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Interim Report – 2007 Testing

TIRE/PAVEMENT AND ENVIRONMENTAL TRAFFIC NOISE RESEARCH STUDY

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16. Abstract

This research study is being conducted in response to CDOT's interest in traffic noise in general, and the tire/pavement interaction in particular. Following a rigid set of testing protocols, data is being collected on highway traffic noise characteristics along with safety and durability aspects of the associated pavements. The overall goal of this research project is to develop and execute a comprehensive, long-term study to determine if a particular pavement surface type and/or texture can be successfully used in Colorado to help satisfy FHWA noise mitigation requirements. The study is needed to accomplish the following:

- Determine the noise generation/reduction characteristics of pavements as functions of pavement type, pavement texture, age, time, traffic loading, and distance away from the pavement;
- Determine a correlation between source measurements using on-board sound intensity (OBSI), and statistical pass-by (SPB) and time-averaged wayside measurements; and
- Accumulate information that can be used for validation and verification of the accuracy of the FHWA Traffic Noise Model (TNM) to use on future Colorado highway projects.

Implementation:

The information included in this report highlights the second in a series of four measurements to be collected over a five-year period. While some of this information can be used immediately for decisions related to pavement design and specification, it is recommended that caution be exercised as the results from future testing will help further define the long-term acoustical durability of these pavement surfaces.

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EXECUTIVE SUMMARY

This report summarizes interim results of a field-testing program to evaluate tire-pavement and environmental noise of representative pavements throughout the State of Colorado. To date, tire-pavement noise has been measured using two unique technologies: close-proximity (CPX) and on-board sound intensity (OBSI). However, testing now focuses on the latter technique since it has become the standard in the USA. Environmental noise was measured using wayside (roadside) microphones that capture traffic noise in a manner that is more relevant to the potential impacts to highway abutters. The test results provided in this interim report are from 2007. Comparisons are also given to the results from testing conducted in 2006. Combined, the testing represents the first two years of a multi-year effort, with additional testing scheduled for 2009 and 2011 in order to further assess the long-term acoustical durability of the various pavements being evaluated.

Implementation Statement

The information included in this report highlights the second in a series of four measurements to be collected over a five-year period. While some of this information can be used immediately for decisions related to pavement design and specification, it is recommended that caution be exercised as the results from future testing will help further define the long-term acoustical durability of these pavement surfaces, which is sometimes (often unintentionally) overlooked as an important variable.

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INTRODUCTION

Background

Traffic noise pollution has become a growing concern to residents worldwide. This is particularly true in urban areas where the population density near major thoroughfares is much higher, and there is a greater volume of commuter traffic. To mitigate the noise – at least for residences directly adjacent to the highway – engineers at the Colorado Department of Transportation (CDOT) and elsewhere commonly resort to costly noise barriers. Although arguably the psychology of a noise wall is a factor, noise barriers including walls have not been shown to be an ideal solution for minimizing noise pollution in all cases. Sound tends to diffract over the top and around the ends of barriers, thus proving ineffective on arterial streets since the openings in the barrier required for side streets and driveways effectively defeat the benefits provided by the barrier. Furthermore, the mountainous terrain commonly found in the State of Colorado can further challenge the effectiveness of barriers.

In recent years, alternative solutions to noise barriers have been advanced – ones that may be able to mitigate noise for drivers, adjacent residences, and even for citizens farther from the highway. Driven in large part by public outcry, national policy, and eventually directives to reduce noise, engineers in the European Union and elsewhere have developed alternative pavement types and surfaces that reduce noise generated at the tire-pavement interface.

The noise produced from tire-pavement interaction is just one of several types of traffic noise. However, for many roads with low truck volumes, it becomes the primary source of traffic noise for vehicular speeds over 35 mph. While not a cure-all, certain pavement type and texture options have led to improvements in noise levels; in some cases, reducing the need for or height of noise walls and improving the quality of life.

For a more thorough discussion on these topics, one of the better sources is the FHWA *Little Book of Quieter Pavements*, which can be downloaded from the website http://www.tcpsc.com/LittleBookQuieterPavements.pdf .

As a matter of federal policy (23 CFR 772), pavement type or texture cannot be considered as traffic noise abatement in projects receiving federal funding. For pavement effects to be considered in determining impacts or as a mitigation technique, a so-called Quiet Pavement Pilot Program (QPPP) must be approved and in place. Under a QPPP, a commitment must be made by the State Highway Agency to guarantee, in perpetuity, noise mitigation through use of a specified pavement type and/or texture. To date, Arizona is the only state that has accepted this challenge, opting for an asphalt-rubber friction course (ARFC) as the "pavement" of choice. A lot has been learned since 2003 when ARFC resurfacing began under the QPPP. However, any state that is interested in asphalt-rubber or any other specific pavement type should first evaluate its noise reducing capabilities under local conditions.

Every state has unique conditions, with differences in characteristics and issues such as climate, traffic, materials availability, and maintenance. Choosing a "quiet pavement" alternative that is best for any state must account for all of these factors along with durability, cost, and safety. Currently, the factors that CDOT considers in pavement selection emphasize safety and durability. Life cycle cost analyses are performed to determine the most appropriate pavement type and/or rehabilitation technique for a given project. While noise is not currently a factor that is considered in CDOT pavement type selection process, it may eventually be used as a secondary consideration in environmentally sensitive areas and in cases where no significant differences in cost among alternatives have been determined.

Given the inherent issues with a QPPP, most states have instead opted to conduct Quiet Pavement Research (QPR). While the data that is collected under a QPPP and QPR is the same, no policy changes are made that would allow for a mitigation contribution from the pavements under investigation. Instead, if research is being conducted on a project that requires abatement, conventional means will need to be used until a QPPP is in place.

To meet the requirements of a Federal Highway Administration (FHWA) QPR program, the research should have an intended purpose, include a Data Acquisition Plan (DAP), and possess a reporting schedule frequent enough to demonstrate the various changes in the properties of the pavements under study over time. Within this research project, CDOT has drafted a DAP, which contains the various data collection, analysis, and reporting elements described in the FHWA model which, in turn, is based on that developed and implemented by the State of Arizona under their QPPP.

Within the current DAP, data are to be collected on tire-pavement and wayside noise, along with pavement, traffic, safety, and meteorological data. These data will be analyzed and reported in a fashion suitable to derive acoustic properties of various pavement types – by season, over time (and cumulative traffic), and correlated to the physical characteristics of the pavement and texture. Additionally, the data will be used to relate various noise measures to one another, particularly as standardization of these measures – at least, in the US – is an ongoing task within the industry.

Scope

This project is about examining current pavements in Colorado to determine their tire-pavement noise characteristics over a long period. In recent years, the FHWA has supported this through establishment of both a QPPP and guidelines for a QPR. For now, CDOT's emphasis will be on the latter, but the intent is to prepare for the possibility of entering the QPPP, depending on the results of the project.

The scope of this project is to assist CDOT with the collection of tire-pavement surface and environmental (wayside) noise data. This data is then organized and reported in such a manner to help fulfill the Department's mission of conducting a proper Quiet Pavement Research program.

Project Objectives

The primary objective of this study is to provide CDOT with tire-pavement and environmental traffic data that are reliable, accurate, and representative given the sheer variety of conditions within the State of Colorado – from both traffic and climatic perspectives. Supporting data on traffic and climate are collected simultaneously with noise measurements. Ultimately, these will be compiled along with numerous other data being collected by CDOT, and interpreted and reported accordingly. The goal is to fulfill the overall QPR requirements as well as the desire of CDOT to learn what various pavement types and/or textures might do to address or supplement overall noise mitigation requirements.

To meet this objective, a specialized database has been developed. It has been populated by data collected from 31 select pavement sections, as described in a QPPP/QPR Data Acquisition Plan (DAP). Along with noise (and related) data collected by Transtec, a variety of other information about the pavement sections will continue to populate this database, including items related to design, materials construction, climate, traffic, and maintenance.

As additional data are collected in subsequent years, the database will be used to fulfill at least three specific objectives, as follows:

1. To establish relationships between the various noise measures, their change over time, and the variables that may be contributors to both.

2. To establish relationships between and within the various noise measurement techniques – near-field (e.g., Close Proximity, CPX and On-Board Sound Intensity, OBSI), wayside (e.g., Statistical Pass-By Index, SPBI), and environmental (e.g., "SPBI+").

3. To assist in providing information suitable for validating and verifying the accuracy of the FHWA Traffic Noise Model (TNM) based on the pavements and other conditions unique to the State of Colorado.

DATA COLLECTION

So far under this project, data have been collected in 2006 and 2007. Additional repeat measurements are planned for 2009 and 2011. Thirty-one unique pavement sections are being evaluated, representing the vast array of pavement types and surface treatment textures that are currently used by CDOT. These are listed in Table 1 along with some additional identifying information.

Table 1. Site Location Information.

Site ID	Road	Direction	Location	Nearest City	Zip Code
1	SH 83	NB	Between. CR-14 & Hess Rd.	Parker	80134
2	I-70	EB	Between Evergreen Pkwy. & CR-65	Golden	80439
3	I-70	WB	Between Federal Blvd. & Pecos St.	Denver	80221
4	US 50	WB	Between 35 6/10 Rd. and Bridgeport Rd.	Grand Junction	81527
5	SH 74	EB	Between Bergen Pkwy. & Lewis Ridge Rd.	Evergreen	80439
6	US 50	EB	Between 35 6/10 Rd. and Bridgeport Rd.	Grand Junction	81527
7	US 85	SB	Between Daniels Park Rd. & Happy Canyon Rd.	Sedalia	80135
8	I-70	EB	Between US 6 & Herman Gulch Rd.	Bakerville (E.Dillon)	80444
9	C-470	WB (N)	Between US 285 & Morrison Rd.	Morrison	80465
10	US 287	SB	Between Bonner Spring Ranch Rd. & SH 14	Laporte	80535
11	SH 82	EB	Between Hunter Logan & Lower River Rd.	Basalt	81654
12	SH 58	WB	Between McIntyre St. & 44th Ave.	Golden	80403
13	I-25	SB	Between CR-12 and CR-10	Erie	80516
14	US 285	NB	Between Surrey Dr. & Goddard Ranch Ct.	Indian Hills	80465
15	I-25	NB	Between Fontanero St. & Fillmore St.	Colorado Springs	80907
16	SH 121	NB	Between Chatfield Ave. & Ken Caryl Ave.	Littleton	80128
17	I-70	WB	Between SH 13 and US 6/24	Rifle	81650
18	US 285	NB	BetweenTurkey Creek Rd. & Chamberlain Rd.	Indian Hills	80465
19	I-70	WB	Between Camino Dorado Rd. & Trail Gulch Rd.	Gypsum	81637
20	US 40	WB	Between CR-8 & SH 94	Kit Carson	80862
21	US 285	SB	Between Kipling Pkwy. & C-470	Morrison	80227
22	US 160	WB	Between CR-103 & Threemile Rd.	Alamosa	81101
23	I-70	EB	Between 23 Rd. & 24 Rd.	Grand Junction	81505
24	I-76	WB	Between CR-49 & SH 52	Hudson	80642
25	I-76	EB	Between 88th Ave. & 96th Ave.	Henderson	80640
26	I-25	SB	Between SH 105 & Higby Rd.	Monument	80132
27	C-470	WB (N)	Between Morrison Rd. & Alameda Pkwy.	Morrison	80228
28	Powers Blvd.	NB (W)	Between Union Blvd. & Old Ranch Rd.	Colorado Springs	80908
29	Powers Blvd.	SB (E)	Btw. Old Ranch Rd. & Union Blvd.	Colorado Springs	80908
30	US 85	NB	Btw. Daniels Park Rd. & SH 67	Sedalia	80135
31	I-70	EB	Btw. 15th St. & US 40	Georgetown	80444

Testing to date under this effort has been conducted by Robert Whirledge, Eric Mun, and Robert Light of Transtec. In 2007, the following measurements were made depending on the type of site:

1. **On-Board Sound Intensity (OBSI) –** a near-field technique that measures tire-pavement noise in close proximity to the source. Instead of measuring levels via sound pressure from a single microphone (as the ISO 11819-2 or "CPX" method does), OBSI measures tire-pavement noise using a phase-matched pair of microphones that are positioned in

such a way to isolate sound generated near the tire-pavement contact patch. The OBSI technique was originally developed by Dr. Paul Donavan of Illingworth & Rodkin while employed by General Motors. It was subsequently refined under sponsorship of Caltrans, and is now standardized nationally as AASHTO TP 76. Both ASTM and SAE also have OBSI standards under development. The current standard tire for OBSI measurements is the ASTM F 2493 Standard Reference Test Tire (SRTT) (P225/60R16). The Goodyear Aquatred III (P205/70R15) tire has also been used for both OBSI and CPX testing in the past. However, it is in the process of being dropped from the test program since it is no longer in production and the test results between the two tires have been found to be highly correlated. The standard test speed used in OBSI measurements is typically 60 mph (although two of the 31 test sections have been tested at 55 mph due to safety concerns).

2. **Statistical Pass-By (SPB) and Time-Averaged (TA) Wayside –** these measurements are made using a tripod-mounted microphone located at a fixed position (50 ft. from and 5 ft. higher than the center of the outside lane). In order to normalize for the traffic present during the measurements, there is a simultaneous collection of vehicle counts, classifications, and speeds. The SPB measurements collected in this effort have been made by adopting components of the ISO 11819-1 standard. To assist in developing Reference Energy Mean Emission Level (REMEL) type data for the various pavements under study, provisions of the FHWA "Measurement of Highway-Related Noise" have also been adopted, particularly those related to site selection, microphone positioning, data processing, and reporting (e.g., third-octave).

3. **Environmental Wayside –** these measurements are intended to be collected in the same manner as SPB/TA wayside measurements. They have been referred to as "SPBI+" by CDOT. The intent is to set up and measure from additional microphone positions at 100, 200, 400, and 800 ft. from the center of the outside lane. The reason that this information is desired is to attempt to characterize if the noise characteristics of different pavement types are significant at these distances, which would correspond to the locations of residences in these areas. Conducting these tests so far has not been possible due to the

inability to obtain the proper clearances for adjacent land access and/or contamination from other sound sources. There has also been issues raised from industry experts about the accuracy and usefulness of these type of measurements; at least, those 200 ft. and greater. In the testing that remains under this program, additional attempts will be made to collect this information.

4. **Supporting Data –** this includes climatic data via an on-site weather station, photographs and digital video, and site surveys to benchmark the begin/end points for each section along with the location of any wayside microphone positions.

Photographs of some of the test equipment can be found in Appendix A. Additional details for each site, along with the types of measurements collected are listed in Table 2.

RESULTS OF 2007 EVALUATION

The work conducted so far under this project has resulted in a large database of information. In addition to the various site reference information, such as that contained in Tables 1 and 2, it contains as-built plans and construction records for many of the 31 sites.

The noise data collected thus far have also been organized into the database and are classified in a hierarchical folder structure for ready access. Appendix B contains a detailed summary of the data collected in 2007 from each of the sites. This includes general information on the sites, followed by details of both the environmental and tire-pavement noise measurements.

A summary of the OBSI data (A-weighted Sound Intensity Level (SIL) in dB ref 1 pW/m^2) is given in Table 3. It should be noted that while the standard tire for OBSI testing is the SRTT, test results using the Aquatred III tire are also included for historical continuity. OBSI levels reported from the 2006 testing are also included, along with a calculated change in level.

Table 4 contains a summary of the SPB wayside testing including levels for both automobiles and heavy trucks. The results from 2006 are included here as well for comparison purposes.

Table 2. Additional Site Information.

Site ID	Surface Type	Construction Accepted [1]	CPX [2]	OBSI	SPB	TA	Approx. Lat.	Approx. Lon.	Approx. Elev. (ft.)	Section Length (ft.)	Wayside Mic Pos. from Begin (ft.)
1	SMA (3/4")	2004	✓	✓		✓	39.4883	104.7591	5960	1558	769
2	SMA (3/4")	1/2004	✓	✓		✓	39.7084	105.3511	7490	5308	4116
3	SMA (3/4")	10/2003	✓	✓			39.7841	105.0186	5330	3575	n/a
4	SMA (1/2")	8/2002	✓	✓	✓		38.8147	108.3385	5110	4847	1422
5	SMA (3/8")	7/2004	✓	✓			39.2861	107.1376	7680	3488	n/a
6	Asphalt (SX, 1/2")	8/2002	✓	✓	✓		38.8994	108.3666	5010	5333	1048
7	Asphalt (SX, 1/2")	2006	✓ [5]	✓ [5]	✓		39.4288	104.9111	6000	2686	1864
8	Asphalt (SX, 1/2")	2005 [3]	✓	✓			39.6976	105.8703	10470	3535	n/a
9	SMA (1/2")	6/2006	✓	✓		✓	39.6410	105.1723	5760	3033	2460
10	Asphalt (S, 3/4")	10/2003	✓	✓	✓ [2]		40.7113	105.1730	5470	3380	2649
11	NovaChip	10/2000	✓	✓			39.3389	106.9989	6880	3228	n/a
12	NovaChip	6/2003	✓	✓		✓	39.7706	105.1895	5600	3082	653
13	Concrete (Long. Tining)	10/2005	✓	✓		✓	40.0667	104.9809	5060	3389	1054
14	Concrete (Long. Tining)	10/1999	✓	✓			39.5838	105.2258	7130	1613	n/a
15	Concrete (Lon. Groov.)	11/2001	✓	✓ [2]			38.8672	104.8340	6130	4485	n/a
16	Concrete (Carpet Drag)	8/2001	✓	✓		✓	39.5741	105.0837	5580	2422	1323
17	Concrete (Dia. Grinding)	11/2005	✓	✓		✓	39.5205	107.8229	5290	6368	1177
18	Concrete (Dia. Grinding)	10/1999	✓	✓			39.5980	105.2255	7050	2069	n/a
19	SMA	8/1996	✓	✓	✓		39.6528	106.8823	6630	3122	443
20	Concrete	4/2002	✓	✓	✓ [2]	✓ [3]	38.8328	103.0540	4520	5241	2668
21	Asphalt (S, 3/4")	11/2003	✓	✓		✓	39.6438	105.1318	5700	3599	1451
22	Asphalt	10/1999	✓	✓	✓		37.5177	105.9948	7610	2930	796
23	Asphalt	10/2004	✓	✓			39.1138	108.6193	4560	3623	n/a
24	Concrete	3/2001	✓	✓			40.0942	104.6143	4940	3345	n/a
25	Concrete	11/2002	✓	✓			39.8655	104.9059	5120	2495	n/a
26	Concrete	10/1996	✓	✓			39.0862	104.8614	7010	1493	n/a
27	Concrete	1/2001	✓	✓			39.6759	105.1869	5890	7873	n/a
28	Concrete (Drag)	12/2004	✓	✓			38.9796	104.7574	7010	1804	n/a
29	SMA	9/2005	✓	✓			38.9790	104.7575	7010	1724	n/a
30	Concrete (Burlap Drag)	2003 [4]	✓ [5]	✓ [5]		✓ [3]	39.4365	104.9514	5870	3019	2657
31	SMA (3/4")	10/2006	✓				39.7286	105.6919	8560	5529	n/a

Notes: [1] Traffic loading may have begun prior to construction acceptance date; [2] 2006 testing only; [3] 2007 testing only; [4] To be confirmed; [5] Testing conducted at 55 mph; all others at 60 mph

Figure 1 includes a chart of measured OBSI levels using the SRTT tire. The rank order sorted by nominal pavement type (color) is based on the levels measured in 2007 (solid bars). The striped bars represent levels measured in 2006.

Table 3. OBSI Test Summary A-weighted SIL (dB ref 1pW/m²).

Site	OBSI – SRTT			OBSI – Aquatred III		
	2007	**2006**	**Chg.**	**2007**	**2006**	**Chg.**
1	102.0	102.7	-0.7	103.6		
2	105.5	102.9	+2.6	106.4		
3	105.1	104.0	+1.1	106.1		
4	102.4	101.4	+1.0	103.2		
5	102.7	102.3	+0.4	103.8		
6	102.7	101.6	+1.1	103.0		
7**	104.3	104.8	-0.6	105.6		
8	106.0	104.0	+2.0	106.8		
9	101.7	100.6	+1.1	103.1		
10	102.9	102.5	+0.4	103.4		
11	104.6	104.3	+0.3	105.4		
12	101.7	101.8	-0.2	103.6		
13	101.5	101.8	-0.3	102.9	103.6	-0.7
14	104.8	104.3	+0.5	105.2	105.5	-0.3
15		102.4				
16	103.3	102.8	+0.6	104.3	104.8	-0.5
17	103.5	101.6	+2.0		102.5	
18	104.7	104.5	+0.1	105.3	106.0	-0.7
19	105.0	104.7	+0.3	105.8		
20	102.1	101.9	+0.1	102.8	103.0	-0.2
21	105.1	104.7	+0.4	106.1		
22	103.2	103.4	-0.2	104.2		
23	103.2	101.6	+1.6	103.9		
24	101.0	102.2	-1.2	102.7		
25	102.2	102.2	0.0	104.1		
26	101.8	102.1	-0.3			
27	103.5	102.4	+1.1	103.8		
28	101.9	101.4	+0.5	103.8	102.8	+1.0
29	102.3	101.4	+0.9	104.6	102.7	+1.9
30**	102.8	102.4	+0.4	103.8		
31	104.9			106.3		

** Note: Results normalized to standard test speed of 60 mph.

Table 4. SPB Test Summary A-weighted SPL (dB ref 20 μPa).

Site	SPB 2007		SPB 2006		Change	
	Car	**Hvy. Truck**	**Car**	**Hvy. Truck**	**Car**	**Hvy. Truck**
4	75.3	80.8	74.1	80.8	+1.2	0.0
6	75.0	82.2	74.4	83.0	+0.6	-0.8
7	73.1	82.0	74.5	83.5	-1.4	-1.5
19	76.5	82.2	76.0	83.0	+0.5	-0.8
22	73.8	81.6	74.5	81.9	-0.7	-0.3

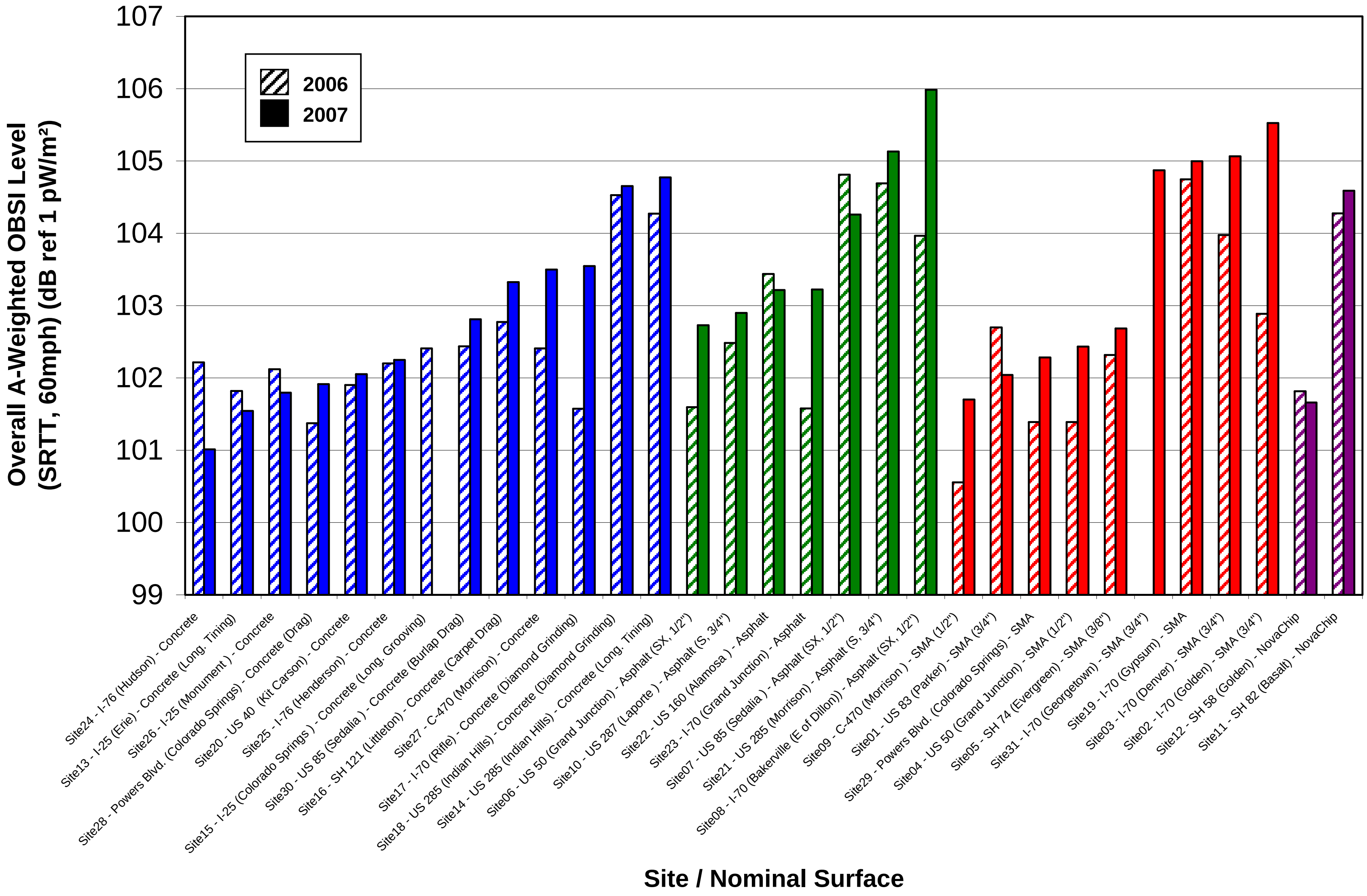

Figure 1. Summary of Overall OBSI Levels.

Relationship between Test Tires

Using the information that has been collected with the OBSI technique, a comparison was made of the overall sound intensity levels of the various test sections using the Aquatred III and SRTT tires. Figure 2 includes the trend that emerged. An additional trend line is included to compare this relationship with that derived from the 2006 OBSI data. In both cases, it can be noted that when the Aquatred III tire is used, the resulting sound level was approximately 1.1 to 1.4 dB higher than when the SRTT tire was used. The trends are good, indicating a high correlation between these two tires. The shift in the trends between the years is partly an artifact of having more sites evaluated with OBSI and both test tires. Numerous other sources of both systematic and random error are also contributors, as illustrated with SEE values of approximately 0.4 to 0.5 dB.

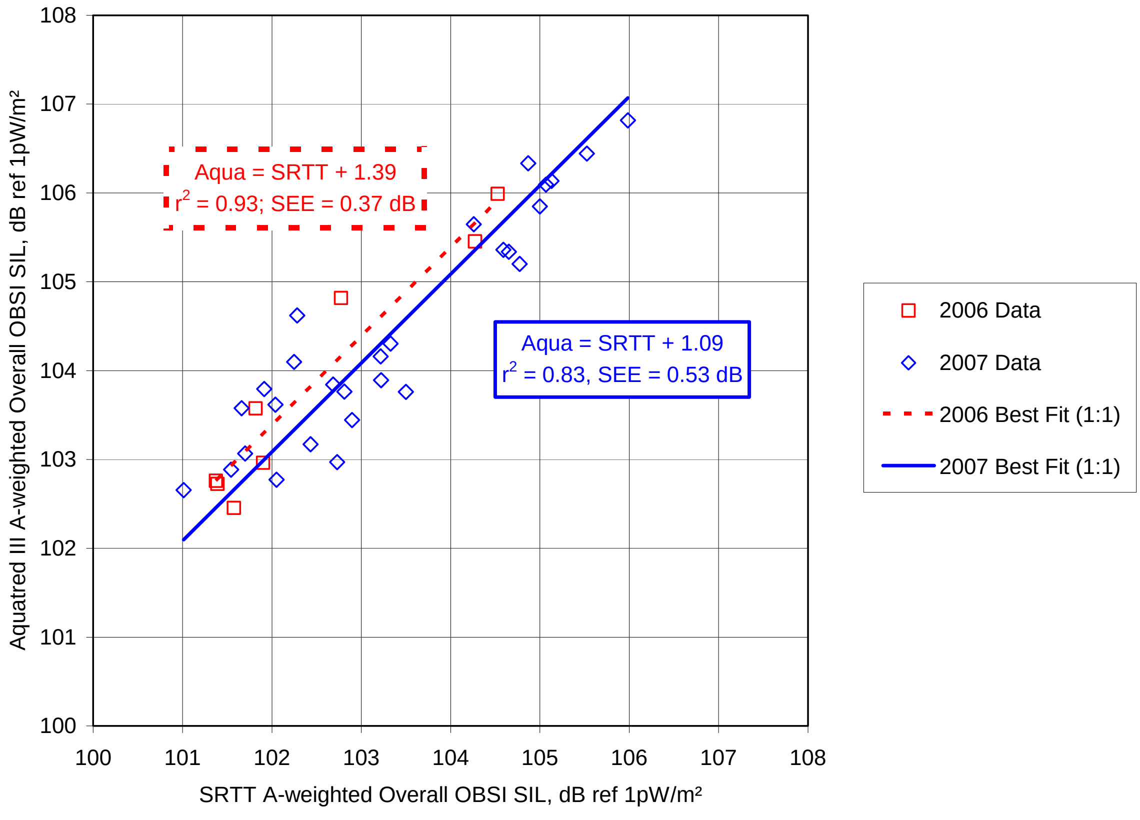

Figure 2. Comparison of OBSI Levels Using Aquatred III vs. SRTT Test Tires.

Relationship between OBSI and SPB Tests

On five of the sites in 2007, SPB data were collected, which permitted the estimate of an "average" car at 60 mph. This average is reported as an index level, as summarized in Table 4.

A comparison was made of the SPBI levels for cars and the corresponding estimated average OBSI levels using the SRTT tire at 60 mph. This is shown in Figure 3. At first glance from this plot, the relationship is rather weak. However, when using a best-fit 1:1 slope, the offset is 28.8 dBA, which is comparable to the offset of 28.5 dBA reported by Dr. Paul Donavan of Illingworth & Rodkin as part of the NCHRP 1-44 project (Noise-Con 2008).

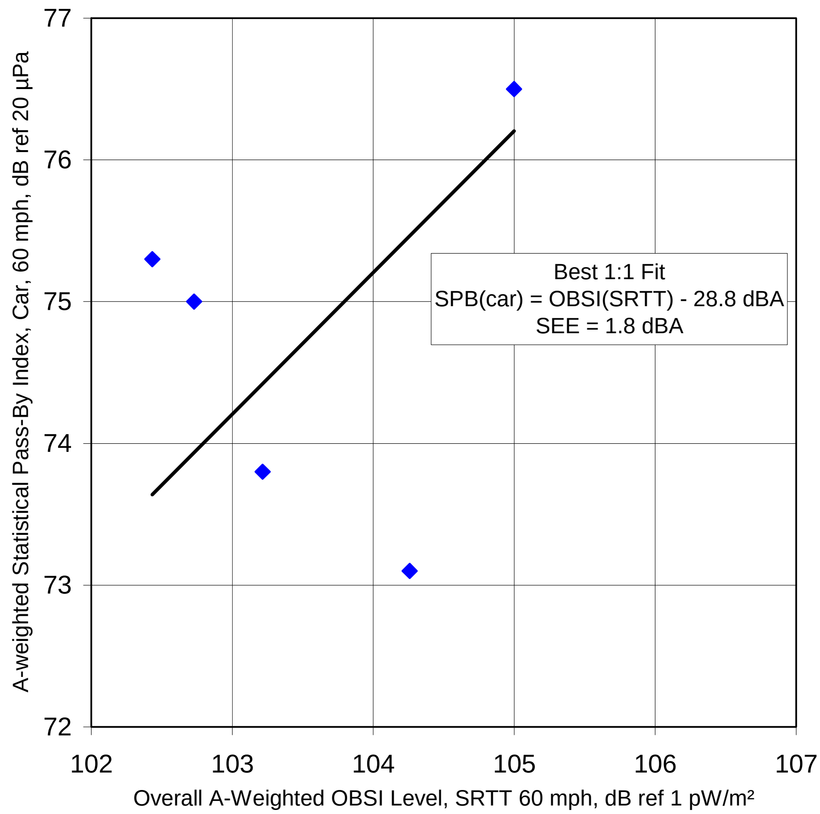

Figure 3. Comparison of OBSI and SPBI Sound Levels.

It should also be noted that the SPB-OBSI offset of 28.8 dBA differs from the SPB-OBSI offset of 29.6 dBA reported in the 2006 CDOT report by 0.8 dBA. For these five sites, the OBSI measured with the Aquatred tire is 0.8 dBA greater than that measured with the SRTT tire, which could explain this difference between 2006 and 2007.

Further Comparison of 2006 and 2007 Tests

In 2006, the CDOT QPR testing was conducted during the fall, from mid-September to early November. However, in 2007, testing occurred largely during the summer months from mid-June to late August. Coinciding with this were average ambient air temperatures during OBSI testing of 63°F in 2006 and 82°F in 2007. While temperatures during testing fell within the range of both specification and good practice, the difference was large enough to warrant further investigation of any influence this might have on the measured levels.

To approach this, a plot was first constructed comparing changes in OBSI (SRTT) level versus the corresponding ambient air temperature between 2006 and 2007. Figure 4 shows this relationship for all of the test sections. It demonstrates a sensitivity of 0.04 dBA/°F and an intercept of 1.4 dBA with a zero temperature change. The sensitivity can be interpreted as a preliminary form of correction factor for OBSI level as a function of temperature. With this correction applied, the intercept can then be interpreted as an average OBSI level difference for all sections between 2006 and 2007.

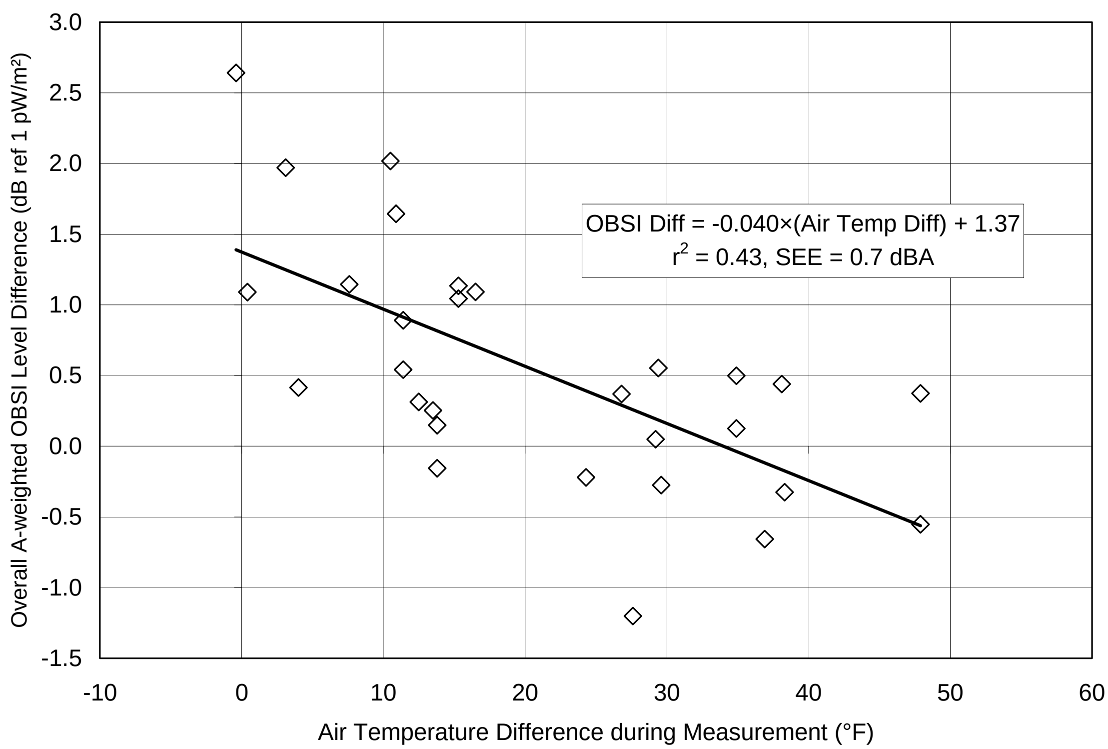

Figure 4. OBSI Level vs. Air Temperature Differences between 2006 and 2007.

It can be reasonably hypothesized that OBSI levels will increase with decreased temperature regardless of pavement type. For example, the tire hardness will increase with decreasing temperature, which will in turn affect the measurement to some degree. An effect of temperature on the dynamic modulus of asphalt will also likely be present, with a level increase resulting from colder, stiffer pavements. Concrete pavement joints will open as temperatures decrease, which will in turn increase the overall level due to an increased contribution of "joint slap" noise. It is reasonable that all of these effects (and others) will vary from pavement to pavement. The possibility of deriving pavement type specific trends therefore exists, with the result of this for the CDOT data illustrated in Figure 5.

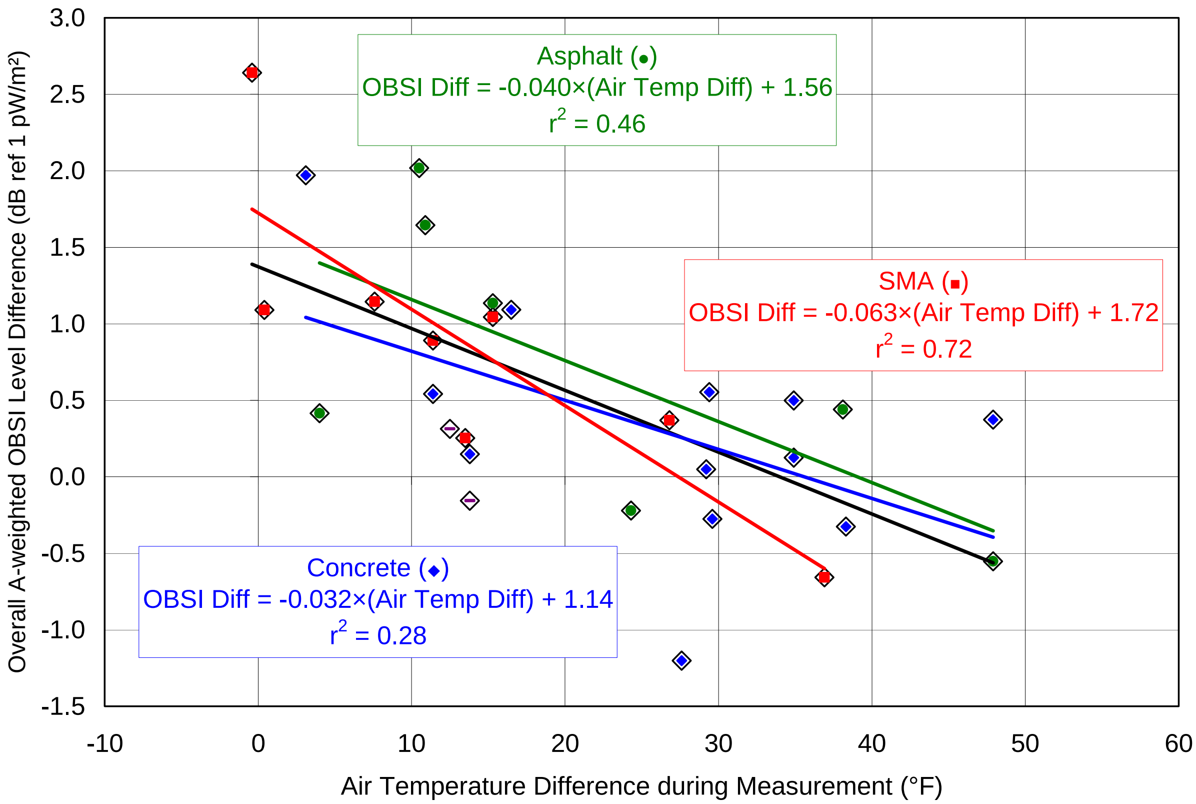

Figure 5. OBSI Level vs. Air Temperature Differences by Pavement Type.

Using the trends (slopes) in Figure 5, the measured 2007 OBSI levels were corrected in order to more directly compare them to the 2006 levels measured under largely cooler conditions. The resulting level calculations, as compared to both the 2006 and uncorrected 2007 levels, are illustrated in Figures 6 and 7.

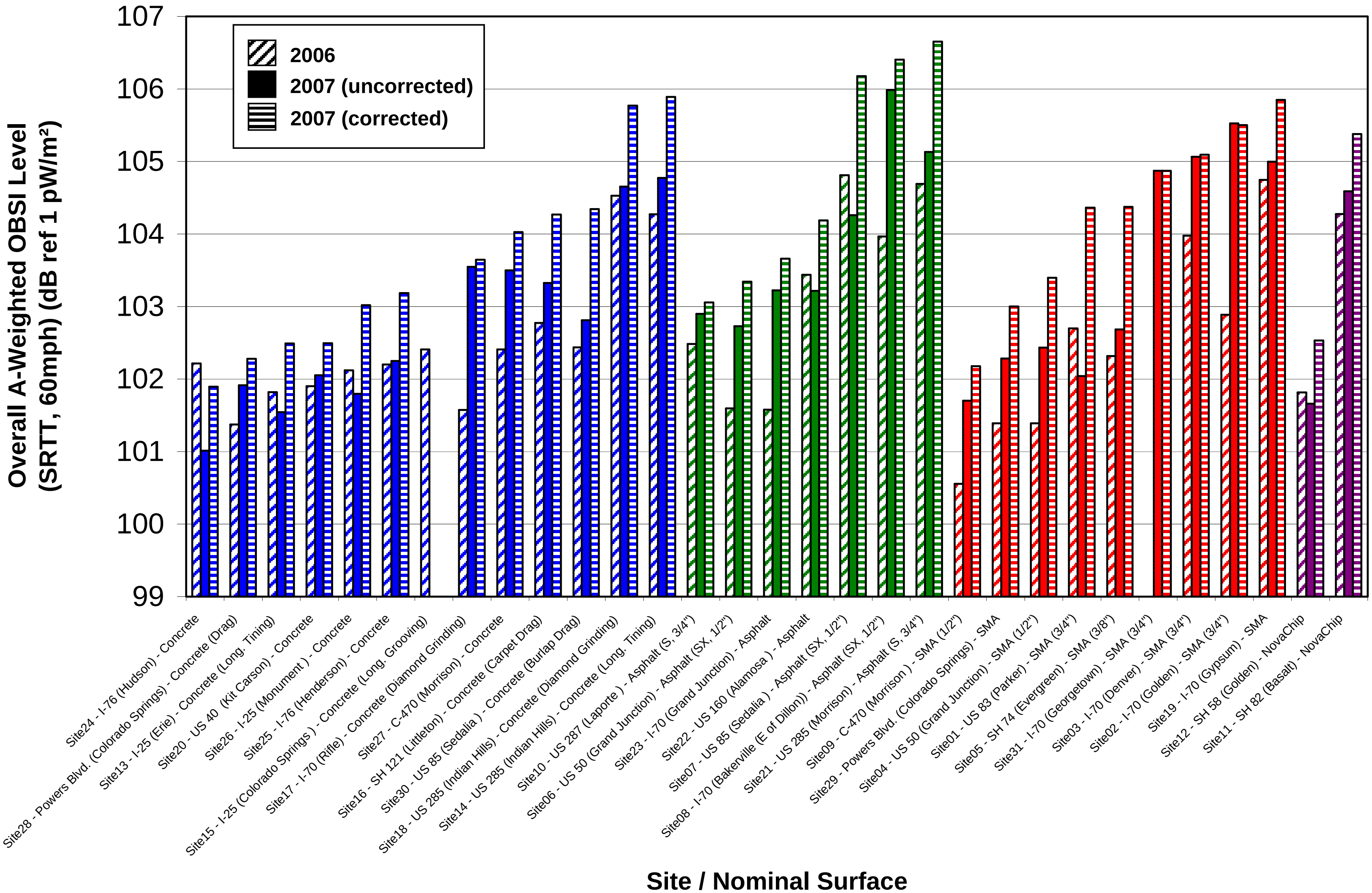

Figure 6. Summary of Temperature-Corrected Overall OBSI Levels.

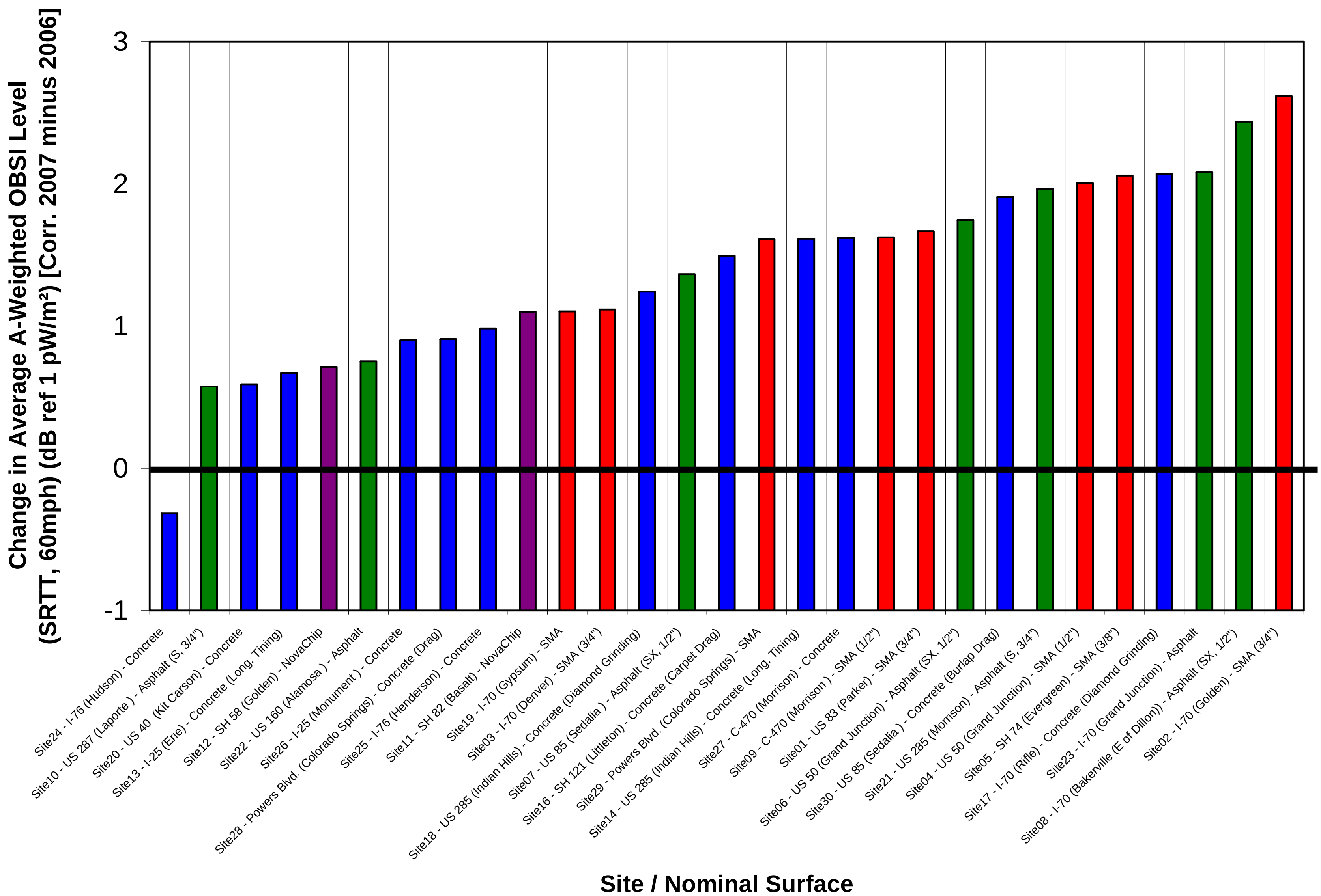

Figure 7. Summary of Changes in Overall OBSI Level from 2006 to 2007 (Temperature Corrected).

Relationship between Wheel Path and Center Lane OBSI Tests

In 2007, OBSI testing was conducted on 20 of the test sections in both the right wheel path and between the wheel paths (with the test tire aligned with approximately the center of the test lane). The rationale for this type of testing was to obtain a relevant indicator of the potential effects that traffic loading might have on a change in noise level. An average overall level difference of 1.2 ± 0.2 dBA was determined from this testing, with the corresponding average spectral level changes (and their standard errors) reported in Figure 8. For each third-octave band, the levels were higher from the measurements in the right wheel path as compared to the center-lane measurements.

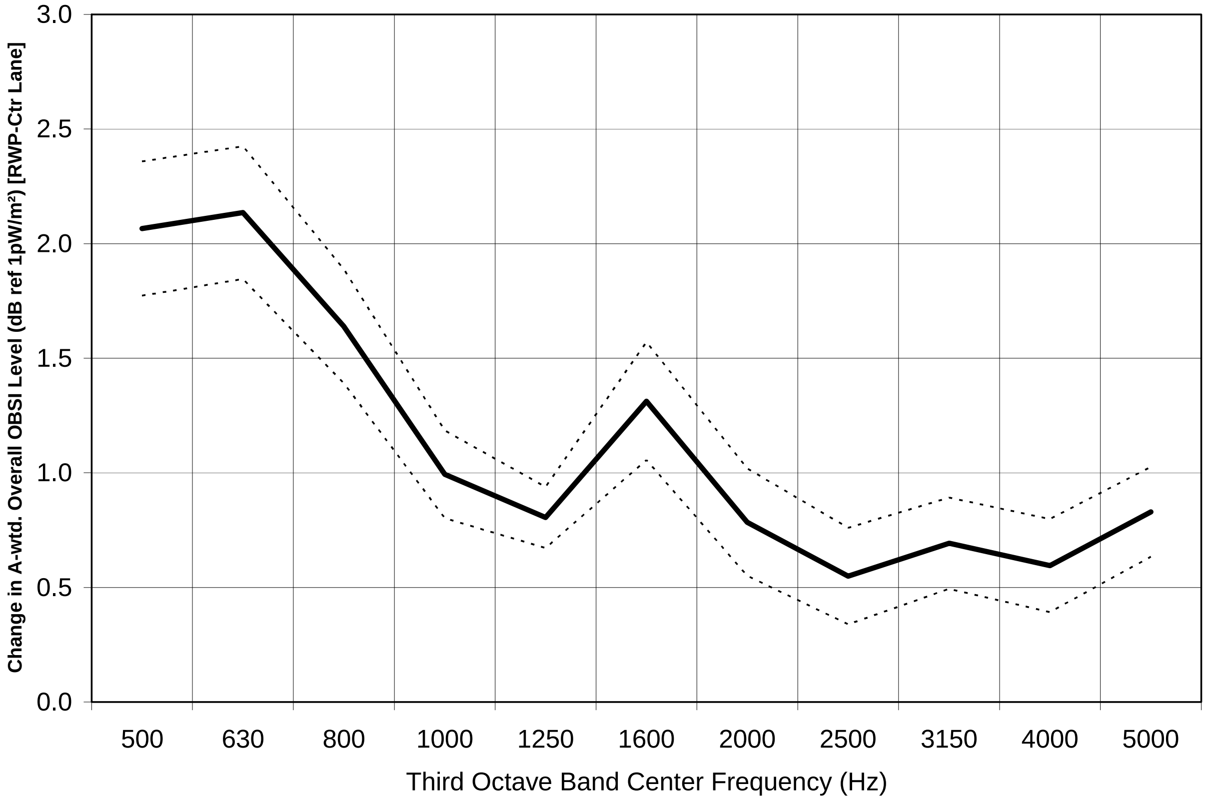

Figure 8. OBSI Spectral Level Differences between Right Wheel Path and Center Lane.

As shown in Figure 8, the more significant change in OBSI level occurs in the lower frequency bands. An additional peak is observed in the 1600 Hz frequency band. To better understand these phenomena, the data were further analyzed to observe the spectral differences within the various categories of pavement type. Figure 9 illustrates the results. It appears that the asphalt pavements (including to a lesser degree, SMA) have the largest differences in their lower frequency content. This could be indicative of aggregate loss (raveling) in the wheelpath due to vehicle loading. The concrete sections appear to be the source of the characteristic peak in the 1600 Hz band. Furthermore, they have greater level differences in the higher frequency bands. This could be the result of a polishing effect due to traffic loading enhancing aerodynamic tire-pavement noise mechanisms. It should be noted that in this cursory analysis, the effect of age is not considered. This and other variables should be considered in a more robust interpretation.

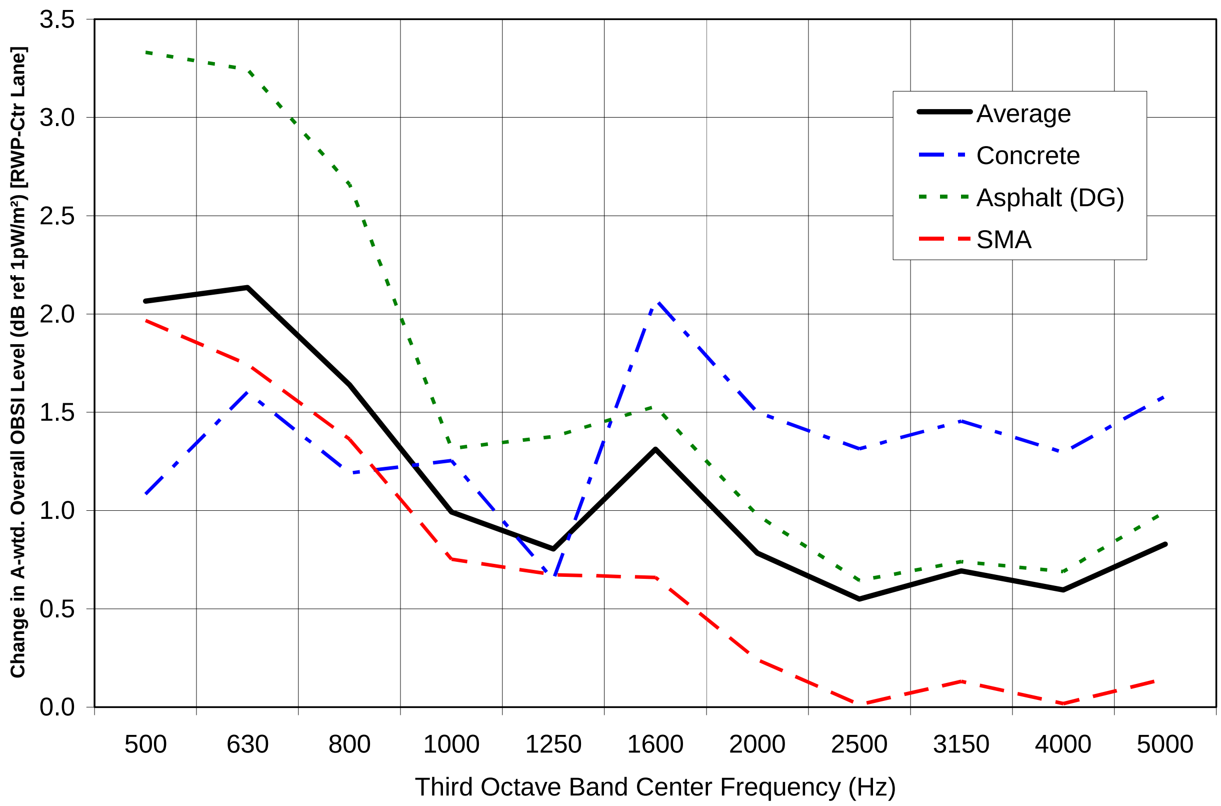

Figure 9. Right Wheel Path vs. Center Lane Differences in OBSI Level Spectra.

CONCLUSIONS AND RECOMMENDATIONS

From the measurements, it can be concluded that no single pavement type can be considered definitively quieter. Each pavement type has a demonstrated range of noise levels that largely overlap. It is anticipated that as additional measurements are made in subsequent years, these levels will change by different amounts, making the conclusion of a single definitive quieter pavement type even less likely.

Preliminary trends of acoustical durability have been identified herein. It was found that nearly all pavements have experienced some increase in level between the 2006 and 2007 measurements. To further define this change, an attempt has been made to derive and then apply temperature corrections to the measured levels. However, the resulting corrected levels should not be used without a more robust analysis such as that forthcoming under potential sponsorship of the FHWA, NCHRP, and/or pooled fund project TPF-5(135).

Another perspective of acoustical durability was illustrated with the comparison of source measurements collected both in the (right) wheel path and the center of the test lanes. Differences in these levels indicate the potential effects that traffic wear have on the pavement noise level. It appears that while both asphalt and concrete pavements show differences, they occur for different physical reasons (e.g., raveling of asphalt versus polishing of concrete). These differences, in turn, manifest themselves as different changes in the OBSI spectra.

Finally, based on the testing conducted to date, the following operational recommendations can be made:

1. The SRTT test tire should continue to serve as the standard for all subsequent testing in Colorado under this study. The Goodyear Aquatred III is no longer in production, and while care has been taken to protect the remaining test tires, changes in their properties are inevitable.

2. There appears to be interesting trends emerging from the comparison of wheel path and center-lane OBSI data. Resources permitting, additional data collection of this type is recommended in future years.
3. The necessity and validity of temperature corrections remains a question, and future testing should attempt to further quantify this variable. For example, two sets of measurements can be collected at varying times of day or immediately before/after a cold front. Such a temperature change without accumulated traffic could be used to validate this effect. Furthermore, relevant national-level research on this topic is expected in the near future, with application of those findings possible in this study.
4. All subsequent testing should continue to be conducted at both the source and wayside. While work is underway as part of NCHRP 1-44 and 10-76 to establish better links between these types of measurements, both measurements still appear to be of value to the CDOT program.
5. Continued efforts should be made to conduct wayside measurements at positions other than 50 ft. Current drafts of potential U.S. guidance and standards for wayside testing are now recommending measurements at 25 ft. In addition to a continued attempt to measure at further distances (SPBI+), it is recommended that the closer microphone position also be considered.
6. Accompanying pavement texture measurements should be considered during at least one of the remaining noise testing periods. These data can potentially be used to evaluate the hypotheses of the pavement surface condition affecting the resulting noise levels (and their spectra).

To date, a wealth of information has been collected concerning the tire-pavement noise and environmental noise on various pavements in Colorado. Thirty-one unique pavement surfaces have been evaluated, and the information reported herein is the first step in constructing acoustical durability relationships. Additional testing is currently scheduled to occur in 2009 and 2011. In the interim, these and other relevant findings and recommendations will be discussed with the project panel in order to ensure the greatest value from this research program.

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APPENDIX A – PHOTOGRAPHS

Figure A.1. OBSI Measurement Bracket Configuration.

Figure A.2. Test Tires – ASTM F 2493 SRTT and Goodyear Aquatred III.

Figure A.3. Wayside Measurement Configuration.

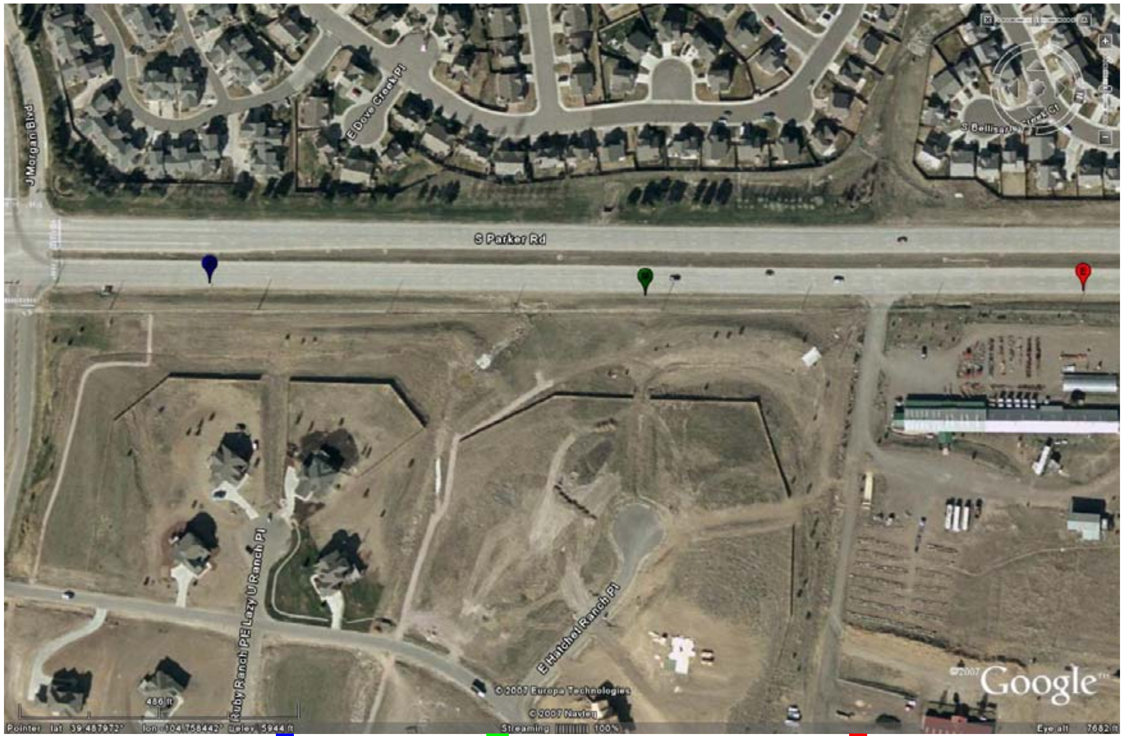
APPENDIX B – DETAILED SITE DATA

Site: 01
General Information

Highway: US Highway 83, Northbound
Location: Between CR-14 & Hess Rd., Parker (80134)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.4883 / 104.7591 / 5960

Nominal Surface: SMA (3/4") **Construction Accepted:** 2004

OBSI?: Yes (8/5/07) **SPB?:** No **TA?:** Yes (8/3/07)
Total Section Length: 1558 ft.
Distance from Begin to Wayside Microphone: 769 ft.



Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 01
Time-Averaged Wayside Test Information

Sampling Periods: 2

Sample Period 1 – 3 Blocks @ 15 min ea. = 45 min. (11:00 am to 11:45 am, 8/3/07)

Traffic Volumes and Speeds during Sample Period

	NB Lane 3 (Outside)	**NB Lane 2**	**NB Lane 1 (Inside)**	**SB Lane 1 (Inside)**	**SB Lane 2**	**SB Lane 3 (Outside)**
Distance from Mic (ft.)	50	62	74	121	133	145
Average Speed (mph)		52			48	
Automobile	102	357	484	312	338	66
Heavy Truck	2	27	3	3	23	1
Medium Truck	5	16	17	12	16	1
Bus	0	1	1	1	0	0
Motorcycle	0	1	1	3	1	1
Auto + 1-Axle Trlr.	0	6	3	1	5	0
Auto + 2-Axle Trlr.	1	2	1	3	5	0
M. Trk. + 1-Axle Trlr.	0	0	0	0	0	0
M. Trk. + 2-Axle Trlr.	1	2	1	0	5	0

Traffic Volumes and Speeds during Sample Period

Block 1	**Block 2**	**Block 3**	**Average**
70.2 dBA	70.4 dBA	70.2 dBA	**70.3 dBA**

Site: 01
Time-Averaged Wayside Test Information

Sample Period 2 – 3 Blocks @ 15 min ea. = 45 min. (11:45 am to 12:30 pm, 8/3/07)

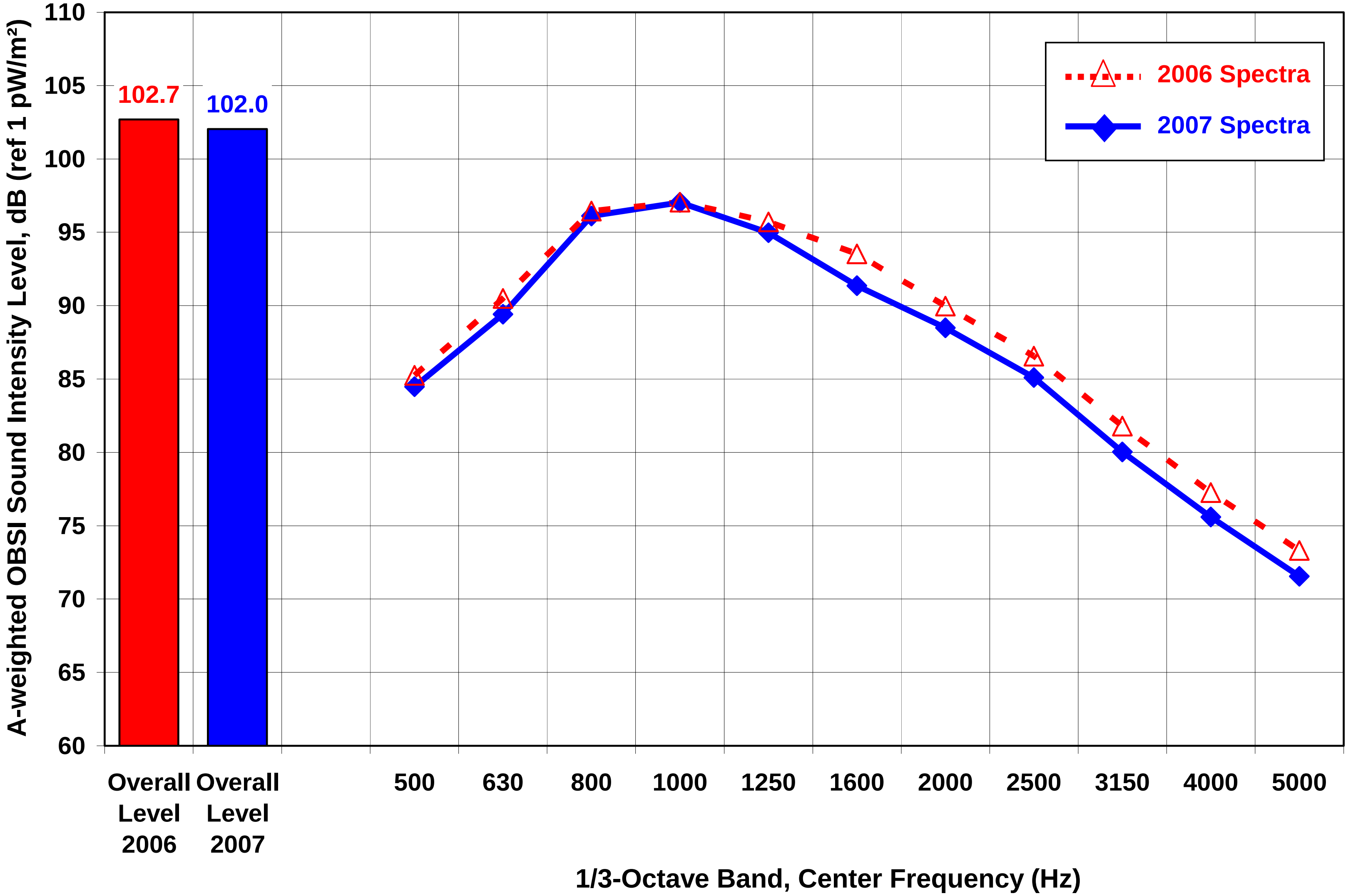
Traffic Volumes and Speeds during Sample Period

	NB Lane 3 (Outside)	**NB Lane 2**	**NB Lane 1 (Inside)**	**SB Lane 1 (Inside)**	**SB Lane 2**	**SB Lane 3 (Outside)**
Distance from Mic (ft.)	50	62	74	121	133	145
Average Speed (mph)		53			51	
Automobile	96	368	411	348	382	66
Heavy Truck	3	16	2	4	20	2
Medium Truck	2	11	8	8	11	0
Bus	0	0	0	1	0	0
Motorcycle	1	3	1	6	4	0
Auto + 1-Axle Trlr.	0	7	2	0	5	0
Auto + 2-Axle Trlr.	4	8	4	1	5	0
M. Trk. + 1-Axle Trlr.	0	1	0	0	0	0
M. Trk. + 2-Axle Trlr.	2	3	1	1	1	0

Traffic Volumes and Speeds during Sample Period

Block 1	**Block 2**	**Block 3**	**Average**
69.6 dBA	70.0 dBA	69.5 dBA	**69.7 dBA**

Site: 01
OBSI (SRTT) Test Information



Site: 02
General Information

Highway: Interstate 70, Eastbound
Location: Between Evergreen Pkwy. & CR-65, Golden (80439)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.7084 / 105.3511 / 7490

Nominal Surface: SMA (3/4") **Construction Accepted:** 1/2004

OBSI?: Yes (7/28/07) **SPB?:** No **TA?:** Yes (7/26/07)
Total Section Length: 5308 ft.
Distance from Begin to Wayside Microphone: 4116 ft.

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 02
Time-Averaged Wayside Test Information

Sampling Periods: 2

Sample Period 1 – 3 Blocks @ 15 min ea. = 45 min. (3:20 pm to 4:05 pm, 7/26/07)

Traffic Volumes and Speeds during Sample Period

	EB Lane 3 (Outside)	EB Lane 2	EB Lane 1 (Inside)	WB Lane 1 (Inside)	WB Lane 2	WB Lane 3 (Outside)
Distance from Mic (ft.)	50	62	74	131	143	155
Average Speed (mph)		74			72	
Automobile	245	658	461	350	608	202
Heavy Truck	76	34	3	1	11	32
Medium Truck	20	24	9	1	5	11
Bus	4	1	0	0	1	4
Motorcycle	7	5	1	1	8	2
Auto + 1-Axle Trlr.	10	6	4	3	12	10
Auto + 2-Axle Trlr.	8	11	0	2	8	8
M. Trk. + 1-Axle Trlr.	1	0	0	0	1	0
M. Trk. + 2-Axle Trlr.	6	3	0	0	4	4

Block 1	Block 2	Block 3	Average
77.8 dBA	78.4 dBA	78.1 dBA	**78.1 dBA**

Site: 02
Time-Averaged Wayside Test Information

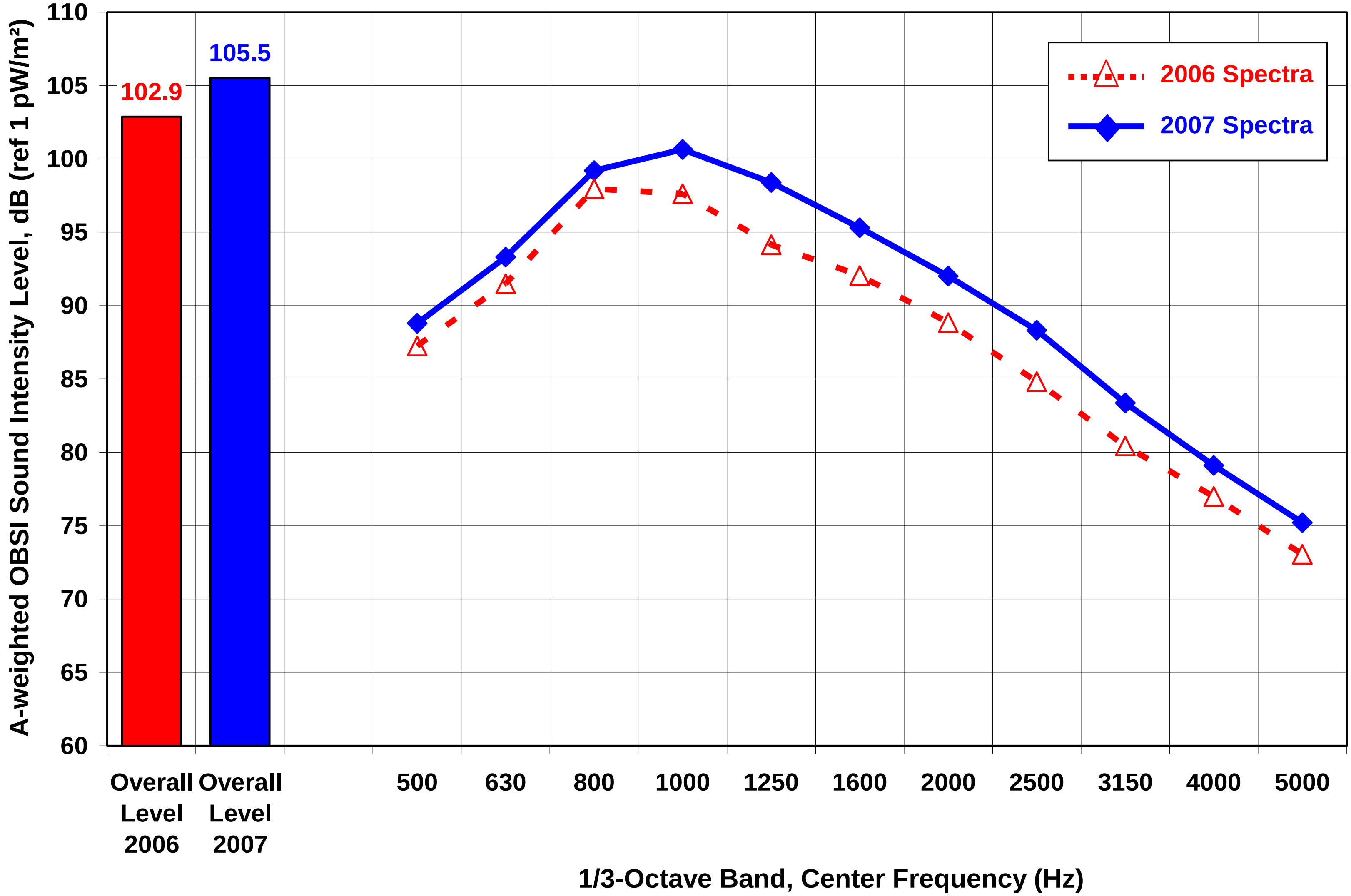
Sample Period 2 – 3 Blocks @ 15 min ea. = 45 min. (4:05 pm to 4:50 pm, 7/26/07)

Traffic Volumes and Speeds during Sample Period

	EB Lane 3 (Outside)	**EB Lane 2**	**EB Lane 1 (Inside)**	**WB Lane 1 (Inside)**	**WB Lane 2**	**WB Lane 3 (Outside)**
Distance from Mic (ft.)	50	62	74	131	143	155
Average Speed (mph)		73			70	
Automobile	263	687	442	381	634	213
Heavy Truck	59	27	3	0	7	45
Medium Truck	18	16	4	0	6	13
Bus	2	1	0	0	0	2
Motorcycle	4	10	2	1	7	0
Auto + 1-Axle Trlr.	10	6	4	6	15	9
Auto + 2-Axle Trlr.	8	5	1	3	6	9
M. Trk. + 1-Axle Trlr.	0	1	0	0	3	0
M. Trk. + 2-Axle Trlr.	8	1	0	0	1	4

Block 1	**Block 2**	**Block 3**	**Average**
78.3 dBA	78.0 dBA	77.6 dBA	**78.0 dBA**

Site: 02
OBSI (SRTT) Test Information

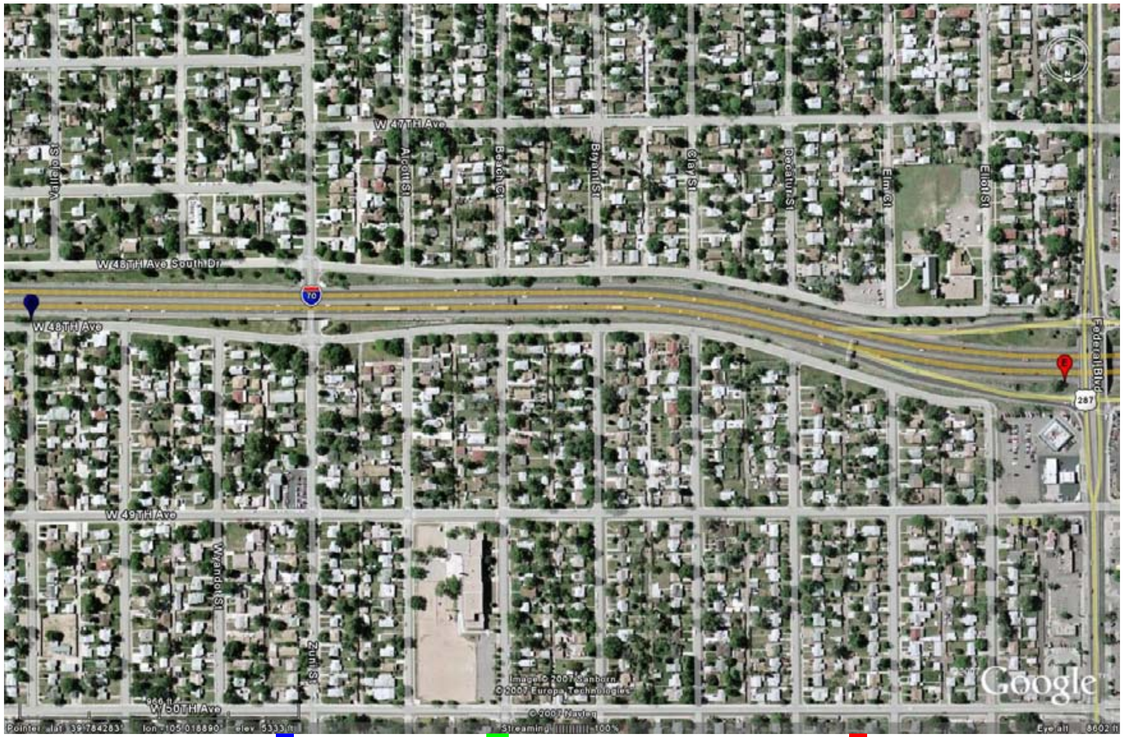


Site: 03
General Information

Highway: Interstate 70, Westbound
Location: Between Federal Blvd. & Pecos St., Denver (80221)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.7841 / 105.0186 / 5330

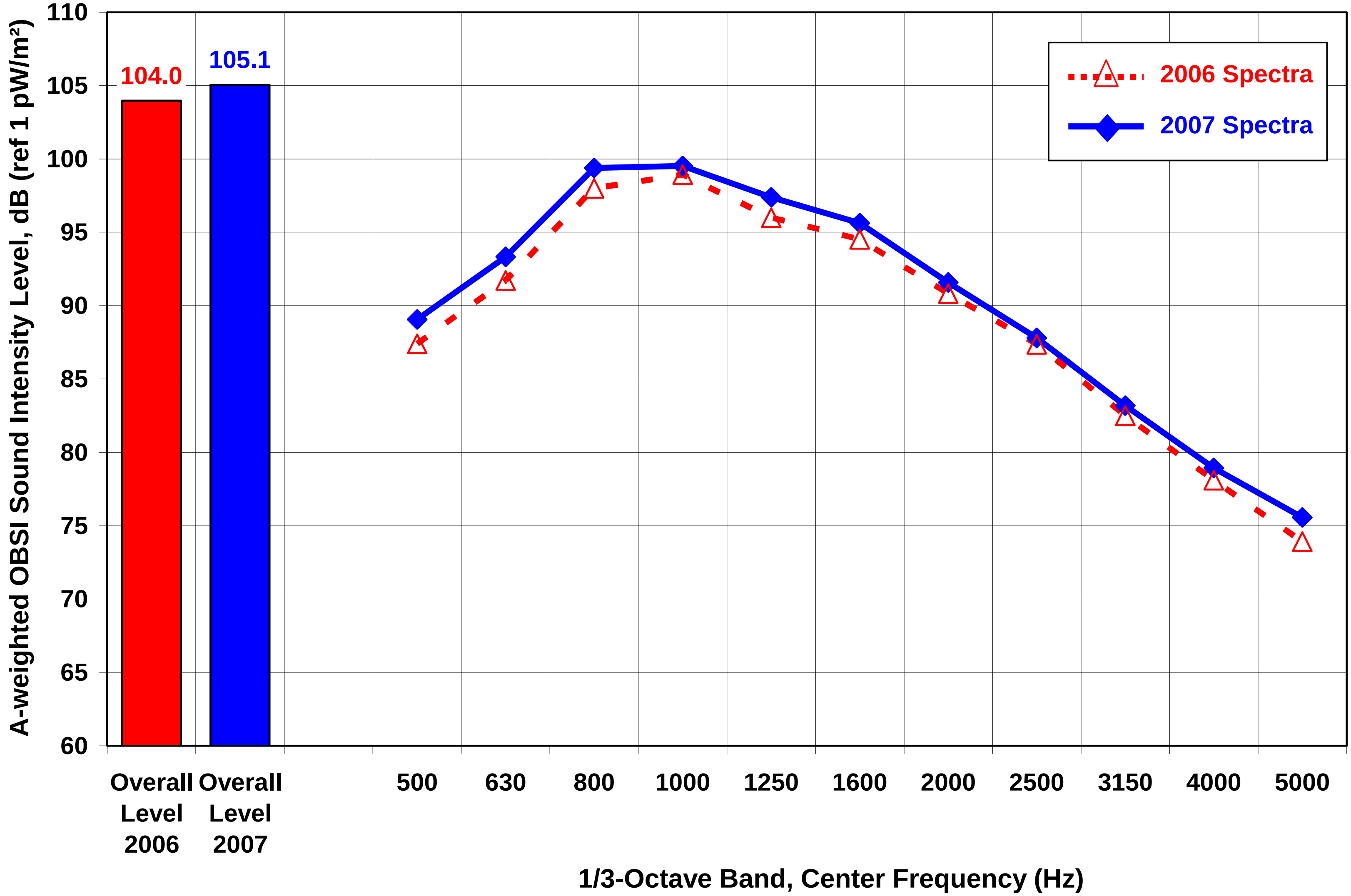
Nominal Surface: SMA (3/4") **Construction Accepted:** 10/2003

OBSI?: Yes (7/29/07) **SPB?:** No **TA?:** No
Total Section Length: 3575 ft.
Distance from Begin to Wayside Microphone: n/a



Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 03
OBSI (SRTT) Test Information



Site: 04

General Information

Highway: US Highway 50, Westbound

Location: Between 35 6/10 Rd. & Bridgeport Rd., Grand Junction (81527)

Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 38.8147 / 108.3385 / 5110

Nominal Surface: SMA (1/2") **Construction Accepted:** 8/2002

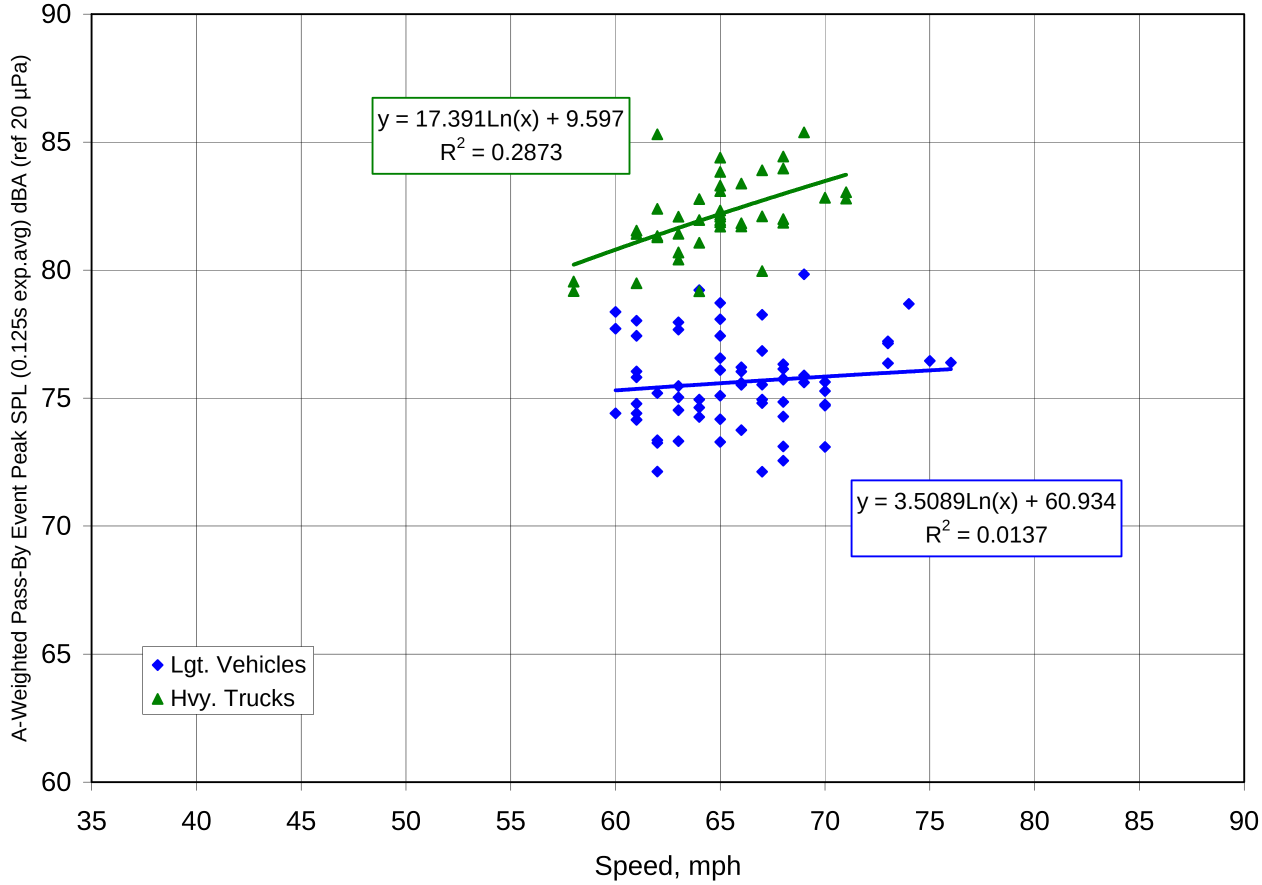
OBSI?: Yes (8/25/07) **SPB?:** Yes (8/27/07) **TA?:** No

Total Section Length: 4847 ft.

Distance from Begin to Wayside Microphone: 1422 ft.

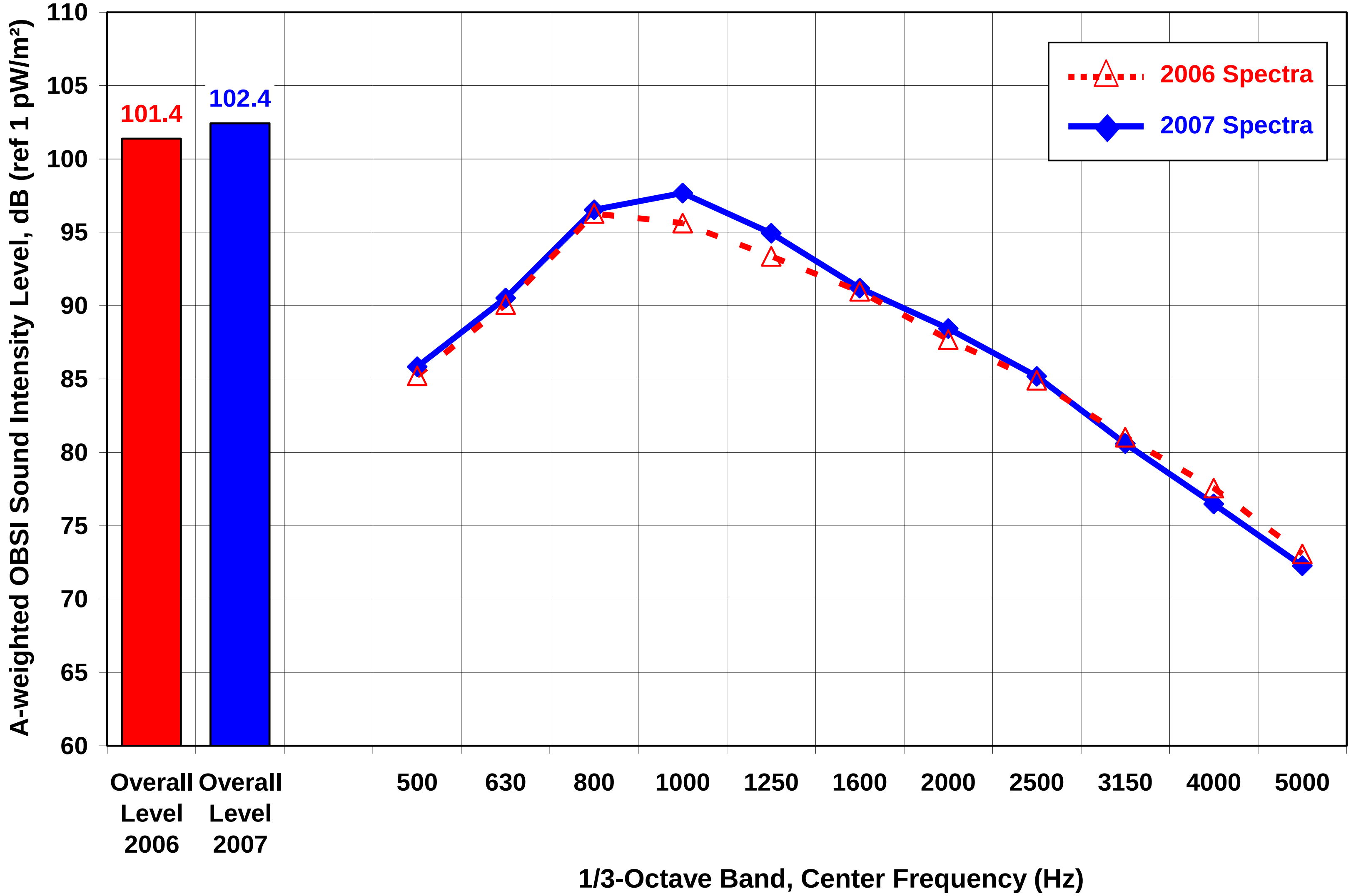
Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 04
SPB Wayside Test Information



SPBI (Car, 60mph): 75.3 dBA
SPBI (H. Truck, 60mph): 80.8 dBA

Site: 04
OBSI (SRTT) Test Information



Site: 05

General Information

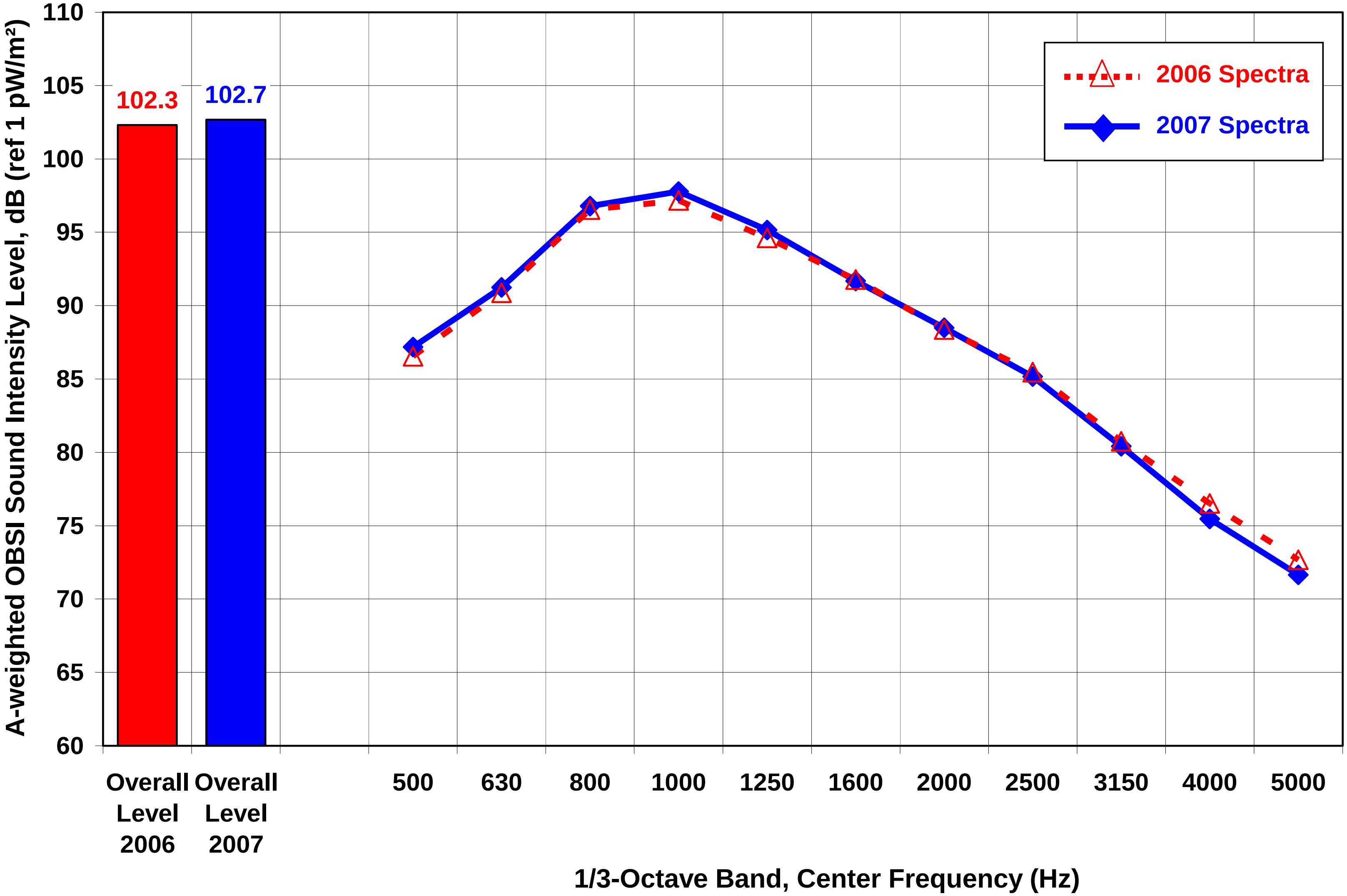
Highway: State Highway 74, Eastbound
Location: Between Bergen Pkwy. & Lewis Ridge Rd., Evergreen (80439)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.2861 / 107.1376 / 7680

Nominal Surface: SMA (3/8") **Construction Accepted:** 7/2004

OBSI?: Yes (6/25/07) **SPB?:** No **TA?:** No
Total Section Length: 3488 ft.
Distance from Begin to Wayside Microphone: n/a

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 05
OBSI (SRTT) Test Information

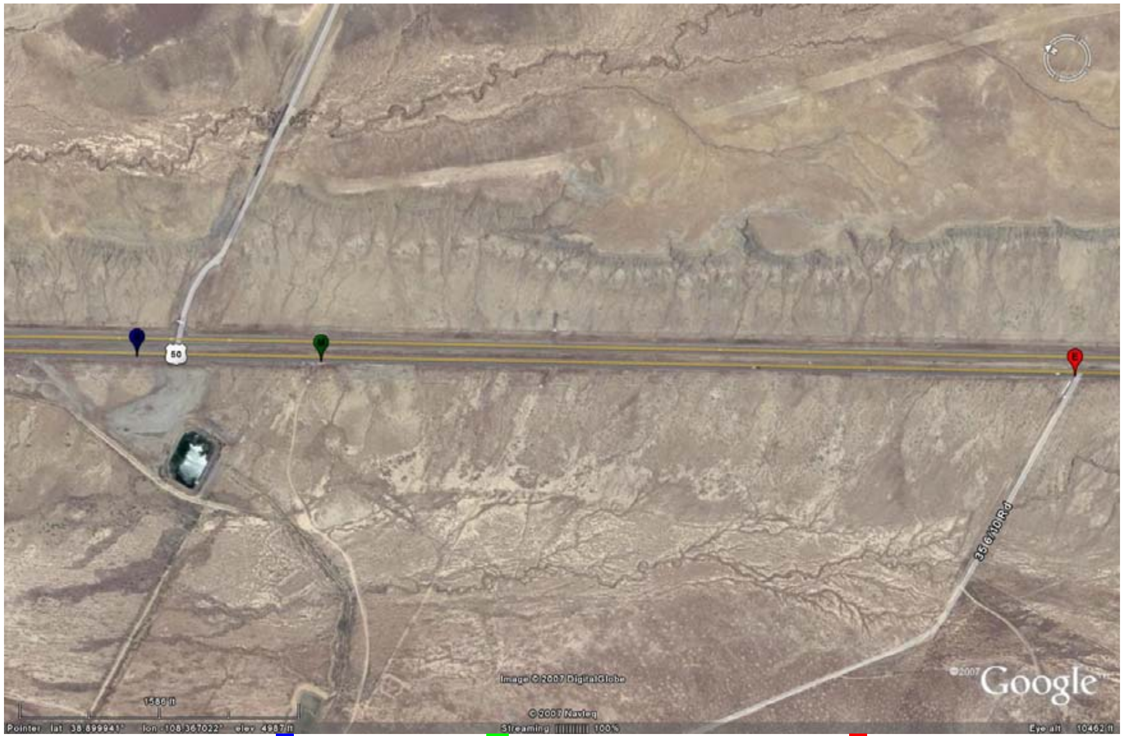


Site: 06
General Information

Highway: US Highway 50, Eastbound
Location: Between 35 6/10 Rd. & Bridgeport Rd., Grand Junction (81527)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 38.8994 / 108.3666 / 5010

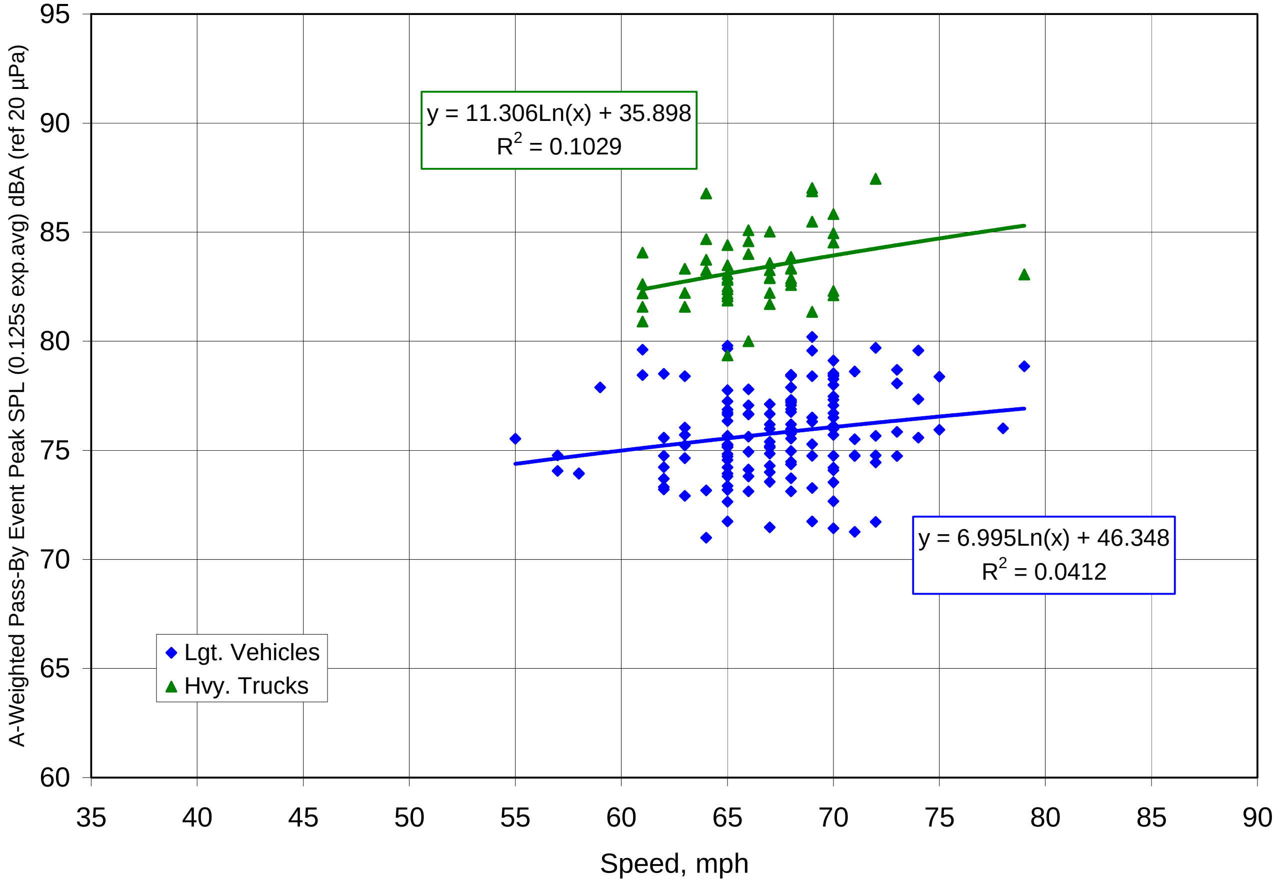
Nominal Surface: Asphalt (SX, 1/2") **Construction Accepted:** 8/2002

OBSI?: Yes (8/25/07) **SPB?:** Yes (8/24/07) **TA?:** No
Total Section Length: 5333 ft.
Distance from Begin to Wayside Microphone: 1048 ft.



Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

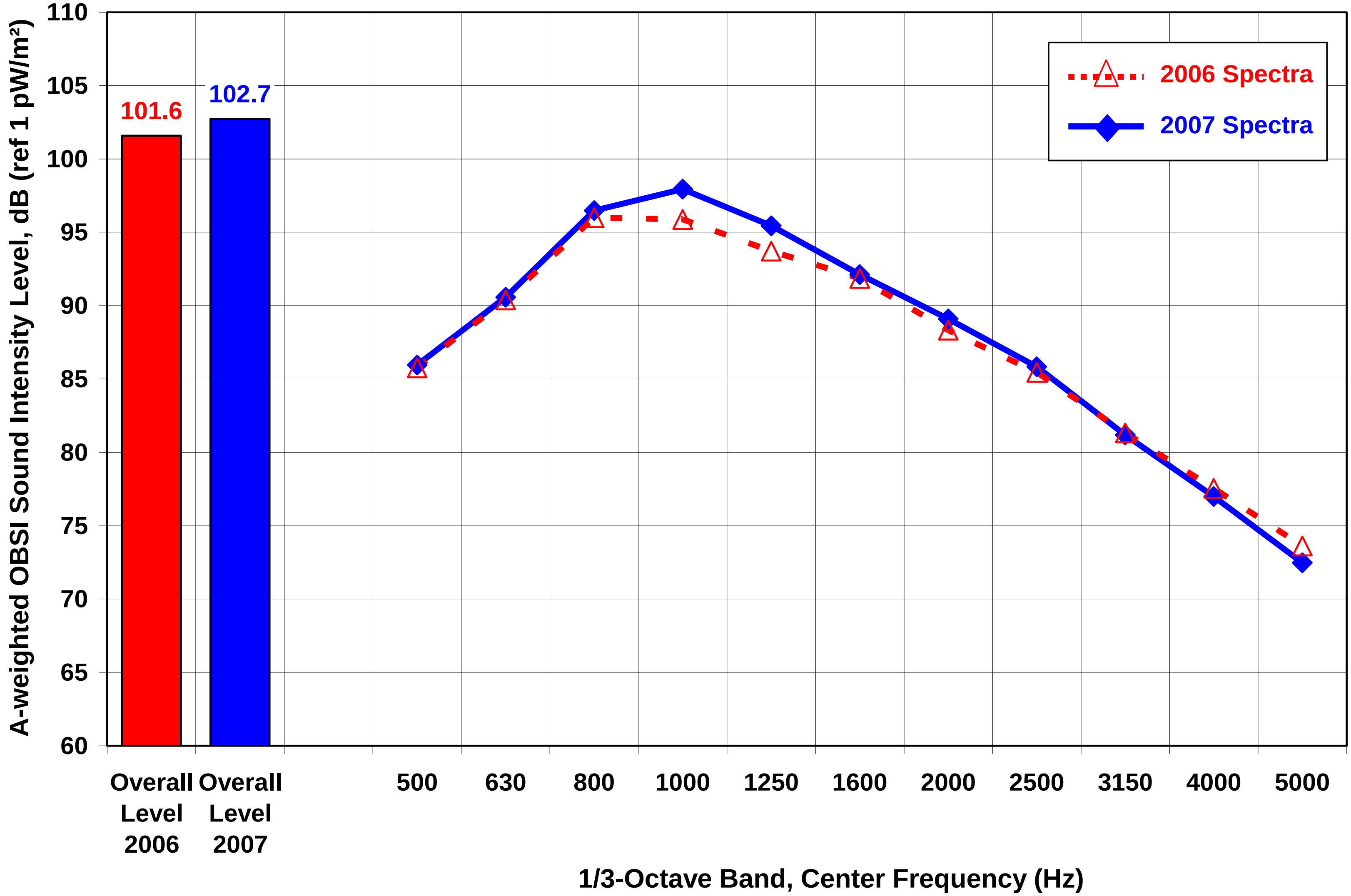
Site: 06
SPB Wayside Test Information



SPBI (Car, 60mph): 75.0 dBA
SPBI (H. Truck, 60mph): 82.2 dBA

Site: 06

OBSI (SRTT) Test Information



Site: 07
General Information

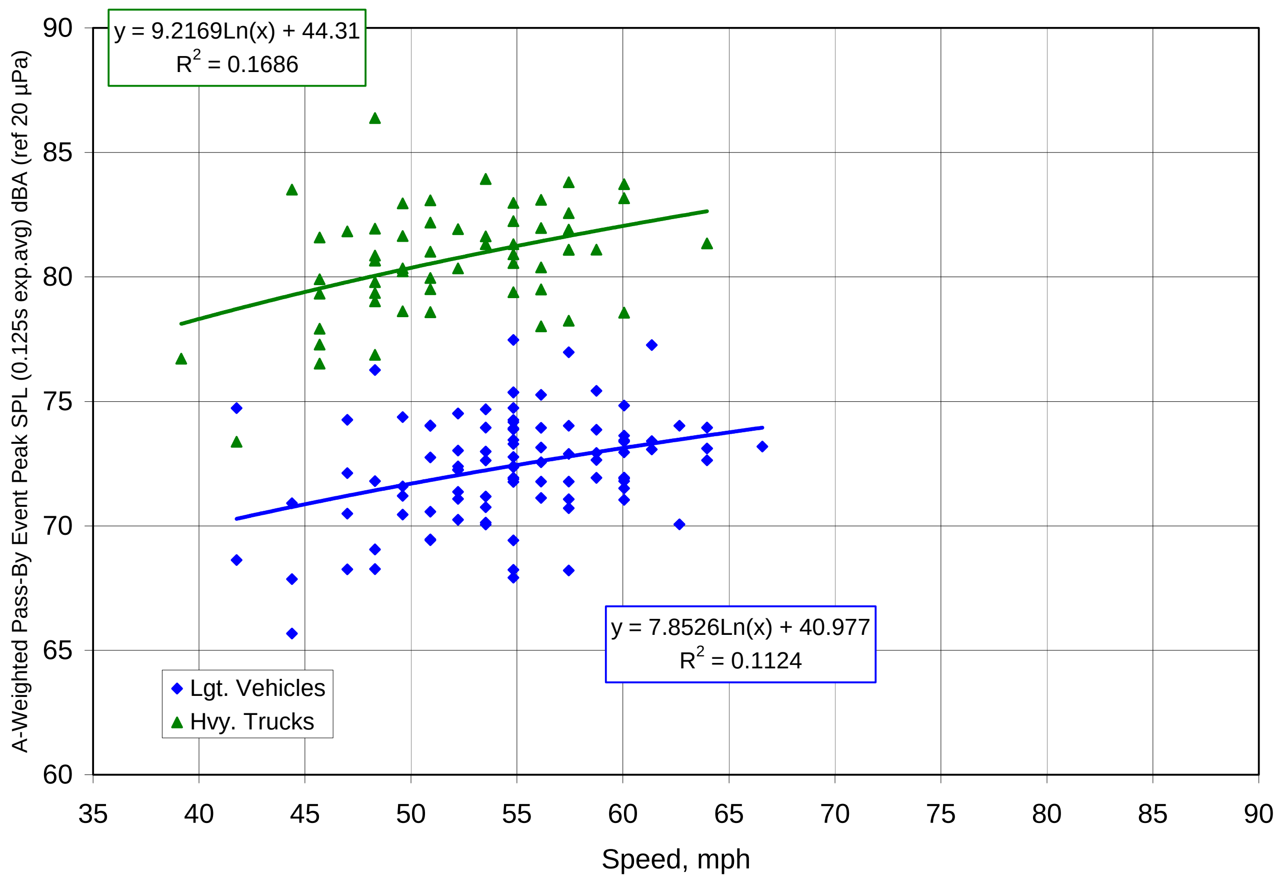
Highway: US Highway 85, Southbound
Location: Between Daniels Park Rd. & Happy Canyon Rd., Sedalia (80135)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.4288 / 104.9111 / 6000

Nominal Surface: Asphalt (SX, 1/2") **Construction Accepted:** 2006

OBSI?: Yes (8/4/07) **SPB?:** Yes (8/9/07) **TA?:** No
Total Section Length: 2686 ft.
Distance from Begin to Wayside Microphone: 1864 ft.

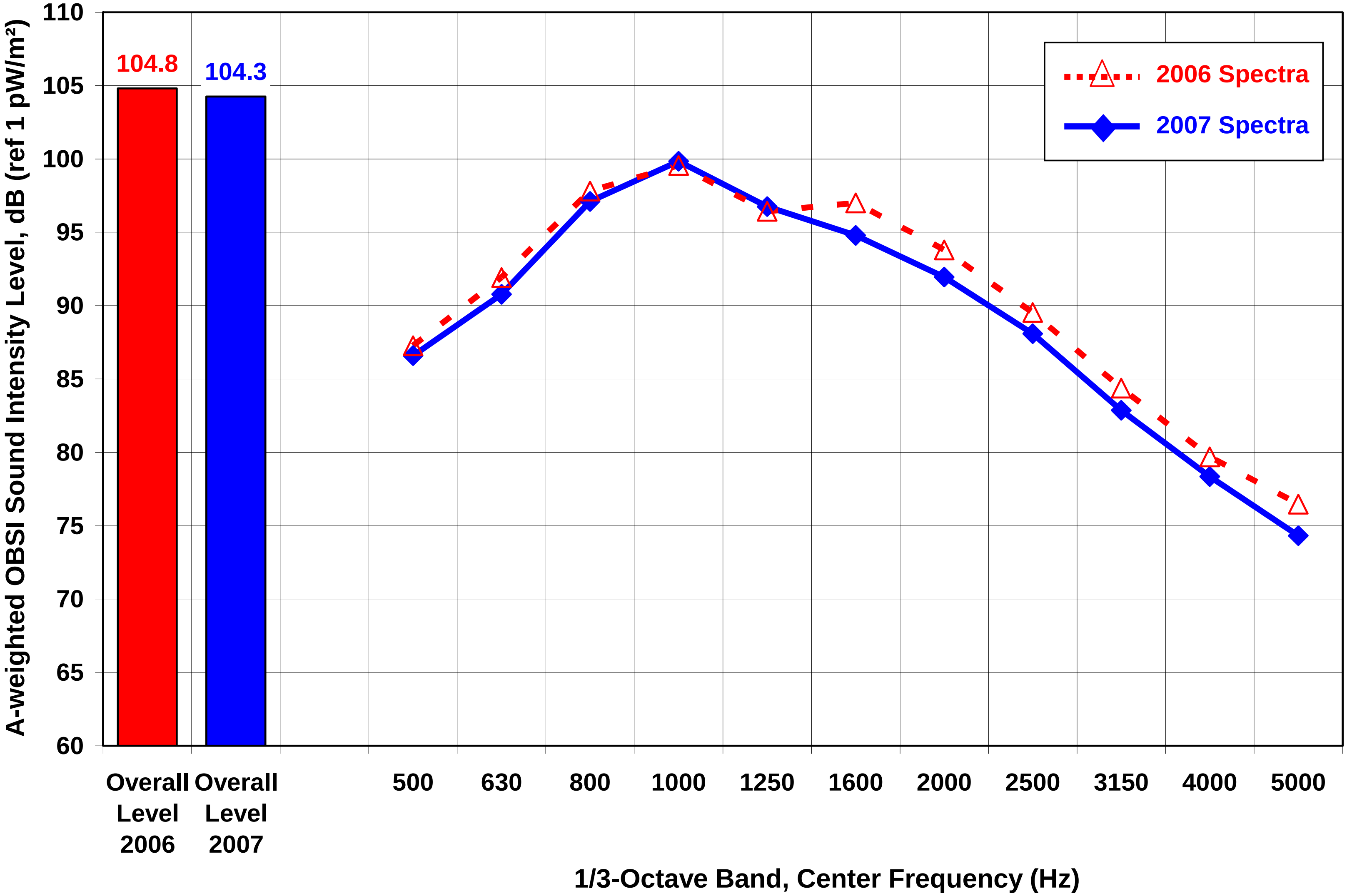
Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 07
SPB Wayside Test Information



SPBI (Car, 60mph): 73.1 dBA
SPBI (H. Truck, 60mph): 82.0 dBA

Site: 07
OBSI (SRTT) Test Information

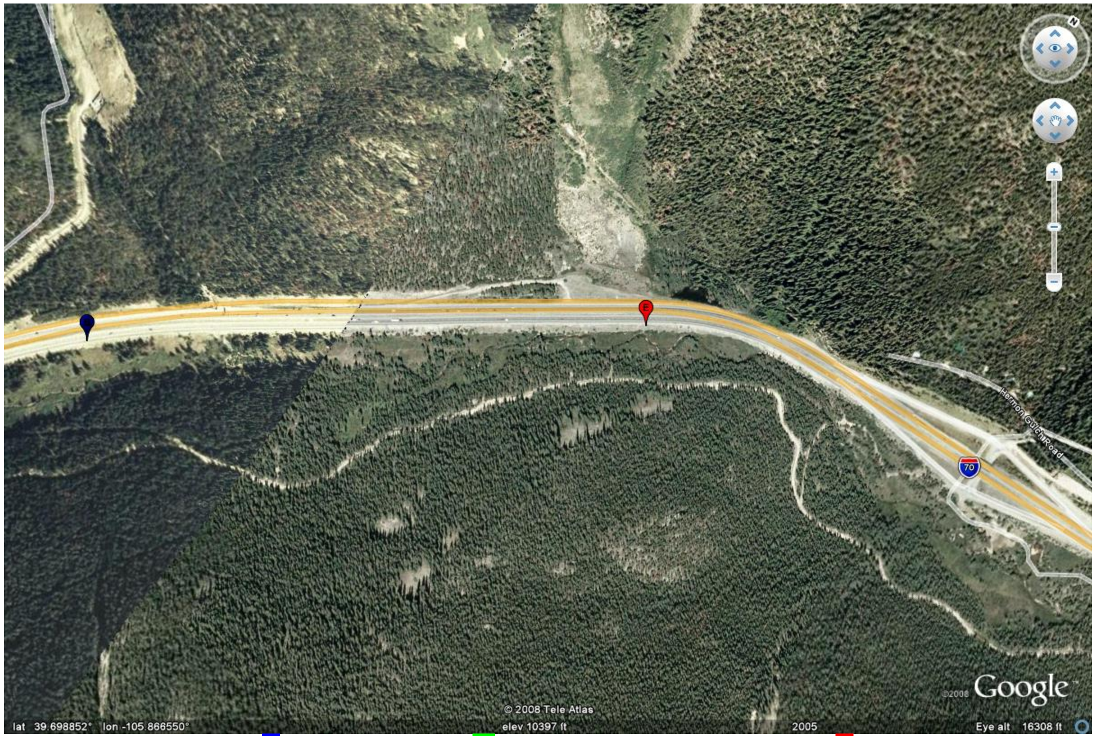


Site: 08
General Information

Highway: Interstate 70, Eastbound
Location: Between US 6 & Herman Gulch Rd., Bakerville (E of Dillon) (80444)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.6976 / 105.8703 / 10470

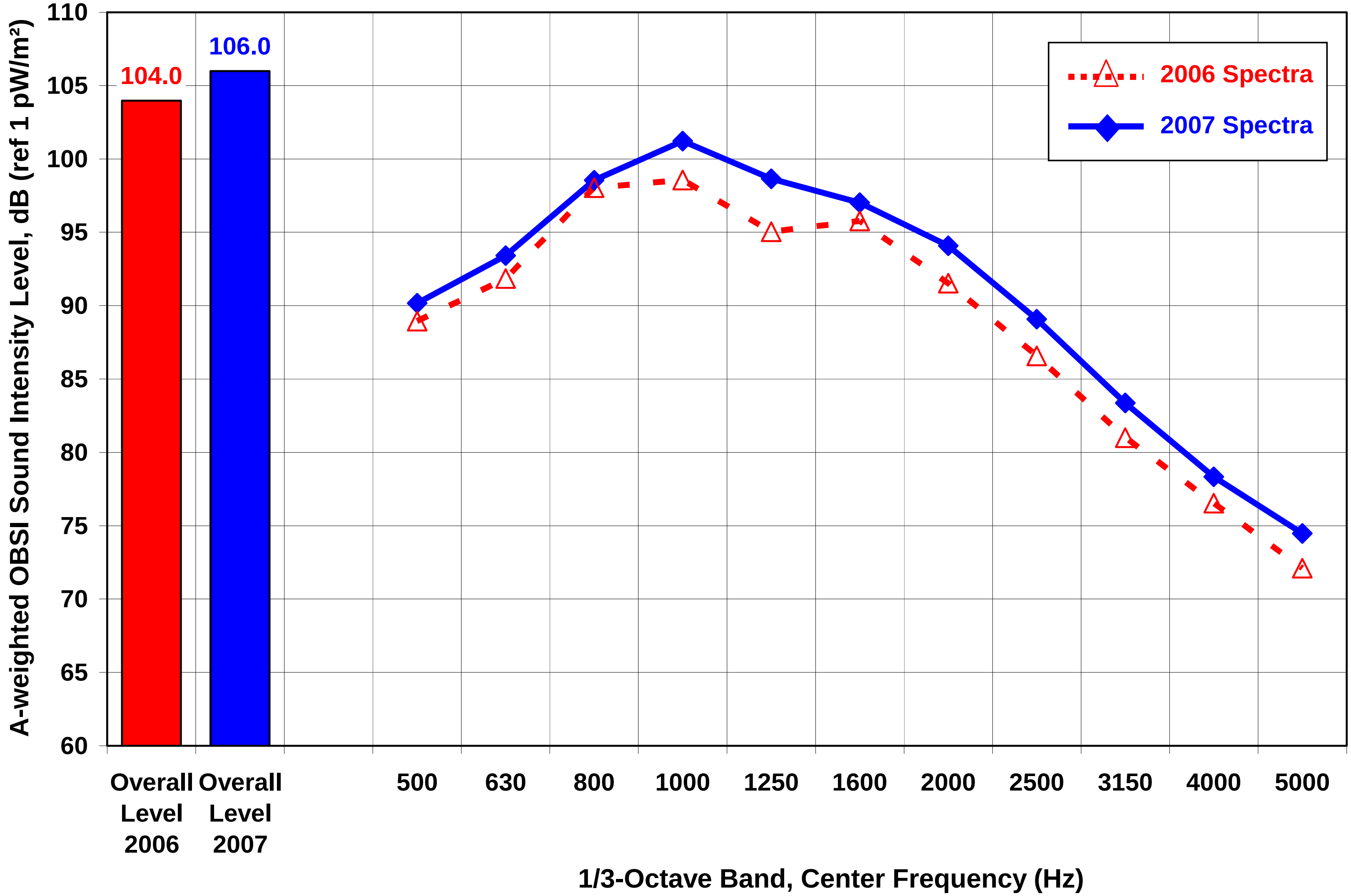
Nominal Surface: Asphalt (SX, 1/2") **Construction Accepted:** 2005

OBSI?: Yes (8/19/07) **SPB?:** No **TA?:** No
Total Section Length: 3535 ft.
Distance from Begin to Wayside Microphone: n/a



Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 08
OBSI (SRTT) Test Information



Site: 09
General Information

Highway: Highway C-470, Westbound (Northbound)
Location: Between US 285 & Morrison Rd., Morrison (80465)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.641 / 105.1723 / 5760

Nominal Surface: SMA (1/2") **Construction Accepted:** 6/2006

OBSI?: Yes (7/16/07) **SPB?:** No **TA?:** Yes (7/19/07)
Total Section Length: 3033 ft.
Distance from Begin to Wayside Microphone: 2460 ft.

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 09
Time-Averaged Wayside Test Information

Sampling Periods: 1

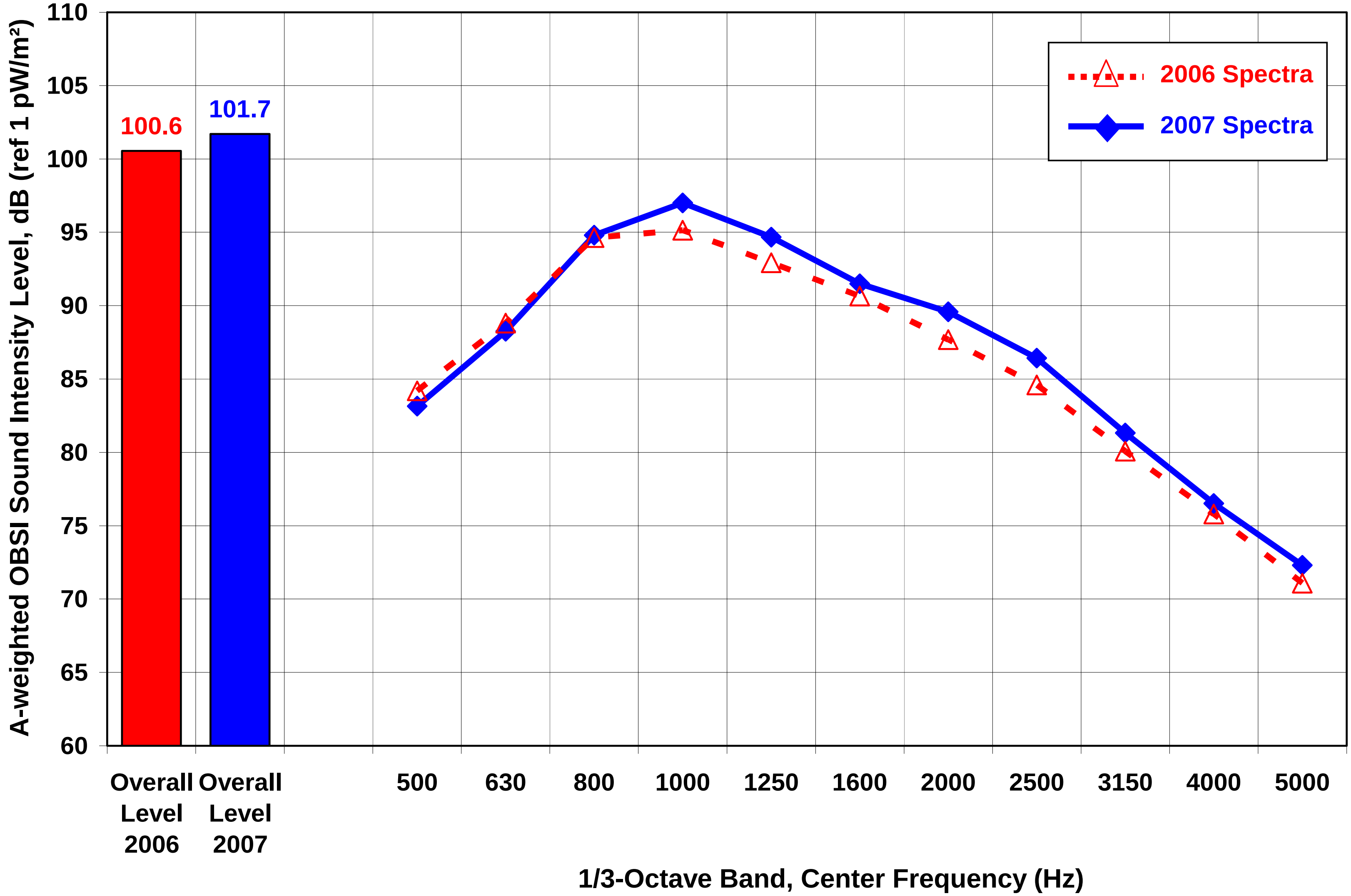
Sample Period 1 – 2 Blocks @ 15 min ea. = 30 min. (9:50 am to 10:20 am, 7/19/07)

Traffic Volumes and Speeds during Sample Period

	WB Lane 3 (Outside)	WB Lane 2	WB Lane 1 (Inside)	EB Lane 1 (Inside)	EB Lane 2	EB Lane 3 (Outside)
Distance from Mic (ft.)	50	62	74	121	133	145
Average Speed (mph)		67			66	
Automobile	173	491	430	227	398	131
Heavy Truck	5	31	14	8	30	18
Medium Truck	4	24	1	2	24	2
Bus	1	3	1	0	0	0
Motorcycle	3	5	2	1	0	1
Auto + 1-Axle Trlr.	3	9	5	2	9	3
Auto + 2-Axle Trlr.	2	9	3	3	3	5
M. Trk. + 1-Axle Trlr.	0	0	0	0	1	0
M. Trk. + 2-Axle Trlr.	0	6	2	0	2	1

Block 1	Block 2	Average
78.0 dBA	77.2 dBA	**77.6 dBA**

Site: 09
OBSI (SRTT) Test Information

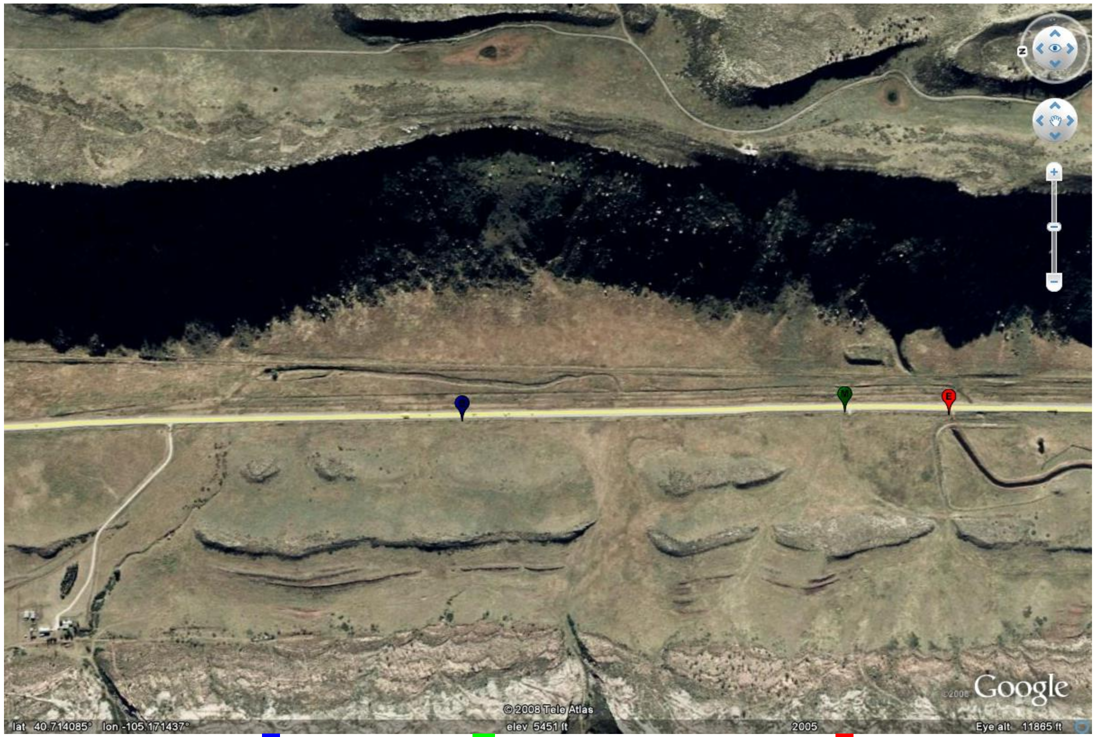


Site: 10
General Information

Highway: US Highway 287, Southbound
Location: Between Bonner Spring Ranch Rd. & SH 14, Laporte (80535)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 40.7113 / 105.173 / 5470

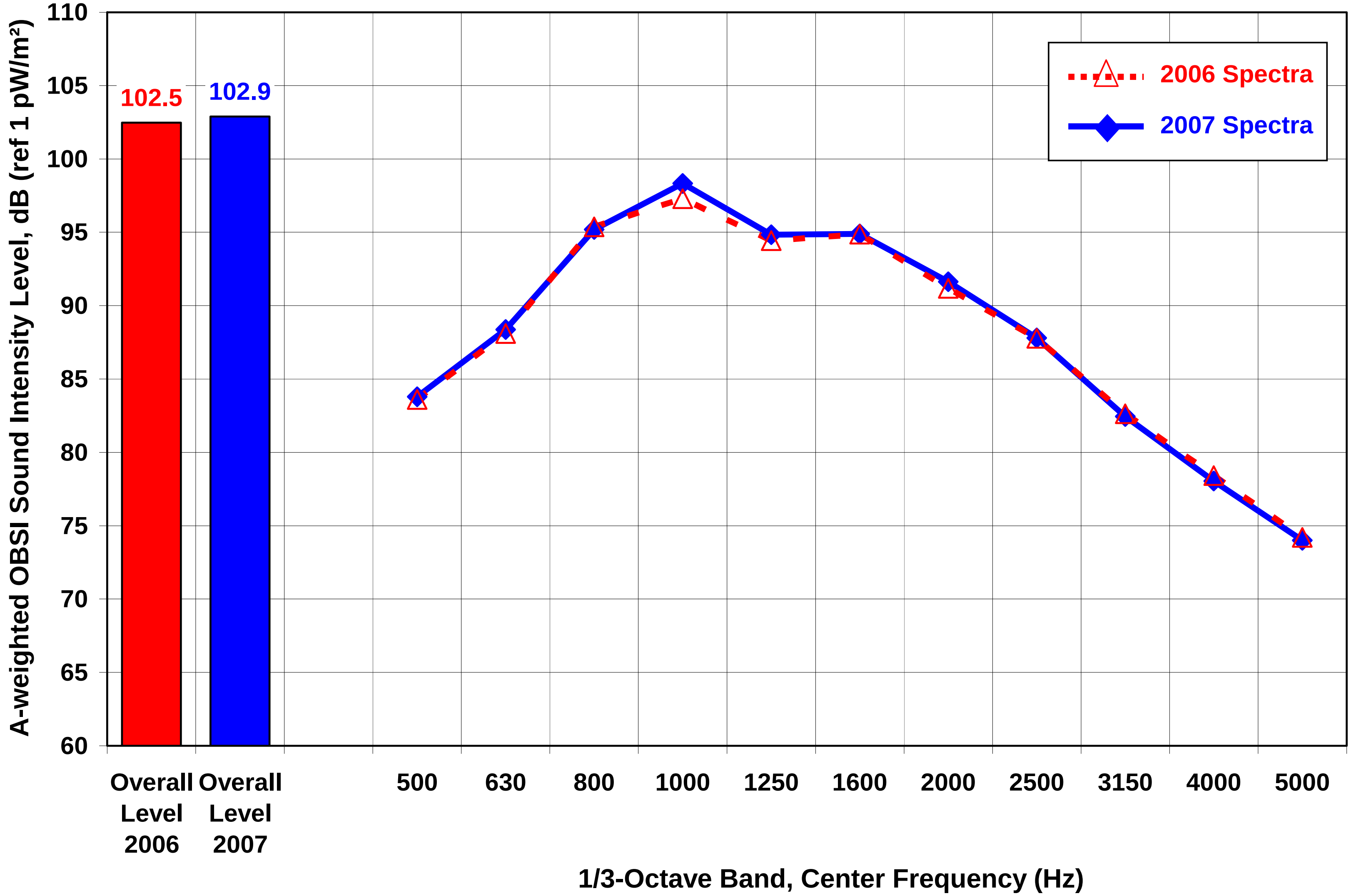
Nominal Surface: Asphalt (S, 3/4") **Construction Accepted:** 10/2003

OBSI?: Yes (8/17/07) **SPB?:** No (attempted 9/1/07, aborted due to contamination) **TA?:** No
Total Section Length: 3380 ft.
Distance from Begin to Wayside Microphone: 2649 ft.



Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 10
OBSI (SRTT) Test Information



Site: 11

General Information

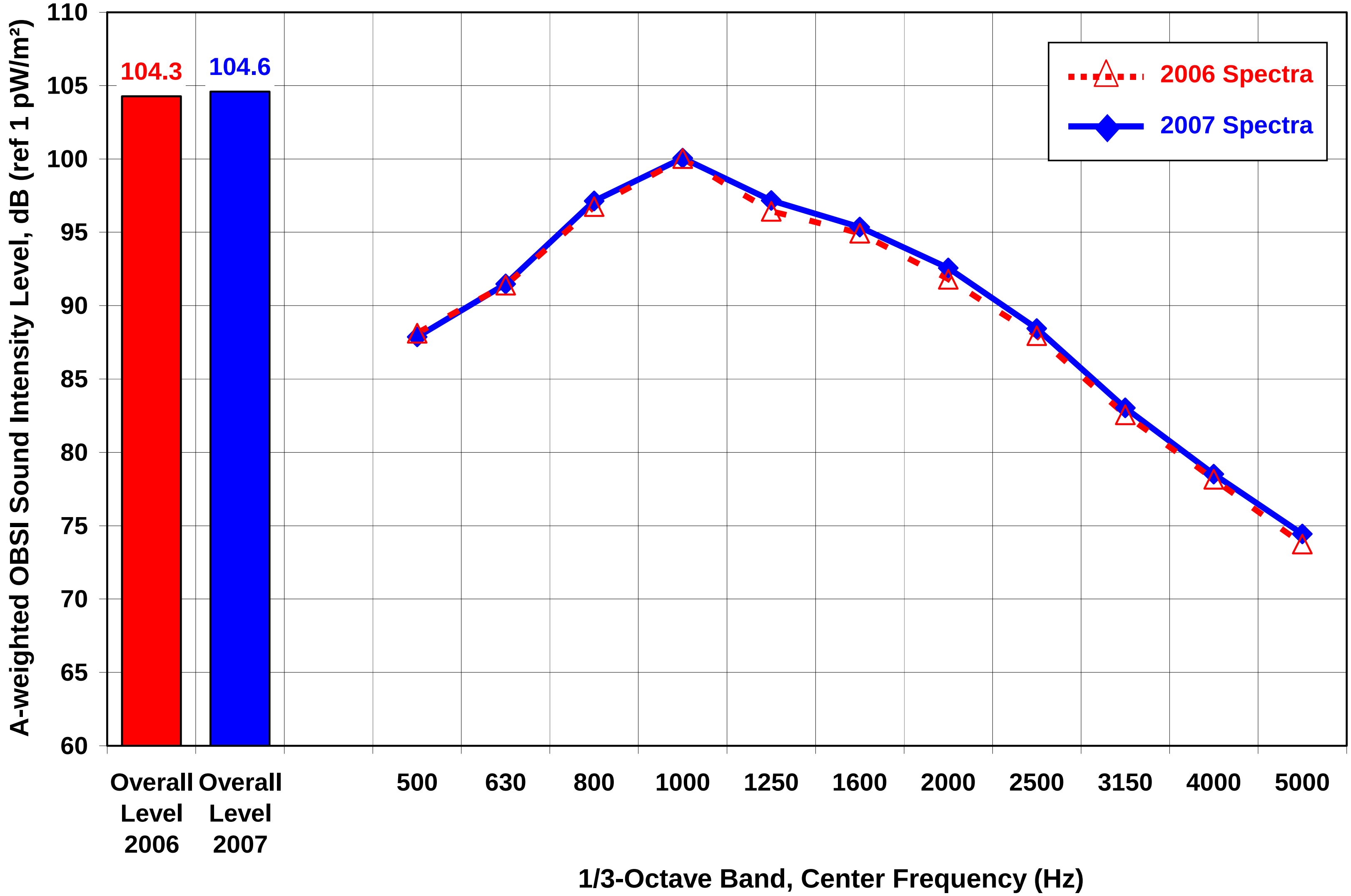
Highway: State Highway 82, Eastbound
Location: Between Hunter Logan & Lower River Rd., Basalt (81654)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.3389 / 106.9989 / 6880

Nominal Surface: NovaChip **Construction Accepted:** 10/2000

OBSI?: Yes (8/22/07) **SPB?:** No **TA?:** No
Total Section Length: 3228 ft.
Distance from Begin to Wayside Microphone: n/a

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 11
OBSI (SRTT) Test Information



Site: 12

General Information

Highway: State Highway 58, Westbound
Location: Between McIntyre St. & 44th Ave., Golden (80403)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.7706 / 105.1895 / 5600

Nominal Surface: NovaChip **Construction Accepted:** 6/2003

OBSI?: Yes (7/29/07) **SPB?:** No **TA?:** Yes (7/30/07)
Total Section Length: 3082 ft.
Distance from Begin to Wayside Microphone: 653 ft.

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 12

Time-Averaged Wayside Test Information

Sampling Periods: 2

Sample Period 1 – 3 Blocks @ 15 min ea. = 45 min. (9:00 am to 9:45 am, 7/30/07)

Traffic Volumes and Speeds during Sample Period

	WB Lane 2 (Outside)	**WB Lane 1 (Inside)**	**EB Lane 1 (Inside)**	**EB Lane 2 (Outside)**
Distance from Mic (ft.)	50	62	111	123
Average Speed (mph)	62		71	
Automobile	265	114	70	226
Heavy Truck	17	1	9	33
Medium Truck	10	0	1	13
Bus	4	0	2	2
Motorcycle	5	0	1	3
Auto + 1-Axle Trlr.	1	0	0	3
Auto + 2-Axle Trlr.	4	1	1	1
M. Trk. + 1-Axle Trlr.	0	0	0	0
M. Trk. + 2-Axle Trlr.	0	0	0	3

Block 1	**Block 2**	**Block 3**	**Average**
69.9 dBA	70.6 dBA	70.9 dBA	**70.5 dBA**

Site: 12
Time-Averaged Wayside Test Information

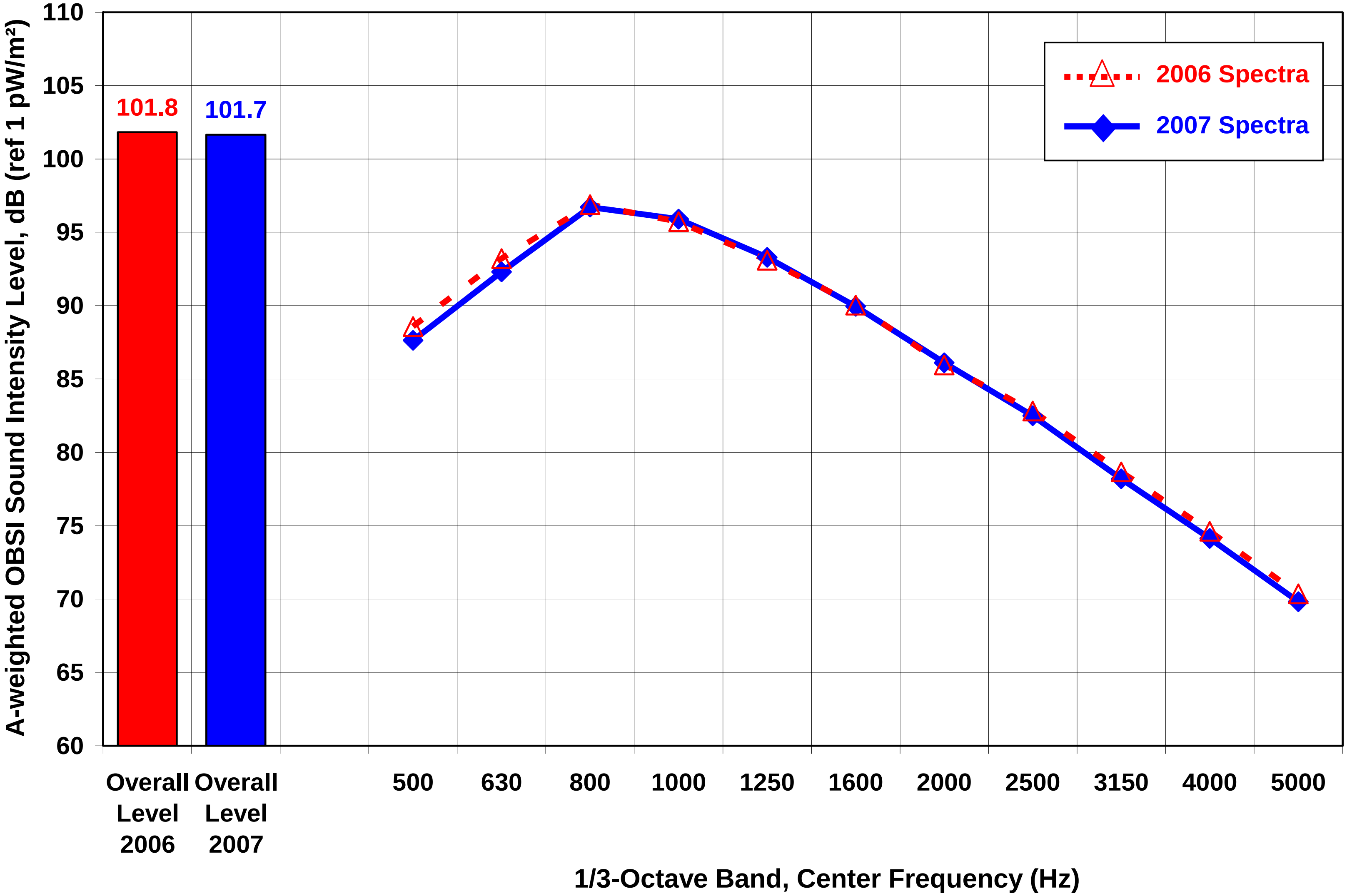
Sample Period 2 – 3 Blocks @ 15 min ea. = 45 min. (9:45 am to 10:30 am, 7/30/07)

Traffic Volumes and Speeds during Sample Period

	WB Lane 2 (Outside)	**WB Lane 1 (Inside)**	**EB Lane 1 (Inside)**	**EB Lane 2 (Outside)**
Distance from Mic (ft.)	50	62	111	123
Average Speed (mph)	63		71	
Automobile	277	97	62	215
Heavy Truck	14	2	8	25
Medium Truck	12	0	2	12
Bus	4	2	1	3
Motorcycle	2	0	0	7
Auto + 1-Axle Trlr.	3	0	0	1
Auto + 2-Axle Trlr.	2	1	3	3
M. Trk. + 1-Axle Trlr.	0	0	0	0
M. Trk. + 2-Axle Trlr.	1	0	0	1

Block 1	**Block 2**	**Block 3**	**Average**
70.4 dBA	70.5 dBA	70.2 dBA	**70.3 dBA**

Site: 12
OBSI (SRTT) Test Information



Site: 13
General Information

Highway: Interstate 25, Southbound
Location: Between CR-12 & CR-10, Erie (80516)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 40.0667 / 104.9809 / 5060

Nominal Surface: Concrete (Long. Tining) **Construction Accepted:** 10/2005

OBSI?: Yes (8/11/07) **SPB?:** No **TA?:** Yes (8/10/07)
Total Section Length: 3389 ft.
Distance from Begin to Wayside Microphone: 1054 ft.

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 13
Time-Averaged Wayside Test Information

Sampling Periods: 2

Sample Period 1 – 3 Blocks @ 15 min ea. = 45 min. (10:20 am to 11:05 am, 8/10/07)

Traffic Volumes and Speeds during Sample Period

	SB Lane 3 (Outside)	SB Lane 2	SB Lane 1 (Inside)	NB Lane 1 (Inside)	NB Lane 2	NB Lane 3 (Outside)
Distance from Mic (ft.)	50	62	74	145	157	169
Average Speed (mph)		72			74	
Automobile	320	746	946	829	713	296
Heavy Truck	98	95	18	13	103	119
Medium Truck	27	38	18	10	42	41
Bus	0	1	0	0	0	2
Motorcycle	5	16	27	11	4	5
Auto + 1-Axle Trlr.	10	8	5	6	26	15
Auto + 2-Axle Trlr.	12	11	6	9	22	16
M. Trk. + 1-Axle Trlr.	1	1	0	1	1	1
M. Trk. + 2-Axle Trlr.	6	10	0	3	11	4

Block 1	Block 2	Block 3	Average
79.8 dBA	79.7 dBA	80.3 dBA	**79.9 dBA**

Site: 13
Time-Averaged Wayside Test Information

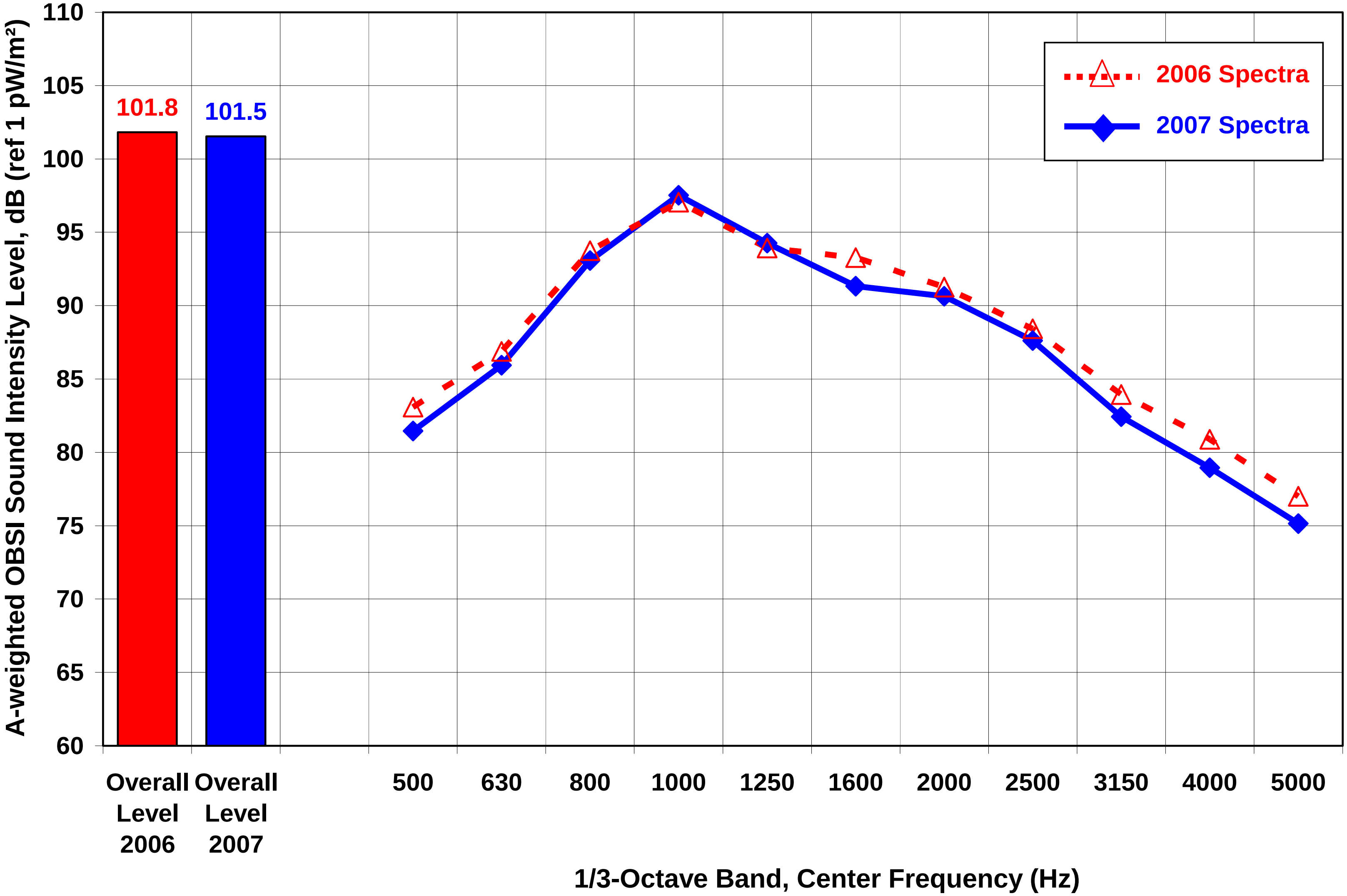
Sample Period 2 – 3 Blocks @ 15 min ea. = 45 min. (11:05 am to 11:50 am, 8/10/07)

Traffic Volumes and Speeds during Sample Period

	SB Lane 3 (Outside)	**SB Lane 2**	**SB Lane 1 (Inside)**	**NB Lane 1 (Inside)**	**NB Lane 2**	**NB Lane 3 (Outside)**
Distance from Mic (ft.)	50	62	74	145	157	169
Average Speed (mph)		74			74	
Automobile	328	691	1009	841	753	273
Heavy Truck	100	114	16	11	98	124
Medium Truck	30	32	13	3	32	39
Bus	0	0	2	0	1	1
Motorcycle	7	31	17	12	10	4
Auto + 1-Axle Trlr.	11	17	7	8	17	13
Auto + 2-Axle Trlr.	11	13	7	6	16	17
M. Trk. + 1-Axle Trlr.	0	1	1	0	0	1
M. Trk. + 2-Axle Trlr.	5	9	2	1	6	7

Block 1	**Block 2**	**Block 3**	**Average**
79.7 dBA	79.8 dBA	79.5 dBA	**79.7 dBA**

Site: 13
OBSI (SRTT) Test Information



Site: 14
General Information

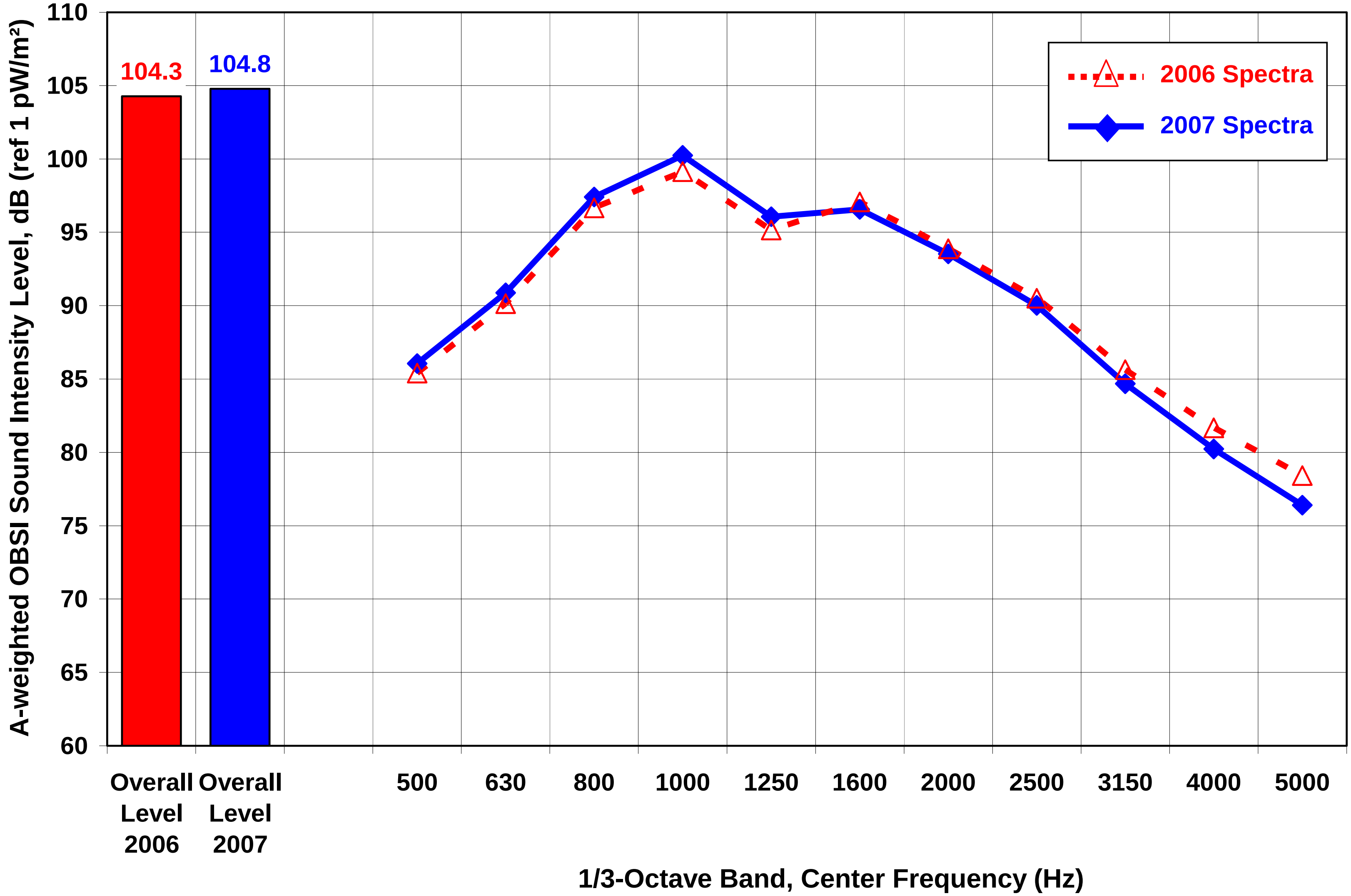
Highway: US Highway 285, Northbound
Location: Between Surrey Dr. & Goddard Ranch Ct., Indian Hills (80465)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.5838 / 105.2258 / 7130

Nominal Surface: Concrete (Long. Tining) **Construction Accepted:** 10/1999

OBSI?: Yes (6/25/07) **SPB?:** No **TA?:** No
Total Section Length: 1613 ft.
Distance from Begin to Wayside Microphone: n/a

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 14
OBSI (SRTT) Test Information



Site: 15
General Information

Highway: Interstate 25, Northbound
Location: Between Fontanero St. & Fillmore St., Colorado Springs (80907)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 38.8672 / 104.834 / 6130

Nominal Surface: Concrete (Long. Grooving) **Construction Accepted:** 11/2001

OBSI?: No **SPB?:** No **TA?:** No (construction in vicinity during measurement)
Total Section Length: 4485 ft.
Distance from Begin to Wayside Microphone: n/a

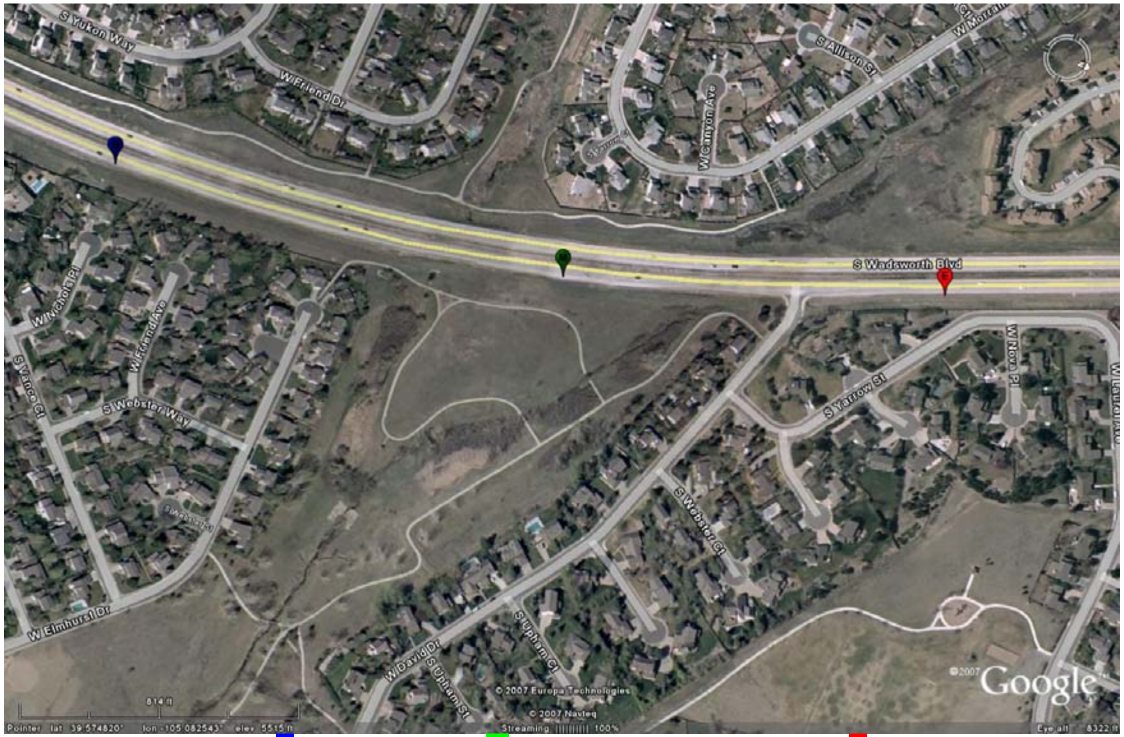
Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 16
General Information

Highway: State Highway 121, Northbound
Location: Between Chatfield Ave. & Ken Caryl Ave., Littleton (80128)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.5741 / 105.0837 / 5580

Nominal Surface: Concrete (Carpet Drag) **Construction Accepted:** 8/2001

OBSI?: Yes (7/31/07) **SPB?:** No **TA?:** Yes (7/31/07)
Total Section Length: 2422 ft.
Distance from Begin to Wayside Microphone: 1323 ft.



Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 16
Time-Averaged Wayside Test Information

Sampling Periods: 2

Sample Period 1 – 3 Blocks @ 15 min ea. = 45 min. (9:20 am to 10:05 am, 7/31/07)

Traffic Volumes and Speeds during Sample Period

	NB Lane 2 (Outside)	**NB Lane 1 (Inside)**	**SB Lane 1 (Inside)**	**SB Lane 2 (Outside)**
Distance from Mic (ft.)	50	62	104	116
Average Speed (mph)	59		58	
Automobile	189	266	246	266
Heavy Truck	3	0	2	4
Medium Truck	3	5	5	12
Bus	1	1	0	1
Motorcycle	0	2	2	2
Auto + 1-Axle Trlr.	2	1	0	2
Auto + 2-Axle Trlr.	1	0	1	2
M. Trk. + 1-Axle Trlr.	0	0	0	0
M. Trk. + 2-Axle Trlr.	0	0	0	2

Block 1	**Block 2**	**Block 3**	**Average**
69.0 dBA	69.5 dBA	69.2 dBA	**69.2 dBA**

Site: 16
Time-Averaged Wayside Test Information

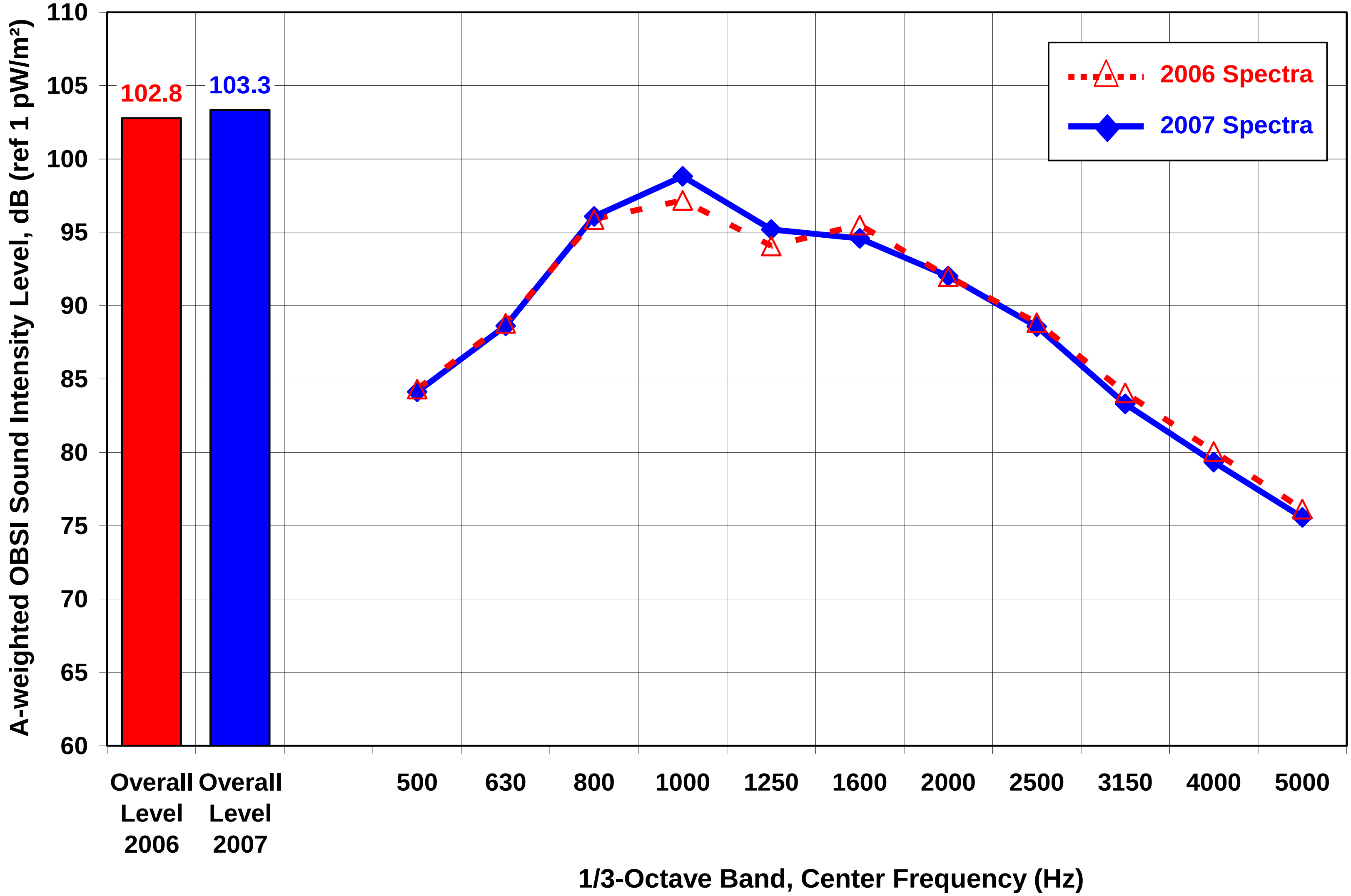
Sample Period 2 – 3 Blocks @ 15 min ea. = 45 min. (10:05 am to 10:50 am, 7/31/07)

Traffic Volumes and Speeds during Sample Period

	NB Lane 2 (Outside)	**NB Lane 1 (Inside)**	**SB Lane 1 (Inside)**	**SB Lane 2 (Outside)**
Distance from Mic (ft.)	50	62	104	116
Average Speed (mph)	58		57	
Automobile	177	249	243	284
Heavy Truck	4	1	1	5
Medium Truck	9	7	3	8
Bus	0	1	1	1
Motorcycle	2	0	0	1
Auto + 1-Axle Trlr.	2	1	0	4
Auto + 2-Axle Trlr.	2	1	0	2
M. Trk. + 1-Axle Trlr.	0	0	0	0
M. Trk. + 2-Axle Trlr.	3	0	0	0

Block 1	**Block 2**	**Block 3**	**Average**
69.0 dBA	69.2 dBA	68.7 dBA	**69.0 dBA**

Site: 16
OBSI (SRTT) Test Information



Site: 17
General Information

Highway: Interstate 70, Westbound
Location: Between SH 13 & US 6/24, Rifle (81650)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.5205 / 107.8229 / 5290

Nominal Surface: Concrete (Diamond Grinding) **Construction Accepted:** 11/2005

OBSI?: Yes (8/23/07) **SPB?:** No **TA?:** Yes (8/23/07)
Total Section Length: 6368 ft.
Distance from Begin to Wayside Microphone: 1177 ft.

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 17
Time-Averaged Wayside Test Information

Sampling Periods: 2

Sample Period 1 – 3 Blocks @ 15 min ea. = 45 min. (5:00 pm to 5:45 pm, 8/23/07)

Traffic Volumes and Speeds during Sample Period

	WB Lane 2 (Outside)	**WB Lane 1 (Inside)**	**EB Lane 1 (Inside)**	**EB Lane2 (Outside)**
Distance from Mic (ft.)	50	62	174	186
Average Speed (mph)	74		73	
Automobile	369	152	80	241
Heavy Truck	41	1	10	69
Medium Truck	23	6	2	13
Bus	0	0	0	0
Motorcycle	4	1	0	1
Auto + 1-Axle Trlr.	1	0	0	2
Auto + 2-Axle Trlr.	9	3	1	4
M. Trk. + 1-Axle Trlr.	0	0	0	0
M. Trk. + 2-Axle Trlr.	6	0	0	2

Block 1	**Block 2**	**Block 3**	**Average**
73.9 dBA	75.6 dBA	75.2 dBA	**74.9 dBA**

Site: 17
Time-Averaged Wayside Test Information

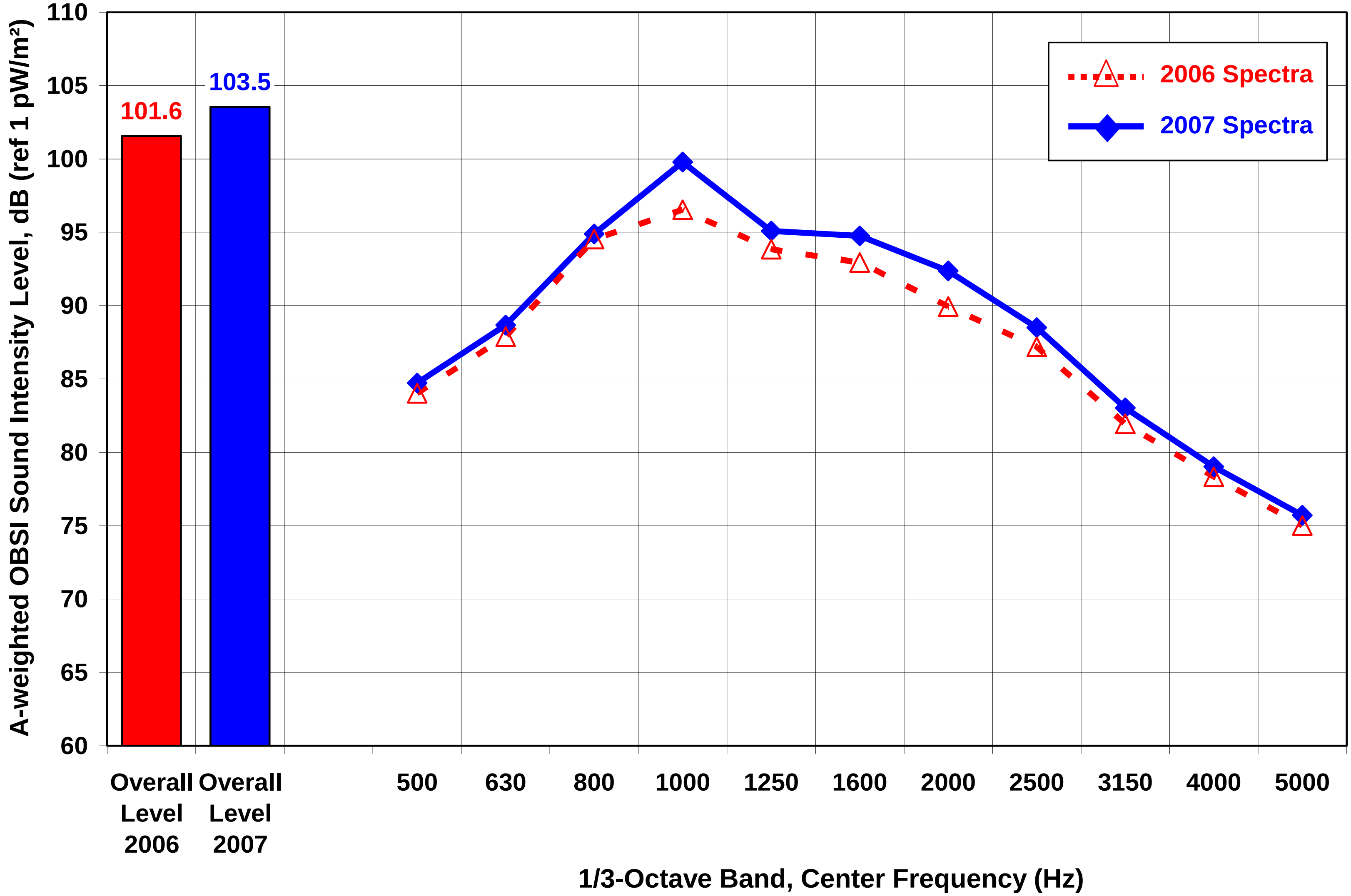
Sample Period 2 – 3 Blocks @ 15 min ea. = 45 min. (5:45 pm to 6:30 pm, 8/23/07)

Traffic Volumes and Speeds during Sample Period

	WB Lane 2 (Outside)	**WB Lane 1 (Inside)**	**EB Lane 1 (Inside)**	**EB Lane2 (Outside)**
Distance from Mic (ft.)	50	62	174	186
Average Speed (mph)	74		73	
Automobile	356	157	80	240
Heavy Truck	63	6	5	55
Medium Truck	18	5	2	15
Bus	3	1	0	2
Motorcycle	2	2	1	3
Auto + 1-Axle Trlr.	5	4	1	4
Auto + 2-Axle Trlr.	4	6	1	6
M. Trk. + 1-Axle Trlr.	0	0	0	1
M. Trk. + 2-Axle Trlr.	6	0	0	0

Block 1	**Block 2**	**Block 3**	**Average**
75.8 dBA	75.9 dBA	76.1 dBA	**75.9 dBA**

Site: 17
OBSI (SRTT) Test Information



Site: 18
General Information

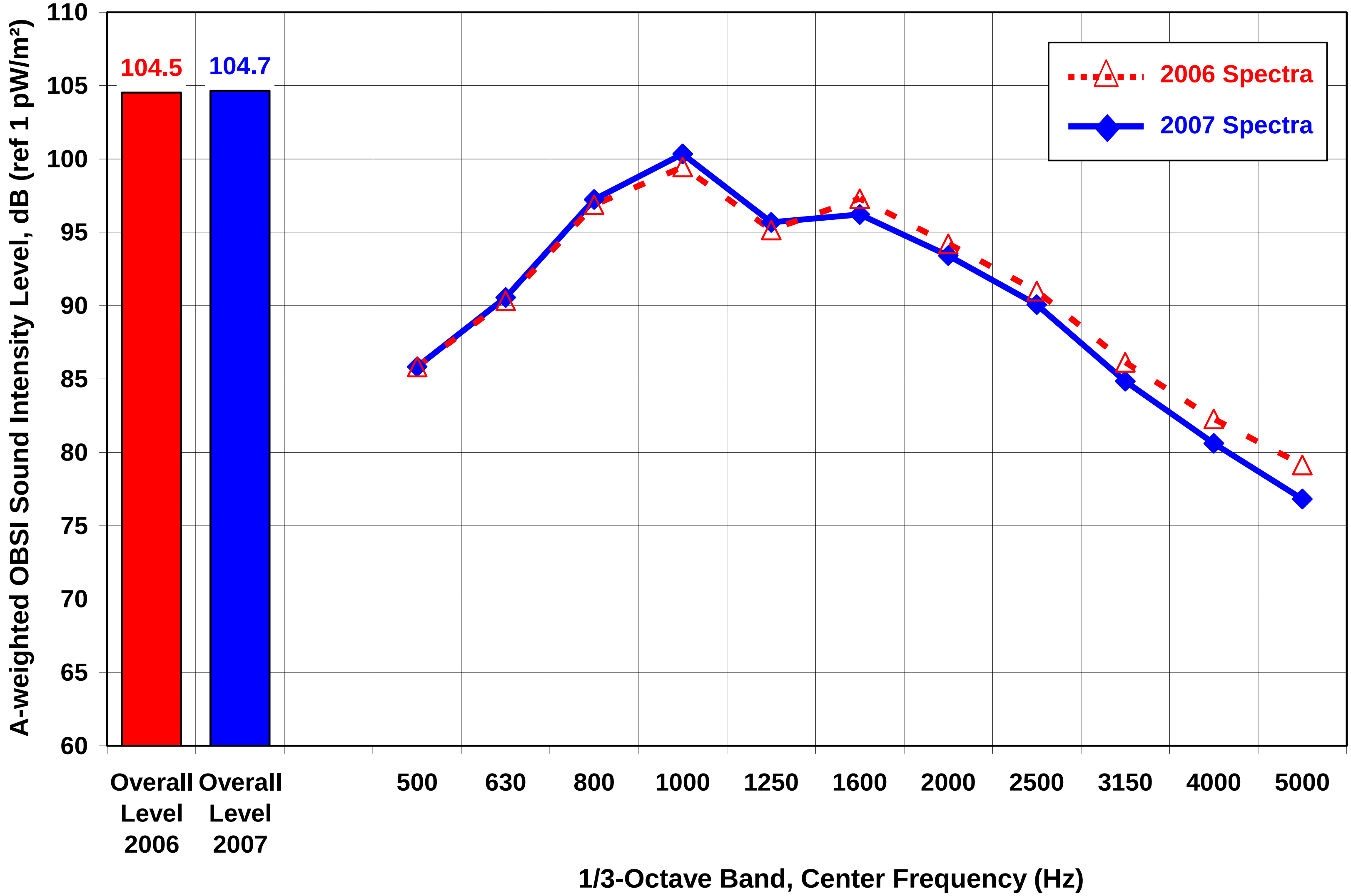
Highway: US Highway 285, Northbound
Location: Between Turkey Creek Rd. & Chamberlain Rd., Indian Hills (80465)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.598 / 105.2255 / 7050

Nominal Surface: Concrete (Diamond Grinding) **Construction Accepted:** 10/1999

OBSI?: Yes (6/25/07) **SPB?:** No **TA?:** No
Total Section Length: 2069 ft.
Distance from Begin to Wayside Microphone: n/a

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 18
OBSI (SRTT) Test Information



Site: 19
General Information

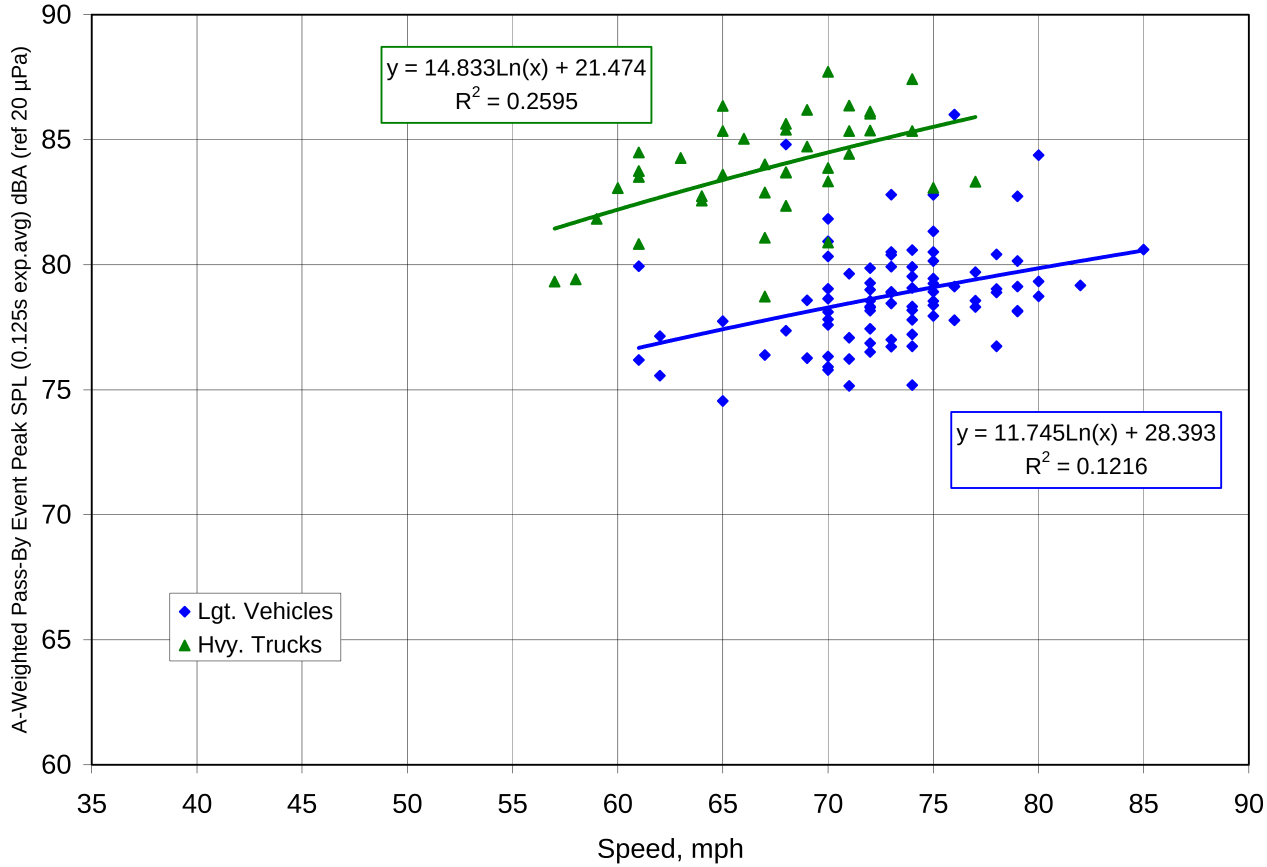
Highway: Interstate 70, Westbound
Location: Between Camino Dorado Rd. & Trail Gulch Rd., Gypsum (81637)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.6528 / 106.8823 / 6630

Nominal Surface: SMA **Construction Accepted:** 8/1996

OBSI?: Yes (8/21/07) **SPB?:** Yes (8/21/07) **TA?:** No
Total Section Length: 3122 ft.
Distance from Begin to Wayside Microphone: 443 ft.

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

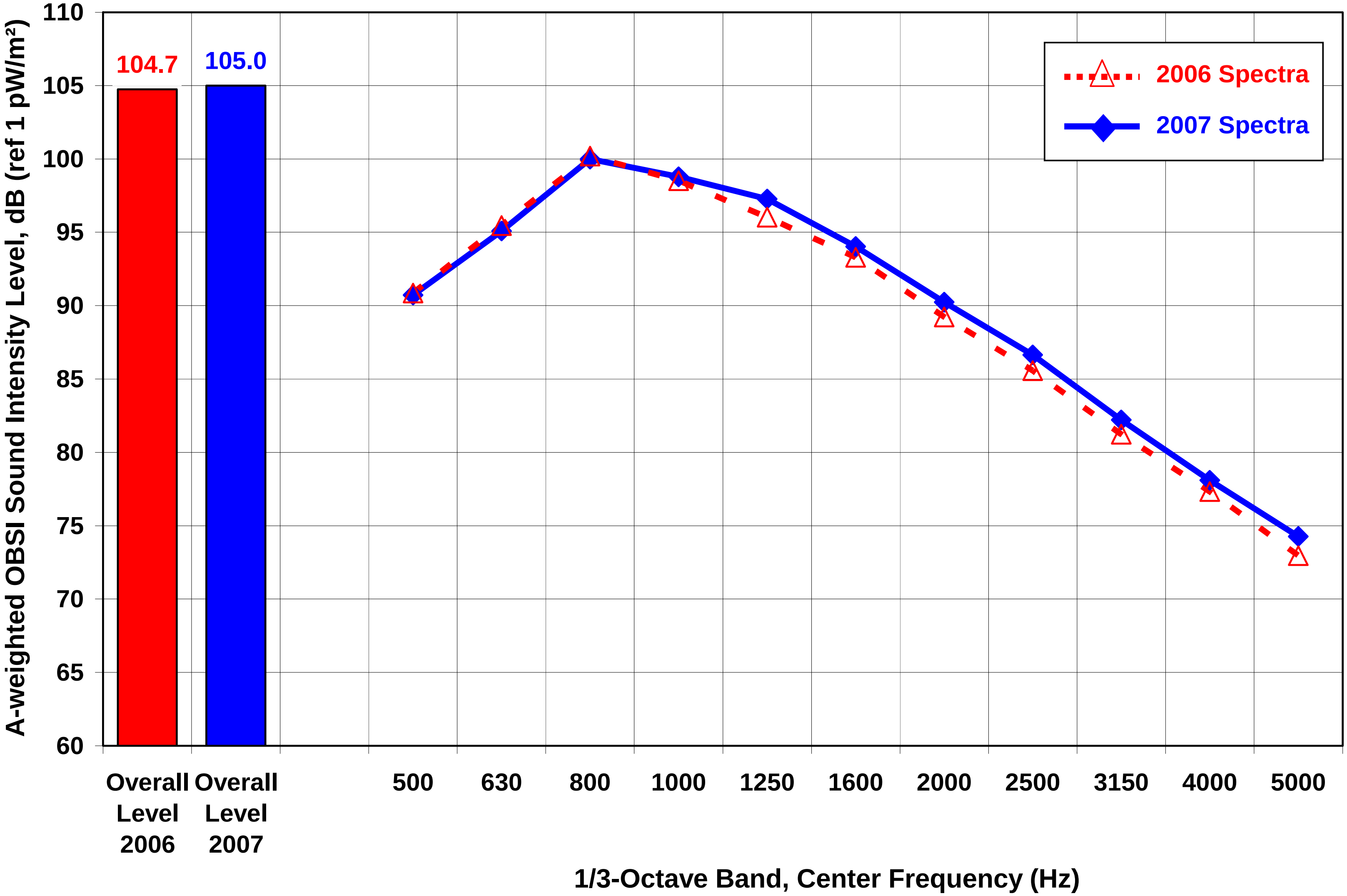
Site: 19
SPB Wayside Test Information



SPBI (Car, 60mph): 76.5 dBA
SPBI (H. Truck, 60mph): 82.2 dBA

Site: 19

OBSI (SRTT) Test Information



Site: 20
General Information

Highway: US Highway 40, Westbound
Location: Between CR-8 & SH 94, Kit Carson (80862)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 38.8328 / 103.054 / 4520

Nominal Surface: Concrete **Construction Accepted:** 4/2002

OBSI?: Yes (8/8/07) **SPB?:** No **TA?:** Yes (8/7/07)
Total Section Length: 5241 ft.
Distance from Begin to Wayside Microphone: 2668 ft.

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 20
Time-Averaged Wayside Test Information

Sampling Periods: 1

Sample Period 1 – 5 Blocks @ 15 min ea. = 75 min. (11:00 am to 12:15 pm, 8/7/07)

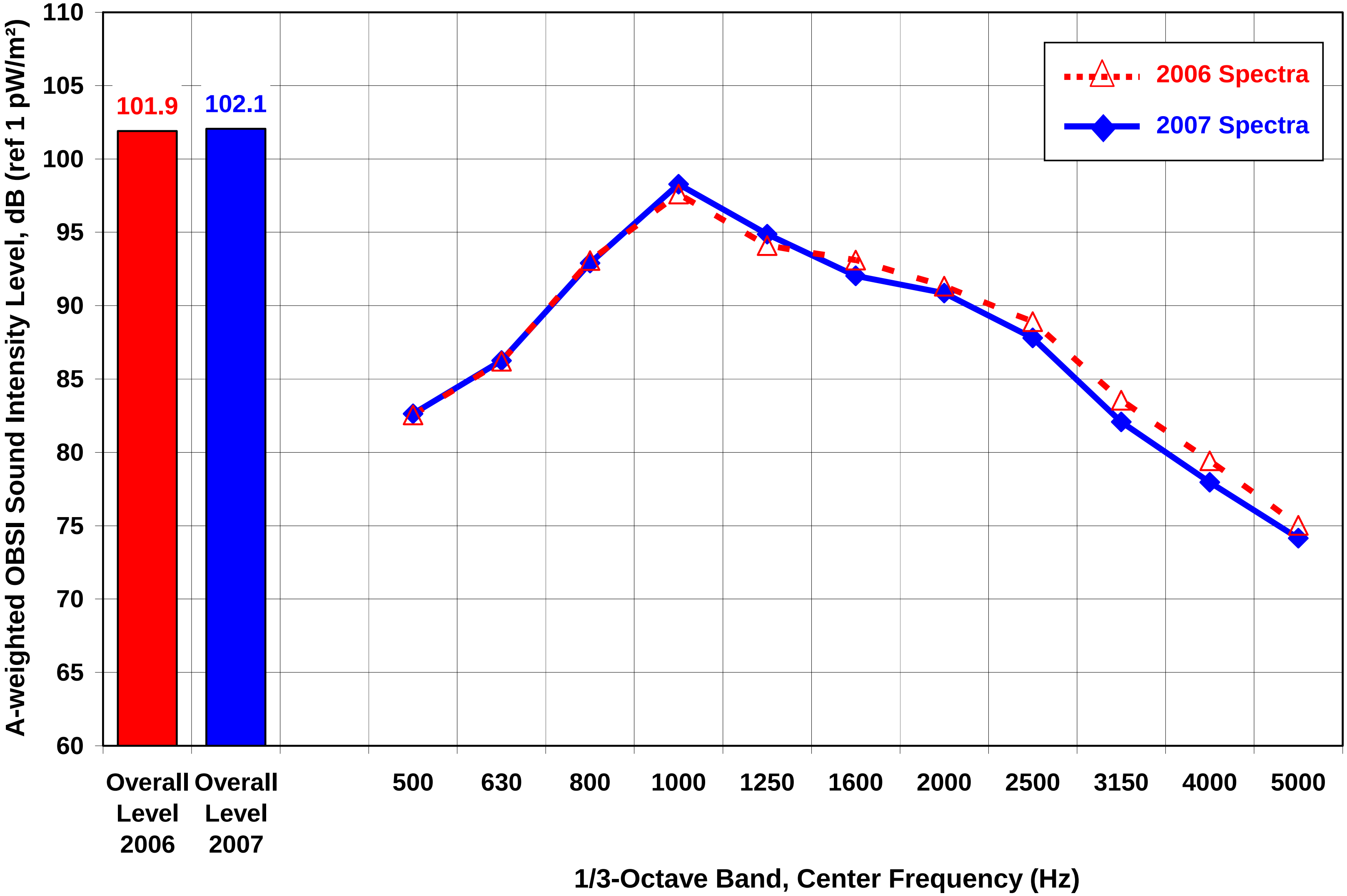
Traffic Volumes and Speeds during Sample Period

	NB Lane 1	**SB Lane 1**
Distance from Mic (ft.)	50	62
Average Speed (mph)	67	69
Automobile	39	38
Heavy Truck	39	56
Medium Truck	3	2
Bus	0	0
Motorcycle	0	2
Auto + 1-Axle Trlr.	0	1
Auto + 2-Axle Trlr.	3	2
M. Trk. + 1-Axle Trlr.	0	0
M. Trk. + 2-Axle Trlr.	5	1

Block 1	**Block 2**	**Block 3**	**Block 4**	**Block 5**	**Average**
69.9 dBA	69.4 dBA	69.9 dBA	69.7 dBA	69.0 dBA	**69.6 dBA**

Site: 20

OBSI (SRTT) Test Information

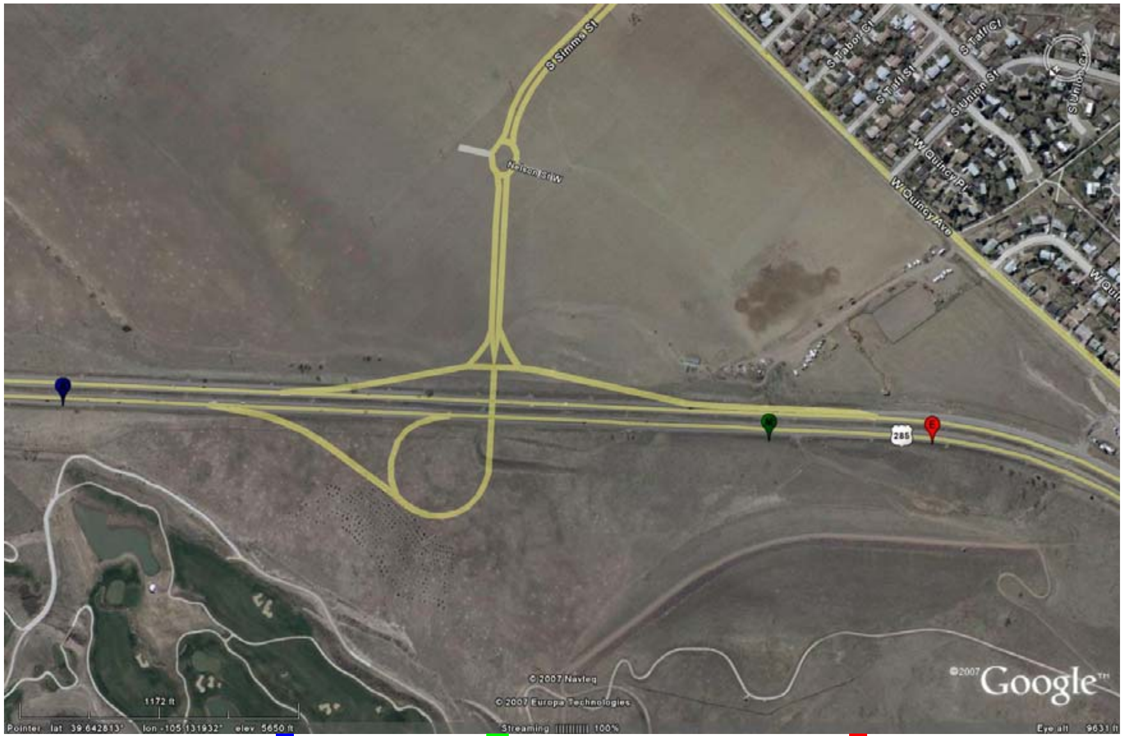


Site: 21
General Information

Highway: US Highway 285, Southbound
Location: Between Kipling Pkwy. & C-470, Morrison (80227)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.6438 / 105.1318 / 5700

Nominal Surface: Asphalt (S, 3/4") **Construction Accepted:** 11/2003

OBSI?: Yes (7/17/07) **SPB?:** No **TA?:** Yes (7/18/07)
Total Section Length: 3599 ft.
Distance from Begin to Wayside Microphone: 1451 ft.



Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 21
Time-Averaged Wayside Test Information

Sampling Periods: 2

Sample Period 1 – 3 Blocks @ 15 min ea. = 45 min. (9:55 am to 10:40 am, 7/18/07)

Traffic Volumes and Speeds during Sample Period

	SB Lane 2 (Outside)	SB Lane 1 (Inside)	NB Lane 1 (Inside)	NB Lane2 (Outside)
Distance from Mic (ft.)	50	62	110	122
Average Speed (mph)	69		66	
Automobile	358	140	110	375
Heavy Truck	29	10	2	18
Medium Truck	11	1	3	5
Bus	1	0	0	1
Motorcycle	4	2	2	5
Auto + 1-Axle Trlr.	2	1	0	2
Auto + 2-Axle Trlr.	3	0	0	1
M. Trk. + 1-Axle Trlr.	2	0	0	0
M. Trk. + 2-Axle Trlr.	5	0	0	5

Block 1	Block 2	Block 3	Average
74.3 dBA	74.4 dBA	75.1 dBA	**74.6 dBA**

Site: 21
Time-Averaged Wayside Test Information

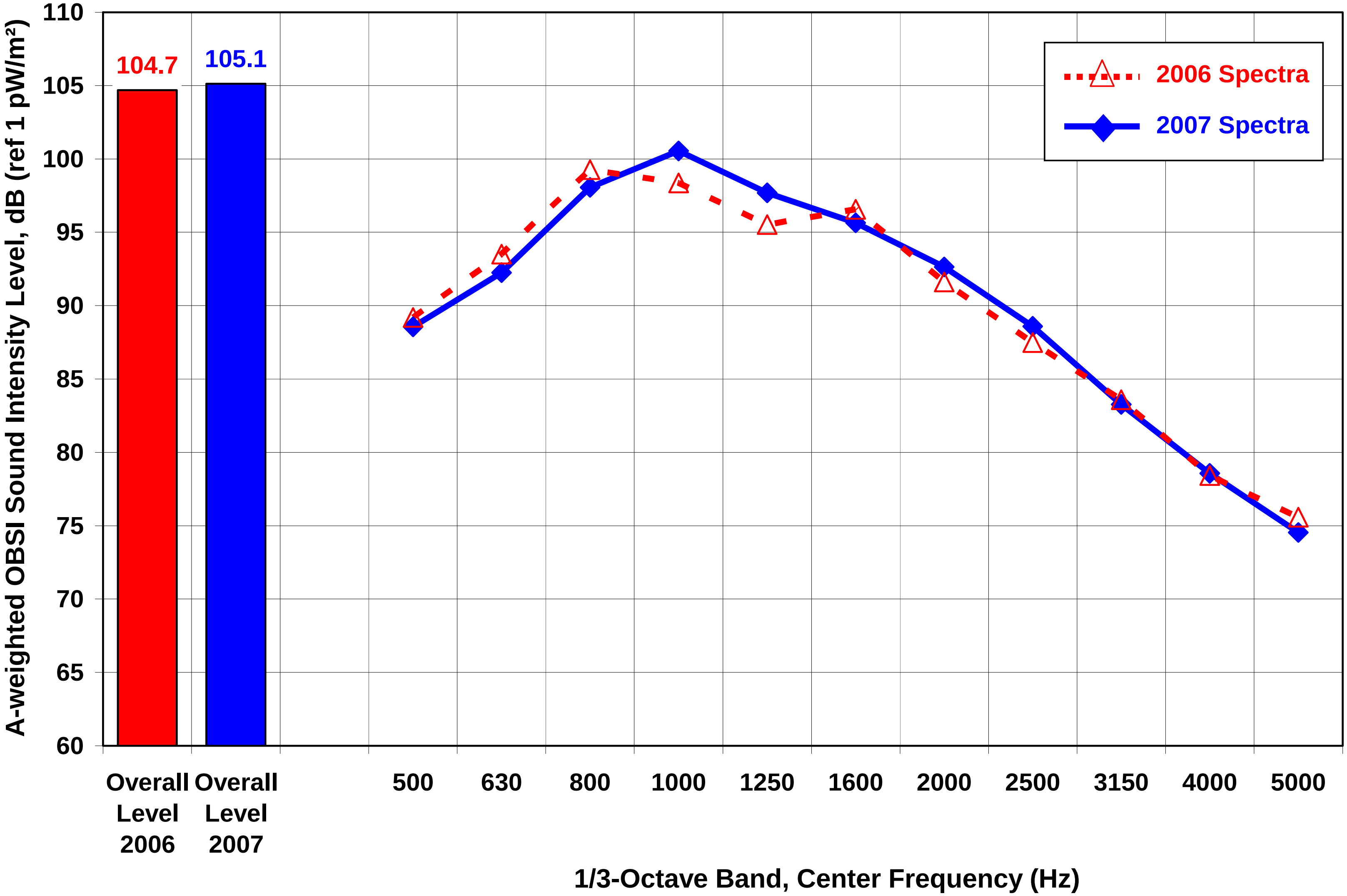
Sample Period 2 – 3 Blocks @ 15 min ea. = 45 min. (10:40 am to 11:25 am, 7/18/07)

Traffic Volumes and Speeds during Sample Period

	SB Lane 2 (Outside)	**SB Lane 1 (Inside)**	**NB Lane 1 (Inside)**	**NB Lane2 (Outside)**
Distance from Mic (ft.)	50	62	110	122
Average Speed (mph)	67		70	
Automobile	398	155	118	397
Heavy Truck	13	7	4	20
Medium Truck	14	3	1	18
Bus	4	0	0	0
Motorcycle	3	0	2	4
Auto + 1-Axle Trlr.	1	0	1	2
Auto + 2-Axle Trlr.	6	1	0	4
M. Trk. + 1-Axle Trlr.	0	0	0	1
M. Trk. + 2-Axle Trlr.	1	0	0	1

Block 1	**Block 2**	**Block 3**	**Average**
75.0 dBA	74.1 dBA	73.8 dBA	**74.3 dBA**

Site: 21
OBSI (SRTT) Test Information



Site: 22
General Information

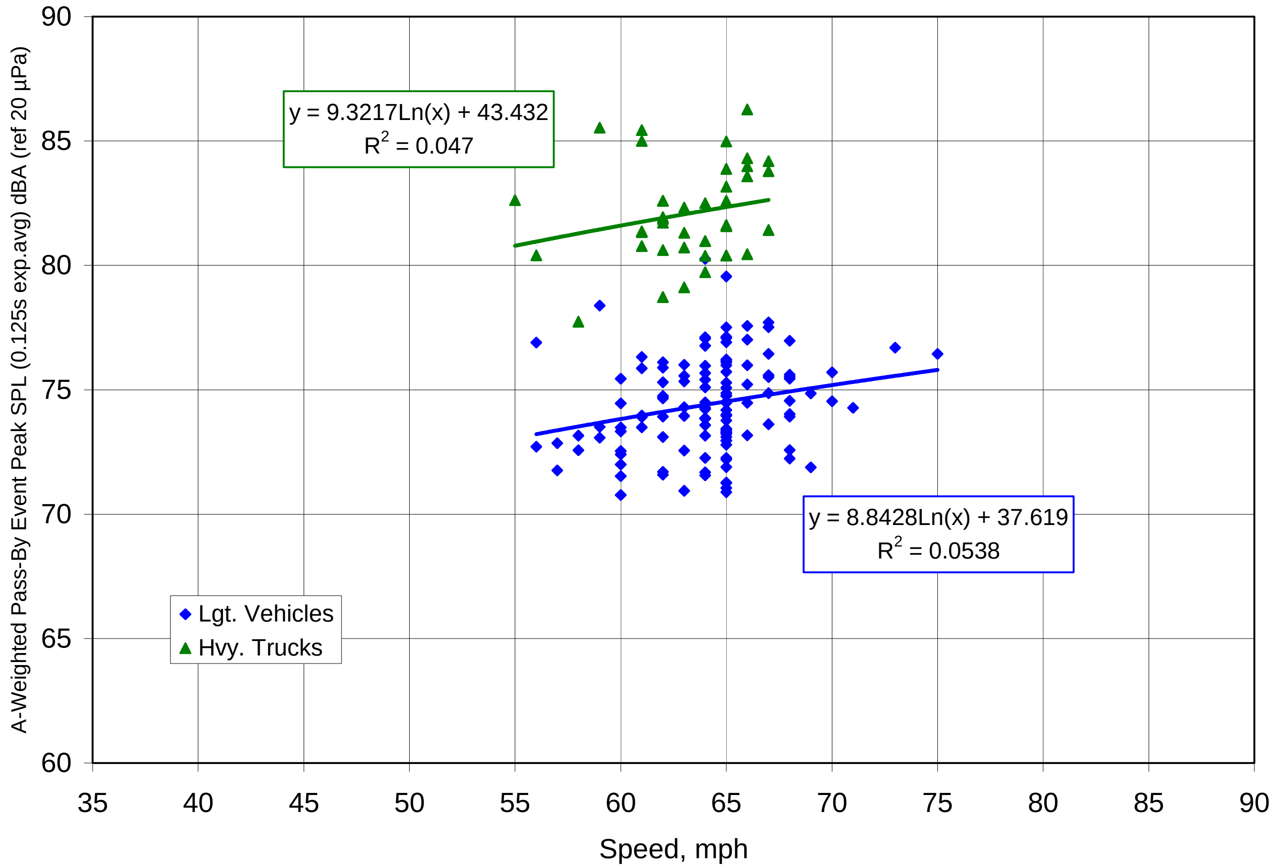
Highway: US Highway 160, Westbound
Location: Between CR-103 & Threemile Rd., Alamosa (81101)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 37.5177 / 105.9948 / 7610

Nominal Surface: Asphalt **Construction Accepted:** 10/1999

OBSI?: Yes (8/29/07) **SPB?:** Yes (8/28/07) **TA?:** No
Total Section Length: 2930 ft.
Distance from Begin to Wayside Microphone: 796 ft.

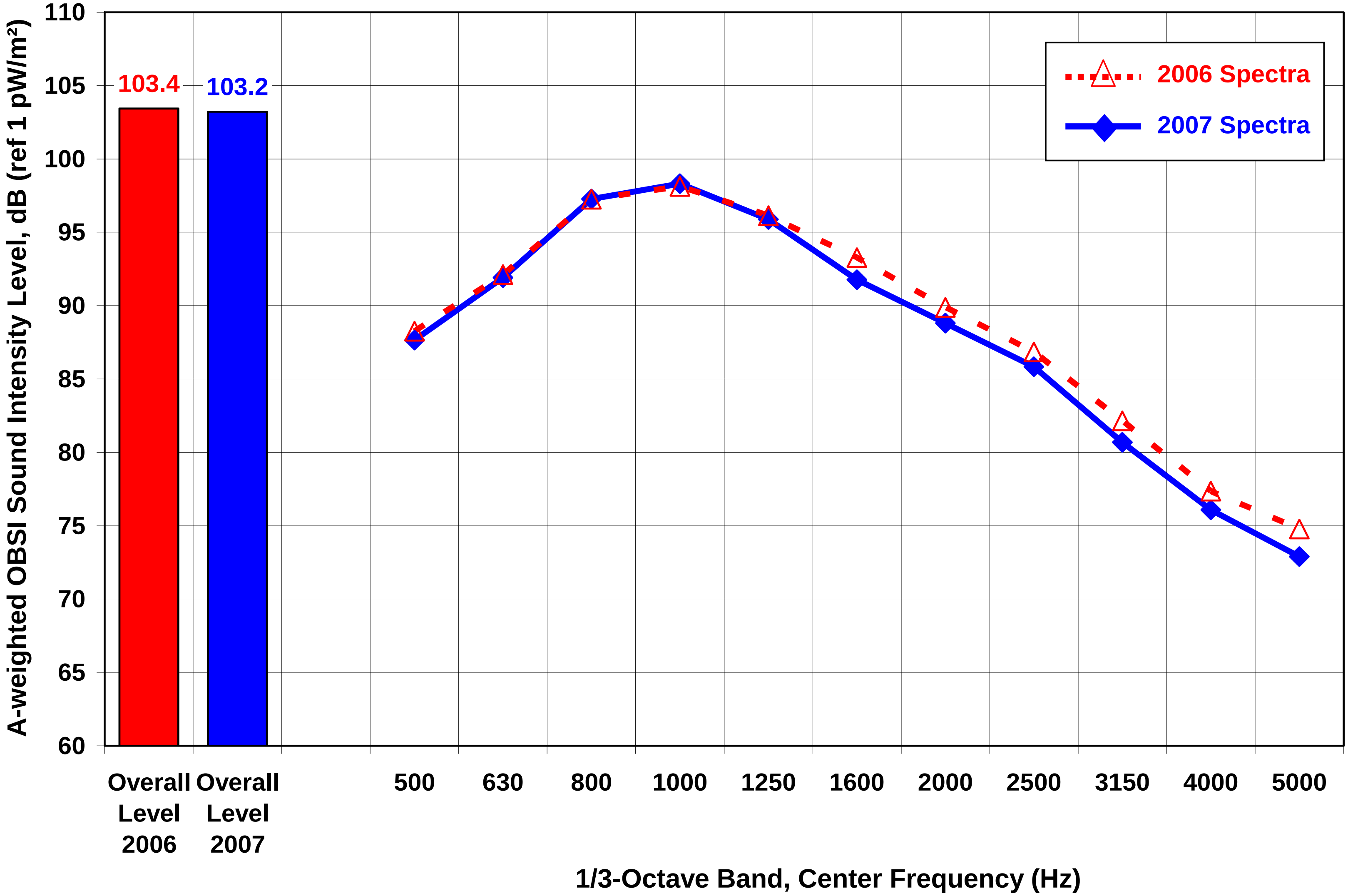
Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 22
SPB Wayside Test Information



SPBI (Car, 60mph): 73.8 dBA
SPBI (H. Truck, 60mph): 81.6 dBA

Site: 22
OBSI (SRTT) Test Information



Site: 23

General Information

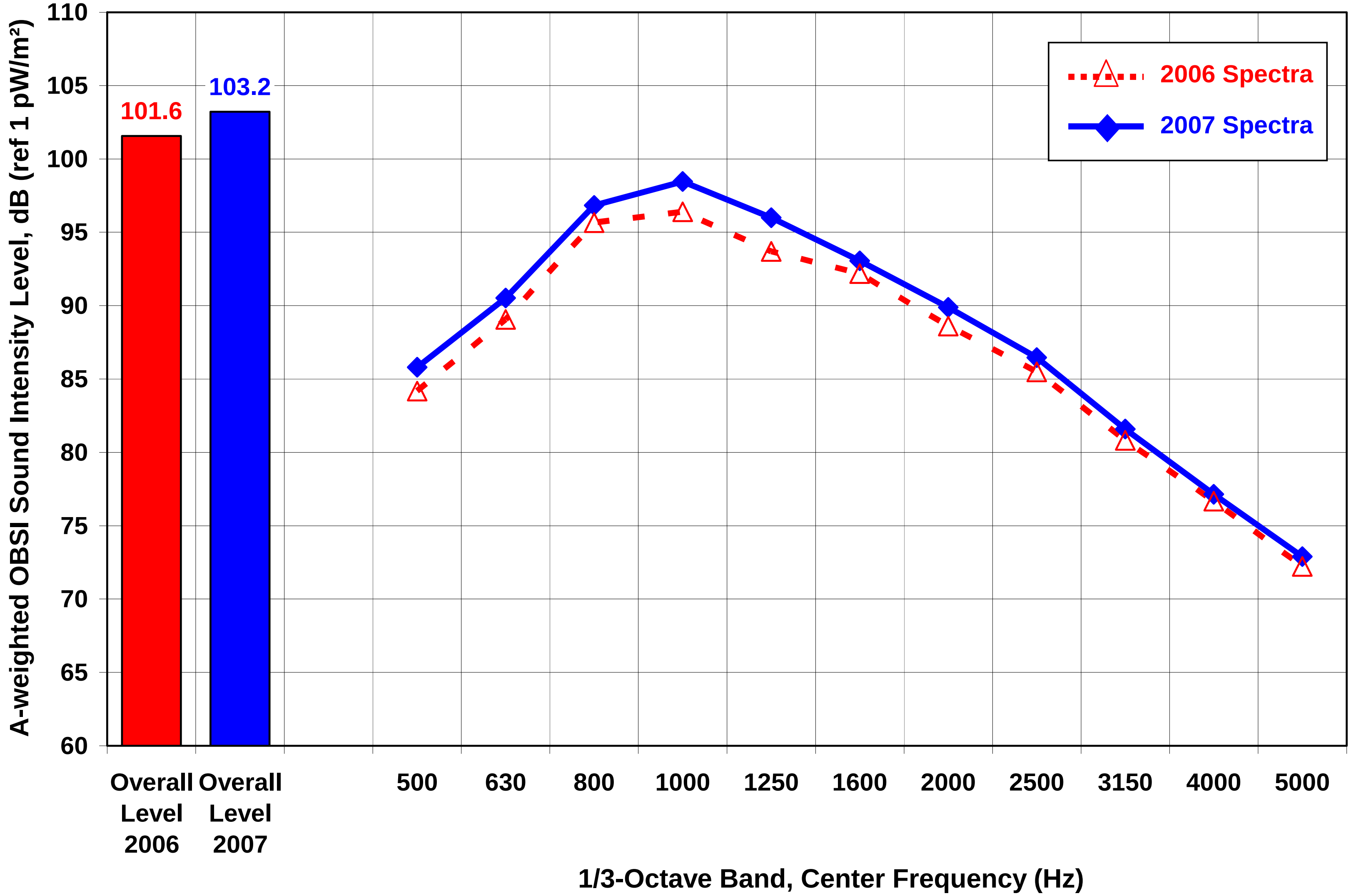
Highway: Interstate 70, Eastbound
Location: Between 23 Rd. & 24 Rd., Grand Junction (81505)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.1138 / 108.6193 / 4560

Nominal Surface: Asphalt **Construction Accepted:** 10/2004

OBSI?: Yes (8/26/07) **SPB?:** No **TA?:** No
Total Section Length: 3623 ft.
Distance from Begin to Wayside Microphone: n/a

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 23
OBSI (SRTT) Test Information



Site: 24

General Information

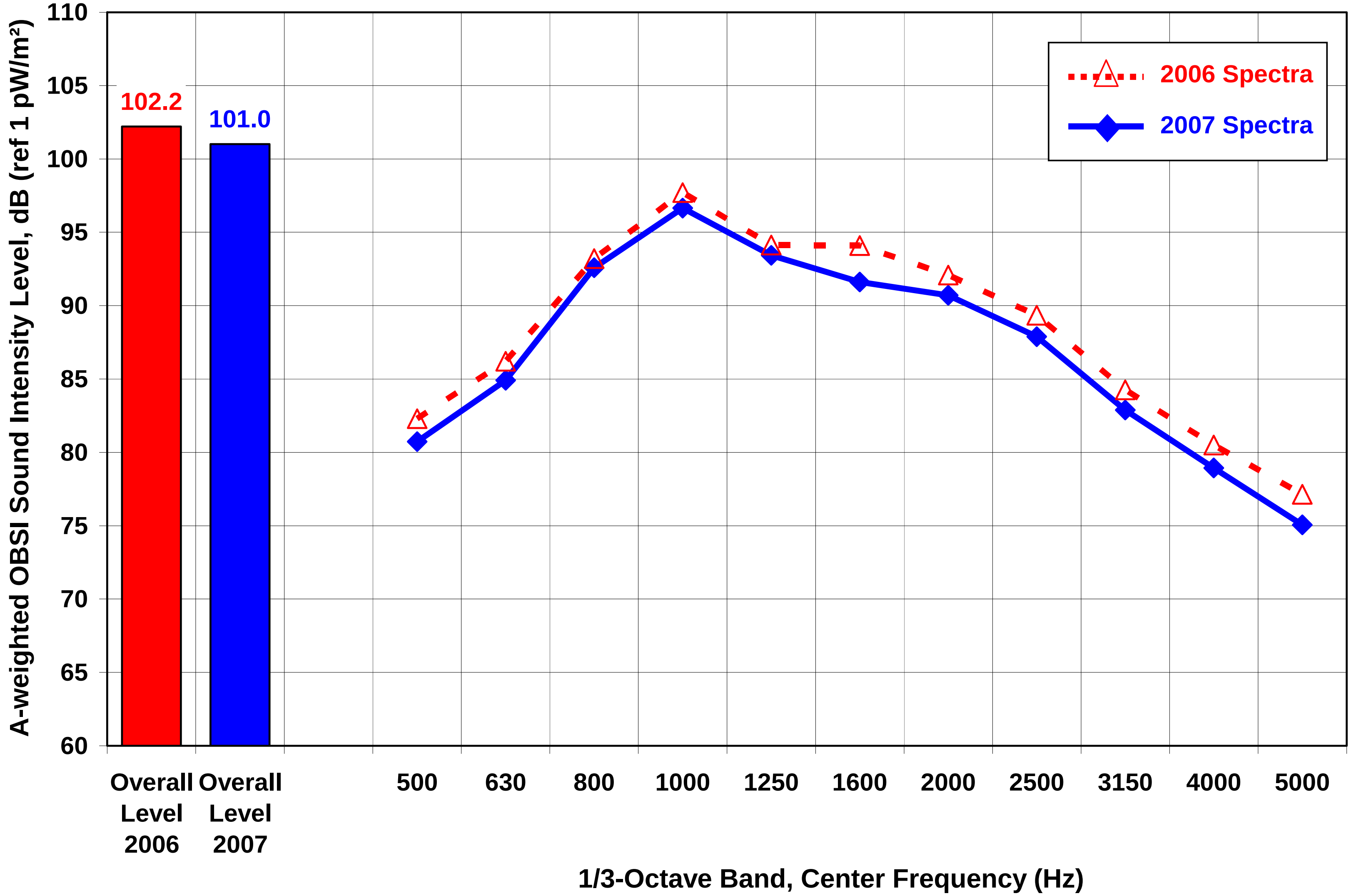
Highway: Interstate 76, Westbound
Location: Between CR-49 & SH 52, Hudson (80642)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 40.0942 / 104.6143 / 4940

Nominal Surface: Concrete **Construction Accepted:** 3/2001

OBSI?: Yes (6/24/07) **SPB?:** No **TA?:** No
Total Section Length: 3345 ft.
Distance from Begin to Wayside Microphone: n/a

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 24
OBSI (SRTT) Test Information

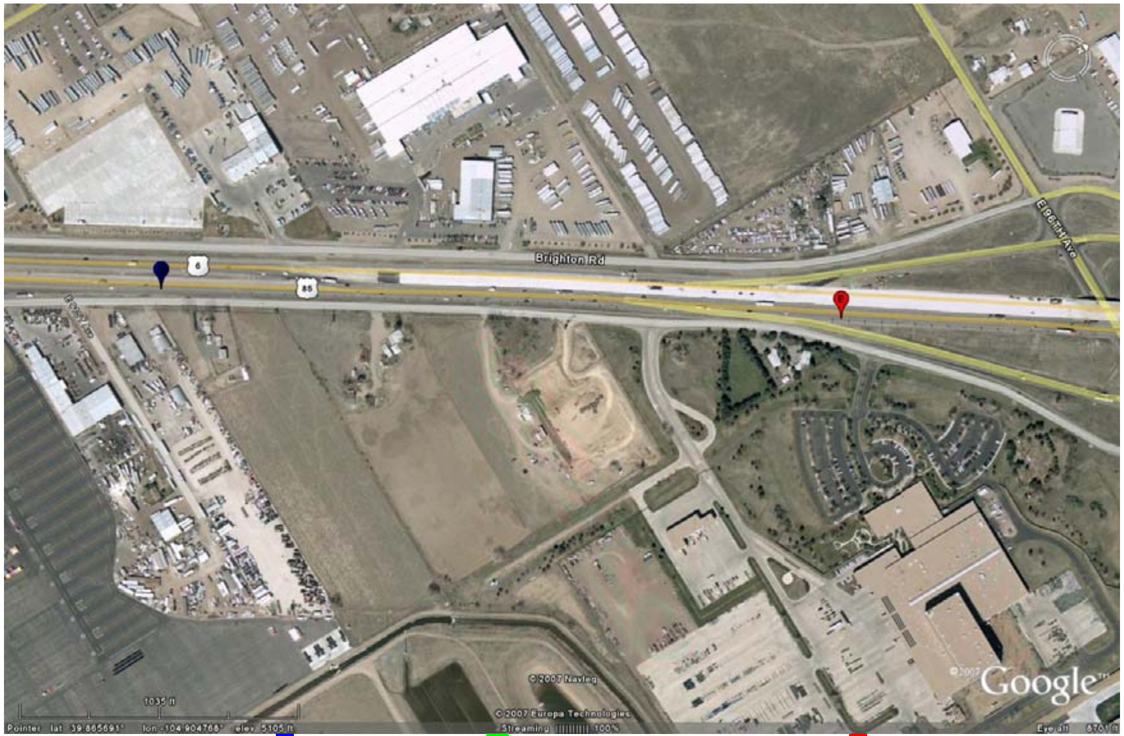


Site: 25
General Information

Highway: Interstate 76, Eastbound
Location: Between 88th Ave. & 96th Ave., Henderson (80640)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.8655 / 104.9059 / 5120

Nominal Surface: Concrete **Construction Accepted:** 11/2002

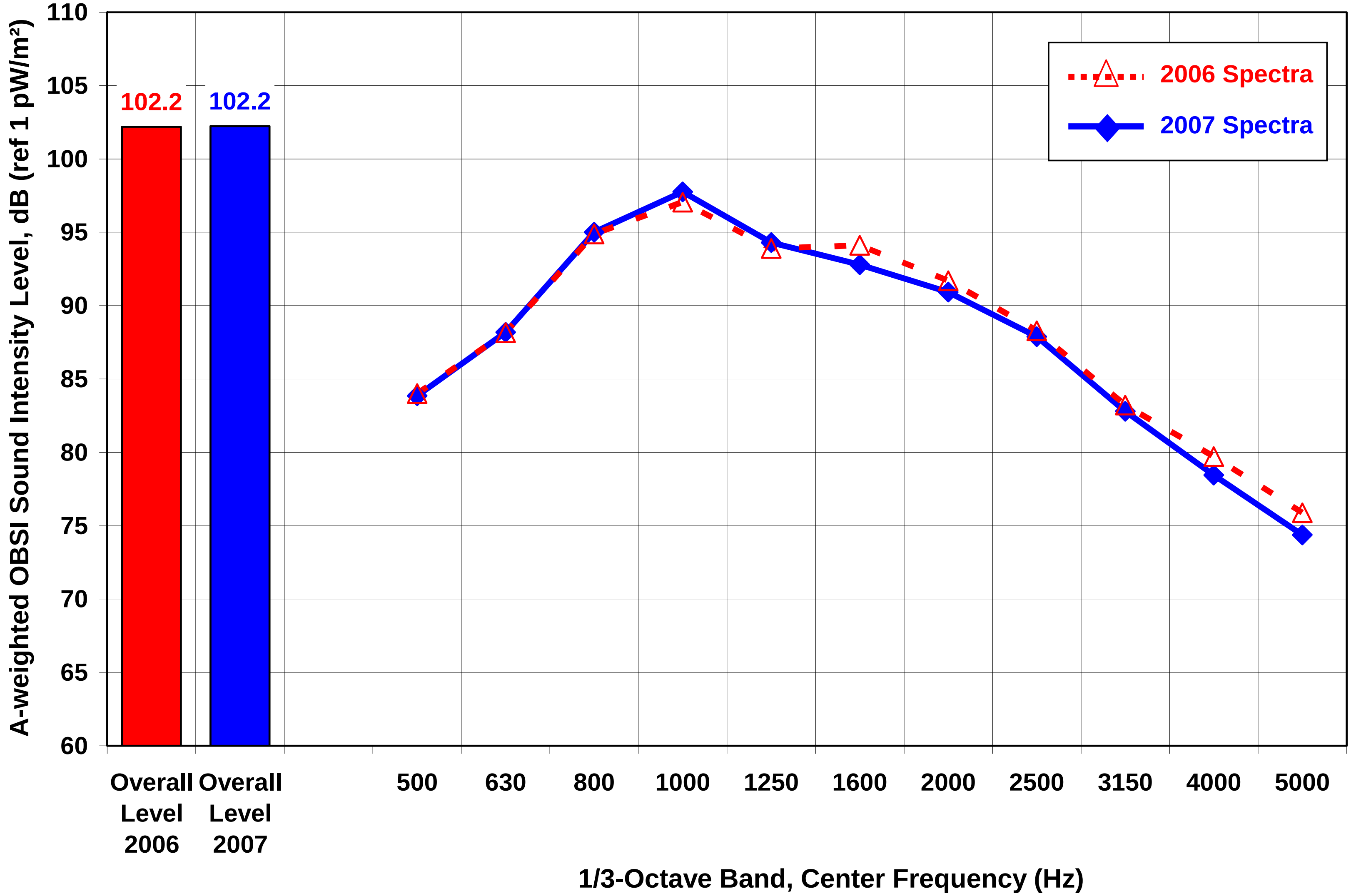
OBSI?: Yes (6/24/07) **SPB?:** No **TA?:** No
Total Section Length: 2495 ft.
Distance from Begin to Wayside Microphone: n/a



Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 25

OBSI (SRTT) Test Information



Site: 26

General Information

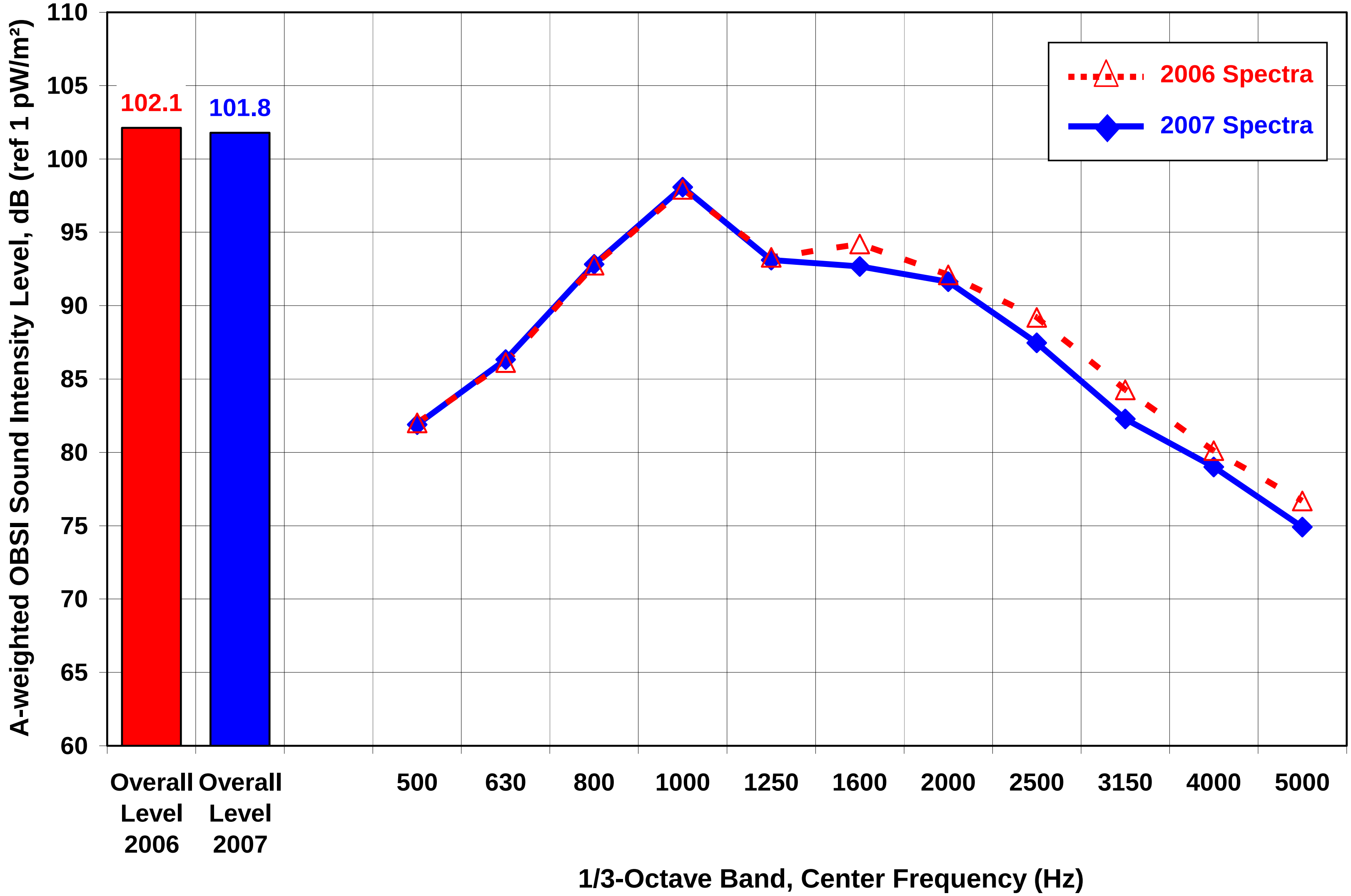
Highway: Interstate 25, Southbound
Location: Between SH 105 & Higby Rd., Monument (80132)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.0862 / 104.8614 / 7010

Nominal Surface: Concrete **Construction Accepted:** 10/1996

OBSI?: Yes (8/12/07) **SPB?:** No **TA?:** No
Total Section Length: 1493 ft.
Distance from Begin to Wayside Microphone: n/a

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 26
OBSI (SRTT) Test Information



Site: 27
General Information

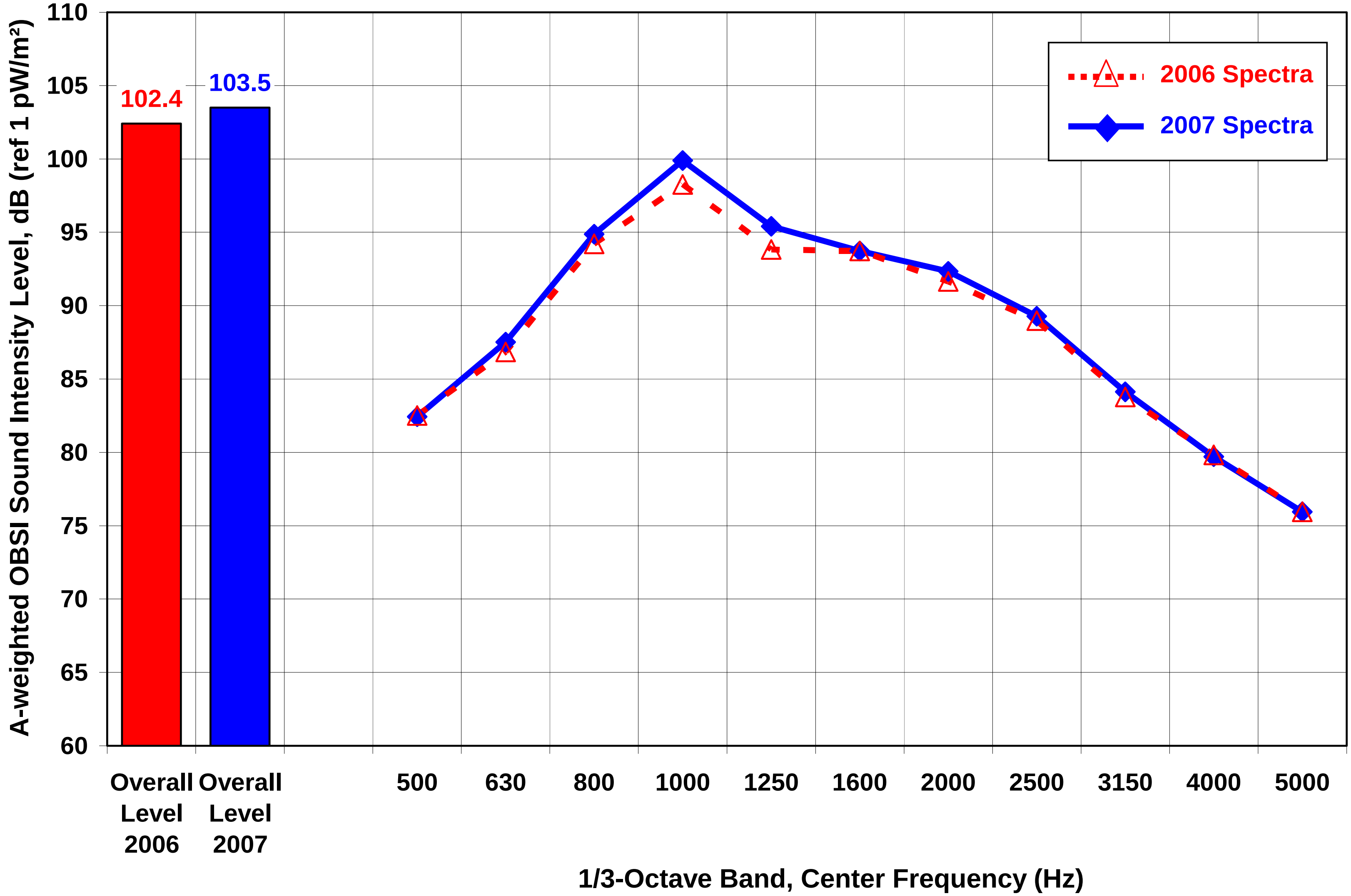
Highway: Highway C-470, Westbound (Northbound)
Location: Between Morrison Rd.& Alameda Pkwy., Morrison (80228)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.6759 / 105.1869 / 5890

Nominal Surface: Concrete **Construction Accepted:** 1/2001

OBSI?: Yes (7/12/07) **SPB?:** No **TA?:** No
Total Section Length: 7873 ft.
Distance from Begin to Wayside Microphone: n/a

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 27
OBSI (SRTT) Test Information

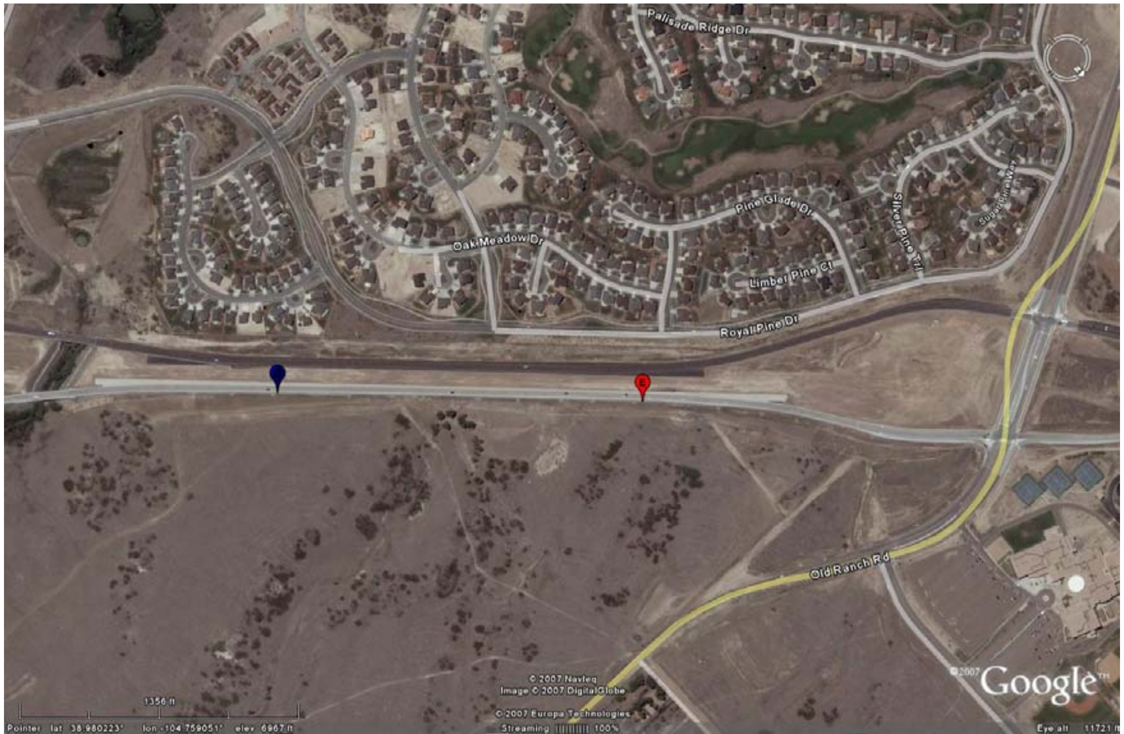


Site: 28
General Information

Highway: Powers Blvd., Northbound (Westbound)
Location: Between Union Blvd. & Old Ranch Rd., Colorado Springs (80908)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 38.9796 / 104.7574 / 7030

Nominal Surface: Concrete (Drag) **Construction Accepted:** 12/2004

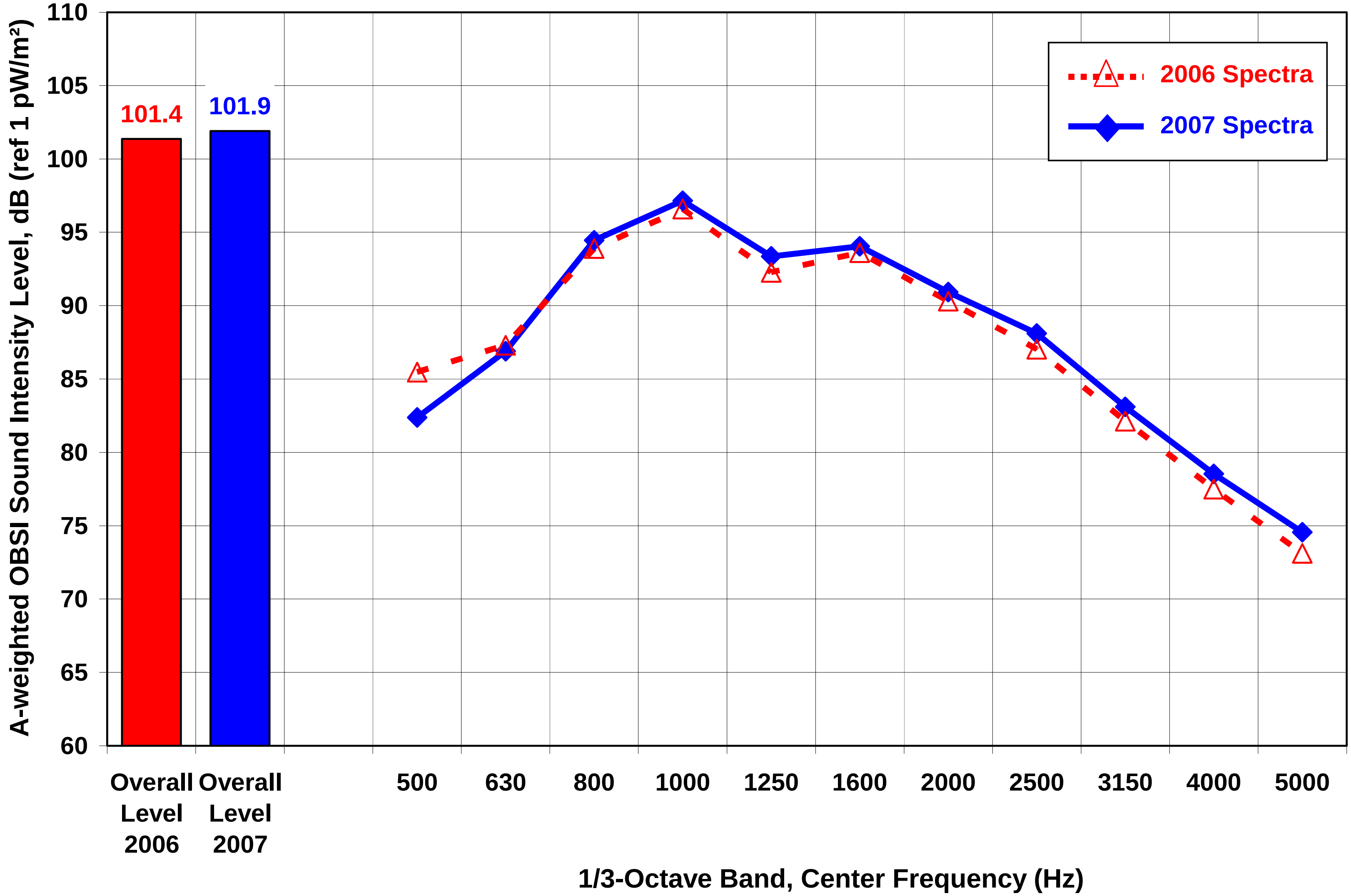
OBSI?: Yes (6/23/07) **SPB?:** No **TA?:** No
Total Section Length: 1804 ft.
Distance from Begin to Wayside Microphone: n/a



Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 28

OBSI (SRTT) Test Information



Site: 29

General Information

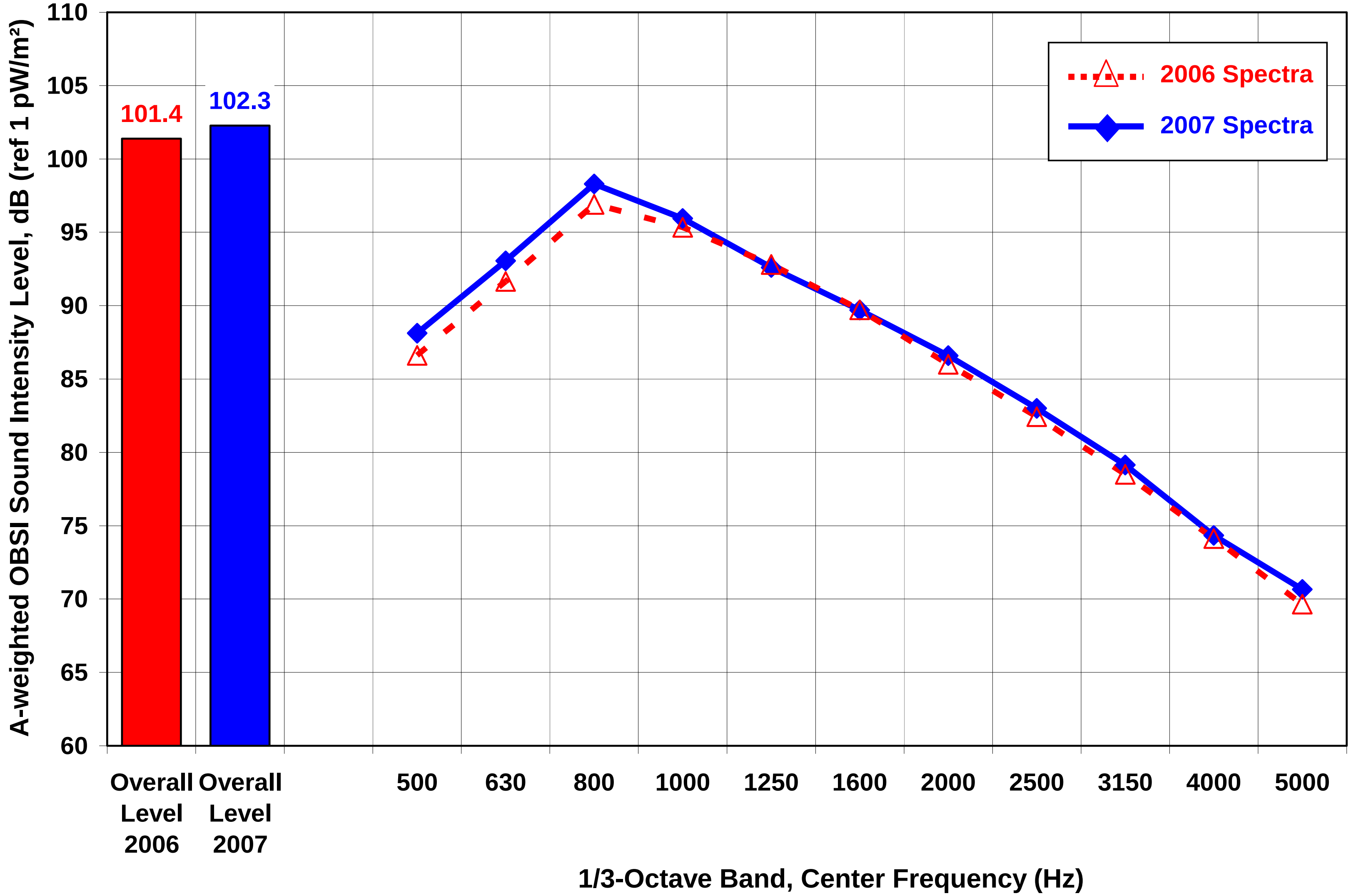
Highway: Powers Blvd., Southbound (Eastbound)
Location: Between Old Ranch Rd. & Union Blvd., Colorado Springs (80920)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 38.979 / 104.7575 / 6990

Nominal Surface: SMA **Construction Accepted:** 9/2005

OBSI?: Yes (6/23/07) **SPB?:** No **TA?:** No
Total Section Length: 1724 ft.
Distance from Begin to Wayside Microphone: n/a

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 29
OBSI (SRTT) Test Information



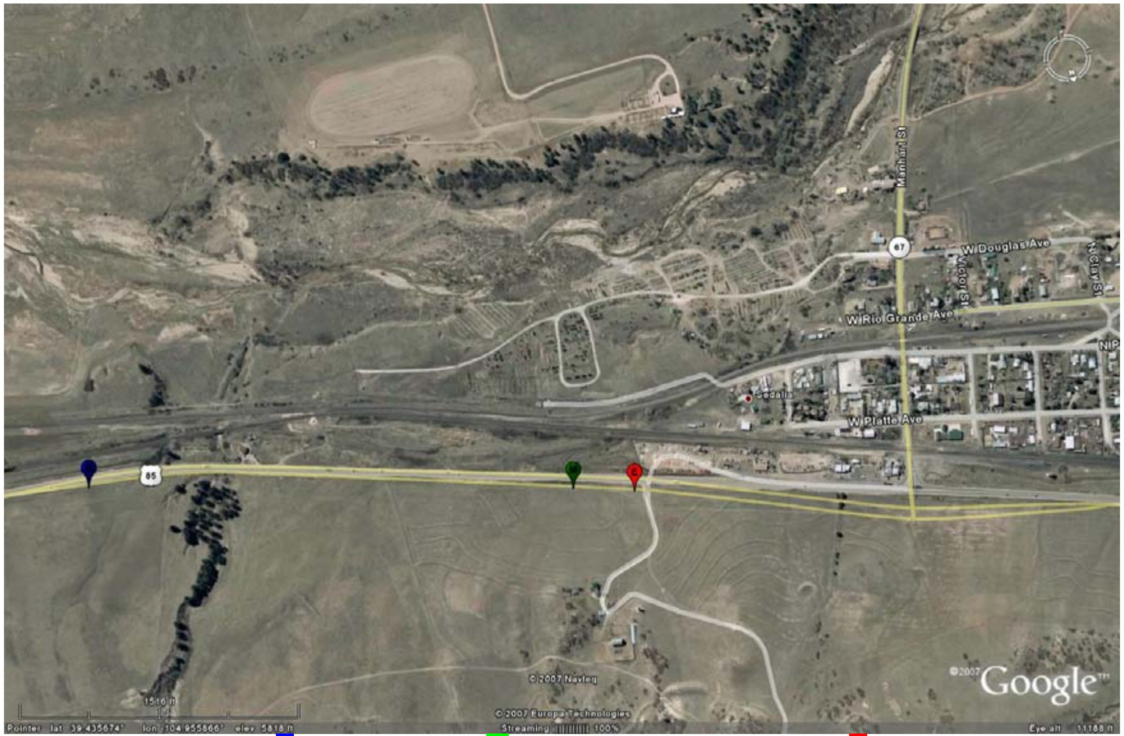
Site: 30

General Information

Highway: US Highway 85, Northbound
Location: Between Daniels Park Rd. & SH 67, Sedalia (80135)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.4365 / 104.9514 / 5870

Nominal Surface: Concrete (Burlap Drag) **Construction Accepted:** 2003

OBSI?: Yes (8/4/07) **SPB?:** No **TA?:** Yes (8/1/07)
Total Section Length: 3019 ft.
Distance from Begin to Wayside Microphone: 2657



Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 30

Time-Averaged Wayside Test Information

Sampling Periods: 2

Sample Period 1 – 3 Blocks @ 15 min ea. = 45 min. (3:30 pm to 4:15 pm, 8/1/07)

Traffic Volumes and Speeds during Sample Period

	NB Lane 2 (Outside)	**NB Lane 1 (Inside)**	**SB Lane 1 (Inside)**	**SB Lane2 (Outside)**
Distance from Mic (ft.)	50	62	90	102
Average Speed (mph)	59		60	
Automobile	164	338	208	219
Heavy Truck	26	14	1	19
Medium Truck	13	8	5	10
Bus	0	1	0	0
Motorcycle	1	2	3	5
Auto + 1-Axle Trlr.	4	2	2	7
Auto + 2-Axle Trlr.	7	7	0	2
M. Trk. + 1-Axle Trlr.	0	2	0	1
M. Trk. + 2-Axle Trlr.	2	2	1	4

Block 1	**Block 2**	**Block 3**	**Average**
69.2 dBA	69.7 dBA	68.3 dBA	**69.1 dBA**

Site: 30
Time-Averaged Wayside Test Information

Sample Period 2 – 3 Blocks @ 15 min ea. = 45 min. (4:15 pm to 5:00 pm, 8/1/07)

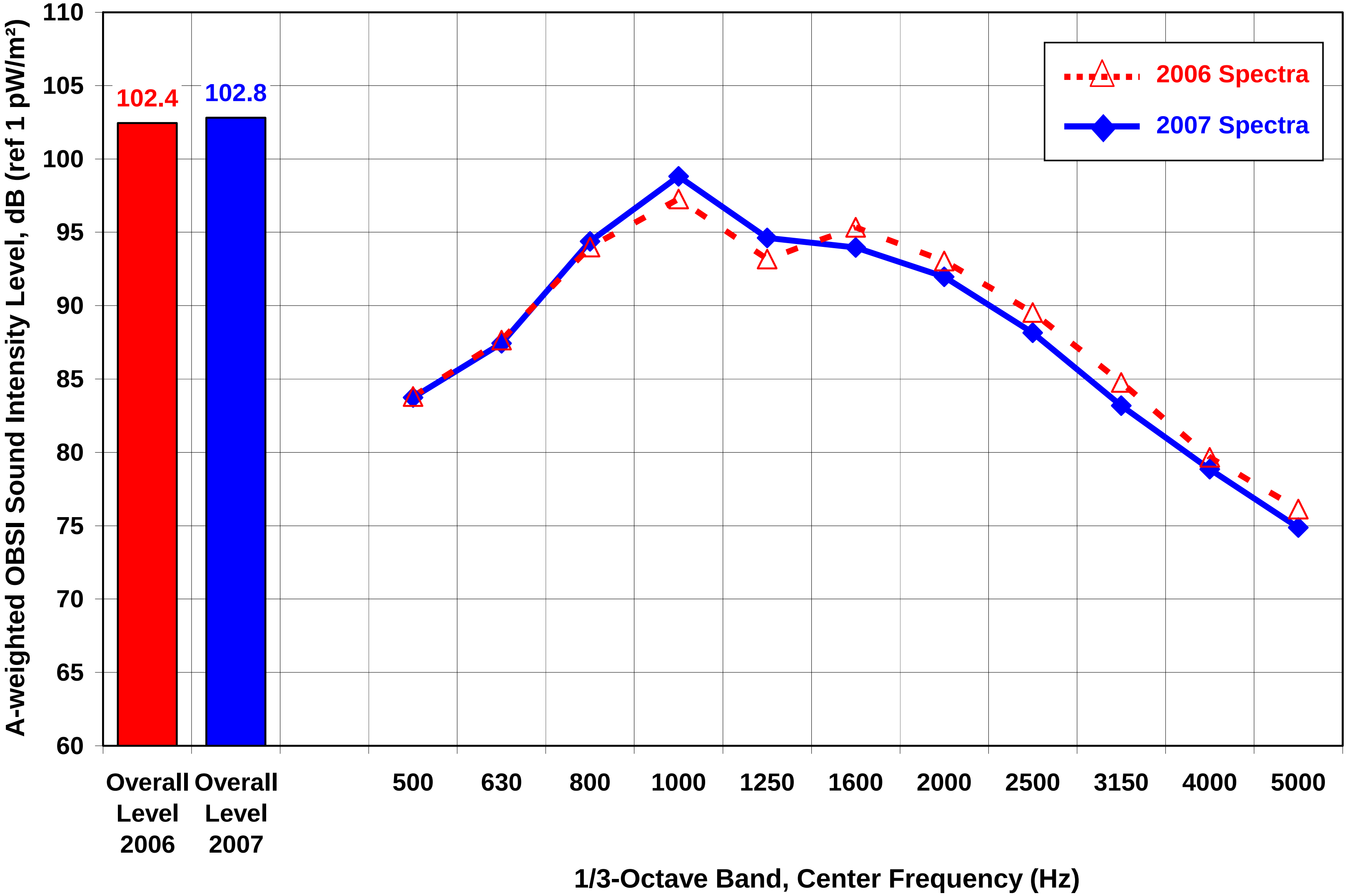
Traffic Volumes and Speeds during Sample Period

	NB Lane 2 (Outside)	**NB Lane 1 (Inside)**	**SB Lane 1 (Inside)**	**SB Lane2 (Outside)**
Distance from Mic (ft.)	50	62	90	102
Average Speed (mph)	60		59	
Automobile	217	350	303	309
Heavy Truck	14	7	5	16
Medium Truck	13	9	3	10
Bus	0	1	0	0
Motorcycle	1	3	1	8
Auto + 1-Axle Trlr.	2	0	1	8
Auto + 2-Axle Trlr.	5	5	3	5
M. Trk. + 1-Axle Trlr.	0	0	0	0
M. Trk. + 2-Axle Trlr.	5	0	0	2

Block 1	**Block 2**	**Block 3**	**Average**
68.0 dBA	68.6 dBA	69.1 dBA	**68.6 dBA**

Site: 30

OBSI (SRTT) Test Information



Site: 31
General Information

Highway: Interstate 70, Eastbound
Location: Between 15th St. & US 40, Georgetown (80444)
Approx. Latitude (°N) / Longitude (°W) / Elevation (ft.): 39.7286 / 105.6919 / 8560

Nominal Surface: SMA (3/4") **Construction Accepted:** 10/2006

OBSI?: Yes (8/20/07) **SPB?:** No **TA?:** No
Total Section Length: 5529 ft.
Distance from Begin to Wayside Microphone: n/a

Placemark Key: B = Begin Section; M = Mid Section (Wayside Mic); E = End Section

Site: 31
OBSI (SRTT) Test Information