VARIATIONS IN SKID RESISTANCE OVER TIME

by

Stephen N. Runkle
Research Analyst

and

David C. Mahone
Senior Research Scientist

Virginia Highway and Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways and Transportation and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

February 1980

VHTRC 80-R33

2128

MAINTENANCE RESEARCH ADVISORY COMMITTEE

R. L. MOORE, Chairman, Resident Engineer, VDH&T

C. M. CLARKE, Assistant District Engineer, VDH&T

D. R. COLLINS, Resident Engineer, VDH&T

R. H. CONNOCK, Jr., Assistant District Engineer, VDH&T

J. A. COPP, Residency Maintenance Supervisor, VDH&T

W. L. HAYDEN, Assistant Materials Engineer, VDH&T

C. O. LEIGH, Maintenance Engineer, VDH&T

J. C. McCABE, Area Engineer, FHWA

J. K. McEWEN, Resident Engineer, VDH&T

D. C. MAHONE, Senior Research Scientist, VH&TRC

J. R. MILLER, Equipment Engineer, VDH&T

C. B. PERRY, Resident Engineer, VDH&T

D. S. ROOSEVELT, Resident Engineer, VDH&T

M. B. VANN, Assistant Construction Engineer, VDH&T

J. E. WILLIAMS, Assistant District Engineer, VDH&T

ABSTRACT

The purpose of this project was to quantify the magnitude of changes in skid resistance over time, to isolate the variables that seem most important with respect to the changes, and, to the degree possible, formulate a model for converting skid resistance values obtained under a given set of conditions to the values that would be measured under a different set of conditions.

The Virginia Department of Highways and Transportation survey skid trailer, the Department's research trailer, the research stopping distance car, and the grease patch method of measuring surface texture were evaluated with respect to time-and weather-dependent changes in measured values.

The grease patch method of measuring texture seems to have the same basic relationship to weather variables as does the Department's survey trailer, but the relationship is inconsistent among sites. Also, the use of this method is time consuming and, consequently, expensive.

The research trailer experienced so many breakdowns that the researchers place little confidence in the results obtained with this testing device.

For the stopping distance car it was found that the average standard deviation for all test speeds on the six sites tested was 3.26 skid numbers.

For the Department's survey skid trailer it was found that adjustments could be made to measured values to predict values for times other than when the measurements were made, either by evaluating weather variables or using specified correction values for designated months.

2130

VARIATIONS IN SKID RESISTANCE OVER TIME

by

Stephen N. Runkle
Research Analyst

and

David C. Mahone
Senior Research Scientist

In the United States, the basic tools for monitoring potential tire-pavement surface friction are locked-wheel skid test trailers meeting the requirements of ASTM Designation E274-77. While these trailers are in wide use, the variabilities in the skid values they provide are not completely understood.

Basically, there are two types of variability; namely, the variability produced at any given time of testing within a test site and the variability obtained over time. The first type, the within-site variability occurring during a single testing sequence, while not completely understood is attributed to differences in the road surface as well as testing variability, and it can be satisfactorily dealt with by conducting enough tests to either assure reasonable confidence limits around the means of the test values or to judge that the area being tested provides such divergent values that it constitutes more than one test site. The second type, variability over time, is much more complicated to deal with, since there is less knowledge regarding its causes and little agreement with respect to its magnitude. It is this variability over time, often called seasonal variation, that was dealt with in the research reported here.

Many factors may contribute to variability over time, including temperature changes; rain frequency, duration, and amount; pavement contamination; and, possibly, changes in pavement texture.

Based on a limited amount of control loop data — i.e., data from repeat tests of sites at frequent intervals over a one-year period — it has been assumed in Virginia that time-dependent variations in skid resistance may result in deviations of about $\pm$ 5 skid numbers around some yearly mean skid value.(1) However, Pennsylvania has reported variations over time in excess of 20 skid numbers. (2) If this large a variation is found in Virginia, then it is obvious that Virginia's procedures should be modified, and probably to the extent that minimum skid resistance values for the year would be predicted on the basis of measured skid resistance and related data affecting the measured skid resistance. For these reasons Virginia, with the support of the Federal Highway Administration (FHWA) undertook research to determine the variability with respect to time and to quantify the influence of several variables believed to affect the time-related changes in skid resistance.

PURPOSE AND SCOPE

The purpose of this research was to quantify the magnitude of changes in skid resistance with time; to isolate the variables seemingly most important with respect to changes in skid resistance; and, to the degree possible, formulate a model to convert skid resistance obtained under a given set of conditions to the skid resistance that would be measured under a different set of conditions.

The report is divided into four main sections with the first three sections being devoted to the three testing devices used — the Virginia Department of Highways and Transportation (VDHT) survey skid trailer, the Virginia Highway and Transportation Research Council (VHTRC) stopping distance car, and the VHTRC skid trailer. The last section is devoted to an analysis of surface texture as measured by the grease patch method. The first section includes analyses of skid results at 64 kph (40 mph) obtained on six control loop sites as obtained by the VDHT trailer and is considered the most important section because of the widespread use within the state of data obtained by this unit. Skid data collected over a four-year time span were included in these analyses. The independent variables considered were the maximum air temperature at the time of the test; the tire tread depth; the maximum air temperature the day of the test; an average maximum air temperature for the week preceding the test; and rainfall in inches for the day of the test, the week preceding the test, and the month preceding the test.

In the second section, skid resistance data obtained by the VHTRC stopping distance car are evaluated in essentially the same manner as the data for the VDHT trailer in the first section. For these analyses data were collected using treaded (ASTM) tires at speeds of 32, 64, and 97 kph (20, 40, and 60 mph) on two sites, and at speeds of 32 and 64 kph (20 and 40 mph) on four additional sites. The testing with the car was conducted over a period of about 14 months. The sites were selected to represent various mix types used in Virginia and were tested at approximately 2-week intervals during the active test periods. Because of weather conditions and mechanical problems, it was not always possible to test at planned intervals. Independent variables considered were those mentioned above plus the temperature of the dry pavement at the time of the test and the temperature of the water used to wet the pavement.

The same basic analyses are performed in the third section, except that the skid resistance data used were obtained at sixteen sites (including the six tested by the car) with the VHTRC trailer. Both bald and treaded tires were used in these tests, and speeds were 32 and 64 kph (20 and 40 mph) at three of the sites and 32, 64, and 97 kph (20, 40, and 60 mph) at the remaining thirteen. The analyses included all the independent variables mentioned above.

In the final section, the influence of texture is considered by evaluating it with respect to changes in skid resistance at six of the sixteen sites. At the six sites tested 10 texture measurements were made at about 4-week intervals. Texture is also evaluated with respect to weather variables, particularly rainfall, which the authors feel may be important in influencing texture and thus skid resistance.

In all analyses, the maximum air temperature the day of the test and the week preceding the test; and all rainfall data were determined based on data from the nearest weather station.

ANALYSES OF VDHT TRAILER TEST RESULTS

Since July 1974, six control test sites in the vicinity of Lynchburg, Virginia, have been periodically tested with the VDHT survey skid trailer as part of the state's regular survey testing program.(1) Results of these tests are shown in Table 1 along with various other data used in an attempt to explain the changes in SN_{40} with time. For these data, each test result (SN_{40}) represents the average of five repeat skid tests at a given site. The other data collected for analysis include the date of tests; tire tread depth; air temperature in deg. F. at the time of the tests; maximum air temperature in deg. F. the day of the tests; average daily maximum air temperature for the week preceding the tests, (including the day of the tests); and inches of rainfall the day of the tests, the week preceding the tests, and the month preceding the tests.

Of the six sites, all of which have been in service for a number of years, 1 and 2 are portland cement concrete, sites 3, 5, and 6 are bituminous concrete (Virginia mix type S-5), and site 4 is a bituminous surface treatment (chip seal). Sites 2 and 6 are the passing lanes adjacent to the traffic lanes of sites 1 and 5, respectively.

Variability of Skid Data

Several analyses were performed to quantify the magnitude of variability over time and, to the extent possible, account for this variability. Table 1 contains the computed standard deviation values for the six sites, which average about 2.9 SN. Also shown is the 2.5 SN standard deviation value for the average SN_{40} values ($\overline{SN}_{40}$), which indicates some trending effects in the data that are consistent from site to site; i.e., this value indicates a significant degree of correlation between the sites. Had the variability with time from site to site been independent, one would expect the standard deviation of the averages to be about 1.2 SN ($2.9/\sqrt{6}$) instead of 2.5 SN. Since the variances are about equal for all sites, the degree of correlation between the sites can be estimated to be about 70% based on the expression

$$r^2 = \frac{(\sigma_{\bar{x}}^2 - \sigma_x^2/6)1.2}{\sigma_x^2}$$

where $\sigma_{\bar{x}}^2$ = the variance of the average SN_{40} values from column 8, Table 1; and

σ_x^2 = the variance of daily SN_{40} values for any given site.

2134

VIRGINIA DEPARTMENT OF HIGHWAYS & TRANSPORTATION SURVEY TRAILER 40 MPH SKID TEST DATA FOR FOUR-YEAR PERIOD ON SIX SITES

DATE OF TEST	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	AVERAGE	AIR TEMP °F	TIRE TREAD DEPTH (inches)	MAX. AIR TEMP., °F DA. OF TEST	WEEK OF TEST	RAINFALL, inches DAY OF TEST	WEEK PRIOR	MONTH PRIOR
7-22-74	40.0	54.2	43.3	43.6	37.2	50.8	44.9	58	0.34	83	83	0	0	1.02
7-29-74	44.4	56.6	47.6	46.4	41.2	52.0	48.0	66	0.31	87	83	0.35	1.62	2.66
9-05-74	46.6	58.4	50.2	48.4	45.4	55.0	50.7	70	0.28	81	81	0.01	2.23	4.85
8-26-74	42.6	56.4	47.2	45.6	39.8	51.0	47.0	84	0.34	86	86	0.42	0.66	4.39
9-03-74	45.0	57.6	49.0	47.4	44.0	52.6	49.3	70	0.31	82	73	0.01	2.76	5.72
9-09-74	45.6	57.4	51.4	46.4	46.6	55.6	50.5	64	0.28	79	81	0	3.52	7.20
9-23-74	42.0	55.2	52.6	47.0	37.0	52.2	47.7	42	0.34	61	71	0	0.03	6.42
9-27-74	42.2	54.4	48.4	45.6	38.0	51.4	46.7	76	0.34	75	71	0.03	0.04	5.82
10-07-74	39.8	54.4	49.0	48.4	40.4	52.6	47.5	78	0.31	78	73	0	0	0.37
10-15-74	39.6	55.0	46.2	47.3	38.2	51.0	46.2	60	0.31	75	51	0	0	0.17
10-24-74	44.0	57.6	48.6	46.8	38.8	53.6	48.2	60	0.28	60	72	0	0.07	0.52
10-28-74	40.0	57.6	48.4	47.6	38.6	54.8	47.8	50	0.28	71	72	0	0	0.38
11-08-74	40.4	55.6	47.0	45.6	38.6	51.0	46.4	62	0.34	62	61	0	0.13	0.51
11-29-74	45.2	57.4	48.0	46.6	41.8	53.0	48.7	48	0.31	50	50	0	0.14	1.68
12-06-74	45.8	59.4	49.8	48.6	41.8	54.0	49.9	49	0.31	42	43	0	1.28	2.93
12-13-74	45.0	59.0	49.0	48.8	42.4	53.8	49.7	46	0.28	48	49	0	1.49	3.29
1-24-75	40.4	57.6	52.2	52.4	37.2	52.0	48.6	46	0.28	60	56	0.27	1.02	3.25
3-06-75	43.8	61.4	50.4	51.4	43.4	52.9	50.5	52	0.31	56	47	0	0.06	0.62
3-18-75	43.8	57.2	49.6	51.2	43.2	53.8	49.8	32	0.25	42	53	0.74	4.27	5.57
3-24-75	46.8	59.0	53.0	52.2	44.8	56.0	52.0	52	0.34	62	59	1.05	3.56	8.02
4-03-75	48.2	63.2	56.4	54.8	47.0	60.6	55.0	42	0.28	61	47	0.34	1.59	10.05
4-21-75	43.2	58.6	51.2	51.2	42.4	54.8	50.2	68	0.28	66	58	0	0.32	2.14
4-28-75	42.4	55.8	48.6	47.6	39.8	52.8	47.6	60	0.34	55	58	0.16	0.98	1.90
7-30-75	43.6	52.2	45.4	44.0	33.2	43.0	43.6	64	0.28	85	83	0	0	4.42
8-18-75	46.0	56.6	48.8	48.3	40.0	52.0	48.6	75	0.25	86	86	0	2.76	4.11
8-27-75	44.4	55.6	48.3	46.4	39.0	51.4	47.5	74	0.22	87	88	0	0	4.67
9-30-75	46.0	59.6	51.2	50.2	42.0	54.2	50.5	74	0.31	76	69	0	1.81	7.42
10-20-75	47.0	60.6	49.6	48.2	42.8	56.4	50.8	42	0.31	60	71	0	1.81	5.07
10-27-75	44.8	58.4	49.4	47.8	42.2	53.4	49.3	52	0.28	65	59	0	0.02	2.41
11-10-75	48.2	60.4	49.4	46.4	44.0	55.4	50.6	52	0.22	73	63	0.14	0.49	2.34
11-17-75	49.0	58.8	50.0	48.8	42.2	55.8	50.6	65	0.19	66	66	0	2.20	2.24
12-01-75	45.8	60.0	50.6	47.4	41.0	54.4	49.0	44	0.34	60	57	0.07	0.10	3.03
12-15-75	48.8		51.2	50.8	44.8	56.6	—	54	0.31	64	41	0.09	0.17	1.42
1-13-76	46.0	60.0	50.8	51.2	42.8	55.2	51.0	38	0.28	50	35	0.05	0.50	4.06
2-04-76	44.0	58.4	51.2	48.8	38.6	55.4	49.4	59	0.28	63	44	0	0.54	2.52
3-29-76	44.2	61.4	51.6	49.0	40.4	55.4	50.3	59	0.25	61	63	0.39	0.53	2.45
4-05-76	44.6	58.0	50.2	45.2	42.4	54.4	49.1	42	0.25	63	66	0	1.70	3.60
4-08-76	43.6	58.0	51.0	46.4	41.2	54.6	49.1	64	0.22	66	55	0	0.05	2.54
4-19-76	41.0	56.4	47.9	44.0	37.4	50.2	46.1	68	0.19	90	87	0	0	2.23
4-29-76	45.6	56.8	47.3	42.2	39.6	51.0	46.5	56	0.34	88	72	0	0.10	0.28
5-11-76	43.4	57.8	49.8	48.0	39.4	53.5	48.6	71	0.32	72	71	0.14	0.14	1.99
5-17-76	43.3	58.6	48.8	43.6	42.8	53.0	46.4	60	0.32	78	77	0	0.94	2.79
5-27-76	44.6	60.2	50.4	46.2	42.4	54.0	49.7	52	0.26	70	77	0.01	0.47	3.11
6-07-76	45.0	54.4	49.8	45.4	44.0	54.8	48.9	70	0.28	83	83	0	1.20	4.87
6-21-76	44.3	59.4	53.6	50.2	44.4	57.0	51.5	60	0.35	80	61	0.04	3.97	8.61
7-07-76	39.4	55.6	50.2	48.0	39.6	52.4	47.5	72	0.34	81	85	0.63	0.77	6.91
7-22-76	39.0	56.2	48.6	43.2	37.2	52.0	46.0	82	0.26	88	89	0.21	0.23	2.56
8-05-76	40.0	55.4	47.4	44.6	37.6	52.2	46.2	62	0.22	87	82	0	0.08	0.52
8-16-76	40.2	55.2	48.6	46.0	38.4	51.2	46.6	62	0.34	80	82	0	0.60	1.22
9-03-76	41.4	56.2	50.8	45.5	42.2	51.4	47.9	70	0.31	68	77	0	0.48	1.36
11-05-76	45.0	53.4	51.0	49.0	40.6	51.4	49.2	51	0.22	73	56	0	3.19	6.07
12-02-76	46.0	61.3	51.2	50.2	43.8	55.0	51.2	40	0.34	51	42	0	1.07	1.39
12-07-76	47.8	61.8	56.6	54.4	47.2	60.0	54.6	49	0.32	52	46	1.13	1.33	2.71
12-13-76		59.4	53.0	50.5	41.6	54.8	—	41	0.32		48			
2-25-77	40.8	58.3	51.6	51.2	45.0	51.4	49.7	51	0.28	70	34	0	0.41	0.50
3-15-77	41.0	57.8	51.2	50.0	44.2	53.8	49.7	50	0.22	73	61	0	0.67	1.70
3-29-77	40.2	57.2	51.0	50.4	43.6	54.8	49.6	62	0.32	77	66	0	0	2.67
4-07-77	43.8	59.4	52.8	49.6	45.0	56.2	51.1	40	0.32	54	76	0	2.73	5.25
4-18-77	42.0	59.0	50.0	45.8	42.0	53.0	48.5	58	0.31	79	76	0	0	3.42
4-25-77		58.6	51.0	48.0	43.0	53.4	—	58	0.28	67	78	0	2.04	4.81
5-05-77	35.6	51.6	46.0	41.0	39.0	48.8	43.3	70	0.32	80	80	0.40	0.50	2.61
5-12-77	37.0	54.2	46.0	42.4	38.0	49.6	44.5	63	0.28	77	75	0	0.09	2.70
5-23-77	37.4	54.4	48.2	45.8	38.2	51.0	45.8	61	0.34	83	85	0	0	0.66
6-06-77	38.4	55.6	48.8	49.2	40.4	52.2	47.4	70	0.32	86	83	0.25	0.57	1.42
6-08-77	34.2	50.0	44.0	43.0	34.6	46.6	42.1	78	0.25	96	90	1.55	2.25	3.21
8-11-77	37.2	55.0	48.4	49.4	38.8	51.4	46.7	80	0.28	89	90	0.90	3.24	4.17
8-25-77		55.6	49.2	47.6	39.8	51.8	—	63	0.28	76	84	0	0.24	5.95
9-01-77		57.6	50.2				—	85	0.28	89	86	0	0.29	5.63
9-15-77	42.0		49.2	45.6	43.4	51.8	—	60	0.16	74	80	0	0.75	2.09
9-22-77	40.8	54.2	48.8	46.2	41.0	50.2	46.9	66	0.34	76	80	0	0.67	2.41
10-06-77	42.0	56.6	49.0	48.4	42.0	52.6	47.7	60	0.28	67	69	0	0.51	1.95
10-20-77	45.6	58.3	51.8	48.2	41.6	53.3	49.8	65	0.25	66	62	0	1.56	3.11
3-13-78	41.6	59.6	53.2	51.9	48.0	54.2	51.4	72	0.34	78	59	0	0	2.62
3-30-78	37.2	55.6	53.3	49.8	45.2	53.6	49.2	48	0.31	62	52	0	1.02	1.15
4-06-78	37.4	52.4	44.8	44.6	37.4	46.2	44.1	54	0.34	68	76	0.01	0.03	1.60
4-17-78	39.5	56.0	46.3	43.2	43.0	48.6	46.5	52	0.34	59	70	0	0.10	1.46
5-11-78			51.6	47.0	41.8	54.4	—	60	0.34	76	70	0	1.52	8.32
5-12-78		57.2					—	50	0.24	77	70	0.06	1.07	8.79
5-16-78	41.2						—	65	0.34	80	69	0	1.37	5.64
5-25-78	43.0	54.0	50.0		40.0	50.4	—	80	0.34	86	83	0	0.24	6.17
6-15-78	44.2	58.0	51.4	52.8	43.6	53.6	50.6	80	0.34	78	81	0	0.28	2.16
6-29-78	42.0	58.0	52.6	52.4	43.6	55.0	50.6	-	—	87	37	0	1.09	1.06
7-19-78	48.0	58.4	56.4	52.6	44.0	56.6	52.7	82	0.31	89	82	0	1.32	3.87
8-02-78	35.6	50.2	45.4	43.0	36.0	45.6	42.7	77	0.25	86	67	0	1.15	4.06
8-11-78	44.0	56.6	54.0	53.0	44.2	54.8	51.4	60	0.28	54	35	0.01	0.50	2.21
8-31-78	42.0	57.2	46.8	46.4	37.4	49.2	47.1	81	0.34	85	90	1.20	3.11	3.55
9-21-78	37.4	51.8	43.8	41.6	33.5	47.3	42.6	75	0.34	55	86	0	0	2.51
N	31	83	85	82	84	84	78							
x	42.7	57.1	49.9	47.8	41.2	52.9	48.5							
σ	3.3	2.6	2.6	3.1	3.1	2.8	2.5							
$\bar{\sigma}$	2.9													

