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Reference Energy Mean Emission Levels Used in STAMINA 2.0 for Highway Noise Prediction in the State of Colorado

Colorado Department of Transportation

Final Report
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U.S. Department of Transportation
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16. Abstract

This report documents the test done on noise emission levels found on vehicles in Colorado. It justifies modifications of the STAMINA 2.0 traffic noise prediction model for use in Colorado.

Vehicle noise emission measurements were made in accordance with FHWA Report No. DP-45-1R. It was determined that STAMINA 2.0 (with FHWA default emission rates) over predicts the noise levels by approximately 4 dBA and that adjustments to the emission rates in the model should be made.

Implementation:

Based on this study CDOT was allowed by FHWA to change the emission rates in STAMINA 2.0.

This change in the model has reduced the cost of noise mitigation by reducing height and extent of noise barriers.

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REQUEST TO MODIFY
REFERENCE ENERGY MEAN EMISSION LEVELS
USED IN STAMINA 2.0
FOR HIGHWAY NOISE PREDICTION IN THE
STATE OF COLORADO

This report constitutes a request to modify the reference energy mean emission levels used in the highway noise prediction program STAMINA 2.0 in the State of Colorado. The study supporting this request was conducted under authority of 23 CFR 772 (§772.17(a)(2)(ii)), which allows for the independent determination of reference energy mean emission levels. These data are used in the FHWA Highway Traffic Noise Prediction Model (Report No. FHWA-RD-77-108), which is the basis of the STAMINA 2.0 computer program. All measurements were conducted in accordance with FHWA Report No. DP-45-1R, "Sound Procedures for Measuring Highway Noise: Final Report," Chapter 4.

VEHICLE NOISE EMISSION MEASUREMENTS

In accordance with DP-45-1R, all measurement test sites were chosen to be level and free of extraneous terrain influence. The microphones were placed at 50 feet from the centerline of the traffic lane, with a clear line of sight to the roadway and an unobstructed arc of at least 150 degrees at the microphone. All roadways had a grade of less than two percent (except for three sites used for a separate grade adjustment study), and were dry asphalt or concrete pavement. Measurements were made during the months of July, August, and December 1993.

Measurement sites were also chosen so as to minimize potential contamination of each sample by noise from other vehicles. This was done by choosing locations with wide medians or locations with low traffic volumes. The sound level meter was carefully watched while the observer physically listened for interference from other vehicles. Careful application of this procedure insured that these emission level samples were not contaminated by noise from other sources. Appendix A contains the site location at which measurements were made along with date and time of the measurements, and the pavement characteristics.

A Bruel and Kjaer 2230 Type I Sound Level Meter was used to record the maximum A-weighted sound level from each vehicle pass-by. This equipment was field calibrated before and after each measurement session to insure accuracy. The speed of each sample vehicle was measured as it passed the microphone using a Speedgun Magnum radar speed detection device, which was also calibrated before and after each measurement session.

Traffic was classified into three groups: 1) automobiles, which included light trucks with four tires; 2) medium trucks, which included trucks with two axles and six wheels; and 3) heavy trucks, which included trucks with three or more axles and all tractor-trailer combinations. Samples for each classification were grouped into speed ranges of ± 3 mph, in accordance with DP-45-1R.

The total number of samples taken at each site, by vehicle class is shown in Table 1. A total of 740 automobiles, 313 medium trucks, and 442 heavy trucks were measured. In order to insure statewide coverage of each vehicle type, sites were chosen on roadways leading to the metropolitan areas of Denver, Colorado Springs, and Grand Junction.

SITE	AUTOS	MED. TRKS.	HVY. TRKS.
1	84	33	5
2	101	28	2
3	200	58	31
4	113	3	0
5	30	0	0
6	32	17	17
7	0	13	56
8	17	11	10
9	0*	0*	38*
10	27	8	60
11	0*	0*	30*
12	0*	0*	32*
13	40	26	40
14	40	28	40
15	16	21	34
16	40	0	0
17	0	17	12
18	0	5	22
19	0	45	13

* Site used for checking grade adjustment on heavy trucks

Table 1: Vehicle Count at Each Measurement Site

STATISTICAL ANALYSIS

The first step in the data analysis was to determine that the measurement samples were taken from data that were normally distributed. Data are considered to be normally distributed when the correlation coefficient between the actual measured emission data and the normalized values of the same data is 0.95 or greater. This test for normality was accomplished by use of the statistical package SPSS with a correlation coefficient being calculated for each vehicle classification. Table 2 shows the results of the normality tests.

Vehicle Classification	Correlation Coefficient
Automobiles	0.994
Medium Trucks	0.983
Heavy Trucks	0.991

Table 2: Correlation Coefficients for Each Vehicle Classification

Table 3 shows the actual number of samples for each vehicle classification by speed range. In addition, Table 3 shows the Confidence Interval (CI) in dB at a 95% Confidence Limit. It should be noted that the Confidence Intervals shown in Table 3 are slightly different than those found in Figure 9 of DP-45-1R for the same number of samples. This is because the method for determining Confidence Intervals in SPSS is exact, while that used in Figure 9 of DP-45-1R is an estimate.

The results shown in Tables 2 and 3 confirm that the population from which the samples were taken was normally distributed, and that enough samples were taken. Accordingly, the data were then regressed to develop mathematical equations that best describe the relationship between reference energy emission levels and speed for each vehicle classification.

