National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Demonstration of Using Quieter Pavement in Death Valley National Park

Natural Resource Technical Report NPS/NSNS/NRTR—2013/759

ON THE COVER
Tire-pavement noise data collection at Death Valley National Park.
Photograph by: Judith Rochat

Demonstration of Using Quieter Pavement in Death Valley National Park

Natural Resource Technical Report NPS/NSNS/NRTR—2013/759

Judith L. Rochat and Michael Lau

U.S. Department of Transportation
Research and Innovative Technology Administration
Volpe National Transportation Systems Center
Environmental Measurement and Modeling Division
55 Broadway, RVT-41
Cambridge, MA 02142

June 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Technical Report Series is used to disseminate results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service mission. The series provides contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available from the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

Please cite this publication as:

Rochat, J .L., and M. Lau. 2013. Demonstration of using quieter pavement in Death Valley National Park. Natural Resource Technical Report NPS/NSNS/NRTR—2013/759. National Park Service, Fort Collins, Colorado.

NPS 143/121246, June 2013

NOTICE

NOTICE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE February 2013	3. REPORT TYPE AND DATES COVERED Final Report
4. TITLE AND SUBTITLE Demonstration of using quieter pavement in Death Valley National Park		5. FUNDING NUMBERS VX82/JT311 VX82/JT312
6. AUTHOR(S) Judith L. Rochat, Michael Lau		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Research and Innovative Technology Administration John A. Volpe National Transportation Systems Center Environmental Measurement and Modeling Division, RVT-41 Acoustics Facility Cambridge, MA 02142		8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-NPS-11-23
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Interior National Park Service (NPS) Natural Resource Program Center Natural Sounds Program Fort Collins, CO 80525		10. SPONSORING/MONITORING AGENCY REPORT NUMBER NPS/NSNS/NRTR—2013/759
11. SUPPLEMENTARY NOTES NPS program managers: Karen Treviño, Randy Stanley, Vicki McCusker		
12a. DISTRIBUTION/AVAILABILITY STATEMENT		12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Death Valley National Park provided an environment that allowed a demonstration of quieter pavement use. Sound measurements near the tire-pavement interface, near the road, and in areas of frequent human use were conducted and analyses performed in order to determine the general sound environment in the park and the potential benefit of using quieter pavements. Tire-pavement noise data were collected using the on-board sound intensity (OBSI) methodology, where sound levels for 15+ locations were identified. The OBSI levels for specific pavements in Death Valley were then used in a special research version of the FHWA Traffic Noise Model® (TNM®) in order to predict the potential effect of using quieter pavements at the park.

14. SUBJECT TERMS quieter pavement, national park noise, tire-pavement interaction noise, FHWA Traffic Noise Model, on-board sound intensity, OBSI			15. NUMBER OF PAGES 56
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

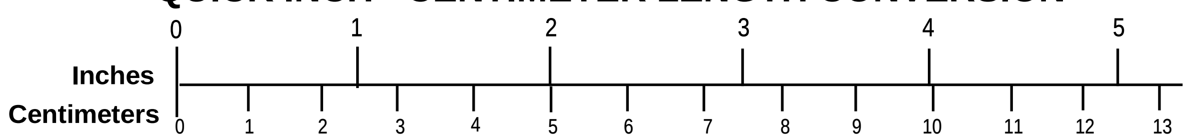
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

ACKNOWLEDGEMENTS

The authors wish to thank the National Park Service Natural Sounds Program, particularly Karen Treviño, Randy Stanley, and Vicki McCusker, for their vision and support of this study. The authors also wish to thank all the folks from the Death Valley National Park who helped our team with permitting (IAR #59112), timing, site locations, etc., including Sarah Craighead, Ainsley Holeso, Victoria Wilkins, and Mary Kruelskie. Thanks also to the Federal Highway Administration (FHWA) for allowing development of a special research version of the FHWA Traffic Noise Model® (TNM®) and for their participation in noise measurements. In addition, the authors wish to thank the other members of the data collection and analysis team for all their dedication and effort: Trevor May, Aaron Hastings, Jon Cybulski, and Adam Alexander. Lastly, the authors wish to thank Dave Read for several discussions regarding measurements in Death Valley.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Table **Page**

1. INTRODUCTION

1.1 Background

National Park Service (NPS) personnel identified several topic areas where road noise research and related products could help parks better assess, predict, and minimize road noise (including tire-pavement noise), providing best practice recommendations. Desired road noise research was also identified through work done to date for the Air Tour Management Plans (ATMPs). (The work described in this report supports the research being conducted for the ATMP Program regarding the determination of ambient sound levels in national parks [Volpe 2007]. Ambient data are used to establish a baseline from which aircraft-related noise impacts can be assessed.)

Of the topics identified, the one reported in this document is to provide improved evaluation and prediction methodologies related to the use of quieter pavements. It is known that pavement types or pavement surface treatments can affect the amount of noise created by tire-pavement interaction; for quieter pavements, the reduction in road noise when compared to louder pavements can be substantial. When applying a quieter pavement, the amount of noise reduction is very much dependent on the type and condition of the existing pavement as well as vehicle type and vehicle speed. Quieter pavements tend to provide the most benefit for medium to high speed roads (~30 mph and above) and for automobiles.

In order to evaluate the impact of using a quieter pavement, it is effective to use the Federal Highway Administration (FHWA) Traffic Noise Model® (TNM®) [Menge 1998][Anderson 1998] to determine noise impacts in a park with the pavement type(s) currently in use and noise impacts with a quieter pavement in place, and compare the two. In order to achieve this, a special test version of TNM v2.5 was modified to incorporate effects for the pavements of interest (this is explained further in Section 4.3.1). Incorporation required on-board sound intensity (OBSI) [AASHTO OBSI] data for the specific pavements of interest and comparisons to average OBSI data for dense-graded asphalt. (Note: TNM v2.5, the most current version, provides predictions for three general pavement categories, portland cement concrete (PCC), dense-graded asphalt (DGAC), and open-graded asphalt (OGAC); in addition, predictions are available for a national average pavement (average of PCC and DGAC). Effects of specific pavements were incorporated for this study.)

OBSI data were collected by driving a vehicle mounted with a sound intensity measurement system over the pavements. Sound pressure level measurements at sensitive park locations that could potentially benefit from quieter pavement were also conducted in order to determine the impact from using quieter pavement(s).

Note: This document presents a demonstration of quieter pavement use. General guidance and recommendations on quieter pavement use is addressed in a separate document [Sohaney 2013].

