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Characterization of PM-10 Emissions From Antiskid Materials Applied To Ice- And Snow-Covered Roadways

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Joint Emissions Inventory Oversight Group

Prepared for Office of Air Quality Planning and Standards

Engineering Research Laboratory

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CHARACTERIZATION OF PM-10 EMISSIONS FROM ANTISKID MATERIALS APPLIED TO ICE- AND SNOW-COVERED ROADWAYS

FINAL REPORT

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ABSTRACT

Several areas of the country in violation of the National Ambient Air Quality Standard for PM-10 have conducted studies which identifi the resuspension of antiskid material applied to paved roadways as an importan source. The application of antiskid materials creates a temporary but substantial increase in the amount of fine particulate on the road surface over and above that which is normally present. Measured emission data are lacking for all types of antiskid materials; therefore, an appropriate field program was undertaken whose objective was to establish a predictive model for PM-10 emissions. Source-oriented emissions sampling was conducted on a section of US 53 near Duluth, Minnesota, during March and April of 1992. The measured emission factors varied from 1 to 11 g/VKT for the three tests conducted. The data were not sufficient, however, to develop any specific correlation between the measured emission factors and source parameters. The only general observation made was that PM-10 emissions appear to increase with the amount of antiskid material applied. A comparison of measured emission factors with those predicted by AP-42 indicated that most of the measured factors are higher than those which would be predicted from silt-loading values alone. Due to the marginal test conditions during the storm events, no definitive assessment of this increase can be made until additional data are obtained.

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SECTION 1

INTRODUCTION

Several areas of the country that are in violation of the National Ambient Air Quality Standard for PM-10 (airborne particles less than or equal to 10 µmA in diameter) have conducted studies to determine the sources of these emissions. One source of PM-10 emissions identified in a number of these studies is the resuspension of antiskid material that is applied to paved roadways. Antiskid materials may consist of abrasives, such as sand, stone, cinders, or other materials, applied to the road surface to improve traction or "deicers," which serve to restore pavement traction by preventing the formation of ice films, weakening the ice/pavement bond, and/or by melting ice and snow.

The application of antiskid materials creates a temporary, but substantial, increase in the amount of fine particles on the road surface over and above that which is normally present. Prior research has established a direct relationship between the loading of silt-size fines (particles < 75 µm in physical diameter) and the PM-10 emission generated by vehicular traffic. The empirical relationship between silt loading and PM-10 emissions is reflected in the EPA-recommended PM-10 emission factors for paved urban roads. This relationship was developed from a data base encompassing the results of tests conducted at eight sites, ranging from a freeway to a rural town road.

According to EPA publication AP-42, the quantity of dust emissions from vehicle traffic on a paved roadway (per vehicle kilometer of travel) may be estimated using the following empirical expression (EPA, 1990):

$$e = 2.28 \left(\frac{sL}{0.5}\right)^{0.8} \qquad (1\text{-}1)$$

where:
- e = PM-10 emission factor (g/VKT)
- s = surface silt content (fraction of particles < 75 µm in physical diameter)
- L = total road surface dust loading (g/m^2)

The total loading (excluding litter) is measured by sweeping and vacuuming lateral strips of a known area from each active travel lane. Using a modified version

of ASTM C 136, the silt fraction is determined by measuring the proportion of loose dry road dust that passes a 200 mesh screen. Silt loading is the product of total loading and silt content.

Recently, in the absence of specific emission test results for antiskid materials, PM-10 emission factors from sanding and salting were estimated as a "gap filling" exercise (Grelinger *et al.*, 1988). The emission factor for sanding assumed that all of the PM-10 content of typical road sand would be suspended. In the case of salting, the emission factor was based on the assumption that (a) 5% of the salt takes the form of a dried film on the pavement, and (b) 10% of the film is liberated as PM-10 particles. Because of the uncertainties in these underlying assumptions, a low quality rating (E) was assigned to the estimated emission factors.

It is clear from Equation (1-1) that techniques for controlling PM-10 emissions resulting from antiskid materials should be aimed at minimizing silt loading on the traveled portion of the roadway (Figure 1-1). Specifically, reduced silt loading may be expected to result from snow/ice control programs that encompass improvements in three areas: the properties of antiskid materials applied, the application protocols and procedures, and the procedures for removal of the antiskid material from roadways.

In a recent EPA study (EPA-450/3-90-007), a literature search, engineering analysis, and laboratory-testing program were performed to provide air pollution control agencies with information on how to identify appropriate antiskid materials that are both durable and effective and produce lower PM-10 emissions (Kinsey, 1991). The primary objectives of this study were to provide guidance on methods to determine: (a) the physical properties and durability of antiskid material selected for use on ice- and snow-covered roadways, and (b) criteria for defining the elements of an effective PM-10 emission control strategy associated with use of antiskid materials. The material selection criteria and decision process developed in this study are provided in Table 1-1 and Figure 1-2, respectively.

Although the above program provided guidance for the selection of antiskid materials, no direct information was developed regarding the actual PM-10 emissions related to their use, the changes in surface silt loading resulting from such application, or the degree of control actually achieved by compliance with the material selection criteria developed in the study. Although measured emissions data are lacking for all types of antiskid material, deicing chemicals have received the least amount of attention. Therefore, an appropriate field program was needed to establish a suitable method for predicting the PM-10 emissions from the use of antiskid materials. This is the primary objective of the work reported here.

To adequately determine the fate and transport of antiskid materials, ideally, a mass balance sampling and analysis approach would be most appropriate. However, in the case of fugitive sources (e.g., snow- and ice-control materials), this is impossible since many of the "outputs" can be neither sampled nor quantified.

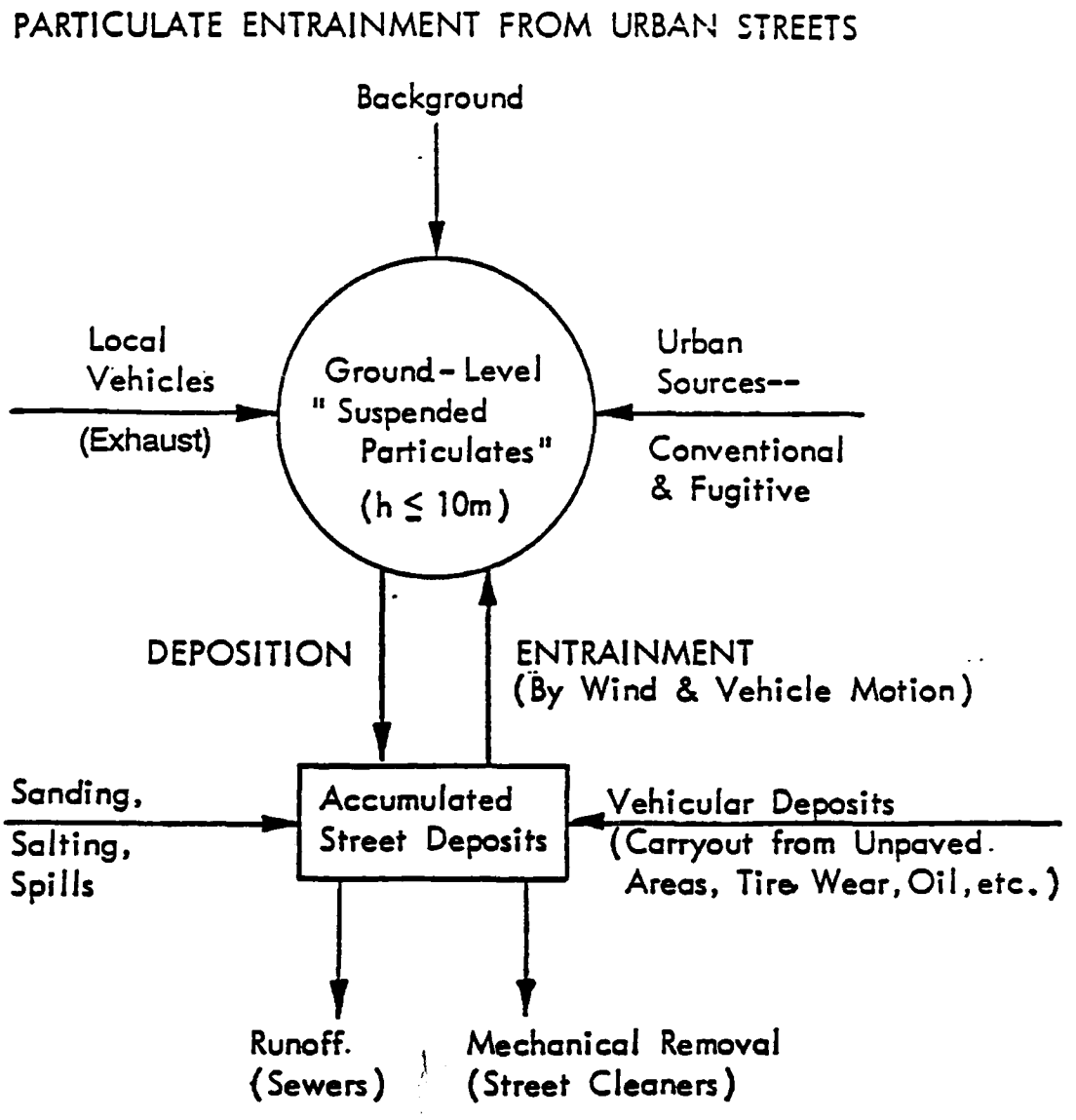

Figure 1-1. Diagram of street surface/atmospheric exchange of particulate matter.