The emission level curves will take the following form:

$$(L_o)_{Ei} = (L_o)_i + 0.115(\sigma_0)_i^2 \tag{1}$$

where $(L_o)_i$, the mean sound level, takes the form of a linear equation in LOG(speed).

$$(L_o)_i = A_i + B_i LOG(S) \tag{2}$$

where A_i and B_i are constants, and $(\sigma_0)_i$ is the standard deviation of the i^{th} vehicle class from the regression analysis.

AUTOMOBILES							
Speed	22-28	29-35	36-42	43-49	50-56	57-63	64-70
Mean	61.5	62.1	65.0	67.7	69.8	71.4	71.8
No.	41	100	80	105	112	129	155
Toler.	±0.5	±0.5	±0.5	±0.4	±0.4	±0.6	±0.6
MEDIUM TRUCKS							
Mean	*	71.2	72.5	74.3	75.2	77.2	81.7
No.		38	47	42	49	71	66
Toler.		±0.8	±0.7	±0.5	±0.8	±0.8	±0.9
HEAVY TRUCKS							
Mean	*	74.7	76.8	78.3	80.5	82.6	83.3
No.		46	41	37	56	86	76
Toler.		±0.6	±0.8	±0.7	±0.6	±0.6	±0.6

* No vehicles measured at this speed.

Table 3: Number of Samples and Confidence Intervals at 95% Confidence Limit

The following equations represent the results of the regression analysis using SPSS and constitute the new equations to be incorporated into the STAMINA 2.0 code once this request has been approved:

$$(L_0)_{Autos} = 19.78 + 28.68LOG(S) \quad (3)$$

$$(L_0)_{MT} = 27.18 + 28.74LOG(S) \quad (4)$$

$$(L_0)_{HT} = 31.01 + 28.77LOG(S) \quad (5)$$

where S is speed in miles per hour

These equations are graphically shown in Figures 1, 2, and 3. Also shown on these figures are the plots of the equations that are currently in use in STAMINA 2.0, i.e., the "National Reference Energy Mean Emission Levels."

It is also necessary to change the standard deviations (sigma, which is coded within the BLOCK DATA portion of STAMINA 2.0) to completely define the relationship found in equation 4 of DP-45-1R (equation 1 of this report). The new values of sigma to be inserted into the BLOCK DATA portion of STAMINA 2.0 are:

Automobiles:	3.02 (replaces 2.5)
Medium Trucks:	3.21 (replaces 3.37)
Heavy Trucks:	2.45 (replaces 2.84)

MODEL VALIDATION

In order to determine if these revised emission equations accurately represent traffic on Colorado highways, three sets of noise level measurements were made at two locations on Colorado 470 south of Denver. Two sets of measurements were taken at mile post 11.15 and one set at mile post 2.3. Traffic volumes and mix, as well as average vehicle speeds, were recorded during each measurement period. Site geometry at both sites was consistent, with two 12 foot lanes (smooth asphaltic concrete) in both directions separated by a 30 foot grass median. The roadways were level and the sites are otherwise free of extraneous terrain influence Receptors were located at 50 feet from the edge and five feet above the nearest travel lane. The intervening ground cover at both sites was short grass. This was done to minimize the number of variables that could possibly influence the measured noise level and thus insure a more accurate comparison of the measured vs. calculated Leq values. Table 4 contains the results of these comparisons.

Site	Volume/Speed			FHWA	CODOT	Meas.
	Autos	Med.	Hvy.	Leq*	Leq**	Leq
1	970/60	20/60	100/60	72.3	68.7	68.3
2	940/60	30/60	170/60	74.2	70.4	69.8
3	800/60	90/60	30/60	69.0	65.9	64.8

* Calculated w/ STAMINA 2.0 Using Nat. Ref. Energy Mean Emission Levels
** Calculated w/ STAMINA 2.0 Using CO Ref. Energy Mean Emission Levels

Table 4: Measured vs. STAMINA 2.0 Leq Values

Examination of columns 5 and 7 in Table 4 clearly illustrates the tendency of the STAMINA 2.0 model to over-predict when using the FHWA National

Reference Energy Mean Emission Levels. However, the ability of the model to accurately calculate Leq values is also clearly demonstrated when using it with updated vehicle noise emission data, as shown by comparing columns 6 and 7 in Table 4. In fact, the STAMINA 2.0 model has consistently demonstrated its ability to accurately calculate noise levels in those states which have re-defined the reference energy mean emission levels.

GRADE ADJUSTMENT FACTORS

Since a significant portion of Colorado is considered mountainous terrain, with resulting steep grades, a number of noise emission samples (see Table 1 and Appendix A) were taken of heavy trucks on various grades (3-4%, 4-5%, and 6%). These samples were gathered in order to evaluate the accuracy of the FHWA grade correction factors for heavy trucks on steep grades.

The grade correction factor calculated by the function GRADE in STAMINA 2.0 is a linear interpolation of the data contained in NCHRP Report 174, with a maximum correction of +5 dB for grades greater than six (6) percent (NCHRP 174, "Highway Noise, A Design Guide for Prediction and Control, Gordan, et al, 1976). This correction is a simple addition of up to 5 decibels to the reference energy mean emission levels. Although the reference energy mean emission levels are a function of speed (Figures 1 through 3), the FHWA grade adjustment factor is constant regardless of vehicle speed. Table 5 presents the difference in the mean of the measured emission level in each speed range on a level grade and the measured emission level on the listed grade. Examination of the measurement data contained in Table 5 and illustrated in Figures 4, 5, 6, and 7 indicate that the effect of grade on the heavy truck emission level is somewhat influenced by vehicle speed.