NOTE: Degrees Centigrade = 5/9 (°F - 32)

Thus $r^2 = \frac{(2.5^2 - 2.9^2/6)1.2}{2.9^2}$,

$= \frac{5.82}{8.41} \simeq 70\%.$

It is, of course, desirable to have a high degree of correlation between sites so that a single model based on average skid numbers recorded for 64 kph (40 mph) tests (SN_{40}) can be used to explain variations over time for all sites.

The variability in SN_{40} is demonstrated graphically in Figure 1, where the average SN_{40} values for all six sites for each date tested are plotted. Graphs for each of the six sites would appear similar, with slightly more variability. No trends in the data are readily apparent from Figure 1, but some become very apparent when the data are averaged by quarter of the year.

Table 2 contains data averaged for the periods January through March, April through June, July through September, and October through December. The fact that the standard deviation values shown at the bottom of Table 2 are smaller than those shown in Table 1 indicates that some of the variability with time is masked by the averaging process. The data in Table 2 are shown graphically in Figures 2 and 3. Figure 2 is a plot of the quarterly averages for all sites combined and indicates a repeating trend from year to year with the lowest SN values occurring in the third quarter. Figure 3 indicates that the annual trend is essentially the same for all sites, with the exception of site 1, which follows a somewhat different pattern for two of the five years (1975 and 1978).

Multiple Linear Correlations and Regressions

Multiple linear correlations and regressions were performed on the individual data using the model $Y = B_o + B, X, + B_2 X_2 \ldots + B_n X_n$ and the independent variables shown in the 7 columns in the right-hand portion of Table 1. The results of the multiple linear correlations and regressions on (SN_{40}) were, as expected, better for the averaged data than for the data from any single site. Table 3 contains the results of the several analyses performed with the averaged data.

As shown in Table 3, the inclusion of all seven independent variables in the analyses explains about 46% of the variance in $\overline{SN}_{40}$, with a resulting standard error of 1.97 SN as compared to the 2.5 SN standard deviation shown in Table 1. The percentage of variance explained (r^2) and the standard error of estimate were essentially as good when only two independent variables were used. However, eliminating the rainfall variables reduced the explained variance from about 40% to 27%, indicating the importance of considering rainfall as a variable.

It should be noted that the range in tire tread depths was such that almost all tests were with tread depths of 5.56 mm (7/32 inch) or greater. Thus, one would expect little influence in these analyses due to tread depth.

With respect to air temperature and rainfall, the best results were obtained when the longest periods were considered (1 week prior to test for air temperature and 1 month prior for rainfall, with 1 week prior for rainfall being

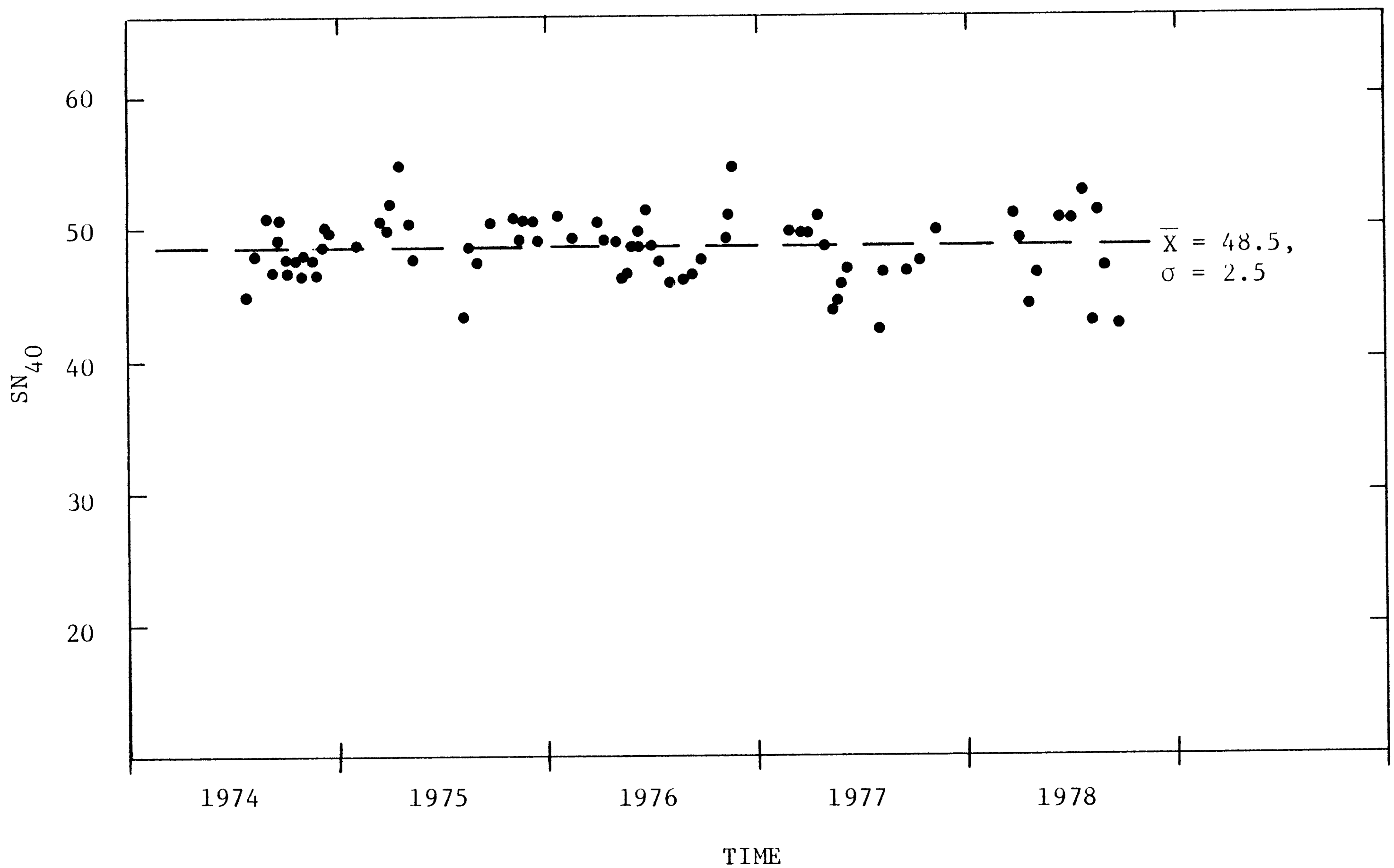

Figure 1. Plot of average SN_{40} data for all six sites for each date tested.

2137

Table 2

QUARTERLY DATA

YEAR	QUARTER	SITE 1		SITE 2		SITE 3		SITE 4		SITE 5		SITE 6		AVERAGE VALUES	
		n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$
74	3	8	43.6	8	56.3	8	48.8	8	46.3	8	41.2	8	52.6	8	48.1
	4	8	42.5	8	57.0	8	48.2	8	47.5	8	40.1	8	53.0	8	48.1
75	1	4	43.7	4	58.8	4	51.3	4	51.8	4	42.2	4	53.6	4	50.2
	2	3	44.6	3	59.2	3	52.1	3	51.2	3	43.1	3	56.1	3	51.1
	3	4	45.0	4	56.0	4	48.4	4	47.2	4	38.6	4	50.2	4	47.6
	4	6	47.1	5	59.6	6	50.0	6	48.2	6	42.8	6	55.3	5	50.1
76	1	3	44.7	3	59.9	3	51.2	3	49.7	3	40.1	3	55.3	3	50.2
	2	9	43.9	9	57.7	9	49.9	9	45.7	9	41.5	9	53.6	9	48.7
	3	5	40.0	5	55.7	5	49.1	5	45.5	5	39.0	5	51.8	5	46.8
	4	3	46.3	4	60.2	4	53.0	4	51.0	4	43.4	4	55.3	3	51.7
77	1	3	40.7	3	57.8	3	51.3	3	50.5	3	44.3	3	53.3	3	49.6
	2	6	39.1	7	56.0	7	49.0	7	46.1	7	40.8	7	52.0	6	46.8
	3	4	38.6	5	54.5	6	48.3	5	46.4	5	39.5	5	50.4	3	45.2
	4	2	43.8	2	57.4	2	50.3	2	48.3	2	41.8	2	53.0	2	49.1
78	1	2	39.4	2	57.6	2	53.2	2	50.8	2	46.6	2	54.0	2	50.3
	2	6	41.2	6	55.9	6	49.9	4	48.2	6	42.1	6	51.7	4	47.9
	3	5	41.4	5	55.2	5	49.7	5	47.7	5	39.0	5	50.7	5	47.3
$\bar{x}$			42.7		57.3		50.2		48.4		41.5		53.0		48.8
σ			2.6		1.7		1.6		2.1		2.1		1.8		1.7

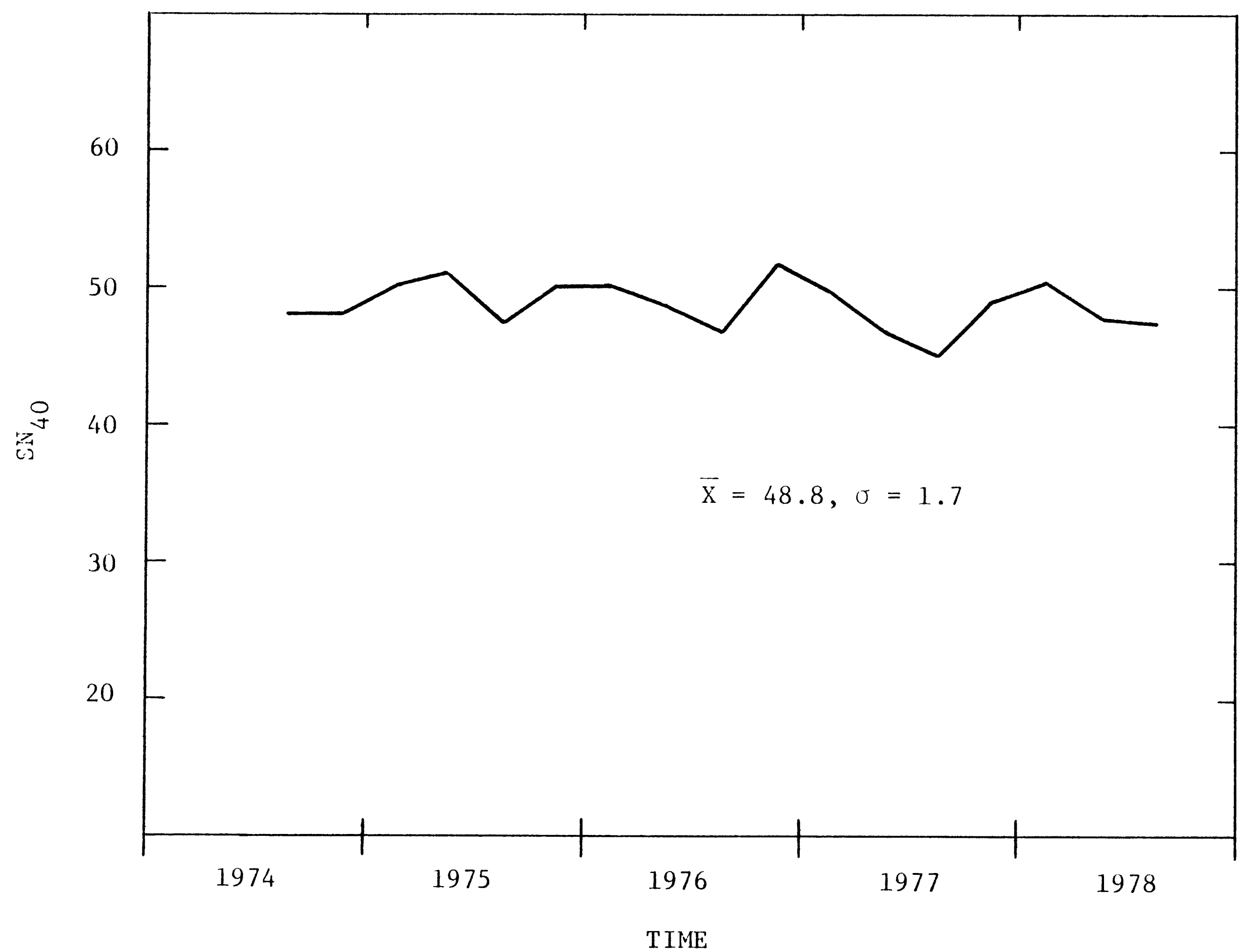

Figure 2. Plot of quarterly averages for all sites combined.

