7th Year Summary Report

I-80 Davis OGAC Pavement Noise Study

Traffic Noise Levels Associated With Aging Open Grade Asphalt Concrete Overlay

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EXECUTIVE SUMMARY

In the summer of 1998, a portion of Interstate 80 near Davis, California with aged asphalt concrete pavement surface was repaved with open grade asphalt concrete (OGAC). This report documents the traffic noise level changes associated with the new and aging open grade asphalt concrete (OGAC) overlay in comparison to the baseline as part of an ongoing study conducted by the California Department of Transportation. The OGAC overlay, which was placed over a structural base section of dense grade asphalt concrete (DGAC) surface, is now more than 7 years old. This study is continuing into the 8th year.

Traffic noise level measurements were made prior to the overlay, just after, and 3 times per year (spring, early summer and late fall) since the overlay was applied. Monitoring occurred over measurement periods on 53 days over the past 7 years for a total of about 210 hours of noise level data at the reference locations. All measurements were made on weekdays from about 9:00am to 1:00 pm during free-flowing traffic conditions. All of the measurement periods included measurements at the reference locations, located 65-ft (20-m) from the edge of the nearest travel way. Distant measurements, located 475-ft (145-m) from the edge of the nearest travel way, were made during the 1999, 2000, 2002 and, 2003 measurements and during the summer 2004 and 2005 measurements. Meteorological and traffic conditions were measured simultaneous to noise monitoring and reference location noise levels were normalized for changing traffic conditions. Because baseline measurements were made during the summer (June), the findings in this study are primarily based on summer measurements. This study does indicate seasonal trends in noise levels, where colder seasons have higher noise levels. Increasing traffic on the frontage road adjacent to the Eastbound Reference site affects the reference noise levels on the order of approximately 0.5 to 1.5 dBA. Because the data collected at the Westbound Reference site is less affected by non-highway traffic noise sources, it is more reliable for evaluating the noise level reductions from the OGAC overlay. Therefore, findings in this study are primarily based on the Westbound Reference data set.

Reference Sites

Reference site measurements were made one month prior to the OGAC overlay and then at least three separate times per year after the overlay occurred in July of 1998. The A-weighted noise levels measured at the reference sites indicate that substantial decreases in traffic noise occurred after the placement of the new OGAC overlays. Measurements were also conducted after the DGAC pavement base overlay occurred, representing recent application conditions of the DGAC pavement type (within 3 weeks of the pavement placement). This study did not collect any additional data that would indicate the acoustical characteristics of the base section of DGAC as it ages. Traffic noise levels following application of the OGAC were substantially lower than the baseline noise levels and continue to be lower after 7 years.

Distant Sites

Measurements at the distant sites (475-ft or 145-m from the near lane) were made one month prior to the OGAC overlay (baseline conditions) and then during the summer monitoring periods of the most years after the overlay. Additional measurements were made in the first and second years. Several factors, besides pavement type, affected noise levels at the distant sites, causing the effects of pavement on noise levels at the distant sites to be difficult to assess. Nevertheless, the data indicate noise levels decreased at these sites after the new pavement was applied.

Conclusions

Due to local traffic interference at the EB Ref location and inconsistent field conditions on the EB side, findings are based primarily on WB Ref and Dist site results. Figures ES-1 and ES-2 indicate the differences between baseline noise levels and noise levels measured after the OGAC overlay for the westbound reference and distant locations, normalized for varying traffic conditions using TNM 2.5 model results with the monitored traffic conditions. Figure ES-3 shows a summary of the frequency spectra for the westbound reference and distant locations under baseline and post-overlay conditions. Principal findings developed from this data set are as follows:

1. At the reference locations, noise levels decreased by about 4 dBA below baseline conditions after application of the DGAC. The acoustical characteristics of DGAC as it ages were not studied.

2. The OGAC pavement overlay provided about 6 dBA of reduction during the first 4 years and has provided a steady ~4.5-5.0 dBA reduction over the last three years. After 7 years, the pavement is calculated to provide 4.3 dBA of noise reduction at the reference sites when compared with the baseline conditions. *Note: I-80 is a major trans-continental Interstate freeway with an AADT of over 140,000 vehicles- including approximately 7 to 10% trucks.*

3. On average, noise levels at the distant positions were reduced below baseline levels by at least 4 dBA with the OGAC overlay. It is difficult to assess this reduction due to the variation in noise levels that is associated with changes in meteorological conditions and ground cover. The noise level reduction was still evident after 7 years after the OGAC overlay.

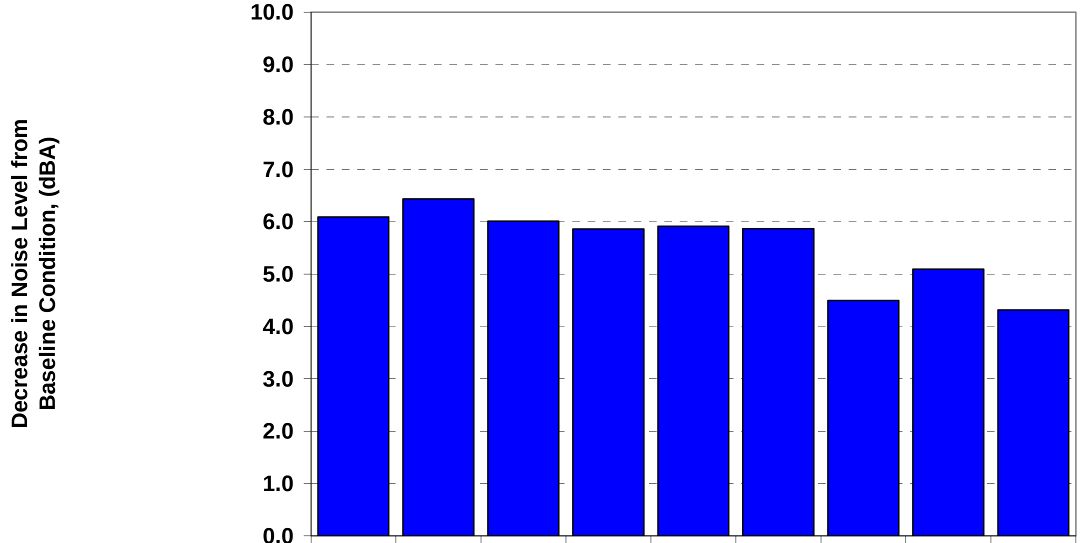
4. 1/3rd octave band spectra show a consistent signature of OGAC conditions for the 7-year aged pavement. This is evident at the reference positions and at the 475-ft (145-m) distant positions for 5-ft (1.5-m) and 15-ft (4.5-m) above ground (Low and High). The signature is evident under both downwind and upwind conditions. *Note: Spectra are not normalized for the slight differences that may have occurred under different traffic conditions and they are not corrected in magnitude for variations in the strength of the wind field.*

5. Seasonal trends with the OGAC overlay show a general tendency for higher noise levels (by about 1 dBA) in the winter months that are apparently attributable to changes in seasonal temperature. *Comparisons to original AC are only made for measurements in June when AC baseline levels were measured.*

6. Wind was found to have a substantial effect on measured traffic noise levels at the distant positions. The effect of the magnitude of the crosswind vector over a range of +4 to –4 m/s was typically 10 dB for the elevated position (15-ft or 4.5-m above ground) and 15 dB for the ground level position (5-ft or 1.5-m above ground).

7. Using *Average* pavement type and *Field Grass* ground cover, the TNM 2.5 model under-predicted baseline traffic noise levels by 0 to 1 dBA and over-predicted post overlay traffic noise levels by 3 to 6 dBA at the reference sites. Under calm wind conditions, TNM 2.5 under-predicted noise levels by about 4 dBA at WB Dist High and by about 6 dBA at WB Dist Low.

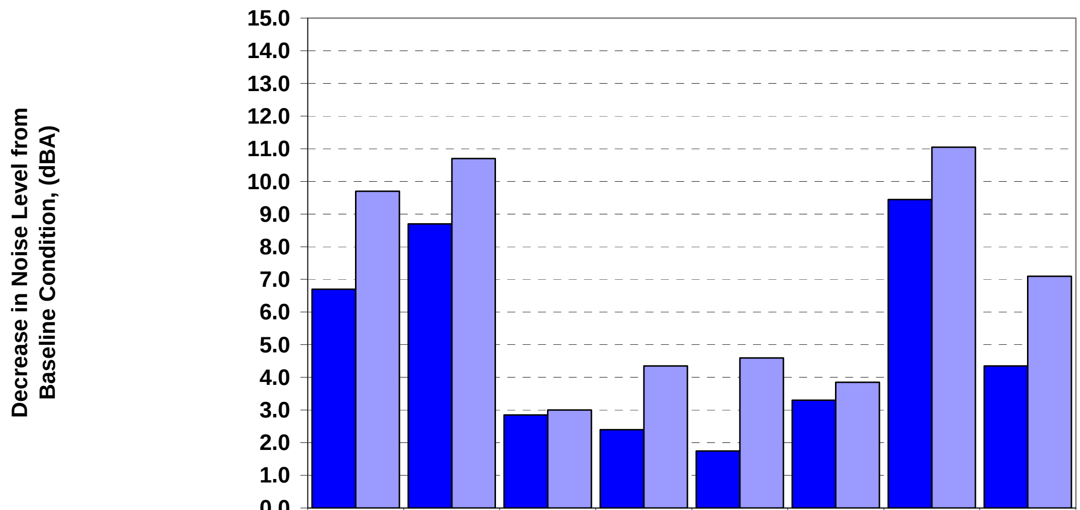
Figure ES-1: Normalized Decrease in Noise Level from the Baseline Condition (WB Ref)



		New OGAC	1 Mo. Aug	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year
WB Reference	78.6	6.1	6.4	6.0	5.9	5.9	5.9	4.5	5.1	4.3

Age of Pavement

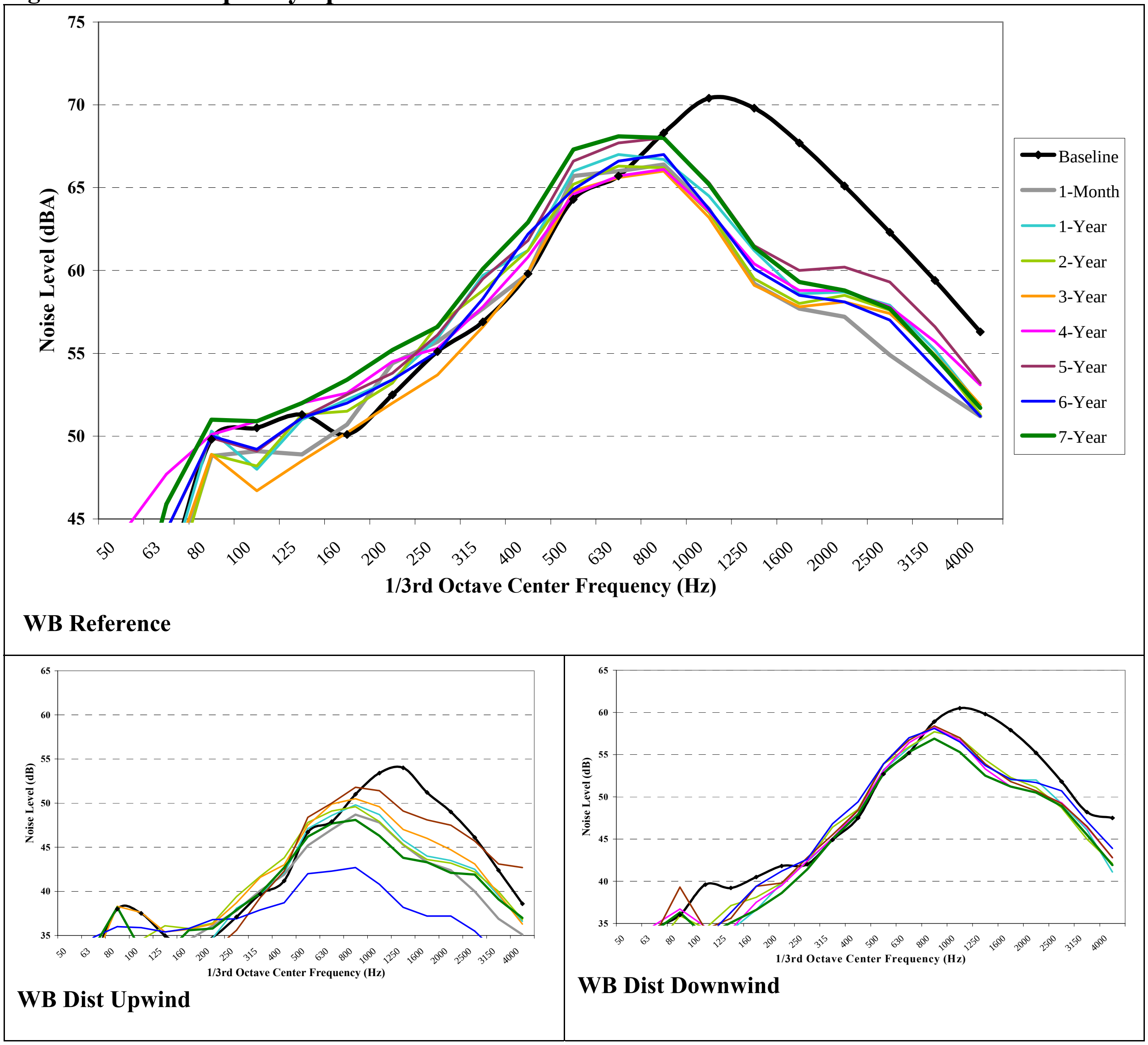
Figure ES-2: Normalized Decrease in Noise Level from the Baseline Condition (WB Dist)