However, this is not considered to be significant for the use of STAMINA 2.0 grade correction factors in Colorado. The reason for this is that since the FHWA method assumes a constant adjustment over all speeds, then an average of the measured grade effects over all speed ranges would provide a reasonable and valid comparison of measured vs. calculated grade adjustments. As Table 5 illustrates, for 3 to 4% grades, the FHWA method would under-predict by approximately 1 decibel when compared to the measured average adjustments over all speed ranges. Likewise, 4 to 5% grades would approximately agree with the FHWA method, and on 6% and greater grades, STAMINA 2.0 would over-predict by approximately 1 decibel.

While this conclusion is based on a limited number of samples, it is not believed that the noted differences are significant enough to warrant further investigation into this matter. Additional information is available relative to the effects of grade on heavy trucks in a report prepared by the California Department of Transportation (FHWA/CA/TL-87/03, "California Vehicle Noise Emission Levels", Hendriks, et al, 1987).

	Speed Range				FHWA	Avg.
Grade	29-35	36-42	43-49	50-56	All Spds.	Adj.
3 - 4%	+4.5	+3.2	+2.5	+1.9	+2	+3.0
4 - 5%	+5.8	+3.5	+1.8	+0.8	+3	+3.0
6%	+3.8	+2.5	+3.1	*	+4	+3.2

* No vehicles measured in this speed range.

Table 5: Decibels Increase Caused by Grade on Heavy Truck Noise Emission Levels

REQUEST TO FHWA BY COLORADO DOT

The Colorado Department of Transportation requests that the above listed reference energy mean emission level equations (equations 3 through 5) and corresponding standard deviations be approved for use in association with highway noise predictions utilizing the FHWA Model (STAMINA 2.0) in the State of Colorado.