1.2 Study Overview and Report Organization

Death Valley National Park was chosen to conduct the quieter pavement demonstration.
The next section (Section 2) describes the measurement sites at the park. Death Valley National Park was chosen for the demonstration based on the following: 1) the park includes medium- to high-speed roads, where tire-pavement noise dominates compared to other vehicle noise sources; 2) the park has very low ambient natural sound; and 3) the typical weather conditions for the park accommodated measurements in November.

Section 3 describes the OBSI measurements, sound level measurements, and supporting measurements conducted. Section 4 describes the data analysis procedures applied to the data collected and the results of each analysis. Section 5 provides conclusions and recommendations.

2. MEASUREMENT SITES

All measurement sites were at Death Valley National Park. Measurement sites were chosen to accommodate three types of measurements: 1) on-board sound intensity (OBSI), 2) wayside near the road, and 3) wayside sensitive receiver locations (areas of frequent human use). Each is described more below.

2.1 OBSI Measurement Sites

In order to evaluate tire-pavement noise in Death Valley using the OBSI methodology, several roadway sections were identified for testing. The selection of roadway sections was based on proximity to near-road and sensitive-receiver locations and on representative sampling stretching about 17 miles (27 km) North and 17 miles south of Furnace Creek. The representative sampling included sections of roadway with a broad range of sound levels as determined by vehicle occupants driving over the pavement[a]. Table 1 provides a list of the OBSI measurement sites. Figure 5 and Figure 6 in Section 4 show the locations on satellite photos. Table 3 in Section 4 shows photos of the pavement at each measurement site. OBSI measurements were conducted on 11/06/2010 for Sites 1-9, 10, and 11, and on 11/07/2010 for Sites 1-4, 6, 10, and 12-15.

[a] This study did not include an examination of pavement specifications for Death Valley National Park. If the Park chooses to apply a quieter pavement when re-paving, pavement specifications for a particular section of highway will need to be sought from Caltrans or the Park's road maintenance department.

Table 1. OBSI measurement sites.

Site ID	Site Location		Milepost	Description
	Latitude	Longitude		
1	36°28'27.55"N	116°52'3.86"W	109.5	Hwy 190, WB side, ~1 mile N or Furnace Creek
2A*	36°30'24.80"N	116°52'42.24"W	107	Hwy 190, WB side, ~3.5 miles N or Furnace Creek
2B*	36°30'24.80"N	116°52'42.24"W	107	Hwy 190, EB side, ~3.5 miles N or Furnace Creek
3	36°34'23.05"N	116°55'9.62"W	101.5	Hwy 190, WB side
4	36°35'38.94"N	116°57'47.56"W	98.5	Hwy 190, WB side
5	36°36'29.23"N	116°59'6.54"W	98	Hwy 190, WB side
6	36°37'23.92"N	117° 3'34.67"W	91.5	Hwy 190, WB side
7	36°36'17.28"N	117° 7'13.73"W	87.5	Hwy 190, WB side
8	36°39'9.25"N	117° 3'1.08"W	1	Daylight Pass Rd, WB side
9	36°36'9.72"N	116°56'40.81"W	1	Beatty St, NB side
10	36°36'18.54"N	117° 6'33.16"W		Hwy 190, WB & EB sides, near sand dunes
11	36°22'54.23"N	116°51'5.04"W		Artist Dr, WB side, near end
12	36°14'12.01"N	116°46'8.62"W	16	Badwater Rd, NB & SB sides, ~0.6 miles N of Badwater visitor parking
13	36°13'0.62"N	116°46'24.31"W	18	Badwater Rd, NB & SB sides, ~1.4 miles S of Badwater visitor parking
14	36°25'52.21"N	116°48'56.38"W	114.5	Hwy 190, EB & WB, ~0.80 miles W of Zabriskie Point
15	36°25'26.04"N	116°48'38.81"W		Hwy 190, EB & WB, ~0.23 miles W of Zabriskie Point

*Site 2B is shown separated by side of highway since the OBSI levels were substantially different. For other sites where the OBSI measurements were conducted on each side of the highway, the OBSI levels were averaged together.

2.2 Wayside Measurement Sites

The near-road wayside measurement locations allowed for the capture of the maximum sound level for a single vehicle passing by (emission level), without intrusion of noise from other vehicles or other noise sources and minimal sound propagation effects. These sites are designated with “R” and are listed in Table 2.

The sensitive receiver locations allowed for the capture of sound levels in areas of frequent human use. These included such locations as park overlooks, hiking/walking trails or areas, photography areas, and popular visitor locations; minimizing road noise at these sites would increase a visitor’s exposure to natural sounds. These sites are designated with “S” and are listed in Table 2. (Note: park personnel helped to identify locations with required site characteristics, and three areas were selected for demonstrations based on the input and site visits.) Measurements from these locations were used to help validate the research version of TNM that includes Death-Valley-specific pavements and to assess the sound environment as experienced by park visitors.

Photos of the wayside measurement sites can be seen in Appendix A.

Table 2. Wayside measurement sites at Death Valley National Park.

Site ID	Site Location	Type of Measurement	Measurement Date
DV01R	Hwy 190, east of Stovepipe Wells, just east of exit for parking for sand dunes, instrumentation deployed adjacent to WB side, measuring sound from vehicles on EB side	emission level	11/06/2010
DV02S	On sand dune closest to Hwy 190, ~650 ft from center of EB lane, hiking area	sensitive receiver	11/06/2010
DV03R	Hwy 190, just west of Zabriskie Point, near mile marker 115.0, instrumentation deployed adjacent to EB side, measuring sound from vehicles on WB side	emission level	11/07/2010
DV04S	On Zabriskie Point Overlook, east side closest to Hwy 190, ~1050 ft from center of WB lane, viewing and photography area	sensitive receiver	11/07/2010
DV05S	Near Zabriskie Point Overlook, west of walking path, elevated point closest to Hwy 190, ~550 ft from center of WB lane, hiking and photography area	sensitive receiver	11/07/2010
DV06R	Badwater Rd, just north of mile marker 16, instrumentation deployed adjacent to SB side, measuring sound from vehicles on NB side	emission level	11/09/2010
DV07S	Badwater visitor area, near Badwater Rd, ~225 ft from end of boardwalk on N side of hiking path	sensitive receiver	11/09/2010
DV08S	Badwater visitor area, near Badwater Rd, ~725 ft from end of boardwalk on N side of hiking path	sensitive receiver	11/09/2010
DV09S	Near Badwater Rd, ~470 ft from center of NB lane, ~0.45 mile SW of Badwater visitor parking area, hiking path at the edge of the salt	sensitive receiver	11/09/2010

3. DATA COLLECTION

Both the tire-pavement noise measurements and the wayside noise measurements are described in this section.