		New OGAC	1 Mo. Aug	1 Year	2 Year	4 Year	5 Year	6 Year	7 Year
WB Dist High	62.8	6.7	8.7	2.9	2.4	1.8	3.3	9.5	4.3
WB Dist Low	58.1	9.7	10.7	3.0	4.4	4.6	3.9	11.1	7.1

Age of Pavement

Figure ES-3: Frequency Spectra for Westbound Measurement Positions



1 INTRODUCTION

Open grade asphalt concrete (OGAC) pavement overlays were applied to a 5.6-mile (9-kilometer) stretch of Interstate 80 (just east of Davis, California) in June and July of 1998. The OGAC overlay, which was placed over a dense grade asphalt concrete (DGAC) surface, is now more than 7 years old. Noise conditions are evaluated as part of an ongoing study conducted by the California Department of Transportation to evaluate the long-term effect of highway pavement types on traffic noise. This report presents noise data collected during the first seven years of the study, including baseline data that represents noise conditions associated with the old pavement (aged asphalt concrete) prior to the overlay. This study is continuing into the 8th year.

2 FIELD MEASUREMENTS

The project study corridor is Interstate 80 in Yolo County between Mace Boulevard and the Yolo Causeway (Yolo County Post Kilometer 9.3). The terrain is relatively flat throughout the study area. Figure 2-1a shows the study area with approximate measurement locations. Specific measurement locations are shown in Figure 2-1b.

Field activities included simultaneous measurements of wayside traffic noise levels near the westbound and eastbound sides of the freeway, traffic volumes and speeds, and meteorological conditions. Sound intensity measurements of tire/pavement noise were made during some measurement periods in 2002, 2003, 2004, and 2005. Measurements were conducted prior to the overlay, just after, and 3 times per year (spring, early summer and late fall) since the overlay was applied. Monitoring was conducted over measurement periods on 53 days over the past 7 years for a total of more than 210 hours of data at the reference locations. All measurements were made on weekdays from about 9:00 am to 1:00 pm during free-flowing traffic conditions. Photographs of the measurement locations are shown in Figure 2-2.

Figure 2-1a: Study Area

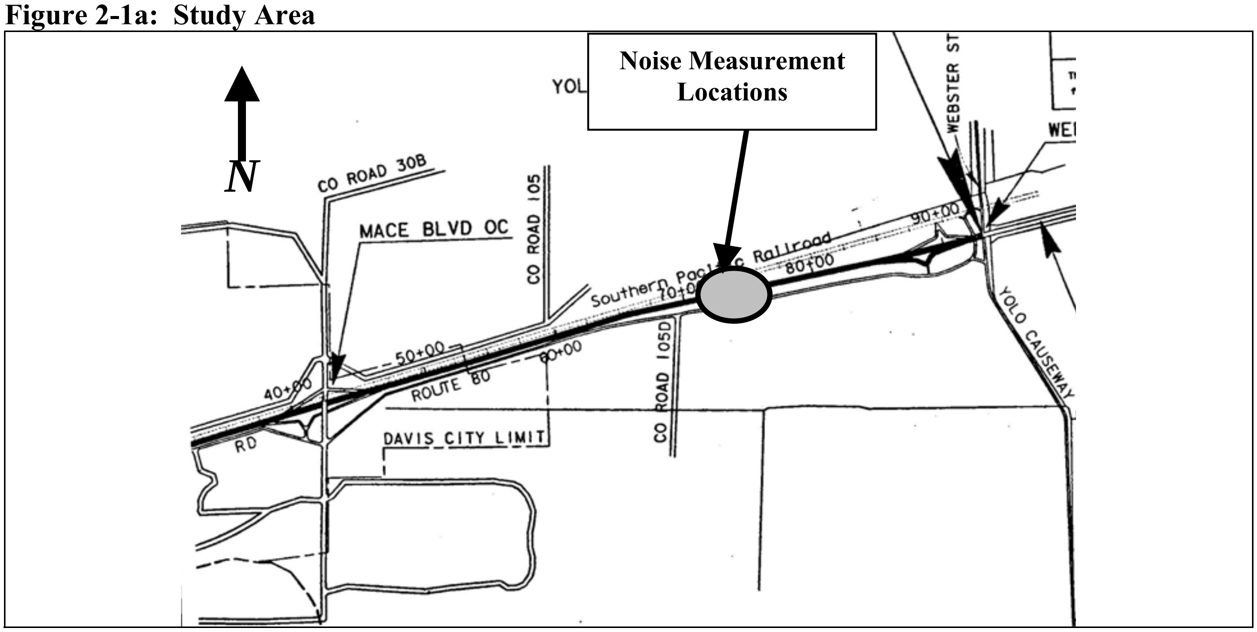
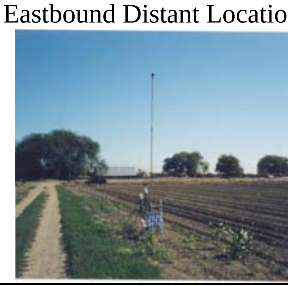
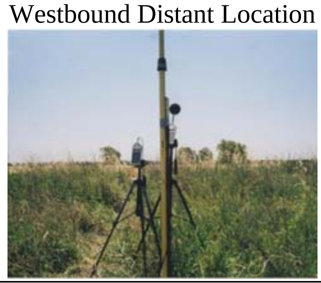


Figure 2-1b: Noise Measurement Locations

Figure 2-2: Photographs of Measurement Locations

Eastbound Reference Location 	Westbound Reference Location 
Eastbound Distant Location 	Westbound Distant Location 
Meteorological Monitoring Location 	Traffic Observation Location 

2.1 Description of Pavement

Interstate 80 and adjacent lands are flat throughout the study area. Prior to the pavement rehabilitation project, the roadway bed consisted of 4.7 to 6.3-inch (120 to 160-mm) of asphalt concrete (AC). The pavement project consisted of the removal of the existing AC surfacing and replacement with the new AC. In some spots, the underlying base was removed and replaced. The new AC surfacing included placement of 2.4-inch (60-mm) of dense-graded asphalt concrete (DGAC) in June and early July 1998, which was subsequently covered with 1.0-inch (25-mm) of open-graded asphalt concrete (OGAC) in July 1998. Existing and project pavement overlay information were obtained from project plans[i]. Measurements of noise conditions occurred before removal of the existing AC (baseline condition), after application of DGAC, after application of OGAC and then periodically during the OGAC pavement aging process. Asphalt material pavement types are described in Chapter 600 of the Highway Design Manual and summarized as follows. Pavement conditions are shown in Figure 2-3.

> **DGAC** consists of a mixture of bituminous material (paving asphalt) and a close graded aggregate ranging from coarse to very fine particles. DGAC is designated as Type A or Type B, depending on the specified aggregate quality and mix design criteria appropriate for the job conditions. Type A DGAC was used for this project.
>
> **OGAC** is a surface course used primarily over DGAC. The primary benefit of using OGAC is the reduction of wet pavement accidents by improving wet weather skid resistance, minimizing hydroplaning, reducing water splash and spray, and reducing nighttime wet pavement glare. Secondary benefits include better wet-night visibility of traffic stripes and markers, better wet weather (day and night) delineation between the traveled way and DGAC shoulders, and increased safety through reduced driver stress during rainstorms. OGAC surfacing is also known as an "open graded friction course".

Figure 2-3: Interstate 80 Pavement Conditions

a. Original AC Pavement

b. New DCAC Application

c. New OGAC Overlay

d. Aged OGAC Overlay

2.2 Noise Monitoring

Noise measurements were made using Larson Davis Model 820 Sound Level Meters with ½ inch diameter G.R.A.S. Model 40DP random incidence microphones. Noise levels were stored in 5-minute intervals and included L_{eq} and L_{50} data. A real-time analyzer (RTA) was used to collect 1/3-octave band data periodically during measurement periods. The systems were calibrated at the beginning and end of each test session with a Larson Davis Model CAL200 Acoustic Calibrator. Traffic noise measurements were made at the following positions from the freeway:

1. WB Ref: 65-ft (20-m) from the edge of the near travel lane, 10-ft (3-m) above the ground
2. WB Dist Low: 475-ft (145-m) from the edge of the near travel lane, 5-ft (1.5-m) above ground
3. WB Dist High: 475-ft (145-m) from the edge of the near travel lane, 15-ft (4.5-m) above ground
4. EB Ref: 65-ft (20-m) from the edge of the near travel lane, 10-ft (3-m) above the ground
5. EB Dist Low: 475-ft (145-m) from the edge of the near travel lane, 5-ft (1.5-m) above ground
6. EB Dist High: 475-ft (145-m) from the edge of the near travel lane, 15-ft (4.5-m) above ground

Reference locations (WB Ref, EB Ref) were measured during all monitoring periods. Distant measurements (WB Dist High, WB Dist Low, EB Dist High, EB Dist Low) were made during the 1999, 2000, 2002, and 2003 and during the summer monitoring periods in 2004 and 2005. Short-term distant measurements were made during all measurement periods. An intermediate westbound location was monitored during the summer 2005 measurement periods.

Onboard sound intensity (OBSI) tire/pavement noise measurements were conducted for the OGAC overlay aged condition in September 2002, April 2003, June 2004, December 2004, April 2005, and June 2005. Measurements were conducted in the right lane of traffic in both the eastbound and westbound traffic directions.

2.3 Interference from Non-Highway Noise Events

To avoid substantial interference from noise sources other than the freeway, noise levels were measured continuously in 5-minute intervals. The reference noise measurement locations were attended periodically during the measurement periods and the distant locations, when used, were attended throughout the length of the measurement period. Observers recorded noise levels associated with non-I-80 traffic events (e.g., aircraft, commuter rail, frontage road local truck traffic, etc.) to allow for editing of non-highway noise events from the data record.

The WB Ref location was mostly unaffected by noise sources other than freeway traffic. When the WB Ref noise levels were suspected of being affected by non-freeway sources, the data were eliminated. This occurred infrequently, but occasional weed control or freeway incidents that lead to interferences with the noise data. The EB Ref location was occasionally affected by trucks using the adjacent frontage road (East Chiles Road). Traffic along this roadway was infrequent during the early years of this study, but appears to be increasing slightly due to development further west. Increasing traffic on the frontage road affects the eastbound reference noise levels slightly throughout the noise monitoring periods. We estimate this effect to currently be on the order of 0.5 to 1.5 dBA. Due to the interference at the EB Ref location, the data collected at the WB Ref site appears to be most reliable for evaluating the noise level reductions from the OGAC overlay. Findings in this study are primarily based on the WB Ref data set.

The WB Dist locations were affected by traffic on the frontage road, as well as occasional aircraft and train passages. Westbound frontage road traffic was infrequent, with a high percentage of trucks that access the nearby landfill and vehicle speeds of about 35 to 45 mph (70 to 80 kph). Although infrequent, local traffic affected the measured L_{eq} substantially during almost all measurement intervals at the WB Dist sites, causing the L_{eq} noise levels for the WB Dist High and WB Dist Low locations to be much greater than the L_{50} levels. Because L_{eqs} at the WB Dist sites were contaminated by non-freeway noise, the L_{50} at these sites along with the L_{50} at the WB Ref site were used to describe noise attenuation. Periodically at the westbound distant sites, simultaneous freeway-only noise measurements were made by pausing the meter when other sources were significant. These data were compared with corresponding continuous L_{50s} measured at the sites and found to be within one dBA agreement.

The EB Dist locations were affected by infrequent farming activities and occasional aircraft or distant train passages. Tall corn or sunflowers during many of the summer measurement periods appeared to substantially affect the propagation of freeway traffic noise at this location, especially the microphone position 5-ft (1.5-m) above the ground. Data for any 5-minute interval that was substantially affected by non-freeway sources were discarded from the data set. As opposed to the WB sites (which are described using L_{50} noise attenuation), the noise attenuation at the EB sites is described using L_{eq} data. Regular monitoring of EB distant locations was discontinued in 2002 due to the difficulty in obtaining comparable data.