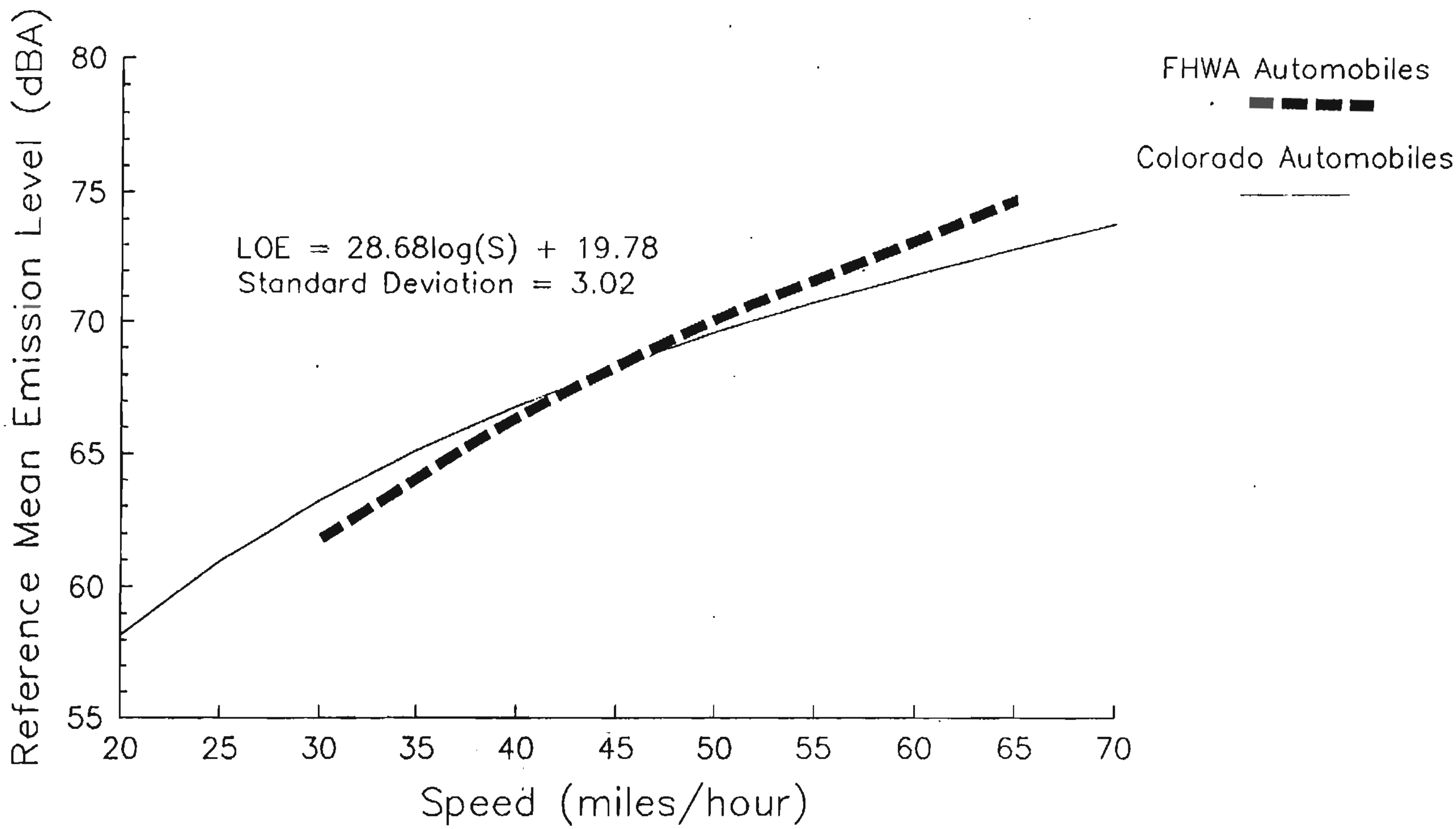

Figure 1: Colorado vs. FHWA Automobiles

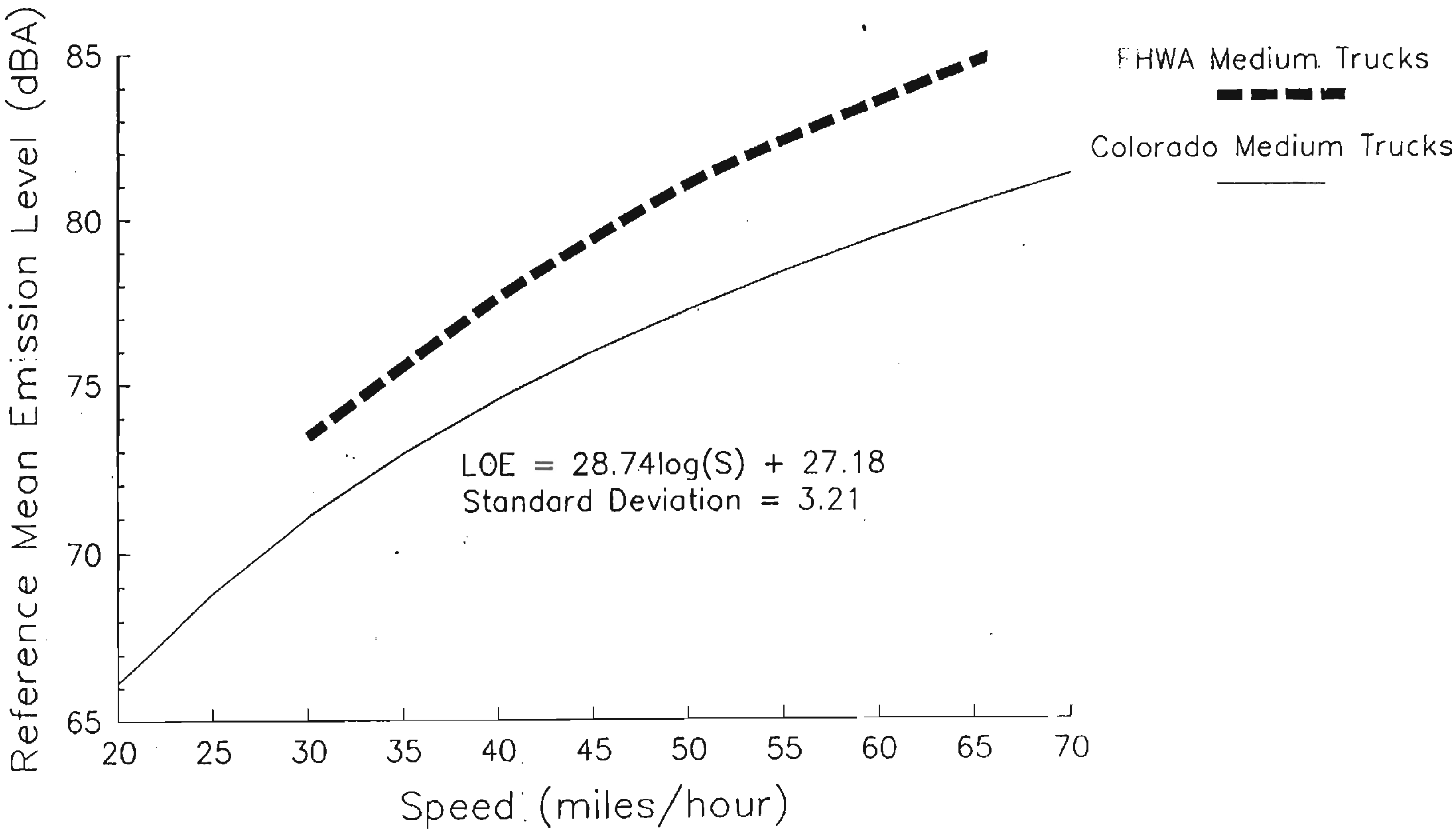

Figure 2: Colorado vs. FHWA Medium Trucks

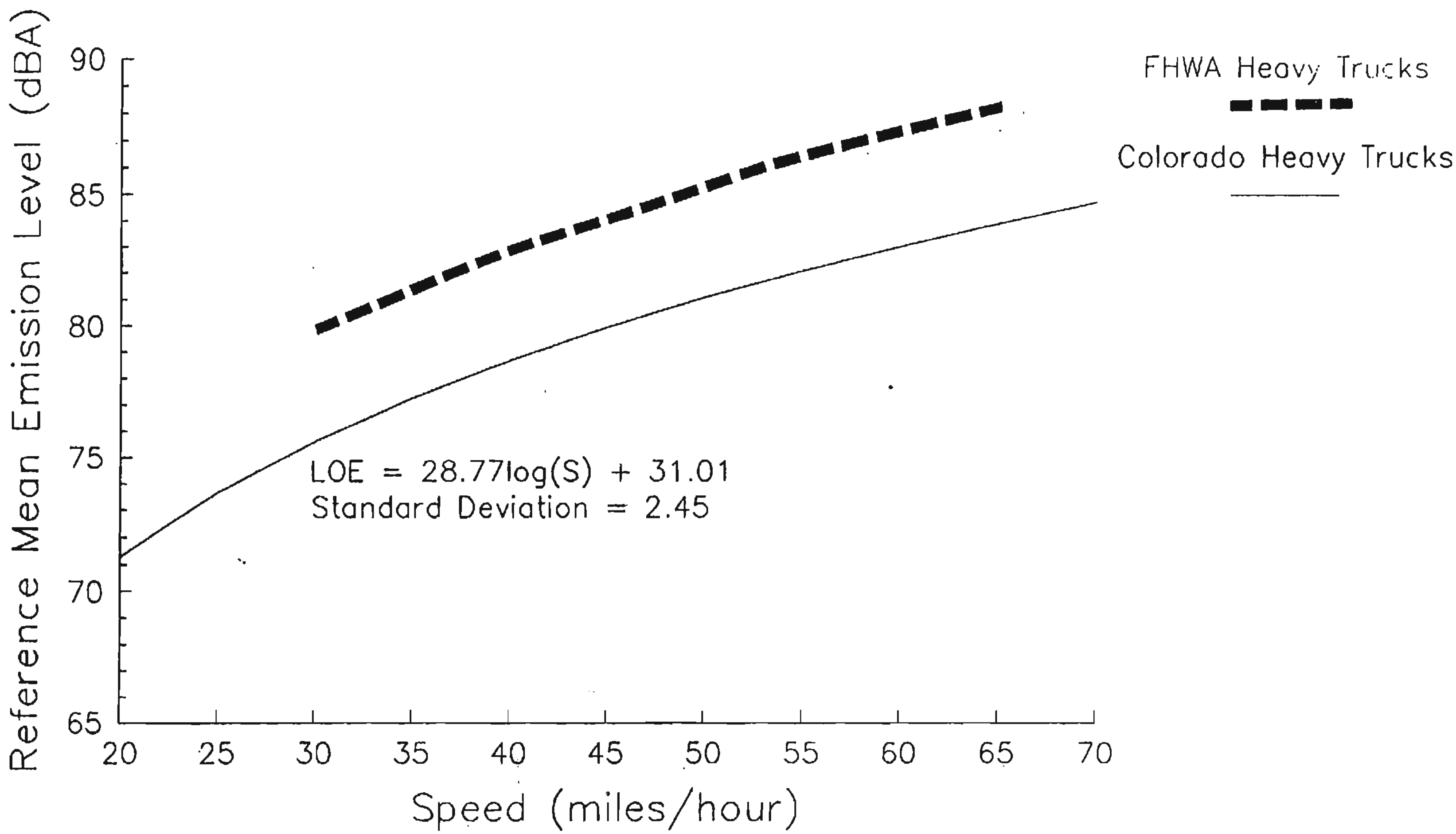

Figure 3: Colorado vs. FHWA Heavy Trucks

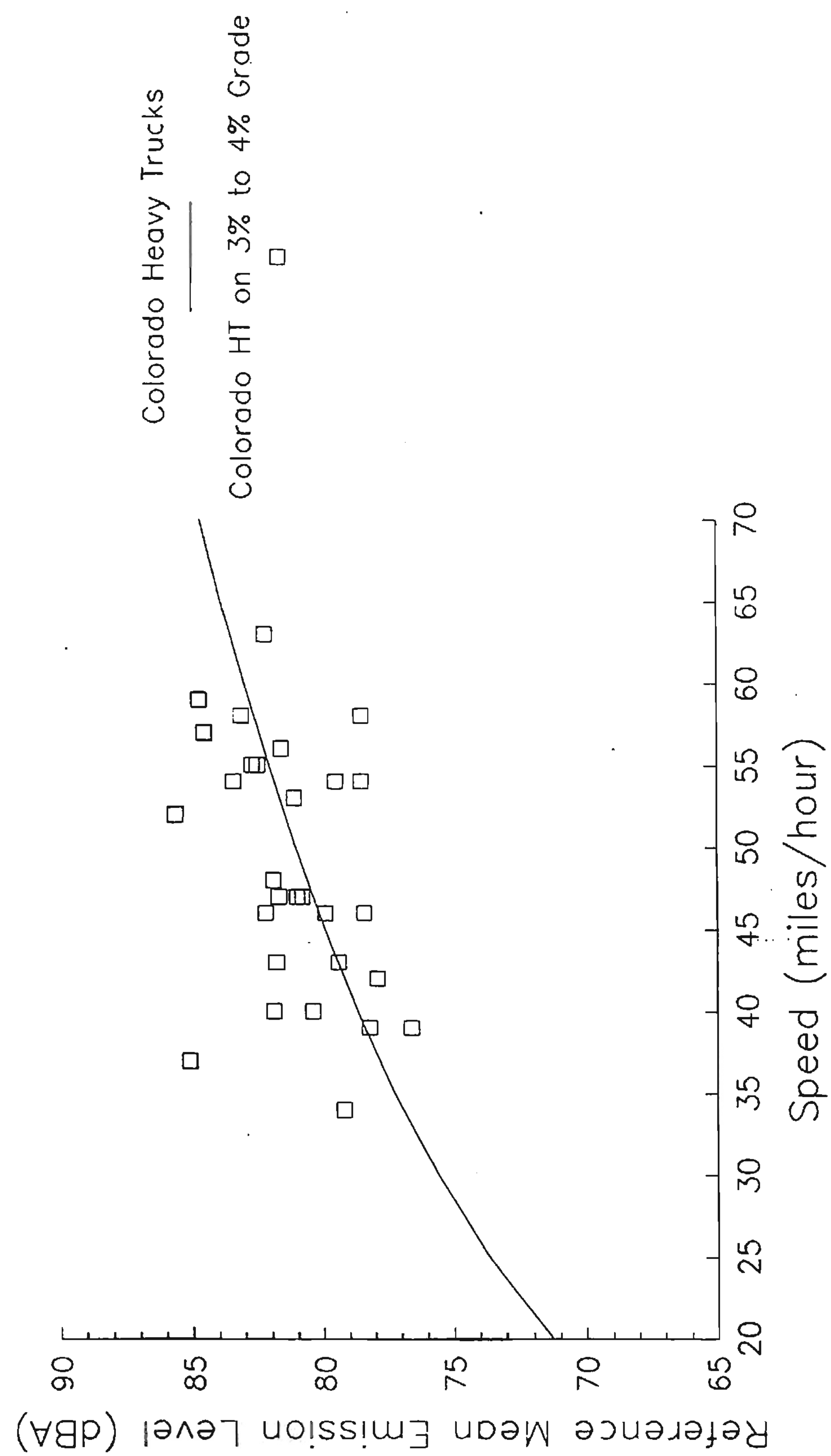

Figure 4: Colorado Heavy Trucks on 3 to 4% Grades

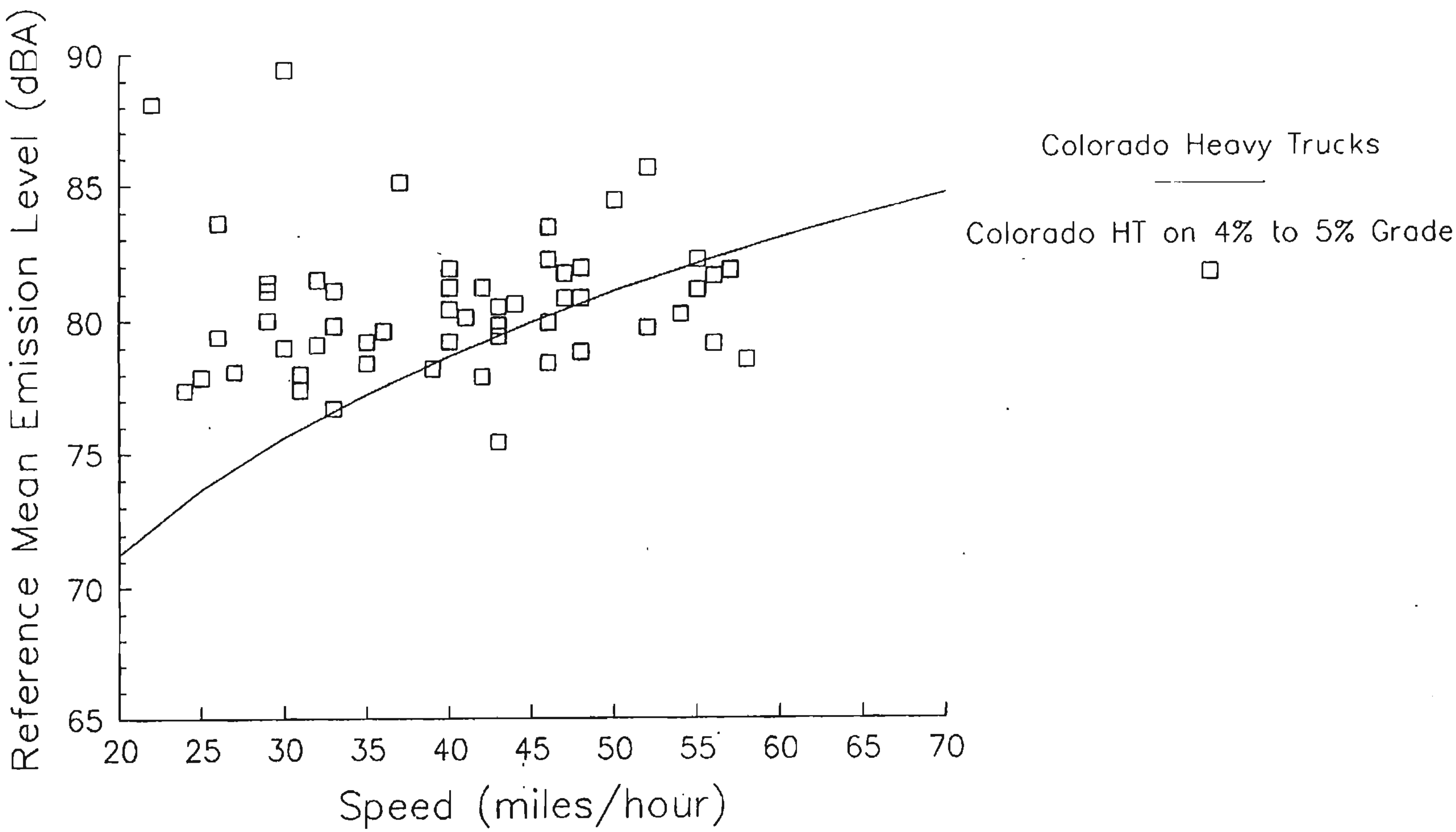

Figure 5: Colorado Heavy Trucks on 4 to 5% Grades