3.1 Noise Measurements near the Tire-Pavement Interface

Tire-pavement noise was measured at the tire-pavement interface at the sites listed in Section 2.1. The methodology used to collect the data was the On-Board Sound Intensity (OBSI) methodology described in AASHTO Specification TP 76-10 [AASHTO OBSI]. On a test vehicle, two intensity probes were positioned near the tire-pavement interface, which resulted in the determination of tire-pavement sound intensity levels[a]; Figure 1 shows the test vehicle equipped with the OBSI instrumentation. This methodology allowed for a direct comparison among pavements of the noise generated at the interface and propagating away from the vehicle toward the side of the road. The OBSI test vehicle drove over each pavement of interest, collecting data for 5 seconds at 60 mph (97 km/h). Multiple passes were made over the same roadway section in order to get an accurate representation of the noise levels associated with the pavement.

Figure 1. OBSI instrumentation.

[a] Sound intensity is the average rate of flow of energy through a unit area normal to the direction of wave propagation; it is not equivalent to sound pressure.

3.2 Wayside Noise Measurements near the Road

Wayside noise measurements were conducted to determine sound levels near the road (vehicle emission levels) and the general sound environment near the roadways of interest. The measurements were conducted in conformance with the procedures in the FHWA measurements report [Lee 1996], with an additional microphone location as described in the Statistical Isolated Pass-By (SIP) methodology [Rochat 2009, AASHTO SIP] (this additional microphone location is not used for analysis in this report, but data are available for future analysis, if desired). The data collection period at each site was approximately 4 hours. Please refer to Appendix A for a list of instrumentation that was deployed at each site.

At all near-road noise emission level sites, sound levels were measured at the following location: distance of 50 ft (15.2 m) from the center of the travel lane and at height 5 ft (1.5 m) above the roadway plane. At some of the sites, an additional microphone was located at a distance of 50 ft (15.2 m), with a height of 12 ft (3.7 m). Figure 2 shows an example of microphones deployed.

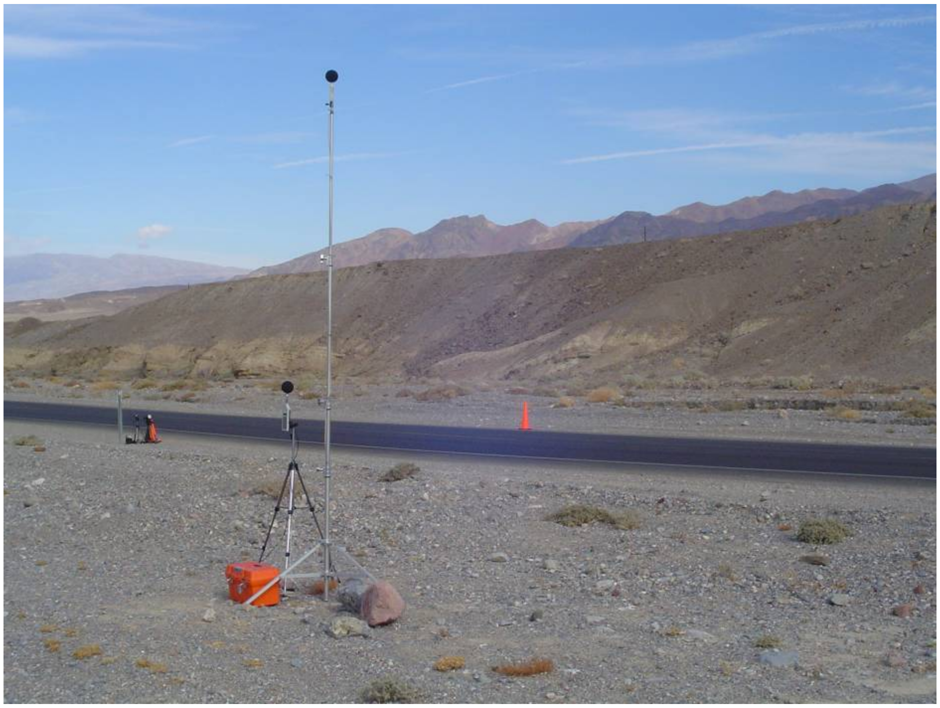


Figure 2. Deployment of microphones at site for collecting the near-road noise emissions levels.

Sound was measured using a class 1 sound level meter and the audio recorded for later analysis. Sound level meters, set on fast response, recorded 1-second A-weighted equivalent sound levels and maximum sound levels.

Meteorological data were also collected. Air temperature, relative humidity, wind speed, and wind direction data were collected in 1-second samples. In addition, pavement temperature and prevailing cloud cover conditions were noted hourly. Please refer to Figure 3 for a photo of meteorological instrumentation.

Figure 3. Deployment of meteorological instrumentation.

Vehicle speed and identification data were also collected. All vehicle pass-by events subjectively determined to be of good quality (no interfering noise and vehicle maintaining constant speed as it drives past the microphones) were logged in a palmtop computer. In addition, speeds were measured using a radar gun and noted in the log along with the time of the pass-by event. In addition, vehicle categories were noted: automobile, medium truck, heavy truck, motorcycle, or bus. Please refer to Figure 4 for a photo of the vehicle data collection instrumentation.

Figure 4. Deployment of vehicle data collection instrumentation.

3.3 Wayside Noise Measurements at Sensitive Receiver Locations

Microphones were deployed at sensitive receiver locations farther from the road, which included overlooks, photography areas, hiking/walking trails and areas, and popular visitor locations. Each of these locations was near one of the near-road emission level locations, and a microphone and sound level meter were deployed at a height of 5 ft (1.5 m) above the ground (distances from the road were approximated and are listed in Appendix A). Sound level meters, set on fast response, recorded 1-second A-weighted equivalent sound levels and maximum sound levels. Audio was recorded for later analysis.

Meteorological instrumentation was also deployed at the sensitive receiver location when sufficiently far from the emission level location (far enough so that the meteorological conditions at the emission level location may not have been representative of those at the sensitive receiver location). In addition, extraneous noise determined to potentially contaminate the road noise measurements was noted in the palmtop log.

The data collection period at each site was approximately 4 hours.

4. DATA ANALYSIS AND RESULTS

The OBSI data were analyzed first to quantify the noise near the tire-pavement interface for each section of pavement tested, where results are presented in Section 4.1. A brief description of the general sound environment at the sensitive receiver locations is presented in Section 4.2. An analysis was conducted using a few examples at some of the near-road and sensitive receiver locations to determine sound level reduction predicted with quieter pavement applied, and the results are presented in Section 4.3.