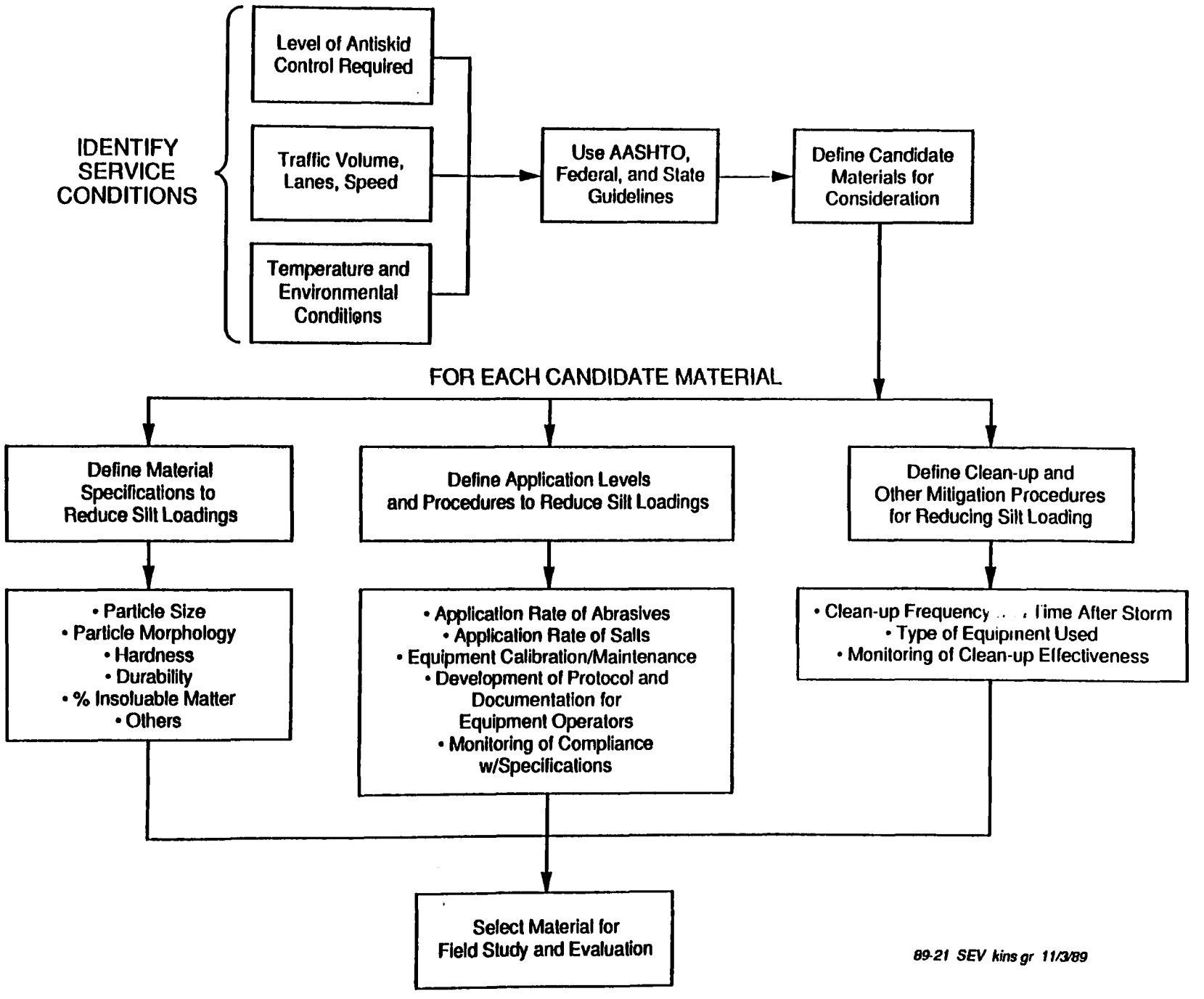

Figure 1-2. Decision "tree" for antiskid material selection.

Instead, source-oriented emissions sampling was employed in the program using MRI's "exposure profiling" approach. The data obtained by this technique were coupled with the results of road surface sampling and materials application data in an attempt to develop a method for predicting PM-10 emissions.

TABLE 1-1. MATERIAL SELECTION CRITERIA FOR ANTISKID ABRASIVES[a]

Measurement parameter	Units	Mean value for acceptable materials	Mean value for unacceptable materials
Modified Los Angeles abrasion loss	Weight %	3	11
Initial silt content[b]	Weight %	0.1	6
Vickers hardness	kg/mm^2	1,000	800
Particle shape index	Dimensionless	10	9

[a] If the properties of a particular material fall between the "acceptable" and "unacceptable" ranges, the material is considered "questionable" and good engineering judgment should be used.

[b] This parameter is coupled to LA abrasion loss and thus included in the material selection criteria.

Originally, the goal of the study was to develop a predictive emission model for the use of "straight" deicing salts. However, due to site-specific conditions, this was not possible. Instead an abrasive/salt mixture was tested in the field program. This was deemed to be representative since relatively few transportation agencies use straight salt because of runoff, vegetative damage, and other environmental concerns (Kinsey, 1991). However, appropriate chemical analyses of selected filter samples were performed in an attempt to isolate the contribution of deicing salt to the total PM-10 emissions from the test road.

The remainder of this report is structured as follows: Section 2 describes the site selection process; Section 3 describes the overall study design; Section 4 describes the results of the field sampling program; and Section 5 discusses quality assurance. Conclusions reached from the experimental data are included in Section 6, and the references cited in the report are listed in Section 7.

SECTION 2

SITE SELECTION

This section describes the site selection process used in the study. Screening methods are described first, followed by details related to the specific location selected.

2.1 SCREENING METHODS

Based on almost 20 years of testing fugitive emission sources, MRI has developed a number of site selection criteria for most generic source categories. These criteria are useful as screening tools for evaluating candidate test locations during the site survey. The following selection criteria apply to roadway source testing:

1. There should be at least 10 m of flat, open terrain downwind of the road.

2. There should be at least 30 m of flat, open terrain upwind of the road.

3. The height of the nearest downwind obstruction should be less than the distance from the road to the obstruction.

4. The height of the nearest upwind obstruction should be less than one-third the distance from the road to the obstruction.

5. A line drawn perpendicular to the road orientation should form an angle of 0° to 45° with the mean daytime prevailing wind direction during test periods of interest.

6. The mean daytime wind speed should be greater than 4 mph.

7. The test road should have an adequate number of vehicle passes per hour to enable completion of a test in less than 3 h in order that testing can be safely completed during daylight hours.

8. The traffic mix during a test should be representative of the type of vehicles that regularly use the road.

In the case of the current program, a number of factors other than those listed above were given special consideration during site selection. First, most previous MRI tests were performed during warm, dry weather to characterize worst-case emissions. However, the present study required testing in cold, wet conditions, which complicated both equipment placement and sample collection.

Second, previous antiskid material emission studies paid relatively little attention to the material(s) being applied to the road, the amount being applied, or the frequency of application (PEDCo, 1981; RTP Environmental Associates, 1990). Therefore, some means had to be provided for the collection of detailed data on source conditions during testing.

2.2 SITE SURVEY AND SELECTION

Based on the best available information, and the short time frame in which the study was to be conducted, it was decided that one of the 14 sites currently active in Strategic Highway Research Program (SHRP) Project H-208A should be used for emission testing. (SHRP is an independent federal agency that performs research in conjunction with various state transportation departments.) This decision was based on the fact that detailed information on winter maintenance practices and roadway conditions was already being collected at these locations as part of that study. Each site is also equipped with a permanently installed Roadway Weather Information System (RWIS) that monitors both ambient and pavement conditions on a continuous basis.

From the 14 candidate sites, the SHRP "control" section located on US 53, northwest of Duluth, Minnesota, was finally selected for testing. (Note that the SHRP "control" section refers to that portion of the roadway that receives standard winter maintenance practices and the "test" section is that portion of the road which receives treatment with only deicing chemicals.) This site was suitable for a number of reasons, including its orientation with respect to ambient winds, good cooperation by the state transportation agency (Minnesota Department of Transportation—MnDOT), and the typical snowfall and temperature expected in the month of March (see Figures 2-1 and 2-2).

The original test site was located on northbound US 53 at Mile Post (MP) 13.35 (or approximately Station No. 452+50). This particular location has good orientation with respect to the wind direction anticipated for periods after storm events, good exposure to ambient winds (i.e., lack of trees in the upwind direction), and a relatively flat median for installation of the air-sampling equipment. The approximate test area is shown on the topographic map included as Figure 2-3.

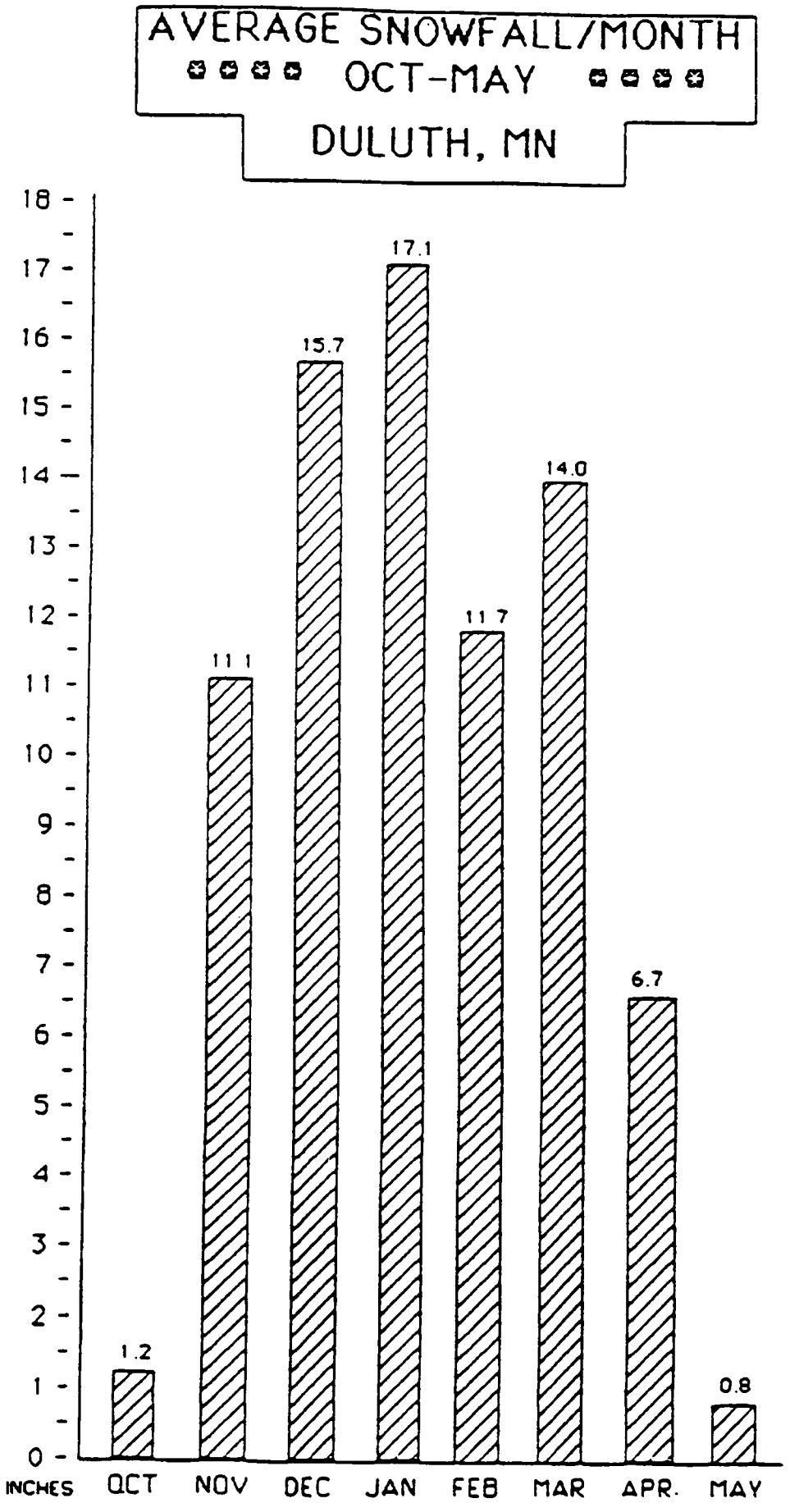

Figure 2-1. Historical average snowfall data for Duluth, Minnesota.