2.4 Meteorological Data

Meteorological conditions, which substantially influence traffic noise levels at distant locations, were measured in 5-minute intervals simultaneous to noise monitoring during most measurement periods. Meteorological monitoring included measurements of air temperature and wind speed/direction. A summary of the measured meteorological conditions for each measurement period is included in Appendix B.

Measurements were conducted during daytime hours (between 9:00 AM and 1:00 PM) and typically consisted of mostly clear skies (sun obscured by clouds less than 30% of each measurement period). Measurements were conducted in late fall under colder conditions 40 to 50ºF (5 to 10ºC) to evaluate any seasonal changes that might be attributable to pavement temperature. Temperatures in late fall were typically in the range of 45 to 55ºF (7 to 12ºC) while summer temperatures were typically 70 to 85ºF (20 to 30ºC). Spring measurements were around 15 to 20ºC. Except for late fall, all periods had a normal low-level temperature lapse of about –0.056ºF/ft (-0.10ºC/m) present. For comparison of spring and summer conditions, these meteorological conditions (with the exception of wind) were considered equivalent in terms of the effect on noise attenuation for all of the measurement periods. Because baseline measurements were conducted under summer conditions, summer measurements are emphasized in the report for comparison to baseline data.

Wind conditions varied considerably between measurement periods. Data for the distant sites were categorized as *Upwind*, *Downwind*, or *Calm* using measured and observed meteorological conditions. Wind conditions are characterized by the magnitude of the cross-vector wind component with respect to the roadway: *Upwind* is less than 3.9-ft/s (+1.2-m/s); *Calm* is between –3.9-ft/s and +3.9-ft/s (–1.2-m/s and +1.2-m/s); *Downwind* is greater than 3.9-ft/s (1.2-m/s). Because the study area topography is flat and open, a wind flow is usually present during spring through fall. Measurements were avoided when winds exceeded about 18-ft/s (5.5 m/s). The magnitude of the vector component of wind velocity that crosses the roadway (cross vector component) was calculated using a roadway bearing of 80º relative to truth north. Winds tend to flow from either northerly or southerly directions, which can be seen in the crosswind vector component data averaged for each period. A wind blowing from the southerly direction from the freeway to the WB Dist positions would be considered "downwind" and the opposite condition would be considered "upwind". Wind direction and strength also changed considerably during some measurement periods; therefore, the average cross-vector component for each period does not describe wind flow accurately. These data indicate that wind was the measured meteorological variable that likely had the greatest effect on traffic noise attenuation to the distant measurement locations.

2.5 1/3-Octave Band Data

Simultaneous with the collection of continuous A-weighted data during each measurements day, at least two 5-minute samples were collected at each location using a real time analyzer (RTA) to measure sound levels at 1/3rd octave bands. The systems were calibrated at the beginning and end of each test session with a Larson Davis Model CAL200 Acoustic Calibrator. The samples were representative of free flowing traffic conditions and do not include any interferences from other sources.

2.6 Traffic Conditions

This section of Interstate 80 is a six lane divided freeway facility that lies in a floodplain, has no grade or cross slope, and is on a long tangent that passes through undeveloped agricultural fields. Urban development is occurring on the western end of the project area and is generating higher traffic on the eastbound frontage road. A dense 20-30 foot wide thicket of oleander vegetation separates the eastbound and westbound traffic lanes. Traffic conditions were monitored during all noise measurements to allow for normalization of the reference location noise levels. Manual vehicle volume counts were made almost continuously and separated into 5-minute intervals to correlate with noise and meteorological measurements. Traffic speeds were estimated from spot measurements of passing vehicles using a handheld radar gun. All traffic data were broken down by vehicle type: light-duty vehicles (e.g., passenger autos and pickup trucks), medium-duty trucks (e.g., delivery trucks with two axles and six wheels), heavy-duty trucks (e.g., trucks with separated trailers and more than two axles and dump trucks), buses, and motorcycles. Hourly average vehicle counts are shown in Appendix D.

Interstate 80 through the study area is a busy freeway with a considerably large amount of truck traffic. Average Annual Daily Truck Traffic reports for 2004 indicate daily traffic of 138,000[1] vehicles. Trucks are reported to make up 7.4% of the volume on a daily basis. Truck volumes counted in this study were found to make up almost 10% of the volume. The higher measured truck percentage (compared to those reported above) may have resulted because the measurements were conducted during off-peak travel periods. Traffic speeds appeared to be constant throughout the study. Typical auto speeds were consistently in the range of 67 to 71 mph (108 to 115 kph), while truck speeds were in the range of 60 to 65 mph (95 to 105 kph).

2.7 Traffic Noise Modeling

Measured traffic conditions were converted to hourly data and input to the Federal Highway Noise Administration's Traffic Noise Model Version 2.5 (TNM)[ii]. TNM was used to normalize traffic conditions for evaluating the noise levels changes at the reference locations attributable to pavement. It was not used to test or validate the model for the measured conditions. At the start of the study (1998), TNM 1.1 was the most up to date traffic model available from FHWA. Results were updated using TNM 2.1 in 2002. A more recent update, TNM 2.5, includes substantial acoustic changes to the model and for this 7th year summary report, all data was remodeled using TNM 2.5. Because modeling is only used in

[1] West of the I-80 and US 50 junction, about 3 kilometers or 5 miles east of the study area.

this study to normalize traffic conditions, normalized results are similar to findings of the previous summary years.

Vehicle mix and traffic speeds were based on field observations and traffic volume counts. TNM showed about a 1-dBA variation in the noise level resulting from the typical variations in traffic speeds encountered. Default (68ºF or 20ºC and 50% humidity) meteorological conditions and default “Average” pavement type were used in the model. A dense vegetation median, 8-ft (2.4-m) high was used to simulate the landscaped median (oleander bushes). Field grass ground type was used to describe the default ground (the selection of different ground types had little effect on the reference location model predictions). Temperature and humidity had up to a 0.3-dBA effect on the results at the reference locations (up to 0.9 dBA at the distant locations). As indicated above, free-flowing traffic speeds did not vary much during the measurements. Slowed traffic conditions were rarely encountered in this study and always occurred during the 9am to 10am hour. All data for slowed traffic (or traffic congestion) were discarded. Some TNM predictions were performed for the distant locations using a small sample of results from each measurement day.

Corrections for temperature or relative humidity were not made to the data. The model inputs included soft ground conditions (i.e., field grass). The exception was on the eastbound side for about 50 percent of summer days when corn was present across much of the sound propagation path (about 330-ft or 100-m of the 475-ft or 145-m path). The cornfield was modeled as a tree zone.

2.8 Normalization of Traffic Noise Levels

Differences in noise levels between baseline and post-overlay conditions were normalized for varying traffic volumes using TNM 2.5. To normalize the data, the calculated difference between modeled traffic volumes for baseline and a post-overlay monitoring period was subtracted from the calculated difference in measured noise levels between the same two monitoring periods as shown below:

$$\Delta_i = (Lmea_i - Lmea_b) - (Lmod_i - Lmod_b)$$

where:

- Δ_i is the normalized difference between the average noise level for a given post-overlay condition (*i*) and the average noise level for the baseline condition (*b*);
- $Lmea_i$ is the average measured noise level for a given post-overlay condition (*i*);
- $Lmea_b$ is the average measured noise level for the baseline condition (*b*);
- $Lmod_i$ is the average modeled noise level for a given post-overlay condition (*i*); and
- $Lmod_b$ is the average modeled noise level for the baseline condition (*b*).

Using this method, changes in noise levels between baseline and post-overlay conditions were adjusted to reflect changes in traffic volumes. Differences between modeled noise levels were small, typically less than 1-dBA.

3 Results of Measurements and Modeling

3.1 Noise Level Monitoring Results: Reference Positions

A summary of the noise levels measured at the WB Ref and EB Ref positions during all summer monitoring periods are shown in Figures 3-1a and 3-1b.

Figure 3-1a: Measured Noise Levels during Summer Monitoring Periods (WB Ref)

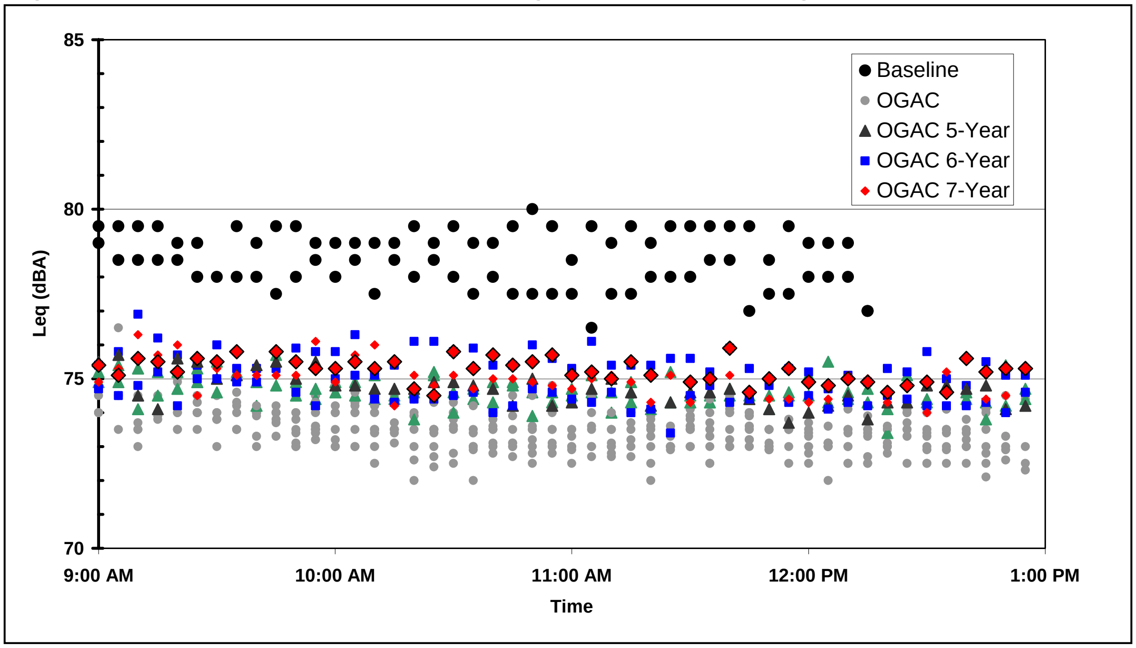
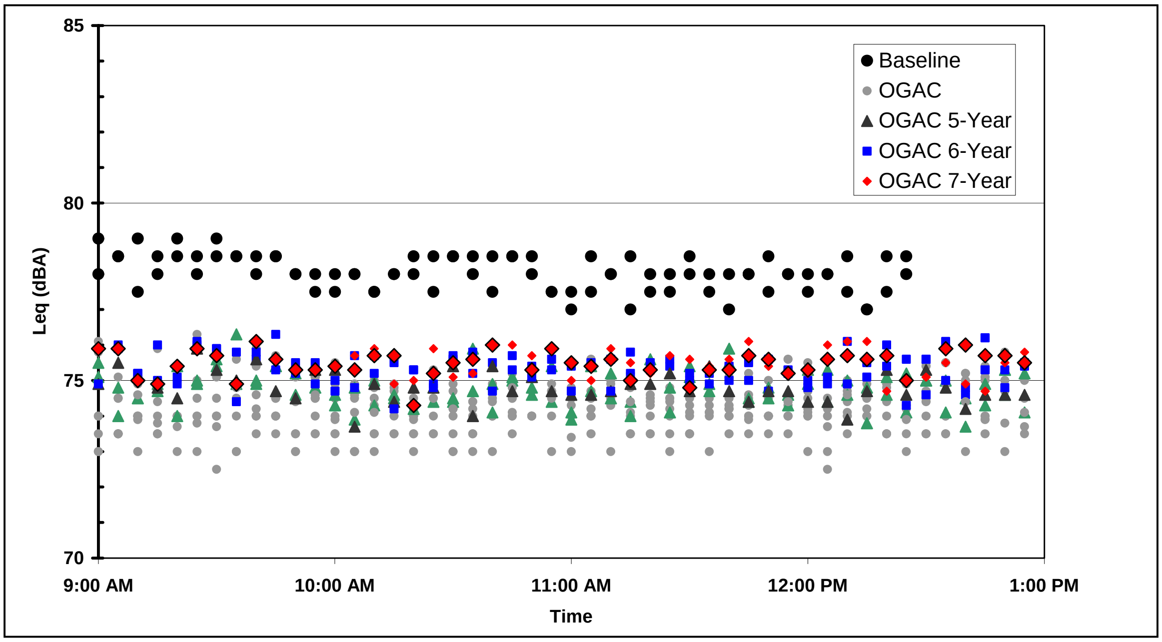


Figure 3-1b: Measured Noise Levels during Summer Monitoring Periods (EB Ref)



Although there is considerable variation in measured noise levels due to traffic, meteorological, and other variables, measured traffic noise levels following application of the OGAC were substantially lower than the baseline noise levels and continue to be lower after 7 years. A daily summary of measured and modeled A-weighted noise levels for WB Ref and EB Ref are shown in Figures 3-2a and 3-2b. Measured noise levels in Figures 3-2a and 3-2b are not normalized for changes in traffic or meteorological conditions.