4.1 Noise near the Tire-Pavement Interface

OBSI data were analyzed according to AASHTO TPN 76-10 [AASHTO OBSI], where multiple passes on a single section of roadway were averaged to obtain a single OBSI level for each test section. For comparison to results presented in this section, a developing database of measured OBSI levels following the TPN 76-10 procedure shows values for asphalt pavements in the range of approximately 96-109 dBA [TPF 2011][Rochat 2007].

The OBSI results can be seen in Figure 5 and Figure 6, and the values are also listed in Table 3, along with a photo of each pavement. Figure 5 is a satellite/map image from Google Earth showing the northern half of the test area in Death Valley National Park, and Figure 6 shows the southern half of the test area, each figure with yellow pushpins designating the OBSI measurement sites. It should be noted that measurements were conducted while air temperatures were in the range of 72-88 °F (22-31 °C). It is known that temperature can affect measured sound levels, generally causing a slight increase in sound level with a decrease in temperature [Bendtsen 2009-1 & 2009-2][Rochat 2010][Rasmussen 2011]. At some of the sites, measurements were conducted at approximately 80 °F (27 °C) and repeated at approximately 72 °F (22 °C); the decrease in temperature resulted in increases in OBSI levels of 0.2-1.3 dBA, most being 0.5 dBA or below. For the results presented here, no adjustments have been made to OBSI levels to account for temperature differences.

The data show that some of the sites have moderately loud pavement, such as Site 9 (Beatty St), Site 11 (Artist Dr), Site 12 (Badwater N of visitor parking), and Site 13 (Badwater S of visitor parking); each had an OBSI level exceeding 103 dBA, with Site 12 being the loudest at 104.7 dBA. There were also some quieter pavements, such as Site 2B (Hwy 190 EB) (note that Site 2A, Hwy 190 WB, was 2 dBA louder than Site 2B, and the pavement photos reveal that there are visual differences), Site 5 (Hwy 190), Site 6 (Hwy 190), Site 7 (Hwy 190), and Site 8 (Daylight Pass Rd); each had an OBSI level less than 100 dBA, with Site 6 being the quietest at 96.8 dBA.[a]

In relation to areas of frequent human use, the pavements were neither loud nor quiet near the sand dunes east of Stovepipe Wells and near Zabriskie Point, and the pavement was moderately loud near the Badwater area. The closest measurements to the Furnace Creek camping areas (Site 1, Hwy 190) was neither particularly loud nor quiet.

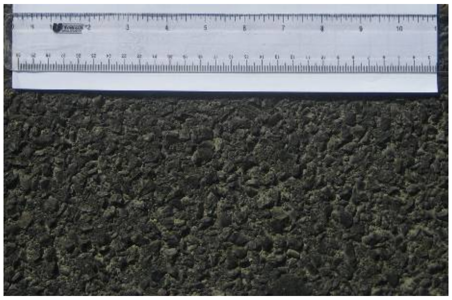
Overall assessment: Death Valley National Park has pavements ranging from very quiet to moderately loud.

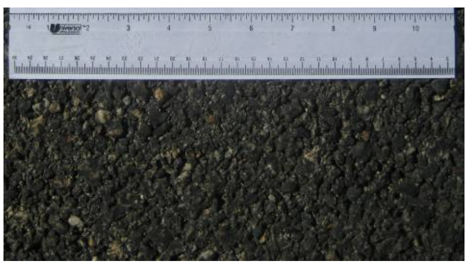
[a] Note that measurement of pavement parameters was outside the scope of this study. Also, obtaining pavement specifications and paving schedules from Caltrans and the Park's road maintenance department was outside the scope of this study; it is possible for those interested to contact Caltrans or the Park's road maintenance department to obtain this information, including maximum aggregate size, porosity, and age, all of which can affect the associated tire/pavement noise level.

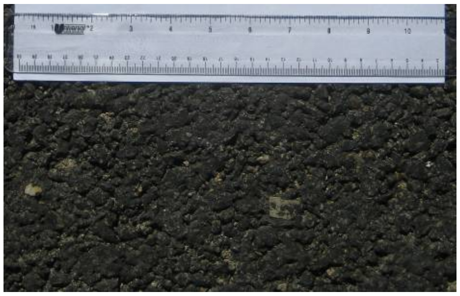
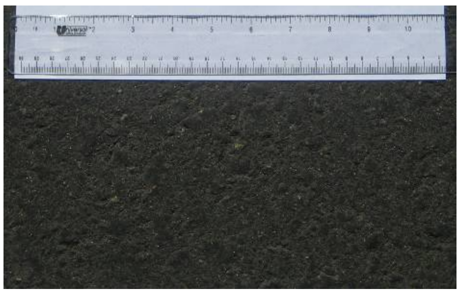
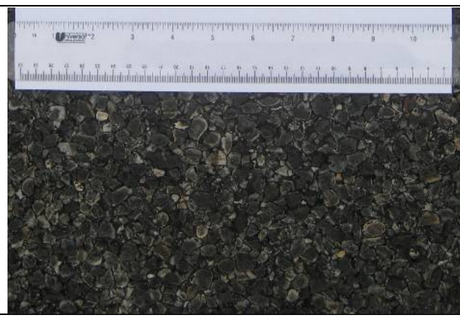
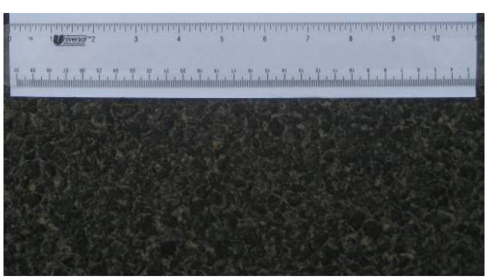
Figure 5. OBSI levels listed by site on satellite/map image; northern portion of test area.

Figure 6. OBSI levels listed by site on satellite/map image; southern portion of test area.

Table 3. OBSI measurement site pavement photos and OBSI levels.

Site ID	Pavement Photo	OBSI Level (dBA)
1		101.1
2A		101.8
2B		99.8
3		102.0
4		102.3

5		97.2
6		96.8
7		99.8
8		99.2
9		103.1

10		100.6
11		104.2
12		104.7
13		103.4
14		100.6

15		100.5

4.2 General Sound Environment at Wayside Sites

It is generally very quiet at Death Valley National Park. For all near-road and sensitive receiver locations, the ambient natural sound (excluding wind[a]) was at or below 20 dBA[b] (equivalent sound level, L_{Aeq}); this is the level for the noise floor of the instrumentation, so the ambient sound was indeterminable[c]. The general sounds that were heard intermittently throughout the days were: wind, people talking, people walking, commercial/private aircraft, military aircraft, and vehicles on the road or in parking lots. Vehicles driving on the road were typically heard as a lengthy pass-by event, where the vehicle approaching and receding could be heard from a considerable distance away.