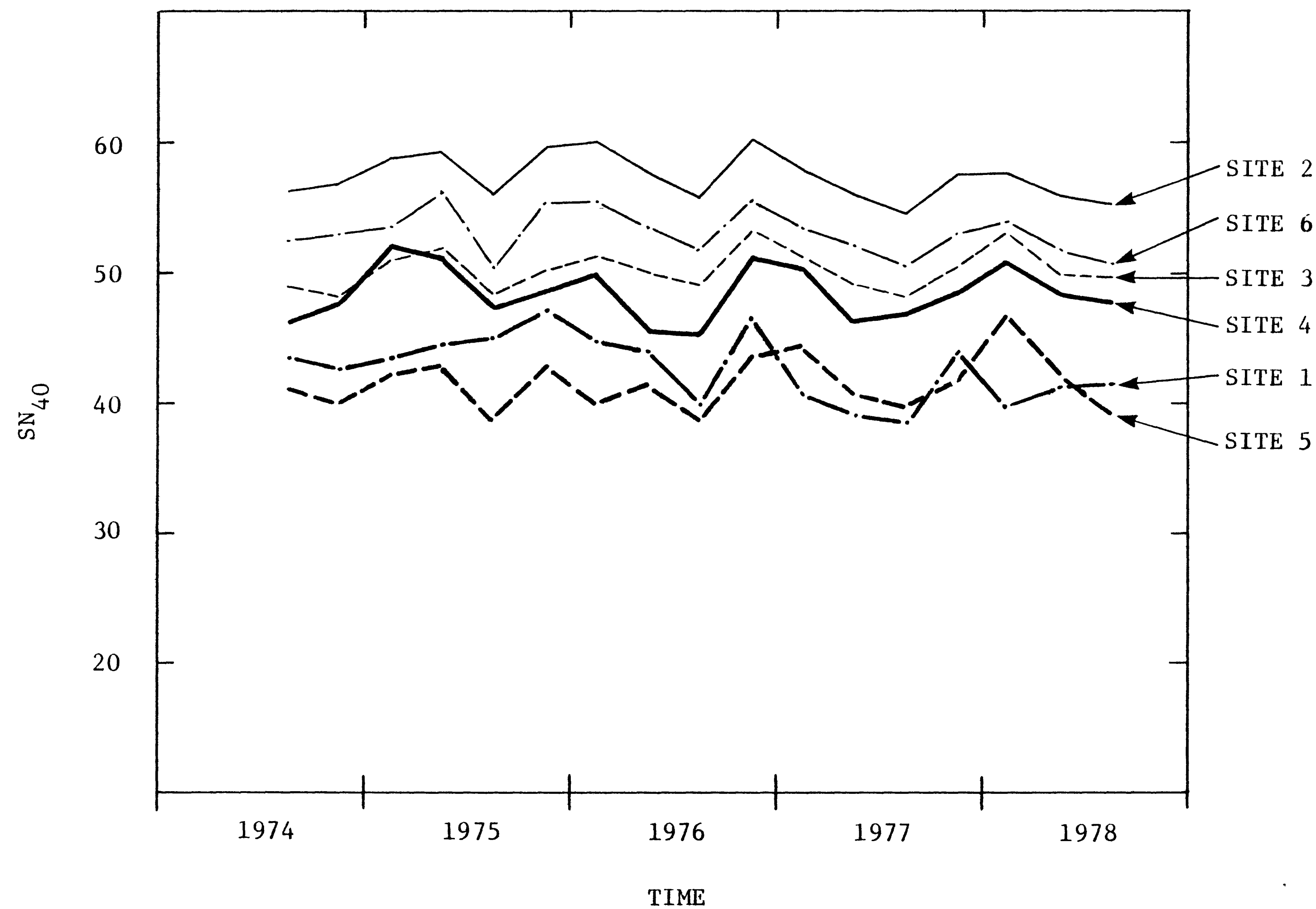

Figure 3. Plot of quarterly averages for test sites.

Table 3

MULTIPLE LINEAR CORRELATION AND REGRESSION ANALYSES COEFFICIENTS

DEPENDENT VARIABLE: AVERAGE DAILY SN_{40} — ALL SITES

Y INTERCEPT, DEPENDENT VARIABLE, OR STATISTIC	RESULTS OF ANALYSIS				
	1	2	3	4	5
Y Intercept	54.37	53.80	54.27	53.80	54.73
Tread Depth	-0.017				
Air Temperature - Time of Test, ^{o}F	+0.020				
Max. Air Temperature - Day of Test, ^{o}F	-0.022				
Max. Air Temperature Week Preceding Test, ^{o}F	-0.091	-0.097	-0.094	-0.097	-0.089
Rain - Day of Test, inches	-1.165				
Rain - Week Preceding Test, inches	+0.575	+0.440	+0.787		
Rain - Month Preceding Test, inches	+0.303	+0.307		+0.451	
r	0.67	0.66	0.63	0.64	.51
r^2	0.46	0.43	0.39	0.41	.26
Standard Error of Estimates (E_s)	1.97	1.95	2.01	1.98	2.20

NOTE: Degrees Centigrade = 5/9 (F^o - 32)

1 inch = 25.4 mm

almost as good). Any of the relationships shown in columns 2, 3, and 4 of Table 3 could be used with about equal results.

Multiple linear correlation and regression analyses were also performed on the quarterly averaged data. For these analyses the independent variables chosen were the quarterly average maximum air temperature and the average monthly rainfall for a 3-month period that overlapped the first 2 months represented by the quarterly average SN_{40}. For instance, the rainfall for June, July, and August was paired with the average SN_{40} value for the quarter July through September. The time period chosen for rainfall data, i.e., the 2-month overlap, appeared to produce better results than other 3-month periods considered. Table 4 contains the temperature and rainfall data used in the analyses, and Table 5 contains the results for the analyses performed for each site and all sites averaged (SN_{40} values from Table 2).

It is not intended that any of the relationships shown in Table 5 be used for predictive purposes, but instead to illustrate the similarity of results for all sites and the obvious correlation with temperature and rainfall. The results were similar for all sites, with the exception of site 1. The differing results for site 1 were discussed earlier and illustrated in Figure 3. For all sites combined, almost 75% of the changes in SN_{40} from quarter to quarter is explained by temperature and rainfall (r^2 = .73). The relationship of SN_{40} with temperature and rainfall is illustrated graphically for the quarterly averaged data in Figure 4.

The association of SN_{40} with the average maximum air temperature is obvious from Figure 4; i.e., how lower SN_{40} values are associated with high temperatures. The association of SN_{40} with average monthly rainfall is not so obvious, but is apparent if specific quarters are observed. For instance, the relatively high SN_{40} values for the second quarter of 1975 and fourth quarter of 1976 are definitely associated with relatively high average monthly rainfalls. This association is illustrated more clearly in Figure 5, in which data are grouped and plotted for each of the four quarters. Here the association of SN_{40} and temperature is minimized (the average maximum air temperature tends to be about the same from year to year for the same quarter).

As one would expect, the equation for all sites for the quarterly averaged data ($SN_{40} = 52.172 - 0.083T + 0.568R$) is quite similar to the equation in column 4 of Table 3 for the individual data ($SN_{40} = 53.80 - 0.097T + 0.451R$), even though the variables T and R do not represent exactly the same data.

Monthly Correction Factors

Although it is clear from the multiple linear correlation and regression analyses that there is an association between SN_{40} and rainfall and temperature, it was considered desirable to investigate the possibility for correcting SN_{40} values strictly on the basis of month tested. Table 6 contains average SN_{40} data by month for all four years of data (January and February were combined because of the few number of tests in these months). Also shown in Table 6 is the standard deviation (σ) computed for each month. The average of all these values is about 2.4 SN.

The data in Table 6 were plotted as shown in Figure 6 and a smooth curve

Table 4

RAINFALL AND TEMPERATURE DATA USED IN QUARTERLY ANALYSES

YEAR	QUARTER	AVERAGE MAXIMUM AIR TEMPERATURE, °F	AVERAGE MONTHLY RAINFALL, INCHES
74	3	81.1	3.68
	4	58.3	2.54
75	1	49.2	3.39
	2	74.0	5.70
	3	81.8	4.26
	4	60.4	4.27
76	1	49.8	2.98
	2	75.8	2.67
	3	82.4	3.26
	4	53.6	5.83
77	1	47.6	1.73
	2	77.4	3.01
	3	85.9	3.42
	4	55.8	5.17
78	1	42.9	3.90
	2	75.5	5.08
	3	84.1	3.75

NOTE: Degrees Centigrade = 5/9 (°F - 32)

1 inch = 25.4 mm

Table 5

MULTIPLE LINEAR CORRELATION AND REGRESSION RESULTS
QUARTERLY AVERAGED DATA

DATA SET	EQUATION [a]	r	r^2	STANDARD ERROR OF ESTIMATE
Site 1	SN_{40} = 41.845 - 0.045T + 1.010R	.50	.25	2.37
Site 2	SN_{40} = 61.285 - 0.086T + 0.448R	.77	.59	1.18
Site 3	SN_{40} = 53.146 - 0.076T + 0.561R	.80	.64	1.01
Site 4	SN_{40} = 53.086 - 0.108T + 0.660R	.83	.69	1.24
Site 5	SN_{40} = 46.419 - 0.099T + 0.454R	.72	.52	1.56
Site 6	SN_{40} = 56.569 - 0.079T + 0.456R	.70	.49	1.37
All Sites	SN_{40} = 52.172 - 0.083T + 0.568R	.85	.73	0.88

[a] Where SN_{40} is the predicted quarterly averaged SN_{40} value, T the average quarterly maximum air temperature, and R the average monthly rainfall for a 3-month period overlapping the first 2 months of the quarter.

2144

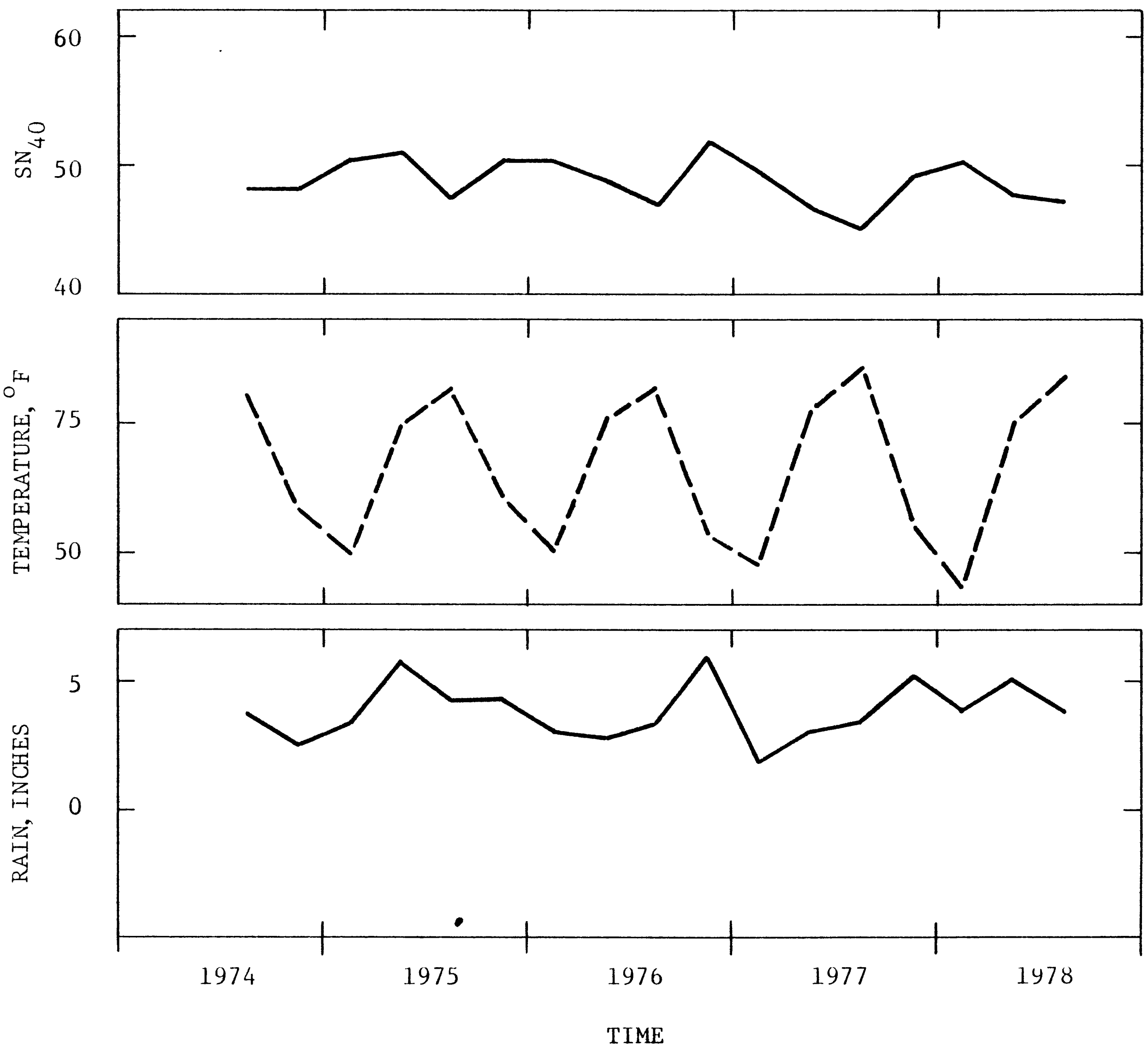

Figure 4. Plot of quarterly averaged SN_{40}, maximum air temperature, and average monthly rainfall.

NOTE: Degrees Centigrade = 5/9 (^{o}F - 32)

1 inch = 25.4 mm

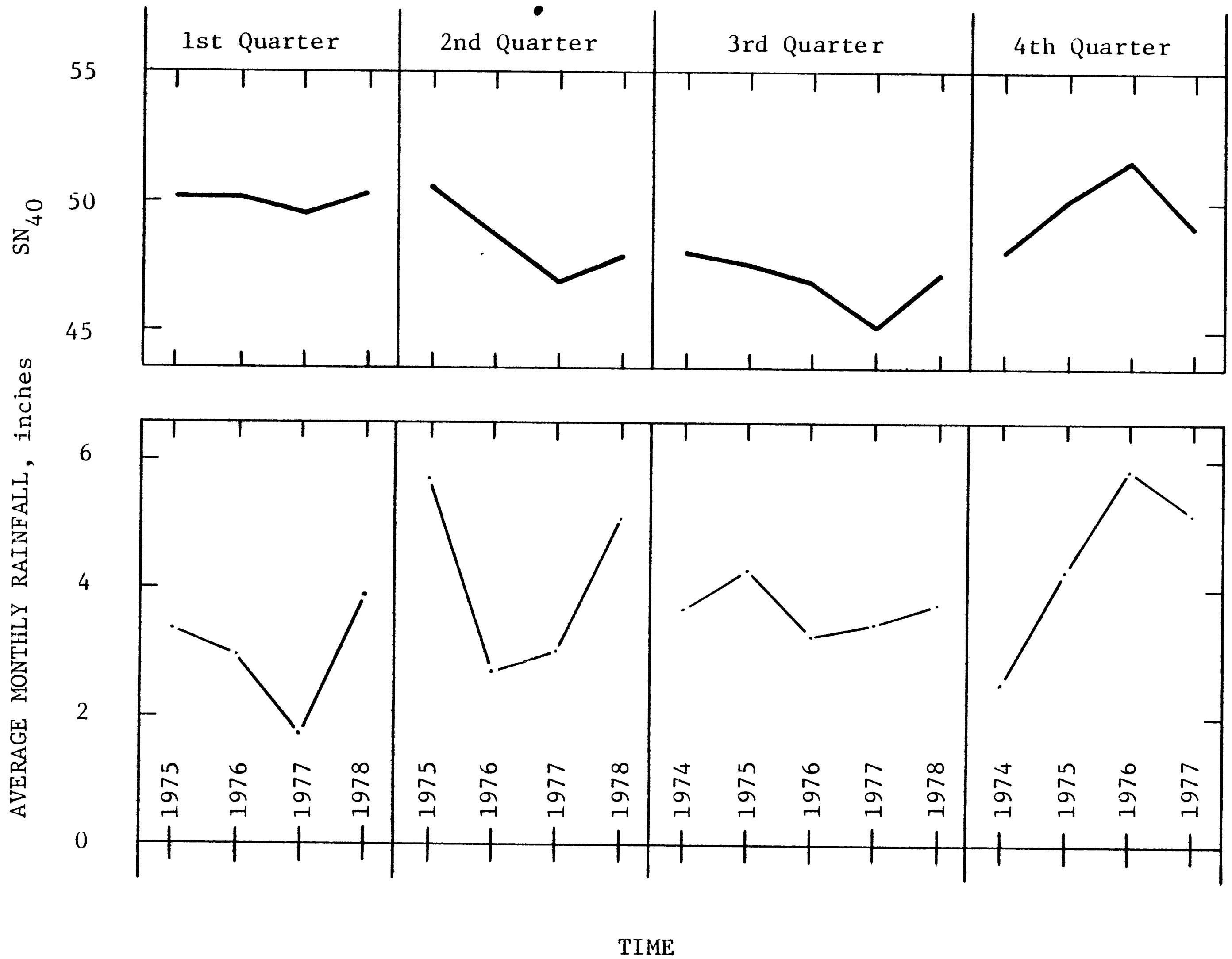

FIGURE 5. Quarterly averaged SN_{40} versus average monthly rainfall.