Figure 3-2a: Trends in Measured and TNM 2.5 Modeled Noise Levels (WB Ref)

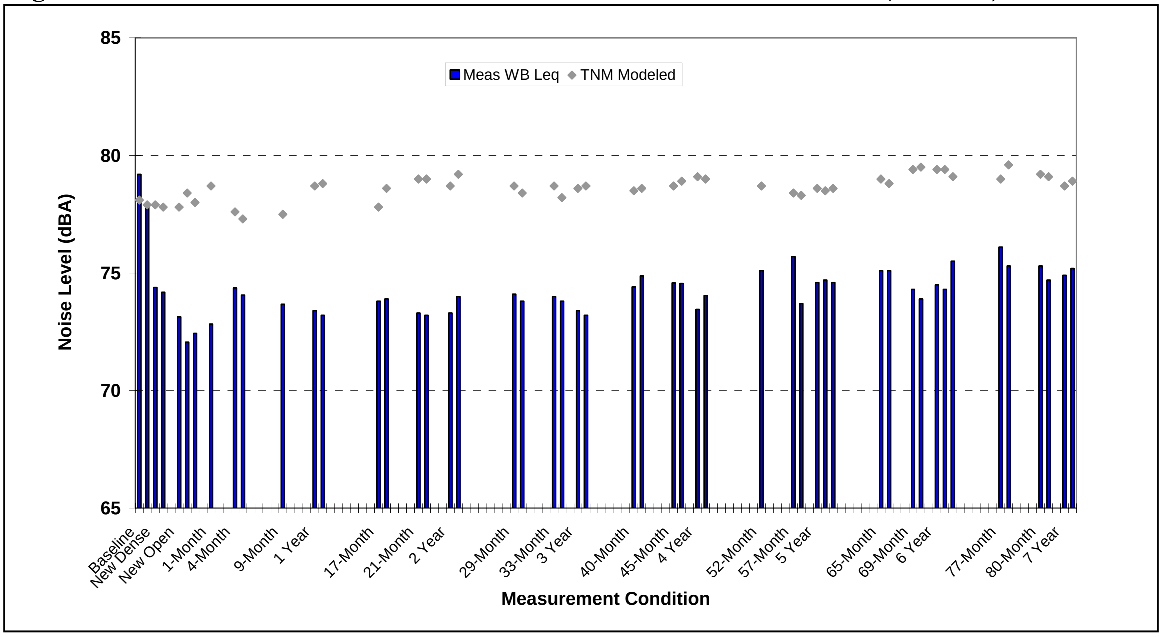
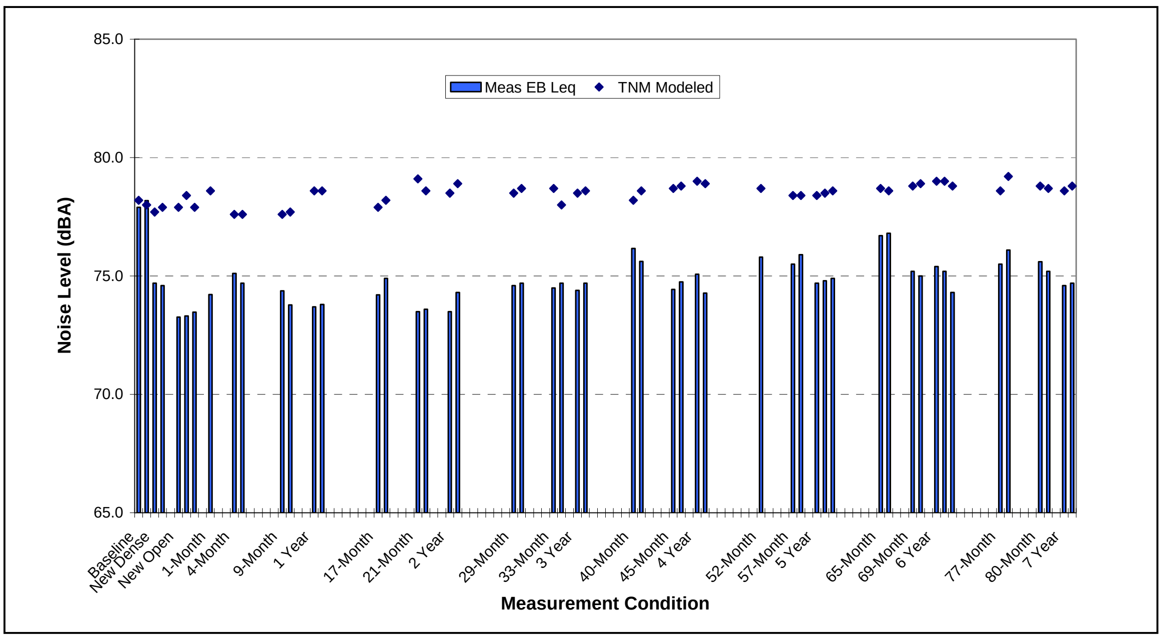


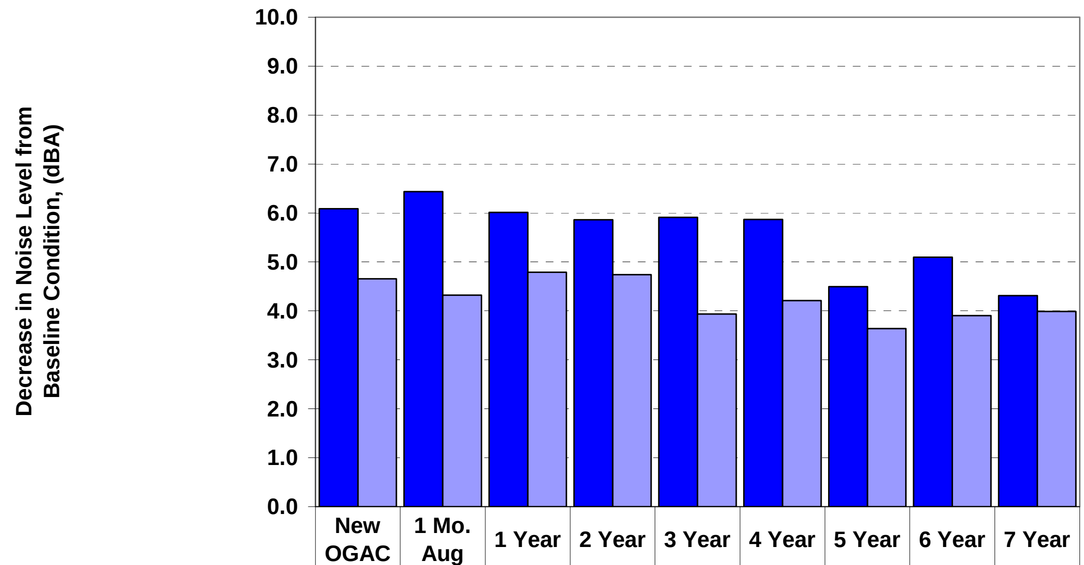
Figure 3-2b: Trends in Measured and TNM 2.5 Modeled Noise Levels (EB Ref)



Based on the TNM 2.5 results, traffic appears to have increased slightly over the last 7 years, accounting for variations of up to 2 dBA between traffic conditions. Post overlay measured traffic noise levels were found to be 4 to 6 dBA lower than the baseline noise levels at WB Ref and 4 to 5 dBA lower than baseline levels at EB Ref throughout all monitoring periods. The TNM modeling results show that this decrease cannot be accounted by traffic conditions.

Figure 3-3 shows the difference between baseline noise levels and levels measured after the OGAC overlay during summer measurement periods for both WB Ref and EB Ref locations normalized using the TNM 2.5 model results with the monitored traffic conditions.

Figure 3-3: Normalized Decrease in Noise Level from the Baseline Condition during Summer Monitoring Periods (WB Ref and EB Ref)



		New OGAC	1 Mo. Aug	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year
WB Reference	78.6	6.1	6.4	6.0	5.9	5.9	5.9	4.5	5.1	4.3
EB Reference	78.1	4.7	4.3	4.8	4.7	3.9	4.2	3.6	3.9	4.0

Age of Pavement

At WB Ref, noise levels decreased by almost 4 dBA with application of the new DGAC (not shown on this figure). The OGAC pavement overlay provided about 6 dBA of noise reduction during the first 4 years and has provided a steady ~4.5-5.0 dBA reduction over the last three years. After 7 years, the OGAC pavement is calculated to provide 4.3 dBA of noise reduction when compared with the original aged pavement.

Noise levels at EB Ref decreased about 3 dBA after application of the new DGAC (not shown on this figure). About 4 to 5 dBA of noise reduction was calculated during the first 4 years below baseline levels. In the 5th, 6th, and 7th year, noise measurements indicated that the noise reduction from OGAC is about 3.5 to 4 dBA.

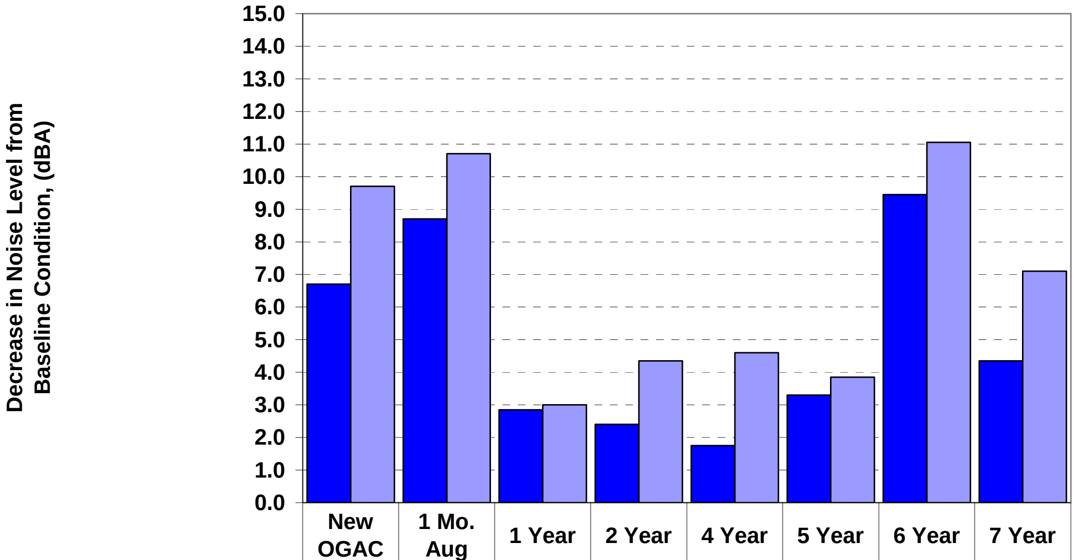
The greater reduction in noise levels at the WB Ref location is likely due to interference from local frontage road traffic at the EB Ref position. Baseline noise levels at the EB Ref locations were about 0.5 dBA lower than the WB Ref location and interferences from local traffic appear to increase the EB Ref noise levels with the OGAC by 0.5 to 1.0 dBA. The actual reduction at EB Ref is probably 0.5 to 1.0 dBA greater than reported due to the interferences from local frontage road traffic.

Overall, the noise measurement and traffic modeling data indicate that the OGAC pavement reduced noise levels by 4 to 6 dBA at a distance of 5-ft (20-m) from the edge of the near travel lane. This reduction is still readily apparent 7 years after application of the OGAC overlay.

3.2 Noise Level Monitoring Results: Distant Positions

Monitoring of EB Dist locations was discontinued in 2002 due to field conditions (the field was used to grow tall corn). The following assessment is based on WB Dist results only. Figure 3-4 shows the difference between baseline noise levels and noise levels measured after the OGAC overlay during summer measurement periods, normalized for varying traffic conditions using TNM 2.5 model results with the monitored traffic conditions. Daily traffic volumes and noise levels were averaged for each summer monitoring period that included distant location monitoring. Results were not normalized for meteorological conditions.