To get a general sense of the sound levels at each of the sensitive receiver locations, the entire approximate 4-hour measurement period was examined, where a histogram analysis was used to determine the frequency of occurrence of sound levels (L_{Aeq}) in 10-decibel bins. Table 4 shows the sensitive receiver locations with the percentage of time that the sound level (LAeq) was in each of the 10-decibel bins listed; the table also includes the natural ambient sound level (excluding wind). Keep in mind that the time includes all sound measured during the period, regardless of the source.

For the sand dunes site, DV02S, and the Zabriskie Point Overlook, DV04S, it can be seen in

[a] Wind was approximately 5 mph or less and could not be heard on audio recordings.
[b] The equivalent sound levels were extracted from sound level meter data files at times determined in the field and by listening to audio recordings to represent the natural sound at the site.
[c] Note that measuring ambient sound levels was not the intent of this study. Some information is provided here strictly for the sake of interest.

Table 4 that the sound level was near natural ambient (≤ 30 dBA) only a very small portion of the time. At Zabriskie Point near the overlook, the sound level was near natural ambient about 26% of the time. At the main Badwater visitor area, DV07S & DV08S, the sound level was near natural ambient about 30% of the time. At the more remote Badwater area, the sound level was near natural ambient about 56% of the time.

To get a better sense of how road noise contributes to the sound environment, an example analysis was conducted for the sand dunes area, Site DV02S. The vehicle log, extraneous noise log, and sound level time history were examined to approximate how much of the time the sound environment was dominated by tire-pavement noise from automobiles (car, SUV, pick-up truck, etc.), the type of vehicle for which the sound level is most affected by pavement type. It was roughly estimated that for about an hour of the approximate 4-hour measurement period, the sound level was dominated by automobile tire-pavement noise. This information can be used to get a general sense of how much of the time a quieter pavement could potentially have an effect on the sound environment. (Note: A more extensive analysis for this example site would need to be performed to obtain a more precise estimate; similar analyses could also be performed for other sensitive receiver sites.)

Table 4. Percentage of time at sensitive receiver locations when sound level resides in each 10-decibel bin.

Site ID	Ambient natural sound level (dBA)	Percentage of time in each of the 10-decibel (dBA) bins, listed below						
		≤ 20-30	30-40	40-50	50-60	60-70	70-80	> 80
DV02S	≤ 20	8%	35%	41%	10%	4%	1%	1%
DV04S	≤ 20	9%	51%	35%	5%	0%	0%	0%
DV05S	≤ 20	26%	37%	28%	8%	0%	0%	0%
DV07S	≤ 20	29%	52%	15%	3%	1%	0%	0%
DV08S	≤ 20	31%	50%	15%	3%	0%	0%	0%
DV09S	≤ 20	56%	33%	9%	2%	0%	0%	0%

4.3 Using OBSI Levels in TNM to Determine Effects of Quieter Pavement

This section provides examples of how quieter pavement could potentially affect sound levels at the near-road and sensitive receiver wayside locations. The examples are given in terms of maximum sound levels for single vehicles driving on the road nearest the microphones. Not all sensitive receiver locations are represented since this is for demonstration purposes only.

4.3.1 Using OBSI levels in TNM

A Federal Highway Administration (FHWA) study is being conducted [Rochat 2007][Rochat 2012] to determine the most effective way to implement the effects of pavement type in the Traffic Noise Model® (TNM®) [Menge 1998][Anderson 1998]. Preliminary results of the study show that an effective implementation technique is to use measured 1/3-octave band OBSI levels for a specific pavement, compare them to average measured OBSI levels for dense-graded asphalt (DGAC), determine the offset between the OBSI levels for the specific pavement and the DGAC, then apply that offset to the model's emission level database for DGAC. Such an analysis was conducted for the Death Valley OBSI data, for the quietest and loudest pavements, as well as the pavements closest to the sensitive receiver locations of interest. A special test version of TNM v2.5 was used for the analysis (a version developed for the FHWA study and described further in Rochat 2012; this version allows for pavement effects to be included using OBSI data). Introducing tire-pavement noise levels for Death Valley-specific pavements in TNM allowed for predictions of sound levels at sensitive receiver locations with the existing pavement and with a quieter pavement.

4.3.2 Calculating potential effect of quieter pavement

Calculations for determining the potential effect of quieter pavement were done for the three main areas of frequent human use examined as part of this study: sand dunes east of Stovepipe Wells, Zabriskie Point, and Badwater. The following wayside measurement locations were modeled: near the road at the sand dune site (DV01R), on a sand dune (DV02S), near the road at the Zabriskie Point site (DV03R), at the Zabriskie Point Overlook (DV04S), near the Zabriskie Point Overlook (DV05S), near the road at Badwater (DV06R), and the remote Badwater site south of the main visitor area (DV09S). Each TNM model represented a single automobile (car, SUV, pick-up truck, etc.) passing by the site (length of road representing one second at travel speed), and the resulting predicted sound level was comparable to the measured maximum sound level (L_{Amax}). Site features were modeled as simply as possible, including roadways (dimensions, vehicle type, and vehicle speed), receivers, changes in ground elevation, and ground type, where approximate locations and elevation changes were modeled based on tools available in Google Earth.

For model validation purposes, TNM predictions were made for the actual pavements at the sites, and sound levels were compared to those measured at the sites. This was done for just one vehicle at each of the sites. Results compared well, which provided confidence to continuing with further TNM analysis. For each of the sites, predictions were also made when applying a quieter pavement. The quieter pavement chosen for this analysis is the one found at OBSI Site 6, since this specific pavement is one already being used in Death Valley. For each location modeled, the predicted sound levels for the site-specific pavement and the quieter pavement were compared and the difference noted. This difference was then applied to the measured sound levels to determine the potential reduced sound levels with quieter pavement applied instead of the actual existing pavement.

4.2.3 Potential effect of quieter pavement

Figure 7, Figure 8, and Figure 9 shown bar charts, one for each area of frequent human use examined. The values in the charts are for the maximum sound level (L_{Amax}) measured for a single automobile passing by and the predicted maximum sound level with quieter pavement applied. Values for these charts are listed in Table 5, along with the predicted potential sound level reduction values.