NOTE: 1 inch = 25.4 mm

Table 6

SN_{40} DATA SUMMARIZED BY MONTH

MONTH	SITE 1			SITE 2			SITE 3			SITE 4			SITE 5			SITE 6		
	x	n	σ	x	n	σ	x	n	σ	x	n	σ	x	n	σ	x	n	σ
Jan.-Feb.	42.8	4	2.7	58.6	4	1.1	51.4	4	0.6	50.9	4	1.5	40.9	4	3.6	53.5	4	2.1
Mar.	42.3	8	3.0	58.6	8	2.1	51.7	8	1.4	50.7	8	1.1	44.1	8	2.1	54.3	8	1.1
Apr.	42.8	11	2.9	57.6	12	2.6	50.0	12	2.9	46.9	12	3.6	41.7	12	2.8	53.2	12	3.4
May	40.7	8	3.4	56.0	8	2.9	48.8	8	2.0	44.7	6	2.4	40.6	8	2.5	51.8	8	2.2
June	42.8	5	2.7	57.1	5	2.0	51.2	5	2.0	50.0	5	3.0	43.2	5	1.6	54.5	5	1.8
July	42.4	6	3.6	55.5	6	2.1	48.7	6	4.4	46.3	6	3.6	38.7	6	3.7	51.1	6	4.5
Aug.	41.2	11	4.1	55.4	12	2.7	48.4	12	2.5	47.0	12	2.8	39.2	12	3.1	51.0	12	2.8
Sept.	42.5	9	2.7	56.0	9	2.4	49.5	10	2.4	46.2	9	2.2	40.9	9	4.0	51.9	9	2.4
Oct.	42.8	8	2.9	57.3	8	2.0	49.0	8	1.5	47.8	8	0.6	40.6	8	1.8	53.5	8	1.6
Nov.	45.4	5	3.2	58.1	5	1.8	49.1	5	1.6	47.3	5	1.5	41.4	5	2.0	53.3	5	2.2
Dec.	46.5	6	1.4	60.1	6	1.1	51.6	7	2.5	50.1	7	2.2	43.3	7	2.2	55.5	7	2.2

NOTE: n = number of tests over 5 year period, each consisting of 5 repeat measurements. Reader should note that standard deviations are based on unequal number of tests.

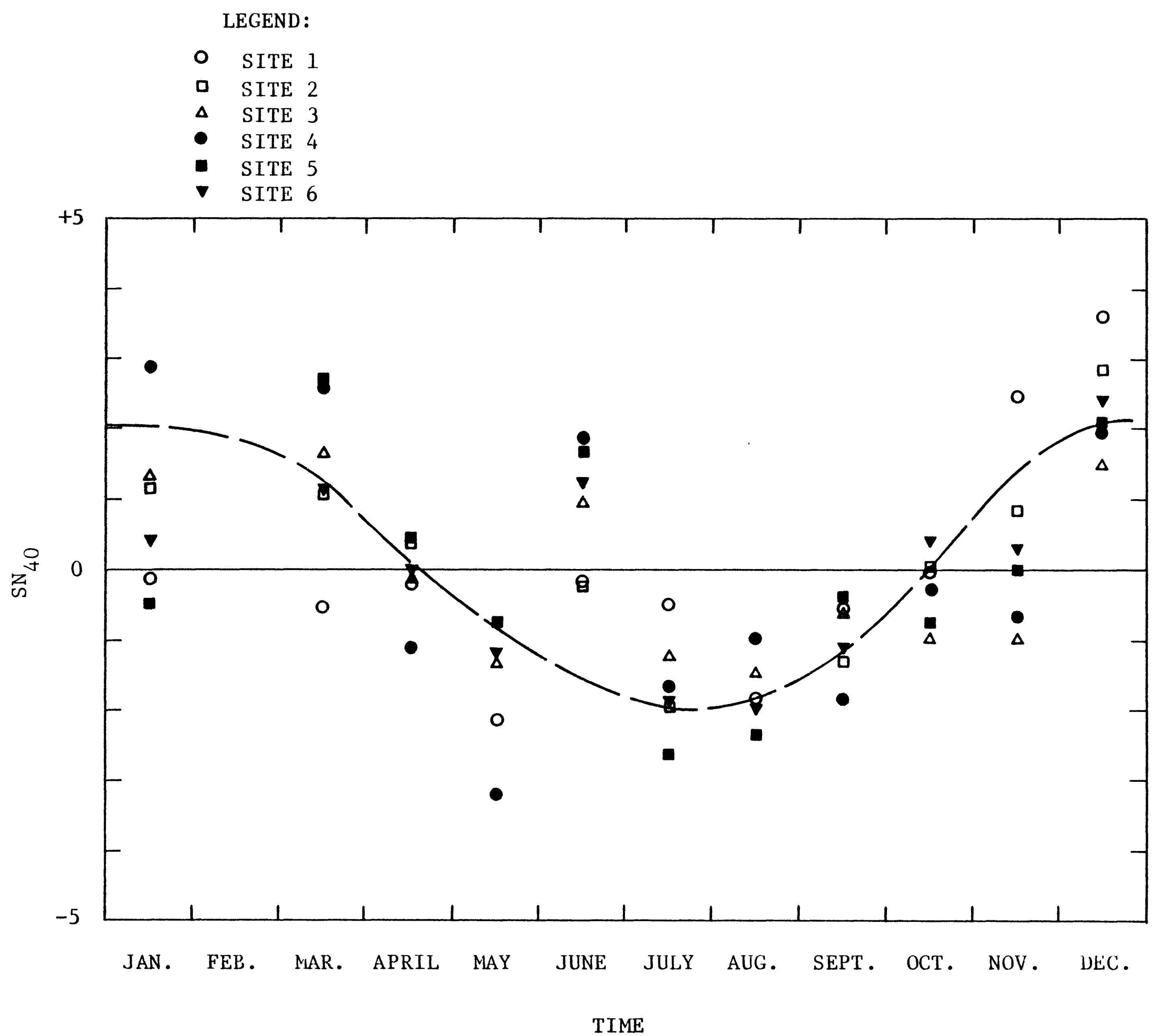

Figure 6. Monthly SN_{40} average values for test sites.

drawn through the points (dashed curve). Monthly correction factors (Table 7) were then determined from the curve with the correction factor chosen so as to adjust SN_{40} values obtained in months other than July and August to the **estimated** value of SN_{40} that would be obtained in July and August. July and August were chosen as the reference months since minimum SN_{40} values occur during that time period.

It is interesting to note that the correction factors shown in Table 7 can be closely approximated by using average monthly rainfall and maximum air temperature data (Table 8) and applying one of the regression equations from Table 3. Using equation 4 from Table 3, correction factors would be as shown in Table 9 computed as below.

Correction factor, $C = (3.5 - R)\ 0.451 - (85 - T)\ 0.097$,

where T = average maximum air temperature for month for which C is being estimated; and

R = average rainfall for month for which C is being estimated.

Minimum Predicted SN_{40} Values and Associated 95% Confidence Intervals

It is, of course, of interest to examine how one might predict the minimum SN_{40} that might occur at a site during the year based on a given measurement of SN_{40} at that site. The three methods considered are:

1. no adjustments to the measured SN_{40} value,
2. adjustments to the measured SN_{40} value based on the monthly corrections (Table 7), and
3. adjustments to the measured SN_{40} value based on equation 4 from Table 3.

The predicted minimum SN_{40} ($PMSN_{40}$) values along with the approximate 95% confidence limits based on the three methods are shown below, where $PMSN_{40}$ is taken to be the estimated average SN_{40} minus 2σ.

Method 1: $PMSN_{40} = [SN_{40} - 2\sigma] \pm 2\sigma$, where

σ = the site standard deviation, or about 2.9 SN.

Method 2: $PMSN_{40} = [SN_{40} - 2\sigma^1 - C] \pm 2\sigma$, where

σ^1 = the within month site standard deviation, or about 2.4 SN; and

C = correction factor from Table 7.

Table 7

MONTHLY CORRECTION FACTORS BASED ON CURVE IN FIGURE 6

Month	Correction Factor
Jan.-Feb.	-3.7
March	-3.1
April	-1.7
May	-0.7
June	-0.3
July	0
August	0
September	-0.6
October	-1.7
November	-3.1
December	-3.7

Table 8

AVERAGE MONTHLY RAINFALL AND MAXIMUM
AIR TEMPERATURE DATA, 1974 - 1978

Month	Average Monthly Rainfall, Inches	Average Monthly Maximum Air Temperature, °F
Jan.-Feb.	2.73 [a]	43.4 [a]
March	4.64 [a]	55.3 [a]
April	3.18 [a]	69.0 [a]
May	4.52 [a]	76.0 [a]
June	4.30 [a]	82.0 [a]
July-Aug.	3.50	85.0
September	4.42 [a]	79.3 [a]
October	4.91 [b]	66.9 [b]
November	2.93 [b]	58.0 [b]
December	3.55 [b]	46.2 [b]

[a] Excludes 1974

[b] Excludes 1978

NOTE: Degrees Centigrade = 5/9 (°F - 32)

1 inch = 25.4 mm

Table 9

CORRECTION FACTORS BASED ON TABLE 7,

EQUATION 4, AND AVERAGE MONTHLY RAINFALL AND TEMPERATURE

Month	Correction Factor Table 7	Correction Factor[a]
Jan.-Feb.	-3.7	-3.7
March	-3.1	-3.4
April	-1.7	-1.4
May	-0.7	-1.3
June	-0.3	-0.6
July-Aug.	0	0
September	-0.6	-1.0
October	-1.7	-2.4
November	-3.1	-2.4
December	-3.7	-3.8

[a] Computed from $C = (3.5 - R)\,0.451 - (85 - T)\,0.097$, using coefficients from column 4 of Table 3 and average monthly rainfall and temperature data from Table 8.

Method 3: $PMSN_{40} = [SN_{40} - 2\sigma'' - (T_2 - T_1)\, 0.097 + (R_2 - R_1)\, .451] \pm 2\sigma''$,

where σ'' = the standard error of estimate based on regression results, or about 2.0 SN;

T_1 = maximum air temperature associated with SN_{40};

T_2 = maximum air temperature associated with $PMSN_{40}$;

R_1 = average monthly rainfall associated with SN_{40}; and

R_2 = average monthly rainfall associated with $PMSN_{40}$.

Thus, assuming an SN_{40} value of 40 was measured in March (with T_1 = 55°F [13°C] and R_1 = 4.6 inches [116.8 mm]) the corresponding $PMSN_{40}$ values and the associated 95% confidence limits would be as follows (where the $PMSN_{40}$ is assumed to be in July or August with T_2 = 85°F [29.4°C] and R_2 = 3.5 inches [88.9 mm].)

Method 1: $PMSN_{40} = [40 - 2\ (2.9)] \pm 2(2.9)$
$= 34.2 \pm 5.8.$

Method 2: $PMSN_{40} = [40 - 2\ (2.4) - 3.1] \pm 2(2.4)$
$= 32.1 \pm 4.8.$

Method 3: $PMSN_{40} = [40 - 2\ (2.0) - (85-55)\ .097 + (3.5 - 4.6)\ .451] \pm 2(2.0)$
$= 32.6 \pm 4.0.$

Either of the last two methods would be better than the first, but it is not necessarily clear which of the last two is more desirable. It would appear method 3 has somewhat better (smaller) 95% confidence intervals, but one must remember this method is dependent on selecting good estimates for T_2 and R_2. For each deg. F. that T_2 is in error, $PMSN_{40}$ will be in error by about 0.1 SN, and for each inch (25.4 mm) R_2 is in error, $PMSN_{40}$ will be in error by 0.451 SN. Since on the average method 2 and method 3 would give about the same results, and because of its ease of application, method 2 is preferred by the authors.

It must be remembered that these methods predict the minimum values that would be obtained over a short period of time, specifically within a month for method 2. The authors feel it is more reasonable to predict the average values rather than minimum values for a short period of time and in this case the initial correction of 2 σ would not be appropriate. Thus method 2 would be modified to

$PMSN_{40} = [SN_{40} - C] \pm 2\ \sigma$, where

σ = the within month site standard deviation, or about 2.4 SN; and

C = correction factor from Table 7.

ANALYSES OF VHTRC STOPPING DISTANCE CAR RESULTS

The results discussed in the first section relative to the VDHT survey skid trailer were not determined from skid data gathered as part of an experimental testing program, but rather were based on an analysis of skid data obtained as a normal part of the survey testing program. An experimental testing program was designed in which the VHTRC skid trailer and stopping distance car were used to perform several repeat test sequences on various surfaces, at various speeds, and with both treaded and bald tires.

Sixteen sites were tested by the VHTRC trailer (these did not include any of the six control loop sites tested by the VDHT trailer) and six sites by the car. These sites are described in Table 10. Also indicated in Table 10 are the test speeds and intended testing frequencies at each of the sites. Both bald and treaded tire (ASTM) tests were performed at the indicated speeds and frequency. All of the sites tested had been in service for a number of years and were felt to have stabilized with respect to skid resistance. As indicated in Table 10, sites 3, 4, 7, 8, 15 and 16 were tested by the stopping distance car using treaded (ASTM) tires. Detailed test results and related data for the sites are included as Appendix A. Shown in Appendix A for each site and test speed of 32, 64, and 97 kph (20, 40 and 60 mph) are the following:

1. Date of test
2. Average skid number
3. Tread depth for treaded tire tests
4. Air temperature in deg. F. at the time of the test
5. Dry pavement temperature in deg. F. at the time of the test
6. Water temperature in the water storage tanks in deg. F. at the time of the test
7. Maximum air temperature for the day of the test in deg. F. as obtained from the nearest weather station
8. Average maximum air temperature for the week preceding the test in deg. F. as obtained from the nearest weather station
9. Rainfall in inches for the day of the test as obtained from the nearest weather station
10. Rainfall in inches for the week preceding the test as obtained from the nearest weather station
11. Rainfall in inches for the month preceding the test as obtained from the nearest weather station

As for the survey trailer, each skid value shown in Appendix A represents five repeat measurements made at a site over a short time span.

Variability of Skid Data

Standard deviation values for the skid data collected by the stopping distance car are shown in Table 11. The average σ value for all test speeds at the six sites is 3.26 SN, or slightly higher than the 2.9 SN discussed earlier for the VDHT trailer. It is felt the value is somewhat higher because of the types of surfaces tested by the car, in particular sites 7 and 8, which are both basically limestone mixes.