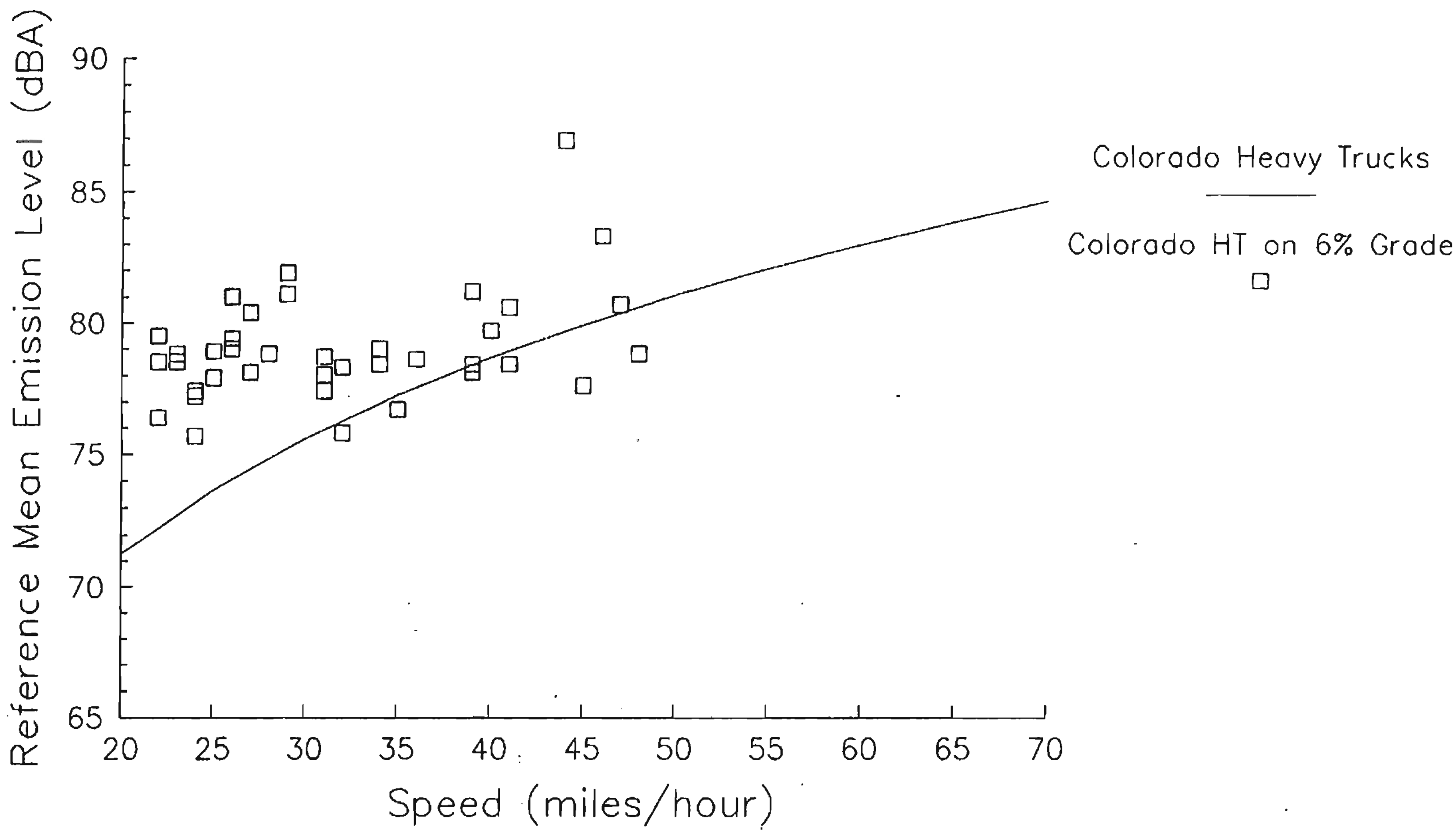

Figure 6: Colorado Heavy Trucks on 6% Grades

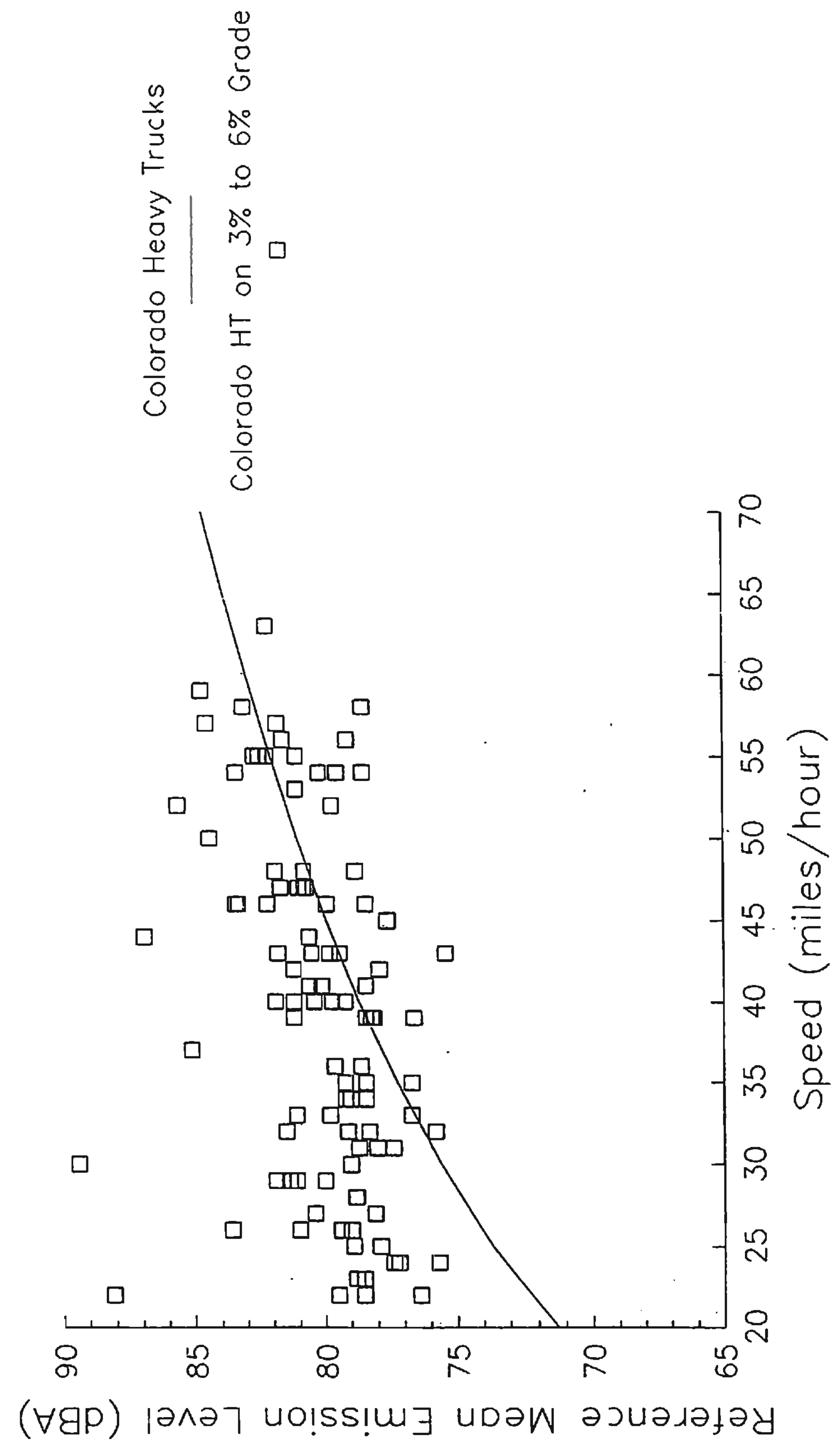

Figure 7: Composite of Colorado Heavy Trucks on all Grades

APPENDIX A

Site Locations/Descriptions

SITE	DATE / TIME	LOCATION	SITE CHARACTERISTIC
1	8/13/93 - 10:20am	Bus.70, 500' E 29 TLD, Grand Junction	Pavement - Smooth DGAC
2	8/13/93 - 12:10pm	Hwy 6, Palisade Naz. Ch., Grand Junction	Pavement - Smooth DGAC