At the sand dunes site, it can be seen that a car passing by at 58 mph (93 km/h) resulted in measured sound levels of 71.3 dBA near the road and 45.8 dBA on the sand dune approximately 650 ft (198 m) from the road. With quieter pavement applied, it is predicted that the sound level could potentially reduce by 2.4 dBA near the road and 0.5 dBA on the sand dune; these reductions are not substantial since the existing pavement was not particularly loud.

At Zabriskie Point, it can be seen that an SUV passing by at 65 mph (105 km/h) resulted in measured sound levels of 73.8 dBA near the road; 53.7 dBA near the overlook, approximately 550 ft (168 m) from the road; and 48.2 dBA on the overlook, approximately 1050 ft (320 m) from the road. With quieter pavement applied, it is predicted that the sound level could potentially reduce by 2.7 dBA near the road, 1.4 dBA near the overlook, and 1.1 dBA on the overlook.

At Badwater, it can be seen that a cross-over passing by at 47 mph (76 km/h) resulted in a measured sound level of 77.0 dBA near the road. An SUV passing by at 45 mph (72 km/h) resulted in a measured sound level of 42.5 dBA at the remote site approximately 470 ft (143 m) from the road. With quieter pavement applied, it is predicted that the sound level could potentially reduce by 7.0 dBA near the road and 3.2 dBA at the remote site; these reductions are substantial since the existing pavement was moderately loud.

It can be seen in all examples that quieter pavement provides a greater sound reduction closer to the road as compared to the farther locations. This is expected because as sound propagates, it loses energy more quickly in the higher frequencies than in the lower frequencies. It’s in this same higher frequency range that typical quieter pavements reduce the sound. At farther distances, where lower frequency sound energy from vehicles passing by contributes the most to the broadband sound level, the effect of quieter pavement is weakened.

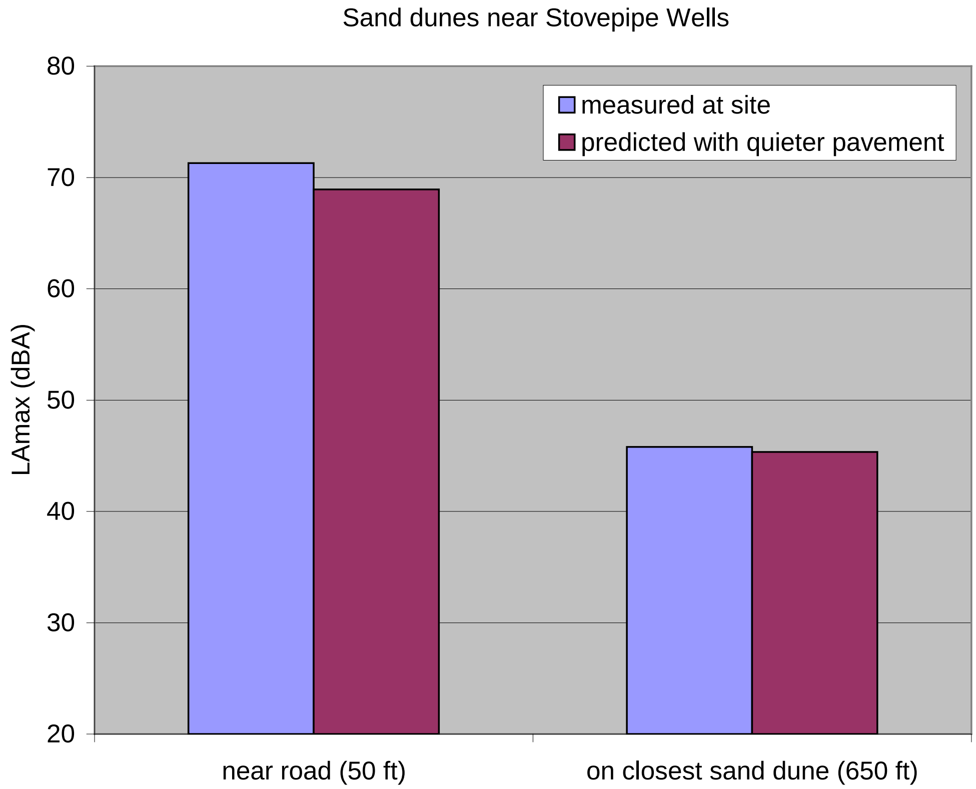


Figure 7. Sand dunes: example sound level reductions applying quieter pavement (listed in order of appearance from left to right: Sites DV01R, DV02S).

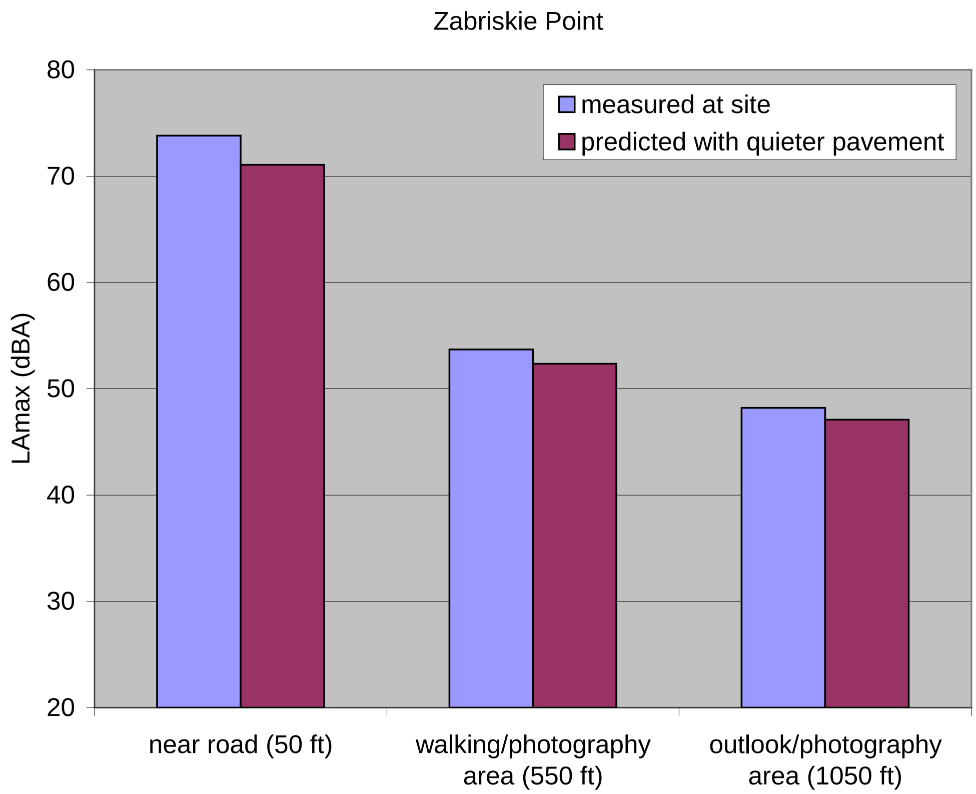


Figure 8. Zabriskie Point: example sound level reductions applying quieter pavement (listed in order of appearance from left to right: Sites DV03R, DV05S, DV04S).