Variances were not found to be significantly different for the various test speeds based on the F test at a 95% confidence level. However, variances for sites 3 and 4 were found to be significantly lower (again at a 95% confidence level), thus reemphasizing the point that the average σ found for the car likely is somewhat higher than that for the VDHT trailer because of the differences in test surfaces.

The variability of the data is illustrated graphically in Figures 7 and 8. In Figure 7 the individual test results for each site and speed are plotted by date. Figure 7 indicates the similar results for all test speeds at a given site and also the difference in variability among sites, with sites 3 and 4 having the least variability and site 8 the greatest variability. Figure 8 graphically displays the data as averaged for all test speeds for grouped sites, with the sites being grouped with respect to similar results and surface types (sites 3 and 4, sites 7 and 8, and sites 15 and 16). Again, the greater variability for sites 7 and 8 and for sites 15 and 16 is illustrated. It is also evident that the SN results are lower during the latter part of 1978 than during the same months in 1977, probably due to decreased rainfall for these months during 1978 as illustrated in Figure 9.

Multiple Linear Correlations and Regressions

As with the VDHT trailer, multiple linear correlations and regressions were performed using the model $y = h_o + h_1 X_1 + h_2 X_2 \ldots + h_n X_n$. Two additional independent variables were considered; namely, dry pavement temperature at the time of the test and the temperature of the water used to wet the pavement for the tests. An analysis was made including all variables for each speed at each site and the results are contained in Appendix B. The r^2 values for all analyses in Appendix B exceeded .5; i.e., at least 50% of the variance in skid resistance was explained.

In order to develop a more meaningful relationship using fewer variables, several additional analyses were performed. In each successive analysis, the least significant variable found in the previous analysis was omitted until just three independent variables remained. The equations resulting from these analyses are shown in Table 12.

As shown by their frequency of occurrence, the most important variables from an overall sense would appear to be the maximum air temperature (either the day of the tests or the average for the week preceding the tests), tire tread depth, and the variables associated with rainfall. With respect to rainfall, the results shown in Table 12 plus the correlation factors among these variables seemed to indicate that rain for either the week preceding the tests or for the month preceding the tests must be considered, but not both variables together. However, it may be desirable to include rainfall the day of the tests with either of the other two rainfall variables. Reducing the number of independent variables from

Table 10

EXPERIMENTAL TEST SITES

SITE	ROUTE	LANE	MIX TYPE	VHTRC TRAILER TEST SPEEDS & FREQUENCY	VHTRC CAR TEST SPEEDS & FREQUENCY
1	I-64	Traffic	PCC	Once weekly at 32, 64 and 97 kph and two additional times weekly at 64 kph.	
2	I-64	Passing	PCC	Once weekly at 32, 64 and 97 kph and two additional times weekly at 64 kph.	
3	29	Traffic	Bit. Concrete S-5	Once weekly at 32, 64 and 97 kph and two additional times weekly at 64 kph.	Once every two weeks at 32, 64 and 97 kph.
4	29	Passing	Bit. Concrete S-5	Once weekly at 32, 64 and 97 kph and two additional times weekly at 64 kph.	Once every two weeks at 32, 64 and 97 kph.
5	I-81	Traffic	Popcorn	Once weekly at 32, 64 and 97 kph.	
6	I-81	Passing	Popcorn	Once weekly at 32, 64 and 97 kph.	Once every two weeks at 32 and 64 kph.
7	340	Traffic	Bit. Concrete S-5 (Sprinkle)	Once weekly at 32, 64 and 97 kph.	Once every two weeks at 32 and 64 kph.
8	625	Traffic	Bit. Surface Treatment (Limestone Aggregate)	Once weekly at 32 and 64 kph.	Once every two weeks at 32 and 64 kph.
9	I-64	Traffic	Slurry Seal	Once weekly at 32, 64 and 97 kph.	
10	I-64	Passing	Slurry Seal	Once weekly at 32, 64 and 97 kph.	
11	I-64	Traffic	PCC 3/4" Longitudinally tined	Once weekly at 32, 64 and 97 kph.	
12	I-64	Passing	PCC 3/4" Longitudinally tined	Once weekly at 32, 64 and 97 kph.	
13	I-64	Traffic	PCC 3/4" Longitudinally Grooved	Once weekly at 32, 64 and 97 kph.	
14	I-64	Passing	PCC 3/4" Longitudinally Grooved	Once weekly at 32, 64 and 97 kph.	
15	250	Traffic	Popcorn	Once weekly at 32 and 64 kph.	Once every two weeks at 32 and 64 kph.
16	250	Passing	Popcorn	Once weekly at 32 and 64 kph.	Once every two weeks at 32 and 64 kph.

NOTE: 1 inch = 25.4 mm

1 kph = 0.6214 mph

Table 11

VARIABILITY OF STOPPING DISTANCE CAR DATA

Site	Speed	$\bar{x}$	n	σ	σ Pooled
3	32 kph	66.44	18	2.38	
	64 kph	62.00	18	3.25	2.88
	97 kph	52.67	18	3.11	
4	32 kph	67.78	18	1.86	
	64 kph	62.00	18	2.11	2.04
	97 kph	54.89	18	2.25	
7	32 kph	48.78	23	4.20	3.73
	64 kph	45.52	23	3.29	
8	32 kph	37.09	23	4.95	4.30
	64 kph	32.87	23	3.65	
15	32 kph	58.06	18	3.70	3.87
	64 kph	53.22	18	4.15	
16	32 kph	57.89	18	3.79	3.35
	64 kph	53.11	18	2.97	
AVERAGE				3.26	

NOTE: 1 kph = 0.6214 mph

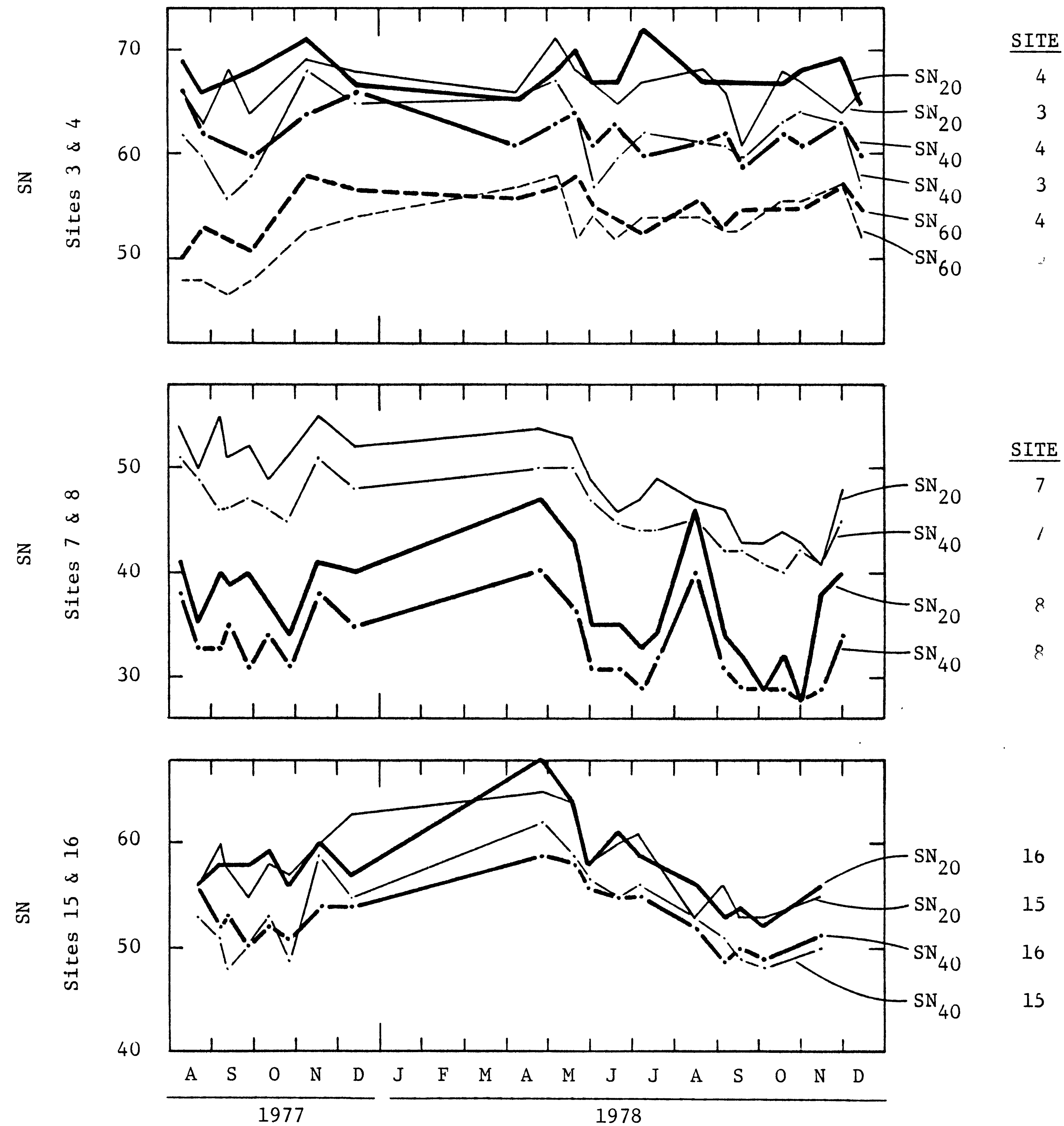

Figure 7. Individual test results — VHTRC car.

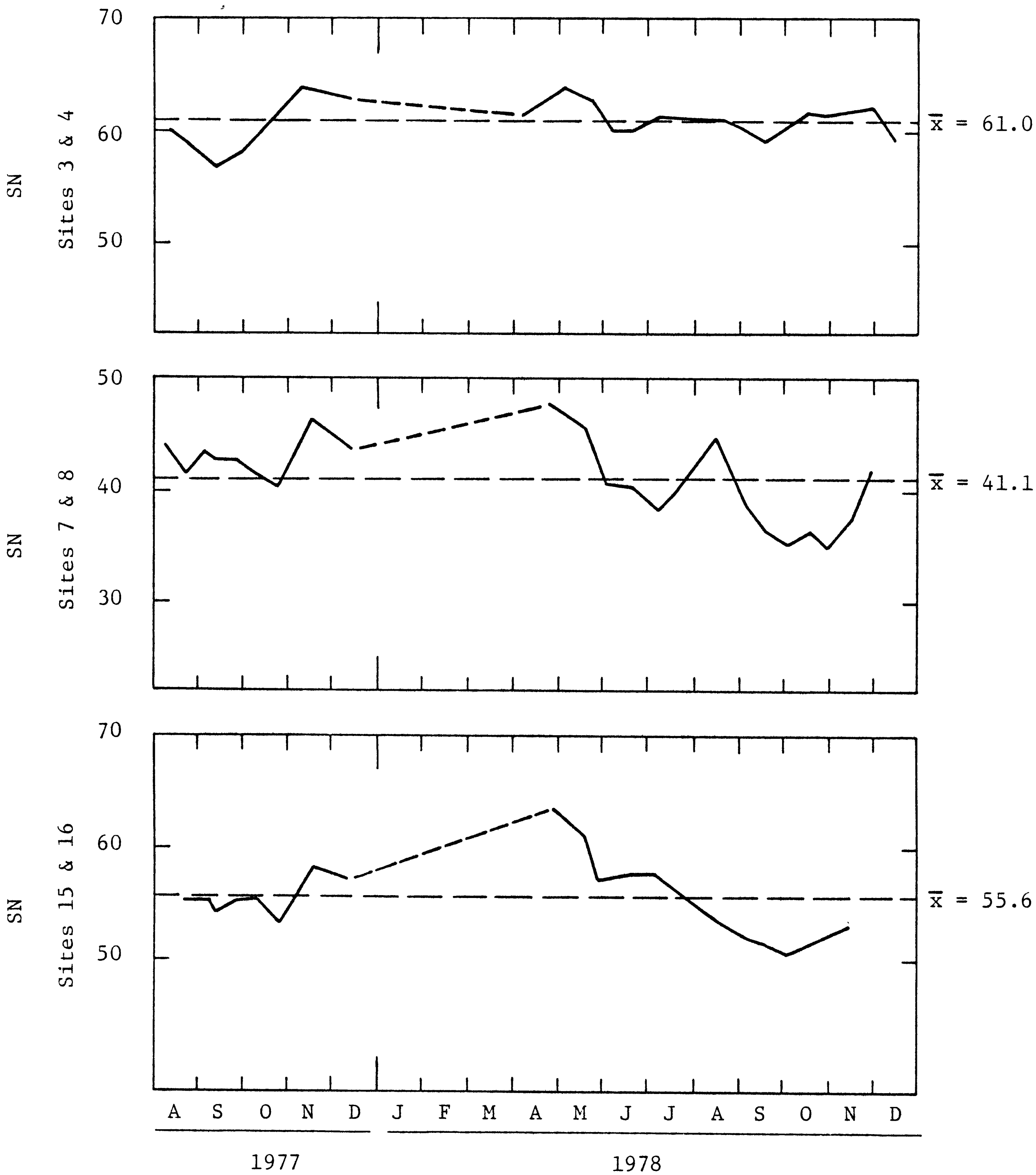

Figure 8. Test results averaged for all speeds by surface types — VHTRC car.

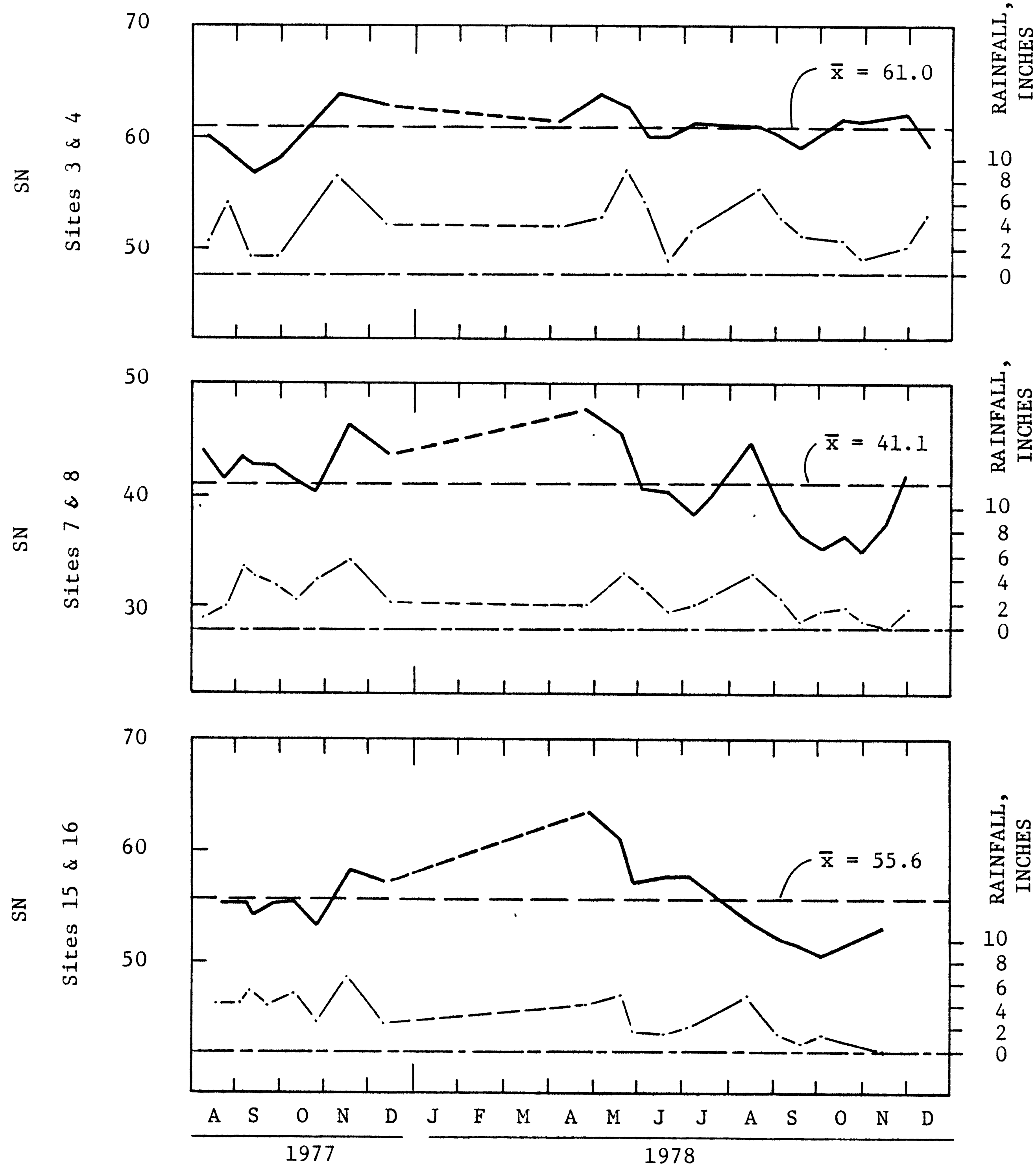

Figure 9. Rainfall versus SN — VHTRC car.