3	8/13/93 - 2:20pm	I70, 0.8 mi. W. 29 Rd., WB, Grand Junction	Pavement - Smooth OGAC
4	8/14/93 - 8:30am	N. Ave @ College Pl, N., Grand Junction	Pavement - Smooth DGAC
5	8/16/93 - 8:10 pm	NB Baseline Road Sch., Denver	Pavement - Smooth OGAC
6	8/17/93 - 9:25am	I25 NB @ Fed. Bldg., Denver	Pavement - Smooth DGAC
7	8/17/93 - 2:00pm	I76 NB, 1 mi. So. Hwy. 85, Denver	Pavement - Smooth DGAC
8	8/18/93 - 12:45 pm	Hwy. 24 WB, MP 321, Colorado Springs	Pavement - Smooth DGAC
9	9/30/93 - 10:30am	I70 Westbound, MP 254.9 (6 % grade)	Pavement - Smooth DGAC
10	8/19/93 - 10:00am	A/P Acc. Rd., 1/2 mi. fm DA, Denver	Pavement - Smooth DGAC
11	8/20/93 - 10:00am	I70 Westbound, MP 221 (3-4% grade)	Pavement - Smooth DGAC
12	8/20/93 - 12:25pm	I70 Westbound, MP 218 (4-6% grade)	Pavement - Smooth DGAC
13	9/28/93 - 11:30am	I25 - MP 280.6 Northbound	Pavement - Smooth PCC
14	9/28/93 - 2:00pm	I25 - MP 236.8 Southbound	Pavement- Smooth DGAC
15	9/30/93 - 9:00am	92nd Ave, 1000' W. Pierce, Denver	Pavement- Smooth DGAC
16	12/28/93-11:50am	Dayton St. NB, opp. Progress St. Denver	Pavement- Smooth DGAC
17	12/28/93-3:45pm	Brighton, SB, 1 mi. N I270, @ park, Denver	Pavement- Smooth DGAC
18	12/28/93-2:00 pm	C-56, Commerce City	Pavement- Smooth DGAC
19	12/28/93-9:30am	I25 Southbound, vic. exit 191	Pavement- Smooth DGAC

Summary of Measurement Time, Location, and Description