Figure 3-4: Decrease in Noise Level from the Baseline Condition during Summer Monitoring Periods, Normalized for Traffic (WB Dist)



	New OGAC	1 Mo. Aug	1 Year	2 Year	4 Year	5 Year	6 Year	7 Year
WB Dist High 62.8	6.7	8.7	2.9	2.4	1.8	3.3	9.5	4.3
WB Dist Low 58.1	9.7	10.7	3.0	4.4	4.6	3.9	11.1	7.1

Although considerable variation in the measured noise levels at the distant site occurred, resulting primarily from wind conditions, noise reduction from the baseline conditions is still apparent by the general trend of the data. An average calculated noise reduction of 7 dBA was found at the ground level position (WB Dist Low) and an average calculated reduction of 5 dBA was found at the raised position (WB Dist High). To further assess the effect of the OGAC overlay on traffic noise levels at the distant positions, measured noise levels for baseline conditions were compared with noise levels associated with the OGAC under comparable wind conditions (see Figures 3-5a and 3-5b). Temperature, vertical temperature structure and humidity were assumed to have only a small or negligible effect on noise propagation to over 450 feet. Noise levels were not normalized for traffic conditions in these figures.

Under downwind conditions, when noise levels are highest, levels appear to be reduced by about 4 to 5 dBA with the OGAC overlay. Upwind conditions produce considerably more variation in measured levels because wind noise interferes with the lower traffic noise levels. Nevertheless, an average reduction of about 3 to 4 dBA is indicated under upwind conditions with the OGAC overlay. These reductions are apparent, even after 7 years.

Figure 3-5a: Measured Noise Levels by Wind Condition during Summer Monitoring Periods (WB Dist High)

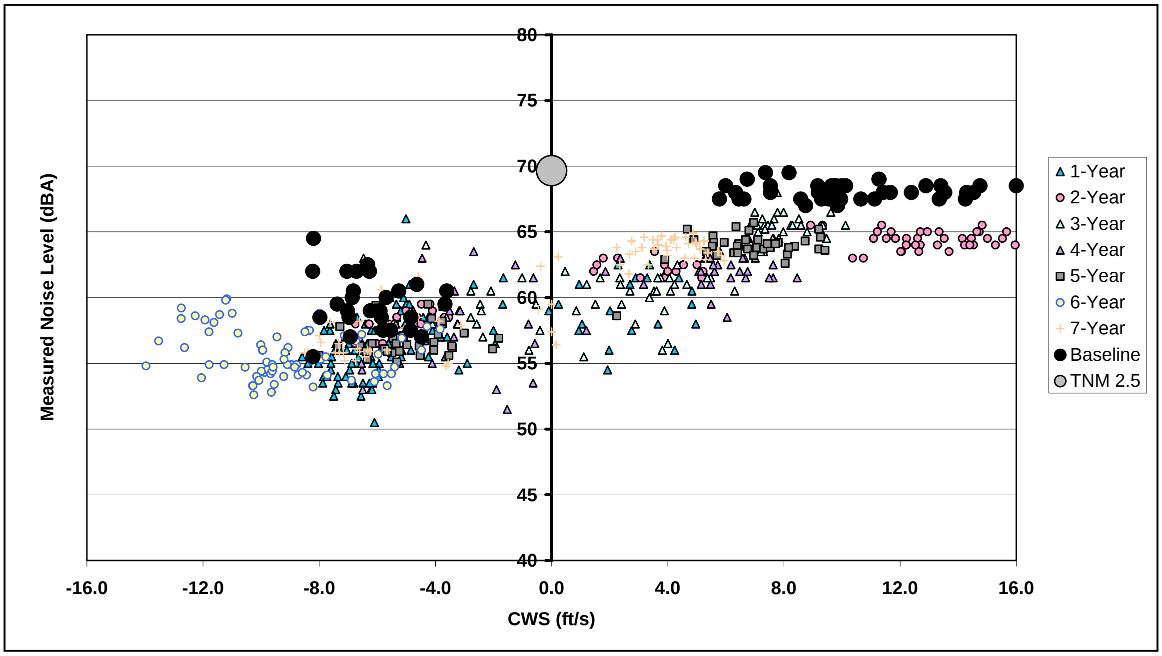
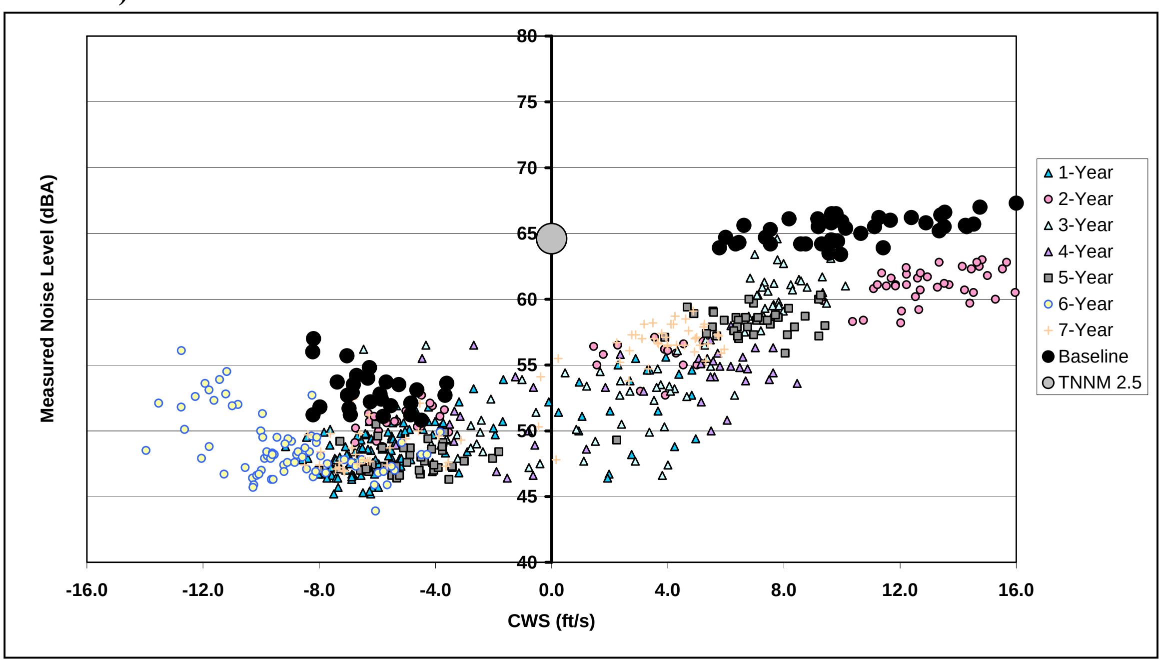


Figure 3-5b: Measured Noise Levels by Wind Condition during Summer Monitoring Periods (WB Dist Low).



3.3 1/3-Octave Band Data

A summary of the spectral data collected at the WB Ref and EB Ref locations during summer measurement periods is shown graphically in Figures 3-6a and 3-6b.

Figure 3-6a: WB Ref Traffic Noise Spectra

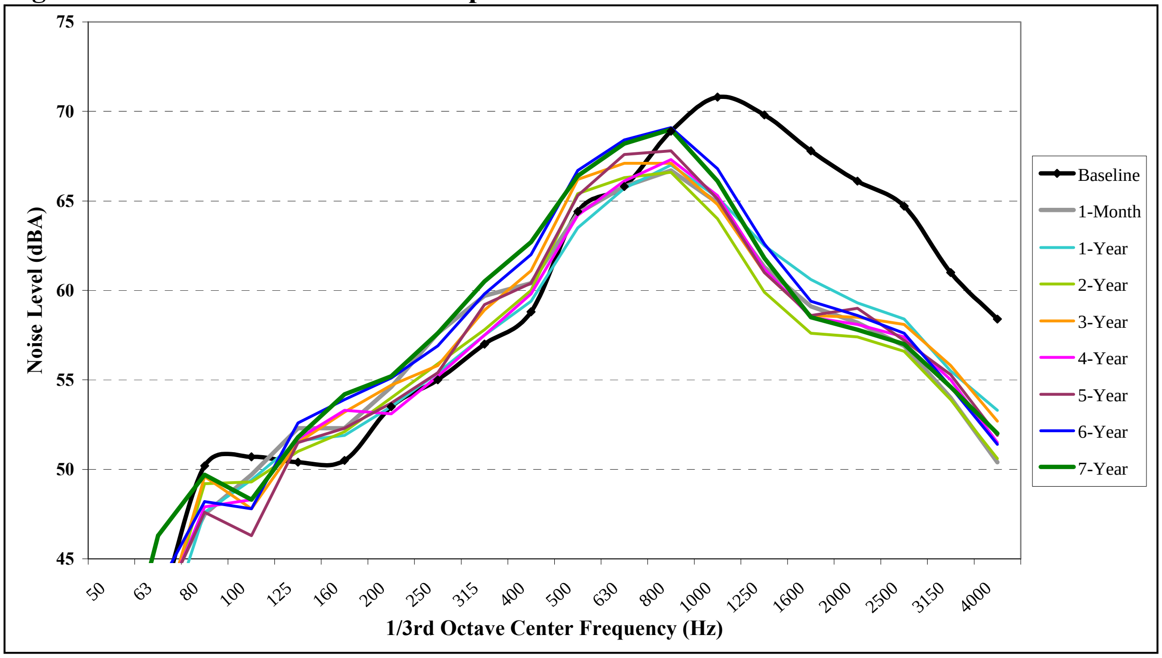
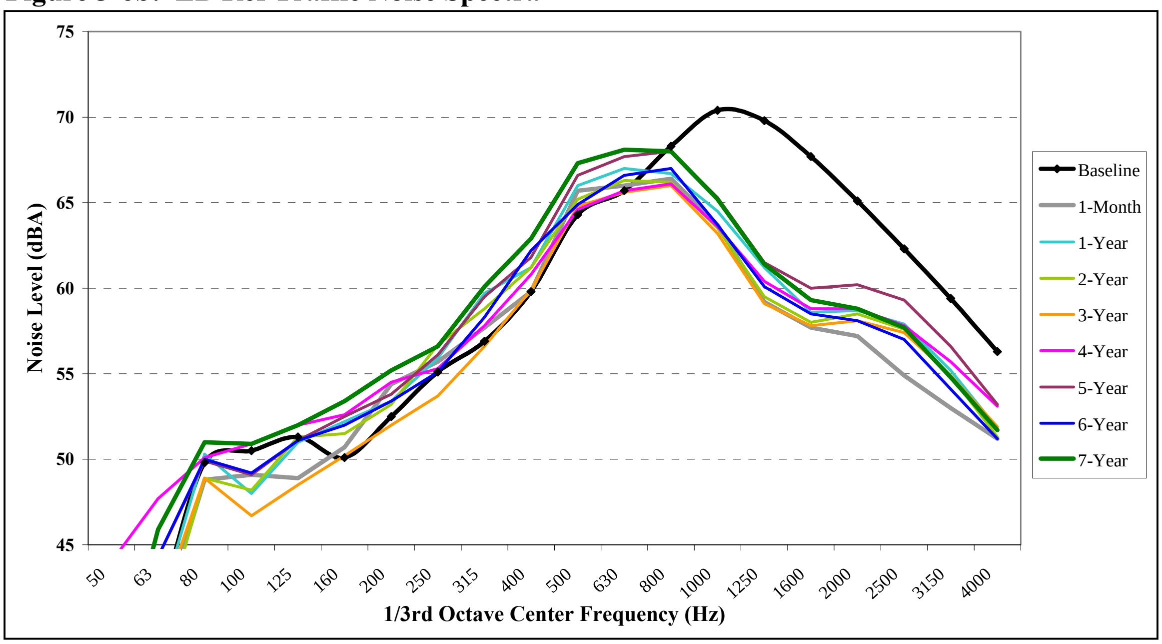


Figure 3-6b: EB Ref Traffic Noise Spectra



The measured noise spectra at the WB Ref and EB Ref locations were similar and showed consistent trends. Noise spectra for the baseline and the OGAC overlay conditions were similar for frequencies below about 1000 Hz. For frequencies between 1000 Hz and 4000 Hz, noise levels associated with the new OGAC overlay were 5 to 10 dB lower than those measured during baseline conditions. The aging OGAC overlay exhibits a slight increase in noise levels over time, while maintaining the same approximate noise spectra characteristics. Now into the 7th year, noise levels continue to be about 4 to 9 dB lower than baseline conditions at frequencies above 1000 Hz.

Summaries of the spectral data collected at the WB Dist High and WB Dist Low locations during downwind conditions are shown graphically in Figures 3-7a and 3-7b.

Figure 3-7a: WB Dist High Traffic Noise Spectra, Downwind

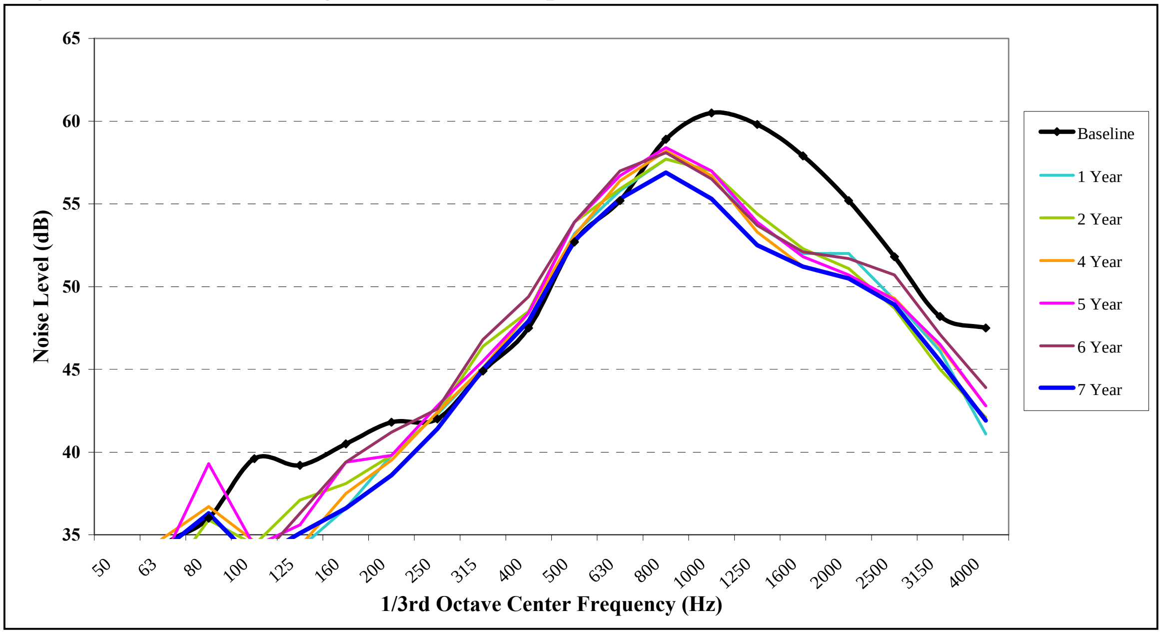
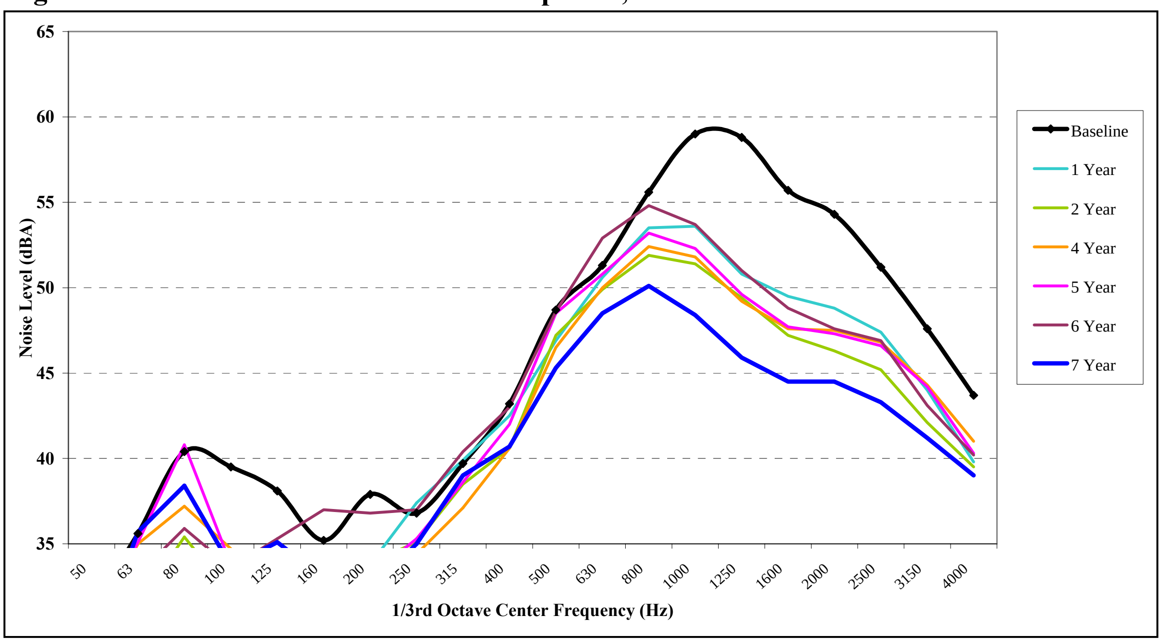


Figure 3-7b: WB Dist Low Traffic Noise Spectra, Downwind



Summaries of the spectral data collected at the WB Dist High and WB Dist Low locations during upwind conditions, which were typically 5 to 10 dB quieter than downwind conditions, are shown graphically in Figures 3-8a and 3-8b.

Figure 3-8a: WB Dist High Traffic Noise Spectra, Upwind

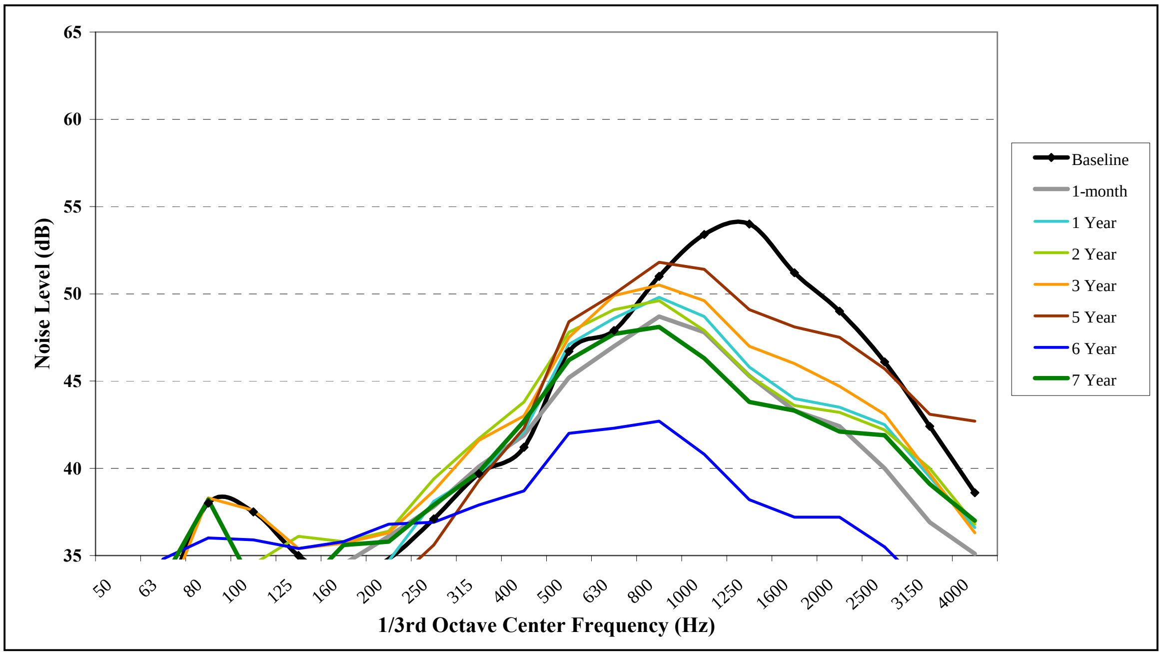
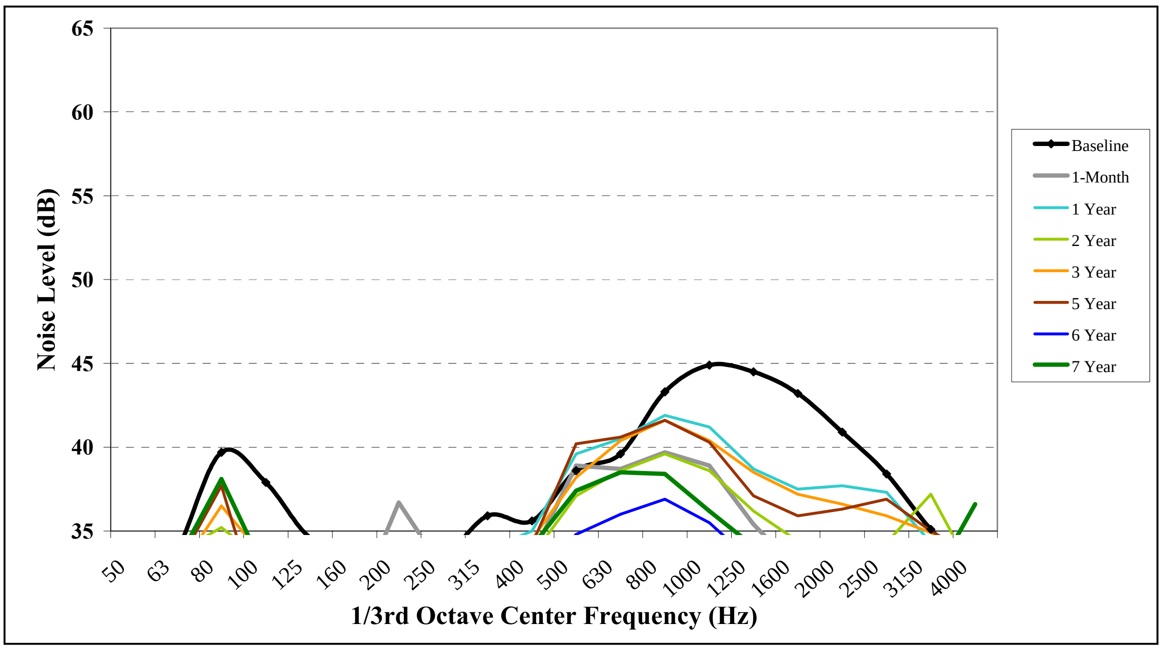


Figure 3-8b: WB Dist Low Traffic Noise Spectra, Upwind



Representative 1/3-octave band data collected at the distant sites (WB Dist High and WB Dist Low) showed similar trends in noise levels with the OGAC overlay those measured at the reference positions, with substantial decreases occurring fro 1000 Hz to 4000 Hz. For all distant sites, baseline noise conditions were higher than OGAC overlay conditions, especially around 1000 to 2000 Hz. Decreases to noise levels occurred at both WB Dist Low and WB Dist High monitoring positions under both downwind and upwind conditions. Although the overall noise level varied between measurements due mainly to differences in wind conditions, the spectral shape at the distant locations was consistent with the OGAC pavement overlay.

3.4 Onboard Sound Intensity

In addition to the wayside data, onboard sound intensity (OBSI) tire/pavement noise was measured for the OGAC overlay aged condition. The sound intensity measurements were conducted using the I&R Subaru Outback test vehicle with the Goodyear Aquatred 3 test tire. Under this procedure, the sound intensity fixture and associated microphones are attached to and supported by the test vehicle to allow for measurement positions that are very close to the leading or trailing edge of the tire contact patch (see Figure 3.9). Data from these two locations are obtained separately for the same section of pavement and then later averaged together to determine the intensity of the sound propagating away from the tire/pavement interface toward the "wayside" or community. Pavement sections were measured in the right lane of both eastbound and westbound directions. Testing was conducted at a test speed of 60 mph (97 kph).

Figure 3.9: Sound intensity probe mounted on right rear wheel of test vehicle

The sound intensity 1/3rd octave band spectra are shown in Figure 3-10a for all measurement periods at the westbound side and in Figure 3-10b for both the eastbound and westbound travel lanes during the 7-year June measurements. OGAC overlay conditions cannot be compared to the baseline condition because sound intensity was not measured for the baseline condition or the new OGAC overlay condition. However, it is apparent in Figure 3-10a that the sound intensity spectra have not changed substantially in the three years of testing.