NOTE: 1 inch = 25.4 mm

Table 12

MULTIPLE CORRELATION AND REGRESSION RESULTS

VHTRC CAR — THREE INDEPENDENT VARIABLES

SITE	SPEED	All Variables Included		Coefficients For Three-Variable Analyses									Three Variables	
		r^2	E_s	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	r^2	E_s
3	20	.50	2.38					- .187	.184		0.758		.43	1.98
	40	.85	1.84				-12.752	- .103			1.115		.60	2.27
	60	.83	1.87				-47.596	- .079				0.299	.72	1.81
4	20	.61	1.71		.022			- .166			0.834		.47	1.50
	40	.68	1.74						- .070	40.5	0.238		.53	1.59
	60	.81	1.42				-20.77		- .075			0.488	.77	1.17
7	20	.91	1.67				58.114		- .074			1.063	.77	2.17
	40	.80	1.91				39.128			6.438		0.621	.58	2.29
8	20	.53	4.40						- .057	11.394		1.680	.44	3.98
	40	.55	3.17						- .034	8.230		1.221	.42	2.98
15	20	.61	3.38	.106					- .236		2.090		.51	2.85
	40	.68	3.39				-45.356			10.149		1.067	.35	3.68
16	20	.59	3.55		.050					8.34		0.534	.41	3.21
	40	.55	2.89			-.132				6.133	0.712		.44	2.44
$\bar{E}_s$			2.52											2.42

Variable Code:
(1) Air temperature (°F) time of test.
(2) Pavement temperature (°F) time of test.
(3) Water temperature (°F) time of test.
(4) Tread depth.
(5) Maximum air temperature (°F) day of test.
(6) Average maximum air temperature (°F) week preceding test
(7) Rainfall (inches) day of test.
(8) Rainfall (inches) week preceding test.
(9) Rainfall (inches) month preceding test.

NOTE: Degrees Centigrade = 5/9 (°F - 32)

1 inch = 25.4 mm

nine to three reduced the r^2 value somewhat, but for all cases except one the value exceeded .40.

Based on the results in Table 12, several additional analyses were performed considering only the independent variables of tread depth, average maximum air temperature for the week preceding the tests, rainfall the day of the tests, and rainfall for the month preceding the tests. These analyses were performed by test speed on data aggregated by mix type; i.e., data for sites 3 and 4 were combined, those for sites 7 and 8 were combined, and those for sites 15 and 16 were combined, and those for all sites were combined. To accommodate these analyses, data were restated by expressing each SN result in terms of its deviation from the grand average for the site. The results of these analyses are shown in Table 13.

As shown by the r^2 values in Table 13, the results considering the four variables mentioned above, or some combination of the four, were in most cases not particularly good. Also, the results with respect to tread depth were somewhat confusing in that negative coefficients occurred at 97 kph (60 mph) for sites 3 and 4 and not at other sites. Negative coefficients also occurred for tread depth for sites 15 and 16 combined, which is probably reasonable because of the coarse macrotexture at these sites. Also consistent is the strong positive influence of tread depth at the limestone sites 7 and 8. Rain the day of the test appears to be an important variable in these analyses where it was not in the VDHT trailer analyses, perhaps due to differences in site surface types. Because of differences in results by site groupings, the analyses for all sites combined yielded no better (higher) r^2 values and, in fact, the values were somewhat less than for the analyses of several individual sites.

The final regression analyses used the skid data averaged for all speeds by surface types as illustrated previously in Figure 8. Only the independent variables rain for the day and for the month preceding the tests and the average maximum air temperature for the week preceding the tests were considered in these analyses. The results are shown in Table 14. Here, three things are of importance. First, the results in terms of coefficients for air temperature and rainfall are similar to those determined for the VDHT trailer, as are the r^2 values, particularly those for sites 3 and 4, which were most similar to the sites tested by the VDHT survey trailer. Second, inclusion of rain the day of the test significantly improves the results in terms of increasing r^2 for sites 7 and 8 and 15 and 16. This was not true for sites 3 and 4 or for the VDHT trailer. Third, rainfall, in general, is a more significant variable for the limestone sites 7 and 8 than for the other sites, which have non-polishing aggregates. These results certainly indicate the probability of requiring various predictive equations depending on the type of surface mix and materials used in the mix (or for various sets of correction factors by mix type, if that method is preferred).

ANALYSES OF VHTRC TRAILER RESULTS

As indicated earlier, as part of the experimental program the VHTRC trailer obtained skid resistance data at the 16 sites shown in Table 10. It was initially planned to test each site weekly over a 14-month period and sites 1-4 an additional two times each week at 64 kph (40 mph). However, due to mechanical

Table 13

RESULTS OF FOUR VARIABLE ANALYSIS
VHTRC STOPPING DISTANCE CAR

SITES	SPEED kph	INTERCEPT	TIRE TREAD DEPTH, INCHES	AVG. MAX. AIR TEMP. WEEK BEFORE TESTS, °F	RAIN DAY OF TESTS, INCHES	RAIN MONTH BEFORE TESTS, INCHES	r^2	E_s
3-4	32	1.980	-1.275	-.037	11.758	0.228	.13	2.05
		0.441	3.368	-.032		0.222	.11	2.05
		1.123		-.028		0.223	.10	2.03
	64	4.734	0.327	-.092	28.616	0.322	.30	2.48
		0.988	11.626	-.080		0.307	.21	2.59
		3.345		-.067		0.310	.18	2.59
	97	12.048	-34.839	-.051	0.374	0.356	.59	1.79
		11.999	-34.691	-.050		0.356	.59	1.76
		4.970		-.090		0.346	.33	2.23
7-8	32	-10.436	37.744	-.070	8.993	1.346	.58	3.08
		-9.123	38.713	-.078		1.195	.49	3.39
		-1.184		-.045		1.562	.37	3.70
	64	-7.960	30.723	-.053	7.138	0.818	.51	2.52
		-6.918	31.492	-.060		0.698	.39	2.77
		-0.460		-.033		0.997	.26	3.01
15-16	32	5.690	-4.048	-.098	7.097	0.534	.36	3.13
		3.552	10.437	-.106		0.291	.20	3.45
		6.016		-.103		0.428	.19	3.41
	64	9.606	-26.48	-.073	9.006	0.758	.42	2.89
		6.894	-8.099	-.083		0.449	.15	3.45
		4.983		-.085		0.342	.14	3.41
ALL SITES	32	-3.402	20.182	-.068	6.466	0.580	.32	3.06
		-3.571	24.667	-.074		0.487	.24	3.22
		0.916		-.052	7.327	0.692	.27	3.15
		1.839		-.055		0.613	.16	3.36
	64	-1.145	12.840	-.066	6.810	0.478	.30	2.77
		-1.323	17.564	-.072		0.380	.19	2.97
		1.602		-.056	7.358	0.550	.28	2.81
		2.529		-.058		0.470	.15	3.04
VDHT TRAILER [a]	64	54.270		-.097		0.451	.41	1.98

[a] From Table 3

NOTE: Degrees Centigrade = 5/9 (^{o}F - 32)

1 inch = 25.4 mm

1 kph = 0.6214 mph

Table 14

RESULTS OF REGRESSION ANALYSES
FOR ALL SPEEDS COMBINED
VHTRC STOPPING DISTANCE CAR

SITES	INTERCEPT	AVG. MAX. AIR TEMP. WEEK BEFORE TESTS, °F	RAIN DAY OF TESTS, INCHES	RAIN MONTH BEFORE TESTS, INCHES	r^2	E_s
3-4	64.497	-0.071	8.194	.330	.45	1.49
	64.147	-0.065		.322	.43	1.47
7-8	38.958	-0.036	8.990	1.407	.60	2.41
	40.502	-0.043		1.260	.42	2.81
15-16	59.968	-0.094	6.700	.475	.45	2.73
	61.545	-0.103		.423	.25	3.07
VDHT TRAILER [a]	54.270	-0.097		.451	.41	1.98

[a] From Table 3

NOTE: Degrees Centigrade = 5/9 (°F - 32)
1 inch = 25.4 mm

2163

and weather problems this testing frequency was not always maintained. In actuality, testing with the VHTRC trailer began in August 1977 and continued through August 1978, when it was discontinued due to severe mechanical problems.

Data collected other than skid data were the same as indicated for the VHTRC car. In addition, daily, weekly and monthly rainfall in inches was also determined for sites 1-4 based on an automated rain guage placed near those sites. Detailed variability and SN data for the sites are shown in Appendix C. Complete data will be maintained at the VHTRC and will be made available upon request.

Variability of Skid Data

The data obtained with the VHTRC trailer proved to be much more variable than those collected with the other testing devices with values ranging from 5.62 to 7.98 by site. It is felt by the authors that this high variability is partly due to the above mentioned mechanical difficulties with the trailer during the study period.

Not a great deal of difference in σ was noticed by site on tire type. As already indicated, σ for 32 and 64 kph (20 and 40 mph) tests ranged from 5.62 to 7.98 by site, with the breakdown shown in Table 15 by general surface type (tests at 97 kph [60 mph] were not considered since this test speed was not used at all sites). There was some apparent tendency for r to decrease with test speed, as shown in Table 16.

The variability of the VHTRC trailer data for 64 kph (40 mph) testing is illustrated graphically in Figure 10. Each point in Figure 10 represents the deviation for the SN_{40} obtained at that site that day from the grand average site SN_{40} for all tests at that site. It can be seen that the results for the VHTRC trailer are somewhat different from those for the two testing units previously discussed in that they were relatively very low in late 1977 and early 1978. It is felt by the authors that the low results in this period were due to mechanical difficulties with the trailer, particularly since major repairs were made during November 1977 (with essentially no tests being run during that month).

Multiple Linear Correlations and Regressions

Because of the authors' lack of confidence in the validity of the VHTRC results (particularly those obtained from November 1977 to March 1978), correlation and regression analyses were limited to the consideration of only the variables found most significant in the analyses previously discussed for the other units. The results of the analyses of the VHTRC data are shown in Table 17.

It is clear from Table 17 that with respect to rainfall and temperature, the results obtained with the VHTRC trailer were quite different from those for the other two testing devices. First, the r^2 values were very low for all sites (generally less than .10). Second, signs of the coefficients were inconsistent and for the most part made little sense; i.e., rainfall frequently had a negative coefficient which indicated a lowering influence on the SN value which, of course, is opposite from the result one would expect. Again, the authors attribute the

Table 15

σ FOR VHTRC TRAILER BY GENERAL SURFACE TYPE

SURFACE TYPE	SITES	σ (SN_{20} and SN_{40})
Portland Concrete Cement	1, 2, 11, 12, 13 & 14	6.51
Bituminous: Surface Treatment	7, 8, 9 & 10	6.41
Slurry Seal		
Sprinkle		
Bituminous, S-5	3 & 4	7.34
Bituminous, Popcorn	5, 6, 15 & 16	7.59

Table 16

SUMMARIZED VHTRC TRAILER σ VALUES
BY TIRE TYPE AND SPEED

SPEED, mph	$\bar{\sigma}$, BALD	$\bar{\sigma}$, TREADED	$\bar{\sigma}$, COMBINED
20	7.05	7.39	7.22
40	6.62	6.35	6.49
60	6.03	6.01	6.02
ALL SPEEDS	6.57	6.58	6.58

NOTE: 1 mph = 1.609 kph

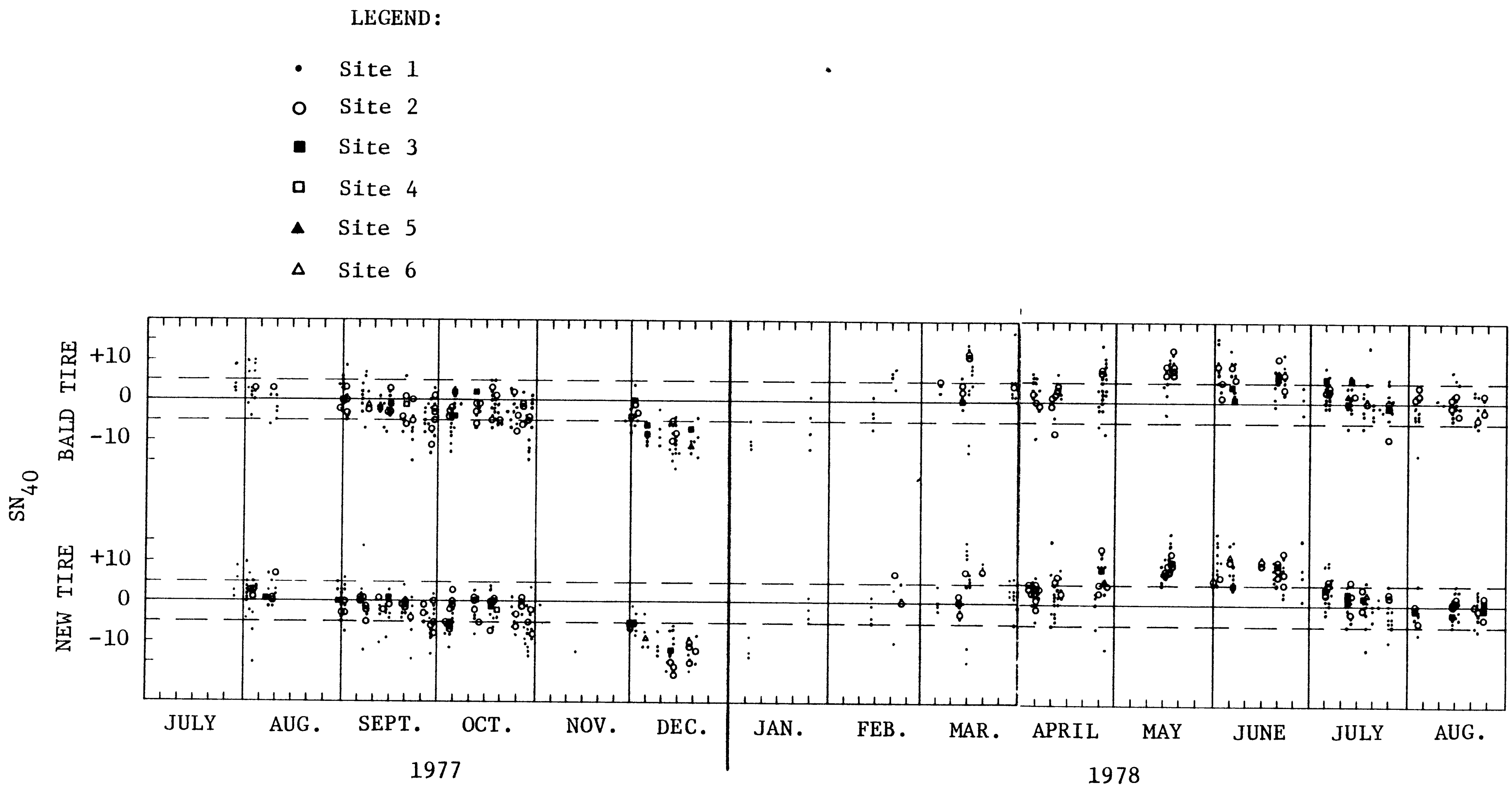

Figure 10. VHTRC trailer results for tests at 40 mph with bald and treaded tires.