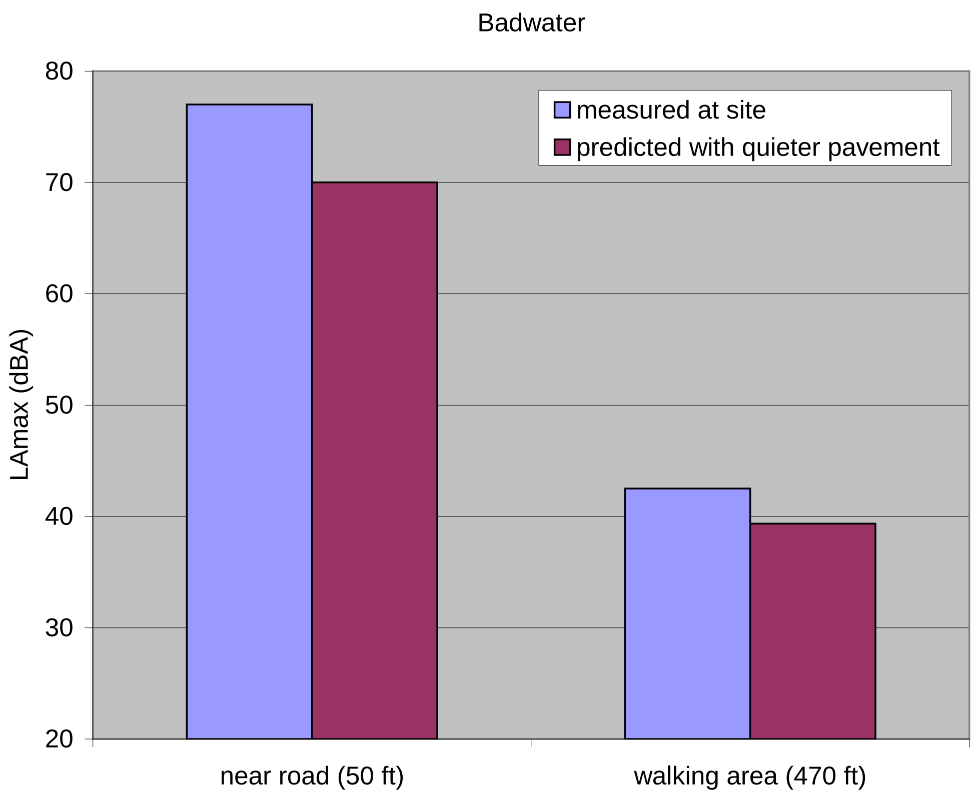


Figure 9. Badwater: example sound level reductions applying quieter pavement (listed in order of appearance from left to right: Sites DV06R, DV09S).

Table 5. Example sound level reductions applying quieter pavement.

Site/location	Distance from center of test lane (ft)	Sound level measured (dBA)	Potential sound level reduction (dBA)	Potential sound level with quieter pavement applied (dBA)
Sand dunes				
DV01R	50	71.3	-2.4	68.9
DV02S	650	45.8	-0.5	45.3
Zabriskie Point				
DV03R	50	73.8	-2.7	71.1
DV05S	550	53.7	-1.4	52.3
DV04S	1050	48.2	-1.1	47.1
Badwater				
DV06R	50	77.0	-7.0	70.0
DV09S	470	42.5	-3.2	39.3

5. CONCLUSIONS AND RECOMMENDATIONS

Death Valley National Park provided an environment that allowed a demonstration of quieter pavement use. Sound measurements near the tire-pavement interface, near the road, and in areas of frequent human use were conducted and analyses performed in order to determine the general sound environment in the park and the potential benefit of using quieter pavements.

On-board sound intensity (OBSI) measurements were conducted to determine tire-pavement noise levels at various locations throughout the park. Results showed that Death Valley has pavements ranging from quiet to moderately loud[a], with the quietest having an OBSI level of 96.8 dBA and the loudest 104.7 dBA. The quietest level was on Hwy 190, where most measurements conducted on this main road through the park were quiet to moderate; the quietest section was labeled as OBSI Site 6, where the exact location can be found in Table 1. The loudest level was on Badwater Rd; most other loud levels were also found on roads that were not the main highway.

Near-road sound measurements and sound measurements conducted in areas of frequent human use (farther from the road) showed that it can be very quiet at these sites, without sound sources such at wind, people walking and talking, aircraft, and vehicles on the road or in parking lots. Automobile pass-by sound levels at these sites were extracted and used as a baseline from which sound levels with quieter pavement applied could be predicted. Predictions with quieter pavement were accomplished with a special test version of the FHWA TNM with Death-Valley-specific pavement effects included via OBSI data. For the cases examined, it was determined that the potential reduction in sound levels ranged from 0.5 to 7.0 dBA, depending primarily on the existing pavement type and distance from the road. A 7.0-dBA reduction in sound level is substantial, considering that the amount of sound energy is reduced by 80% and that a 10-dBA reduction is perceived as being half as loud.

[a] As described in Section 4.1 and for comparison to Death Valley OBSI data, a developing national database of measured OBSI levels for asphalt pavements shows values in the range of approximately 96-109 dBA [TPF 2011][Rochat 2007].

The examples provided allow for a demonstration of the benefit of quieter pavement in Death Valley National Park, and additional data for various vehicles at the different sites could be analyzed to provide more examples or for other research purposes. Note that a similar study could be applied to other parks to help identify quieter pavement solutions.

Additional information (subjective) …
Driving over the various pavements in Death Valley, it was apparent, as a vehicle passenger, that some pavements were quieter than others. The louder pavements were certainly more annoying in the vehicle than the moderate or quieter ones; the louder ones could be described as more fatiguing. This louder tire-pavement noise, which affects both vehicle passengers and park visitors at overlooks, hiking, etc., could be addressed when scheduled paving maintenance occurs; when sections of roadway need to be repaved, choosing a quieter pavement (such as the one at OBSI Site 6 on Hwy 190) would help reduce the general sound environment. The specifications for the OBSI Site 6 pavement can be sought from Caltrans or the Park's pavement maintenance department. It should be noted that another quieter pavement may also be effective in the Death Valley environment. Another NPS report on the topic of quieter pavement [Sohaney 2013] should be referenced to determine other pavements that may be effective; for example, Arizona DOT uses an open-graded rubberized asphalt that has proven to be durable and quiet in the Phoenix area, which has weather similar to Death Valley.