Figure 3-10a: Tire/Pavement Sound Intensity Spectra OGAC Overlay, Westbound

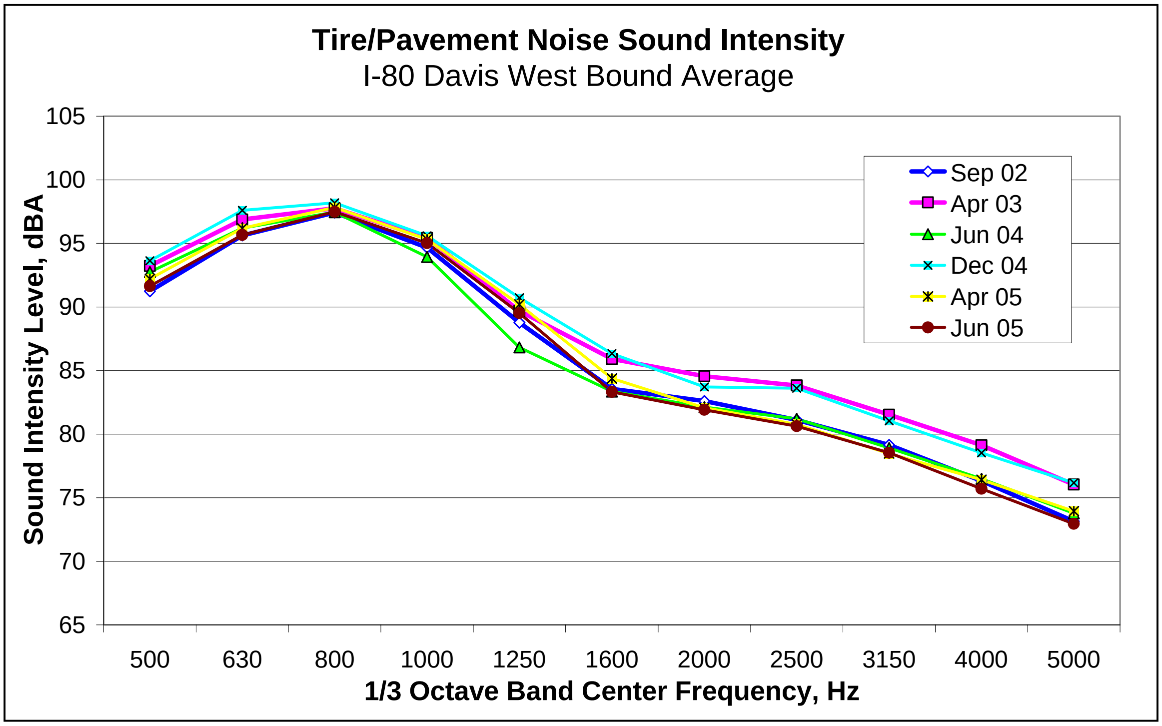


Figure 3-10b: Tire/Pavement Sound Intensity Spectra OGAC Overlay, June 2005

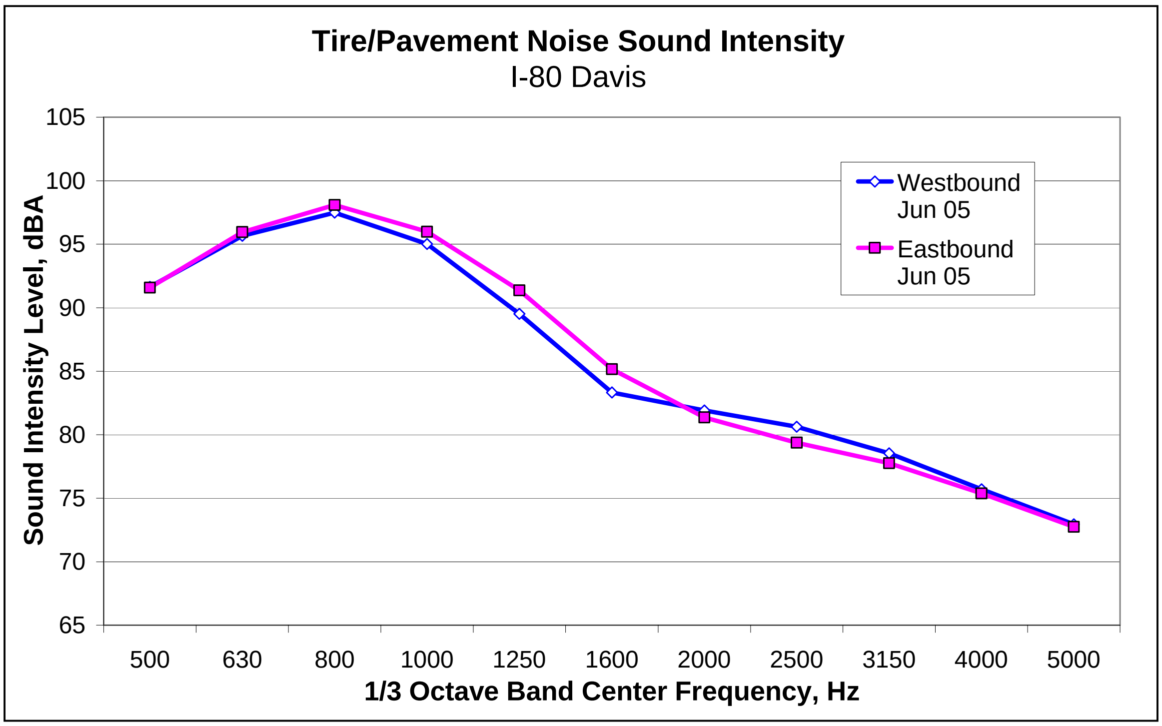
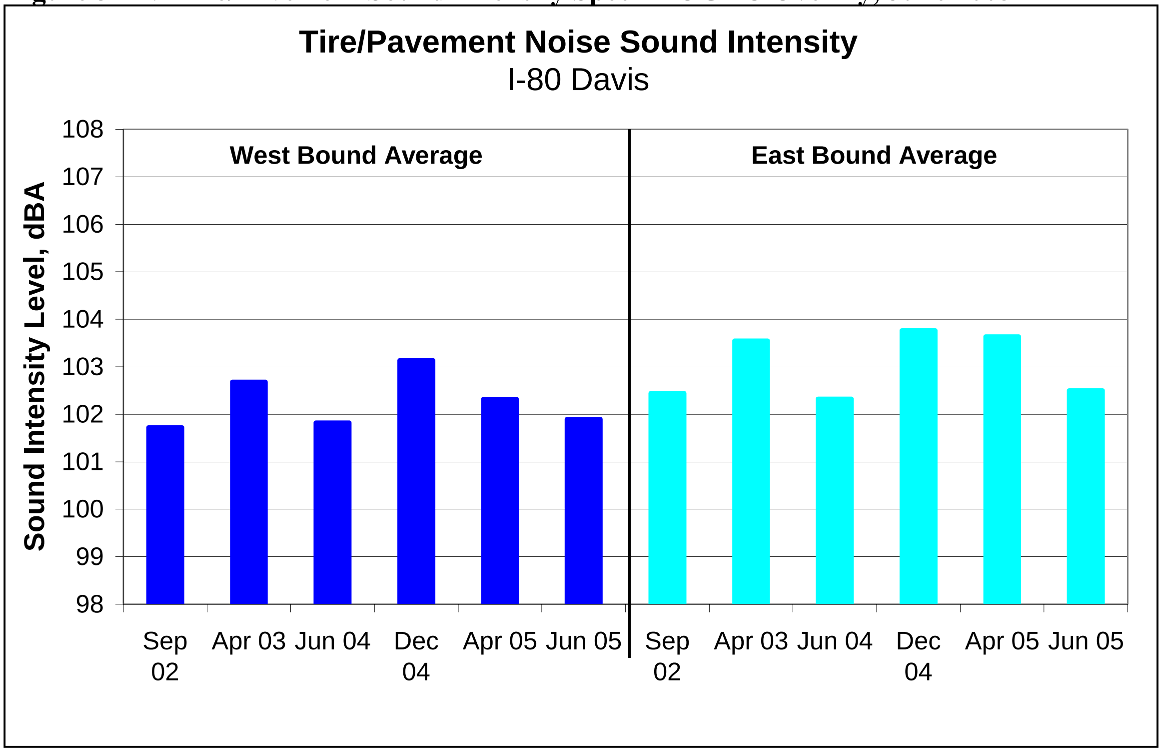


Figure 3-11 shows the A-Weighted sound intensity level measured during each measurement period. Similarly to wayside measurements, OBSI levels consistently varied by season, but did not appear to be increasing. Noise levels were approximately 1 dBA louder during winter measurements than during summer measurements, implying that temperature has some effect on the measured levels. This is also apparent in the spectra shown in Figure 3-10a. In addition, sound intensity levels were about 0.5 dBA quieter as measured on the eastbound side of I-80 than on the westbound side.

Figure 3-11: Tire/Pavement Sound Intensity Spectra OGAC Overlay, June 2005



3.5 Meteorological Conditions

Measurements conducted in June and April were made under mostly clear daytime conditions where a temperature lapse rate was present. Considerable fluctuation in measured traffic noise levels occurred at the distant sites due primarily to changes in meteorological conditions. The study area and surroundings are flat, causing wind flow to be essentially unobstructed. The freeway runs generally east-west. Wind primarily blows across the roadway from southerly or northerly directions. This typically results in a downwind or upwind condition at the measurement positions. Figures 3-12a and 3-12b show the affect of wind on sound propagation at the distant sites and the attenuation predicted by TNM for neutral conditions. The sound propagation is calculated as the *delta* or drop off rate between the reference position and the distant position.

Wind was found to have a substantial effect on measured traffic noise levels at the distant positions. The effect of the magnitude of the crosswind vector over a range of +4 to –4 m/s was typically 10 dB for the elevated position (15-ft or 4.5-m above ground) and 15 dB for the ground level position (5-ft or 1.5-m above ground). Wind appeared to affect the ground level position differently than the elevated position, especially for downwind conditions. The effect of wind on received noise levels appears to be complex. There was considerable scatter in the data, especially for calm and upwind conditions, indicating that wind was not the only variable and/or that the measurement methodology used to describe wind is too simplistic to be completely accurate. In addition, traffic noise levels are low under upwind conditions at the distant positions, causing wind noise to become more dominant at higher wind speeds.

TNM 2.5 under predicted the attenuation by about 6 dBA at the WB Dist Low position and by about 3 dBA at the WB Dist High position under neutral wind conditions.

Figure 3-12a: Effect of Wind on Noise Propagation – WB Dist High

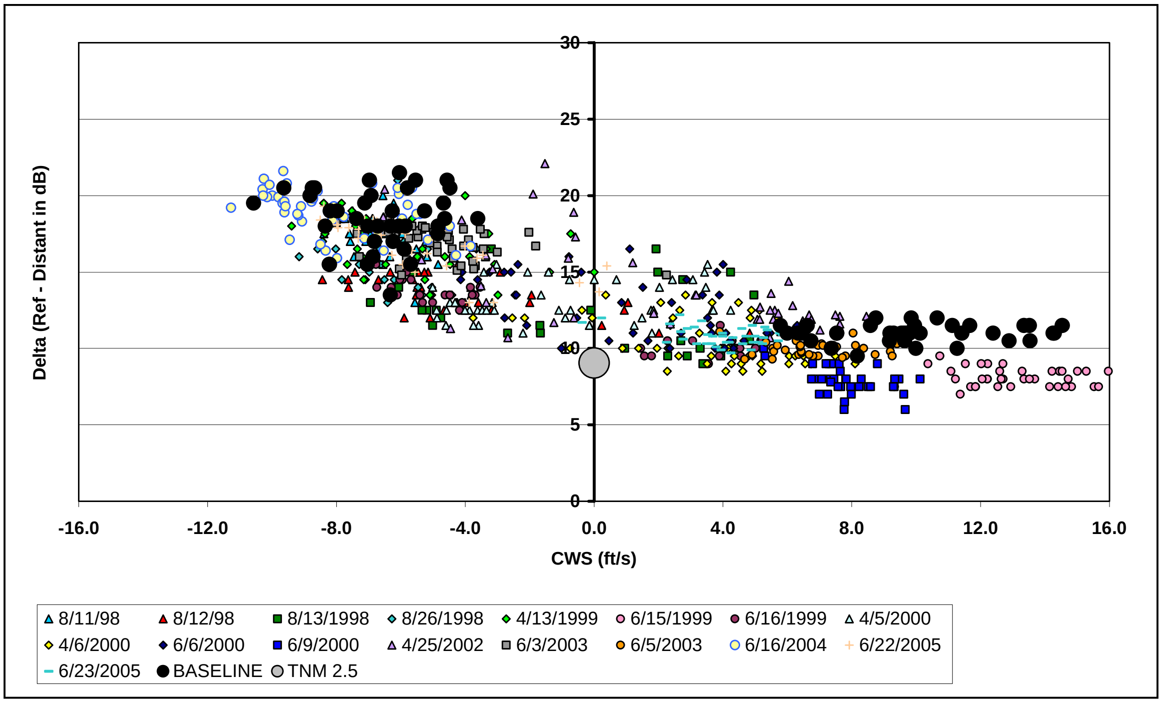
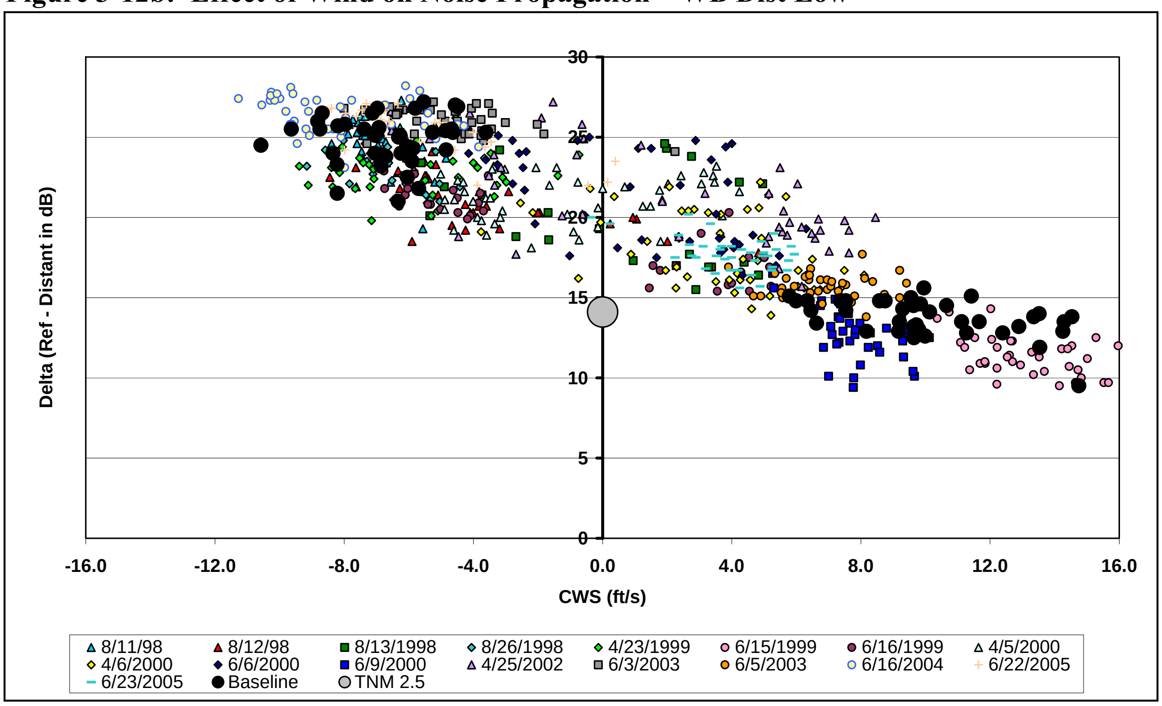


Figure 3-12b: Effect of Wind on Noise Propagation – WB Dist Low



4 EQUIVALENT NOISE BARRIER ANALYSIS

TNM 2.5 was used to determine the barrier height that would be required to obtain the same amount of noise reduction as that produced by the OGAC overlay. In this analysis, the average hourly traffic data for the June 2005 measurement periods was input to the model with a *field grass* ground type and *average* pavement type. The barrier was modeled for the westbound side of the roadway only and was modeled at the edge of the westbound shoulder. Results of the analysis are presented in Table 4-1 for barrier height increments of 2-ft (0.6-m) over the range from 6 to 16-ft (1.8 to 4.9 m).

Table 4-1: Analysis of Traffic Noise Reduction Produced by Roadside Sound Wall

Measurement Position	*Measured Noise Reduction*	Barrier Height (Ground type=Field Grass)					
		6-ft	8-ft	10-ft	12-ft	14-ft	16-ft
WB Ref	***4 to 6***	3	6	8	11	13	15
WB Dist High	***4 to 5***	4	5	6	6	11	12
WB Dist Low	***4 to 5***	2	2	3	6	7	8

Review of these results indicates that an 8-ft (2.4-m) high barrier would be required to achieve the same level of noise reduction performance at the WB Ref and WB Dist High positions as that of the OGAC overlay. A 12-ft (3.7-m) high barrier would be required to achieve the same reduction at the WB Dist Low measurement position.

5 TRAFFIC NOISE MODELING SENSITIVITY TEST

The purpose for using the TNM model was to normalize measurement results for the varying traffic conditions, rather than accurately predict traffic noise levels at the microphone positions. However, the large differences in measured and modeled noise levels warrant some investigation. The model inputs included soft ground conditions (i.e., field grass), and *Average* pavement type. The exception was on the eastbound side for about 50 percent of summer days when corn was present across much of the sound propagation path (about 330-ft of the 475-ft path), which was modeled as a tree zone. A dense vegetation median, 8-ft (2.4-m) high was used to simulate the landscaped median (oleander bushes). The model under predicted noise levels by about 3 dBA for both 65-ft (20-m) measurement locations under pre-overlay pavement conditions. Corrections for temperature or relative humidity were not made to the data.

TNM 2.5 under-predicted traffic noise levels by about 0 to 1.0 dBA for the test baseline cases at the reference positions and over predicted traffic noise levels by 3 to 6 dBA after placement of the OGAC during summer and spring monitoring periods. TNM 2.5 showed about a 1-dBA variation in the noise level resulting from the typical variations in traffic speeds encountered.

Table 5-1 shows the difference at each westbound measurement position between the different pavement and ground type conditions and the "standard" condition used throughout the study. The following discussion is based on modeling results using the average hourly traffic conditions for the 7th Year Summer measurements (2005). WB Int represents an intermediate position measured during the summer 2005 monitoring period, 130-ft (40-m) from the edge of the near travel lane, and 5-ft (1.5-m) above the ground.

Table 5-1: Analysis of TNM Modeling Conditions of Pavement Type and Ground Cover

Measurement Position (Measured Post-Overlay Level)	TNM 2.5 Model Results (dBA)					
	Average Pavement Type		OGAC Pavement Type		PCC Pavement Type	
	Field Grass (Standard)	Hard Soil	Field Grass	Hard Soil	Field Grass	Hard Soil
WB Ref (75 dBA)	**78.7**	**79**	**76.9**	**77.4**	**80.8**	**81.1**
WB Int (68 dBA)	**75.1**	**76.4**	**73.2**	**75.4**	**77.2**	**78.3**
WB Dist High (64 dBA)	**69.9**	**70.1**	**67.5**	**69.1**	**71.1**	**71.9**
WB Dist Low (57 dBA)	**65.2**	**69.3**	**60.8**	**69.1**	**64.0**	**70.6**
	Modeled Difference From Standard Model Condition					
WB Ref		0.3	-1.8	-1.3	2.1	2.4
WB Int		1.3	-1.9	0.3	2.1	3.2
WB Dist High		1	-1.6	0	2	2.8
WB Dist Low		6.8	-1.7	6.6	1.5	8.1

5.1 Sensitivity to Ground Type

It is difficult to assess the measured drop off rate, due to the meteorological influences at the distant positions, which are not accounted for in TNM 2.5. However, the measured average drop off rate is estimated to be 6 to 7 dBA per doubling of the distance from the roadway. TNM 2.5 indicates that noise levels drop off at a rate of about 5 to 6 dBA per doubling of the distance from the roadway using *Field Grass* and about 3 to 4 dBA per doubling of the distance from the roadway using *Hard Soil*. Changing the ground type to *Hard Soil* raised the modeled noise levels by 0.3 at the WB Ref position, by 1 to 2 dBA at the WB Dist High and WB Int positions, and by 7 dBA at the WB Dist Low positions.

5.2 Sensitivity to Pavement Type

Using *Average* pavement type, TNM 2.5 over-predicted the measured levels for the 2005 summer OGAC overlay conditions by about 4 dBA at the reference positions and by 6 to 8 dBA at the distant sites. A modeled pavement type of *OGAC* with *Field Grass* predicted noise levels of about 2 dBA below *Average* pavement conditions, but would still result in over-predictions of about 2 dBA at the WB Ref position, about 7 dBA at the WB Int position, and by about 4 dBA at the distant positions.

6 CONCLUSIONS

The A-weighted noise levels measured at the reference and distant sites on each side of the road indicate that substantial decreases in traffic noise occurred after the placement of the new OGAC overlays. Measurements conducted after the DGAC pavement base overlay occurred represent recent application conditions of the structural DGAC pavement type (within 3 weeks of the top lift of OGAC pavement placement). This study did not collect any data that would indicate the acoustical characteristics of base lift of DGAC as it ages.

Traffic noise levels following application of the OGAC were substantially lower than the baseline noise levels at the reference locations and continue to be lower after 7 years. The effect of pavement on noise levels at the distant sites was difficult to assess due to the variation in meteorological conditions and ground cover. Results were normalized for changes in traffic conditions using TNM 2.5, but the effects due to changes in ground cover and meteorological conditions could not be used to assess the data. Despite these complications, the data indicates a noise level decrease at distant sites after the new pavement was applied. Due to local frontage road traffic interference at the EB Reference location and inconsistent field conditions on the EB side, findings are based primarily on WB Ref and Dist site results. Principal findings developed from this data set are as follows:

1. At the reference locations, noise levels decreased by about 4 dBA below baseline conditions after application of the structural DGAC. The long-term acoustical characteristics of this briefly exposed structural section of DGAC as it ages were not studied.

2. The pavement overlay of OGAC (Type A) provided about 6 dBA of reduction during the first 4 years and has provided a steady ~4.5-5.0 dBA reduction over the last three years. After 7 years, the pavement is calculated to provide 4.3 dBA of noise reduction at the reference sites when compared with the baseline conditions.

3. On average, noise levels at the distant positions were reduced below baseline levels by at least 4 dBA with the OGAC overlay. It is difficult to assess this reduction due to the variation in noise levels that is associated with changes in meteorological conditions and ground cover. The noise level reduction was still evident after 7 years since the OGAC overlay.

4. 1/3rd octave band spectra show a consistent signature of OGAC conditions for the 7-year aged pavement. This is evident at the reference positions and at the 475-ft (145-m) distant positions for 5-ft (1.5-m) and 15-ft (4.5-m) above ground. The signature is evident under both downwind and upwind conditions.

5. Seasonal trends with the OGAC overlay show a general tendency for higher noise levels (by about 1 dBA) in the winter months that are apparently attributable to changes in seasonal temperature.

6. Wind was found to have a substantial effect on measured traffic noise levels at the distant positions. The effect of the magnitude of the crosswind vector over a range of +4 to –4 m/s was typically 10 dB for the elevated position (15-ft/4.5-m above ground) and 15 dB for the ground level position (5-ft/1.5-m above ground).

7. Using *Average* pavement type and *Field Grass* ground cover, the TNM 2.5 model under-predicted baseline traffic noise levels by 0 to 1 dBA and over-predicted post overlay traffic noise levels by 3 to 6 dBA at the reference sites. Under calm wind conditions, TNM 2.5 under-predicted noise levels by about 4 dBA at WB Dist High and by about 6 dBA at WB Dist Low.

Findings of this study are so far limited to conditions on I-80, which included a relatively high percentage of trucks (about 2-3% medium-duty and 7% heavy-duty trucks), and high traffic speeds (~70 mph or ~110 kph). Effects, such as vehicle mix, vehicle speed, baseline pavement condition, and shielding effects, could affect the magnitude of noise level reductions attributable to OGAC overlays. This portion of I-80 does not experience snow and freezing conditions with moisture are rare.

7 PERSONNEL

The Principal Investigator for this report was Mr. James Reyff of Illingworth & Rodkin, Inc. Technical direction and oversight was provided by Mr. Richard Rodkin, P.E. and Dr. Paul Donavan of Illingworth & Rodkin, Inc. Ms. Dana Lodico of Illingworth & Rodkin provided field support and was the author of this report. Additional field support was provided by Mr. Mike Thill (noise measurements), Mr. Phil Williams (traffic measurements), and Mr. Jared McDaniel of Illingworth & Rodkin. Additional field staff was provided from Denise Duffy and Associates and in previous years by Haygood & Associates and Woodward Clyde. Technical and management oversight by Caltrans was provided by Mr Bruce Rymer, P.E., Mr. James Andrews, P.E., Mr. Keith Jones, P.E, and Mr. Rudy Hendriks (retired from Caltrans, currently consults with Jones and Stokes Associates, Inc.). This work was begun under task orders issued through the statewide "on-call" noise and vibration contract (Contract No. 43A0009) managed by Mr. Rob Greene of URS (formerly Woodward Clyde Consultants) and was conducted under the recent contract managed by Mr. James Reyff of Illingworth & Rodkin, Inc. (Contract No. 43A0063).

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[i] Project Plans for Construction on State Highway in Yolo County in and near Davis from the Solano County Line to Yolo Causeway West, California Department of Transportation (Caltrans), Contract No. 03-444904, July 14, 1997.
[ii] FHWA Traffic Noise Model® User's Guide", Final Report, U.S. Department of Transportation, January 1998, revised Final Report April 2004.