NOTE: 1 mph = 1.609 kph

Table 17

VHTRC TRAILER MULTIPLE LINEAR CORRELATION AND REGRESSION RESULTS

SITES	TIRE TYPE	SPEED, mph	INTERCEPT	MAX. AIR TEMP. WEEK OF TESTS, °F	RAIN FOUR WEEKS BEFORE TESTS, INCHES	r^2	E_s
1, 2	Bald	20	49.586	-.021	1.067	.07	10.00
	Treaded	20	53.131	.164	.757	.09	10.36
	Bald	40	33.978	.003	.195	.003	8.34
	Treaded	40	54.373	.011	.385	.008	10.64
	Bald	60	21.504	.031	.246	.01	7.23
	Treaded	60	39.825	.063	.269	.02	9.87
3, 4	Bald	20	51.967	.072	.668	.05	8.66
	Treaded	20	56.020	.175	.470	.15	7.57
	Bald	40	39.817	.050	.262	.01	9.29
	Treaded	40	55.237	.063	.026	.02	7.20
	Bald	60	27.652	.081	.422	.05	7.51
	Treaded	60	42.479	.112	.201	.07	7.04
5, 6	Bald	20	70.603	.049	-1.148	.12	6.67
	Treaded	20	74.507	.013	- .803	.05	7.14
	Bald	40	61.469	.065	-1.297	.13	7.23
	Treaded	40	64.375	.030	- .970	.07	7.24
	Bald	60	57.859	.026	-1.529	.15	7.22
	Treaded	60	57.985	.030	-1.464	.18	6.23
7, 8	Bald	20	55.410	-.172	- .524	.08	7.50
	Treaded	20	57.401	-.147	- .212	.04	9.22
	Bald	40	47.237	-.160	- .493	.10	6.23
	Treaded	40	48.907	-.124	- .248	.04	7.30
	Bald	60	45.537	-.180	- .554	.15	5.75
	Treaded	60	47.322	-.872	- .489	.07	4.81
9, 10	Bald	20	49.379	.146	- .075	.10	6.44
	Treaded	20	54.500	.201	.116	.13	7.25
	Bald	40	47.701	.007	- .740	.06	7.150
	Treaded	40	54.308	.084	- .488	.07	6.85
	Bald	60	31.547	.091	- .468	.14	4.63
	Treaded	60	40.307	.157	- .340	.18	55.55
11, 12	Bald	20	52.722	.172	.126	.09	7.57
	Treaded	20	51.451	.220	- .043	.16	7.67
	Bald	40	45.577	.085	- .149	.03	8.12
	Treaded	40	53.023	.084	- .069	.03	7.49
	Bald	60	40.324	.027	- .019	.002	8.52
	Treaded	60	44.819	.099	- .215	.05	7.66
13, 14	Bald	20	46.451	.208	- .116	.28	5.23
	Treaded	20	50.496	.161	.038	.19	5.00
	Bald	40	45.988	.099	- .224	.11	5.09
	Treaded	40	47.462	.111	.106	.10	4.67
	Bald	60	35.788	.101	- .183	.09	5.37
	Treaded	60	40.848	.101	- .135	.10	5.23
15, 16	Bald	20	67.107	-.044	- .769	.05	7.90
	Treaded	20	78.669	-.173	-1.133	.16	7.72
	Bald	40	58.727	-.065	- .509	.04	7.21
	Treaded	40	62.654	-.094	- .611	.07	6.75
	Bald	60					
	Treaded	60					

NOTE: Degrees Centigrade = 5/9 (°F-32)
1 inch = 25.4 mm
1 mph = 1.609 kph

inconsistencies in the VHTRC trailer data to frequent equipment problems which may have made much of the data suspect, particularly those collected from November 1, 1977 to March 1, 1978.

ANALYSES OF TEXTURE DATA

As indicated earlier under Purpose and Scope, texture measurements were made at sites 3, 4, 7, 8, 15 and 16 at approximately monthly intervals throughout the research testing phase. The grease patch method of test was employed, and tests with both the VHTRC car and trailer were made during one of the regularly scheduled skid testing days. Results of these tests along with the skid test results and selected weather variables are shown in Table 18. The weather variables included are those considered to be most important based on previously discussed regression results for the skid testing devices.

Regression analyses were performed to determine the relationship of texture and the weather variables mentioned above. The results of these analyses, shown in Table 19, indicate the same basic relationship with the weather variables as exists between skid number measurements and the weather variables; i.e., coefficients associated with temperature are negative while coefficients associated with rainfall data are positive. It is also true, as indicated by the r^2 values, that the relationship is significantly better for some sites than for others, an outcome that is hard to explain unless it is indicative of the lack of sensitivity of the type of texture test used at certain types of sites or inappropriate weather variables for those sites having the low r^2 values.

At sites 3, 7 and 8, where the relationship between texture and the weather variables is high (high r^2 values — Table 19), one would expect the regression results having skid numbers as the dependent variable would not improve a great deal if texture were included as an independent variable. At sites 4, 15 and 16 the inclusion of texture as an independent variable may be of benefit. These thoughts are borne out in Table 20, which shows r^2 values for regression analyses including the three weather variables discussed above plus texture values, analyses including only the weather variables, and analyses including only texture.

SUMMARY AND RECOMMENDATIONS

As reported by various other researchers, skid resistance values as measured with a locked wheel trailer vary significantly with time. In Virginia it is felt the best estimate of the magnitude of the variability is reflected in results discussed in this report for the VDHT trailer and VHTRC stopping distance car. For the VDHT trailer the computed standard deviation for SN over time is about 3.0 and that for the car about 3.25.

For both these testing devices, it was found that several independent variables influenced the change in SN over time, with rainfall for month prior to the testing and maximum air temperature the week preceding testing probably being the most important ones. However, even when several independent variables

2170

Table 18

TEXTURE MEASUREMENTS

SITE	DATE	VHTRC TRAILER TREADED TIRE SN	VHTRC TRAILER BALD TIRE SN	VHTRC CAR SN	MAX. AIR TEMP. WEEK BEFORE TESTS, °F	RAIN DAY OF TESTS, INCHES	RAIN MONTH BEFORE TESTS, INCHES	TEXTURE
3	8-10-77	62	42	62	60	0	2.88	.17
	9-14-77	59	39	59	93	0	1.10	.16
	10-24-77	58	47	61.3	65	0	1.41	.19
	5-23-78	77	62	61.3	83	0	6.00	.20
	6-19-78	72	50	60.3	89	0	3.73	.16
	7-07-78	61	41	57.0	82	0	1.53	.16
	8-21-78	86	40	61.0	86	0	7.27	.17
	9-28-78	-	-	58.0	82	0	1.42	.18
	10-16-78	-	-	58.7	91	0.15	2.76	.17
	11-09-78	-	-	63.3	58	0.02	8.70	.21
4	8-10-77	69	53	61.3	86	0	7.27	.31
	9-14-77	62	53	61.7	89	0	3.73	.24
	5-23-78	78	65	64	83	0	6.00	.32
	6-19-78	73	60	61.3	93	0	1.10	.23
	7-07-78	68	57	59.7	82	0	1.53	.24
	8-21-78	86	40	61.0	86	0	7.27	.17
	9-28-78	-	-	60.3	82	0	1.42	.26
	10-16-78	-	-	61.3	60	0	2.88	.24
	11-09-78	-	-	64.3	65	0	1.41	.30
7	8-08-77	48	39	52.5	94	0	1.12	.34
	9-12-77	49	40	48.5	73	0	4.83	.33
	10-25-77	45	40	48.0	66	0	4.64	.49
	12-13-77	-	-	50.0	40	0	2.52	.50
	4-27-78	55	51	52.0	47	0.69	2.17	.39
	6-06-78	52	48	48.0	81	0	3.84	.36
	7-17-78	50	38	46.5	82	0.11	2.99	.35
	8-15-78	52	42	46.0	84	0	5.05	.38
	9-19-78	-	-	42.5	90	0.05	0.64	.34
	10-03-78	-	-	42.0	71	0	1.56	.35
	11-28-78	-	-	47.0	57	0.08	1.90	.45
8	9-12-77	36	35	37.0	73	0	4.83	.63
	10-25-77	33	31	32.5	66	0	4.64	.71
	12-13-77	-	-	37.5	40	0	2.52	.74
	4-27-78	47	46	43.5	47	0.69	2.17	.70
	6-06-78	38	37	36.5	81	0	3.84	.73
	7-17-78	36	33	33.0	82	0.11	2.99	.56
	8-15-78	51	43	43.0	84	0	5.05	.51
	9-19-78	-	-	30.5	90	0.05	0.64	.51
	10-03-78	-	-	29.0	71	0	1.56	.51
	11-28-78	-	-	37.0	57	0.08	1.90	.71
15	8-23-77	56	53	54.5	83	0.60	4.39	.61
	9-12-77	56	54	55.0	73	0	4.83	.58
	10-25-77	53	50	53.0	66	0	3.01	.65
	12-13-77	-	-	59.0	40	0	2.52	.71
	4-27-78	72	67	58.5	47	0.69	2.17	.81
	5-18-78	69	67	62	74	0	5.38	.79
	7-06-78	59	58	63.5	79	0	2.10	.81
	8-15-78	60	60	53.0	84	0	5.05	.50
	9-19-78	-	-	51.0	90	0.05	.64	.56
	10-03-78	-	-	50.5	71	0	1.56	.74
	11-14-78	-	-	53.0	60	0	0.54	.62
16	8-23-77	60	50	56.0	83	0.60	4.39	.66
	9-12-77	57	55	55.5	73	0	4.83	.58
	10-25-77	55	56	53.5	66	0	3.01	.64
	12-13-77	-	-	55.5	40	0	2.52	.78
	4-27-78	74	69	63.5	47	0.69	2.17	.86
	5-18-78	73	72	61	74	0	5.38	.84
	7-6-78	61	62	55	79	0	2.10	.82
	8-15-78	62	61	54	84	0	5.05	.63
	9-19-78	-	-	52	90	0.05	.64	.62
	10-03-78	-	-	50.5	71	0	1.56	.56
	11-14-78	-	-	54	60	0	0.54	.54

NOTE: Degrees Centigrade = 5/9 (°F − 32)

1 inch = 25.4 mm

Table 19

REGRESSION ANALYSES
OF TEXTURE DATA

SITE	r^2	REGRESSION COEFFICIENT			
		INTERCEPT	MAX. AIR TEMP., °F	DAILY RAINFALL, INCHES	4 WEEK RAINFALL, INCHES
3	.55	.219	-.00068	.034	.0029
4	.05	.330	-.0010	—	.0018
7	.66	.621	-.0032	-.120	.0025
8	.97	.377	-.082	100.363	1.171
15	.19	.840	-.0018	.056	-.014
16	.26	.807	-.0027	.119	.018

NOTE: Degrees Centigrade = 5/9 (°F - 32)
1 inch = 25.4 mm

Table 20

REGRESSION RESULTS WITH AND WITHOUT TEXTURE MEASUREMENTS

SITE	r^2 WEATHER & TEXTURE VARIABLES			r^2 WEATHER VARIABLES ONLY			r^2 TEXTURE ONLY		
	CAR	TREADED TIRE	BALD TIRE	CAR	TREADED TIRE	BALD TIRE	CAR	TREADED TIRE	BALD TIRE
3	.74	.99	.65	.74	.98	.15	.41	.04	.55
4	.42	.43	.88	.15	.23	.25	.35	.11	.51
7	.24	.87	.52	.21	.84	.52	.06	.15	.004
8	.60	.95	.997	.59	.93	.90	.11	.17	.02
15	.82	.62	.76	.72	.27	.72	.41	.39	.31
16	.80	.95	.92	.61	.36	.30	.59	.67	.66

are considered there are still unexplained variances in SN of 40% to 60% or more. In general, results obtained with the VHTRC trailer were considered to be suspect by the authors and were not extensively analyzed. The analyses performed confirmed this suspicion.

Because of the remaining large unexplained variances in SN and because of a smaller total variation in SN than reported by several sources, it is felt the best approach in Virginia is to utilize method 2 as modified to predict average SN values; i.e., use

$$PMSN_{40} = [SN_{40} - C] \pm 2\sigma, \text{ where}$$

σ = the within month site standard deviation, or about 2.4 SN; and

C = correction factor from Table 7.

The grease patch method of measuring texture used in this study indicated that the same basic relationship exists between texture and weather variables as exists between skid number measurements and weather variables. However, the relationship is somewhat inconsistent from site to site. While the authors feel texture measurements can provide some insight into skid number changes with time they do not believe that enough is understood regarding this relationship to allow accurate skid number predictions from texture measurements as obtained by current methods. The authors further feel that obtaining texture measurements is so time consuming and expensive that their use would not be practical in routine skid measurement surveys.

Based on the above, it is therefore recommended that Virginia include in its computer computations of survey skid data the appropriate adjustment resulting from the equation $PMSN_{40} = [SN_{40} - C] \pm 2\sigma$ to the measured average skid number for a sight to reflect the predicted average skid number that would be obtained in July and August for that site.

APPENDIX A

Detailed Data for VHTRC Skid Test Car

Table A-1

SITES 3 AND 4, S-5 MIX

SITE 3

DATE	SN_{20}	SN_{40}	SN_{60}	AIR TEMP., °F	PAVEMENT TEMP., °F	WATER TEMP., °F	TREAD DEPTH INCHES	MAX. AIR TEMP. DAY OF TEST, °F	MAX. AIR TEMP. WEEK OF TEST, °F	RAIN DAY OF TEST, INCHES	RAIN WEEK BEFORE TEST, INCHES	RAIN MONTH BEFORE TEST, INCHES
8-10-77	66	62	48	85	92	82	0.38	91	91	0.15	0.27	2.76
8-24-77	63	60	48	85	100	75	0.38	84	84	0	0.74	6.15
9-14-77	68	56	47	78	92	77	0.34	82	77	0	0.59	1.53
9-28-77	64	58	48	77	92	75	0.34	74	80	0	0.09	1.42
11-09-77	69	68	53	58	64	56	0.34	62	64	0.02	5.48	8.70
12-12-77	68	65	54	36	47	37	0.31	30	38	0	0.50	4.39
4-06 78	66	65	57	73	76	52	0.28	74	75	0	0	4.25
5-05-78	71	67	58	68	68	64	0.28	51	64	0	1.61	4.93
5-19-78	68	64	52	76	98	85	0.28	78	68	0.01	3.10	9.07
6-01-78	67	57	54	70	101	78	0.28	85	83	0.03	0.33	6.32
6-19-78	65	60	52	86	122	77	0.28	93	82	0	0.40	1.10
7-07-78	67	62	54	80	110	74	0.28	81	79	0	0.88	3.73
8-21-78	68	61	54	74	102	65	0.25	84	88	0	0.02	7.24
9-07-78	66	61	53	82	108	73	0.25	86	82	0	1.25	4.86
9-18-78	61	60	53	86	108	75	0.25	87	79	0	0.19	3.28
10-16-78	68	63	55	42	61	49	0.25	60	70	0	0.02	2.88
10-30-78	67	64	53	52	75	54	0.25	65	69	0	0	1.39
11-29-78	64	63	55	38	60	58	0.25	56	52	0	0.79	2.43

SITE 4

DATE	SN_{20}	SN_{40}	SN_{60}	AIR TEMP., °F	PAVEMENT TEMP., °F	WATER TEMP., °F	TREAD DEPTH INCHES	MAX. AIR TEMP. DAY OF TEST, °F	MAX. AIR TEMP. WEEK OF TEST, °F	RAIN DAY OF TEST, INCHES	RAIN WEEK BEFORE TEST, INCHES	RAIN MONTH BEFORE TEST, INCHES
8-10-77	69	66	50	90	114	83	0.38	91	91	0.15	0.27	2.76
8-24-77	66	62	53	85	100	75	0.38	84	84	0	0.74	6.15
9-28-77	68	60	51	77	92	75	0.34	74	80	0	0.09	1.42
11-09-77	71	64	58	58	64	56	0.31	62	64	0.01	5.48	8.70
12-12-77	67	66	57	36	44	37	0.28	30	38	0	0.50	4.39
4-06-78	65	61	56	73	76	52	0.28	74	75	0	0	4.25
5-05-78	68	63	57	68	68	67	0.28	51	64	0	1.61	4.93
5-19-78	70	64	58	76	98	85	0.28	78	68	0.01	3.10	9.07
6-01-78	67	61	55	80	101	71	0.28	85	83	0.03	0.33	6.32
6-19-78	67	63	54	86	122	77	0.28	93	82	0	0.40	1.10
7-07-78	72	60	53	85	111	74	0.28	81	79	0	0.88	3.73
8-21-78	67	61	56	75	103	67	0.25	84	88	0	0.02	7.24
9-07-78	67	62	53	82	108	73	0.25	86	82	0	1.25	4.86
9-18-78	67	59	55	86	112	75	0.25	87	79	0	0.19	3.28
10-16-78	67	62	55	42	61	49	0.25	60	70	0	0.02	2.88
10-30-78	68	59	55	55	75	56	0.25	65	69	0	0	1.39
11-29-78	69	63	57	40	65	58	0.25	56	52	0	0.79	2.43
12-14-78	65	60	55	40	52	56	0.25	49	54	0	1.27	5.04