REFERENCES

AASHTO OBSI *Standard Method of Test for Measurement of Tire/Pavement Noise using the On-Board Sound Intensity (OBSI) Method*, American Association of State Highway and Transportation Officials, AASHTO Specification TP 76-10 (2010).

AASHTO SIP *Standard Method of Test for Determining the Influence of Road Surfaces on Vehicle Noise Using the Statistical Isolated Pass-By Method (SIP)*, Federal Highway Administration Technical Working Group on Tire-Pavement Noise, methodology submitted to AASHTO for consideration as provisional standard (2010).

Anderson 1998 Anderson, Grant S., Cynthia S.Y. Lee, Gregg G. Fleming, and Christopher W. Menge, *FHWA Traffic Noise Model, Version 1.0: User's Guide*, Report No.s FHWA-PD-96-009 and DOT-VNTSC-FHWA-98-1, U.S. Department of Transportation, John A. Volpe National Transportation Systems Center, Massachusetts (1998, TNM v2.5 Addendum 2004).

Bendtsen 2009-2 Bendtsen, Hans, et al., "Temperature influence on OBSI noise measurements," presentation at Transportation Research Board Committee on Transportation-Related Noise and Vibration summer meeting (2009).

Bendtsen 2009-1 Bendtsen, Hans, et al., *Temperature influence on road traffic noise – Californian OBSI measurement study*, Report 169, Road Directorate, Danish Road Institute, Copenhagen, Denmark (2009).

Lee 1996 Lee, Cynthia S.Y. and Gregg G. Fleming, *Measurement of Highway Related Noise*, Report No. FHWA-PD-96-046, U.S. Department of Transportation, Volpe National Transportation Systems Center, Acoustics Facility, Cambridge, MA, USA (1996).

Menge 1998 Menge, Christopher W., Christopher F. Rossano, Grant S. Anderson, and Christopher J. Bajdek, *FHWA Traffic Noise Model, Version 1.0: Technical Manual*, Report No.s FHWA-PD-96-010 and DOT-VNTSC-FHWA-98-02, U.S. Department of Transportation, John A. Volpe National Transportation Systems Center, Massachusetts (1998, 2004 update sheets available from FHWA).

Rasmussen 2011 Rasmussen, Robert Otto, *Tire/Pavement and Environmental Traffic Noise Research Study*, Report No. CDOT-2011-1, prepared by The Transtec Group, Inc., Texas for Colorado Department of Transportation, Colorado (2011).

Rochat 2012 Rochat, Judith L., Aaron L. Hastings, David R. Read and Michael Lau, *FHWA Traffic Noise Model (TNM) Pavement Effects Implementation Study: Progress Report 1*, Report Nos. FHWA (TBD) and DOT-VNTSC-FHWA-12-01, U.S. Department of Transportation, Volpe National Transportation Systems Center (2012).

Rochat 2010 Rochat, Judith L., *Investigation of Temperature Correction for Tire/Pavement Noise Measurements*, Report No.s FHWA-HEP-11-005 and DOT-VNTSC-FHWA-11-01, U.S. Department of Transportation, John A. Volpe National Transportation Systems Center, Massachusetts (2010).

Rochat 2009 Rochat, Judith L., "Developing U.S. wayside methods for measuring the influence of road surfaces on traffic noise," Proceedings of Inter-Noise 2009, Ottawa, Canada (2009).

Rochat 2007 Rochat, Judith, Aaron Hastings, and Mark Ferroni, "Investigating the implementation of pavement effects via OBSI data in the FHWA Traffic Noise Model® (FHWA TNM)," Proceedings of Noise-Con 2007, Reno, Nevada, USA (2007).

Sohaney 2013 Sohaney, Richard, et al., *Quieter Pavements Guidance Document*, Report No. DOT-VNTSC-FHWA-11-16, U.S. Department of Transportation, John A. Volpe National Transportation Systems Center, Massachusetts (2013).

TPF 2011 Tire/Pavement Noise Consortium TPF-5(135), developing OBSI database (2011).

Volpe 2007 Volpe National Transportation Systems Center, *National Parks Air Tour Management Plan (ATMP) Program Implementation Plan* (2007).

APPENDIX A. WAYSIDE MEASUREMENT SITE PHOTOS AND INSTRUMENTATION

Included in this appendix are the Death Valley National Park wayside measurement site (near the road and at sensitive receiver locations) photos and a list of the key instrumentation deployed at each site.

A.1 Measurement Site Photos

Following are site photos for each measurement site.

Figure 10. DV01R – East of Stovepipe Wells near sand dunes, site photo.

Figure 11. DV02S – East of Stovepipe Wells on sand dune, site photo.

Figure 12. DV03R – Zabriskie Point near road, site photo.

Figure 13. DV04S – Zabriskie Point overlook, site photo.

Figure 14. DV05S – Zabriskie Point elevated point nearest road, site photo.

Figure 15. DV06R – Badwater Rd near road, site photo.

Figure 16. DV07S & DV08S – Badwater visitor area, site photo.

Figure 17. DV09S – Badwater Rd hiking area near edge of salt, site photo.

A.2 Measurement Instrumentation

Table 6 lists the measurement sites and instrumentation deployed. Photos of instrumentation deployment can be seen in Section 3 of this document.

Table 6. Measurement sites and deployed instrumentation.

Site ID	Site Location	Microphone Distances*/Heights** (ft)	Other Instrumentation
DV01R	Sand dunes near road	50/5	Radar gun Meteorological sensors Video cameras
DV02S	Sand dune	~650/-10 (5 above ground)	
DV03R	Zabriskie Point near road	50/5 50/12	Radar gun Meteorological sensors Video cameras
DV04S	Zabriskie Point Overlook	~1050/64 (5 above ground)	Meteorological sensors
DV05S	Zabriskie Point elevated area closest to road	~550/19 (5 above ground)	
DV06R	Badwater Rd near road	50/5 50/12	Radar gun Meteorological sensors Video cameras
DV07S	Badwater visitor area closest to parking	~535/-6 (5 above ground)	Meteorological sensors
DV08S	Badwater visitor area farthest from parking	~1035/-6 (5 above ground)	
DV09S	Badwater Rd hiking area near edge of salt	~470/-8 (5 above ground)	Meteorological sensors

*Distances measured from center of near travel lane.
**Heights measured above center of near travel lane, except where noted.

NPS 143/121246, June 2013

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA ™