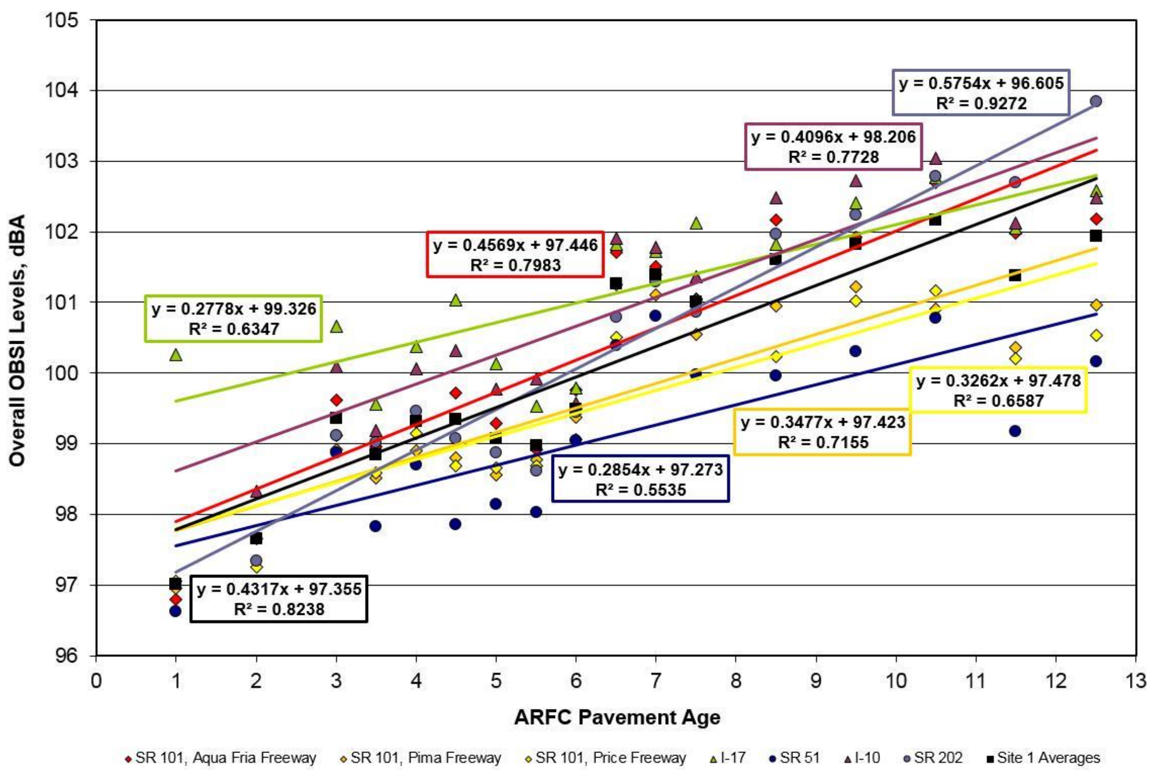


Figure B5. Measured Overall Sound Intensity Levels Versus ARFC Pavement Age (Uncorrected for Temperature)

Table B2. Summary of the Coefficients of Determination from the Averaged Function of OBSI Levels Versus ARFC Age (in Years) for Each Roadway Segment

Roadway Segment	Coefficients of Determination		Differences
	Measured	Corrected	
SR 101, Aqua Fria	0.798	0.916	0.118
SR 101, Pima	0.716	0.875	0.159
SR 101, Price	0.659	0.846	0.187
I-17	0.635	0.844	0.209
SR 51	0.554	0.795	0.241
I-10	0.773	0.901	0.128
SR 202	0.927	0.967	0.040
Type 1 Averages	***0.824***	***0.934***	***0.110***

Table B3 summarizes the measured overall OBSI levels averaged over each pavement segment of Type 1, and Table B4 summarizes the calculated noise level reduction of each post-overlay testing period average compared to the *pre*-overlay average at each segment. From the final measurement period, the measured levels resulted in an average reduction of 3.8 dB from the *pre*-overlay testing period, while the average reduction from the temperature-corrected was calculated to be 3.2 dB.

Table B3. Measured OBSI Levels for All Testing Periods Through October 2015, dB (Uncorrected)

Testing Period	SR 101, Agua Fria	SR 101, Pima	SR 101, Price	I-17	SR 51	I-10	SR 202	Average
PCC	105.3	103.9	106.8		104.1	106.7	106.4	**105.0**
2004 (Year 1)	96.8	97.0	97.1	100.3	96.6		97.0	**97.0**
Mar 2005 (Year 2)		97.7	97.3			98.3	97.3	**97.7**
Mar 2006 (Year 3)	99.6	98.9	99.1	100.7	98.9	100.1	99.1	**99.4**
Nov 2006 (Year 3.5)	99.0	98.5	98.6	99.6	97.8	99.2	99.0	**98.8**
Mar 2007 (Year 4)	99.3	98.9	99.1	100.4	98.7	100.1	99.5	**99.3**
Oct 2007 (Year 4.5)	99.7	98.8	98.7	101.0	97.9	100.3	99.1	**99.3**
Mar 2008 (Year 5)	99.3	98.6	98.7	100.1	98.1	99.8	98.9	**99.1**
Oct 2008 (Year 5.5)	98.9	98.8	98.7	99.5	98.0	99.9	98.6	**99.0**
Mar 2009 (Year 6)	99.8	99.4	99.1	99.8	99.0	99.6	99.4	**99.5**
Nov 2009 (Year 6.5)	101.7	101.3	100.5	101.8	100.4	101.9	100.8	**101.3**
Mar 2010 (Year 7)	101.5	101.1	101.4	101.7	100.8	101.8	101.3	**101.4**
Nov 2010 (Year 7.5)	101.1	100.5	101.0	102.1	100.0	101.4	100.9	**101.0**
Nov 2011 (Year 8.5)	102.2	100.9	100.2	101.8	100.0	102.5	102.0	**101.6**
Oct 2012 (Year 9.5)	101.9	101.2	101.0	102.4	100.3	102.7	102.2	**101.8**
Oct 2013 (Year 10.5)	102.7	100.9	101.2	102.8	100.8	103.0	102.8	**102.2**
Oct 2014 (Year 11.5)	102.0	100.4	100.2	102.1	99.2	102.1	102.7	**101.4**
Oct 2015 (Year 12.5)	102.2	101.0	100.5	102.6	100.2	102.5	103.8	**101.9**

Table B4. Reductions in OBSI Levels Produced by ARFC Through October 2015, dB (Uncorrected)

Testing Period	SR 101, Agua Fria	SR 101, Pima	SR 101, Price	I-17	SR 51	I-10	SR 202	Average
2004 (Year 1)	8.5	6.9	9.7	N/A	7.5		9.4	8.4
Mar 2005 (Year 2)		6.2	9.5			8.4	9.1	8.4
Mar 2006 (Year 3)	5.7	5.0	7.7		5.2	6.6	7.3	6.2
Nov 2006 (Year 3.5)	6.3	5.4	8.2		6.3	7.5	7.4	6.9
Mar 2007 (Year 4)	6.0	5.0	7.7		5.4	6.6	6.9	6.3
Oct 2007 (Year 4.5)	5.6	5.1	8.1		6.2	6.4	7.3	6.5
Mar 2008 (Year 5)	6.0	5.3	8.1		6.0	6.9	7.5	6.6
Oct 2008 (Year 5.5)	6.4	5.1	8.1		6.1	6.8	7.8	6.7
Mar 2009 (Year 6)	5.5	4.5	7.7		5.1	7.1	7.0	6.1
Nov 2009 (Year 6.5)	3.6	2.6	6.3		3.7	4.8	5.6	4.4
Mar 2010 (Year 7)	3.8	2.8	5.4		3.3	4.9	5.1	4.2
Nov 2010 (Year 7.5)	4.2	3.4	5.8		4.1	5.3	5.5	4.7
Nov 2011 (Year 8.5)	3.1	3.0	6.6		4.1	4.2	4.4	4.2
Oct 2012 (Year 9.5)	3.4	2.7	5.8		3.8	4.0	4.2	4.0
Oct 2013 (Year 10.5)	2.6	3.0	5.6		3.3	3.7	3.6	3.6
Oct 2014 (Year 11.5)	3.3	3.5	6.6		4.9	4.6	3.7	4.4
Oct 2015 (Year 12.5)	3.1	2.9	6.3		3.9	4.2	2.6	3.8

Table B5 summarizes the measured OBSI levels recorded for each testing period at each of the Type 3 locations and the corresponding reductions. While from March 2006 through March 2009, the average OBSI level reductions calculated for the measured data ranged from 7.3 to 8.2 dB, by October 2015, the average reduction was 4.5 dB.

Table B5. OBSI Levels and Noise Reductions Measured at the Type 3 Sites, dB (Uncorrected)

Testing Period	Site 3A		Site 3B		Site 3C		Site 3D		Site 3E		Average	
	Level	Δ	Level	Δ	Level	Δ	Level	Δ	Level	Δ	Level	Δ
PCC	104.6	--	109.5	--	107.1	--	109.2	--	105.5	--	107.2	--
2004 (Year 1)	--	--	--	--	--	--	--	--	96.9	8.6	96.9	8.6
Mar 2006 (Year 3)	98.9	5.7	100.6	8.9	100.0	7.1	100.3	8.9	99.7	5.8	99.9	7.3
Nov 2006 (Year 3.5)	99.0	5.6	99.1	10.4	98.4	8.7	99.5	9.7	98.8	6.7	99.0	8.2
Mar 2007 (Year 4)	98.9	5.7	99.8	9.7	100.1	7.0	99.9	9.3	99.5	6.0	99.7	7.5
Oct 2007 (Year 4.5)	99.2	5.4	100.7	8.8	99.3	7.8	100.5	8.7	97.6	7.9	99.5	7.7
Mar 2008	98.0	6.6	100.3	9.2	97.6	9.5	101.0	8.2	98.4	7.1	99.1	8.1

Testing Period	Site 3A		Site 3B		Site 3C		Site 3D		Site 3E		Average	
	Level	Δ	Level	Δ	Level	Δ	Level	Δ	Level	Δ	Level	Δ
(Year 5)												
Oct 2008 (Year 5.5)	98.6	6.0	101.0	8.5	98.8	8.3	98.5	10.7	98.9	6.6	**99.1**	**8.1**
Mar 2009 (Year 6)	99.1	5.5	100.0	9.5	99.0	8.1	99.1	10.1	100.2	5.3	**99.5**	**7.7**
Nov 2009 (Year 6.5)	101.5	3.1	100.9	8.6	101.7	5.4	102.0	7.2	102.7	2.8	**101.8**	**5.4**
Mar 2010 (Year 7)	101.3	3.3	102.0	7.5	100.0	7.1	103.4	5.8	102.8	2.7	**101.9**	**5.3**
Nov 2010 (Year 7.5)	100.9	3.7	101.3	8.2	--	--	102.2	7.0	102.1	3.4	**101.6**	**5.6**
Nov 2011 (Year 8.5)	101.9	2.7	102.1	7.4	100.7	6.4	102.9	6.3	102.8	2.7	**102.1**	**5.1**
Oct 2012 (Year 9.5)	101.3	3.3	103.0	6.5	102.1	5.0	103.9	5.3	103.4	2.1	**102.7**	**4.5**
Oct 2013 (Year 10.5)	102.4	2.2	102.9	6.6	101.2	5.9	104.2	5.0	103.0	2.5	**102.7**	**4.5**
Oct 2014 (Year 11.5)	101.2	3.4	--	--	--	--	104.0	5.2	--	--	**102.6**	**4.6**
Oct 2015 (Year 12.5)	102.0	2.6	103.0	6.5	100.9	6.2	105.5	3.7	101.9	3.6	**102.7**	**4.5**

TYPE 1 OBSI LEVELS

This section 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). Due to the magnitude of the project and time constraints, a single measurement was taken at each milepost location. Therefore, variability due to construction, missing milepost-markers, inference from traffic, lane shifting, weather, etc., was found in the data.

Table B6. Corrected Overall OBSI Levels Measured Along SR 101 in the Counterclockwise Direction

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	ARFC Mar 2008	ARFC Oct 2008	ARFC Mar 2009	ARFC Nov 2009	ARFC Mar 2010	ARFC Nov 2010	ARFC Nov 2011	ARFC Oct 2012	ARFC Oct 2013	ARFC Oct 2014	ARFC Oct 2015
101	SB	1																		
101	SB	2				97.8		99.0		101.0	100.2	100.6			104.3	103.4	103.1	103.7	105.0	
101	SB	3	108.3			98.2		102.3	102.0	102.2	102.1	100.3	104.5	103.3	104.1	103.5	104.8	106.1		103.3
101	SB	4	109.8			97.3	100.4	100.3	100.6	99.4	101.5	101.2	103.0	102.9	102.0	100.9	104.4	103.7	103.2	
101	SB	5	109.0					101.4		100.0	97.3	98.9	99.0	98.7	100.3	101.2	102.2	101.7	102.2	102.3
101	SB	6				98.3	100.3	99.4	101.7	102.0	102.3	102.8	103.3	101.2	103.2	105.7	104.6	104.1	103.6	104.6
101	SB	7				98.0	98.9	98.6	100.2	99.8	100.9	100.4	101.9	100.9	100.5	97.2	99.6	98.9	99.1	
101	SB	8				96.4	98.7	98.4	99.6	98.8	99.6	100.1	100.0	102.1	101.4	103.2	102.8	103.9		103.5
101	SB	*Site 3B*	109.9			100.3	99.6	99.9	101.1	101.0	101.8	100.6	100.8	101.9	101.2	102.4	103.4	103.2		104.1
101	SB	9				99.6	99.8	100.9	101.1	100.5	100.5	101.8	100.9	102.8	100.9	103.1	103.3	103.6	104.2	
101	SB	10				99.7	100.2	101.6	99.9		101.4	99.2		100.1	100.7	101.9	103.4	104.6	104.4	
101	SB	11				100.6	100.0	98.2	100.4	100.0	100.2	100.0	101.5	101.3	102.2	102.3	102.1	103.1	101.8	102.6
101	SB	12				98.6	99.4	99.0	101.2	100.7	101.2	101.0	103.3	101.1	103.0	102.2	103.9	104.2	103.1	104.2
101	SB	13				98.7	99.9	99.9	100.2	100.3	99.3	99.8	102.9	101.7	101.9	102.2	103.1	103.7	103.4	103.1
101	SB	14				98.8	99.6	98.7	100.0	99.7	99.9	100.2	102.9	102.4	101.5	104.1	103.0	104.2	103.7	103.6
101	SB	15				97.9	100.3	98.5	101.4	99.7	101.7	99.5	100.7	101.0	100.2		103.2	103.5	102.1	
101	SB	16	102.8	96.0		98.9	98.2	99.4	98.9	97.3	98.8	99.1	100.0	102.1	101.1	103.5	103.8	104.0	104.3	104.6
101	WB/SB	17	104.5	97.3		97.8	98.8	98.3	99.4	99.2	98.6	100.5	102.4	101.5	102.6	105.5	103.3	104.5	104.8	105.3
101	WB/SB	18	104.8	97.4		97.8	98.8	98.4	99.2	98.9	98.8	99.2	99.8	100.3	99.9	101.6	101.1	101.7	100.0	101.8
101	WB/SB	19	104.9	96.6		98.8	99.0	99.1	99.3	98.8	99.3	99.3	100.8	100.1	100.5		101.5	100.5	100.0	101.6
101	WB/SB	20	104.2	97.2		98.8	99.0	99.0	99.0	98.3	98.8	99.7	100.9	99.4	100.0	101.5	100.9	101.7	101.0	102.6
101	WB/SB	*Site 3A*				98.6	99.5	99.0	99.6	98.7	99.4	99.7	101.4	101.3	100.9	102.2	101.8	102.6	102.2	103.1
101	WB/SB	21	105.0	97.1		98.9	98.9	99.2	99.3	99.2	99.4	99.4	101.4	100.9	100.6	101.4	101.3	102.4	101.5	103.1
101	WB/SB	22	104.1	96.7		98.5	99.2	99.5	99.9	100.2	99.7	100.0	101.7	101.7	101.5	101.8	101.6	101.9	102.3	100.7
101	NB/WB	23	106.7				98.9	99.6	98.3	99.1	99.2	99.1	100.6	100.3	98.9	100.1	100.2	101.1		101.9
101	NB/WB	24	104.6				97.4	99.4	99.4	98.9	98.3	97.3	99.9	100.0	97.5	100.4	99.7	101.4	99.7	100.1
101	NB/WB	25	102.1	96.3		99.1	100.1	100.3	100.2	100.5	100.6	98.8	101.2		100.5	98.7	98.0	99.2	99.6	102.4
101	NB/WB	26	102.5			97.5	98.5	99.0	98.2	98.1	100.0	97.9	98.9	99.2	99.3	97.8	99.8	97.9	98.5	100.4
101	NB/WB	27	102.0				98.4	99.6	99.9	99.2	99.9	99.9	100.8	100.9	100.7	98.8	98.9	98.4	98.2	102.0
101	NB/WB	28	101.9	96.5		98.7	99.3	98.9	99.2	98.6	99.7	98.6	99.9	99.9	99.8	98.5	99.1	98.1	97.5	98.3
101	NB/WB	29	106.7				98.9	98.8	99.2	98.0	99.3	99.3		100.5	98.7	97.7	98.2	98.2	98.0	98.8
101	NB/WB	30	104.4				97.9	98.2	98.0	97.9	98.6	98.2	99.4	98.6	97.8	99.5	100.2	99.7	98.5	100.0
101	NB/WB	31	104.1	97.6			99.2	100.0	99.1	100.4	100.2	100.1	101.3	101.6	101.4	102.0	102.5		101.9	102.6
101	NB/WB	32	105.6			99.3	99.5	100.8	99.2	99.3	97.9	98.8	100.7	100.6	101.0	101.7	100.8	102.1	102.3	103.0
101	NB/WB	33	102.3			98.3	97.7	98.7	98.4	98.1	100.3	99.7		100.0	99.6	99.2	100.7	100.7	99.7	100.6
101	NB/WB	34	102.2			97.8	97.8	99.1	98.8	96.9	99.7	100.6	100.5	99.8	99.6	102.1	100.1	100.5	100.6	101.5
101	NB/WB	35	107.6	96.7		98.6	100.0	98.9	100.3	98.0	99.5	101.3	101.0	100.8	100.6	101.1	101.4	102.0	102.1	103.0
101	NB/WB	36	107.6	97.2		98.4	99.8	99.4	99.8	99.1	99.8	100.0	102.5	100.9	101.6	101.5	102.9	102.6	102.8	104.2
101	NB	37	102.7	96.1		98.0	97.9	98.7	98.7	98.9	98.0	101.1	100.6		99.9	101.1	101.0		101.1	102.5
101	NB	38	103.3	97.0		97.4	99.1	98.5	98.8	98.9	99.7	99.2	100.7	100.8	101.1	101.2	102.4	102.0	102.4	102.4
101	NB	39	102.7	97.4			98.1	98.4	99.1	99.5	99.6	100.2	100.5	101.0	99.7	101.3	100.4	102.0	101.7	103.4
101	NB	40	103.8	96.3		97.8	98.7	97.8	98.4	99.0	97.5	98.2		100.5	100.0	101.2	100.3	101.6	101.2	101.7
101	NB	41		96.4		98.1	98.0	98.0	98.6	98.9	97.0	99.6	100.9	100.2	99.8	100.0	100.4	101.4	101.3	101.9
101	NB	42		98.6		99.4	101.1	99.7	99.4	100.9	101.1	98.1	101.3	100.8	101.6	102.3	102.2	102.4	102.4	103.8
101	NB	43	106.0			99.1	99.6	99.9	99.7	100.1	99.1	100.5	102.2	101.7	102.0	103.0	102.5	103.3	103.3	103.5
101	NB	44	106.0	97.9		99.1	99.5	99.9	99.3	99.7		99.4	102.1	101.7	100.7	102.8	102.1	103.3	103.7	103.3
101	NB	45	104.2			99.1	101.6	100.2	100.0	103.5	100.8	99.2	102.8	102.6	102.4	103.7	103.8	103.5	101.9	102.9
101	NB	46				99.1	98.5	101.0	102.0	100.7	100.2	101.1	103.2	102.1	102.1	104.1	104.4	104.7		102.4
101	NB	47	105.7	97.1		99.5	100.1	98.9	98.2	99.0	99.6	100.8	102.0	102.7	101.1	103.2	103.0	103.7	103.1	104.1
101	NB	*Site 3E*	105.7	97.1		99.5	100.1	98.9	98.2	99.0	99.6	100.8	102.6	102.7	102.0	103.2	103.8	103.7	102.9	104.1
101	NB	48	105.5	96.7		99.7	100.2	101.5	98.5	99.7	99.9	101.1	103.4	101.9	101.0	102.8	102.7	102.9	102.7	104.4
101	NB	49		98.2			101.4	99.7	100.9	101.6	100.4	100.4	101.6	102.1	102.5	103.4			102.0	104.0
101	NB	50		98.2		98.9	100.1	102.6		100.6	103.2	101.3	103.9	103.7	102.5	104.6		103.3	101.8	103.6
101	NB	51	105.7	98.3		99.5	100.6	100.1			101.8	101.6	103.4	102.5	102.4	103.6	102.7		103.8	103.5
101	NB	52		98.2		96.2	97.6		97.8		98.0	100.4	98.5		98.5	99.1	100.0	102.6		101.2
101	NB	53				98.3	98.1	99.1	99.0	97.8	100.0	98.1	100.2	100.1	100.7	101.6	103.8	100.5	101.3	101.7
101	NB	54				98.9	98.3	99.0	98.9	98.8	100.6	99.1	99.5	100.3	100.6	100.5	103.0	101.8	102.4	104.2
101	NB	55		95.9		99.2	97.4	98.8	97.6	98.2	98.0	98.8	99.3	100.3	99.8	101.0	103.1		100.9	101.9
101	NB	56	107.4	96.5	96.6	98.4	99.7	99.0	99.4	99.6	99.8	99.0	101.2	102.2	101.9	102.0	101.8	103.3	101.8	103.6
101	NB	57	107.7	97.2	97.6	98.0	99.1	99.6	99.0	100.0	100.3	100.2	101.1	102.0	101.1	101.5	101.8	103.6	103.2	102.9
101	NB	58	108.7	96.8	96.8	98.4	99.3	99.3	99.9	100.0	98.4	100.3	100.2	101.2	101.4	102.0	102.6	102.2	100.9	102.5
101	NB	59	108.5	96.7	97.2	100.7	99.5		100.5	100.7	100.5	100.1	102.0	101.1	101.6	102.1	104.3	103.3	102.5	103.8
101	NB	60	106.0	98.0	97.5	100.4	99.9		100.4	100.4	101.2	99.6	101.4	102.0	101.8	97.6	99.2		99.3	100.0
101	NB	61											103.0	102.1	102.3		100.3	99.5	99.2	100.5

Table B7. Corrected Overall OBSI Levels Measured Along SR 101 in the Clockwise Direction

Road	Direction	Milepost	SR 101																	
			Pre-Overlay	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC
			PCC	2004	Mar 2005	Mar 2006	Nov 2006	Mar 2007	Oct 2007	Mar 2008	Oct 2008	Mar 2009	Nov 2009	Mar 2010	Nov 2010	Nov 2011	Oct 2012	Oct 2013	Oct 2014	Oct 2015
101	NB	1												102.7						
101	NB	2						100.2		101.0		102.0	102.8	101.9	102.2					103.578
101	NB	3				98.2	99.9	100.3	101.7	101.3	100.0	100.7	103.1	103.6	102.1	103.4		104.9	104.9	
101	NB	4				99.9	100.9	100.6	101.2	99.0	101.4	100.7	103.3	102.9	103.0	103.7	103.3	104.3	102.9	104.0
101	NB	5				100.7		99.5		100.7	101.4	102.7	101.1	101.8	99.5	105.2	102.6	102.9	104.2	
101	NB	6				99.7	101.2	102.4	102.4	100.2	100.9	101.2	102.1	104.1	103.2	100.8	100.5	100.0	100.7	104.2
101	NB	7				100.2	100.5	100.3	101.2	102.1	99.5	102.0	103.3	102.6	100.9	104.1	102.1	103.4	102.9	
101	NB	8				101.1	100.2	102.4	102.2	102.1	100.3	102.9	103.2	101.6	102.0	104.5	102.7	105.1	104.4	105.1
101	NB	*Site 3B*				100.5	100.6	101.4	101.4	102.0	99.8	98.8	103.6	101.9	102.3	105.0	104.1	104.7		
101	NB	9				101.8	100.3	97.7	100.9	99.7	99.7	102.4	103.2	103.5	102.7	103.7	104.5	104.5	104.4	105.1
101	NB	10				100.4	99.2	100.1	101.1	100.7	100.7	101.1	102.8		100.0	104.1	104.1		101.8	
101	NB	11				101.0	98.9	98.7	99.3	98.0	98.9	100.8	101.9	101.3	100.0	103.4	102.7	103.0	103.3	
101	NB	12				101.8	99.7	100.0	100.5	99.1	99.7	101.1	102.6	101.6	101.3	102.6	102.9	103.7	103.4	104.8
101	NB	13				99.3	99.4	97.9	100.7	100.2	98.9	99.9	102.4	103.1	100.7	103.0	103.5	104.5	103.6	104.8
101	NB	14					98.9	97.7	99.8	100.3	99.7	100.9	101.8	102.1	99.1	100.4	102.0	103.5	102.6	103.4
101	NB	15				99.3	99.5	99.0	100.3	98.4	99.3	99.3	102.0	102.4	100.0	102.0	104.8	103.9	103.8	105.2
101	NB	16	103.8	97.7		99.1	98.1	98.1	99.3	100.4	98.5	100.7	101.0		99.3	104.9	98.6	100.9	98.9	101.8
101	NB	17	103.6	96.7		100.6	99.6	99.6	100.1		99.3	101.3	101.8	99.8	101.5	103.5	102.0	105.4	104.9	104.4
101	NB/EB	18	104.9	97.2		99.1	99.8	98.0	98.9	99.7	98.5	100.2	100.9	100.3	99.7	100.9	100.5	101.9	100.5	102.6
101	NB/EB	19	104.7	97.6		98.9	98.4	98.6	98.4	100.4	96.6	100.1	100.5	100.7	99.2	101.5	101.3	102.0	100.9	102.5
101	NB/EB	20	104.5	96.6		98.3	98.8	98.9	98.5	99.7	97.8	98.7	99.5	99.3	98.8	100.6	100.8	101.9	101.1	102.0
101	NB/EB	*Site 3A*				100.1	99.3	98.1	99.3	97.9	98.5	100.1	99.4	99.8	100.2	102.3	102.1	102.1		102.1
101	NB/EB	21	105.0	96.4		99.7	98.3	97.4	97.1	99.5	97.7	99.1	99.4	99.9	97.3	100.6	100.1	100.1	99.5	101.6
101	NB/EB	22	105.2	97.4		99.3	98.1	97.6	97.9	98.1	96.6	98.8	98.6	100.2	98.2	99.9	100.5	99.4		100.4
101	SB/EB	23	107.4			99.1	99.1	99.1			99.2	99.7	99.5		100.1			101.2	101.8	102.1
101	SB/EB	24	107.4	96.1		97.6	98.8	98.7			99.3	99.8	101.0		99.9			98.2	98.9	99.0
101	SB/EB	25	102.2	97.6		98.3	98.7	98.5	99.6	99.9	98.8	99.5	100.1	100.7	99.4	100.3	100.0	98.3	98.9	98.7
101	SB/EB	26	102.3	96.9			98.9	98.5	98.6	98.6	97.6	99.8	100.5	100.0	99.3	99.5	100.0	98.5	99.7	100.1
101	SB/EB	27	101.1	98.2			100.5	98.1	101.3	102.1	100.6	101.6	101.4	102.0	101.5	99.2	99.7	99.7		100.5
101	SB/EB	28	101.5	96.7		98.6	98.9	98.7	99.8	99.6	99.7	100.6	101.0	101.0	100.0	97.6	101.5	99.5	99.1	99.3
101	SB/EB	29	102.4	96.2		98.4	97.8	98.3	101.1	99.1	97.9	100.9	100.6	101.3	98.6	99.1	99.7	99.6	99.4	100.6
101	SB/EB	30	102.0	96.5		100.1	98.9			100.2	99.7	102.1	101.3		100.7			99.9		100.2
101	SB/EB	31	104.2	95.9		97.0	97.3	97.4	97.8	98.6	98.1	98.7	100.6	101.1	99.4	101.6	100.8		98.9	102.6
101	SB/EB	32	105.2			97.0	97.5	98.2	98.6	97.8	97.0	99.8	99.6	100.1	99.1	100.3	100.3	99.8		100.5
101	SB/EB	33	102.4				97.2		97.6	98.6	99.9	99.6	100.4	100.3	99.9	99.8	100.5	101.0	99.6	100.2
101	SB/EB	34	102.5			96.8	97.6	97.2	97.8		100.3	100.4	99.5	99.4	98.4	99.7	100.5	100.7	99.7	101.2
101	SB/EB	35	108.5	96.9		97.7	98.7	97.5	99.3		98.6	100.1	101.9	99.8	99.9	102.0	103.0	102.6	101.1	102.2
101	SB/EB	36	108.8	96.8		97.6	98.7	98.3	98.2		98.6	99.9	100.4	100.6	100.0	101.1	103.8	102.0	100.7	103.0
101	SB	37	105.0			98.3	98.2	97.9	98.5	99.0	98.2	99.3	100.4	99.7	99.5	100.9	100.0			100.5
101	SB	38	103.6	96.9		97.6	97.8	98.0	99.1	98.5	101.6	100.4	99.2	100.4	99.1	101.2	102.7	101.9	101.1	102.9
101	SB	39	104.6	96.3		98.0	98.2	98.1	98.5	97.5	98.4	98.0	99.8	100.2	100.0	101.2	103.0		101.9	103.4
101	SB	40	104.0	96.4		97.7	98.0	98.1	98.7	96.5	97.3	98.3	98.6	100.2	100.2	101.4	104.3	101.2	99.6	100.7
101	SB	41	104.7	96.4			98.0	96.5	98.5	98.6	97.1	97.7	100.4	99.7	99.3	100.2	104.3	101.4	101.3	101.2
101	SB	42	104.7	99.2		99.1	99.6	99.5	100.8	99.9	101.3	102.1	102.2	102.7	101.8	103.2	102.9	100.9	98.5	100.7
101	SB	43		98.1		99.4		98.7	99.7	98.1	99.4	98.8	101.0	101.5	101.2	102.3	102.0	102.6	102.3	103.2
101	SB	44		97.3		99.6	100.3	99.2	99.9	98.5	99.7	100.7	101.9	101.5	101.3	103.2	103.9	103.3	103.1	104.9
101	SB	45	104.8			99.0		99.2	100.0		99.1	101.2	102.1	102.1	100.9	103.5	104.4	103.7	103.8	103.3
101	SB	46	105.9	97.1		99.6	98.2	98.0	99.5	97.9	100.2	100.0	100.7	100.7	100.8	102.0	105.1	102.5	101.7	102.9
101	SB	47	105.9	97.1		99.3	99.3	99.6	98.0	98.1	100.8	101.4	102.3	102.6	101.0	103.2	102.5	103.5	101.8	102.9
101	SB	*Site 3E*	105.9	97.1		99.3	99.3	99.6	98.0			101.1	102.3	102.6	100.4	103.5	102.5	104.1	101.8	102.9
101	SB	48	106.2	97.9		98.6	100.3	98.7	98.8	99.5	101.7	102.0	103.0	103.4	103.2	104.4	105.0	104.8	102.1	103.0
101	SB	49		97.8	97.9	98.6	100.6	100.3	99.2	99.6	101.5	101.6	102.3	103.0	103.1	103.2	104.6	104.0		102.9
101	SB	50		96.9	97.4	99.1	99.9	99.9		98.9	101.6	101.7	101.4	102.7		103.8	102.2	104.1		103.6
101	SB	51		98.3		98.3		98.7			99.3	100.8	101.9	101.5	101.2	99.8			102.9	103.5
101	SB	52			97.9	98.3	99.8	100.6		101.1	100.1	100.8	101.3	102.4	102.3	101.9	102.8	103.0		101.1
101	SB	53		98.4	96.7	97.7	99.2		99.9	99.2	99.7	98.9	99.1	100.8	100.0	100.7	101.5	102.0	102.6	102.4
101	SB	54					99.0	98.7	98.6		99.7	100.5	100.6	101.9	100.0	99.1	99.6		98.6	
101	SB	55		95.6	97.3	99.1	99.7	99.8	100.0	100.3	100.5	102.3	100.7	101.3	102.1	100.1	100.1	99.9	99.8	100.1
101	SB	56	105.9	96.9	97.4	98.2	99.3	99.3	99.2	99.0	99.6	99.3	99.5	100.2	101.2	99.3	97.9	100.3	100.8	100.8
101	SB	57	107.4	96.2		98.2	99.1	98.7	97.9	98.2	98.2	98.5	99.8	101.0	100.2		100.7	102.0	102.2	102.5
101	SB	58	107.7	97.3		98.6	99.0	99.1	98.6	96.8	97.9	98.4	99.6	101.5	100.7		101.7	102.0		99.6
101	SB	59	106.1	98.8		99.6	99.4	99.7	99.0	98.9	98.5	99.9	100.0	101.6	101.0		103.0	102.6		100.3
101	SB	60	107.0	99.0		100.4	99.7	98.8	98.9	99.5	98.9	99.8	100.3	100.9	100.6			100.8	100.7	101.0
101	SB	61											100.8	102.7	101.2		100.9		100.2	99.9

Table B8. Corrected Overall OBSI Levels Measured Along I-17 in the Northbound and Southbound Directions

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	ARFC Mar 2008	ARFC Oct 2008	ARFC Mar 2009	ARFC Nov 2009	ARFC Mar 2010	ARFC Nov 2010	ARFC Nov 2011	ARFC Oct 2012	ARFC Oct 2013	ARFC Oct 2014	ARFC Oct 2015
17	NB	196								97.7					100.7					
17	NB	197								97.7					102.6					104.3
17	NB	198									99.0	98.3		100.0	99.8	100.1				102.4
17	NB	199						101.1	100.7		100.3	101.1	103.4	103.6	102.2	104.0	104.8		103.6	105.5
17	NB	200		100.3			98.6	99.3	102.6	101.7	102.7	101.1	104.6	101.7	102.9	105.1	104.8	102.9	104.0	105.2
17	NB	201				100.4	99.5	100.9	101.5	101.7	103.2	97.6	99.1	99.5	104.2	102.6	105.1	103.3	104.5	
17	NB	202		100.6		100.9	102.0	102.7	103.4		102.9	102.5	103.8	103.3	103.2	104.1	104.3	104.1	103.4	106.2
17	NB	203								104.2					103.4					
17	NB	204								103.0					103.1					
17	NB	208									100.0	100.2			101.8					
17	NB	209									100.5	100.9			101.7					
17	NB	210									100.0	101.5			102.4					105.9
17	NB	211				101.0	102.2	102.5	103.4	102.2	97.5	99.2	101.2	99.9	101.3	101.3	101.0	103.1		102.2
17	NB	212				100.4	100.5	101.3	99.9	98.7	99.1	100.4	100.5	101.2	100.8	101.3	100.8	102.1		102.5
17	NB	213				100.1	98.9	98.2	99.5	99.0	97.7	100.0	100.8	100.6	100.2	101.2	102.6	101.7	100.8	101.9
17	NB	214				98.9	98.6	97.1	99.5	98.9	99.2	99.7	101.3	100.6	100.5	101.5	101.0	101.4	101.0	102.1
17	SB	196								98.8					100.7					
17	SB	197								99.7					104.3					
17	SB	198								102.4	100.4	101.9		101.2						103.5
17	SB	199					100.5	101.6	101.9	101.8	103.5	99.9	102.6	103.2	103.7	102.4	103.5	104.6	102.7	103.5
17	SB	200					98.2	99.5		100.8	101.5	99.9	100.8	104.2	104.5	104.1	102.6	104.1		105.2
17	SB	201						99.4		98.8	100.7	99.2	101.0	101.6	100.5	102.6	102.1	104.0	103.3	103.4
17	SB	202					102.8	103.7	103.5	102.2	103.1	103.0	103.2	104.1	103.7	102.6	103.6	104.3	103.5	103.6
17	SB	203								101.3					101.8					
17	SB	204								102.8					103.1					
17	SB	208									99.9	100.9			102.5					
17	SB	209									99.4	100.2			101.8					
17	SB	210									99.6	100.7			103.0					103.7
17	SB	211					102.4	103.1	105.1	105.1	98.5	100.4		102.6	100.7	100.5	102.1	102.2		104.1
17	SB	212					98.2	99.2	100.3	99.5	99.3	100.4	100.7	100.7	101.0	102.1	103.7	103.6		
17	SB	213					98.8	99.4	100.2	100.6	99.0	98.4	100.9	101.2	100.8	101.3	101.2	102.6		102.1
17	SB	214					99.2	98.7	98.5	98.4		102.1		101.2	100.7	100.3		101.6		101.4

Table B9. Corrected Overall OBSI Levels Measured Along SR 51 in the Northbound and Southbound Directions

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	ARFC Mar 2008	ARFC Oct 2008	ARFC Mar 2009	ARFC Nov 2009	ARFC Mar 2010	ARFC Nov 2010	ARFC Nov 2011	ARFC Oct 2012	ARFC Oct 2013	ARFC Oct 2014	ARFC Oct 2015
51	NB	2																		
51	NB	3								97.4										
51	NB	4								98.4										
51	NB	5																		
51	NB	6								99.1										
51	NB	7								98.0										
51	NB	8								97.9					98.9					
51	NB	9								100.8					99.4					
51	NB	10	103.8				98.3		97.9	98.3	98.2	99.3		100.4	100.6		101.6	101.7		102.3
51	NB	11	105.1				98.9	99.5	97.5	100.1	98.3	99.5	101.1	101.2	101.4	102.0	102.2	102.3	101.2	102.1
51	NB	12	104.4			97.4	97.9	98.5	98.1	98.7	98.7	98.9	99.1	100.1	100.0	100.3	101.3	101.8	101.2	101.7
51	NB	13	103.4			98.4	98.2	98.4	97.8	100.2	98.4	99.3	100.5	100.5	100.8	101.5	101.9	101.7	101.3	102.6
51	NB	14		98.8		99.2	98.3	98.6	98.4	101.0	99.2	99.8	100.5	101.7	102.2	98.1	98.3	99.0	98.0	99.1
51	NB	15		95.9		99.8	98.3	98.1	99.6		101.5	102.8	99.9	100.3	98.8	99.9			98.5	
51	SB	2								97.9										
51	SB	3								99.8										
51	SB	4								98.2										
51	SB	5								98.2										
51	SB	6								98.5										
51	SB	7								98.8										
51	SB	8																		
51	SB	9								98.8										
51	SB	10	104.7				96.5			97.2	97.0	98.3			99.2					101.0
51	SB	11	104.0			97.9	99.1	99.2	98.9	98.4	99.2	100.5	101.1	101.4	101.4	102.6	102.2	106.8		103.3
51	SB	12	104.4			98.2	97.5	97.8	98.0	97.8	97.3	98.6	99.3	99.3	99.9	100.2	101.1	100.6	99.9	100.6
51	SB	13	106.0			100.1	100.7	100.1	98.9	99.7	99.4	101.0	100.3	101.8	101.4	102.9	103.2	103.8	104.3	103.0
51	SB	14		95.3		97.6	97.1	98.7	97.8	98.1	100.0	98.4	99.6	100.0	98.1	98.6	98.2	98.6	97.6	98.2
51	SB	15		97.3		97.9	98.9	99.3	97.9		98.2	99.5	101.4	101.9	96.4	97.2	97.9	98.1	97.6	99.3

Table B10. Corrected Overall OBSI Levels Measured Along I-10 in the Eastbound and Westbound Directions

Road	Direction	Milepost	I-10																	
			Pre-Overlay	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC
			PCC	2004	Mar 2005	Mar 2006	Nov 2006	Mar 2007	Oct 2007	Mar 2008	Oct 2008	Mar 2009	Nov 2009	Mar 2010	Nov 2010	Nov 2011	Oct 2012	Oct 2013	Oct 2014	Oct 2015
I-10	EB	133								100.0					98.4					
I-10	EB	134								101.0					100.3					
I-10	EB	135								96.9				99.4	98.8			101.2		103.3
I-10	EB	136								102.4				99.4	99.1		101.7	101.9		102.1
I-10	EB	137								103.0	99.9	97.6		99.6	98.8		100.9	103.4	101.3	
I-10	EB	138			97.5	98.7	98.7		102.1	99.4	102.0	101.2	103.3	100.3	101.1	103.5	102.6	103.3		
I-10	EB	139			97.8	98.3	98.3	101.1	101.0	99.4	103.1	100.7	102.7	103.8	102.1	103.8	103.8	103.9	103.8	103.4
I-10	EB	140			98.0	100.4	99.7	100.9	102.0	101.4	102.0	100.6	104.9	104.9	101.9	103.4	104.3	106.7		104.3
I-10	EB	141				99.1		101.5	101.1	97.7	100.3	102.5	104.2	104.8	104.9	106.5	104.9	107.3		105.6
I-10	EB	142			99.5	98.6	99.5	100.3		97.5	100.9	100.0	101.5	102.9	103.7	105.1	101.6	106.1		103.1
I-10	EB	143								97.8	100.6	101.0	102.3	100.9	103.2	103.9	103.2			105.4
I-10	EB	144			98.4	100.7	101.5		100.1	99.8	103.0	99.9	102.4	102.5	102.4	102.3	105.5	104.4		105.2
I-10	EB	145				99.7	99.9		100.7	97.9	101.0	99.6		101.1	100.6	99.7	103.7	102.5		103.9
I-10	EB	146	107.3		98.4	99.7	100.3		101.1		100.8	101.3	102.0	103.6	101.3	105.0	104.4	104.8	105.7	104.9
I-10	EB	147	106.9				100.0		98.4	100.1	101.8	98.9	99.7	99.6	101.3	103.5	102.6	102.6		103.7
I-10	EB	148	107.6						99.9	98.7	101.2		103.2	101.9	101.4	103.0	104.4			
I-10	EB	149								100.3				101.2	101.8					
I-10	EB	150								98.5					100.6					
I-10	EB	151																		
I-10	EB	155													102.4					
I-10	EB	156				100.0		99.6	101.2	100.7		101.7	102.1	102.2	103.4	103.6	104.9		103.5	103.2
I-10	EB	157				99.5	99.8	99.1		99.0	98.2	99.4	99.4	100.2	100.9	102.7	101.1	102.9	102.1	102.3
I-10	EB	158				99.8	99.5	99.9	100.1	99.0	99.7	100.4	100.3	100.7	100.7	101.3	102.1	101.2	100.4	102.4
I-10	EB	159				100.1	99.6	100.4	100.7	99.5	99.1	101.4	101.6	101.1	99.8	101.0	101.6	103.2		102.0
I-10	EB	*Site 3C*	107.6			99.7	98.9	100.2	99.7	98.2	99.5	99.6	101.6	100.0		101.1	102.5	101.9	100.7	102.0
I-10	EB	160					105.3				98.0	100.5	100.3	102.4	102.0	103.1	105.2	103.6	103.8	
I-10	EB	161												102.4						
I-10	EB	162																		
I-10	WB	133													100.3					
I-10	WB	134													100.4					
I-10	WB	135								98.0				99.9	99.3					
I-10	WB	136								100.1				100.2	99.0			101.8		104.5
I-10	WB	137								98.9	100.1	100.4		101.6	100.5		102.2	103.2	102.1	103.0
I-10	WB	138				101.1	100.2			101.2	102.3	100.2	103.5	100.7	102.6	104.7	103.4	105.4		104.8
I-10	WB	139				100.8	98.3	101.1	102.9	101.0	102.8	100.2	101.3	100.7	101.4		104.8	105.1		105.9
I-10	WB	140				100.3	100.4	100.9	102.0	101.6	102.3	100.3	102.1	103.5	103.1	103.8	105.2	103.6		104.4
I-10	WB	141				100.9	100.6	101.5	102.1	101.8	100.9	102.4	103.2	103.7	100.8	104.9	103.6	103.3	102.5	104.1
I-10	WB	142				100.1	98.9	100.3	100.5	101.7	100.2	99.4	101.5	103.4	100.9	102.5	103.6	103.1		
I-10	WB	143								105.9	106.3	100.7	107.1	105.8	105.6		106.1		102.4	
I-10	WB	144					100.9	100.6	102.7	107.8	101.8	102.0	99.5	102.6	102.5	102.6	102.8		103.7	103.5
I-10	WB	145					100.5	99.5	100.8		102.0	97.3		102.7	102.6		104.8	103.7	104.7	103.6
I-10	WB	146				100.6	100.7	100.6	101.2	101.9	101.6	101.2	103.3	102.1	102.0	103.7	104.1	105.3		104.8
I-10	WB	147	106.5			100.7		99.4	100.1		100.2	99.8	100.5	101.1	100.9	102.4	103.2	104.3		105.6
I-10	WB	148									100.2		101.6	102.6	101.0	103.1	103.9			103.8
I-10	WB	149												104.8	103.0	103.0				
I-10	WB	150								98.8					100.8					
I-10	WB	151								99.6										
I-10	WB	155								100.8					104.4					
I-10	WB	156				98.5		99.5	98.9	98.6	98.9	99.0	100.3	100.5	99.6	99.9	100.5	102.0		101.9
I-10	WB	157				99.5	98.6	98.7	98.9	98.7	97.0	99.5		101.4	99.7	101.5		100.7	101.4	102.7
I-10	WB	158				98.1	98.1	99.4	99.7	98.7	98.7	99.3	100.2	101.7	99.1	101.3	102.5	103.6		102.4
I-10	WB	159				98.3	99.4	100.3	99.8			100.3	100.2	100.9	101.4	100.7	101.7	102.6	101.8	101.4
I-10	WB	*Site 3C*					99.1	99.0		99.8	100.1	99.5	100.2	99.5		104.1	99.9	103.2	100.6	101.4
I-10	WB	160								104.1	98.7	98.3	99.8	102.2	99.5	101.1	101.8	102.0	100.6	101.7
I-10	WB	161								105.4	98.3			100.3		102.2				
I-10	WB	162								102.9										

Table B11. Corrected Overall OBSI Levels Measured Along SR 202 in the Counterclockwise Direction

Road	Direction	Milepost	SR 202																	
			Pre-Overlay	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC	ARFC
			PCC	2004	Mar 2005	Mar 2006	Nov 2006	Mar 2007	Oct 2007	Mar 2008	Oct 2008	Mar 2009	Nov 2009	Mar 2010	Nov 2010	Nov 2011	Oct 2012	Oct 2013	Oct 2014	Oct 2015
202	WB	1		95.9		98.6		98.7		98.7	99.9	100.5	101.3	101.8	101.6	103.6		104.1	104.6	105.3
202	WB	2		95.2		98.6	99.2	99.7		98.7	99.7	101.8	100.6	100.5	101.3	102.6	102.1	103.5	103.9	104.6
202	WB	3		95.4		98.3	98.3	98.7	99.2	99.5	100.1	100.6	100.7	100.6	101.4	102.8	102.5	103.0	100.8	104.8
202	WB	4		95.1		98.0	98.4	97.3	98.2	98.9	98.8	99.4	99.8	100.7	99.7	101.7		101.0	100.3	103.5
202	WB	5								99.5	99.2	99.9	100.6	100.7	100.2		104.3	103.7		104.6
202	WB	6								99.4	99.9	99.8	99.7	99.9	101.6	102.4	102.6	103.7		
202	WB	7								100.2	98.9	99.0	100.4		99.6	100.5	102.4	100.7		104.1
202	WB	8								100.2	98.9	98.8	98.8		97.0	98.2	102.6			
202	WB	9								100.2	99.4	100.9	100.9		102.0	98.9				
202	WB	10											100.0		100.7	101.2	102.6			
202	WB	11								98.7	99.9	100.9	99.4		102.2	103.2	102.6	104.5	103.4	
202	WB	12	104.0	99.5		99.0	99.7	98.3	99.4	99.8	98.3	101.0	100.5		101.1		102.0	103.1	103.4	
202	WB	13	105.5	97.7		98.9	99.7	99.3	98.1	99.6	97.7	98.8	101.3		101.4	101.7		103.2	103.2	
202	WB	14	107.6	97.7		99.0	99.7	100.1	99.9	100.3	100.0	100.1	100.8	101.2	101.5	103.2	103.4	103.5	103.0	
202	WB	15	107.2	98.2		98.6	99.7	99.5	99.8	97.8	98.3	99.7	99.2	101.1	100.6	103.1	100.8	103.4	102.0	
202	WB	16	107.3	97.6		99.8	99.0	100.9	100.4	99.9	98.9	99.9	101.0	99.9	100.9	103.2	103.1	102.5		
202	WB	17		98.5		99.4	99.8	101.6	101.1	99.8	100.3	101.3	100.7	101.7	101.1	103.7	104.0	103.9	106.1	106.0
202	WB	18	108.7	98.6		99.3	100.2	101.7	101.5	99.0	100.3	101.5	103.8	100.7	102.2	103.0	102.9	104.6	104.9	105.7
202	WB	*Site 3D*	109.6			99.9	100.0	100.0	100.9	101.6	99.2	99.7	101.9	103.3	102.1	103.2	104.4	104.8	105.0	106.6
202	WB	19	108.0	96.1		98.6	100.0	101.6	102.0		99.2	101.1	98.8	102.7	101.9	104.3	102.5	103.9		103.0
202	WB	20	109.2	97.1		98.1	100.1	98.6		99.5	100.7	97.7	101.3	99.9	100.8	102.2	102.6	104.0	103.2	
202	WB	21				98.5	99.5	98.6	99.2	99.5	98.2	99.5	101.6		101.1		102.8	104.4	103.7	105.0
202	WB	22								99.5		99.4	100.5	102.0	100.8			104.3		105.6
202	WB	23								99.7	99.1	99.5	99.8	100.5	99.9					
202	NB/WB	24													100.8					
202	NB/WB	25												102.9	102.5					
202	NB/WB	26													102.5					
202	NB/WB	27													99.6					
202	NB	28													99.3					
202	NB	29													100.2					
202	NB	30													100.3					
202	NB	31													99.2					
202	NB	32													99.6					
202	NB	33													99.6					
202	NB/EB	34													97.8					
202	EB	35													97.4					
202	EB	36													99.1					
202	EB	37													98.2					
202	EB	38													99.3					
202	NB/EB	39													100.3					
202	NB	40													99.3					
202	NB	41													98.7					
202	NB/EB	42													101.1					
202	EB	43													99.3					
202	EB	44													101.0					
202	EB	45													101.7					
202	EB	46													101.6					
202	EB	47													102.0					
202	EB	48													104.4					
202	EB	49													104.8					
202	EB	50													102.1					
202	EB	51												101.0	99.3					
202	EB	52		97.7	97.3	96.6	98.9			100.0	99.9	100.9		102.5	101.5	104.3		106.5	105.2	108.5
202	EB	53										100.7	101.2	103.0	102.7	104.9	104.7	106.6	105.0	108.4
202	EB	54								100.4	101.1	101.0	101.9	102.7	101.6	104.1	103.8	105.4	104.4	106.4
202	EB	55	104.8						97.6	96.6	96.8	97.9		98.9	98.0		98.9	98.5	99.4	
202	EB	56	105.5						96.8	97.2	97.4			98.6	98.4	99.1	99.1	99.7	100.4	

Table B12. Corrected Overall OBSI Levels Measured Along SR 202 in the Clockwise Direction

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	ARFC Mar 2008	ARFC Oct 2008	ARFC Mar 2009	ARFC Nov 2009	ARFC Mar 2010	ARFC Nov 2010	ARFC Nov 2011	ARFC Oct 2012	ARFC Oct 2013	ARFC Oct 2014	ARFC Oct 2015
202	EB	1						98.8			98.8	98.2			99.6	100.4	102.3	104.5		
202	EB	2				100.3		98.3		100.4	101.3	102.0			101.7		102.6	101.6	103.0	
202	EB	3				100.4		97.9	98.3	98.8	99.5	98.6			98.4	99.8	102.8	99.9	104.0	
202	EB	4				99.0		98.5	98.8	97.2	98.4	98.7			98.8	99.7	101.7	100.8	100.9	101.3
202	EB	5								99.6	99.8	99.6	102.0		98.4	101.3	102.4	100.7	104.5	
202	EB	6								98.0	99.8	99.9	99.7		102.3	101.3				105.1
202	EB	7								98.8	100.3	99.5	98.7		98.9	100.7	102.7		100.2	101.4
202	EB	8								98.5	99.7	98.9	100.1		101.5	104.0				104.7
202	EB	9									100.6	99.8	100.9		101.7				102.9	103.5
202	EB	10											100.8		100.7					97.8
202	EB	11								100.5	98.9	100.2	101.1		101.4	102.8	103.0	101.7	104.3	
202	EB	12	104.3			98.4	98.9	99.5	101.2	100.7	100.3	101.0	102.9	104.4	103.2	103.4	104.3	104.3		
202	EB	13	106.7	97.8			99.7	100.2	99.7	100.0	99.3	100.9	100.6	102.2	101.4	103.4	104.3	103.8	101.9	
202	EB	14	107.2	97.7		98.7	100.2	100.5	100.7	101.3	99.3	101.9	101.4	101.0	103.0	104.0	102.9	104.7	104.3	
202	EB	15	107.3	97.7		99.4	99.7	98.4	100.3	100.3	99.5	100.4	100.2	100.8	101.4	102.5	102.0	103.6		100.0
202	EB	16	102.8	97.4		99.8	100.4	99.4	99.3	100.3	98.9	99.7		101.0	101.5	102.2	103.9	103.0	103.1	
202	EB	17		96.8		98.5	99.9	99.7	100.3	100.3	99.2	99.0	101.6	101.9	103.0	102.7	104.4	105.2	104.2	107.7
202	EB	18	109.7	96.3		98.9	99.6	99.6	100.0	100.3	98.6	100.9	102.0	100.7	101.3	102.8	104.2	105.2	105.0	106.6
202	EB	*Site 3D*				99.2	100.4	99.4		100.3	99.6	99.6	100.9	101.1	102.4	104.0	103.6	103.3	103.3	106.3
202	EB	19	108.3	96.7		98.2	99.7	98.6	98.2	100.3	98.0	99.1	99.7	99.4	100.2	100.7	101.5	101.5	102.1	101.1
202	EB	20	108.8			97.7	98.7	99.7	99.8	98.8	99.5	100.8	99.7	103.0	100.7	102.8	101.8	102.9	102.7	107.4
202	EB	21				98.4	98.3	99.1	98.8	99.3	98.6	99.6	100.3	99.9	101.0		102.9	104.9	103.1	106.9
202	EB	22								99.5		100.1	102.4	103.4	102.5			105.6		106.8
202	EB	23								100.9	101.4	100.7	101.1	101.6	101.8					
202	SB/EB	24												101.9	102.0					
202	SB/EB	25												99.2	99.0					
202	SB/EB	26													99.0					
202	SB/EB	27													97.4					
202	SB	28													102.0					
202	SB	29													97.2					
202	SB	30													98.2					
202	SB	31													100.1					
202	SB	32													99.0					
202	SB	33													99.4					
202	SB/WB	34													100.6					
202	WB	35													99.7					
202	WB	36													99.1					
202	WB	37													100.1					
202	WB	38													99.6					
202	SB/WB	39													102.1					
202	SB	40													103.5					
202	SB/WB	41													100.8					
202	SB/WB	42													100.3					
202	WB	43													102.5					
202	WB	44													101.2					
202	WB	45													101.8					
202	WB	46													101.3					
202	WB	47													102.0					
202	WB	48													103.8					
202	WB	49													102.7					
202	WB	50													102.4					
202	WB	51													102.3			104.0		
202	WB	52		97.8		99.2	99.4	99.5		99.5	100.4	100.1	100.0	101.8	101.5	102.7	103.9	103.6	107.5	106.3
202	WB	53								100.5	101.3	100.6		103.1	101.9	102.4	103.4	103.7	107.1	105.9
202	WB	54								97.3	97.3	101.4		102.1	102.1	102.1	102.7		106.2	105.4
202	WB	55	104.3						96.6	95.9		97.2	99.3	98.6	99.0	100.5	100.7	99.8	97.7	
202	WB	56	108.6						97.2			100.2	100.9	99.7	98.9	99.1	100.1	101.1	99.2	101.2

APPENDIX C:
TYPE 3 WAYSIDE NOISE MEASUREMENT RESULTS

Included in this appendix are aerial and site photographs and additional measurement results for all Type 3 measurement locations.

SITE 3A PHOTOGRAPHS AND DATA

Figure C1. Aerial Photograph of Site 3A on SR 101 with Microphone Positions Indicated

(a) August 2003

(b) April 2005

(c) October 2015

Figure C2. SR 101 Wayside at Site 3A During *Pre*-Overlay Testing (August 2003) and During *Post*-Overlay Testing Prior to Roadwork (April 2005) and in the Final Testing Period (October 2015)

(a) August 2003

(b) April 2005

(c) October 2015

Figure C3. Frontage Roadway (West Beardsley Road) at Site 3A During *Pre*-Overlay Testing (August 2003) and During *Post*-Overlay Testing Prior to Roadwork (April 2005) and in the Final Testing Period (October 2015)

(a) August 2003

(b) April 2005

(c) October 2015

Figure C4. 50- and 100-ft Microphone Positions at Site 3A During *Pre*-Overlay Testing (August 2003) and During *Post*-Overlay Testing Prior to Roadwork (April 2005) and in the Final Testing Period (October 2015)

(a) August 2003

(b) April 2005

(c) October 2015

Figure C5. 175-ft Microphone Position at Site 3A During *Pre*-Overlay Testing (August 2003) and During *Post*-Overlay Testing Prior to Roadwork (April 2005) and in the Final Testing Period (October 2015)

Table C1. Summary of Environmental Conditions at Site 3A During the *Pre*-Overlay Testing Period in August 2003 and During *Post*-Overlay Testing Periods from October 2003 to October 2015

Test Periods	Testing Times	Temperature		Relative Humidity	Barometric Pressure	Wind Speed
		Range	Average			
Aug 7, 2003	11:00-13:00	100-105°F (38-41°C)	102°F (39°C)	20-24%	1009-1010 hPa	1-7 m/s (WSW, SW)
Aug 8, 2003	10:00-12:00	97-101°F (36-38°C)	99°F (37°C)	24-28%	1011-1012 hPa	2-7 m/s (N, variable)
Oct 16, 2003	11:00-15:00	90-95°F (32-35°C)	93°F (34°C)	17-23%	1014-1016 hPa	Calm-8 m/s (W)
Sep 28, 2004	9:00-11:00	83-92°F (28-33°C)	87°F (31°C)	21-27%	1013 hPa	1-4 m/s (SE, E)
Sep 29, 2004	9:00-11:00	75-85°F (24-29°C)	80°F (27°C)	15-34%	1009-1009 hPa	2-5 m/s (ESE, SE)
Apr 29, 2005	9:00-11:00	65-80°F (18-27°C)	72°F (22°C)	32-40%	1016 hPa	Calm-4 m/s (W, S, SW)
Mar 14, 2006	9:00-11:00	60-67°F (16-19°C)	63°F (17°C)	26-40%	1017-1018 hPa	Calm-1 m/s (NE)
Mar 15, 2006	9:00-11:00	63-69°F (16-19°C)	66°F (19°C)	29-45%	1016-1017 hPa	1-2 m/s (SW)
Nov 17, 2010	10:00-14:00	73-77°F (23-25°C)	75°F (24°C)	18-38%	1019-1020 hPa	Calm-1 m/s (variable direction)
Nov 2, 2011	14:00-16:00	75-78°F (24-26°C)	77°F (25°C)	4-6%	1017-1018 hPa	2-5 m/s (N, ENE, NNE)
Nov 3, 2011	9:00-11:00	63-75°F (17-24°C)	69°F (21°C)	11-18%	1017-1018 hPa	Calm-5 m/s (E, ESE)
Oct 25, 2012	8:55-13:15	66-81°F (19-27°C)	75°F (24°C)	8-22%	1012-1016 hPa	Calm-2 m/s (E, NE, ENE)
Oct 29, 2013	9:30-11:30	66-68°F (19-20°C)	67°F (19°C)	33-42%	1010-1012 hPa	Calm-2 m/s (SW, NW, WNW)
Oct 30, 2013	8:50-11:00	60-65°F (16-18°C)	63°F (17°C)	27-39%	1014-1015 hPa	Calm-2 m/s (W)
Oct 21, 2014	9:00-11:20	79-88°F (26-31°C)	84°F (29°C)	35-47%	1012-1013 hPa	Calm-3 m/s (ENE, E)
Oct 22, 2014	8:50-11:00	73-84°F (23-29°C)	78°F (26°C)	39-50%	1015-1016 hPa	Calm
Oct 13, 2015	9:00-11:35	82-90°F (28-32°C)	86°F (30°C)	33-39%	1016-1017 hPa	Calm-2.0 m/s (SE,WNW)
Oct 14, 2015	8:55-11:05	85-90°F (29-32°C)	88°F (31°C)	26-37%	1013-1014 hPa	1.6-4.1 m/s (ESE)
Oct 13, 2015	9:00-11:35	82-90°F (28-32°C)	86°F (30°C)	33-39%	1016-1017 hPa	Calm-2.0 m/s (SE,WNW)
Oct 14, 2015	8:55-11:05	85-90°F (29-32°C)	88°F (31°C)	26-37%	1013-1014 hPa	1.6-4.1 m/s (ESE)

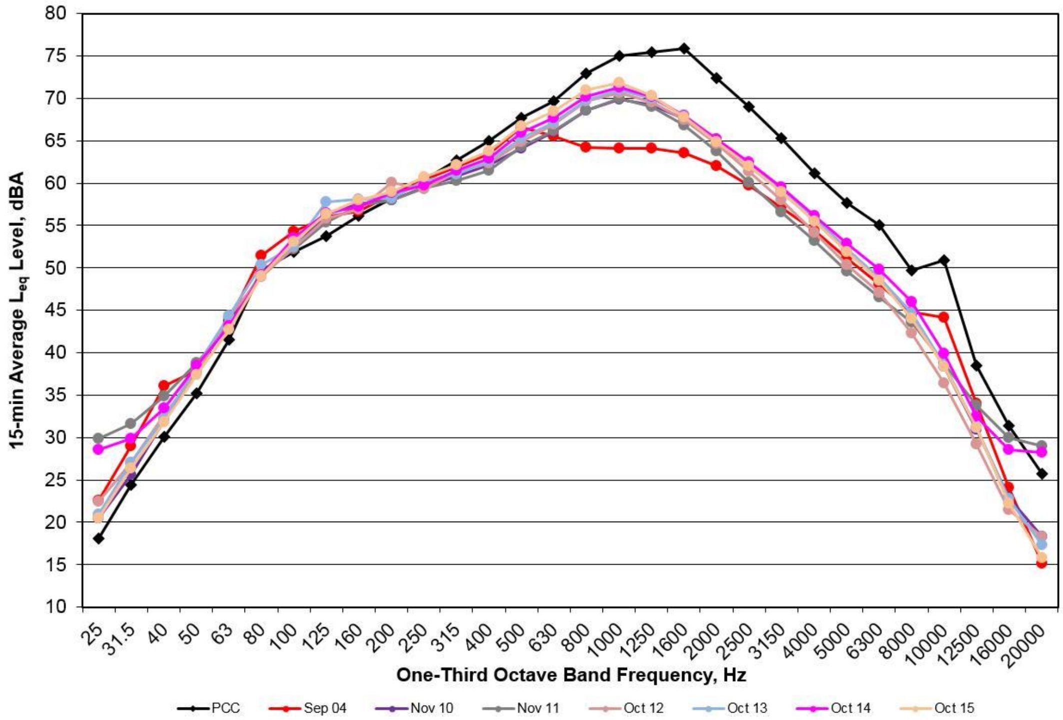


Figure C6. One-Third Octave Band Spectra for Measured Noise Levels at Site 3A at the 50ft/12ft Microphone for PCC *Pre*-Overlay and *Post*-Overlays in 2004 and 2010 Through 2015

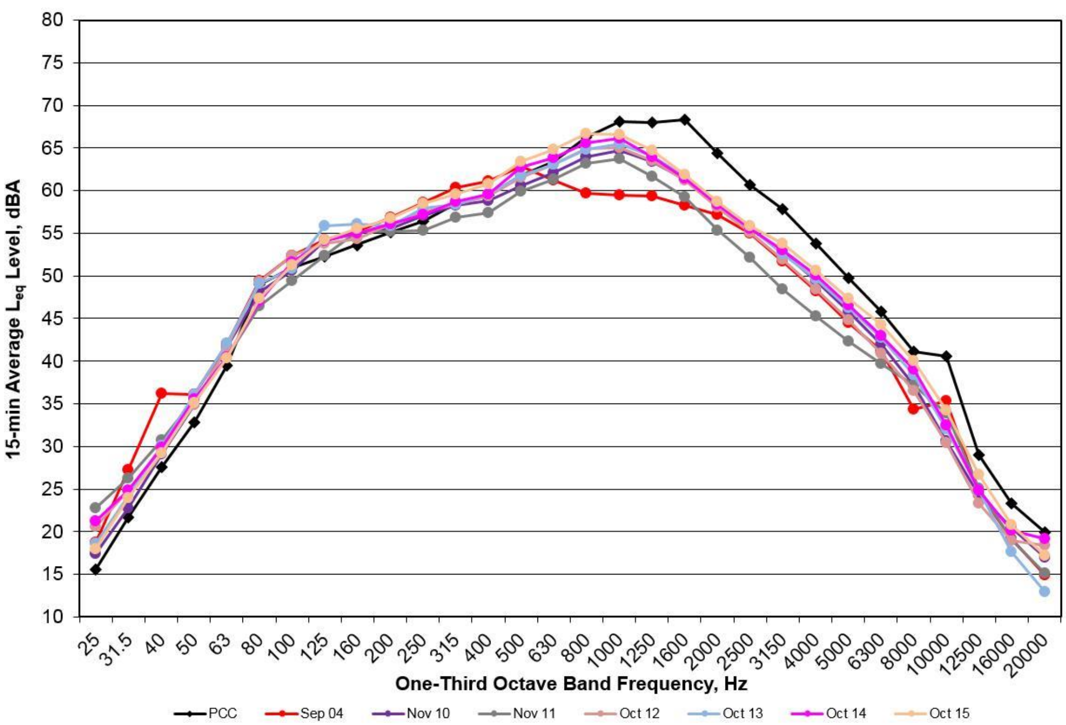


Figure C7. One-Third Octave Band Spectra for Measured Noise Levels at Site 3A at the 100ft/5ft Microphone for PCC *Pre*-Overlay and *Post*-Overlays in 2004 and 2010 Through 2015

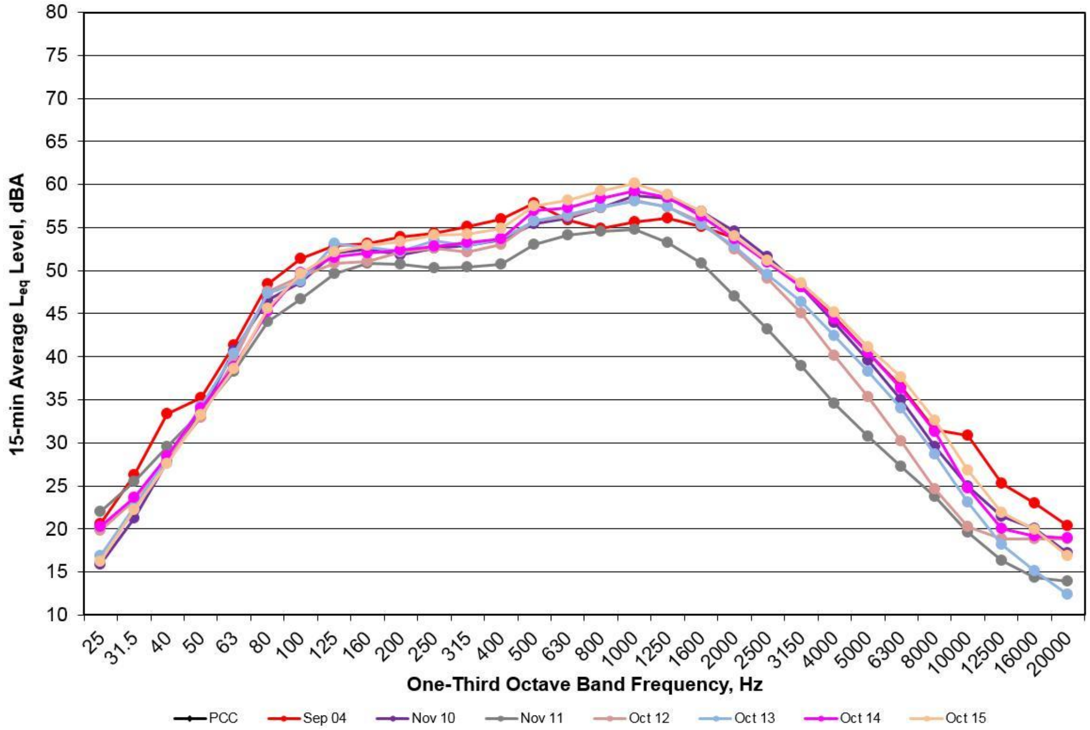


Figure C8. One-Third Octave Band Spectra for Measured Noise Levels at Site 3A at the 175ft/5ft Microphone for PCC *Post*-Overlays in 2004 and 2010 Through 2015 (Note, *Pre*-Overlay Measurements Were Made at this Distance)

SITE 3B PHOTOGRAPHS AND DATA

Figure C9. Aerial Photograph of Site 3B on SR 101 with Microphone Positions Indicated

(a) June 2004 *(b) August 2005*

Figure C10. SR 101 Wayside at Site 3B During *Pre*-Overlay Testing (June 2004) and During *Post*-Overlay Testing (August 2005)

Table C2. Summary of Environmental Conditions at Site 3B During the *Pre*-Overlay Testing Period in June 2004 and During *Post*-Overlay Testing Periods from August 2005 to June 2015

Test Periods	Temperature		Relative Humidity	Barometric Pressure	Wind Speed
	Range	Average			
Jun 17, 2004	90-102°F (32-39°C)	97°F (36°C)	10-17%	1008-1011 hPa	3-5 m/s (ESE, SE, S)
Aug 24, 2005	88-99°F (31-37°C)	94°F (34°C)	28-46%	1006-1012 hPa	Calm-5 m/s (ESE, SSE, WNW)
Jun 7, 2006	90-105°F (32-41°C)	99°F (37°C)	14-27%	1004-1009 hPa	2-5 m/s (ENE, E, SW, WSW, ESE)
Oct 4, 2007	85-94°F (29-34°C)	91°F (33°C)	28-41%	1002-1007 hPa	Calm-5 m/s (SSE, S, SE, SW, W)
Jun 4, 2008	81-95°F (27-35°C)	91°F (33°C)	7-16%	993-999 hPa	3-7 m/s (SE, S, WSW, SW)
Jun 15, 2011	89-107°F (32-42°C)	100°F (38°C)	7-15%	1003-1008 hPa	Calm-5 m/s (SSE, S, SE)
Jun 12, 2013	94-103°F (34-43°C)	103°F (39°C)	7-15%	1006-1009 hPa	2-4 m/s (ESE, NNW, NW, W)
Jun 3, 2015	86-101°F (30-38°C)	95°F (35°C)	4-13%	1004-1008 hPa	2-5 m/s (ESE, NNE, WSW, W)

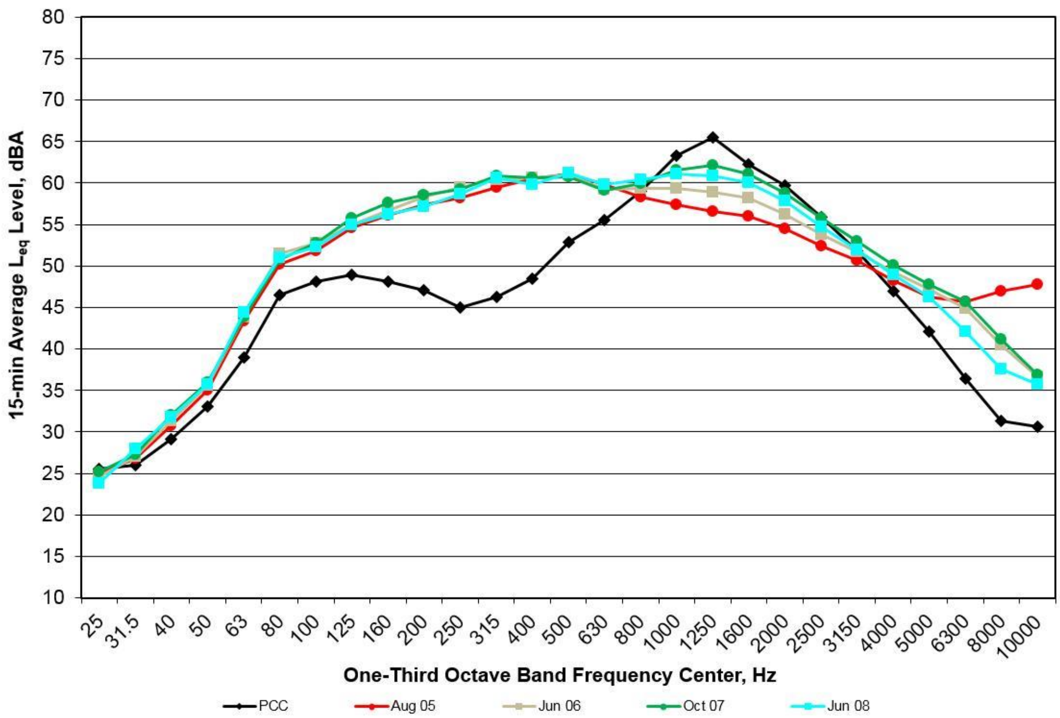


Figure C11. One-Third Octave Band Spectra for Measured Noise Levels at Site 3B at the 95ft/5ft Microphone for PCC *Pre*-Overlay and *Post*-Overlays in 2005 Through 2008

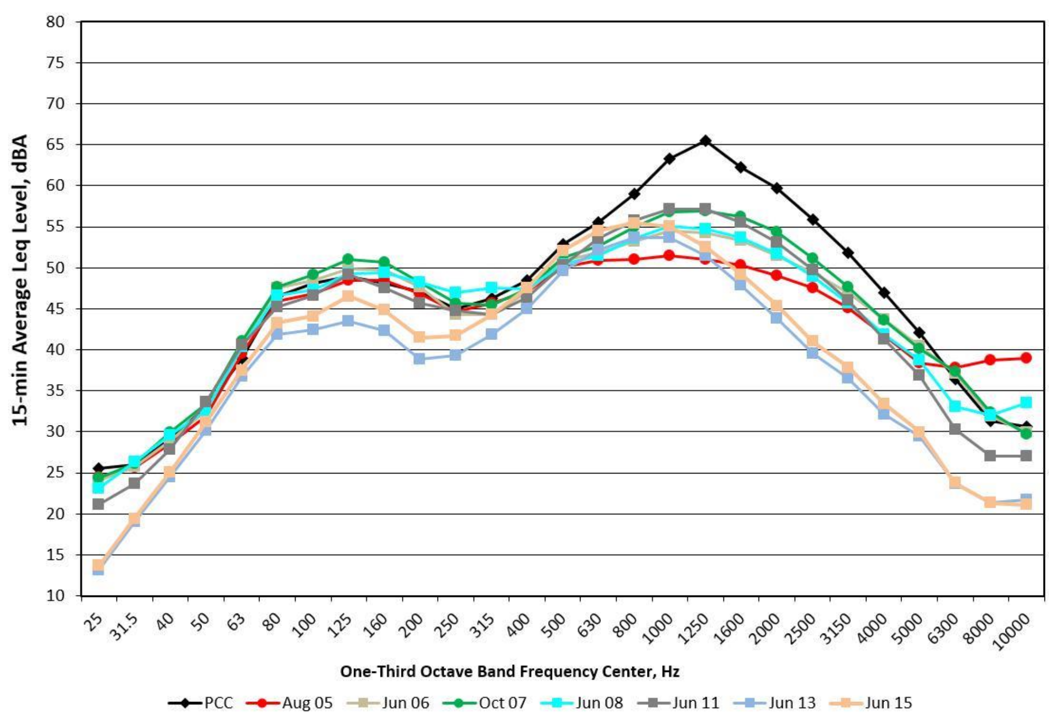


Figure C12. One-Third Octave Band Spectra for Measured Noise Levels at Site 3B at the 246ft/5ft Microphone for PCC *Pre*-Overlay and *Post*-Overlays in 2005 Through 2015

SITE 3C PHOTOGRAPHS AND DATA

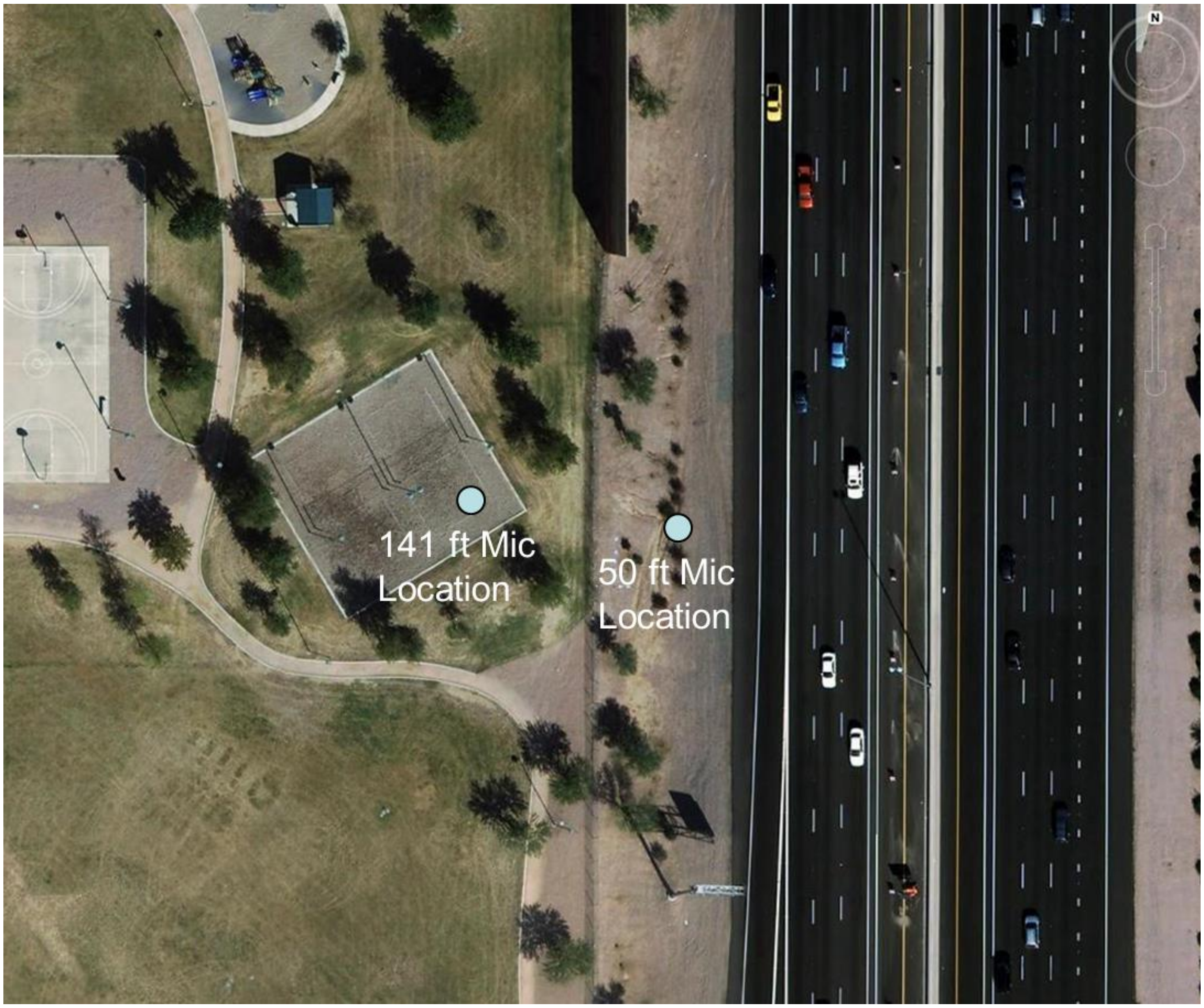


Figure C13. Aerial Photograph of Site 3C on I-10 with Microphone Positions Indicated

(a) June 2004

(b) June 2005

Figure C14. I-10 Wayside at Site 3C During *Pre*-Overlay Testing (June 2004) and During *Post*-Overlay Testing (June 2005)

Table C3. Summary of Environmental Conditions at Site 3C During the *Pre*-Overlay Testing Period in June 2004 and During *Post*-Overlay Testing Periods from June 2005 to June 2015

Test Periods	Temperature		Relative Humidity	Barometric Pressure	Wind Speed
	Range	Average			
Jun 16, 2004	89-102°F (32-39°C)	96°F (36°C)	7-15%	1006-1008 hPa	2-6 m/s (SE, SSE, S)
Jun 7, 2005	81-94°F (27-34°C)	88°F (31°C)	11-21%	1006-1008 hPa	Calm-5 m/s (Variable, W)
Jun 6, 2006	91-105°F (33-41°C)	99°F (37°C)	13-23%	1004-1008 hPa	2-7 m/s (N, SSE, SW, WSW, W)
Jun 3, 2008	84-98°F (29-37°C)	93°F (34°C)	4-14%	1002-1007 hPa	Calm-6 m/s (NE, SW, S)
Jun 14, 2011	87-103°F (31-39°C)	97°F (36°C)	5-10%	1007-1013 hPa	2-3 m/s (E, W, NW, S)
Jun 12, 2013	94-103°F (34-43°C)	103°F (39°C)	7-15%	1006-1009 hPa	2-4 m/s (ESE, NNW, NW, W)
Jun 2, 2015	89-104°F (32-40°C)	98°F (37°C)	6-15%	1006-1010 hPa	2-8 m/s (SE, SW, SSE, NW, W)

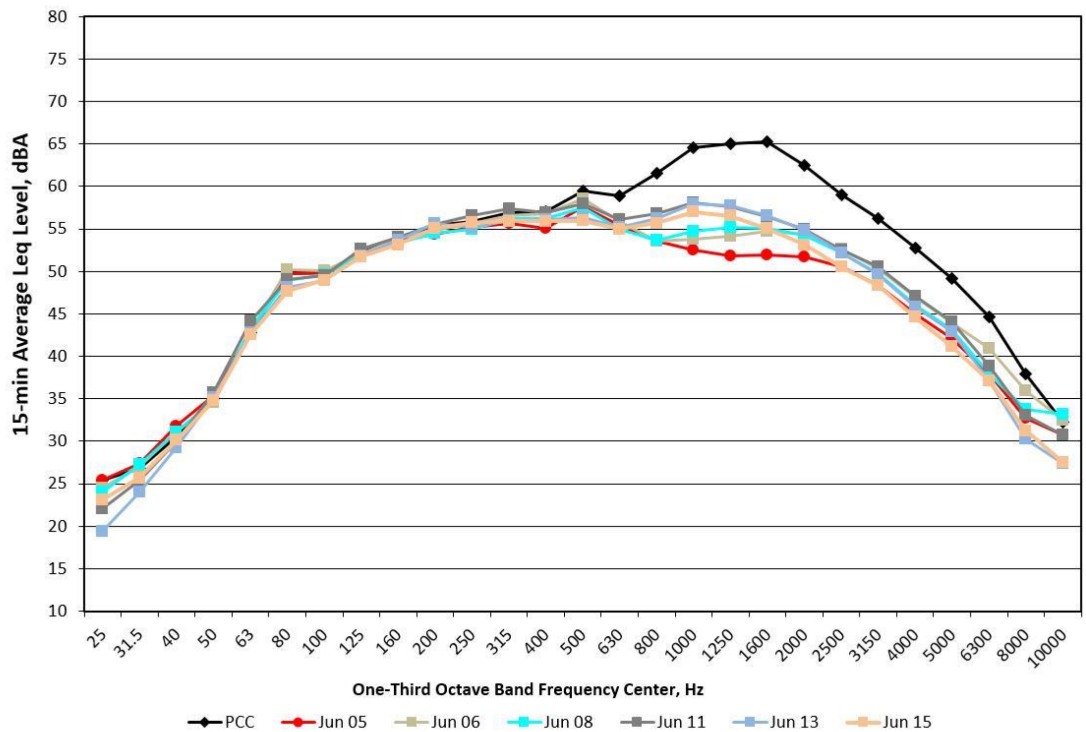


Figure C15. One-Third Octave Band Spectra for Measured Noise Levels at Site 3C at the 141ft/5ft Microphone for PCC *Pre*-Overlay and *Post*-Overlays in 2005 Through 2015

SITE 3D PHOTOGRAPHS AND DATA

Figure C16. Aerial Photograph of Site 3D on SR 202 with Microphone Positions Indicated

(a) October 2003

(b) October 2004

(c) October 2014

Figure C17. SR 202 Wayside at Site 3D During *Pre*-Overlay Testing (October 2003) and During *Post*-Overlay Testing (October 2004) and During the Final Testing Period (October 2014)

(a) October 2003

(b) October 2004

(c) October 2014

Figure C18. 50- and 100-ft Microphone Positions at Site 3D During *Pre*-Overlay Testing (October 2003) and During *Post*-Overlay Testing (October 2004) and in the Final Testing Period (October 2014)

(a) October 2003

(b) October 2004

(c) October 2014

Figure C19. 250-ft Microphone Position at Site 3D During *Pre*-Overlay Testing (October 2003) and During *Post*-Overlay Testing (October 2004) and in the Final Testing Period (October 2014)

Table C4. Summary of Environmental Conditions at Site 3D During the *Pre*-Overlay Testing Period in October 2003 and During *Post*-Overlay Testing Periods from October 2004 to October 2014

Test Periods	Testing Times	Temperature		Relative Humidity	Barometric Pressure	Wind Speed
		Range	Average			
Oct 16, 2003	10:00-12:00	86-95°F (30-35°C)	91°F (33°C)	18-27%	1016-1019 hPa	Calm-5 m/s (S, SE, W)
Oct 17, 2003	7:00-9:00	73-82°F (23-28°C)	77°F (25°C)	23-37%	1017-1018 hPa	4-12 m/s (SE, ESE)
Oct 5, 2004	8:45-10:45	80-85°F (27-29°C)	83°F (28°C)	21-25%	1014 hPa	Calm-3 m/s (E, NE, ENE)
Oct 6, 2004	8:45-10:45	75-85°F (24-29°C)	80°F (27°C)	19-23%	1014 hPa	1-3 m/s (N, NE, NNE)
Mar 1, 2005	9:30-11:30	58-70°F (14-21°C)	62°F (17°C)	45-55%	1017-1018 hPa	Calm-3 m/s (N, NE, NNE, ENE)
Mar 2, 2005	9:15-11:15	59-73°F (15-23°C)	65°F (18°C)	45-61%	1017 hPa	1-3 m/s (E, NE, NNE, ENE)
Oct 19, 2005	9:00-11:00	70-76°F (21-24°C)	73°F (23°C)	40-68%	1019 hPa	Calm-3 m/s (NE, ENE, N, WNW)
Oct 20, 2005	9:00-11:00	63-75°F (17-24°C)	69°F (21°C)	43-58%	1017 hPa	Calm-2 m/s (NE, E, SE, SW)
Mar 9, 2006	9:00-11:00	59-68°F (15-20°C)	64°F (18°C)	22-28%	1010-1011 hPa	2-4 m/s (ENE, E)
Mar 13, 2006	9:00-11:00	50-69°F (10-21°C)	64°F (18°C)	40-49%	1023 hPa	1-4 m/s (NE)
Nov 7, 2006	7:00-11:00	65-75°F (18-24°C)	70°F (21°C)	22-30%	1016-1017 hPa	3 m/s (E, ENE)
Nov 8, 2006	7:00-11:00	62-70°F (17-27°C)	69°F (21°C)	22-37%	1011-1015 hPa	1-5 m/s (E)
Mar 20, 2007	9:00-11:00	65-70°F (18-21°C)	68°F (20°C)	13-17%	1017 hPa	1-3 m/s (NE, ESE, SE, SW)
Mar 21, 2007	6:15-11:00	60-75°F (16-24°C)	69°F (21°C)	24-34%	1009-1011 hPa	Calm-3 m/s (SE, W, SW)
Oct 10, 2007	9:00-11:15	70-88°F (21-31°C)	81°F (27°C)	17-22%	1013-1015 hPa	1-2 m/s (SE, S, SW)
Oct 11, 2007	8:35-11:05	70-80°F (21-27°C)	75°F (24°C)	10-21%	1012-1013 hPa	1-4 m/s (E, N, NW, NNW)
Mar 11, 2008	9:00-11:00	59-68°F (15-20°C)	64°F (18°C)	24-31%	1022-1023 hPa	2-6 m/s (E)
Mar 12, 2008	9:00-11:00	60-70°F (16-21°C)	65°F (18°C)	23-34%	1016 hPa	1-3 m/s (variable direction)
Oct 21, 2008	9:00-11:00	75-83°F (24-28°C)	78°F (26°C)	19-25%	1017-1018 hPa	1-3 m/s (East, ENE)
Oct 22, 2008	9:00-11:00	72-80°F (22-27°C)	76°F (24°C)	5-13%	1020 hPa	3-5 m/s (NE, ENE)

Test Periods	Testing Times	Temperature		Relative Humidity	Barometric Pressure	Wind Speed
		Range	Average			
Mar 10, 2009	9:00-11:00	60-70°F (16-21°C)	65°F (18°C)	30-53%	1017-1018 hPa	Calm-2 m/s (E)
Mar 11, 2009	9:00-11:00	55-65°F (13-18°C)	60°F (16°C)	26-38%	1016-1018 hPa	1-3 m/s (E)
Nov 4, 2009	9:00-11:00	65-75°F (18-24°C)	70°F (21°C)	10-18%	1017-1018 hPa	Calm-3 m/s (NE, ENE)
Nov 5, 2009	9:00-11:00	68-72°F (20-22°C)	70°F (21°C)	20-28%	1019 hPa	Calm-2 m/s (SW)
Mar 16, 2010	9:00-11:00	--	65°F (18°C)	--	1026-1027 hPa	3-5 m/s (E, NE)
Mar 17, 2010	9:00-11:00	--	65°F (18°C)	--	1021 hPa	2-3 m/s (NE, ENE)
Nov 11, 2010	9:00-13:00	55-70°F (13-21°C)	64°F (18°C)	20-33%	1018 hPa	1-4 m/s (N, NE, NW)
Nov 18, 2010	9:00-11:00	67-73°F (19-23°C)	70°F (21°C)	12-22%	1021 hPa	3-5 m/s (N)
Oct 25, 2011	9:00-11:00	76-84°F (24-29°C)	80°F (27°C)	31-33%	1013-1014 hPa	2-4 m/s (E, SE)
Nov 1, 2011	9:10-11:10	70-79°F (21-26°C)	75°F (24°C)	16-23%	1010-1012 hPa	Calm-2 m/s (SE, ESE)
Oct 23, 2012	8:50-11:30	72-79°F (22-26°C)	76°F (24°C)	40-49%	1010-1011 hPa	Calm-3 m/s (ESE, SE)
Oct 24, 2012	8:35-11:15	72-79°F (22-26°C)	75°F (24°C)	25-41%	1011 hPa	Calm-3 m/s (W)
Nov 5, 2013	9:00-11:05	61-79°F (16-26°C)	68°F (20°C)	39-54%	1015-1016 hPa	1-3 m/s (E, N, variable)
Nov 6, 2013	8:55-11:05	56-71°F (13-22°C)	65°F (18°C)	10-12%	1023-1024 hPa	2-5 m/s (NE, ENE, variable)
Oct 28, 2014	9:00-11:05	69-77°F (21-25°C)	73°F (23°C)	32-44%	1016 hPa	Calm
Oct 29, 2014	8:45-11:05	68-79°F (20-26°C)	73°F (23°C)	31-43%	1017 hPa	Calm-3.5 m/s (WSW)

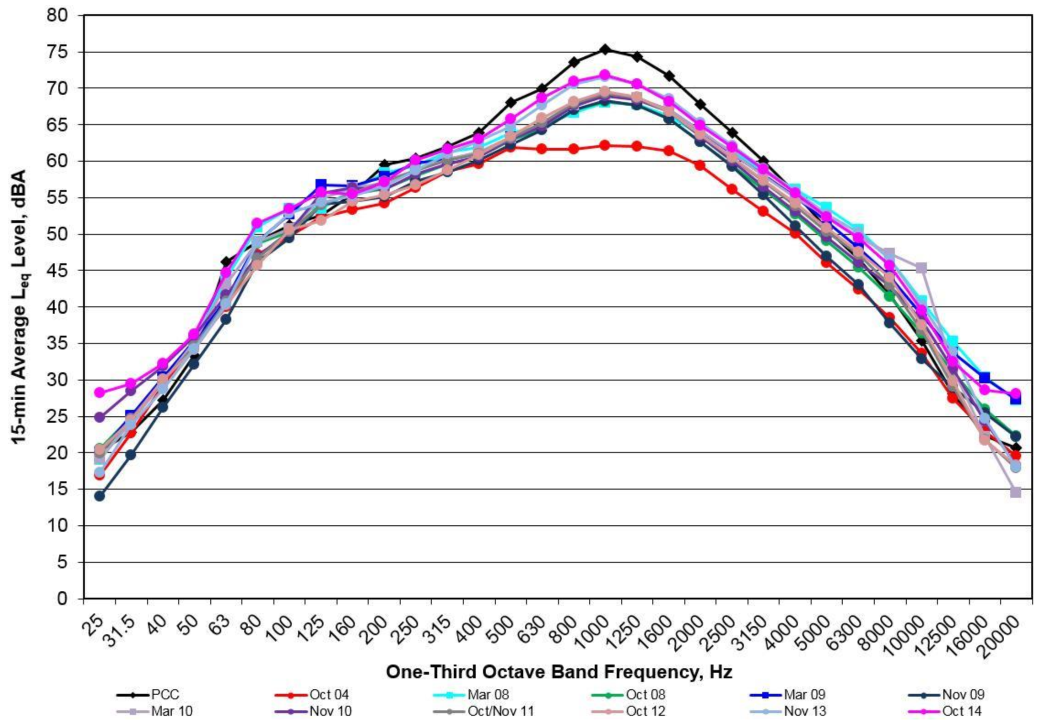


Figure C20. One-Third Octave Band Spectra for Measured Noise Levels at Site 3D at the 50ft/12ft Microphone for PCC *Pre*-Overlay and *Post*-Overlays in 2004 and 2008 Through 2014

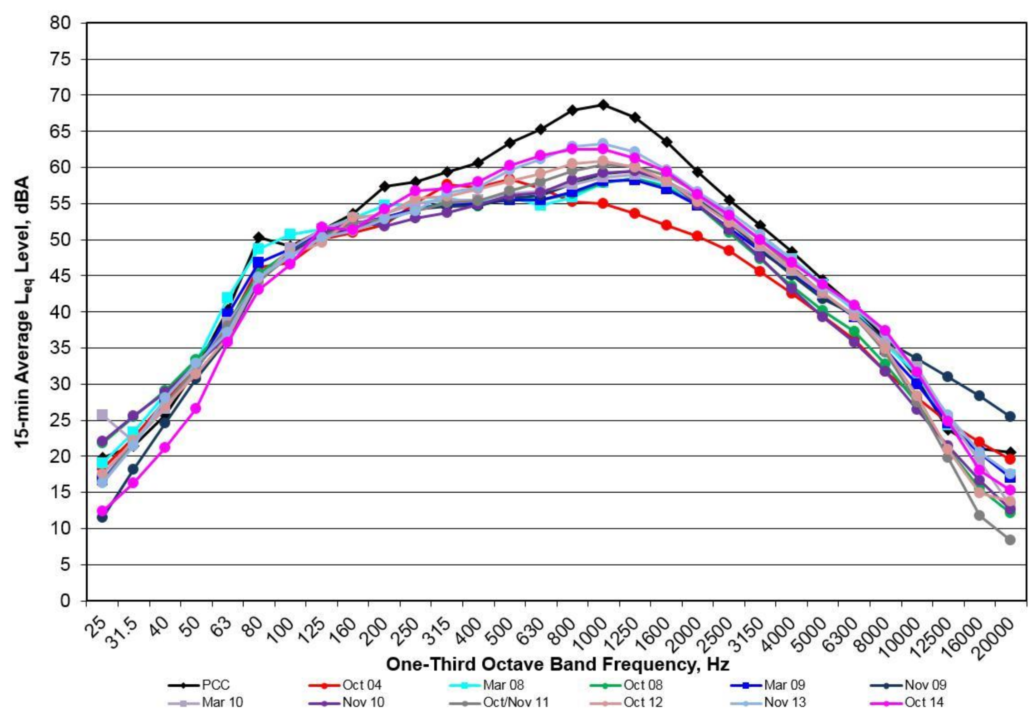


Figure C21. One-Third Octave Band Spectra for Measured Noise Levels at Site 3D at the 100ft/5ft Microphone for PCC *Pre*-Overlay and *Post*-Overlays in 2004 and 2008 Through 2014

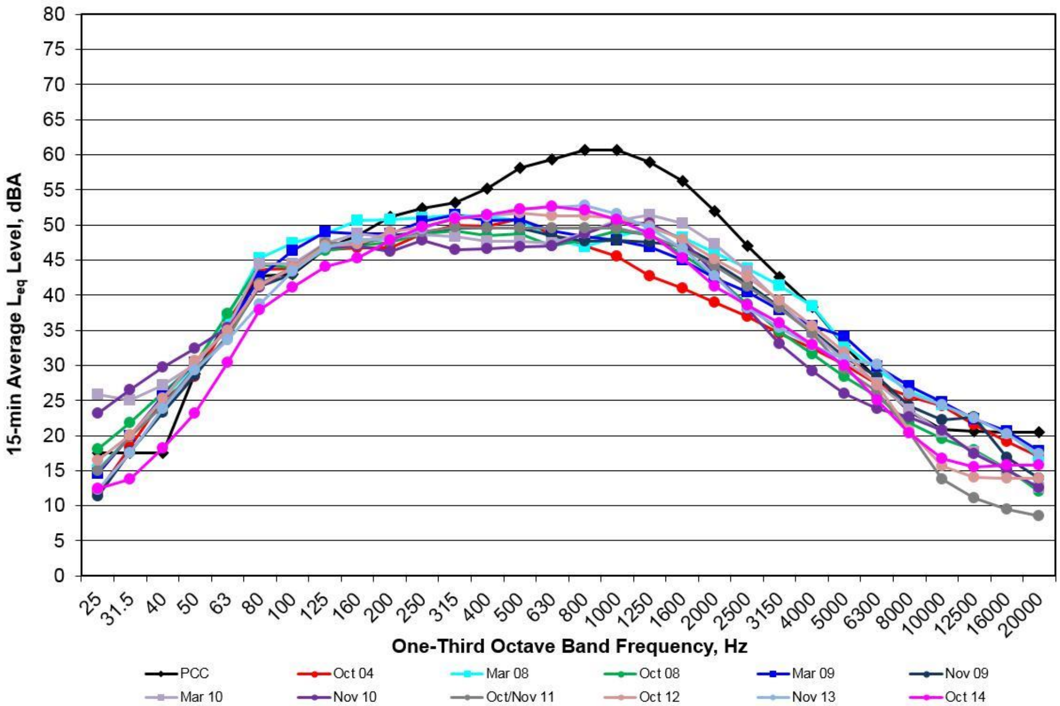


Figure C22. One-Third Octave Band Spectra for Measured Noise Levels at Site 3D at the 250ft/5ft Microphone for PCC *Pre*-Overlay and *Post*-Overlays in 2004 and 2008 Through 2014

SITE 3E PHOTOGRAPHS AND DATA

Figure C23. Aerial Photograph of Site 3D on SR 202 with Microphone Positions Indicated

(a) April 2004

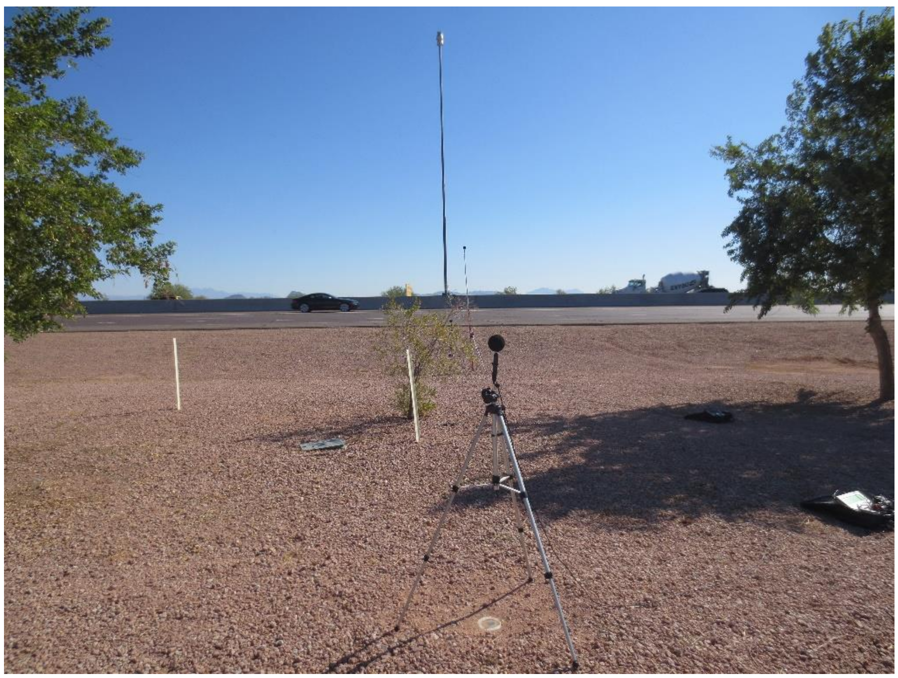
(b) October 2004

(c) October 2013

Figure C24. SR 101 Wayside at Site 3e During *Pre*-Overlay Testing (April 2004) and During *Post*-Overlay Testing (October 2004) and During the Final Testing Period (October 2013)

(a) April 2004

(b) October 2004



(c) October 2013

Figure C25. 50- and 100-ft Microphone Positions at Site 3E During *Pre*-Overlay Testing (April 2004) and During *Post*-Overlay Testing (October 2004) and in the Final Testing Period (October 2013)

Table C5. Summary of Environmental Conditions at Site 3E During the *Pre*-Overlay Testing Period in April 2004 and During *Post*-Overlay Testing Periods from October 2004 to October 2013

Test Periods	Testing Times	Temperature		Relative Humidity	Barometric Pressure	Wind Speed
		Range	Average			
Apr 6, 2004	9:00-11:00	65-69°F (18-21°C)	67°F (19°C)	49-63%	1015 hPa	2-4 m/s (variable)
Apr 7, 2004	9:00-11:00	69-75°F (21-24°C)	72°F (22°C)	37-47%	1012-1013 hPa	1-3 m/s (E, ENE)
Oct 19, 2004	9:00-11:00	65-75°F (18-24°C)	70°F (21°C)	42-52%	1014 hPa	2-3 m/s (SE, SSE)
Oct 20, 2004	9:15-11:25	69-76°F (21-24°C)	73°F (23°C)	37-54%	1010-1013 hPa	2-5 m/s (S, SSE, ESE, SE, E)
Oct 25, 2005	9:15-11:15	70-80°F (21-27°C)	76°F (24°C)	28-43%	1014-1015 hPa	1-4 m/s (E, SE, SSE)
Oct 26, 2005	9:00-11:00	65-75°F (18-24°C)	71°F (22°C)	40-49%	1014-1015 hPa	Calm-2 m/s (E, SE, NE)
Mar 7, 2006	9:00-11:00	60-71°F (16-22°C)	69°F (21°C)	20-28%	1018 hPa	Calm-2 m/s (variable, SE, S)
Mar 8, 2006	9:00-11:00	55-65°F (13-18°C)	61°F (16°C)	36-43%	1013 hPa	2-4 m/s (WSW, SW, W)
Oct 10, 2006	7:00-11:30	60-80°F (16-27°C)	70°F (21°C)	26-56%	1013-1014 hPa	1-6 m/s (NE, SE, E, ESE)
Oct 11, 2006	7:00-11:30	60-80°F (16-27°C)	70°F (21°C)	23-50%	1014 hPa	Calm-6 m/s (NE, NNE, N)
Mar 6, 2007	8:25-11:25	55-74°F (13-23°C)	64°F (18°C)	10-24%	1020-1021 hPa	2-4 m/s (E, NE, ENE)
Mar 7, 2007	8:10-11:00	58-71°F (14-22°C)	64°F (18°C)	15-28%	1017-1018 hPa	Calm-1 m/s (W, SW)
Mar 17, 2009	9:00-11:00	64-80°F (18-27°C)	72°F (22°C)	18-29%	1019-1020 hPa	Calm-2 m/s (NE, E, ENE)
Mar 18, 2009	9:00-11:00	65-76°F (18-24°C)	71°F (22°C)	19-38%	1016-1017 hPa	Calm-4 m/s (NE, E, SE)
Nov 17, 2009	9:00-11:00	60-68°F (16-20°C)	64°F (18°C)	14-23%	1017-1018 hPa	Calm-3 m/s (NE)
Nov 18, 2009	9:00-11:00	57-66°F (14-19°C)	61°F (16°C)	21-30%	1014 hPa	Calm-3 m/s (E, NE)
Mar 24, 2010	9:00-11:00	67-77°F (18-25°C)	71°F (22°C)	27-42%	1017-1018 hPa	Calm-1 m/s (E, SE)
Mar 25, 2010	9:00-11:00	63-76°F (17-24°C)	71°F (22°C)	29-53%	1017-1018 hPa	1-2 m/s (S)
Nov 11, 2010	9:00-13:00	55-70°F (13-21°C)	64°F (18°C)	35%	1015-1016 hPa	1-3 m/s (S, SSE)
Oct 26, 2011	9:00-11:00	73-75°F (23-24°C)	74°F (23°C)	41-53%	1009 hPa	3-5 m/s (W, NW)
Oct 27, 2011	9:00-11:00	66-70°F (19-21°C)	68°F (20°C)	25-33%	1015-1016 hPa	Calm-6 m/s (E, NNE)
Nov 6, 2012	9:30-11:30	69-82°F (21-28°C)	76°F (25°C)	14-23%	1017-1018 hPa	2-4 m/s (ESE, E, SE, S)
Nov 7, 2012	9:00-11:00	71-84°F (22-29°C)	78°F (25°C)	13-25%	1014-1016 hPa	Calm-3 m/s (ESE, SE)
Oct 22, 2013	9:15-11:30	76-86°F (24-30°C)	82°F (28°C)	10-20%	1014-1016 hPa	Calm-6 m/s (ESE,E,NE)
Oct 23, 2013	9:00-11:00	80-87°F (27-31°C)	84°F (29°C)	11-16%	1010-1012 hPa	3-5 m/s (ESE,E)

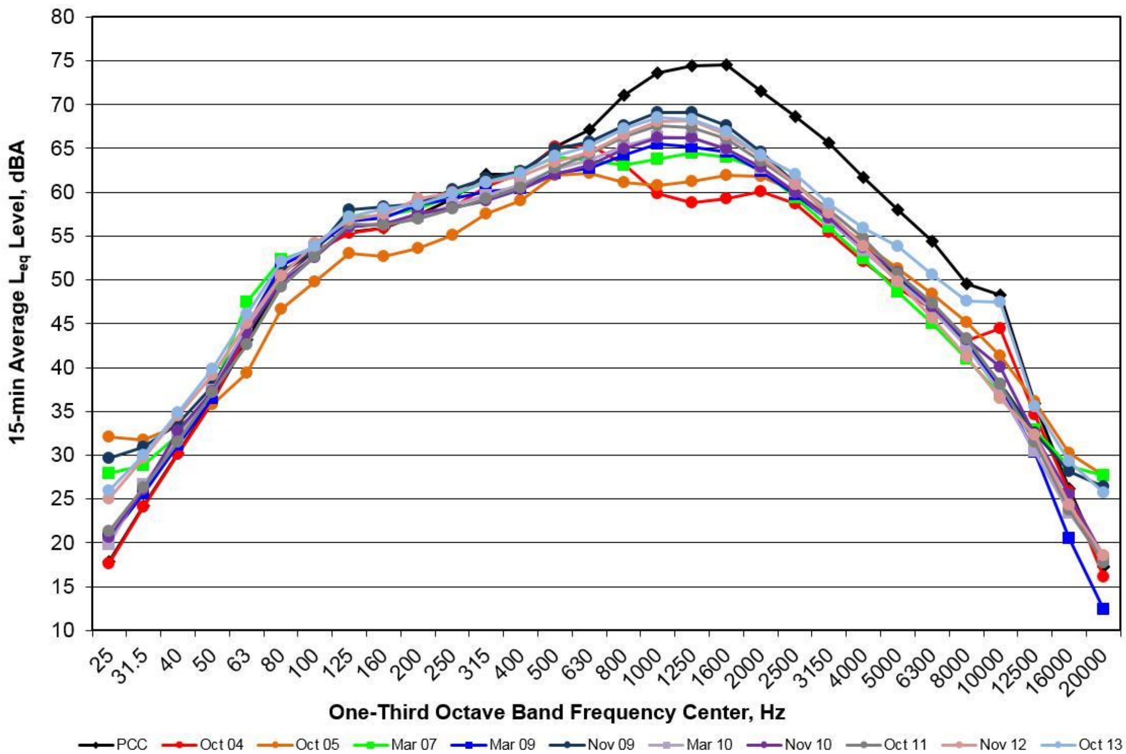


Figure C26. One-Third Octave Band Spectra for Measured Noise Levels at Site 3E at the 50ft/1.3ft Microphone for PCC *Pre*-Overlay and *Post*-Overlays in 2004 and 2009 Through 2013

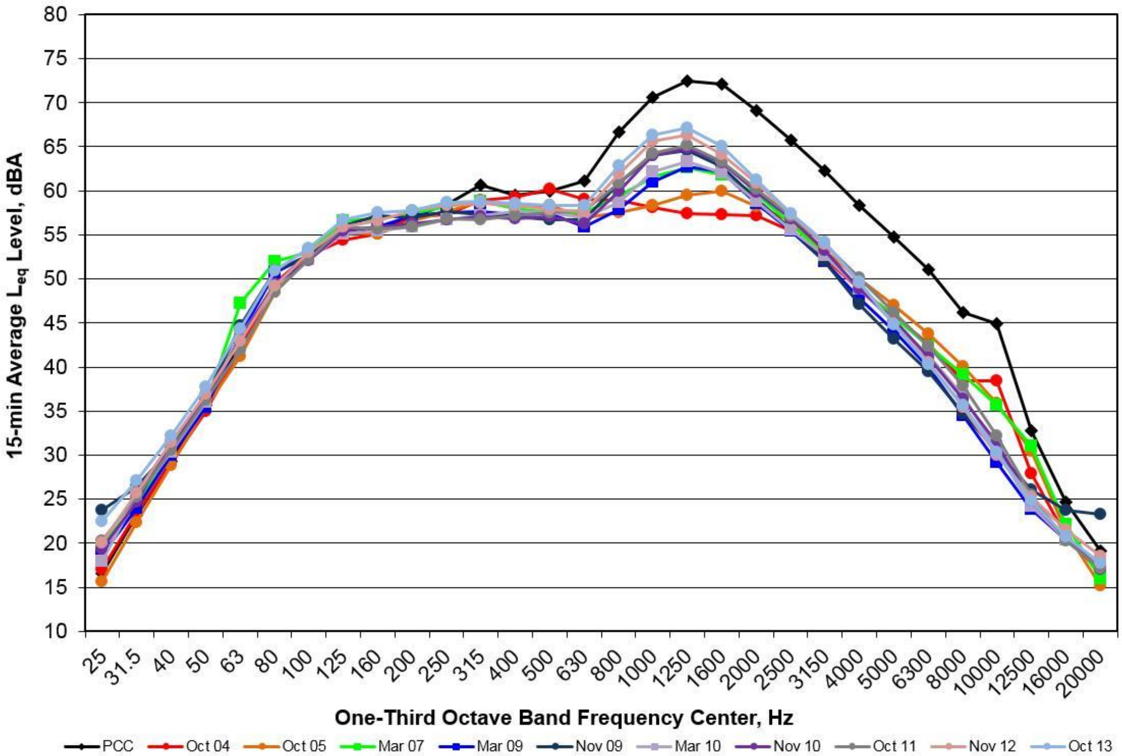


Figure C27. One-Third Octave Band Spectra for Measured Noise Levels at Site 3E at the 100ft/5ft Microphone for PCC *Pre*-Overlay and *Post*-Overlays in 2004 and 2009 Through 2013

APPENDIX D:
ACOUSTIC LONGEVITY AND CORRELATION OF RESULTS

ACOUSTIC LONGEVITY – TYPE 1 AND TYPE 3 TESTING

In Figure 17 of the main report, the overall noise levels for both Types 1 and 3 were plotted versus the age of the pavement. This plot can be further expanded to show the trends for each microphone location at each Type 3 site. Figures D1 through D5 show the trends of each microphone over time, as well as the trends for the OBSI measurement made over time at Sites 3A, 3B, 3C, 3D, and 3E, respectively.

The trend lines for both of the 50-ft microphones (5 ft and 12 ft heights) at Site 3A in Figure D1 show great correlation, with R^2 of 0.95 and 0.97. Also shown with the regression results are the 95 percent confidence limits for the regressions themselves. The limits of the slope determination of the regression line lies within these limits with a 95 percent certainty. The scatter of the data points about the trend line gets greater with distance. The R^2 for the 100-ft and 175-ft microphones were 0.74 and 0.21, respectively, although based on the confidence limits, the indicated slope are fairly well determined. The R^2 for the OBSI measurements at this site falls between the R^2 for the 50-ft and 100-ft positions (0.86) and slope is well determined. The slope of the trend lines for wayside results in Figure D1 decreases as distance from the noise source increases implying the acoustic performance is less effected by aging at the farther distances. The OBSI measurements were made directly at the source and resulted in an increase at Site 3A of 0.48 dB/year, while the 50-ft microphone noise levels increased at rates of 0.32 and 0.34 dB/year and the 100-ft and 175-ft levels increased at rates of 0.25 and 0.11 dB/year, respectively.

The OBSI trend line at Site 3B shown in Figure D2 had similar results to that measured at Site 3A, with an increase of 0.46 dB/year and a R^2 of 0.86 and a well-defined slope. However, the R^2 of the trend lines for each of the microphones were lower at both the 50-ft and 95-ft microphones. For the 95-ft distance, although the three data points appear to be relatively similar to the corresponding 50-ft data, the confidence in the slope is quite low based on the uncertainty limits and the very limited data. The four data points at the 246-ft microphone resulted in a better R^2 of 0.33, and a faster rate of increase of 0.26 dB/year than the 175-ft microphone at Site 3A. The rate of increase for both the distant microphones was greater than at the 50-ft microphone, however, there is not as much confidence in the regression slopes.

Similar to Site 3B, the slopes of the trend lines are less than Site 3A as shown in Figure D3. The R^2 of the trend lines for the OBSI, 50-ft, and 141-ft measurements are also lower than Site 3A, and the measurement at 50 ft was only slightly higher at Site 3C than at Site 3B. The rate of increase of the OBSI trend line was 0.36 dB/year, which was about 0.1 dB less per year than both of the Sites 3A and 3B. The rate of increase at 50 ft was 0.2 dB/year, which was about 0.1 dB less than at Site 3A and about 0.1 greater than at Site 3B. With a rate of increase of 0.02 dB/year, the trend line at the 141-ft microphone was essentially flat; however, the slope is reasonably defined based on the confidence limits.

The R^2 of the trend line at Sites 3D and 3E shown in Figures D4 and D5 were comparable to Site 3A at the measurement positions within 100 ft. Sites 3D and 3E had R^2 of 0.86 and 0.79, respectively, for OBSI measurements, 0.81 to 0.98 at the 50-ft microphones, and 0.61 to 0.87 at the 100-ft microphones. For these distances, the slopes of the regression lines were also well defined. The distance microphone at Site 3D resulted in lower R^2 with a coefficient of 0.05 at 250 ft similar to the distant microphone at Site 3C. With rates of increase of 0.59 and 0.71 dB/year, the OBSI levels measured at Sites 3E and 3D, respectively, were steeper than each of the other sites. At Site 3D, the rates of increase at the 50-ft microphones were 0.46 and 0.48 dB/year, while at Site 3E the 50-ft microphone levels increased at rates of 0.52 and 0.63 dB/year. These rates from both sites were greater than the previous sites at 50 ft.

Similarly, the rates of increase measured at 100 ft were steeper at Sites 3D and 3E than at the other sites, with rates of 0.42 and 0.65 dB/year, respectively. For Site 3E, the slope at 100 ft is essentially the same as at the 50ft/5ft position. The distant microphone at 250 ft for Site 3D was practically flat, with a rate of increase of 0.07 dB/year; however, the confidence limits are good indicating that there actually very little, if any, dependence on age.

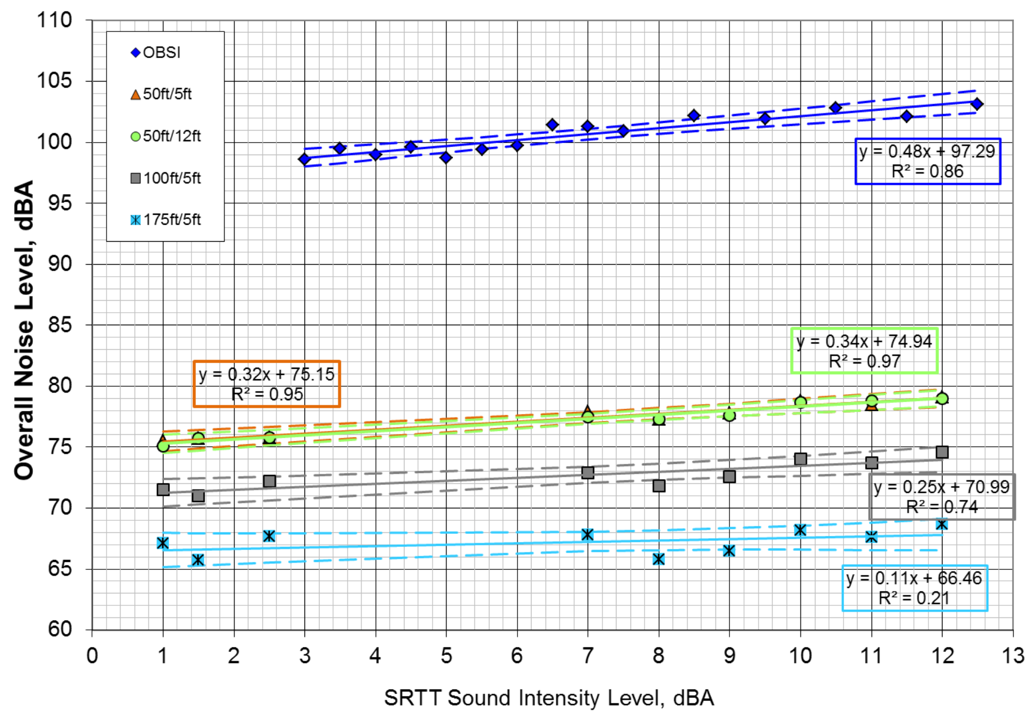


Figure D1. Overall Levels Versus Age of Overlay for Type 1 and Type 3 Measurements at Site 3A with 95 Percent Confidence Limits of the Regression Line Indicated by Dashed Lines

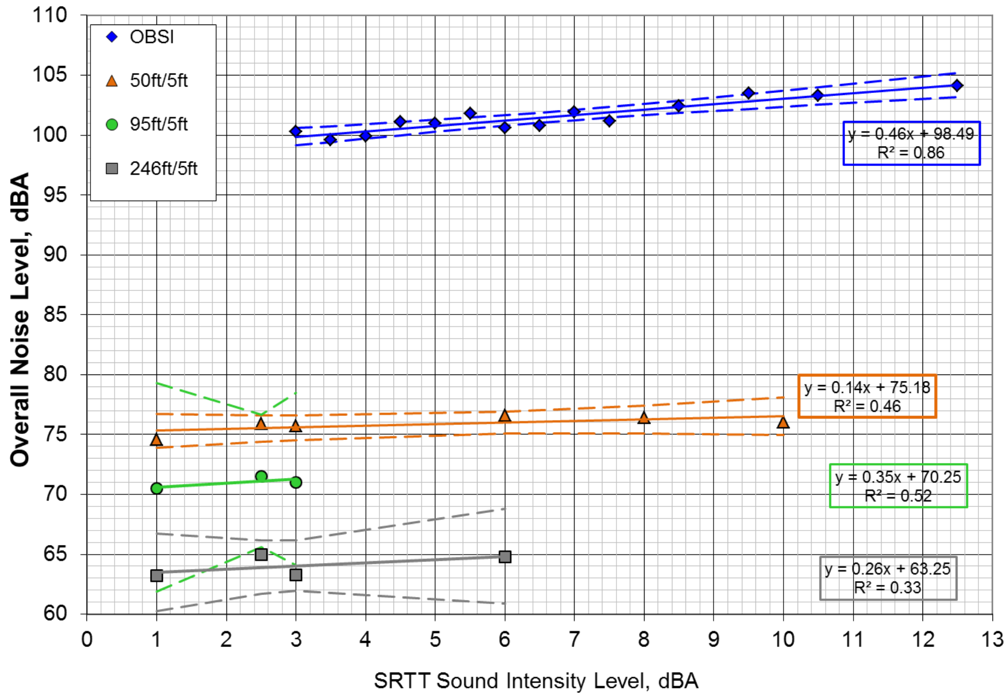


Figure D2. Overall Levels Versus Age of Overlay for Type 1 and Type 3 Measurements at Site 3B with 95 Percent Confidence Limits of the Regression Line Indicated by Dashed Lines

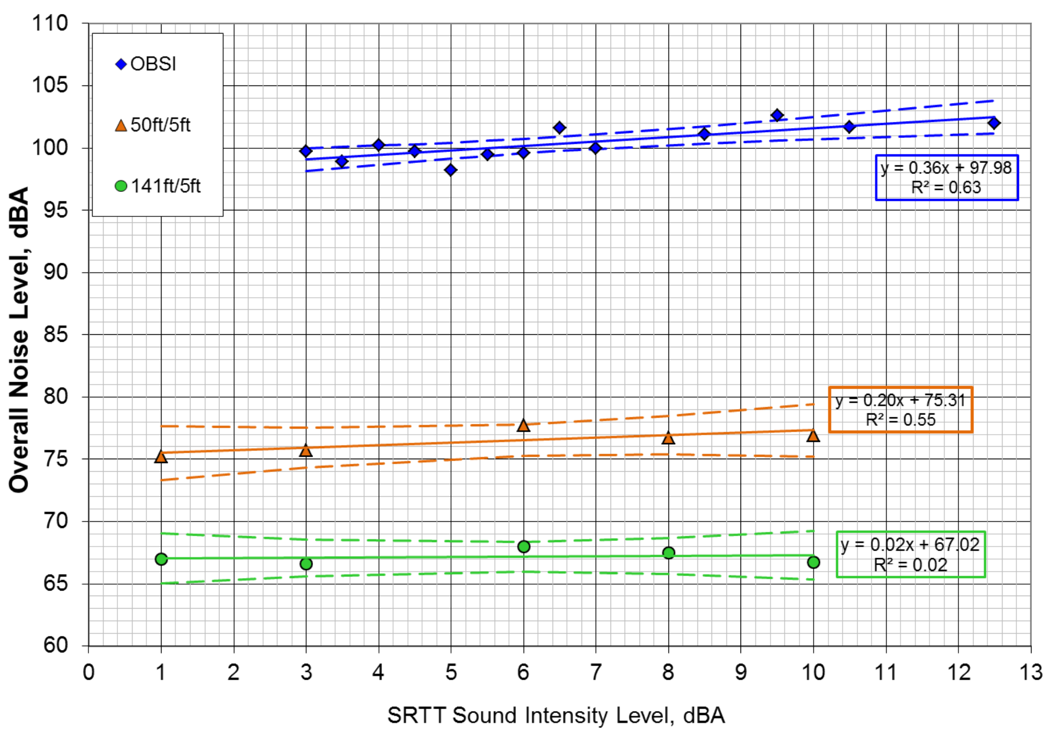


Figure D3. Overall Levels Versus Age of Overlay for Type 1 and Type 3 Measurements at Site 3C with 95 Percent Confidence Limits of the Regression Line Indicated by Dashed Lines

The lack of dependence on pavement is particularly interesting for the measurement locations greater than 100 ft. For the sites that have well defined relationships, such as Sites 3A, 3C, and 3D, the initial reductions compared to the previous PCC pavement continue to be maintained throughout the duration of the project. For Site 3A, the final reduction was still 5.9 dB with 5.9 dB also at Site 3C and 7.3 dB at Site 3D. Even for Site 3B, which had a higher rate of 0.25 dB/year, the final reduction was 8.2 dB. This indicates that the effect of quieter pavement may persist at distances farther from the highway.

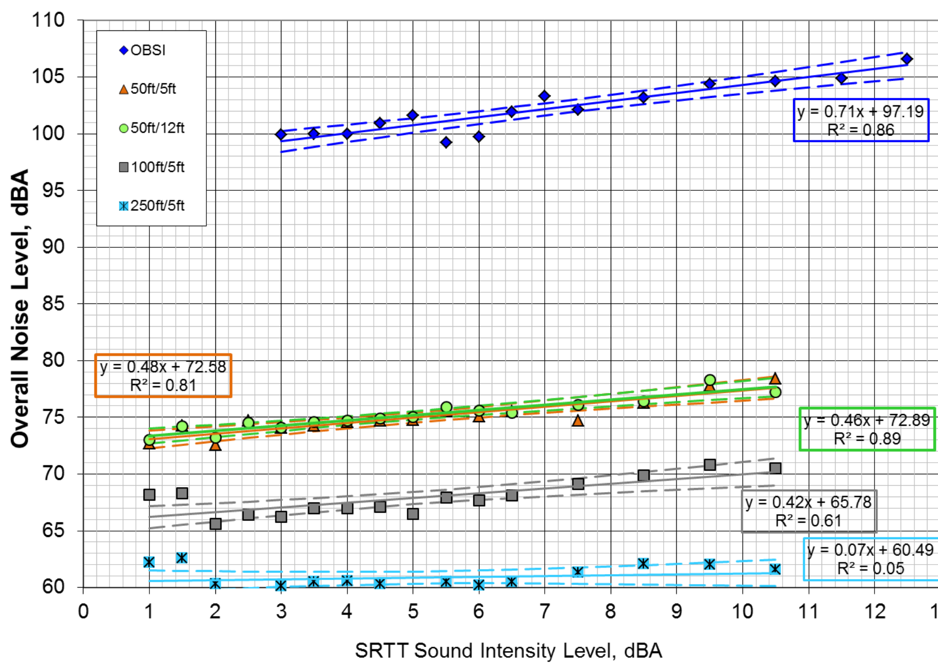


Figure D4. Overall Levels Versus Age of Overlay for Type 1 and Type 3 Measurements at Site 3D with 95 Percent Confidence Limits of the Regression Line Indicated by Dashed Lines

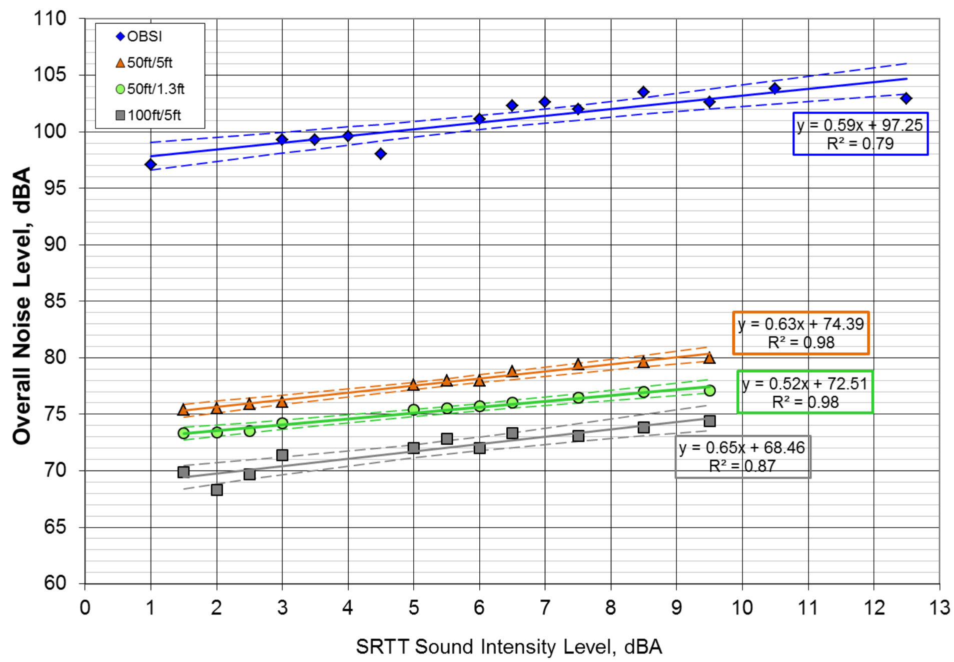


Figure D5. Overall Levels Versus Age of Overlay for Type 1 and Type 3 Measurements at Site 3E with 95 Percent Confidence Limits of the Regression Line Indicated by Dashed Lines

CORRELATION OF RESULTS

While Type 2 measurements were limited during *post*-overlay years, Types 1 and 3 were measured consistently throughout the life of the ARFC pavement. Therefore, additional comparisons can be made between the longevity measurements made at each of the Type 3 sites.

The Type 3 noise reductions measured at the 50-ft and 100-ft microphones during each of the *post*-overlay testing periods were compared with the corresponding Type 1 noise reductions summarized in Table 4 of the main report. Figure D6 shows the comparison of the 50-ft reductions versus the Type 1 reductions. This data includes the 50ft/5ft at all five Type 3 sites, the 50ft/12ft at Sites 3A and 3D, and the 50ft/1.3ft at Site 3E. These results indicate a reasonable R^2 of 0.80 and some confidence in the defined slope even with the more pronounced scatter for the higher Type 1 and Type 3 values. Figure D7 shows the comparison of the 100-ft reductions versus the Type 1 reductions. This trend line also demonstrates a reasonable R^2 of 0.81 and some confidence in the slope of Type 1 and Type 3. These results indicate that the relative increase over time measured with both of these measurement methods would adequately capture the degradation of the pavement.

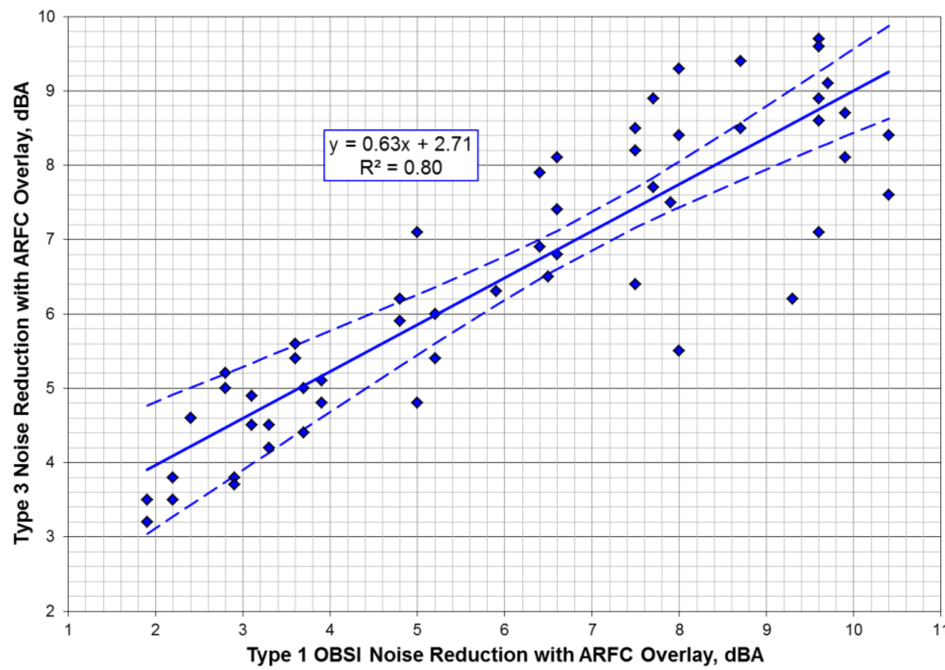


Figure D6. Linear Regression of Type 3 Noise Reductions at 50 ft Versus Type 1 Noise Reductions for the Entire Project Duration

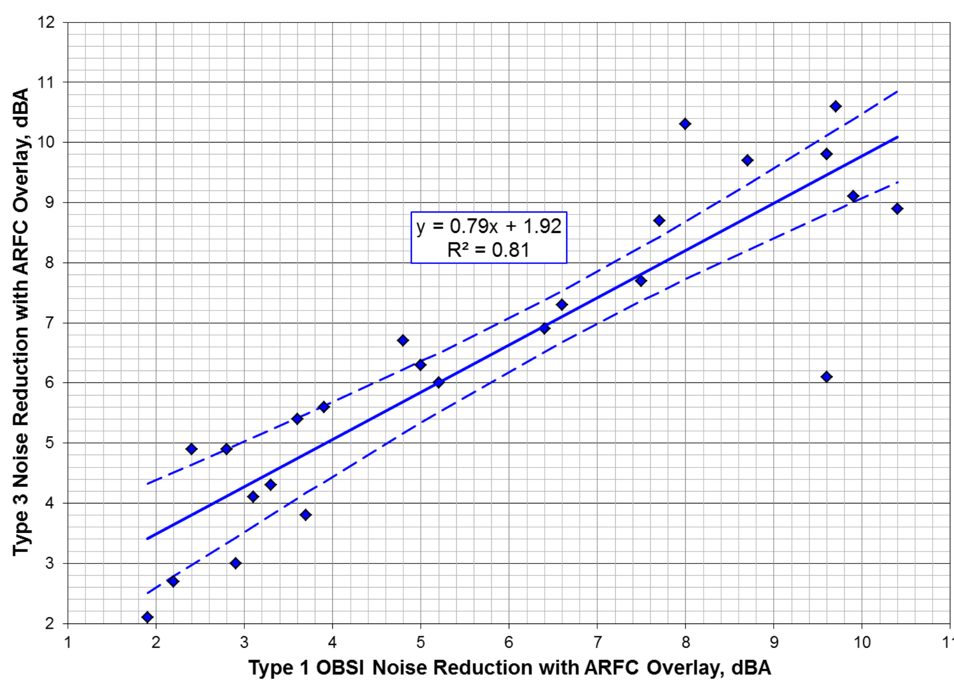


Figure D7. Linear Regression of Type 3 Noise Reductions at 100 ft Versus Type 1 Noise Reductions for the Entire Project Duration

APPENDIX E:
TYPE 2 DATA

TYPE 2 – BEFORE, AFTER, AND FOLLOW-UP DATA

This appendix reports the detailed data from the Type 2 *before, after,* and *follow-up* measurements of neighborhood noise levels and accompanying weather and traffic data.

Table E1. Data from “Before” Type 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
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

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	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 E2. Data from 'After' Type 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

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	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
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 E3. Data from 'Follow-up' Type 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

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
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 F:
QUIET PAVEMENT PILOT PROGRAM:
CORRELATION BETWEEN SITE 1, SITE 2, AND SITE 3 MEASUREMENTS
(2013 DRAFT REPORT)

EXECUTIVE SUMMARY OF 2013 DRAFT REPORT (APPENDIX F)

ADOT initiated the Arizona Quiet Pavement Pilot Program (QP3) in April of 2003 with approval from FHWA. The QP3 consists of two components: construction and research. The construction component consists of overlaying approximately 115 miles of existing transversely tined Portland cement concrete (PCC) on urban freeways with asphalt rubber friction course (ARFC). The research component evaluates the potential for using ARFC as a noise mitigation measure. The acoustic performance has been monitored with three different measurement types or "sites": Site 1 examines tire/pavement noise reduction at the source; Site 2 examines noise reduction in residential neighborhoods near the freeways; Site 3 evaluates noise reduction using direct measures of traffic noise adjacent to the freeways.

For the Site 1 measurements, the initial reductions in tire/pavement noise through the first year after the overlay were between 8½ dB. For the Site 2 neighborhood noise measurements, the initial reduction at 78 locations was slightly more than 5 dB with a great deal of scatter. For the Site 3 measurements, the initial reduction in traffic noise was about 9 dB including all five site locations and microphone positions up to 100 ft away from the roadway. In this report, an attempt is made to reconcile the differences in noise reduction for the three types of site measurements. Most of the effort was focused on the Site 2 measurements due to the relatively good correlation between the Site 1 and 3 results. Of the original 78 sites, sufficient information was obtained to evaluate 52 sites in some detail. From this analysis no consistent trends were found between individual site parameters such distance from the highway, intervening barriers, highway recesses, differences in the pre-overlay measurements, temperature, or the presence of arterial streets. It was found at sites with frontage roads between the highway and the measurement location that noise reductions were about 1½ dB lower on average than sites without frontage roads. Otherwise, no consistent explanation of why the Site 2 noise reductions were lower than Site 1 and 3 could be found.

It was noted that almost all of the Site 2 locations had features that provide noise reduction beyond that of the flat, un-obscured Site 3 geometries. To systematically explore what effect these features had on the measured Site 2 noise reductions, a version of TNM that accounts for differences in tire-pavement noise source levels was used to predict the expected noise reductions. Using Site 1 OBSI data from the QP3 and the characteristics of the Site 2 measurement locations, it was found that when the effect of the reduced tire-pavement source strength was added to the already existing noise reductions due to barriers, recessed roadway, etc., the additional noise reductions due to the pavement averaged about 5 dB. This predicted reduction is consistent with the measured reductions and provides a linkage between the Site 1 tire-pavement noise reductions and the Site 2 results. In this sense, the Site 2 and Site 1 do "correlate", and this correlation extends to the Site 3 results through the correlation found between the Site 1 and Site 3 results.

I. INTRODUCTION OF 2013 DRAFT REPORT (APPENDIX F)

In the fall of 2003, the Arizona Department of Transportation (ADOT) initiated a Quiet Pavement Pilot Program (QP3) in cooperation with the Federal Highway Administration (FHWA)[1]. Under this program, many freeway segments in the Phoenix metropolitan area constructed with portland cement concrete (PCC) pavement received one-inch thick asphalt rubber friction course (ARFC) overlays to reduce highway traffic noise. The overlays were applied to existing freeways and will be applied to newly built freeways as they are completed. This pilot program represents the first time that a quieter pavement surface type has been allowed as a noise mitigation strategy on federally funded projects. As a condition of using pavement type as a noise mitigation strategy, ADOT developed a 10-year, $3.8 million research program for the FHWA to evaluate the efficacy of using quieter pavement solutions. Noise performance is evaluated by means of three testing methods:

- Site 1 – On-Board Sound Intensity (OBSI), which measures the tire/pavement noise levels at the source. OBSI measurements averaged over a 5-second period are taken at each milepost in the project area and in each travel direction.

- Site 2 – Short-term, time-averaged noise levels measured at 78 select locations in neighborhoods surrounding various segments of the freeway. These were typically one-hour in duration at the time when the highest noise levels are produced by the traffic flow. There may or may not be a direct line-of-sight to the freeway and may also be subject to noise from sources other than the freeway.

- Site 3 – Time-averaged traffic noise levels measured at five “research grade” sites, conforming to the site requirements specified in FHWA measurement procedures[2] at the 50-foot microphone location.

From the early presentations of the results of the QP3, it became apparent that the pre- and post-overlay noise reductions measured by these methods were producing somewhat different values. From the Site 1 OBSI data as measured at the Site 3 locations, preliminary noise reductions averaged about 11.2 dB[3]. From the Site 3 measurements for three of the locations, the reductions averaged 8.8 dB with a range from 11.3 to 6.8 dB at the microphone position located 50 ft from the highway[2]. From the Site 2 measurements, the average reduction was 4.9 dB[4]. Subsequent to these presentations, QP3 Progress Report No. 2 was written by ADOT[5]. In this report, Site 1 reductions were not reported for each of the Site 3 locations, however, an average over all the available Site 1 milepost levels produced an average reduction of 8.3 dB with a range from 4.1 to 13.2 dB. The Site 2 data now included a second round post-overlay measurements and average reduction was reported as 5.4 dB with a range of -1.3 dB (noise increase) to +12.3 dB and 33% of the locations producing reductions less than 4 dB. With the inclusion of all 5 Site 3 locations, the wayside reductions averaged 8.6 dB with a range of 11.3 to 6.8 dB. A final version of QP3 Progress Report No. 3 was published in 2012 with results through 3 to 3½ years since the overlay[6]. Comparing similar time durations of approximately 1½ years after the overlay, this report indicated average reductions of 7.7 dB for Site 1 data taken at the Site 3 locations, 5.1 dB for the Site 2 data, and 7.9 dB for the 5 Site 3 locations.

Consistent throughout the documentation of the first several years after the ARFC overlay, the reductions measured at the Site 2 locations were clearly lower than those of both the Site 1 and Site 3 results. Concern of this discrepancy was expressed during the review phase of Progress Report No. 3. The Site 2 locations were supposed to be representative of locations where residents would hear the noise in their yards, however, these locations apparently were not experiencing the full benefit of the reduced source level or receiving the reduced levels that were measured in the open settings of the Site 3 locations. Several hypotheses have been advanced for this discrepancy such as the Site 2 locations being further away than Site 3's, possible shielding of the Site 2 locations, or the influence of non-freeway background noise at the Site 2 locations. With apparent discrepancy between the Site 2 results and those of Sites 1 and 3, an investigation of the "correlation" between the three types of measurements was initiated. This also included a closer examination of the relationship between Site 1 OBSI results and the Site 3 wayside results. The purpose of this report is to document the findings of these investigations.

II. DESCRIPTION OF QP3 MEASUREMENTS (APPENDIX F)

Summary of Measurement Types

The results of the QP3 measurements along with details of the specific measurement locations are documented in Progress Report 3[4] and will only be summarized in this report.

Site 1 Measurements

Site 1 noise measurements were taken at more than 330 mileposts on Arizona I-17, SR 51, SR 101, SR 202, and I-10 in the metropolitan Phoenix area and are identified by triangular markers in Figure 1. The mileposts and their numbers for the each freeway segment included in the QP3 are shown in detail in Appendix A along with the locations of the Site 2 and 3 measurements.

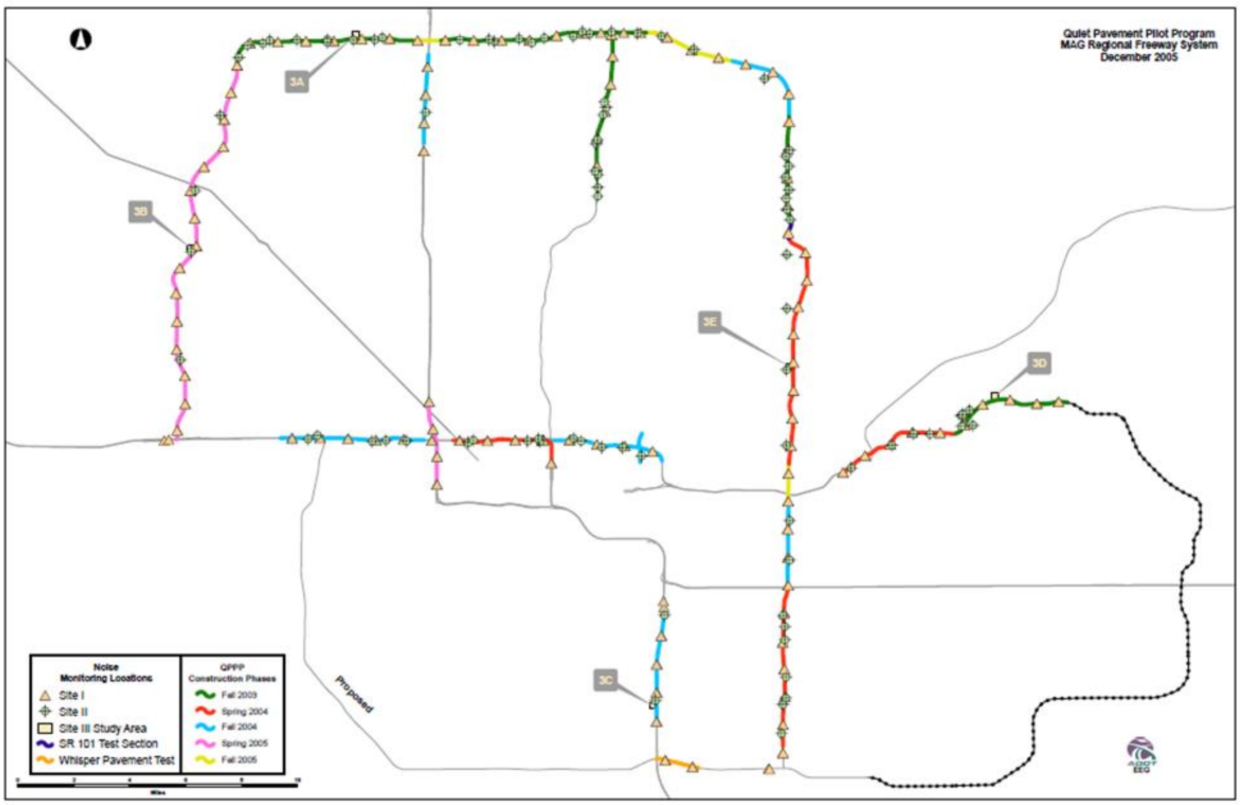


Figure 1: Locations for Site 1, 2, and Site 3 Measurement

The intent of the Site 1 measurements is to quantify the influence of the pavement on the strength of the tire/pavement noise source in isolation from other vehicle noises. It is known that tire/pavement noise is the dominate contributor to vehicle pass-by noise at highway speeds[7,8]. Further, at highway speeds (55 mph and above), a nearly 1-to-1 relationship exists between OBSI levels for different pavements and light vehicle and truck pass-by levels measured on those same pavements[9]. Although there are direct relationships established for OBSI and pass-by level of individual vehicle types, there is no single direct relationship between traffic noise and pass-by noise levels for individual vehicles or OBSI. Traffic is a mix of vehicle types and for each type, there is a different individual statistical relationship between pass-by level, vehicle type, and speed. The traffic noise level also depends on the volume of traffic within the measurement time window. However, the trends between different pavement types are expected to be similar when measured with either wayside time average methods (i.e. Site 2 and 3) and statistical individual pass-by methods, or OBSI. The FHWA Traffic Noise Model (TNM) provides a means to correlate measured traffic noise to pass-by levels for individual vehicle types and pavement effects quantified by OBSI. TNM predicts traffic noise based on statistical pass-by levels by vehicle types and account for traffic variables such as speed and volume. The effect of pavement on traffic noise can be incorporated in TNM predictions by using modifications of the ground level source strength (GLSS) based on OBSI data[10].

For the QP3, the use of OBSI for Site 1 measurements routinely began only after 2006. Prior to that, the ISO Close Proximity (CPX) method[11] was used. As described in QP3 Progress Report No. 3, a correlation was developed in 2006 to relate the CPX and OBSI results. The Site 1 results used in this report for the years before 2006, are converted to equivalent OBSI levels based this correlation. Beginning in 2006, Illingworth & Rodkin, Inc. was tasked with conducting the Site 1 testing on a routine and ongoing basis. The OBSI test procedures followed those developed for Caltrans[12] which are now included in the AASHTO 10-76 test procedure[13]. Prior to 2006, the Site 1 data were limited for 2004 and especially for 2005. Most of the Site 3 locations do not have initial pre- and post-overlay OBSI data. As a result, the initial reductions for the missing sites had to be estimated from other Site 1 data or OBSI data taken at the Site 3 locations for other purposes in the appropriate time frame. After about 1½ years (March 2006) OBSI data is available for all the Site 3 locations.

Whether using CPX or OBSI methods, the procedures for actually collecting the Site 1 data were the same. The 5-second average was begun just as the milepost was passed. However, on occasion there could be some delay of several seconds in actually beginning the data acquisition due to traffic conditions. The testing was conducted at a constant speed of 60 mph and, although this is below the posted speed limit, at times slower vehicles delayed a start or caused a single milepost to be not measured in a series of tests. Also, some milepost markers were missing and the location had to be approximated. The measurements were conducted in the outer most lane of vehicle travel; however, at times this was ill-defined as through lanes appeared and disappeared on the freeways, particularly near exits and freeway intersections. Also, some mileposts occurred on bridge decks where bridge joint created non-pavement noise. These joints were typically avoided by starting the measurement early or late. As a result of all these issues, there is some uncertainty in the data at any one milepost over time. Beginning in 2010, the Site 1 measurements were adjusted for temperature using the gradient of 0.04dB/°F that was developed in the NCHRP Project 1-44-1[14] and adopted in the AASHTO OBSI TP 76 procedure[13]. This adjustment was applied retroactively throughout the entire data set making the results more consistent for comparing one set of measurements to another. All of the Site 1 data cited in this report include this temperature adjustment.

Site 2 Measurements

The Site 2 neighborhood wayside measurements consisted of one-hour average L_{eq} levels acquired before and after the AFRC overlay. The one-hour levels were determined using an average of three 20-minute L_{eq} samples which were consecutive unless one of the samples varied by 3 dB or more in which case, additional 20-minute blocks were acquired until the 3 dB criterion was met. The time of day for the measurements was chosen to represent the typical maximum noise hour of the day based on term-long, 24-hour noise measurements. In addition to the noise data, traffic data of vehicle counts and typical speeds were obtained for the measurement period and meteorological conditions were documented. Eighty-six locations were originally identified for the Site 2 measurements as shown in Figure 1 and 88 were identified in QP3 Progress Report No. 2. Of these sites, noise reductions between pre- and post-overlay were measured at 78 locations producing an average reduction of 5.3 dB. A second set of post measurements were taken approximately 18 months afterwards; however, only 24 locations were measured[4]. This later set of post-overlay data gave an average reduction of 5.2 dB. The intent of the traffic data was to use it to model each site in TNM. These results would then be used to compare to the 4 dB credit that ADOT received from FHWA as a condition for using the quieter pavement for noise abatement and to provide a means of normalizing the subsequent post-overlay data to account for traffic differences.

Unfortunately, documentation of the Site 2 measurement program is minimal. The results were never presented or reported in a public forum other than a brief presentation in 2005[3]. If a report was written, it could not be located within ADOT. The personnel within the consulting group that performed the measurements have since left that organization. Aerial locations of some of the measurement sites are available, however, some locations are not known. For the sites included in the first set of post-overlay measurements, the locations of only 52 sites could be determined.

Site 3 Measurements

The Site 3 locations are indicated in Figure 1. Although the Site 3 noise measurements are similar to those of Site 2, the sites for the measurements were intentionally chosen to be open with a minimum of 150° view of the freeway from each microphone location. The measurements were conducted over longer time periods than the Site 2 measurements, typically including 4 hours of data either measured in two-hour periods in the mornings of consecutive days or in the morning and afternoon of one day. Although the measurements were conducted by different organizations (I&R and the US DOT Volpe Center), the methods were essentially equivalent and follow the practices defined in the AASHTO 10-99 CTIM procedure for continuous time integrated traffic noise measurements[15]. The slight differences in the procedures used by the teams were documented in QP3 Progress Report 3[4]; however, these differences have essentially no impact on the comparability of the results of the various Site 3 results. At all five Site 3 locations, common microphone positions of 50 ft from the center of the nearest lane of through traffic and 5 ft above the surface of the roadway were used. The data from these locations are the primary point of comparison although data at different distances and microphone heights are available from individual sites. Traffic counts and vehicle speeds were determined for all of the measurements. Each site was modeled in TNM to develop adjustment factors to account for differences in traffic over the course of measurement periods and for comparing measurements made on different days and years.

Although the measurement procedures and results are well documented, three of the five locations experienced changes over the course of the QP3 measurements to date. At Site 3A, an auxiliary lane was added and site geometry between the outside lane of through travel and 50 ft distant microphone position was altered. For Sites 3B and 3E, HOV lanes were added to the inside of the through lanes of travel and median barriers were installed. To account for these changes, the TNM models were updated accordingly and the normalized noise levels were found to be approximately equivalent to those from before the modifications. In all cases, the surfaces of the original through lanes of travel were not re-surfaced. All of the Site 3 data used in this analysis is for the freeway conditions prior to the modifications described above.

Timing of Measurements

Timing of the testing for different site types and freeway segments was dictated in part by when specific segments were to be overlaid and by the schedule of the different measurement teams. As indicated in Figure 1, the overlays took place over a two-year period from 2003 to 2005 in fall or spring of the years (see Appendix A for more detailed information for each freeway segment). Consistent Site 1 testing did not begin until May 2006 although some data was reported for September 2004 after the initial freeway segments were overlaid. In general, the testing was not synchronized for any given freeway segment and Site 1, Site 2, and Site 3 data cannot be aligned to even within a month. As a result, the comparison between data types is somewhat uncertain as the first post-overlay measurements vary from a month or two to almost a year for Site 2 and 3 results and as much as 2½ years for Site 1 results. During the first year after the overlay, the noise reduction performance of the ARFC was found to decrease by about 1 dB for both the Site 1 and Site 3 data[4]. The timing of the overlays and the pre- and post-overlay Site 1, Site 2, and Site 3 measurements are shown in Tables 1 through 7. The dates of the pre-overlay Site 1 measurements are not/available (n/a) as these measurements were completed at time when ADOT was conducting these tests and documentation is limited. Reviewing Table 1-6 for Site 1 and Site 2 measurement timing indicates that most of the time, the initial Site 1 measurements often lags those of the Site 2 locations by about ½ to 2½ years. For the Site 2 and Site 3 measurements, the differences were generally smaller with the initial overlay Site 3 measurements lagging the Site 2 data by ¼ to 1¼ years.

Table 1: Timing of QP3 Overlay and Measurements on AZ SR 101 Agua Fria Freeway Segments

SR 101 Agua Fria Segments						
	Overlay Fall 2003			Overlay Spring 2005		
	Site 1	Site 2	Site 3A	Site 1	Site 2	Site 3B
Pre-Overlay	n/a	Aug-03	Aug-03	Jun-04	Jun-04	Jun-04
Post-Overlay 1	Sep-04	Nov-03	Sep-04		Aug-05	Aug-05
Post-Overlay 2	Mar-06		Apr-05	May-06		Jun-06
Post-Overlay 3	Nov-06		May-06	Nov-06		
Post-Overlay 4	Mar-07	Mar-07		Mar-07	Mar-07	Oct-07

Table 2: Timing of QP3 Overlay and Measurements on AZ SR 101 Pima Freeway Segments

SR 101 Pima Freeway Segments					
	Overlay Fall 2003		Overlay Spring 2004		
	Site 1	Site 2	Site 1	Site 2	Site 3E
Pre-Overlay	n/a	Jul-03	n/a	Apr-04	Apr-04
Post-Overlay 1	Sep-04	Jan-04	Sep-04	Aug-04	Oct-04
Post-Overlay 2					Mar-05
Post-Overlay 3					Oct-05
Post-Overlay 4	Mar-06		May-06		Mar-06
Post-Overlay 5	Nov-06		Nov-06		Oct-06
Post-Overlay 6	Mar-07	Mar-07	Mar-07		Mar-07

Table 3: Timing of QP3 Overlay and Measurements on AZ SR 202 Red Mountain Freeway Segments

SR 202 Red Mountain Frewway Segments					
	Overlay Fall 2003			Overlay Spring 2004	
	Site 1	Site 2	Site 3D	Site 1	Site 2
Pre-Overlay	n/a	Oct-03	Oct-03	n/a	May-04
Post- Overlay 1	Sep-04	Dec-03	Oct-04	Sep-04	Nov-04
Post- Overlay 2			Mar-05		
Post- Overlay 3			Oct-05		
Post- Overlay 4	May-06		Mar-06	May-06	
Post- Overlay 5	Nov-06		Oct-06	Nov-06	
Post- Overlay 6	Mar-07		Mar-07	Mar-07	May-07

Table 4: Timing of QP3 Overlay and Measurements on I-10 Maricopa Freeway Segments

I-10 Maricopa Freeway			
	Overlay Fall 2004		
	Site 1	Site 2	Site 3C
Pre-Overlay	n/a	Apr-04	Jun-04
Post-Overlay 1		Aug-04	
Post-Overlay 2			
Post-Overlay 3			Jun-05
Post-Overlay 4	Mar-06		Jun-06
Post-Overlay 5	Nov-06		
Post-Overlay 6	Mar-07		

Table 5: Timing of QP3 Overlay and Measurements on I-10 Pagago Freeway Segments

I-10 Pagago Freeway				
	Overlay Fall 2004		Overlay Spring 2004	
	Site 1	Site 2	Site 1	Site 2
Pre-Overlay	n/a	Jun-04	n/a	Mar-04
Post-Overlay 1	Mar-05	Jun-05		Nov-04
Post-Overlay 2				
Post-Overlay 3				
Post-Overlay 4	Mar-06		Mar-06	
Post-Overlay 5	Nov-06		Nov-06	
Post-Overlay 6	Mar-07	Apr-07	Mar-07	Apr-07

Table 6: Timing of QP3 Overlay and Measurements on SR 51 Piestewa Freeway Segments

SR 51 Piestewa Freeway		
	Overlay Fall 2004	
	Site 1	Site 2
Pre-Overlay	n/a	Aug-03
Post-Overlay 1	Sep-04	Oct-03
Post-Overlay 2		
Post-Overlay 3		
Post-Overlay 4	Mar-06	
Post-Overlay 5	Nov-06	
Post-Overlay 6	Mar-07	

Table 7: Timing of QP3 Overlay and Measurements on SR 101 Price Freeway Segments

SR 101 Price Freeway		
	Overlay Spring 2004	
	Site 1	Site 2
Pre-Overlay	n/a	Jun-04
Post-Overlay 1	Sep-04	Jun-05
Post-Overlay 2		
Post-Overlay 3	Mar-05	Mar-05
Post-Overlay 4	Mar-06	
Post-Overlay 5	Nov-06	
Post-Overlay 6	Mar-07	

III. INITIAL COMPARISON OF MEASUREMENT TYPES (APPENDIX F)

From Section II, it is apparent that direct comparison of the Site 1, Site 2, and Site 3 results is problematic. Ideally, these data would all have been taken at virtually the same time on each freeway segment at a consistent time relative to the placement of the overlay. In the absence of such coordination, the results can be compared in several different manners to lead to some conclusions about the correlation of the measurements. These comparisons include considering the average of all Site 1, 2, and 3 results from the initial post-overlay data, considering freeway segment average data for the Site 1 and 2 results from the initial post-overlay data, and considering the most appropriate data corresponding to the Site 3 locations for all three data types.

Comparison of Averages

To compare the averages of the Site 1, 2, and 3 results, the noise reductions resulting from the pre-overlay and initial post-overlay measurements are used. As noted in regard to Tables 1-7, this comparison has several caveats. First, the time between the Site 3 measurements lags the initial Site 2 measurements by about 3 to 15 months. Given the rate of increase in tire/pavement noise with time, this would tend to bias the Site 2 reductions to be greater than those of Site 3. For the Site 1 data, only results for 113 mileposts (out of 230) are available in a time frame of 10 to 12 months later than the Site 2 results. A more complete set of the Site 1 data is available from 2006, however, these are as much as 36 months post-overlay. From the Site 1 data taken in 2004, the increase in level by 2006 was about 2 dB. This increase is too large for comparison to the Site 2 and 3 data so only the average of the reductions for the 113 mileposts from 2004 are used. For the Site 3 reductions, the initial reductions from all 5 sites are averaged including all microphone locations providing a total of 12 data points. For the Site 1 and 2 measurements, 71 and 78 data points, respectively, are included in the averages.

Using the data points described above, the average, maximum, minimum, and standard deviation of the Site 1, 2, and 3 noise reductions are shown in Figure 2. On average, the Site 2 reductions are about 3 dB lower than the Site 1 and almost 4 dB lower than Site 3 leaving the Site 1 and 3 averages separated by less than 1 dB with Site 1 reductions being lower. The maximum reductions are more consistent among the 3 data sets with the Site 2 maximum essentially equal to Site 3 with the Site 1 result being about 1½ dB higher than Site 2 and 3. For the minimum values, Site 2 is slightly negative implying that the noise level is greater after the overlay application than before for at least one location. The minimum values for Site 1 and 3 are both positive, however, the Site 3 minimum is about 3½ dB greater than the Site 1 value. As indicated by the standard deviations, the Site 1 and 2 reductions display more variation than the Site 3 data even though the latter data includes results from several different distances away from the freeway.

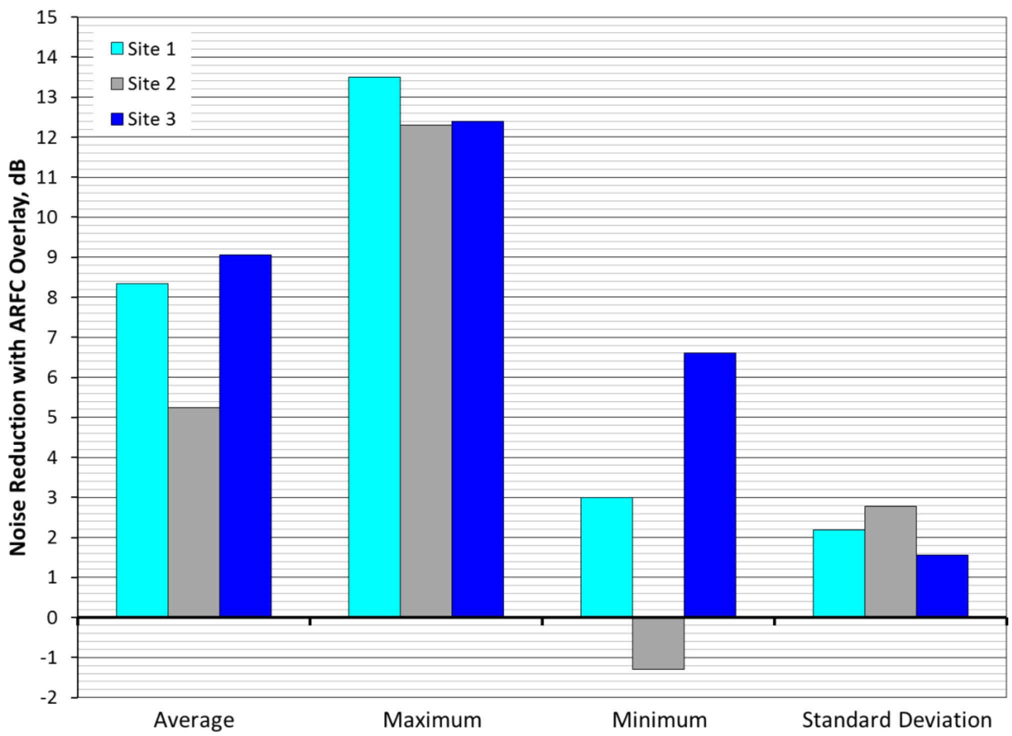


Figure 2: Comparison of average, maximum, minimum, and standard deviation of noise reductions for Site 1, 2, and 3 measurements

As might be expected, the distribution of the frequency of occurrence of noise reduction levels within a 1 dB band, are also different for the three data types. In Figure 3, the fractional occurrences of the Site 1, 2, and 3 noise reductions are shown. From this presentation, it is apparent that Site 2 results display a definite bias toward lower noise reductions compared to the Site 1 and 3 results. The results for the Site 3 data show a relatively narrow distribution that may be a result of the more controlled nature of these measurements. The Site 1 distribution shows only slight bias to be lower than Site 3 and the distribution is also slightly wider than Site 3. The larger spread in the Site 1 results may be due to the greater uncertainty in exactly repeating the measurement at each milepost and some ambiguity in defining the outside lane for testing near freeway interchanges and exits.

Comparison Freeway Segments

The Site 1 and 2 measurements can be organized to reflect different freeways and freeway segments providing another basis of comparison between the data sets. For this comparison, the definition of the segments is provided in Table 8 (see Figure 1 and Appendix A for visual definition of the segments). Site 1 data is from the September 2004 measurements as was used for the averages shown in Figure 2. The timing of the Site 2 measurements at the locations of Table 8 corresponds to those shown in Tables 1 through 7.

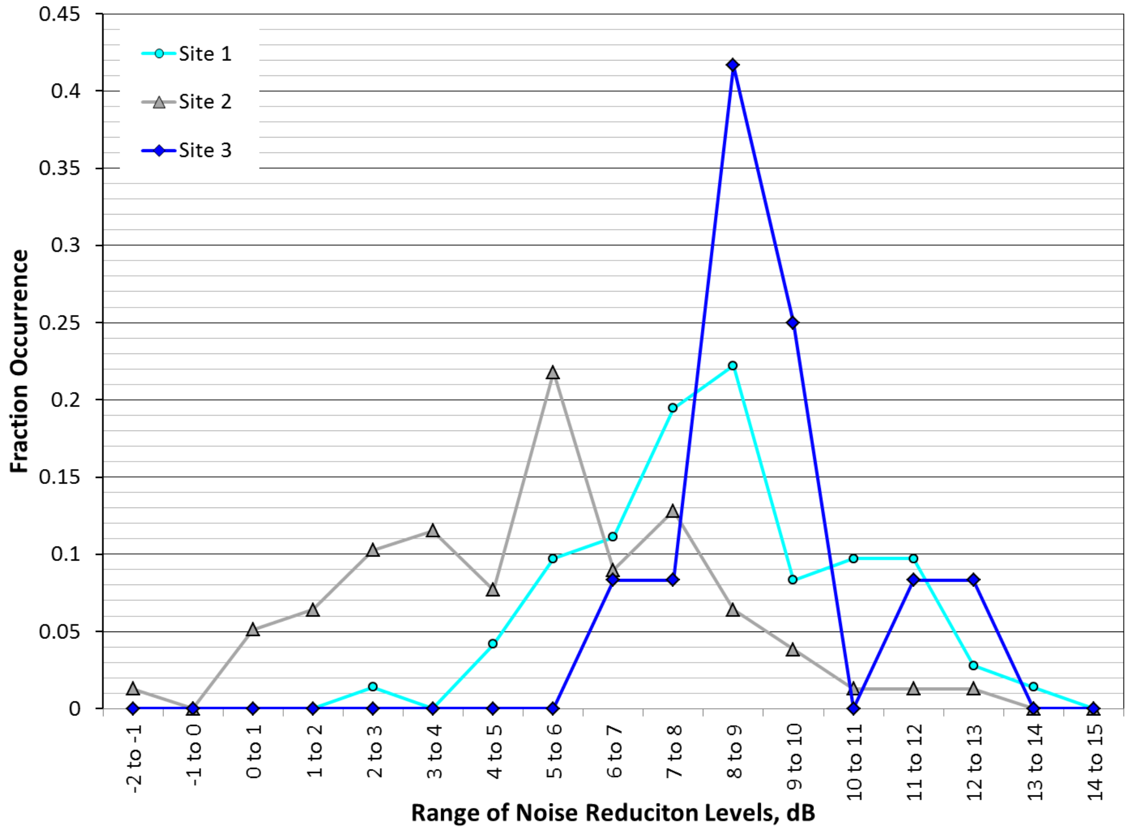


Figure 3: Fractional frequency of occurrence of noise reduction levels for Site 1, 2, and 3 results

Table 8: Definition of QP3 freeway segments with corresponding Site 1 mileposts and locations numbers for Site 2 measurements

Designation	Description	Site 1 Mileposts	Site 2 Location No.
Pima 1	SR 101 Pima West of SR 51	24-31	1-11
Pima 2	SR 101 Pima North of Site 3E	38-42	31-38
Pima 3	SR 101 Pima Around Site 3E	42-51	61-64
Agua Fria	SR 101 Agua Fria West of I-17	16-23	21-30
Red Mt 1	SR 202 Red Mountain West of Site 3D	12-16	52-55
Red Mt 2	SR 202 Red Mountain Around Site 3D	17-20	39-44
Price	SR 101 Price South of US 60	55-61	45-51

Using these data, the averages for the Site 1 and Site 2 noise reductions are shown for each segment in Figure 4 along with the standard deviations for each data type. For these averages, both data types display considerable variation from segment-to-segment with the Site 1 reductions ranging from about 5½ to 12 dB and the Site 2 reductions from 3 to 7½ dB. With the exception of segment 1 on the Red Mountain Freeway, the Site 1 reductions are greater than the Site 2 by 2.7 dB on average with a maximum of about 4½ dB on the Pima 3, Red Mt 2 and Price segments. The average difference of 2.7 dB between the Site 1 and Site 2 reductions is similar to the 3 dB difference noted in Figure 2 for all of the data points.

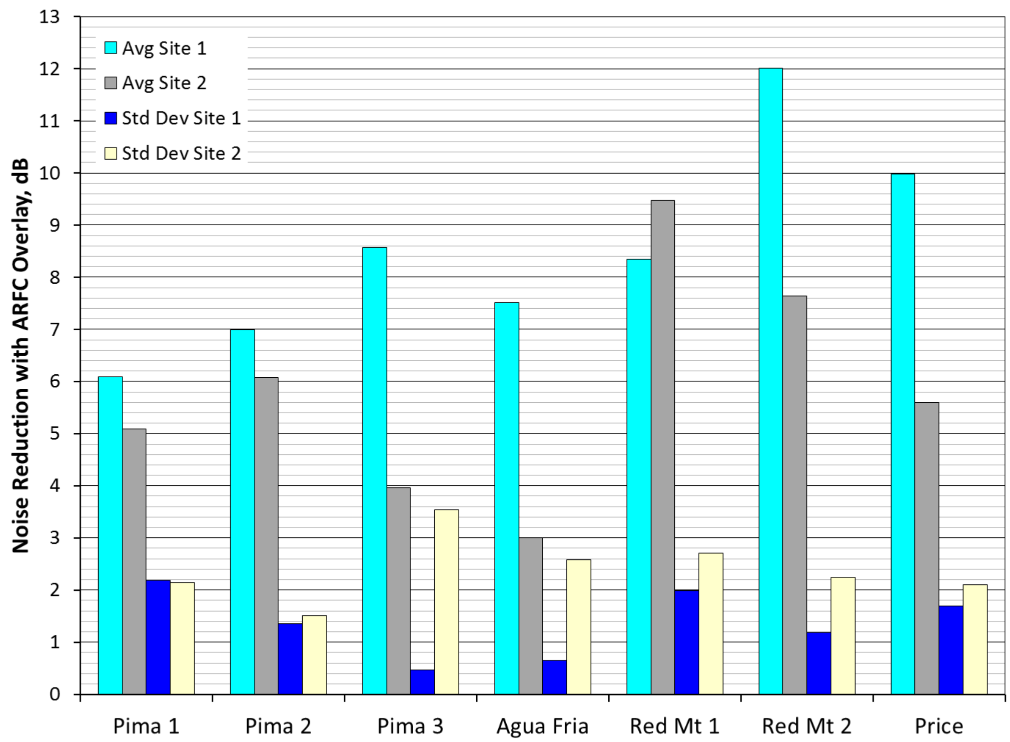


Figure 4: Averages and standard deviations of Site 1 and 2 noise reductions for different freeway segments

The scatter in the results, as indicated by the standard deviations for any one segment, is typically greater for Site 2 than for Site 1. As an example, for the Agua Fria Freeway, the range in the individual Site 2 reductions is from 0.1 to 7.1 dB for 10 measurement locations compared to the range from 6.2 to 8.7 dB for 14 measurement locations for the Site 1 data. Considering the timing of the measurements, the three segments displaying the smallest difference between the Site 1 and Site 2 (Pima 1, Pima 2, and Red Mt 1) are also those where the Site 1 measurements were made 8 to 9 months later than the Site 2 measurements. In this case, the Site 1 noise reductions may be slightly lower due to the aging of the overlay. Conversely, for 3 out of 4 of those segments displaying the largest difference (Pima 3, Red Mt 2, and Price), the Site 1 measurements were made prior to or about the same time as the Site 2 measurements. This suggests that timing may also be a factor in comparing the results of the two types of data as well as larger scatter in the Site 2 results.

Comparison of Site 2 Locations

The noise reductions indicated by the Site 1 and Site 2 results can be compared by pairing the OBSI levels at each milepost with the nearest location of a Site 2 location using the maps in Appendix A. For initial Site 1 measurements in 2004, the data are somewhat limited; however 63 pairs of data points could be identified. In Figure 5, the Site 2 reductions are plotted against the Site 1 results. This plot displays virtually no correlation between the noise reductions with a coefficient of determination of 0.05. The average reduction for the Site 1 results is 7.8 dB while the Site 2 is 4.7 dB giving a difference of about 3 dB.

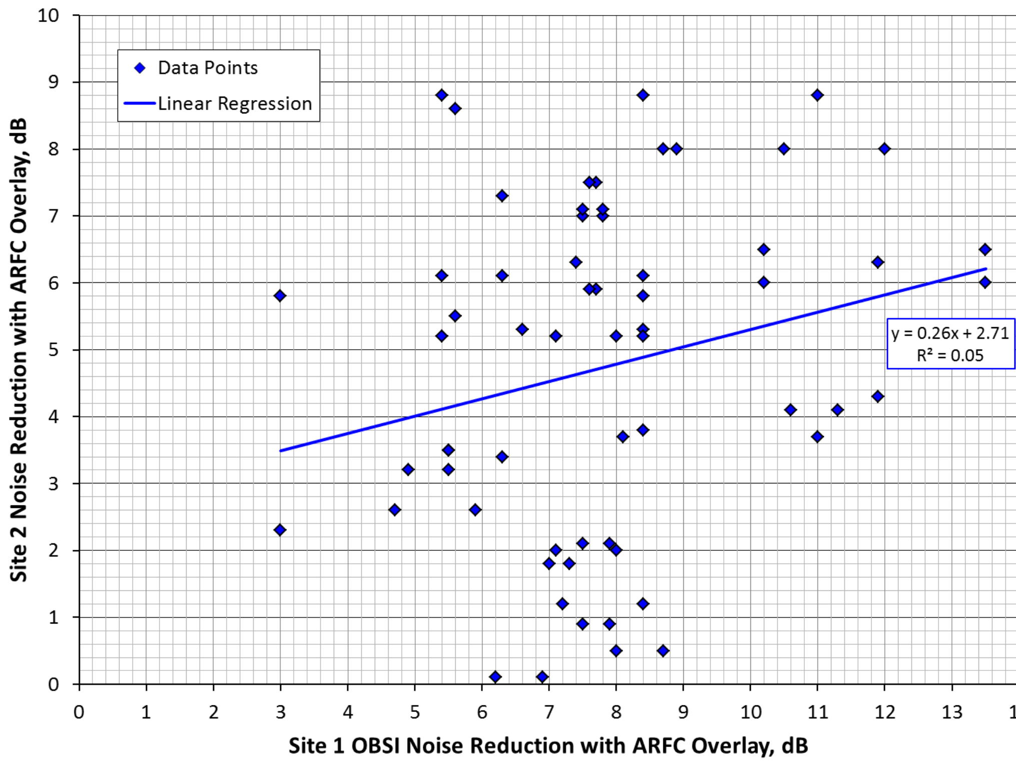


Figure 5: Linear regression of Site 1 noise reductions versus Site 2 noise reductions

Comparison of Site 3 Locations

Another means of comparing the results of the different measurement types is to compare the results for specific locations of the Site 3 measurements. As indicated in Figure 1 and more explicitly in Appendix A, , Site 2 measurements were conducted in close proximity to the Site 3 measurement locations. For Site 3A, the corresponding Site 2 location is 29; for 3B, it is 85; for 3C, it is 71; for 3D, it is 42; and for 3E, it is 62. In principle, there should be Site 1 data available for the specific Site 3 location or at least within a half mile or less. However, specific pre- and post-overlay Site 1 data exist only at Site 3D and near 3A. As a result, just the levels and noise reduction from the Site 2 and 3 measurements are shown in Table 9. The noise reductions are shown graphically in Figure 6. There are a number of observations to be made in examining Table 9 and Figure 6. Consistent with Figure 2, the noise reductions (Figure 6) produced by the Site 2 data are always lower than those of the Site 3 data even for all microphone distances of the Site 3 results. In some cases, the differences between the Site 2 and 3 noise reductions are quite large. For Site 3A, the reduction from the Site 2 measurements is only 0.5 dB while the Site 3 data reductions are 9.1 dB and 9.5 dB at the two 50 ft positions.

Table 9: Pre- and post-overlay overall A-weighted noise levels and noise reductions for Site 3 measurement locations and nearest Site 2 locations

Description	Pre-Overlay Level, dBA	Post-Overlay Level, dBA	Noise Reduction, dB
Site 2 Location 29	69.6	69.1	0.5
Site 3A 50ft/12ft	82.5	73.0	9.5
Site 3A 50ft/5ft	82.3	73.2	9.1
Site 2 Location 85	67.6	61.7	5.9
Site 3B 50ft/5ft	82.8	73.6	9.2
Site 3B 95ft/5ft	77.1	69.8	7.3
Site 3B 246ft/5ft	70.3	61.4	8.9
Site 2 Location 71	63.2	57.6	5.6
Site 3C 50 ft/5ft	83.2	74.4	8.8
Site 3C 141ft/5ft	72.6	66.0	6.6
Site 2 Location 42	58.8	52.3	6.5
Site 3D 50ft/12ft	84.3	70.4	12.4
Site 3D 50ft/5ft	83.2	70.6	11.1
Site 3D 100ft/5ft	76.8	65.4	10.0
Site 3D 275ft/5ft	68.9	59.5	8.1
Site 2 Location 62	63.9	55.9	8.0
Site 3E 50ft/5 ft	84.2	75.0	9.1
Site 3E 50ft/1.3ft	81.6	73.3	8.3
Site 3E 100ft/5ft	78.7	69.8	8.9

For 3D, the Site 2 level change is 6.5 dB while the different distances of the Site 3 measurements range from 12.4 dB at 50 ft to 8.1 dB at 275 ft. For the other locations, the differences in Site 2 and Site 3 noise reductions are not as great, but are still typically in the range of 1 to 3 dB. For two of the sites (3C and 3D), the reductions become smaller with increasing distance. This may contribute to the lower noise reductions for the Site 2 results as these sites are typically more than 100 ft away from the freeway. However, for two other sites, 3B and 3E, the reductions for the Site 3 data are the same at the 50 ft distance as they are for the most distant microphone locations at these sites.

Reviewing Table 9, it is seen that the Site 2 noise levels are lower than the Site 3 levels except for the measurement 246 ft away from the freeway at Site 3B after the overlay. On average considering all of the Site 3 microphone location data, the levels for Site 3 are 15.2 dB higher than the Site 2 levels for the pre-overlay values and 11.4 dB higher for the post-overlay values. If this analysis is restricted to exclude the 50 ft microphone locations, the Site 3 levels exceed the Site 2 levels by an average of 10.8 dB pre-overlay and 8.4 dB post-overlay. The lower levels for the Site 2 data suggests that there is some additional attenuation occurring at the Site 2 locations relative to the flat, unobstructed Site 3 locations.

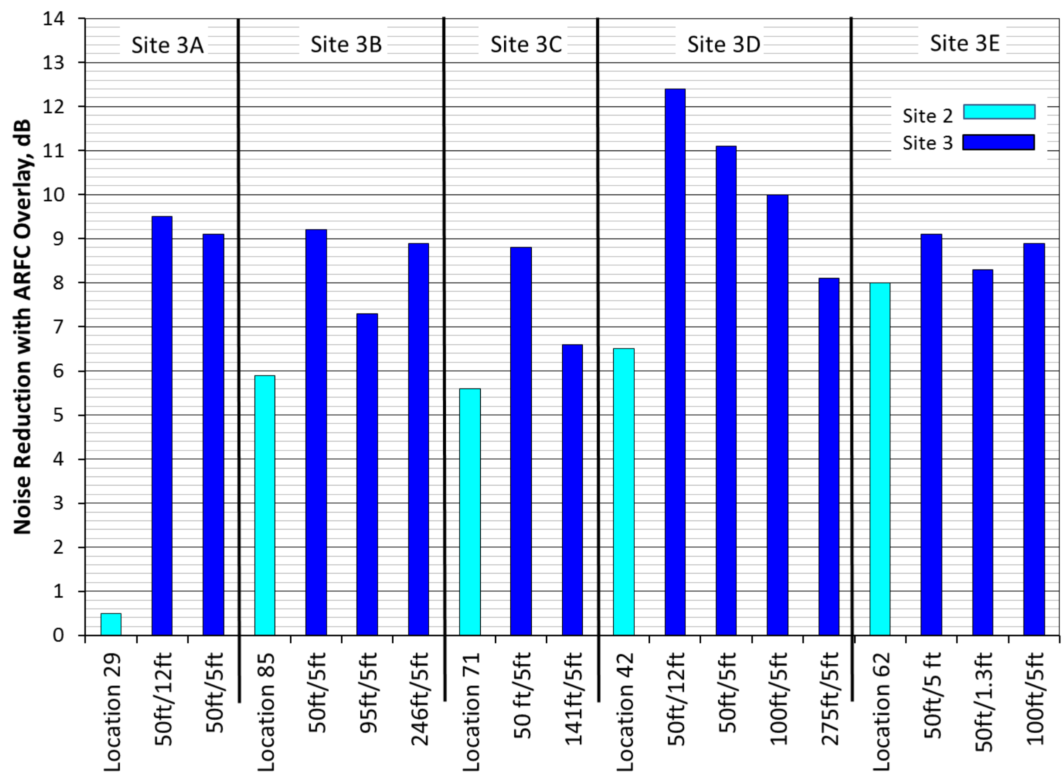


Figure 6: Comparison of pre- and post-overlay noise reductions for Site 3 measurement locations and nearest Site 2 locations

Rather than using the individual Site 2 results closest to the Site 3 wayside locations, the average reduction for the Site 2 measurements within the segment of the corresponding Site 3 location can be considered. For Site 3A, the Site 2 result increases to a reduction of 3.0 dB instead of 0.5 dB and comes at least a little closer to the Site 3A measured reduction. For Site 3B, the Site 2 averaged noise reduction actually decreases from 5.9 to 3.7 dB providing even less correlation to the Site 3 results ranging from 7.3 to 9.2 dB. The other three sites also show mixed results with both 3C and 3D showing slightly higher reductions (by 0.6 dB and 1.1 dB, respectively) while the Site 2 results at 3E decreased by 1.9 dB. The use of the segment averaged Site 2 noise reductions generally did not improve the correlation between the Site 2 and Site 3 results.

Site 1 data noise reductions at locations 3A and 3E can also be compared to those of Table 9. For 3E, Site 1 measurements were made directly at the Site 3 location producing a reduction of 8.9 dB for the southbound direction nearest the wayside microphones and 8.7 dB in the northbound direction. These values compare closely to the Site 2 value of 8.0 dB and to Site 3 values of 8.3 to 8.9 dB. For the Site 1 measurements near 3A, the average of the westbound levels (closest to the wayside microphones) was 7.5 dB with 8.3 dB for the eastbound direction. These are somewhat lower than the 9.5 and 9.1 dB reductions measured at the 50 ft locations, but are substantially higher than the 0.5 dB reduction measured at the corresponding Site 2 location.

Other sources of Site 1 data can also be used to compare these types of measurements to the Site 3 results. In the fall of 2004, I&R conducted post-overlay OBSI measurements at the Site 3A, 3D, and 3E locations at part of the Noise Intensity Testing in Europe (NITE) project sponsored by Caltrans[16]. These measurements were done using the same OBSI procedures as those used for Site 1 measurements after 2005 for the QP3. For the pre-overlay measurements, the results from the Site 1 measurements at Site 3A and 3E described above can be used. Site 3D, OBSI levels for pre-overlay, random transverse tined PCC surface near this site were measured as part of the research completed prior to the start of the QP3 in the fall of 2002[17]. The noise reductions produced by these Site 1 measurements are compared to the initial pre- and post-overlay results for the three Site 3 locations in Figure 7. These results indicate that the Site 1 reductions are within about 1 dB or less of the Site 3 reductions for the microphones located 50 ft from the freeways. The rank ordering of the reductions at each location also are consistent between the two data types.

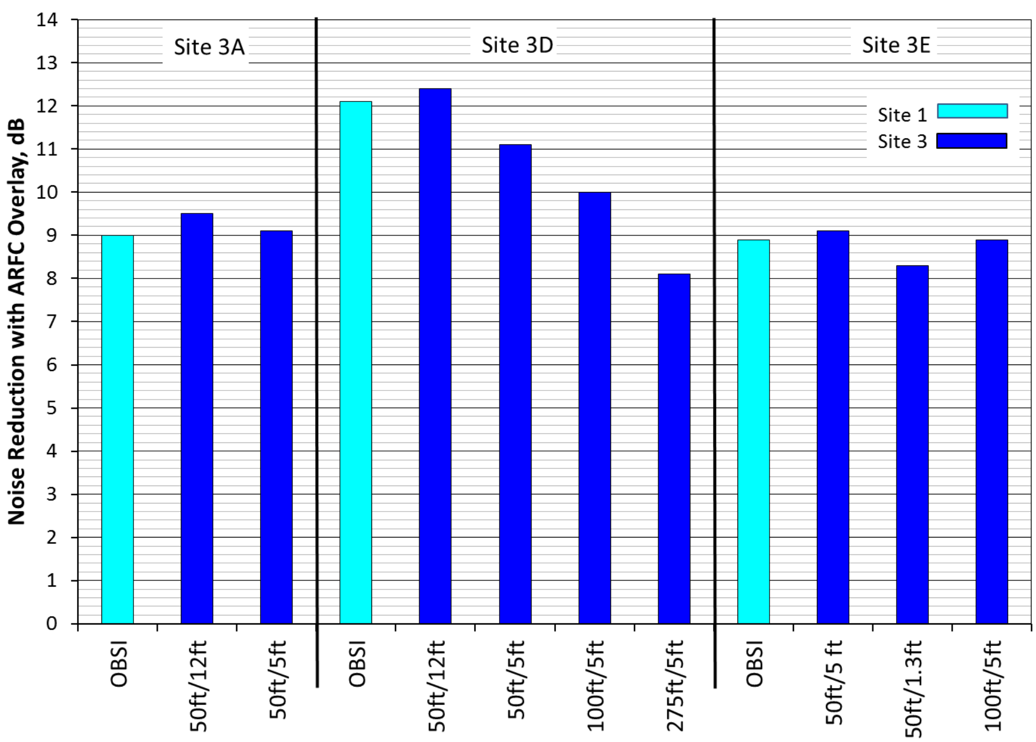


Figure 7: Comparison of pre- and post-overlay noise reductions for Site 1 OBSI and Site 3 wayside measurements

For Site 3D only, there is sufficient data available for a spectral comparison of the noise reductions from the OBSI and the wayside measurement. These are presented in Figure 8 for the 5 ft high microphone positions at 50, 100, and 275 ft from the center of the near travel lane along with the reduction in OBSI level. There is generally good agreement between these data indicative of their correlation.

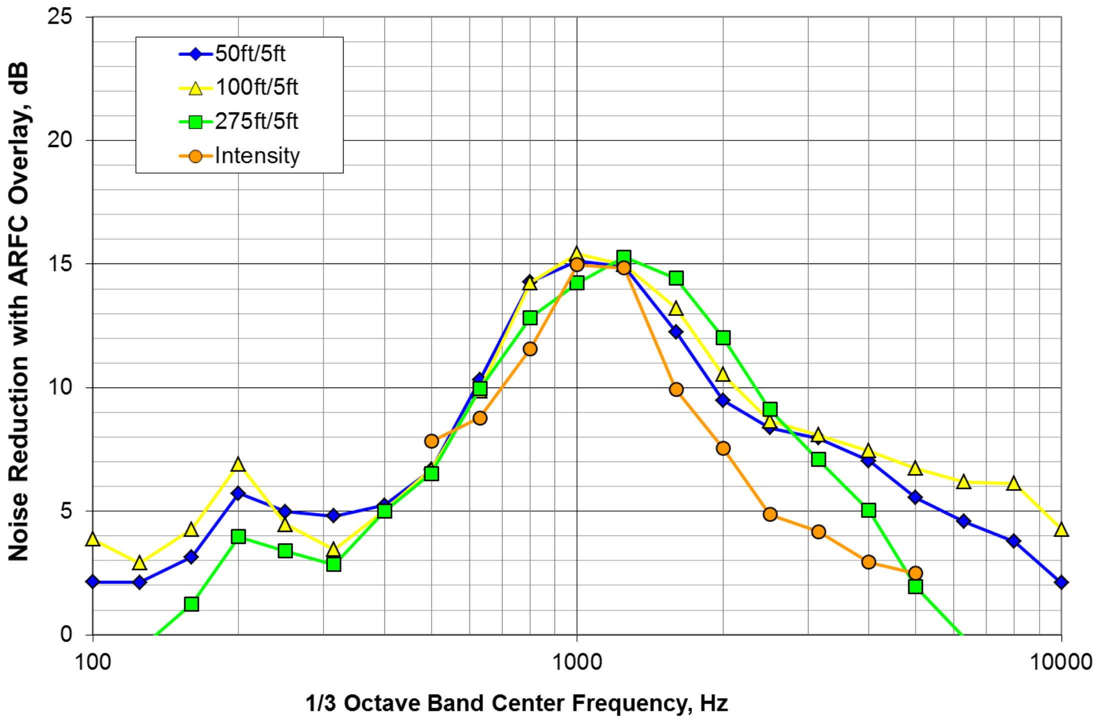


Figure 8: Comparison of pre- and post-overlay ⅓ octave band noise reduction spectra for Site 1 OBSI and Site 3 wayside measurements

Summary

The results presented in this section indicate that although the Site 1 and 3 measurements are consistent with each other in terms of the noise reduction produced by the ARFC overlay, the Site 2 measurements regularly indicate less noise reduction. The initial average noise reductions for Site 1 and 3 measurements demonstrate reductions of about 8 to 9 dB. For the Site 2 measurements, the noise reduction average about 5 dB or about 3 to 4 dB lower than Site 1 and 3, respectively. The scatter in the Site 2 noise reductions is also greater than for Site 1 and 3 and shows a definite bias to lower values. In direct comparison of the Site 2 and Site 3 wayside noise data at the locations of the Site 3 measurements, for 4 of the 5 sites, the Site 2 data indicates reduction that are from 3 to 9 dB less than the Site 3 results. The Site 2 results are intended to indicate the noise reduction that nearby residents would experience in their own backyard (or other outdoor use spaces). It is therefore important to understand why less noise reduction is measured in these locations. In the next section, the locations and data from the Site 2 measurements are examined in more detail in an attempt to determine an explanation for lower correlation between the Site 2 and the other two types of measurements.

IV. ANALYSIS OF SITE 2 MEASUREMENTS (APPENDIX F)

As noted in Section III, the Site 2 data indicate lower noise reductions than those of the Site 1 and 3 measurements with the ARFC overlay. The Site 2 data also show more scatter in the distribution of noise reductions than the other results (see Figure 3). Also, from Figure 5, there appears to be no relationship between the Site 1 OBSI reductions and those of Site 2 measurements. In this section, the Site 2 data is examined in more detail to determine the causes of the lower noise reductions for this data set.

Available Site 2 Information

The intent of the Site 2 measurements was "to evaluate noise reductions in residential neighborhoods due to the application of ARFC overlays"[1]. The most complete documentation of this portion of the QP3 is provided in Progress Report No. 2[5]. In this document, 88 receiver locations (see Appendix A) are identified for the Site 2 measurements for which pre-overlay data is provided. For a variety of reasons, the post-overlay measurements and results included a total of 78 locations[5]. Limited documentation for 37 sites are provided in the first progress report and no specific site information (e.g. distance from the freeway, location of structures, location of noise walls, etc.) are given in this report[1] or in Progress Report No. 2 although photographs and sketches of each site were reportedly taken. Of the 78 locations, 52 were documented on aerial photographs that were available for the current analysis. Using these photographs, the measurement locations were determined using Google Earth. These aerial views could then be used to determine approximate distances to the freeway, the location of structures and existing noise walls, and the relative elevation of the freeway to the measurement location. Using the Google Street View tool, the sites were examined in more detail to determine the approximate height of existing noise walls, freeway recess or elevation, and any other of site geometry nuances that might affect received noise levels. In this manner, the sites were characterized by:

- Open or obstructed view of the freeway
- Flat, elevated, or recessed geometry between the freeway and measurement location,
- Presence of single or multiple barriers and earth berms and approximate height
- Distances from the near lane of vehicle travel to the receiver location and to any intervening barriers or features
- The presence of any nearby potentially high traffic volume streets or other noise sources such intervening frontage roads
- General notes about each site.

Environment conditions that could potentially influence the pre- and post-overlay measurements were tabulated from the information provided in Progress Report No. 2. These included air temperature and wind speed and direction. As described in the Progress Reports, each site was modeled with FHWA TNM primarily for normalizing the pre- and post-overlay noise levels for traffic conditions. The results of this modeling are not available nor are the models which could be used for examining site specific factors.

Initial Data Analysis

The data analysis was limited to the 52 points for which explicit site information was available. The average noise reduction for these points was 5.2 dB compared to 5.3 dB for the complete 78 data points providing some assurance that the analysis of the smaller number of points would be representative of the complete set. The measurement points for the analysis are shown in Table 10 as identified by their location number (see Appendix A) along with their distance from the center of the nearest through lane of vehicle travel, site geometry (recessed or elevated), the presence of frontage roads or arterial streets, the results of the noise measurements, the difference in air temperature for pre-overlay measurements minus post-overlay, and the distance and height of any barriers present. There are several variables that can be tested to determine if they have a relationship to the measured noise reductions. One hypothesis is that the sites with the higher pre-overlay noise levels would be highly dominated by freeway traffic and hence should record the largest noise reductions with the overlay. Conversely, sites with low initial levels may have other contributing sources and hence would produce only small noise reductions. In Figure 9, plotting noise reduction against the pre-overlay levels shows no correlation between the initial noise levels and the measured reductions indicating the higher initial levels did not translate into greater noise reductions. A related hypothesis is that the noise reduction would be less with increasing distance from the highway[18]. In Figure 10, this is shown not to be a factor as significant scatter persists in the data and there is essentially no correlation with distance. This result may not be unexpected as the Site 3 results also only show a small decrease in noise reduction with distance (see Figure 6).

The data of Table 10 can also be used to examine the influence of frontage roads and arterials streets in the vicinity of the Site 2 locations. For frontage roads, 21 sites had frontage roads between the freeway and the measurement location. On average, these sites produced noise reductions of 4.3 dB. The 31 sites without frontage road averaged 5.8 dB. Based on this analysis, there is a possibility that noise from the frontage roads resulted in lower noise reductions due to the post-overlay measurements being elevated by these noises. For arterial streets, only 3 sites out of the 52 had this feature. These data are limited and it is difficult to make any conclusion. Contrary to the frontage roads, the sites with the arterial streets actually were slightly higher on average than the overall average of the Site 2 noise reductions.

Another factor that could affect the noise reduction produced by a quieter pavement is the presence of a barrier or a recessed freeway. Using TNM analysis, it has been reported that noise reductions due to quieter pavement are diminished relative to flat, unobstructed sites in the presence of barriers or when a freeway is recessed relative to the receiver location[17]. It is further concluded that as the height of the barrier increases or the depth of the recess increases, the reductions due to quieter pavement should also diminish.

Table 10: Site information, parameters, and noise levels for 52 Site 2 locations with sufficient available documentation for analysis

Freeway	Site No.	Receiver Geometry (ft)			Other Sources		Measurements (Leq)			Temperature	Noise Barrier		
		Distance	Freeway Recess	Freeway Elevated	Frontage Road	Arterial Road	Pre-Overlay	Post Overaly	Reduction	Difference, Pre-Post (F°)	Occurrence	Distance (ft)	Height (ft)
Pima	1	75	0	0	0	0	74.6	69.3	5.3	18.1	no		0
Pima	2	500	0	0	0	1	64.3	55.7	8.6	32.3	no		0
Pima	3	150	0	7	0	1	64.6	58.5	6.1	18.8	K-rail	24	3
Pima	4	160	0	2	0	0	66.5	59.2	7.3	24.1	yes - 2	24	12
Pima	5	610	0	0	0	0	55.6	52.2	3.4	36.2	yes	102	12
Pima	6	330	4	0	1	0	59.3	56.1	3.2	18.6	yes	84	12
Pima	7	450	0	1	0	0	60.7	58.4	2.3	20.1	K-rail	15	3
Pima	8	200	0	0	2	0	64.9	59.1	5.8	14.4	yes	133	8
Pima	9	140	0	0	1	0	73.1	69.6	3.5	16.1	no		0
Pima	10	125	0	0	1	0	69	65.5	3.5	17.9	yes	60	12
Pima	11	180	0	0	1	0	70.1	67.5	2.6	24.1	yes	112	12
Piestewa	12	125	11	0	0	0	64.2	59.2	5	33	yes	95	8
Piestewa	13	120	9	0	0	0	66.3	63.3	3	30	yes	102	18
Piestewa	14	190	10	0	0	0	68.4	58.4	10	28.4	yes	112	8
Piestewa	15	80	2	0	0	0	67.4	57.6	9.8	40	yes	62	8
Piestewa	16	105	9	0	0	0	65.6	57	8.6	21.7	yes	78	8
Piestewa	17	200	14	0	1	0	63	60.2	2.8	21.4	berm	90	14
Piestewa	18	140	12	0	0	0	62.4	57.9	4.5	6.2	berm	87	8
Piestewa	19	85	0	0	0	0	62.8	58.6	4.2	7.8	K-rail	12	3
Piestewa	20	240	0	0	0	0	57.4	54.9	2.5	23.9	yes	186	14
Agua	21	140	0	0	1	0	64.3	62.2	2.1	30.1	yes	97	10
Agua	22	225	0	0	1	0	65.2	63.2	2	17.4	yes	124	10
Agua	23	190	13	0	1	0	65.9	64.7	1.2	19.7	yes	86	10
Agua	24	300	15	0	2	0	62.2	55.2	7	31.6	yes	115	10
Agua	25	140	0	0	0	0	63.2	63.1	0.1	22.9	yes	96	12
Agua	26	145	2	0	0	0	58.5	56.7	1.8	22.9	yes	92	12
Agua	27	225	10	0	1	0	67.7	60.6	7.1	34	yes	134	12
Agua	28	150	0	0	1	0	72.4	67.2	5.2	32.6	yes	40	10
Agua	29	135	0	0	1	0	69.6	69.1	0.5	35.5	no		0
Agua	30	125	0	4	1	0	73.9	73	0.9	39.7	yes	41	12
Pima	31	290	18	0	0	1	61.9	55.8	6.1	30.2	yes	130	8
Pima	32	220	18	0	0	0	58.8	53.6	5.2	31.3	yes	166	14
Pima	33	260	8	0	0	0	64.7	58.8	5.9	40.3	yes 1st row	144	12
Pima	34	110	12	0	0	0	64	58.5	5.5	34.2	yes	65	20
Pima	35	175	16	0	0	0	59.3	55.5	3.8	25.3	yes multi	82	10
Pima	36	160	10	0	0	0	66.9	61.1	5.8	40.4	yes	78	16
Pima	37	225	14	0	1	0	64.4	56.9	7.5	33.2	yes	113	8
Pima	38	210	12	0	0	0	60.8	52	8.8	25.6	Yes	95	8
Price	45	145	7	0	1	0	63.3	59.6	3.7	-6.2	yes	52	12
Price	46	170	3	0	1	0	61.7	57.4	4.3	-5.8	yes	58	10
Price	47	225	11	0	0	0	64.1	60.4	3.7	-15	yes x2	97	12
Price	48	150	3	0	1	0	68.7	62.4	6.3	-5.8	yes	66	12
Price	49	215	9	0	1	0	59.6	51.6	8	-11	yes	166	10
Price	50	340	17	0	1	0	62.1	58	4.1	-11.1	yes 1st row	84	3
Price	51	165	13	0	1	0	64.9	56.1	8.8	-8.7	yes multi	67	10
Red	52	155	0	0	0	0	63.6	56.7	6.9	15.7	partial	95	16
Red	53	130	0	6	0	0	62.8	50.5	12.3	-17.9	K-rail	22	3
Red	54	200	15	0	0	0	60.5	51.3	9.2	9.4	yes	81	10
Maricopa	56	160	16	0	0	0	65.7	62	3.7	10.4	yes	106	8
Maricopa	58	225	15	0	0	0	65.8	59.9	5.9	4.5	berm/part	92	17
Maricopa	59	175	15	0	0	0	68.7	62.5	6.2	4.9	yes	112	6
Maricopa	60	100	22	0	0	0	67.8	60.5	7.3	5.6	yes	94	8

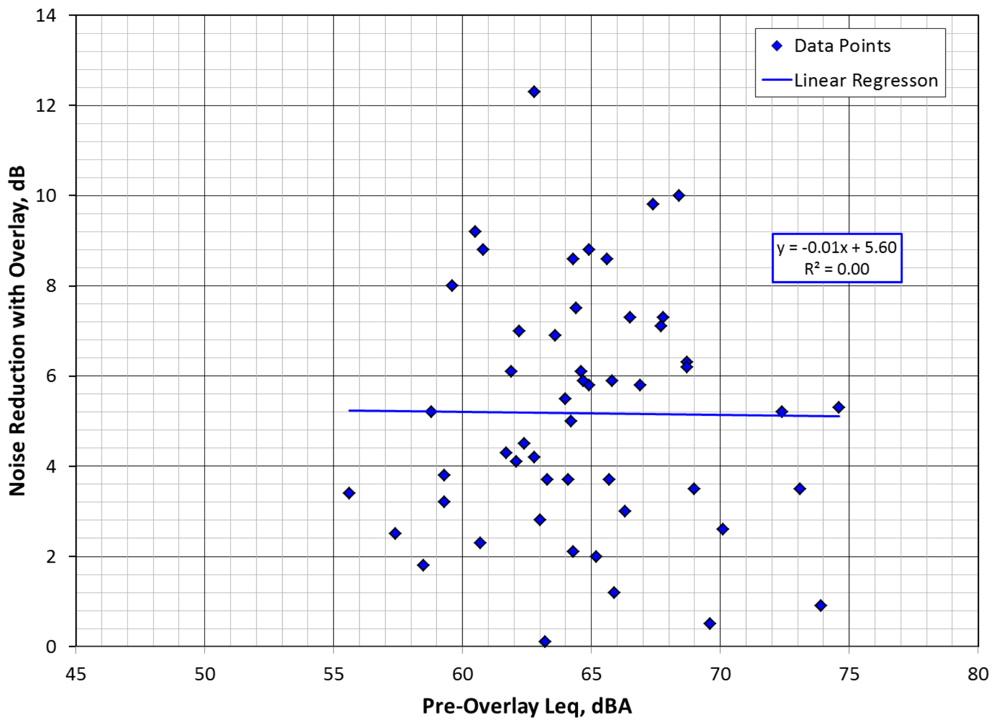


Figure 9: Linear regression Site 2 pre-overlay overall noise levels versus noise reduction

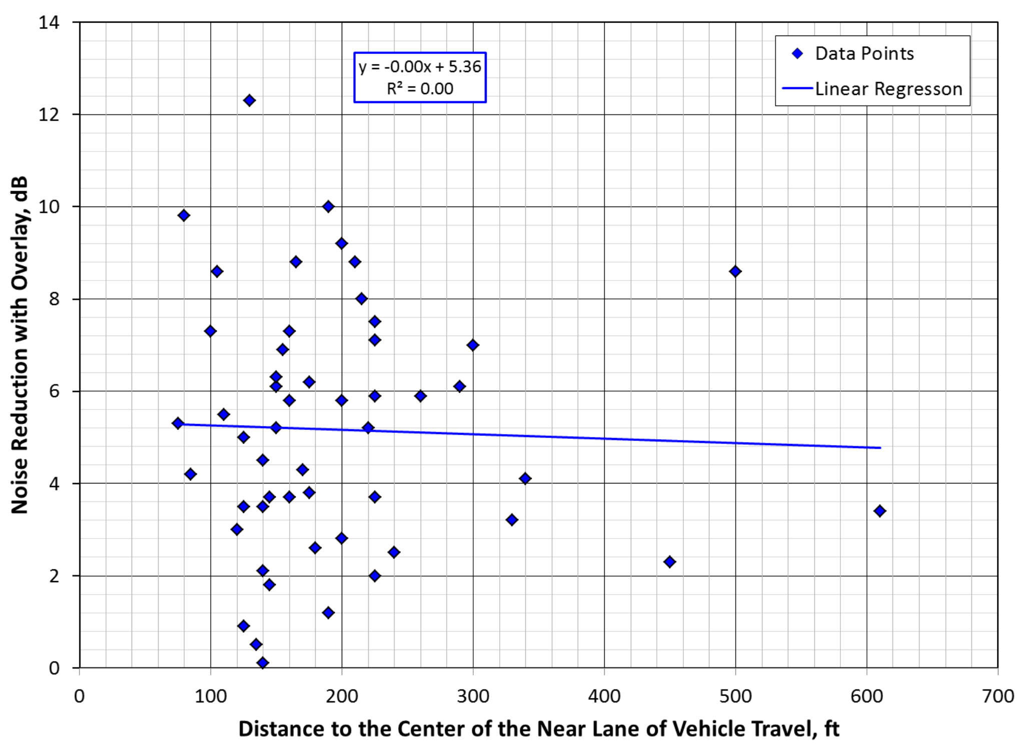


Figure 10: Linear regression of distance to the roadway for Site 2 locations versus noise reduction

Using the data from Table 10, noise reductions due to the overlay as a function of barrier height and freeway recess are plotted in Figures 11 and 12, respectively. These plots also show very little correlation between the noise reductions with the overlay and barrier height or recess depth. The results are also contradicting; increased barrier height shows a slight trend of decreased noise reduction due to the overlay, as would be expected, but increased recess depth shows increased noise reduction. These results are not entirely conclusive, however, because the shadow zones created by the barriers and recesses are a function of the distance of the receiver from the obstruction and the freeway from the obstruction. These relationships could be more properly taken into account with TNM.

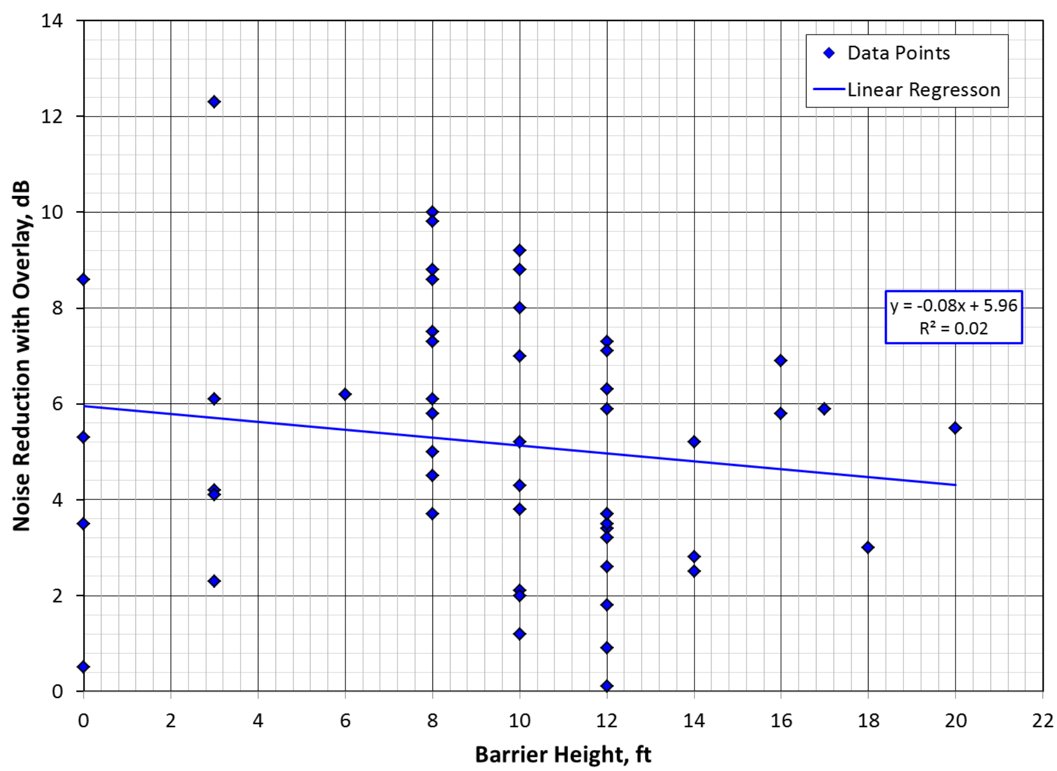


Figure 11: Linear regression of barrier height for Site 2 locations versus noise reduction

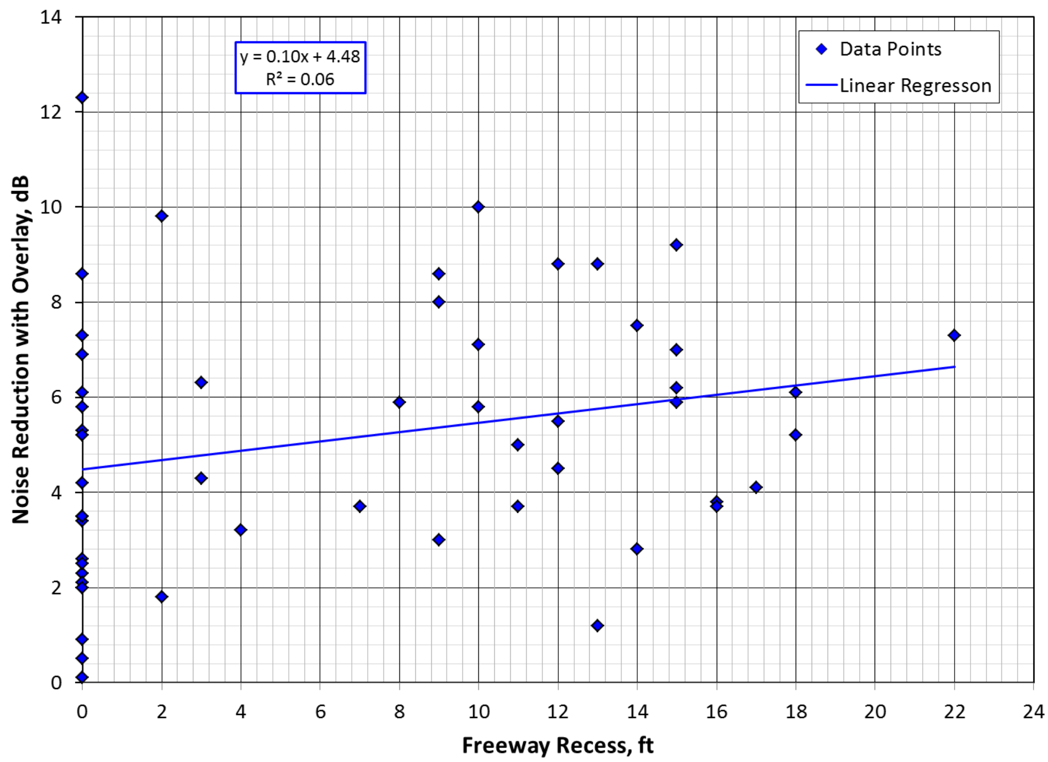


Figure 12: Linear regression of the depth of roadway recesses for Site 2 locations versus noise reduction

Another aspect of the pre- and post-overlay Site 2 measurements is the range in air temperature under which the data was taken. From Table 10, most of the pre-overlay measurements were taken in hotter conditions by as much as 30 to 40°F. Tire/pavement noise is widely reported to decrease with increasing temperature[19, 20 ,21]. In the recently completed NCHRP Project 1-44-1 study, OBSI tire/pavement noise levels were found to decrease with temperature at an average rate of about 0.04 dB/°F for a range of ten pavement types[14]. From the QP3, Sites 3B and 3C were reported to show similar gradients ranging from -0.03 dB/°F to -0.09 dB/°F[22]. Using the average gradient of -0.06/°F from the QP3 results, the difference in the Site 2 reductions for the data taken when the pre-overlay temperatures were 30 to 40°F higher would be 1.8 to 2.4 dB lower than if the pre- and post-overlay measurements were completed at the same temperature. Noise reduction versus the difference in temperature between the pre- and post-overlay measurements in is shown in Figure 13. This plot shows only a very slight trend for noise reductions being smaller for greater temperature differences and the correlation is poor as indicated by the coefficient of determination of 0.03.

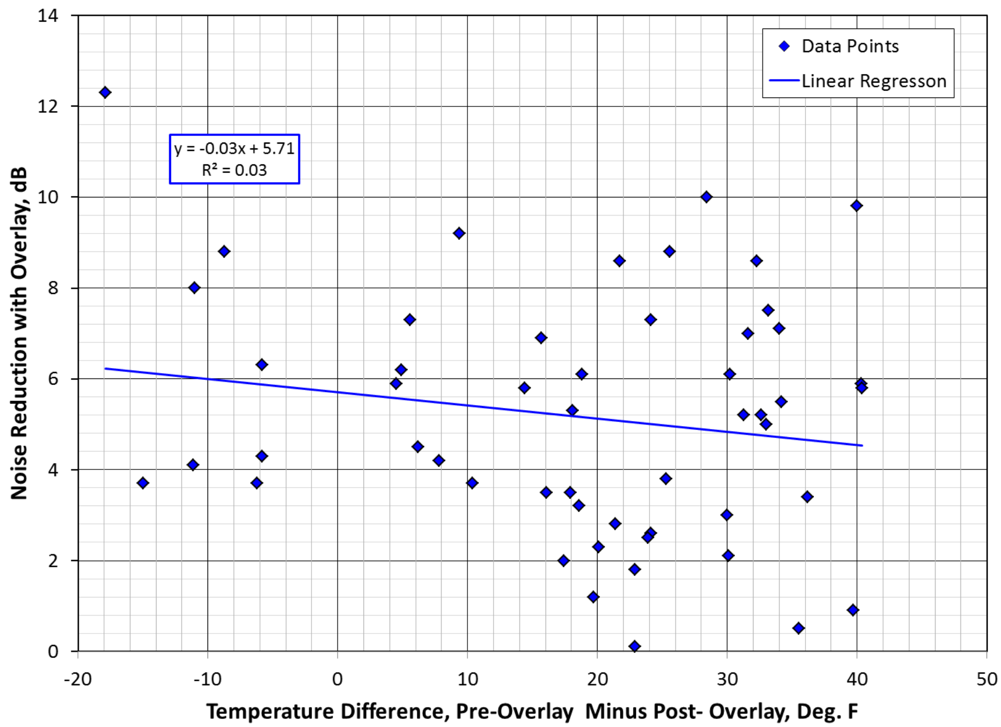


Figure 13: Linear regression of pre- and post-overlay measurement temperature differences for Site 2 locations versus noise reduction

The results of the Site 2 measurements were also compared to the Site 3 data to examine the role of Site 2 geometries on the indicated reductions. The Site 3 measurement locations were selected to provide relatively ideal measurement conditions: flat terrain and no obstructed view of the freeway. Assuming relatively equivalent traffic conditions, the levels from these Site 3 pre- and post-overlay measurements should provide an upper bound of noise level versus distance for comparison to the Site 2 results at various distances. The difference between the pre- and post-overlay Site 3 levels as function of distance should also provide a reference for the Site 2 reductions that should be independent of traffic. The levels from the five Site 3 locations were averaged together for similar distances and results of the pre- and post-overlay data are shown in Figure 14. A logarithmic regression of the levels for the pre-overlay average provides a fall-off rate of about 5.7 dB per doubling of distance (DD) which is closer to the theoretical fall-off rate of 6 dB/DD for a point noise source than it is to the 3 dB/DD for a line source. For the post-overlay ARFC, the fall-off is only slightly less at 5.3 dB/DD. The coefficients of determination in both cases are also very nearly 1.

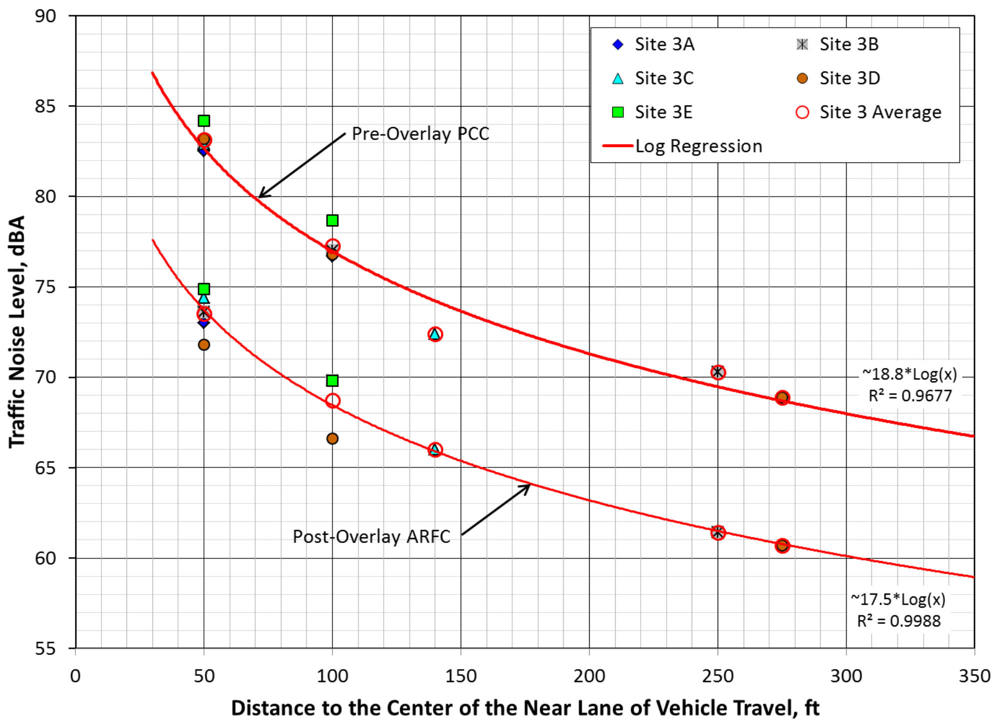


Figure 14: Logarithmic regression of pre- and post-overlay wayside levels versus distance from the roadway for Site 3 measurement locations

The measured Site 3 trend lines are compared to the Site 2 levels as a function of distance in Figure 15 for the pre-overlay data. It is seen that all of the measured Site 2 levels fall below the Site 3 averages by 1 to 16 dB with the average being 7.9 dB. This implies that if there are additional sources of noise at the specific Site 2 locations, the levels that they produce are less than those generated by the adjacent freeway prior to the overlay. These data also imply that there is additional attenuation at most of the sites beyond that expected for the open field conditions of the Site 3 measurements.

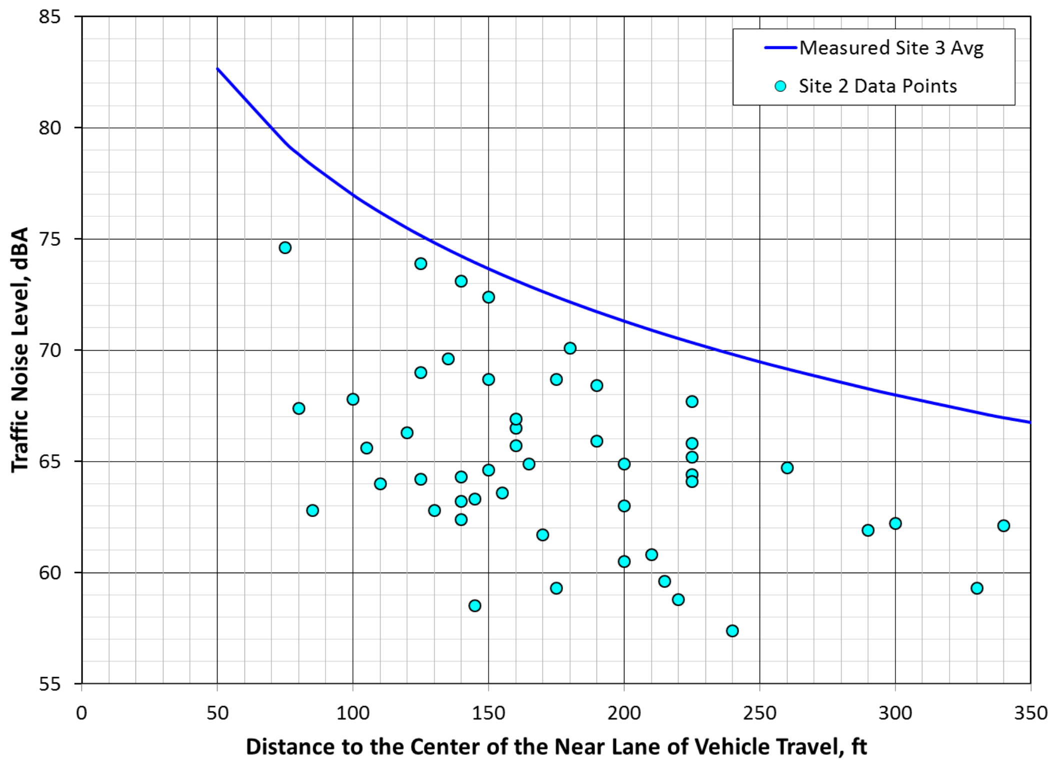


Figure 15: Site 2 pre-overlay noise levels compared to Site 3 average pre-overlay levels as a function of distance from the roadway

Comparison of the Site 3 averages to the Site 2 post-overlay noise levels is shown in Figure 16. In this case, seven of the Site 2 levels are actually higher than the Site 3 levels by about 1 to 3 dB with one data point 6 dB greater. For six out of seven of these data points, the reduction with the ARFC is small, between ½ to 3½ dB, compared to about 8 dB for the Site 3 results. In principle, it is not possible for the Site 2 post-overlay measurements to be greater than those of the Site 3 averages except for some uncertainty in Site 3 averages, the contribution of noise sources other than the freeway alone in the Site 2 data, or unaccounted traffic differences between the Site 2 pre- and post-overlay measurements. The Site 3 averages developed in Figure 14 can also be used to generate a comparison between the Site 2 and Site 3 noise reductions. The post-overlay level averages from Figure 14 were subtracted from the pre-overlay results to determine Site 3 noise reduction as a function of distance from the freeway.

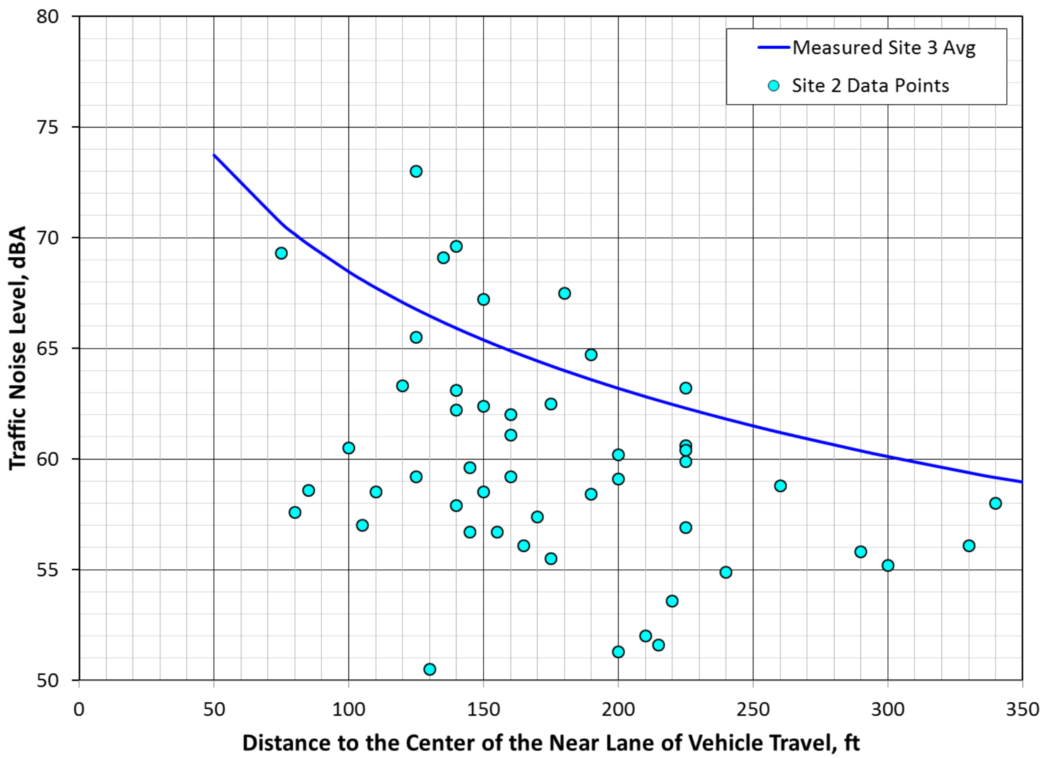


Figure 16: Site 2 post-overlay noise levels compared to Site 3 average post-overlay levels as a function of distance from the roadway

In Figure 17, the average Site 3 noise reductions are compared to those of the Site 2 measurements. This plot re-enforces the observation that the noise reductions determined in the Site 2 measurements are typically lower than the Site 3 results. Within about 2 dB, the Site 2 reductions are similar or lower than the Site 3 averages with the exception of a single data point indicating a reduction slightly greater than 12 dB. This point is identified as location 53 in Table 10 and is one of the few elevated freeway data points. This data point was also measured when the temperature in the post-overly condition was about 18°F lower than the pre-overlay condition which could contribute to the noise reduction being higher (see Figure 13).

The initial evaluations of this subsection provide little substantive information on why the Site 2 noise reductions are lower than those of Site 1 and 3 and why there is a large scatter in the Site 2 results. The intent was to determine if any one (or more) parameters correlated with the Site 2 noise reductions in order to normalize, or at least understand, the lower values. However, the Site 2 noise reductions were not found to be a function of the pre-overlay noise levels (i.e. lower levels could have produced lower reductions due to masking), nor to be a function of distance to the freeway, intervening barrier height, amount of freeway recess, or temperature; although temperature could still be factor. There was an indication that the presence of frontage roads may be a factor in producing lower reductions. Comparison of the individual Site 2 results to the Site 3 averages did show that the Site 2 pre-overlay levels were below those for flat, unobstructed sites indicating some additional location-specific attenuations for the Site 2 locations. The post-overlay levels were also generally lower than the Site 3 averages indicating that additional attenuations are affecting these data also.

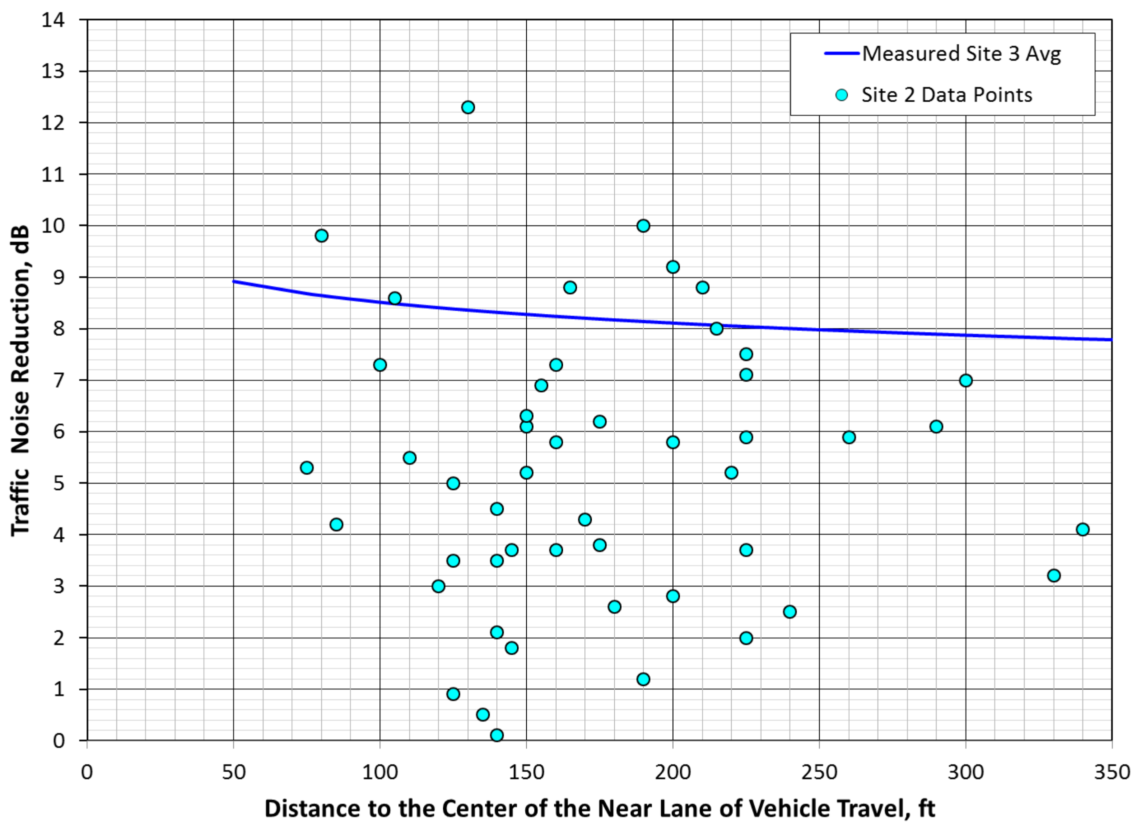


Figure 17: Site 2 noise reductions compared to Site 3 average noise reductions as a function of distance from the roadway

Analysis Using TNM

As discussed earlier in this section, any existing TNM models of the Site 2 locations were not available for this analysis. Constructing individual, new TNM models for each site was beyond the scope of what could be accomplished in this investigation. However, more generic TNM models that could be tailored to reflect different classes of site geometry were constructed. Upon review of the aerial photographs from the original Site 2 study and those from Google Earth, it was found that the roadway geometries were basically the same in the areas around the Site 2 measurement locations. At the time of the Site 2 measurements, the freeways were typically 3 lanes in each direction with a large median in between. Since the time of the Site 2 measurements, in most cases, one inner HOV lane has been added in each direction with a median barrier separating them as shown on current Google Earth aerial photographs. A geometry typical of the older configuration was chosen for TNM analysis which consisted of three

12 ft wide lanes in each direction separated by a 48 ft wide median and with 20 ft wide shoulder/clear areas in either direction adjacent to the outside lanes. Based on the traffic data from the Site 2 measurements, a typical traffic condition was developed with 8,000 vehicles per hour at 65 mph, 3% medium truck, and 2% heavy trucks. A lane distribution was assumed with 50% of the medium trucks in lanes 2 and 3; 67% of the heavy trucks in lane 3 with the other 33% in lane 2; and 20% of the light vehicles in lane 3 with the rest equally distributed in lanes 1 and 2. The intent of this model was not to accurately reproduce the measured levels but rather to evaluate the differences in predicted levels between flat, open sites (Site 3 locations) and groupings of the Site 2 geometries. Since the same roadway geometry, traffic conditions and distributions were used in all cases, the relative differences between the sites are not expected to be very dependent on these parameters.

To conduct these evaluations, a modified version of TNM was used that was developed by the US DOT Volpe Center as part of the FHWA Pavement Effects Implementation Study[23]. In TNM, vehicle noise is represented by a vertical distribution of two sources, one at ground height to represent tire/pavement noise, and one at a height of either 5 ft above the ground for light vehicles and medium duty trucks or one at 12 ft above the ground for heavy duty trucks. In the modified version of TNM, the ground level source strength (GLSS) is scaled by using actual OBSI data so that effects of pavement on vehicle emissions can be taken into account in the predicted traffic noise levels. This approach was more fully developed in the NCHRP Project 10-76 by expanding the database of OBSI levels to include the ASTM Standard Reference Test Tire (SRTT), which is currently specified in the AASHTO TP 10-76 OBSI test procedure[10]. The expanded data base improved the accuracy of the GLSS scaling factors. Using this modified version of TNM, the effect of different pavements can be predicted as well as combinations of quieter pavement, noise barriers, and site geometries. For application to the QP3, representative OBSI spectra were selected for new ARFC and the pre-overlay uniform transverse tine PCC as shown in Figure 18. These data correspond to a reduction of 9.8 dB which is typical of the higher reductions measured in the Site 1 data (see Figure 4).

Application of the GLSS Modified TNM

Using the GLSS modified TNM, the flat terrain case can be compared to the Site 3 averages (from Figure 14) as a function of distance as shown in Figure 19 for PCC and ARFC OBSI levels. Even with a soft ground option, the sound level fall-off with distance is less for the TNM predictions (4.3 and 4.5 dB/DD) than for the measured data (5.3 and 5.7 dB/DD). At 50 ft, the measured Site 3 noise reduction is 9.0 dB, the TNM prediction is 7.6 dB and the OBSI reduction is 9.8 dB. The under prediction of noise reduction by the GLSS modified TNM was also found in the NCHRP Project 10-76 and was thought to be due the distribution of the strength between the ground level and elevated sources used in TNM[13]. Despite the differences in fall-off rates between the measured and predicted noise levels, the differences between the pre- and post-overlay levels are fairly consistent for both as a function of distance.

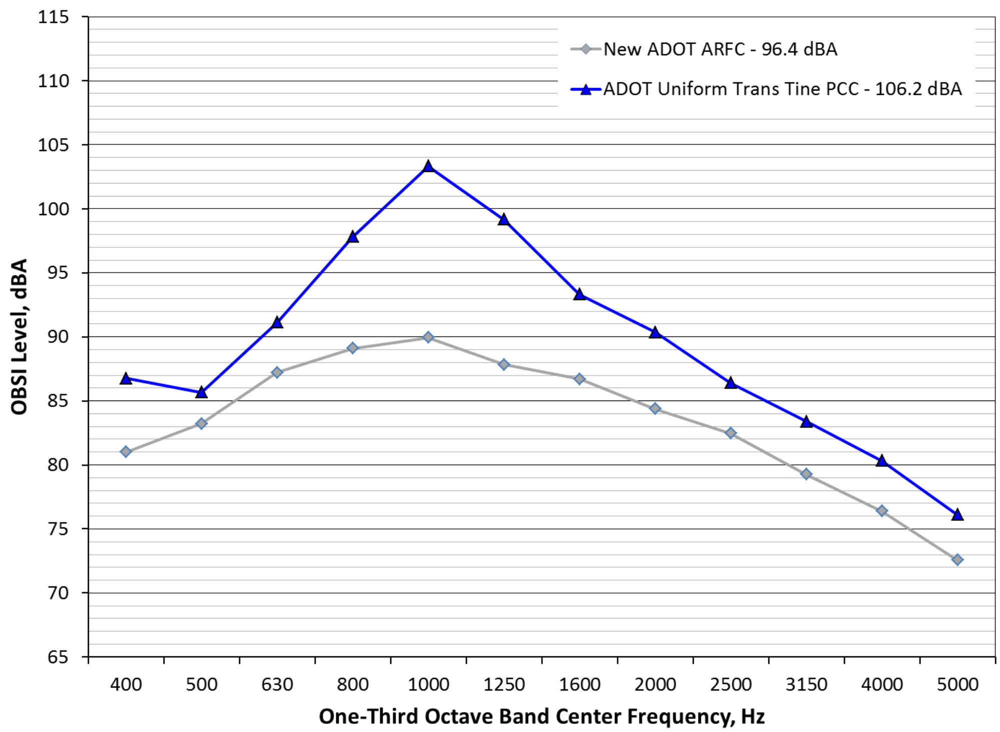


Figure 18: OBSI spectra representing pre-overlay uniform transversely tined PCC and post-overlay ARFC for use in the GLSS modified TNM

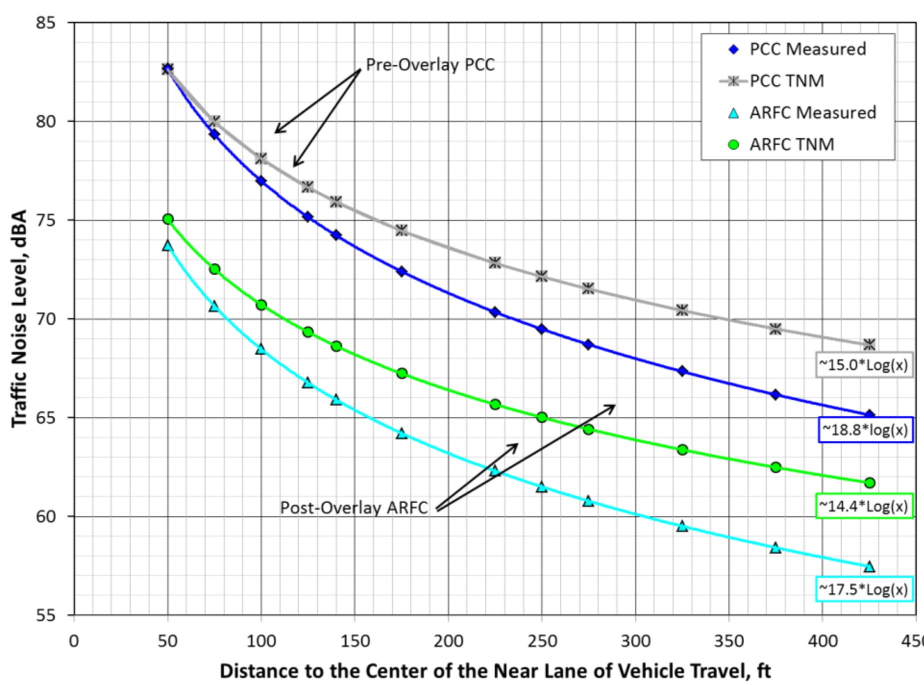


Figure 19: Comparison of measured and predicted Site 3 wayside levels pre- and post-overlay as a function of distance from the roadway

The noise reduction changes due to the ARFC overlay as determined by the Site 3 measurements and TNM for flat, open sites are shown in Figure 20. This plot indicates a relatively constant offset of about 1 dB between the measured and predicted noise reductions with distance. Allowing for this “calibration” factor, the noise reductions at the Site 2 locations should be adequately modeled using GLSS modified TNM results corresponding to transverse tined PCC and ARFC OBSI data.

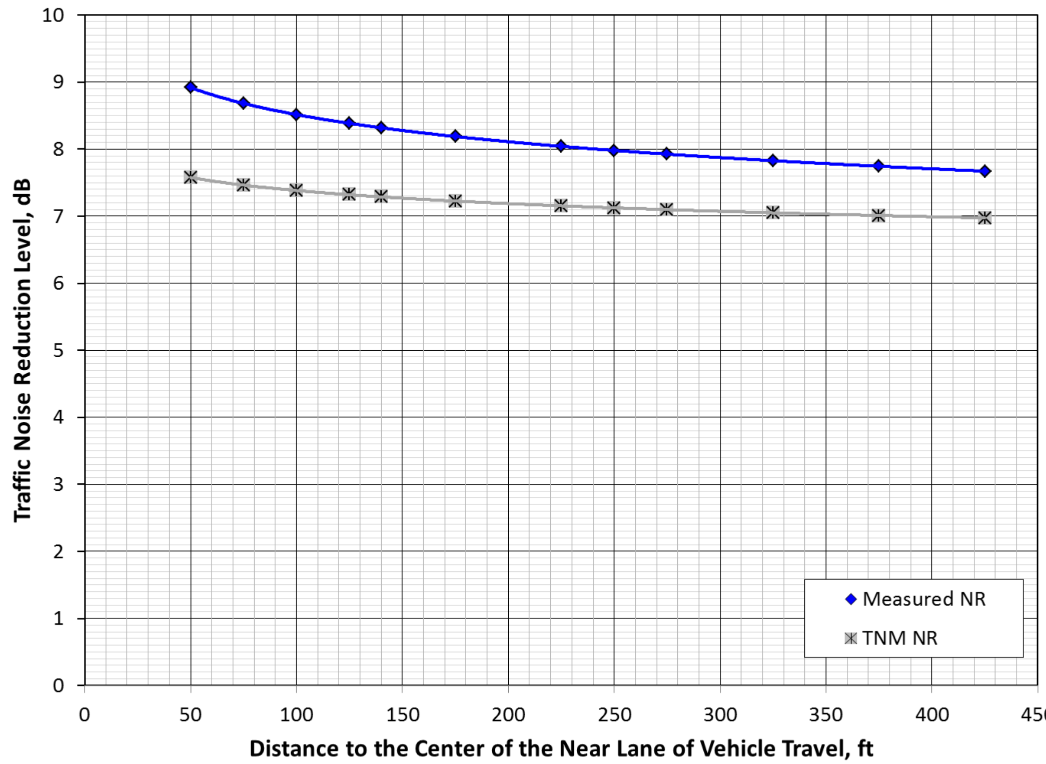


Figure 20: Comparison of measured and predicted Site 3 wayside level noise reductions as a function of distance from the roadway

Using the above roadway geometry, 13 site geometries were modeled to represent the Site 2 measurement locations shown in Table 10. These fell into three groupings; flat terrain, recessed highway, and elevated highway. From Table 10, most of the Site 2 locations were near recessed roadways. Within this grouping, the amount of recess was split into two subgroupings; 6 and 12 ft. In the 12 ft recess subgrouping, barrier heights were split into further subgroupings of no barrier, barriers 8 ft high, or barriers 12 ft high based on the ranges of barrier height in Table 10. For each barrier height, several distances between the barrier and the edge of the roadway were selected based on the ranges found in Table 10. Similar methods of grouping were applied for the flat terrain and elevated roadway cases and are presented in Table 11, along with the recessed roadway cases. For each case in Table 11, receiver locations were analyzed at distances of 75 to 425 ft from the center of the near lane of travel in 50 ft increments. The model was run for the PCC and ARFC cases and the noise reduction due to the pavement change was determined at each location. From TNM, each calculation point generates a level with and without a barrier.

Table 11: Groupings, features, and parameters for TNM analysis of Site 2 results

Site Configuration	Feature Depth/Height	Barrier Geometry	
		Height	Distance from near Lane
Flat	0	0	-
		12 ft	40, 110, & 180 ft
		3 ft K-Rail	20 ft
Recessed	6 ft	0	-
		12 ft	53,100, & 160 ft
	12 ft	0	-
		8 ft	70 & 120 ft
		12 ft	70, 110, & 150 ft
Elevated	4 ft	0	-
		3 ft K-Rail	20 ft

For the recessed cases, there is also a noise reduction due to the barrier effect of the recess aside from the reduction produced by an installed noise barrier. This site effect noise reduction can be determined by subtracting the flat, open TNM predictions for PCC from those for the recessed geometries.

Predicted noise levels for a 12 ft recessed freeway with a noise barrier 70 ft from the roadway are shown in Figure 21 as an example. The highest predicted levels occur for an open site with the pre-overlay PCC. The next highest levels (still with PCC) show the effects of the recess. The recess provides virtually no reduction near the roadway as there is unobstructed line-of-sight to the traffic. Noise reduction increases at more distant receiver locations as the recess obscures the roadway. When the noise barrier is taken into account, the next lowest levels are produced. In this case, the noise barrier provides substantial reduction near the freeway as the line-of-sight is totally blocked. Finally, the effects of the ARFC overlay are included, and additional noise reductions of about 3 dB are seen with the new pavement. For a Site 2 location corresponding to this geometry with a 12 ft barrier, the application of ARFC would only provide the final 3 dB of reduction as determined by a corresponding Site 2 measurement.

For comparison, the predicted levels for a flat site with a 12 ft high barrier 110 ft from the roadway are shown in Figure 22. In this case the site effect is small compared to the open case. Just behind the barrier at 125 ft from the roadway, the reduction is large, about 13 dB. At farther distances from the freeway (250 to 425 ft), the reduction is smaller providing about 7 to 8 dB. When the AFRC is applied, the levels drop another 5 dB.

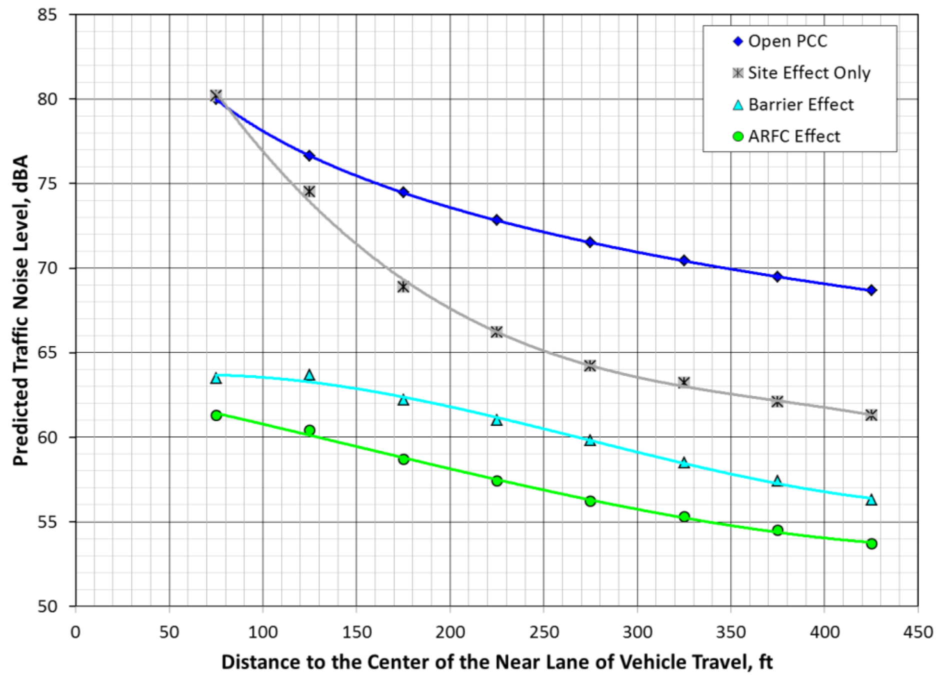


Figure 21: Example of TNM predictions for a roadway recessed 12 ft (site effect), with an added 12 ft barrier 70 ft from the roadway (barrier effect), and with ARFC added (AFRC effect)

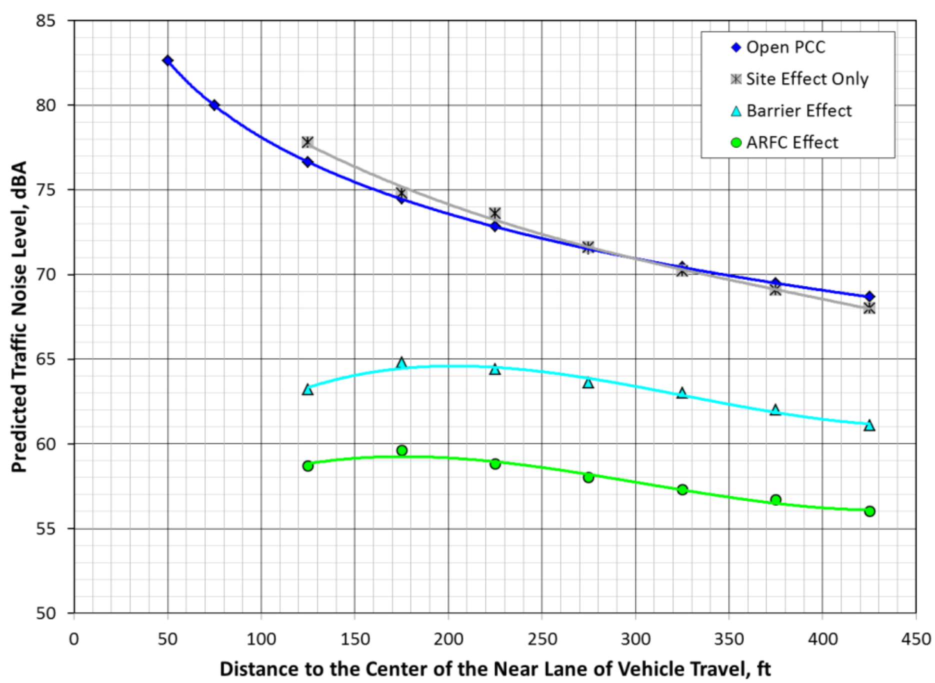


Figure 22: Example of TNM predictions for a flat roadway geometry (site effect), with an added 12 ft barrier 110 ft from the roadway (barrier effect), and with ARFC added (AFRC effect)

Results for a 4 ft elevated roadway with a K-rail at the edge of the roadway are shown in Figure 23. Again the site effects without the K-rail are similar to the open case. For this geometry, the K-rail provides a fairly constant 5 to 6 dB reduction with distance. When the ARFC is applied in this case, an additional reduction of 5 to 6 dB occurs.

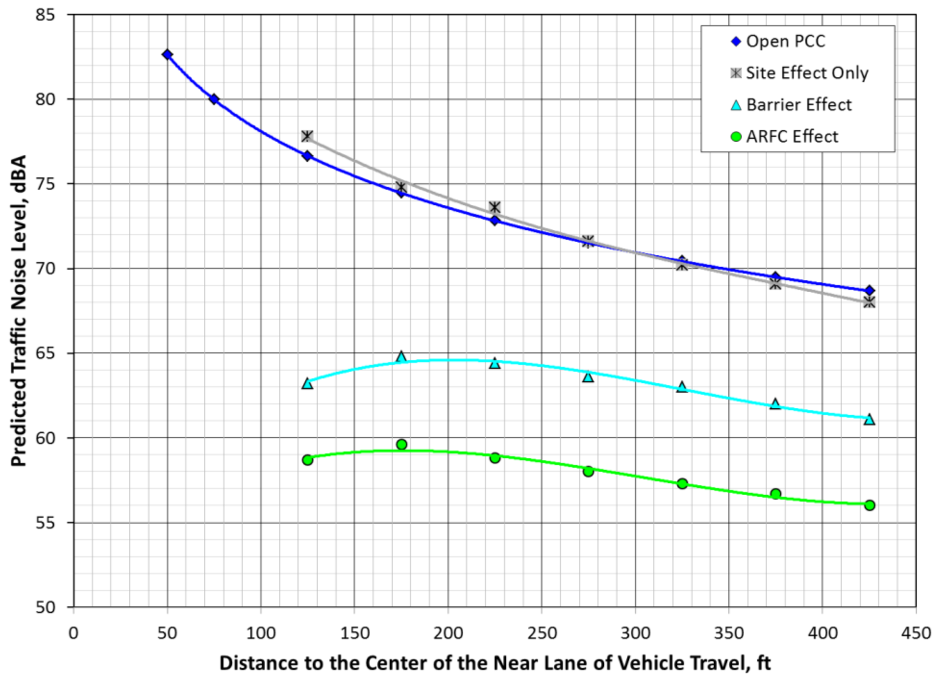


Figure 23: Example of TNM predictions for a 4 ft elevated roadway (site effect), with an added 3 ft K-rail at the edge of the roadway (barrier effect), and with ARFC added (AFRC effect)

The predicted levels for a 6 ft recessed freeway case are presented in Figure 24 for a 12 ft high barrier, 100 ft away from the roadway. The results are somewhat similar to the 12 ft recess case except that with the shallower recess, the line of line-of-sight to the roadway becomes obscured farther at greater distance. In this case, the application of the ARFC reduces the levels behind the barrier by about 5 dB.

The results of Figures 21 through 24 can also be represented as noise reductions. Using the predicted noise levels as shown in Figure 24, noise reductions can be calculated for the sequential effects of the recess alone, the addition of the 12 ft sound wall, and the application of ARFC as shown in Figure 25. To simplify the application of the model results for different barrier and recess distances from the roadway, the noise reductions at each distance (50 to 425 ft) were averaged together to produce a single curve for the recess and barrier. This was done for all of the cases shown in Table 11 where the barrier distances varied. These averaged data points were fit with a second or third order curve so that the ARFC noise reduction at any receiver location could be readily estimated using the site data from Table 10. The use of this averaging process introduces some uncertainty in the ARFC noise reductions as the exact geometries for each Site 2 location are not used (e.g. barrier height); however, this is consistent with the imprecise knowledge of each Site 2 location. Using plots such as Figure 25, the noise reduction produced at individual sites by the application of ARFC could be estimated even for those sites already receiving noise reduction from existing barriers and/or freeway recesses.

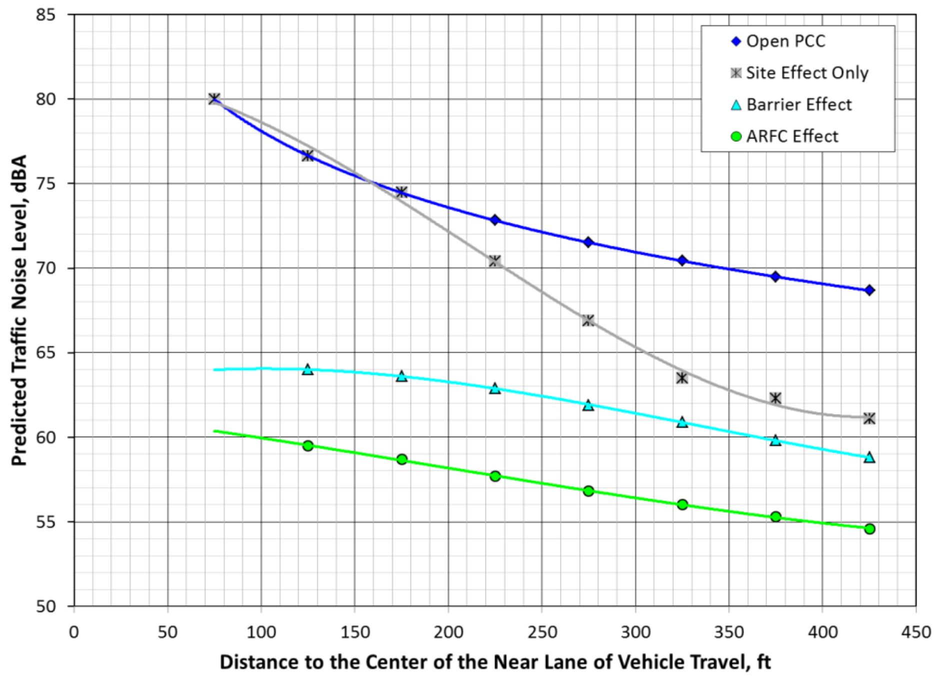


Figure 24: Example of TNM predictions for a roadway recessed 6 ft (site effect), with an added 12 ft barrier 100 ft from the roadway (barrier effect), and with ARFC added (AFRC effect)

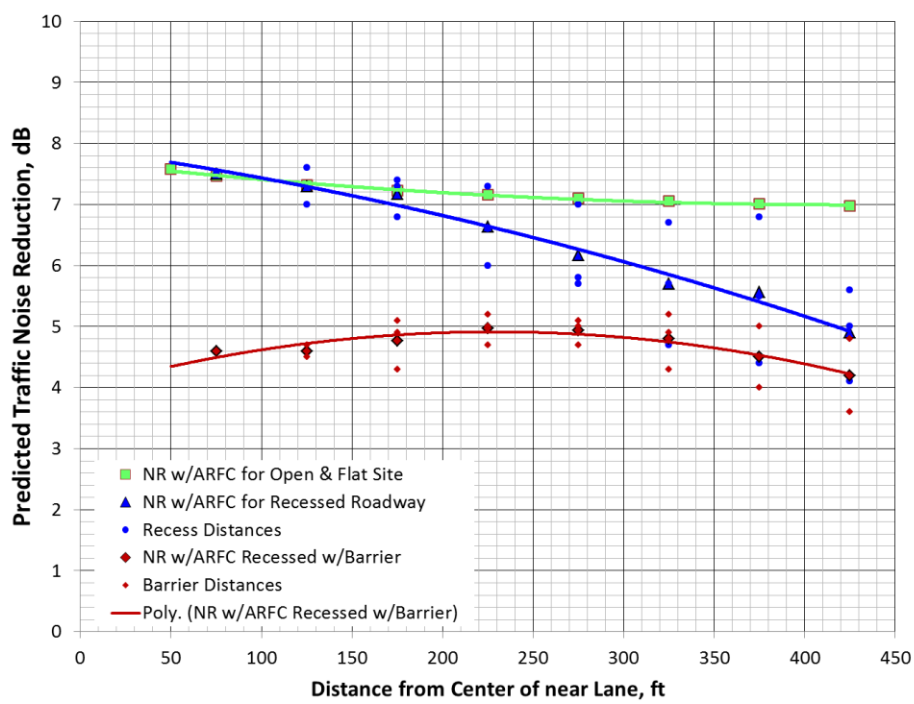


Figure 25: Incremental noise reduction for ARFC added to a flat site, a 6 ft recessed site, and a recessed site with a 12 ft barrier

Implications of TNM Results for Site 2 Data

The noise reductions predicted to occur with the ARFC overlay for each of the 52 Site 2 locations used in this analysis are shown in Figure 26, along with a logarithmic curve fit through the data points. The average reductions as a function of receiver distance measured for the Site 3 locations are also shown.

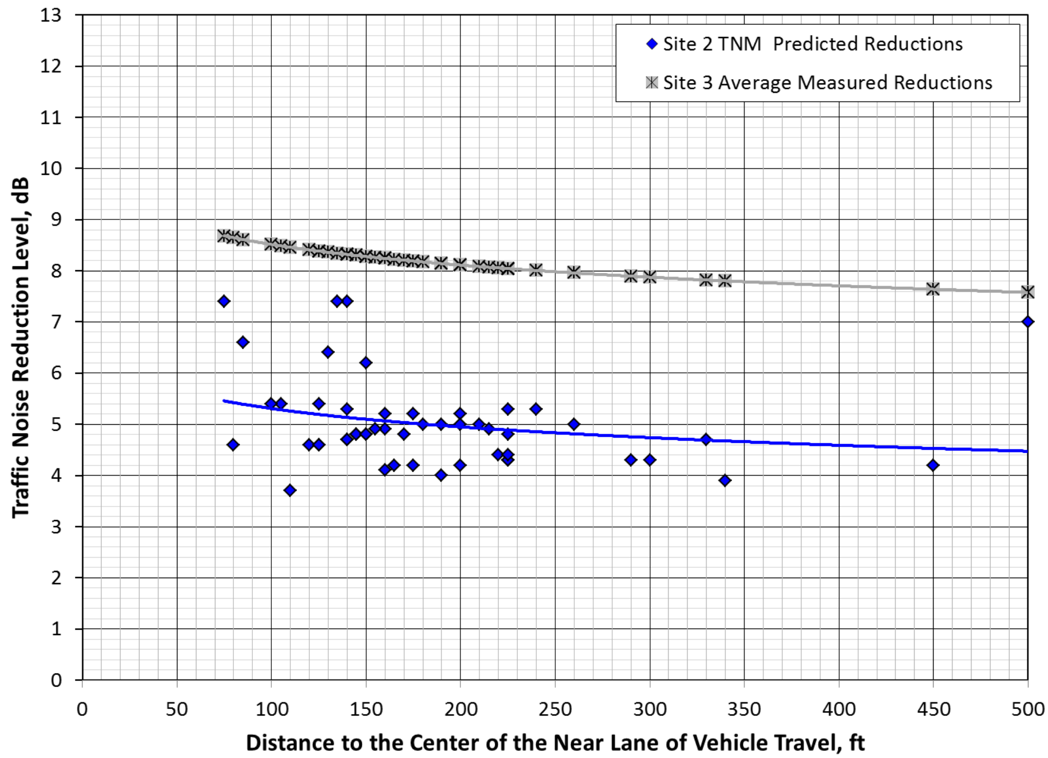


Figure 26: Predicted noise reductions for the Site 2 locations with logarithmic regression compared to the average noise reduction from the Site 3 measurements

Based on this analysis, the Site 2 reductions should fall below that for the flat, open Site 3 locations which receive reduction only through the application of the ARFC and not through other noise-reducing features such as noise barriers or recessed roadways. Of the 52 Site 2 locations, only four correspond to the flat, open Site 3 locations. These four sites are also the only sites without some type of barrier. In Figure 26, the noise reductions for these four sites are those that are 7 dB or greater. The reductions for these four sites are similar to those of Figure 20. The three noise reductions produced by the ARFC that fall between 6 and 7 dB in Figure 26 have K-rails near the roadway and are either elevated roadways or flat sites. These cases are represented in the Figure 22 by those reductions falling into a range of 4.4 to 6.9 dB. All the other noise reductions in Figure 26 correspond to measurement locations where existing barriers occur. Of these, 32 have recessed roadways for which the noise reduction produced by the ARFC ranges from 3.7 to 5.5 dB. The remaining 16 locations are either flat terrain or elevated roadway with barriers for which the predicted reductions with the ARFC range from about 4.4 to 5.7 dB. The curve through the predicted Site 2 reductions parallels the Site 3 curve with an offset of 3.1 to 3.2 dB.

Adding this offset to the Site 2 average bar in Figure 2 brings the reductions for all three Site measurements within less than 1 dB of each other.

The results of Figure 26 provide a reasonable basis for the Site 2 measurements yielding a lower average noise reduction than the Site 1 and 3 reductions. However, the TNM results do not account for variance in individual points or the large scatter in the measured Site 2 reductions. In Figure 27, the measured Site 2 reductions are plotted versus distance along with the curve defined by these data points and the curve for Site 3 averages.

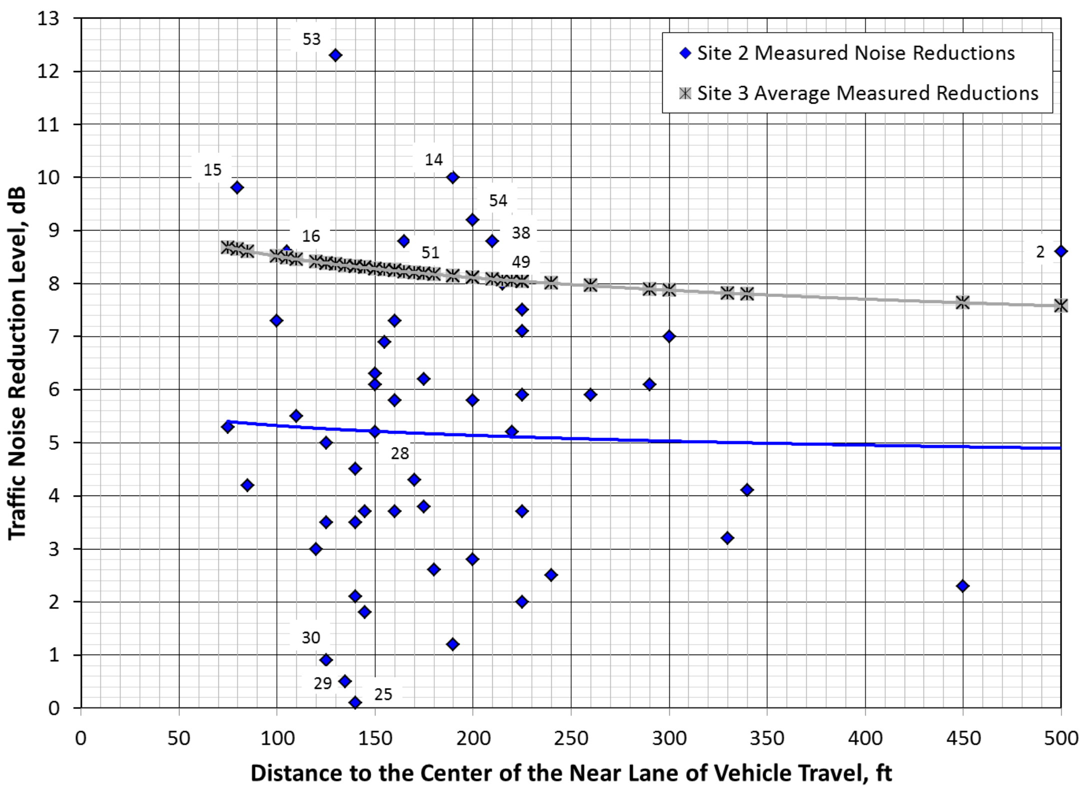


Figure 27: Measured noise reductions for the Site 2 locations with logarithmic regression compared to the average noise reduction from the Site 3 measurements

These reductions display a range of 0.1 to 12.3 dB compared to 3.7 to 7.4 for the TNM predicted reductions. For the measured Site 2 reductions, the average deviation from their regression curve is 2.2 dB. For the predicted reductions of Figure 26, the average deviation is only 0.6 dB. Although there is a large scatter in the measured reductions, the average, as represented by the logarithmic curve fit, is almost identical to (within 0.4 dB) that of the TNM predicted noise reductions of Figure 26. This supports the conclusion that difference in the average noise reductions for the Site 3 and Site 1 results compared to Site 2 is to be expected and is due to noise reducing features already present at most of the Site 2 measurement locations prior to the ARFC overlay.

Scatter in the Site 2 Results

Although the average of the noise reductions from the Site 2 measurements is consistent with that predicted by the GLSS modified TNM, it is instructive to explore potential causes for the increased scatter of the measured Site 2 results. In comparison to the TNM predictions, the data points at the extremes of high and low noise reduction can be considered in more detail. As shown in Figure 27, nine data points exceed the Site 3 average post-overlay curve which could be considered as an upper bound on the noise reduction due to the pavement change only. These nine points are Site 2 locations identified in Figure 27 as sites 2, 14, 15, 16, 38, 49, 51, 53, and 54 (see Table 10). In Figure 28, the curve fit for the post-overlay levels at the Site 3 locations is shown arbitrarily lowered from the actual average by 9 dB in order to identify data points that are particularly low compared to the expected level.

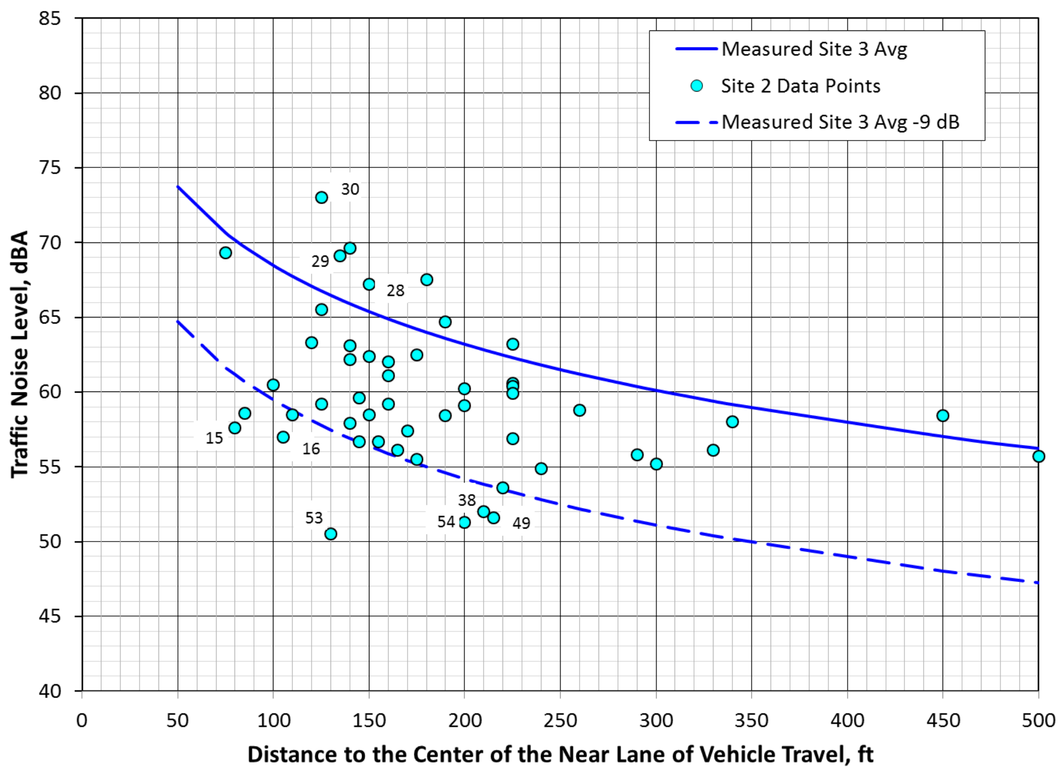


Figure 28: Site 2 post-overlay noise levels compared to the measured Site 3 averages and to the Site 3 averages offset 9 dB lower

Of the 7 data points below -9 dB curve, 6 correspond to the 9 sites identified in Figure 27 with high noise reductions and one (site 51) is on the -9 dB curve. Reviewing the site information compiled in Table 10, there does not appear to be any consistent factors to indicate why these levels are low compared to other levels. These sites include some that are recessed and some that are flat or elevated. Some have barriers and some do not. Some have frontage roads or nearby arterial streets and some do not. For some, the differences in temperature between the pre- and post-overlay measurements are large and positive, and some are negative. More extensive information on each site is given in Appendix B; however, these provide no additional insight on why these sites should be lower.

Two of the 9 points identified in Figure 27 did not have unusually low post-overlay levels but instead, had pre-overlay levels that were among the highest. In Figure 29, the Site 2 pre-overlay levels are shown in comparison to the Site 3 pre-overlay average level curve and to a curve offset 4 dB lower than the average.

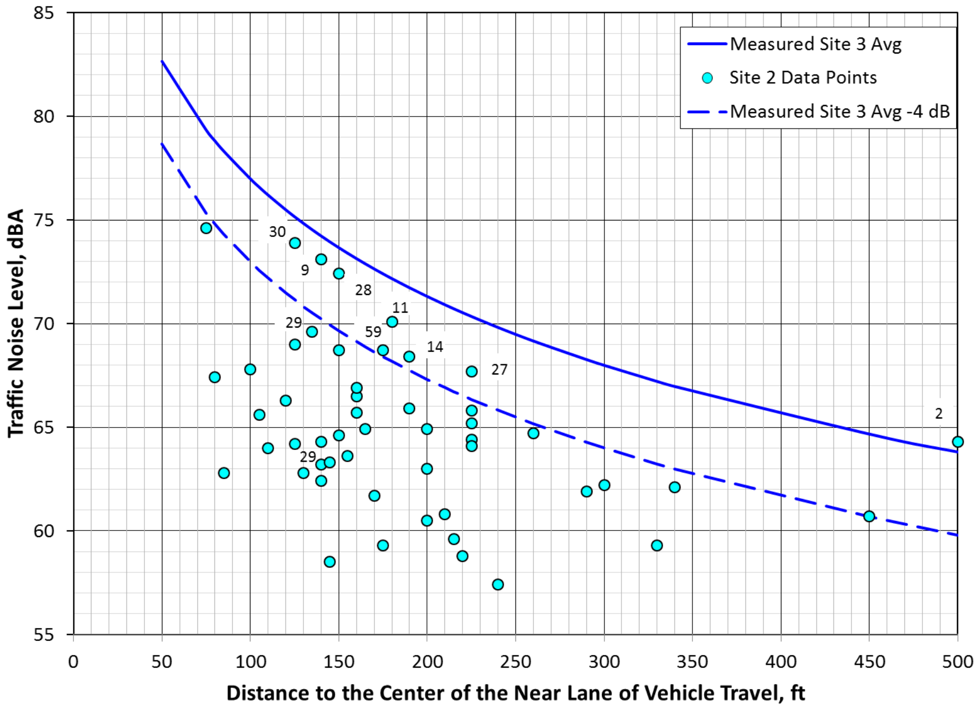


Figure 29: Site 2 pre-overlay noise levels compared to the measured Site 3 averages and to the Site 3 averages offset 4 dB lower

Eight data points fall above the offset curve. Two of these points (2 and 14) are among those that displayed high noise reductions in Figure 27. However, the other 6 data points above the -4 dB offset curve did not display unusually high Site 2 noise reductions. There is also a mixture of site features for these 8 data points. For locations 2 and 14, one is flat and open with no barrier, and the other is recessed with a barrier. Also, one has a nearby arterial street and the other does not. The remaining 6 locations indicating elevated pre-overlay levels are also a mixture of barrier and no barrier locations and of flat, elevated, and recessed geometries.

In addition to the locations that were identified because they had unusually low post-overlay levels or unusually high pre-overlay levels, other locations also have issues that cannot be easily reconciled. As an example, locations 9 and 28 from Figure 29 had levels of 73.1 dBA and 72.4 dBA, respectively, and are within 1½ dB of the Site 3 pre-overlay levels (see Figure 29). As pictured in Figure 30, location 9 (A9) is open and flat and similar to the Site 3 geometries and the level is expected to be and is close to the Site 3 results. As shown in Figure 31, location 28 (C10) is also open flat, but is behind a 10 ft barrier and should show levels at least 5 dB lower than the non-barrier location 9 as there is no line-of-sight to the freeway.

Figure 30: Photograph of Site 2 measurement location 9 (101 A9)

Figure 31: Photograph of Site 2 measurement location site 28 (101 C8)

The traffic volume for location 28 is about 28.5% greater than location 9 and could account for about 1 dB of the difference between the locations. After the overlay, the open location 9 was reduced by only 3.5 dB, about 4.5 dB less than what was measured at the similar Site 3 locations. For location 28, the reduction was 5.2 dB which is the same as predicted by the TNM analysis. Locations 9 and 28 both have frontage roads and differences in traffic on these could be a factor in the elevated pre-overlay levels for location 28 and elevated post-overlay levels at location 9.

Other examples of inconsistency in the Site 2 data are also apparent when some locations are considered in detail. Location 29 is indicated in Figure 27 as one where the measured noise reduction is far less than expected. Shown in Figure 32, location 29 (C9) is virtually identical to location 9 (Figure 30). However, the pre-overlay levels are 69.6 dB or 3.5 dB lower than location 9 even though the traffic volume at location 29 was 18% greater. The reduction at location 29 was only 0.5 dB, which is virtually impossible given the unobstructed view of the freeway and the known reduction in tire/pavement noise.

Figure 32: Photograph of Site 2 measurement location 29 (101 C9)

Location 30 is also identified in Figure 27 as a location with lower than expected noise reduction. A photograph of location 30 is shown in Figure 33 and it is similar to location 28 (see Figure 30). Both locations are shielded by barriers with measurement locations at about the same distance from the freeway and barrier.

Figure 33: Photograph of Site 2 measurement location 30 (101 C10)

The initial level at location 30 was 73.9 dBA and is also indicated to be one of the higher pre-overlay data points (see Figure 27). The pre-overlay level at location 30 is 1.5 dB higher than location 28 even though the traffic volume is 64% lower. After the overlay, the reduction is 4 dB greater at location 28 than at location 30. In comparison to locations without barriers (i.e. location 9 and 29 and the Site 3 averages), the level measured at site 30 with a barrier should be at least 5 dB lower than the no barrier locations, but instead, it is higher than locations 9 or 29. The post-overlay measurement is equally inconsistent showing a reduction of only 0.9 dB from the original PCC pavement which again is one of the lowest identified in Figure 27. In this case, it may be that the measurements in both the pre- and post-overlay conditions are influenced by traffic on the frontage road.

As discussed in Section II, a second set of post-overlay Site 2 measurements were made in 2007. The noise levels measured in both sessions are cross-plotted in Figure 34 with a linear regression and the 1-to-1 line shown. As with the original set of Site 2 noise reductions, these data also display considerable scatter with some 2nd post measurements being 1 to as much as 5½ dB higher than the 1st measurements and some being 2 to 7 dB lower. However, the average of the differences is 0 dB. As with the noise reductions of Figure 27, it appears that though there is scatter in the individual values, the average produces a more expected result.

The above examples indicate that there are inconsistencies in Site 2 results that cannot be explained with the available information. As a result, it is more productive to compare averages of the Site 2 to the Site 1 and 3 results rather than to compare individual data points.

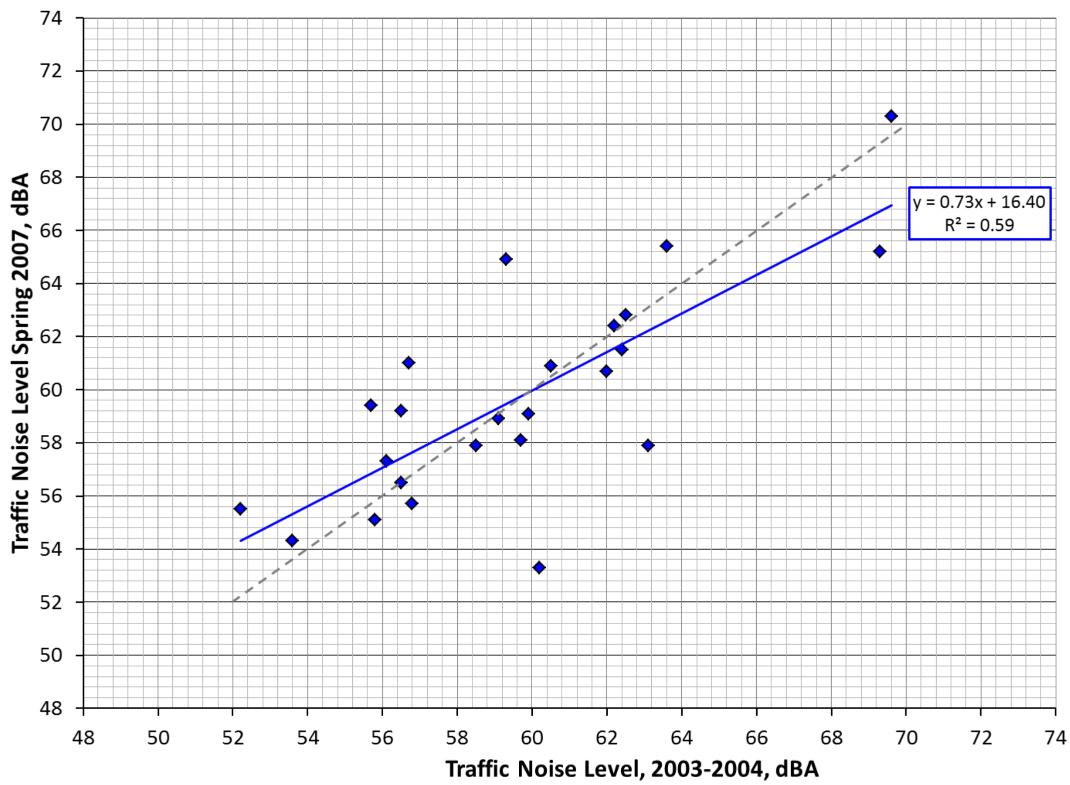


Figure 34: Post-overlay noise levels measured at same Site 2 locations in 2003-2004 and 2007

V. CONCLUSIONS OF 2013 DRAFT REPORT (APPENDIX F)

Given the available Site 1, Site 2, and Site 3 data, definitive correlation is problematic. The measurements were not made at the same time and in some cases were separated up to a year. Since the performance of the pavement has been found to change with time, the noise reduction measured shortly after the overlay was applied will likely be larger than that measured at a later date. There is also missing data or data that was not sufficiently documented. However, by using averages of Site 1, 2, and 3 data, there is sufficient information to draw some conclusions. The Site 1 and Site 3 average noise reduction results compare quite well and are within less than 1 dB of each other for wayside microphone locations within 50 ft of the freeway. Comparison of the available Site 1 and Site 3 noise reduction spectra also compared well leading to a general conclusion that these two data sets "correlate". For the Site 2 results, the average reduction produced by the ARFC overlay was only slightly greater than 5 dB, 3 to 4 dB lower than that for the Site 1 and Site 3 results, respectively. Initial examination of the Site 2 results indicated that the discrepancy between these and the Site 1 and 3 results was not consistently related to individual parameters such as distance from freeway, intervening barriers, highway recesses, differences in the pre-overlay measurements, temperature, or the presence of arterial streets. Some dependence on the occurrence of frontage roads was found, however, with the noise reductions being about 1½ dB lower on average when there was an intervening frontage road. This effect was not sufficient to explain why the Site 2 reductions were consistently lower than Sites 1 or 3.

By reviewing the individual locations of the Site 2 measurements, it was found out of that of 52 locations analyzed in detail, only four locations were open and flat like the Site 3 locations. In the other Site 2 locations, features such as existing noise walls, recessed highway geometries, or shoulder K-rails were present that provided some initial noise reduction that was not present in the Site 3 locations. To systematically explore what effect these existing noise reducing features had on the measured Site 2 noise reductions, a version of TNM that accounts for differences in tire-pavement noise source levels was used to predict the expected noise reductions. Using Site 1 OBSI data from the QP3 and the characteristics of the Site 2 measurement locations, it was found that the predicted Site 2 noise reductions averaged about 5 dB which is consistent with the measured reductions. In this sense, Site 2 and Site 1 do "correlate" and this correlation extends to the Site 3 results through the Site 1 to 3 correlations noted above. For reference, reductions due to the quieter pavement of 7 to 8 dB were predicted by TNM for flat, unobstructed locations similar to the noise reductions measured at the Site 3 locations.

The analysis of the Site 1, 2, and 3 indicates the utility of measuring all three types of data when assessing the effect of pavement changes on noise. Comparison of the Site 1 and 3 results give a direct relationship between the tire-pavement noise source strength reduction and reduction in wayside levels. The Site 2 results provide information on how the reduction in tire-pavement noise source strength is passed on to locations where additional noise reducing features are present. This analysis also demonstrates the value of using a version of TNM in which the vehicle source strength can be modified to more accurately account for pavement.

The results of the Site 2 measurements also demonstrate the effectiveness of using a quieter pavement even when there is noise reducing measures in place. On average, the pavement change produced a reduction of more than 5 dB, which would be considered to be a “feasible” reduction under the FHWA 23 CFR 772 and ADOT policy. Additionally, of the 52 Site 2 locations, 30 locations would be defined as noise impacted using the ADOT Noise Abatement Criterion (NAC) of 64 dBA even with barriers in place and reductions present due recessed roadways. After the overlay, the number of impacted receptor locations was reduced to 7. Further, 28 of the 52 locations would be classified as “benefited” receptors under ADOT policy as reductions of 5 dB or more were provided by the overlay. Of these 28 locations, 14 achieved a reduction of 7 dB or more meeting the ADOT reasonableness design goal of at least half of the benefitted receptors receiving this level of reduction.

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