NOTE: Degrees Centigrade = 5/9 (°F - 32)

Table A-2

SITE 7, SPRINKLE MIX

DATE	SN_{20}	SN_{40}	AIR TEMP., °F	PAVEMENT TEMP., °F	WATER TEMP., °F	TREAD DEPTH, INCHES	MAX. AIR TEMP. DAY OF TEST, °F	MAX. AIR TEMP. WEEK OF TEST, °F	RAIN DAY OF TEST, INCHES	RAIN WEEK BEFORE TEST, INCHES	RAIN MONTH BEFORE TEST, INCHES
8-08-77	54	51	81	106	76	0.38	94T	91T	0	1.06	1.12
8-22-77	50	49	78	83	68	0.38	85T	82T	0.10	0.78	2.15
9-06-77	55	46	92	106	68	0.38	87	88	0.04	3.35	5.85
9-12-77	51	46	71	85	61	0.34	73	78	0	0.15	4.83
9-27-77	52	47	58	78	64	0.34	77	77	0	0.27	4.17
10-11-77	49	46	58	88	64	0.31	67T	66T	0	1.06	2.71
10-25-77	51	45	62	69	59	0.31	66T	66T	0	0	4.64
11-16-77	55	51	61	70	60	0.31	63	53	0	0.20	6.46
12-13-77	52	48	62	66	59	0.31	40	36	0	0	2.52
4-27-78	54	50	60	90	60	0.28	47	58	0.69	1.74	2.17
5-18-78	53	50	76	117	69	0.28	70	66	0	1.50	5.03
6-01-78	49	47	78	111	75	0.28	82	80	0	0.45	3.78
6-20-78	46	45	85	121	68	0.28	90	81	0.45	0.45	1.63
7-06-78	47	44	86	130	70	0.28	79	82	0	0.53	2.10
7-17-78	49	44	82	125	69	0.28	82	80	0.11	0.93	2.99
8-15-78	47	45	84	112	70	0.25	84	86	0	1.02	5.05
9-06-78	46	42	84	128	68	0.25	82	82	0	0.02	1.62
9-19-78	43	42	88	128	75	0.25	90	81	0.05	0.09	0.64
10-03-78	43	41	75	105	68	0.25	71	70	0	0	1.56
10-18-78	44	40	60	96	67	0.25	51	65	0	0.50	1.95
10-31-78	43	42	50	80	56	0.25	60	66	0	0	0.74
11-14-78	41	41	52	69	60	0.25	55	61	0	0.04	0.10
11-28-78	48	45	50	70	60	0.25	57	50	0.08	0.98	1.90

NOTE: Degrees Centigrade = 5/9 (°F - 32)

1 inch = 25.4 mm

Table A-3

SITE 8, LIMESTONE SURFACE TREATMENT

DATE	SN_{20}	SN_{40}	AIR TEMP., °F	PAVEMENT TEMP., °F	WATER TEMP., °F	TREAD DEPTH, INCHES	MAX. AIR TEMP. DAY OF TEST, °F	MAX. AIR TEMP. WEEK OF TEST, °F	RAIN DAY OF TEST, INCHES	RAIN WEEK BEFORE TEST, INCHES	RAIN MONTH BEFORE TEST, INCHES
8-08-77	41	38	92	125	81	0.38	94T	91T	0	1.06	1.12
8-22-77	35	33	87	108	80	0.38	85T	82T	0.10	0.78	2.15
9-06-77	40	33	84	99	84	0.38	87	88	0.04	3.35	5.85
9-12-77	39	35	71	98	67	0.34	73	78	0	0.15	4.83
9-27-77	40	31	74	86	72	0.34	77	77	0	0.27	4.17
10-11-77	37	34	57	89	64	0.31	67T	66T	0	1.06	2.71
10-25-77	34	31	62	71	60	0.31	66T	66T	0	0	2.74
11-16-77	41	38	62	74	61	0.31	63	53	0	0.20	6.46
12-13-77	40	35	58	71	48	0.31	40	36	0	0	2.52
4-27-78	47	40	54	70	58	0.28	47	58	0.69	1.74	2.17
5-18-78	43	36	76	107	67	0.28	70	66	0	1.50	5.03
6-01-78	35	31	74	98	72	0.28	82	80	0	0.45	3.78
6-20-78	35	31	81	104	65	0.28	90	81	0.45	0.45	1.63
7-06-78	33	29	82	125	70	0.28	79	82	0	0.53	2.10
7-17-78	34	32	72	108	72	0.28	71	80	0.11	0.93	2.99
8-15-78	46	40	84	112	70	0.25	84	86	0	1.02	5.05
9-06-78	34	31	76	110	68	0.25	82	82	0	0.02	1.62
9-19-78	32	29	86	112	70	0.25	90	81	0.05	0.09	0.64
10-03-78	29	29	73	92	65	0.25	71	70	0	0	1.56
10-18-78	32	29	51	63	55	0.25	51	65	0	0.50	1.95
10-31-78	28	28	50	80	56	0.25	60	66	0	0	0.74
11-14-78	38	29	52	69	60	0.25	55	61	0	0.04	0.10
11-28-78	40	34	45	65	58	0.25	57	50	0.08	0.98	1.90

NOTE: Degrees Centigrade = 5/9 (°F - 32)

1 inch = 25.4 mm

Table A-4

SITES 15 AND 16, POPCORN MIX

DATE	SN_{20}	SN_{40}	AIR TEMP., °F	PAVEMENT TEMP., °F	WATER TEMP., °F	TREAD DEPTH, INCHES	MAX. AIR TEMP. DAY OF TEST, °F	MAX. AIR TEMP. WEEK OF TEST, °F	RAIN DAY OF TEST, INCHES	RAIN WEEK BEFORE TEST, INCHES	RAIN MONTH BEFORE TEST, INCHES
SITE 15											
8-23-77	56	53	79	89	64	0.38	83T	81T	0.60	1.11	4.39
9-07-77	60	51	73	82	71	0.38	87	88	0.04	3.35	4.32
9-13-77	58	48	67	76	67	0.34	74	76	0	0.11	5.55
9-28-77	55	50	72	84	70	0.34	74	75	0	0.27	4.17
10-11-77	58	53	47	73	67	0.31	67T	66T	0.18	1.69	5.23
10-25-77	57	49	55	58	53	0.31	66T	66T	0	0	2.74
11-16-77	60	59	57	59	56	0.31	61	54	0	0.20	6.83
12-13-77	63	55	44	45	42	0.31	40	36	0	0	2.52
4-27-78	65	62	52	51	58	0.28	47	48	0.69	1.74	2.17
5-18-78	64	59	68	83	57	0.28	70	66	0	1.50	5.03
5-30-78	58	57	80	94	72	0.28	82	80	0	0.06	1.83
6-20-78	60	55	75	98	65	0.28	90	81	0.45	0.45	1.63
7-05-78	61	56	71	80	70	0.28	79	82	0.04	0.53	2.10
8-15-78	53	53	81	108	72	0.25	84	86	0	1.02	5.05
9-06-78	56	51	74	82	65	0.25	82	82	0	0.02	1.62
9-19-78	53	49	83	100	68	0.25	90	81	0.05	0.09	0.64
10-03-78	53	48	64	85	65	0.25	71	71	0	0	1.56
11-14-78	55	50	52	59	60	0.25	55	61	0	0.04	0.10
SITE 16											
8-23-77	56	56	79	89	64	0.38	83T	81T	0.60	1.11	4.39
9-07-77	58	52	73	82	71	0.38	87	88	0.04	3.35	4.32
9-13-77	58	53	67	86	67	0.34	74	76	0	0.11	5.55
9-28-77	58	50	72	84	70	0.34	74	76	0	0.27	4.17
10-11-77	59	52	47	73	67	0.31	67T	66T	0.18	1.69	5.23
10-25-77	56	51	55	58	64	0.31	66T	66T	0	0	2.74
11-16-77	60	54	59	59	55	0.31	61	54	0	0.20	6.83
12-13-77	57	54	44	45	42	0.31	40	36	0	0	2.52
4-27-78	68	59	52	51	58	0.28	47	58	0.69	1.74	2.17
5-18-78	64	58	68	83	57	0.28	70	66	0	1.50	5.03
5-30-78	58	56	80	94	72	0.28	82	80	0	0.06	1.83
6-20-78	61	55	75	98	65	0.28	90	81	0.45	0.45	1.63
7-05-78	59	55	71	80	70	0.28	79	82	0.04	0.53	2.10
8-15-78	56	52	81	108	68	0.25	84	86	0	1.02	5.05
9-06-78	53	49	74	82	70	0.25	82	82	0	0.02	1.62
9-19-78	54	50	88	110	68	0.25	90	81	0.05	0.09	0.64
10-03-78	52	49	64	85	65	0.25	71	71	0	0	1.56
11-14-78	56	51	52	69	60	0.25	55	61	0	0.04	0.10

NOTE: Degrees Centigrade = 5/9 (°F - 32)

1 inch = 25.4 mm

APPENDIX B

MULTIPLE REGRESSION AND CORRELATION RESULTS
VHTRC STOPPING DISTANCE CAR - ALL VARIABLES

SITE	SPEED (kph)	INTERCEPT	AIR TEMP. TIME OF TESTS, °F	MAX. AIR TEMP. DAY OF TESTS, °F	AVG. MAX AIR TEMP. WEEK BEFORE TESTS, °F	PAVEMENT TEMP. TIME OF TESTS, °F	WATER TEMP. TIME OF TESTS, °F	TIRE TREAD DEPTH, INCHES	RAIN DAY OF TESTS, INCHES	RAIN 1-WEEK BEFORE TESTS, INCHES	RAIN MONTH BEFORE TESTS, INCHES	r^2	E_s
3	32	67.362	-.016	-.267	.226	.041	.030	-12.292	12.919	.813	.037	.50	2.38
	64	81.399	.167	-.112	-.001	-.036	-.165	-34.389	39.166	1.303	.007	.85	1.84
	97	75.649	.129	-.105	.026	-.040	-.085	-62.272	17.238	.096	.260	.83	1.87
4	32	65.843	.074	-.185	-.009	.165	.012	.020	8.330	1.310	-.219	.61	1.71
	64	63.256	-.047	-.078	-.085	.137	-.084	19.770	31.077	.337	.227	.68	1.74
	97	65.087	.051	.083	-.127	-.054	-.024	-20.788	- 4.121	.131	.379	.81	1.42
7	32	23.362	-.129	.022	-.175	.111	.112	79.280	5.659	.220	1.238	.91	1.67
	64	20.385	-.147	.116	-.221	.063	.267	57.395	7.818	-2.990	.788	.88	1.91
8	32	32.968	.061	-.063	-.167	.045	.079	6.826	9.020	1.457	1.194	.53	4.40
	64	27.988	-.028	-.017	-.129	.115	-.039	18.821	7.756	.625	.998	.55	3.17
15	32	69.341	.181	.214	-.278	-.195	.015	-17.561	1.666	2.044	.256	.61	3.38
	64	63.432	.358	.197	-.453	-.199	.184	-56.906	5.855	1.777	.903	.68	3.39
16	32	62.594	.209	-.082	-.183	-.086	.194	-32.144	7.870	1.837	.690	.59	3.55
	64	58.406	.181	-.066	.046	-.052	-.060	-13.189	8.71	.827	.400	.55	2.89

NOTE: Degrees Centigrade = 5/9 ($^{o}F - 32$)
1 inch = 25.4 mm
1 kph = 0.6214

2181

APPENDIX C

VHTRC TRAILER σ VALUES

SITE	TIRE	SPEED, MPH	$\bar{x}$	n	σ
1	Bald	20	44.36	170	7.28
	Bald	40	28.17	385	5.68
	Bald	60	19.02	169	5.35
	Treaded	20	60.37	170	8.41
	Treaded	40	48.19	488	7.20
	Treaded	60	36.92	169	6.11
2	Bald	20	59.89	170	7.07
	Bald	40	41.59	384	5.13
	Bald	60	30.20	170	4.86
	Treaded	20	74.60	175	8.06
	Treaded	40	65.00	489	6.61
	Treaded	60	53.64	170	5.84
3	Bald	20	54.05	175	6.99
	Bald	40	37.57	400	6.74
	Bald	60	29.27	180	5.84
	Treaded	20	67.74	175	7.73
	Treaded	40	56.35	490	6.74
	Treaded	60	47.41	175	6.54
4	Bald	20	65.08	175	8.45
	Bald	40	51.24	390	7.07
	Bald	60	40.85	175	6.19
	Treaded	20	72.46	175	8.17
	Treaded	40	63.25	495	6.80
	Treaded	60	54.83	175	6.95
5	Bald	20	71.39	115	7.15
	Bald	40	63.89	115	7.44
	Bald	60	58.22	112	8.24
	Treaded	20	74.17	115	7.01
	Treaded	40	64.47	115	7.23
	Treaded	60	58.03	115	7.36
6	Bald	20	73.86	115	7.29
	Bald	40	65.98	115	8.01
	Bald	60	57.98	115	7.63
	Treaded	20	74.98	115	7.65
	Treaded	40	67.57	115	7.35
	Treaded	60	59.08	115	6.43
7	Bald	20	46.12	130	6.94
	Bald	40	38.07	130	6.16
	Bald	60	31.47	130	6.48
	Treaded	20	52.59	130	6.53
	Treaded	40	44.88	130	5.57
	Treaded	60	40.73	130	5.43

NOTE: 1 mph = 1.609 kph

SITE	TIRE	SPEED, MPH	$\bar{x}$	n	σ
8	Bald	20	37.87	130	6.89
	Bald	40	31.38	125	6.11
	Treaded	20	39.89	130	7.84
	Treaded	40	33.92	130	5.35
9	Bald	20	55.99	135	5.67
	Bald	40	41.16	145	4.81
	Bald	60	34.10	140	4.33
	Treaded	20	66.56	133	6.96
	Treaded	40	54.88	140	6.07
	Treaded	60	47.34	140	5.23
10	Bald	20	63.57	135	6.15
	Bald	40	49.52	140	7.68
	Bald	60	38.51	140	6.03
	Treaded	20	72.82	135	7.28
	Treaded	40	62.15	140	6.35
	Treaded	60	52.96	140	6.24
11	Bald	20	60.78	130	6.98
	Bald	40	45.75	144	7.17
	Bald	60	36.76	145	6.09
	Treaded	20	63.82	130	5.74
	Treaded	40	53.72	145	5.86
	Treaded	60	46.09	145	5.01
12	Bald	20	71.26	130	6.37
	Bald	40	57.76	145	7.50
	Bald	60	48.97	145	7.09
	Treaded	20	72.74	130	8.14
	Treaded	40	64.90	145	5.38
	Treaded	60	57.68	145	5.84
13	Bald	20	61.95	130	6.21
	Bald	40	51.61	145	5.13
	Bald	60	39.36	145	4.85
	Treaded	20	63.18	125	5.65
	Treaded	40	55.59	140	5.47
	Treaded	60	46.01	140	5.75
14	Bald	20	62.18	130	6.75
	Bald	40	54.52	145	6.91
	Bald	60	46.80	145	5.47
	Treaded	20	62.56	125	5.94
	Treaded	40	56.84	140	5.40
	Treaded	60	50.42	139	5.45

NOTE: 1 mph = 1.609 kph

SITE	TIRE	SPEED, MPH	$\bar{x}$	n	σ
15	Bald	20	61.11	115	8.30
	Bald	40	50.52	114	7.12
	Treaded	20	63.55	115	8.14
	Treaded	40	53.27	115	6.84
16	Bald	20	64.05	115	8.32
	Bald	40	55.54	114	7.24
	Treaded	20	64.64	115	8.97
	Treaded	40	56.19	115	7.38

NOTE: 1 mph = 1.609 kph

2186