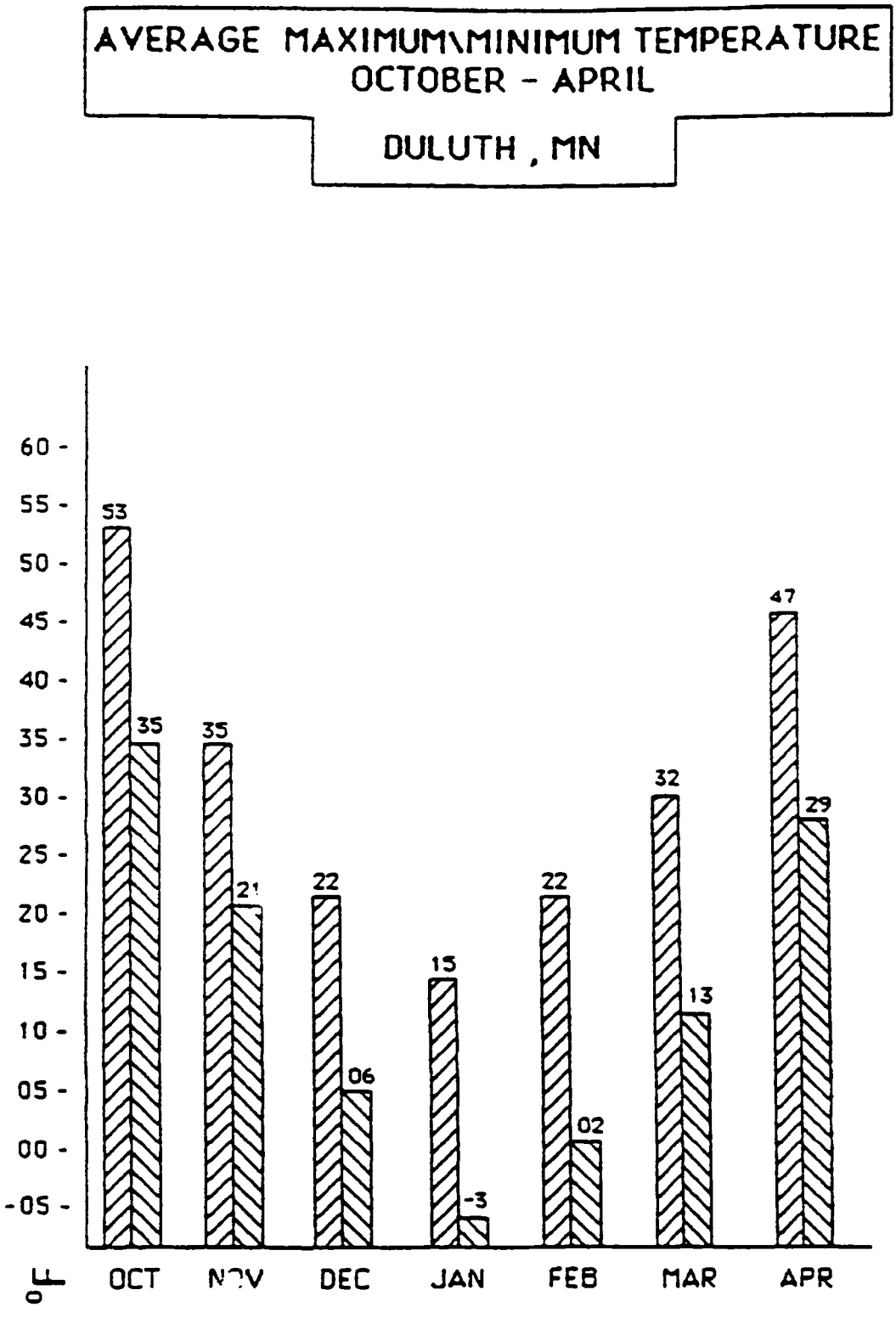

Figure 2-2. Historical maximum and minimum temperature data for Duluth, Minnesota.

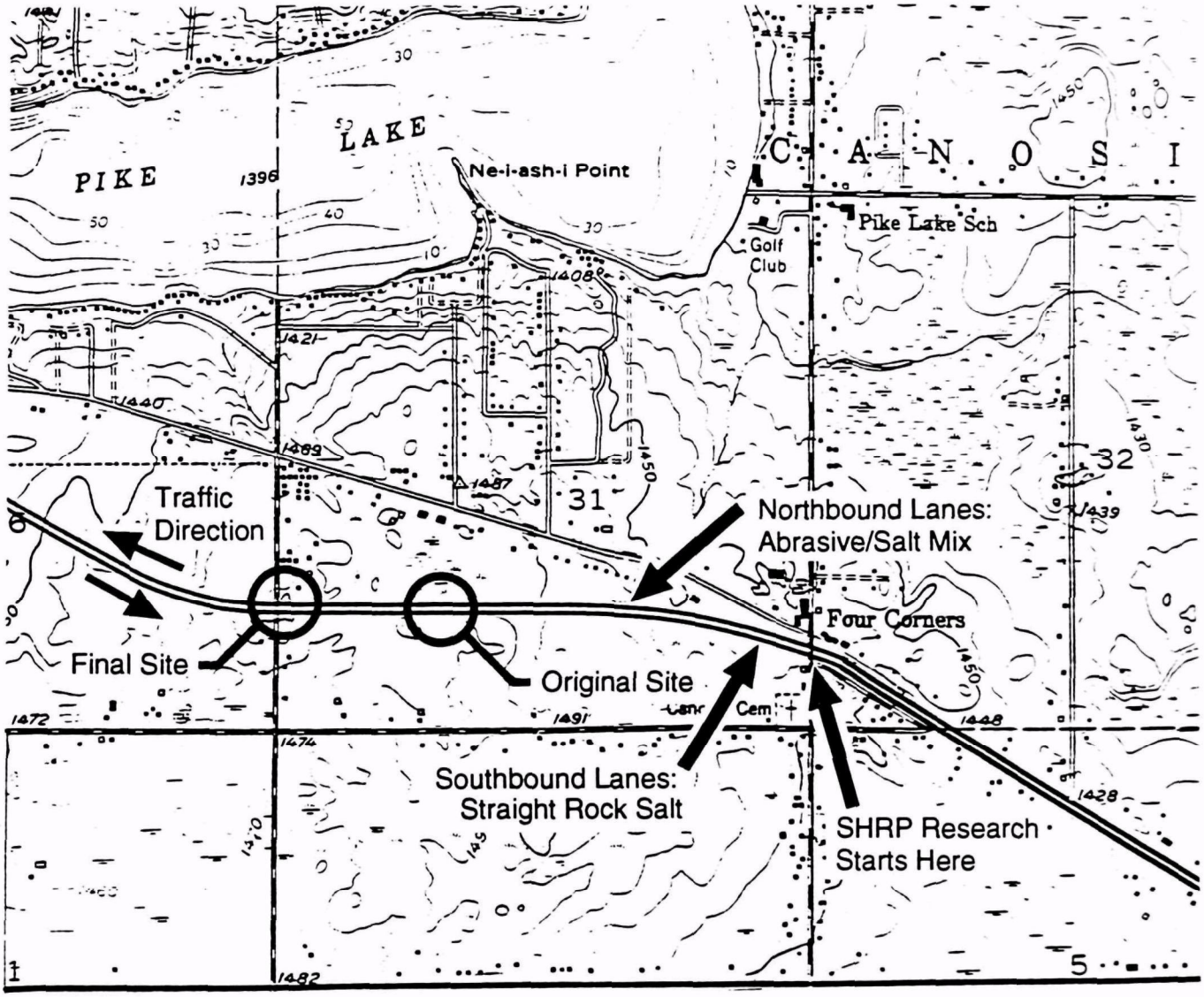

Figure 2-3. Approximate location of original and final test sites on US 53 near Duluth, Minnesota.

Several shortcomings were noted with respect to air sampling at the original location on US 53. First, the expected prevailing winds after storm events allowed sampling of only the northbound lanes which use an abrasive/rock salt mix. Thus, the PM-10 emissions from the application of straight deicing salts could not be directly measured. In addition, certain upwind influences from a nearby county road ("old" US 53 or Miller Trunk Highway) could not be avoided. This road is a low-volume route located some distance from the site which mitigates its contribution. Nevertheless, MRI was convinced that this location was the best site of those readily available.

However, due to the mild winter in Duluth, the original test site could not be used. The site was selected on the assumption that the ground would remain frozen throughout the sampling period, allowing equipment to be safely placed in the median. When the ground remained thawed, the sampling site was moved approximately ¼ mile (0.4 km) northbound (i.e., to the west) to an area near the intersection of US 53 with a county road (Figure 2-1). This area provided a firm surface for location of the sampling equipment but also had substantial stand of trees bordering the northern portion of the right-of-way which did not conform to selection criterion 2 and 4 listed above. For this and other related reasons, only one of the three test series conducted met all of the MRI QC criteria for wind speed and direction. This non-compliance with established criteria adversely affected data quality as discussed below.

SECTION 3

OVERALL STUDY DESIGN

The source-directed field sampling conducted in this study employed the "exposure profiling" approach to quantify source emission contributions. After two minor storm events, a series of exposure profiling tests were performed, beginning approximately at the point when the pavement became dry. This section describes the overall study design used during source testing, testing procedures, chemical analysis, ancillary sample collection, and emission factor calculations.

3.1 GENERAL AIR SAMPLING EQUIPMENT AND TECHNIQUES

The "exposure profiling" technique for particulate source testing is based on the isokinetic profiling concept used in conventional (stack) testing. The passage of airborne pollutant immediately downwind of the source is measured directly by means of simultaneous multipoint sampling over the effective cross section of the open dust source plume. This technique uses a mass flux measurement scheme similar to EPA Method 5 for stack testing rather than requiring indirect emission rate calculation through the application of a generalized atmospheric dispersion model. Further details of the exposure profiling method can be found in earlier technical reports such as the recent EPA collaborative study (Pyle and McCain, 1986).

For measurement of particulate emissions from roads, a vertical network of samplers (Table 3-1) was positioned just downwind and upwind from the edge of the road. The downwind distance of 5 m was far enough that sampling interferences due to traffic-generated turbulence was minimal, but close enough to the source that the vertical plume extent could be adequately characterized with a maximum sampling height of 5 to 7 m. In a similar manner, the 10-m distance upwind from the road's edge was far enough from the source that (a) source turbulence did not affect sampling; and (b) a brief reversal would not substantially impact the upwind samplers. The 10-m distance was, however, close enough to the road to provide the representative background concentration values needed to determine the net (i.e., due to the source) mass flux.

As shown in Figure 3-1, the planned equipment deployment scheme made use of four downwind vertical sampling arrays, D1 through D4. Downwind arrays D1, D3, and D4 (as well as upwind array U2) made use of high-volume (hi-vol) air samplers equipped with constant-flow electronic controllers and cyclone preseparators.

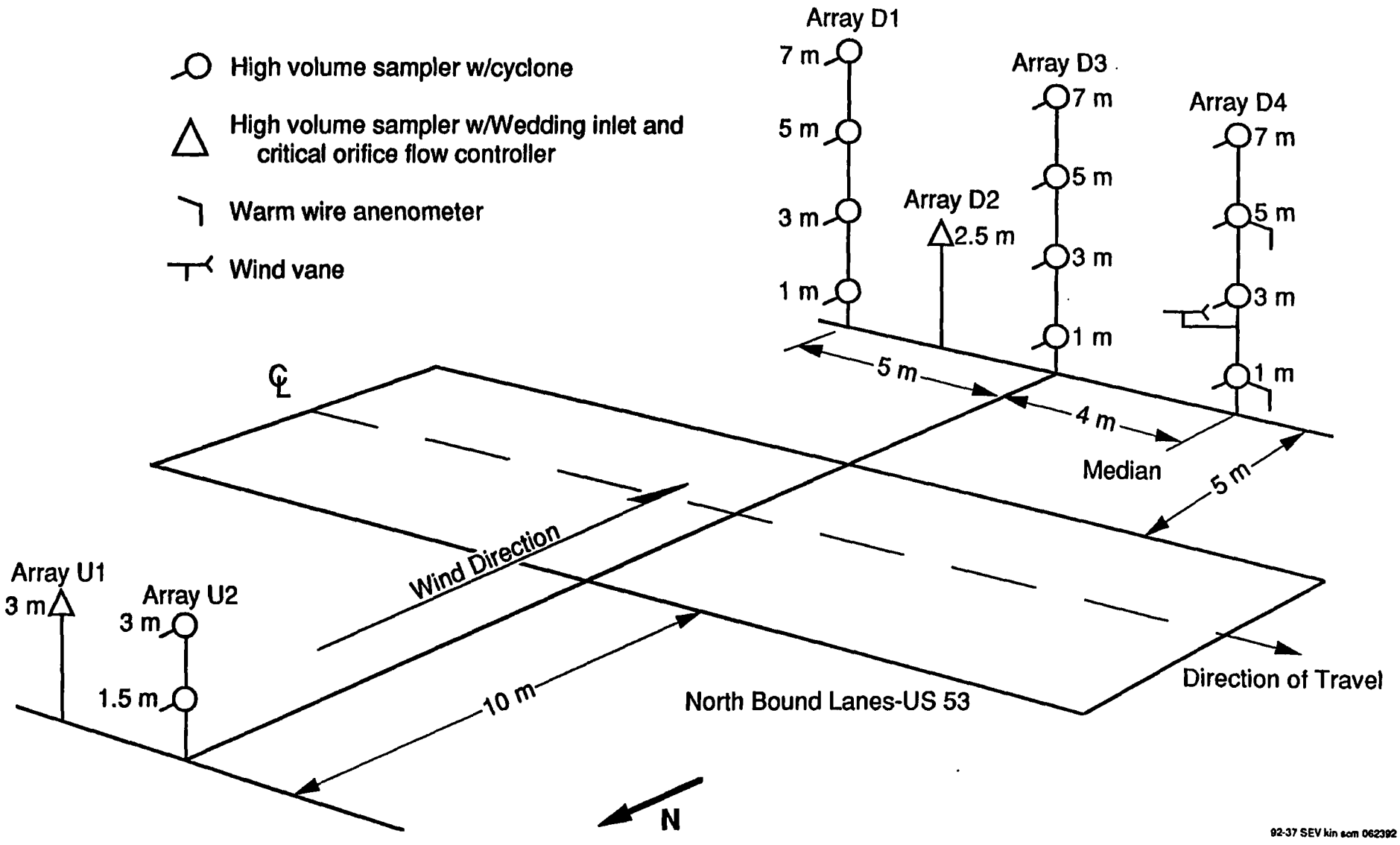

Figure 3-1. Sampler deployment scheme.

Arrays D2 and U1, used hi-vols equipped with Wedding PM-10 inlets and critical orifice flow controllers. Also installed at the site were concrete barricades, sand barrels, and related safety equipment required by MnDOT regulations.

TABLE 3-1. SAMPLER DEPLOYMENT[a]

Sampler array ID	No. of instruments	Measurement height(s) (m)	Type of sampler or instrument	Parameter(s) measured
U1	1	3	Hi-vol + Wedding inlet	PM-10, Pb
U2	2	1.5, 3	Hi-vol + Cyclone	PM-10
D1, D3, D4	4	1, 3, 5, 7	Hi-vol + Cyclone	PM-10, Na^+, Cl^- (Selected arrays only)
D4	2	1, 5	Warm wire anemometer	Wind velocity
D4	1	3	Wind vane	Wind direction
D2	1	2.5	Hi-vol + Wedding inlet	PM-10, Pb

[a] Certain downwind sampling equipment could not be used during testing due to persistent generator problems (see text).

For each profiling trailer (i.e., Array D1, D3, and D4), PM-10 samples were collected at four downwind measurement heights. Also, PM-10 (as well as Pb) concentrations were determined at a single height both upwind and downwind of the road using the EPA ambient reference method. The latter measurements were used for comparison against data collected by the cyclone samplers.

The primary air sampling device in this program was a standard high-volume air sampler fitted with a Sierra Model 230CP cyclone preseparator (Figure 3-2). The cyclone exhibits an effective 50% cutoff diameter (D_{50}) of approximately 10 microns (μm) in aerodynamic diameter when operated at a constant flow rate of 40 cfm (68 m^3/h).

Throughout each test, wind speed was monitored by warm-wire anemometers (Kurz Model 465) at two heights, and the vertical wind speed profile was determined assuming a logarithmic distribution. Horizontal wind direction was also monitored by a wind vane at a single height, with 10-min averages determined electronically prior to and during the test. The sampling intakes were adjusted for proper directional orientation based on the approximate average wind direction.

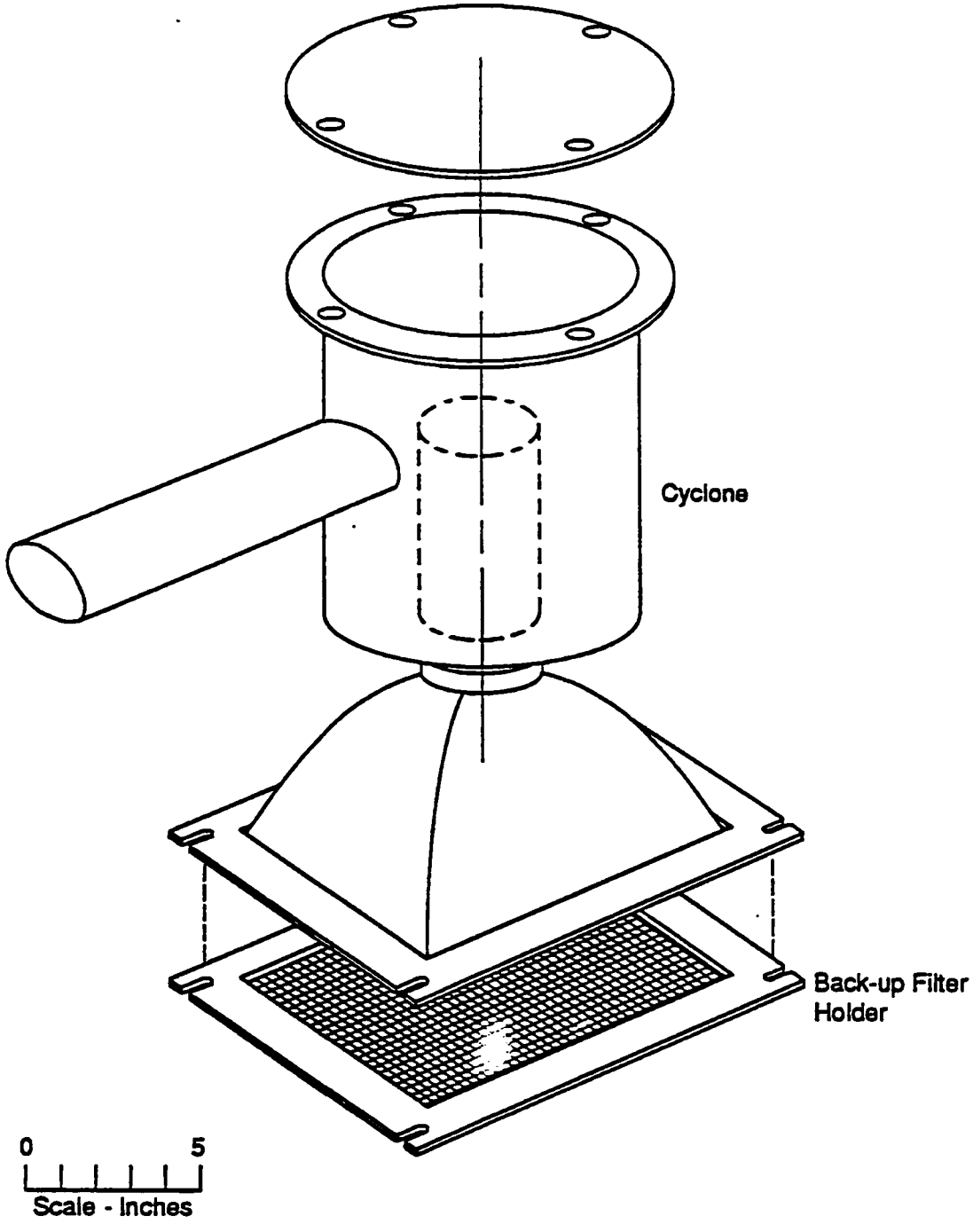

Figure 3-2. Diagram of high-volume cyclone sampler.

3.2 TESTING PROCEDURES

3.2.1 Preparation of Sample Collection Media

Particulate samples were collected on Type AH grade glass fiber filters. Prior to the initial weighing, the filters were equilibrated for 24 h at constant temperature and humidity in a special weighing room. During weighing, the balance was checked at frequent intervals with standard (Class S) weights to ensure accuracy. The filters remained in the same controlled environment for a second 24-h period, after which another second analyst reweighed them as a precision check. If a filter could not pass audit limits, the entire lot was reweighed. Ten percent of the filters taken to the field were used as blanks. The quality control guidelines pertaining to preparation of sample collection media are presented in Table 3-2.

As indicated in Table 3-2, a minimum of 5% laboratory blanks and 5% field blanks were collected for QC purposes (EPA, 1977). This procedure involved handling at least 1 filter in every 10 in an identical manner as the others to determine systematic weight changes. These changes were then used to mathematically correct the net weight gain determined from gravimetric analysis of the filter samples. In the case of laboratory blanks, this involved only those procedures followed in MRI's gravimetric analysis laboratory. For field blank collection, filters were actually loaded into samplers and then recovered without air actually being passed through the media.

3.2.2 Pretest Procedures/Evaluation of Sampling Conditions

Prior to actual sample collection, a number of decisions were made as to the potential for acceptable source-testing conditions. These decisions were based on forecast information obtained either from the local U.S. Weather Service office and/or from the Roadway Weather Information System (RWIS) located at the site. If conditions were considered acceptable, the sampling equipment was prepared for testing. Pretest preparations included calibration of the various air sampling instruments, insertion of filters, and so forth. The quality control guidelines governing this activity are found in Table 3-3.

Once the source testing equipment was set up and the filters inserted, air sampling was conducted. Information recorded on specially designed reporting forms included:

a. Air samples—Start/stop times, wind speed profiles, flow rates, and wind direction relative to the roadway perpendicular (10-min average). See Table 3-4 for QC procedures.

b. Traffic count by vehicle type and speed.

c. General meteorology—Wind speed, wind direction, and temperature.

TABLE 3-2. QUALITY CONTROL PROCEDURES FOR SAMPLING MEDIA

Activity	QC check/requirement
Preparation	Inspect and imprint glass fiber media with identification numbers.
Conditioning	Equilibrate media for 24 h in clean controlled room with a relative humidity of 45% (variation of less than ±5%) and with a temperature of 23°C (variation of less than ±1%).
Weighing	Weigh hi-vol filters to nearest 0.1 mg.
Auditing of weights	Independently verify final weights of 10% of filters (at least four from each batch). Reweigh batch if weights of any hi-vol filters deviate by more than ±2.0 mg. For tare weights, conduct a 100% audit. Reweigh tare weight of any filters that deviate by more than ±1.0 mg.
Correction for handling effects[a]	Weigh and handle at least one blank for each 10 filters of each type for each test.
Calibration of balance	Balance to be calibrated once per year by certified manufacturer's representative. Check prior to each use with laboratory Class S weights.

[a] Includes both laboratory blanks and field blanks (see text).

TABLE 3-3. QUALITY CONTROL PROCEDURES FOR SAMPLING FLOW RATES

Activity	QC check/requirement
• High volume air samplers	Calibrate flows in operating ranges using calibration orifice upon arrival and every 2 weeks thereafter.
• Orifice and electronic calibrator	Calibrate against displaced volume test meter annually.
• Warm wire anemometers	Calibrate annually in standard wind tunnel.

TABLE 3-4. QUALITY CONTROL PROCEDURES FOR SAMPLING EQUIPMENT

Activity	QC check/requirement[a]
Maintenance • All samplers	Check motors, gaskets, timers, and flow measuring devices prior to testing.
Operations • Timing	Start and stop all downwind samplers during time span not exceeding 1 min.
• Isokinetic sampling (cyclones)	Adjust sampling intake orientation whenever mean wind direction dictates.
	Change the cyclone intake nozzle whenever the mean wind speed approaching the sampler falls outside of the suggested bounds for that nozzle. This technique allocates no nozzle for wind speeds ranging from 0 to 10 mph, and unique nozzles for four wind speed ranges above 10 mph.
• Prevention of static mode deposition	Cap sampler inlets prior to and immediately after sampling.

[a] All means refer to 5- to 15-min averages.

MRI has developed criteria for suspending or terminating a source test. These criteria are presented in Table 3-5. In the case of the current program, however, a number of these criteria could not be followed in most of the tests conducted for a variety of reasons unique to this project. These are discussed briefly below.

TABLE 3-5. CRITERIA FOR SUSPENDING OR TERMINATING A TEST

A test may be suspended or terminated if:

1. Precipitation ensues during equipment setup or when sampling is in progress.

2. Mean[a] wind speed during sampling moves outside the 1.3- to 8.9-m/s (2- to 20-mph) acceptable range for more than 20% of the sampling time.

3. The angle between mean wind direction and the perpendicular to the path of the moving point source during sampling exceeds 45 degrees for two consecutive averaging periods.

4. Daylight is insufficient for safe equipment operation.

5. Source condition deviates from predetermined criteria (e.g., occurrence of wet pavement conditions.)

[a] "Mean" denotes a 5- to 15-min average.

First, due to the extremely mild winter in Duluth, testing opportunities were, at best, limited. For this reason, testing was often conducted under less than optimum wind conditions for the sake of practicality and economy. Each decision to conduct a sampling trip was discussed in advance with the EPA project officer to obtain his concurrence.

Second, to meet the objectives of the program, sampling had to take place as soon as possible after the road became dry to characterize the maximum emissions potential resulting from application of the antiskid material. Thus, if the wind speed and direction could be in any way accommodated by the sampling array, testing was performed. Also, testing under highly variable wind conditions, which would normally preclude sampling, was likewise conducted for the same reason.

Finally, the criteria listed in Table 3-5 were originally intended for source testing under hot, dry conditions, which would represent worst case. In the current study, however, frozen precipitation and wet road conditions were required preparatory to sample collection. Therefore, although the road surface was slightly damp outside of the wheel tracks, testing may have been initiated.

3.2.3 Sample Handling and Analysis

To prevent particulate losses, the exposed media were carefully transferred at the end of each run to protective containers for transportation. In the field laboratory, exposed filters were placed in individual glassine envelopes and then into numbered file folders. When exposed filters and the associated blanks were returned to the MRI laboratory, they were equilibrated under the same conditions as the initial weighing. After reweighing, 10% of the filters were audited to check weighing accuracy.

3.3 CHEMICAL ANALYSES

Selected filters were extracted and chemically analyzed by an outside laboratory to determine the concentration of chloride (Cl^-), sodium (Na^+), or lead (Pb) in the particulate sample collected (see Table 3-1). The analytical procedures, and associated QA/QC, used for this purpose are described below.

3.3.1 Chlorine Analysis

Selected filter samples were extracted following the 40 *CFR* 50, Appendix G, procedure and analyzed for Cl^- using EPA Method 300.0 as published in EPA-600/4-84-017, dated March 1984. These procedures involved the extraction of the sample using dilute nitric acid, followed by analysis using ion chromatography. Replicates, spikes, spiked duplicates, split samples, blanks, calibration checks, reagent checks, and detection limit checks were used to assure quality control during the analyses.

3.3.2 Sodium Analysis

Sodium content (Na^+) of the filter samples was extracted following the 40 *CFR* 50, Appendix G, procedure and determined using EPA Method 273.1 as published in EPA-600/4-84-017, dated March 1984. These techniques consisted of sample extraction using dilute nitric acid, followed by flame atomic absorption spectroscopic analysis. Replicates, spikes, spiked duplicates, split samples, blanks, calibration checks, reagent checks, and detection limit checks were used to assure quality control of the analyses.

3.3.3 Lead Analysis

Analysis of selected filters for lead (Pb) content were performed using the 40 CFR 50, Appendix G, procedure for extraction and EPA Method 239.1 as published in EPA-600/4-84-017, dated March 1984, for analysis. These techniques consisted of sample extraction using dilute nitric acid, followed by graphite furnace atomic absorption spectroscopic analysis. Replicates, spikes, spiked duplicates, split samples, blanks, calibration checks, reagent checks, and detection limit checks were used as part of the QA/QC for the analyses conducted.

3.4 ANCILLARY SAMPLE COLLECTION AND ANALYSIS

The types of ancillary samples and information to be collected fell into two broad categories:

- Antiskid materials and roadway surface samples.
- Source activity levels.

Each category is described in greater detail below.

3.4.1 Material Sample Collection and Analysis

In conjunction with the emissions tests, samples were taken of the antiskid material applied to the road and the dust remaining on the surface after it became dry. These samples were needed not only to evaluate the performance of existing emission models but also to develop improved models for antiskid materials.

3.4.1.1 Sampling and Analysis of Antiskid Materials--

To characterize the antiskid materials applied during the study, appropriate material samples were collected and analyzed for moisture and silt content. Grab samples were taken of both the stockpiled materials as well as the abrasive/rock salt (NaCl) mixture that was actually distributed by the spreader trucks. The standard MRI procedures used for the collection and analysis of antiskid material samples are provided in Appendix A.

To further characterize the antiskid material samples collected, a number of key physical and chemical properties were also determined. These properties are listed in Table 3-6, along with the appropriate ASTM measurement method. The properties shown in Table 3-6 were determined to be good general indicators of the overall silt production potential of antiskid materials as determined in the laboratory study described earlier (Kinsey, 1991).

TABLE 3-6. TEST METHODS FOR ANTISKID MATERIALS

Type of material	Material property	ASTM method	Method modified
Abrasives	LA abrasion loss	C131	Yes
	Initial silt content	C136	Yes
		C117	Yes
	Vickers hardness	E384	Yes
	Particle shape/texture	D3398	No
Deicers	Insoluble matter-NaCl	E534	No

As indicated in Table 3-6, most of the ASTM methods have been specially modified by MRI for the analysis of antiskid abrasives (Kinsey, 1991). Except for Vickers hardness, these modifications are generally minor changes to the basic methods to facilitate application to typical antiskid abrasives. Appendix B, Tables B-1 and B-2, provide the modifications made to the ASTM methods for LA abrasion loss and Vickers hardness, respectively. The modified method for the determination of silt content is also provided in Appendix A.

3.4.1.2 Road Surface Sampling and Analysis--

Although exposure profiling was only performed on the emissions from the northbound lanes on US 53, surface sampling was conducted on both the northbound and southbound sections of the highway. (Recall that an abrasive/salt mixture is used on the northbound lanes and straight salt is used on the southbound lanes—see Figure 2-3.) The specific procedures used to collect and analyze paved road surface samples to determine silt loading are described in Appendix A.

3.4.2 Source Activity Monitoring

Source extent and activity data were collected with a variety of tools. For example, in addition to visual observation and note taking, pneumatic traffic counters were used to determine source activity on US 53. A radar gun was also used to determine the average speed of vehicles passing the sampler array.

Vehicle-related parameters were obtained using a combination of manual and automated counting devices. Pneumatic tube axle counters were used to obtain traffic volume data. Because these counters only record the number of passing axles, it was also necessary to obtain manual traffic mix information (e.g., number of axles per vehicle) to convert axle counts to the number of vehicle passes. Vehicle mixes were observed visually. Comparison of the observed vehicle mix to the pneumatic counter totals also allowed the accuracy of the axle counter to be assessed.

Finally, as mentioned in Section 2.2, the site selected for testing in the current program was also used as part of SHRP Project H-208A. In conjunction with the SHRP program, detailed information was collected by MnDOT personnel on the condition of the weather and pavement during the course of the storm, the types and amounts of antiskid materials applied to the test road, and a general indication of the residual deicing chemical on the road surface at various points in time. Although MRI was not directly responsible for collecting these data, they were used to augment the information obtained on source activity. Also, additional surface sampling was conducted between storms to develop a silt-loading "history" during data analysis. Sample forms completed by MnDOT personnel in the SHRP program are included in Appendix C.

3.5 EMISSION FACTOR CALCULATION PROCEDURE

To calculate emission rates, a conservation of mass approach was used. The passage of airborne particulate (i.e., the quantity of emissions per unit of source activity) was obtained by spatial integration of distributed measurements of exposure (mass/area) over the effective cross section of the plume. Exposure is the point value of the flux (mass/area-time) of airborne particulate integrated over the time of measurement, or equivalently, the net particulate mass passing through a unit area normal to the mean wind direction during the test. The steps in the calculation procedure are described below.

3.5.1 Particulate and Compound-Specific Concentration/Exposures

The concentration of PM-10 measured by a sampler is given by:

$$C = 10^3 \frac{m}{Qt} \tag{3-1}$$

where:
- C = particulate concentration ($\mu g/m^3$)
- m = particulate sample weight (mg)
- Q = sampler flow rate (m^3/min)
- t = duration of sampling (min)

The concentration (C_i) of Na^+, Cl^-, or Pb measured by the sampler is given by:

$$C_i = \frac{m_i}{Qt} \tag{3-2}$$

where:
- C_i = concentration of component i determined by filter analysis ($\mu g/m^3$)
- m_i = mass of component i collected on the filter (μg)
- Q = sampler flow rate (m^3/min)
- t = duration of sampling (min)

To be consistent with the National Ambient Air Quality Standards, all concentrations and flow rates are expressed in standard conditions (25°C and 101 kPa or 77°F and 29.92 in Hg).

The isokinetic flow ratio (IFR) is the ratio of a directional (i.e., cyclone) sampler's intake air speed to the mean wind speed approaching the sampler. It is given by:

$$IFR = \frac{Q}{aU} \tag{3-3}$$

where: Q = sampler flow rate (m^3/min)
a = intake area of sampler (m^2)
U = mean wind speed at height of sampler (m/min)

The above ratio is of interest only in the sampling of total particulate, since isokinetic sampling ensures that particles of all sizes are sampled without bias. Note that because the primary interest in this program is directed to PM-10 emissions, sampling under moderately nonisokinetic conditions poses no difficulty. It is readily agreed that 10 µm (aerodynamic diameter) and smaller particles have weak inertial characteristics at normal wind speeds and, thus, are relatively unaffected by anisokinesis (Davies, 1968). Therefore, IFR was not calculated for the downwind samplers in the current program.

Exposure represents the net passage of mass through a unit area normal to the direction of plume transport (wind direction) and was calculated by:

$$E_{10} = 10^{-7} \times CUt \tag{3-4}$$

where: E_{10} = PM-10 exposure (mg/cm^2)
C = net concentration (µg/m^3)
U = approaching wind speed (m/s)
t = duration of sampling (s)

Compound-specific exposures (i.e., for Na^+, Cl^-, and Pb) can be found analogously.

Exposure values vary over the spatial extent of the plume. If exposure is integrated over the plume effective cross section, then the quantity obtained represents the total passage of airborne particulate matter (i.e., mass flux) due to the source.

For the test roadway, a one-dimensional integration scheme was used:

$$I = \int_0^H E_{10}\, dh \tag{3-5}$$

where: I = integrated PM-10 (or compound-specific) exposure (m-mg/cm^2)
E_{10} = PM-10 exposure (mg/cm^2)
h = vertical distance coordinate (m)
H = effective extent of plume above ground (m)

The effective height of the plume (H) in Eq. 3-5 is found by linear extrapolation of the uppermost net concentrations to a value of zero.

Because exposures are measured at discrete heights of the plume, a numerical integration is necessary to determine I. The exposure must equal zero at the vertical extremes of the profile (i.e., at the ground where the wind velocity equals zero and at the effective height of the plume where the net concentration equals zero). However, the maximum exposure usually occurs below a height of 1 m so that there is a sharp decay in exposure near the ground. To account for this sharp decay, the value of exposure at ground level is set equal to the value at a height of 1 m. The integration is then performed using Simpson's rule.

3.5.2 PM-10 Emission Methodology

The emission model for PM-10 generated by vehicular traffic on roadways treated with antiskid materials, expressed in grams of emissions per vehicle-kilometer traveled (VKT), is given by:

$$e = 10^4 \frac{I}{N} \tag{3-6}$$

where: e = PM-10 emissions (g/VKT)
I = integrated PM-10 exposure (m-mg/cm^2)
N = number of vehicle passes (dimensionless)

Similar results can also be generated for NaCl and Pb by substituting the appropriate integrated exposure into the above calculation scheme.

SECTION 4

FIELD SAMPLING PROGRAM

The preceding section described the study design as it was originally envisioned. However, a number of unanticipated events required that portions of the original plan be altered to accommodate project-specific conditions. This section discusses the program as it evolved in response to these events, as well as the results of the field sampling conducted in Duluth, Minnesota.

4.1 MODIFICATIONS TO STUDY DESIGN

Discussions with EPA regarding the current study began in late November of 1991 with field testing expected to begin in late January or early February of 1992. However, due to administrative delays, assignment, all required planning and equipment preparation was conducted during February with field testing starting in early March. A decision to test during this period, based on historical snowfall and temperature data obtained for the Duluth area (see Figures 2-1 and 2-2), was discussed and approved by the EPA Work Assignment Manager.

In keeping with the extremely mild winter nationwide, Duluth experienced less than 1 in of total precipitation during the month of March, which substantially eliminated source testing. (Note that only one aborted attempt was made during the entire month.) Therefore, in an attempt to "salvage" the experimental program, special measures were taken (with the full concurrence of the EPA Work Assignment Manager) to extend field testing into April. Each of these measures is described below.

First, rather than maintain a full-time sampling crew on-site (with its associated cost impact), personnel were dispatched from Kansas City on an as-needed basis. This was usually accomplished within 18 h of receiving a prediction of measurable precipitation either from the U.S. Weather Service, the Roadway Information System, or a contract forecasting service (i.e., Accu-Weather) provided to MnDOT. Such a procedure allowed the maximum possible opportunity for testing within the time available; however, it did not allow for recalibration of the sampling equipment prior to one test (Test AY-4). Based on MRI's previous experience, this noncompliance with normal QC procedures would not be expected, in itself, to substantially affect data quality.

The second special measure taken during the program involved the protocol used for application of antiskid materials to the road surface. Normally, antiskid material is only applied to US 53 when significant frozen precipitation occurs and road conditions become hazardous. In these conditions, multiple passes are usually made while applying a sand/salt mixture at typical rates of 400 to 500 lb/lane-mi (110 to 140 kg/lane-km). (Note that the application rates used by MnDOT are substantially lower than those set by many other transportation agencies, which can be as high as 2,000 lb/lane-mi or 560 kg/lane-km.)

However, due to the extraordinarily mild winter in Duluth and the low number of storm events, arrangements were made for antiskid material to be applied to the road surface **anytime** that precipitation occurred, **regardless of type or quantity**, even though conditions might not actually warrant the application of such material. Although this procedure resulted in only a very limited amount of material being applied to the road, it was at least marginally adequate for test purposes. The **frequency and amount** of material applied during testing **cannot, however, be considered typical** of common winter maintenance practices. Therefore, the results of this study might better be regarded as a conservative "best case" (rather than "representative") estimate of the PM-10 emissions resulting from the application of antiskid materials to the test road due to the relatively small amount of antiskid material applied (and thus available for resuspension) during testing.

Special measures were also taken during the field sampling program with respect to the acceptability of test conditions. Because of the relatively low amounts of antiskid material applied to the road (and its low traffic volume of < 5,000 vehicles/ day), testing had to be started as soon as possible after the road surface became dry in order to obtain measurable downwind concentrations. This necessitated the **collection of air samples during periods when wind conditions (i.e., speed and direction) were not normally considered appropriate for exposure profiling** (see Table 3-5). In this study, **testing was performed whenever the ambient winds were from any northerly direction**, as long as the other required test conditions could be met. This procedure adversely affected data quality as will be discussed later.

Finally, ongoing generator problems plagued the field sampling program, which resulted in either samplers not being operated and/or samples being lost. Repeated attempts by the equipment leasing company to rectify these problems proved to be unsuccessful. Special operational procedures were implemented, therefore, to collect the maximum amount of useful data within the limitations of available generator power.

During each test conducted, efforts were directed towards the operation of at least one downwind profiler array and the Weddi[illegible]M-10 sampler (Figure 3-1). In certain instances, two profilers may have been operated for some period of time but, generally, only one was able to operate for the entire test. The lack of generator

power adversely affected both sampling efficiency and completeness, which severely limited the amount of experimental data collected during the program.

4.2 SOURCE DESCRIPTION AND ACTIVITY

As stated in Section 2.2, the test site used in the experimental program was located on northbound US 53 on the outskirts of metropolitan Duluth, Minnesota. US 53 is an unlimited-access, four-lane, high-speed roadway carrying commuter traffic to and from Duluth at an approximate volume of 5,000 vehicles/day. Data collected during field sampling showed that the majority of the traffic were two-axle, light-duty vehicles traveling between 88 and 97 km/h (55 and 60 mph). Surface loadings determined both visually and by sampling were generally very low, with normal silt loadings in the range of 0.2 g/m^2.

Exposure profiling was performed after two minor storm events that occurred on April 10 and on April 21 and 22, 1992. One test series was conducted on April 11, with additional testing performed on April 23 and 26. A summary of the test conditions for each sampling period is provided in Table 4-1.

During the April 10 storm, approximately 4 to 6 in of wet snow fell on US 53 during a 24-h period. Four applications of an abrasive/salt mixture were made to the road over a period of approximately 10 h, totaling 395 kg/lane-km (1,400 lb/lane-mi). For the second storm, a combination of wet snow and freezing rain fell during approximately a 36-h period. In this case, only one application of 197 kg/lane-km (700 lb/lane-mi) was made to each lane especially for test purposes (see Section 4.1).

As noted above, the application rates used by MnDOT are far below those of most other transportation agencies as determined in previous research conducted by MRI (Kinsey, 1991). Also, much of the material applied was either cast off by the snow plow during clearing operations or eliminated by melted precipitation. What material that did remain on the surface was quickly lost to the atmosphere by the action of passing vehicles. Thus, surface loadings were generally low with higher loadings observed in the passing (left) lane as compared to the driving (right) lane.

4.3 EXPOSURE PROFILING RESULTS

A summary of the three exposure profiling tests conducted on US 53 was provided previously in Table 4-1. The test results are discussed in detail below with the particulate sampling data described first, followed by the results of the chemical analyses and ancillary sampling/analysis.

4.3.1 PM-10 Sampling Results

The results of the gravimetric analyses performed on the filter samples collected in the field are summarized in Table 4-2. Note that the data provided in this

TABLE 4-1. SOURCE TEST SUMMARY

Test ID	Date of test	Sampler array[a]	Operating period		Mean wind speed (m/s)[b]		Mean wind direction (degrees)	Total vehicle passes during test period	Total antiskid material applied to roadway (kg/lane-km)	Time since last antiskid application (h)	Approx. number of vehicle passes since last application[c]
			Start time (h)	Stop time (h)	1.0-m height	5.0-m height					
AY-3	4/11/92	U1	1435	1909	—	—	—	1,419	395[d]	20.6	5,200
		U2	1435	1909	—	—	—	1,419	395[d]	20.6	5,200
		D1	1519[e] 1612	1524 1904	3.8	6.1	294	1,175	395[d]	21.3	5,400
		D2	1527	1612	[f]	[f]	[f]	—	395[d]	21.5	[illegible]
		D4	1503	1804	3.9	6.6	293	983	395[d]	21.1	5,[illegible]
AY-4	4/23/92	U1	0841	1438	—	—	—	1,200[g]	197[h]	22.9	4,800
		U2	0841	1438	—	—	—	1,200[g]	197[h]	22.9	4,800
		D1	0914	101[illegible]	0.58	1.2	38	220[g]	197[h]	23.5	4,900
		D2	0857[e] 1035	1017 1103	0.56	1.2	50	380[g]	197[h]	23.2	4,900
		D4	0924	1410	0.54	1.2	46	962	197[h]	23.7	5,000
AY-5	4/26/92	U1	0829	1417	—	—	—	1,030[g]	197[h]	94.7	16,800
		U2	0829	1417	—	—	—	1,030[g]	197[h]	94.7	16,800
		D2	0936	1316	1.4	1.9	336	650	197[h]	95.9	17,000
		D4	0936	1316	1.4	1.9	336	650	197[h]	95.9	17[illegible]

[a] Array D-3 used for field blanks due to generator failure (see text).

[b] Average of 10-min integration periods over duration of test.

[c] Based on vehicle counts obtained during testing.

[d] Two passes of 113 kg/lane-km (400 lb/lane-mi) of a 90%:10% abrasive/rock salt mixture plus two passes of 85 kg/lane-km (300 lb/lane-mi) of a 80%:20% percent abrasive/rock salt mixture.

[e] Sampler stopped and restarted due to generator failure.

[f] Sampling aborted due to generator failure.

[g] Vehicle counts estimated from available data.

[h] One pass of 197 kg/lane-km (700 lb/lane-mi) of a 90%:10% abrasive/rock salt mixture.

TABLE 4-2. RESULTS OF GRAVIMETRIC ANALYSES[a]

Test ID No.	Array ID No.	Sampling height (m)	Filter ID No.	Filter tare weight (mg)	Filter final weight (mg)	Weight difference (mg)
AY-3 (4/11/92)	D1	1	9221024	4,303.75	4,309.50	5.75
		3	9221025	4,308.05	4,313.30	5.25
		7	9221027	4,313.75	4,319.05	5.30
	D3 (Blanks)	1	9221009	4,253.15	4,252.30	−0.85
		3	9221010	4,227.05	4,226.30	−0.75
		5	9221011	4,237.20	4,237.80	0.60
	D4	1	9221020	4,214.60	4,231.90	17.30
		3	9221021	4,238.45	4,246.90	8.45
		5	9221022	4,237.80	4,240.40	2.60
		7	9221023	4,353.20	4,354.50	1.30
	U1	3	9221013	4,197.75	4,199.80	2.05
	U2	1.5	9221028	4,275.75	4,276.90	1.15
		3	9221029	4,318.80	4,322.45	3.65
AY-4 (4/23/92)	D1	1	9221031	4,296.35	4,303.30	6.95
		3	9221032	4,300.45	4,305.05	4.60
		5	9221033	4,338.00	4,341.15	3.15
		7	9221034	4,293.00	4,295.85	2.85
	D2	2.5	9221046	4,281.55	4,293.00	11.45
	D3 (Blanks)	1	9221042	4,298.40	4,298.75	0.35
		3	9221043	4,290.90	4,295.30	4.40
	D4	1	9221038	4,314.00	4,357.25	43.25
		3	9221039	4,311.85	4,313.80	1.95
		5	9221040	4,333.30	4,336.45	3.15
		7	9221041	4,308.00	4,313.05	5.05
	U1	3	9221035	4,287.15	4,298.40	11.25
	U2	1.5	9221037	4,353.00	4,363.45	10.45
		3	9221036	4,339.70	4,346.15	6.45
AY-5 (4/26/92)	D2	2.5	9221051	4,330.20	4,333.40	3.20
	D3 (Blanks)	1	9221059	4,265.30	4,266.10	0.80
		3	9221060	4,284.10	4,285.70	1.60
		5	9221061	4,339.85	4,331.15	−8.70
	D4	1	9221052	4,291.35	4,296.20	4.85
		3	9221053	4,311.80	4,315.65	3.85
		5	9221054	4,332.80	4,335.95	3.15
		7	9221055	4,336.20	4,339.70	3.50
	U1	3	9221057	4,334.65	4,337.80	3.15
	U2	1.5	9221058	4,314.75	4,318.00	3.25
		3	9221056	4,270.10	4,273.90	3.80

[a] Includes only valid samples.

table include only those samples that were considered valid and subsequently used to develop PM-10 emission estimates.

Using the raw data provided in Table 4-2, the measured (i.e., blank-corrected) PM-10 concentration was determined for the various sampling locations using the calculation scheme outlined in Section 3.5. In these calculations, the net sample weight for each filter was first determined by subtracting the average filter blank value (from Array D3) from the gross weight difference (Table 4-2). The resulting values were then entered into Eq. 3-1, along with the applicable sampler flow rates and operating times to obtain the measured PM-10 concentration at each location. The results of these calculations are provided in Table 4-3, along with any comments relevant to the experimental data.

Using the data shown in Table 4-3, net (i.e., upwind-corrected) PM-10 concentrations were calculated at each height by subtracting estimates from a straight line fit of the measured upwind concentrations. (Note that net concentrations were calculated only for arrays with adequate information for integration purposes.) Using these net concentrations, the net PM-10 exposure was calculated for each measurement location using Eq. 3-4. Exposure integration was then performed by the two-step process described in Section 3.4.1 with the effective plume height (H) defined as that height (possibly extrapolated) at which the net PM-10 concentration was zero. Finally, PM-10 emission factors were calculated from the data using Eq. 3-6. The results of this analysis are shown in Table 4-4 with a sample calculation for Test AY-5 provided in Appendix D.

Several factors should be noted with regard to the experimental results shown above. First, the field blank values used to correct for handling were generally higher than normally would be expected for this type of sampling and were neither consistently positive or negative. The influence of emissions from the diesel-powered generator, as well as site logistics, might explain some of the high blank values, and steps should be taken to mitigate these influences in any future testing.

Second, the net filter catches measured during the program were generally very low, thus enhancing systematic sampling errors. Net sample weights of approximately 1 to 10 mg for most filters (Table 4-2) are only slightly above blank correction values, which complicates data analysis and interpretation.

Another factor of interest involves the exposure profiles themselves. As shown by Table 4-4, some of the profiles (e.g., Test AY-4) are essentially flat (i.e., little difference in exposure with height) over the first 7 m of plume height. Flat exposures are generally indicative of a highly undefined plume (and associated mass flux) and poor test conditions during sample collection. The QC criteria developed for exposure profiling (Table 3-5) are based on those conditions that MRI has found to be necessary for a well-defined plume and associated exposure profile.

TABLE 4-3. SUMMARY OF EXPERIMENTAL RESULTS[a]

Test ID	Test date	Array ID No.[b]	Sampling height (m)	Net filter weights (mg)		Sampler flow rate (std m³/min)[d]	Sampling time (min)	Measured PM-10 concentration (μg/m³)	Comments/problems
				Gross catch	Blank-corrected[c]				
AY-3	4/11/92	U1	3	2.05	2.38	1.31	274	6.63	Array D1 did not run the entire test period due to generator trip. Array D2 could not be operated due to inadequate generator capacity.
		U2	1.5	1.15	1.48	1.19	274	4.54	
			3	3.65	3.90	1.19	274	12.0	
		D1	1	5.75	6.08	1.19	177	28.9	
			3	5.25	5.58	1.19	177	26.5	
			5	Void	Void	1.19	177	—	
			7	5.30	5.63	1.19	177	26.7	
		D4	1	17.30	17.63	1.19	181	81.8	
			3	8.45	8.78	1.19	181	40.8	
			5	2.60	2.93	1.19	181	13.6	
			7	1.30	1.63	1.19	181	7.57	
AY-4	4/23/92	U1	3	11.25	8.87	1.28	357	19.4	Arrays D1 and D2 did not operate entire period due to generator trip. 3-m and 5-m samplers on Array D4 failed to operate due to generator problems. Run time for these units estimated from available information.
		U2	1.5	10.45	8.07	1.03	357	21.9	
			3	6.45	4.07	1.35	357	8.44	
		D1	1	6.95	4.57	1.26	63	57.6	
			3	4.60	2.22	1.26	63	28.0	
			5	3.15	0.77	1.28	63	9.55	
			7	2.85	0.47	1.52	63	4.91	
		D2	2.5	11.45	9.07	1.33	108	63.1	
		D4	1	43.25	40.87	1.53	286	93.4	
			3	1.95	Nil	1.10	103[e]	Nil	
			5	3.15	0.77	1.38	103[e]	5.42	
			7	5.05	2.67	1.16	286	8.05	
AY-5	4/26/92	U1	3	3.15	5.25	1.27	348	11.9	Continuing generator problems prevented the use of Arrays D1 and D3.
		U2	1.5	3.25	5.35	1.16	348	13.3	
			3	3.80	5.90	1.16	348	14.6	
		D2	2.5	3.20	5.30	1.30	220	18.5	
		D4	1	4.85	6.95	0.948	220	33.3	
			3	3.85	5.95	1.21	220	22.4	
			5	3.15	5.25	1.14	220	20.9	
			7	3.50	5.60	1.19	220	21.4	

[a] Results of all calculations to three significant figures.

[b] Array D3 could not be operated due to reoccurring generator problems which were not solved despite repeated attempts to do so.

[c] Corrected by average of field blank values from Array D3.

[d] All airflows based on posttest flow rate audits except for Test AY-3 which used the calibration values. Test AY-4 did not meet "every two week" QC check for flow rate recalibration.

[e] Run time estimated.

TABLE 4-4. RESULTS OF EMISSION FACTOR CALCULATIONS[a]

Run No.	Array No.	Sampler height (m)	Net PM-10 concentration (µg/std m³)[b]	Wind speed (m/s)	Net PM-10 exposure (µg/cm²)	Integrated exposure (m-µg/cm²)[c]	No. of vehicle passes	PM-10 emission factor (g/VKT)
AY-3	D-1	1	26.9	3.8	109	459	1,175	3.91
		3	14.5	(5.4)	83.2			
		5	–	6.1	(41.6)			
		7	0	(6.7)	0			
	D-4	1	79.8	3.9	338	1,038	983	10.6
		3	28.8	(5.7)	178			
		5	0	6.6	0			
		7	0	(7.3)	0			
AY-4	D-1	1	31.2	0.58	6.84	31.8	220	1.44
		3	19.6	(1.0)	7.41			
		5	1.11	1.2	0.50			
		7	0	(1.4)	0			
AY-5	D-4	1	20.4	1.4	37.7	149	650	2.29
		3	7.8	(1.7)	17.5			
		5	4.5	1.9	11.3			
		7	3.3	(2.1)	9.14			

[a] Parentheses denote inter/extrapolated values.

[b] Net concentration calculated as difference between measured downwind and upwind concentrations. Upwind data inter/extrapolated for different heights.

[c] Integration scheme assumes constant value of exposure from 0 to 1 m height, with Simpson's rule used for integration between 1 m and effective plume height (H). Maximum effective plume height (H) assumed ≤ 9 m.

Finally, certain inconsistencies were noted with the individual emission factors shown in Table 4-4. During the first storm tested (Test AY-3), the emissions appear to decrease with time after application (i.e., the emission factor for Array D4 is higher than that for Array D1). The opposite trend was observed, however, during the second storm (Tests AY-4 and AY-5), which showed emissions increasing with time after application (i.e., the emission factor for Test AY-5 is higher than for Test AY-4). Therefore, no constant relationship was found between the emission factors developed in the study and the time after application of the antiskid material.

Taking all of the above factors into consideration, it might be expected that the emission factors shown in Table 4-4 are probably within the same order of magnitude as the "true" PM-10 emissions from the test road. The interpretation of these results is discussed further in Section 4.5.

4.3.2 Results of Chemical Analyses

As mentioned in Section 3.3, selected filters (including blank filters) were submitted for chemical analysis for either lead (Pb) or sodium (Na^+) and chloride (Cl^-) content. The concentration of particulate lead was determined both upwind and downwind of the road during Tests AY-4 and AY-5 using samples collected by the two Wedding PM-10 instruments. Similar analyses could not be performed for Test AY-3 due to an downwind sample that was invalidated by generator problems.

In the case of sodium and chloride, filter sets from one downwind profiler array for each of the three tests were submitted for chemical analysis. The purpose of these analyses was to determine the relative contribution of rock salt to the total PM-10 emissions from the roadway. The results of the chemical analyses performed are summarized in Table 4-5.

As shown by the data in Table 4-5, the analyte mass found on most of the filters did not exceed the blank values for either of the three species. Of the few filters that did show a net increase in analyte mass over the blank value, the quantity determined was generally so slight as to be negligible. There is no particular reason for these high blank values except for the pervasive existence of all three elements in ambient air near roadways as well as the relatively high elemental background associated with the filter media used for sample collection. Therefore, for the purpose of this study, it was assumed that the contribution of both particulate Pb and NaCl to the total PM-10 emissions from the road was not significant and thus could be ignored. For this reason, no specific emission factors were developed for either Pb or NaCl in the current program.

TABLE 4-5. RESULTS OF CHEMICAL ANALYSES

Analyte	Test No.	Array No.	Sampling height	Filter No.	Total particulate mass on filter (mg)[a]	Mass of analyte per filter (mg)[b]
Lead (Pb)	AY-4	U1	3	9221035	11.25	**0.0027**
		D2	2.5	9221046	11.45	0.0011
	AY-5	U1	3	9221057	3.15	0.0011
		D2	2.5	9221051	3.20	0.0008
	Blank	D3	5	9221011	0.60	0.0012
Sodium (Na^+)	AY-3	D4	1	9221020	17.30	**14.37**
			3	9221021	8.45	**12.70**
			5	9221022	2.60	**13.63**
			7	9221023	1.30	**12.95**
	AY-4	D1	1	9221031	6.95	**12.20**
			3	9221032	4.60	9.999
			5	9221033	3.15	**11.73**
			7	9221034	2.85	**11.82**
	AY-5	D4	1	9221052	4.85	**12.40**
			3	9221053	3.85	**11.85**
			5	9221054	3.15	**13.10**
			7	9221055	3.50	**12.10**
	Blank	D3	1	9221059	0.80	10.53
Chloride (Cl^-)	AY-3	D4	1	9221020	17.30	1.067
			3	9221021	8.45	0.887
			5	9221022	2.60	0.456
			7	9221023	1.30	**1.166**
	AY-4	D1	1	9221031	6.95	1.044
			3	9221032	4.60	1.049
			5	9221033	3.15	1.138
			7	9221034	2.85	1.021
	AY-5	D4	1	9221052	4.85	**1.156**
			3	9221053	3.85	1.005
			5	9221054	3.15	1.131
			7	9221055	3.50	1.059
	Blank	D3	1	9221059	0.80	1.140

[a] Not blank-corrected.

[b] Includes background from glass fiber substrate. Values above blank indicated in boldface type.

4.4 RESULTS OF ANCILLARY SAMPLING AND ANALYSIS

4.4.1 Antiskid Material Samples

Samples of both the abrasive/rock salt mixture and straight rock salt were collected from the MnDOT storage piles and/or spreader trucks according to the procedures outlined in Appendix A. These samples were then analyzed for moisture and silt content as well as for the various key material properties listed previously in Table 3-6. The analytical results obtained for the antiskid material samples collected are summarized in Table 4-6.

TABLE 4-6. PROPERTIES OF ANTISKID MATERIAL SAMPLES[a]

Sample origin	Sample composition	Average moisture content (wt %)	Modified LA abrasion loss (wt %)	Average silt content (wt %)	Average Vickers hardness (kg/mm^2)	Weighted average particle shape index (dimension-less)	Average percent insoluble matter
Storage pile	90:10 abrasive/ rock salt mix[b]	3.6	1.9	2.1	461	7.23	N/A
Storage pile	Rock salt	0.31	—	0.56	—	—	1.28
Spreader truck	90:10 abrasive/ rock salt mix	3.9	—	1.4	—	—	N/A
Spreader truck	80:20 abrasive/ rock salt mix	4.5	—	1.3	—	—	N/A

[a] N/A = Not applicable.
— indicates no data available.

[b] This material is considered as "questionable" quality according to the criteria specified in EPA-450/3-90-007.

Using the data in Table 4-6 for the abrasive/salt mixture, a comparison was made of its properties with the material selection criteria listed previously in Table 1-1. This comparison showed that the abrasive/salt mixture (storage pile sample) used by MnDOT did not meet three out of the four key parameters thought to be important for high material durability. For this reason, the abrasive/salt mixture analyzed in the current program was classified as "questionable" quality, based on the results of previous MRI testing (Kinsey, 1991).

With regard to the rock salt samples obtained from the MnDOT storage pile, a preliminary selection criterion of < 2% insoluble matter was also established by Kinsey

(1991). As noted from Table 4-6, the average insoluble content of the two salt samples analyzed is well below the 2% value and thus easily meets the above criterion for chloride deicers.

4.4.2 Road Surface Sampling

Road surface sampling was performed throughout the period that field testing was attempted in Duluth, Minnesota. Samples were collected and analyzed to determine silt loading using the procedures outlined in Appendix A. Surface samples were collected from both the driving (right) and passing (left) lane on each side of the highway near the air sampling site with the majority of the samples collected from the northbound lanes. (Recall that a 90:10 [weight percent] sand/salt mix was used on the northbound lanes and straight rock salt was used on the southbound lanes as part of the SHRP project—see Section 2.2.) The silt-loading values obtained from the various samples collected are shown in Table 4-7.

Using the data provided in Table 4-7, a "silt-loading history" was developed for both the northbound and southbound lanes during the entire period that samples were collected. These histories are shown in Figures 4-1 and 4-2. Also shown on these figures are the storm event periods and the days on which source testing was performed. (Note that a fairly substantial storm hit Duluth on February 24, which was also included on Figures 4-1 and 4-2 as a starting point.)

As shown by the above figures, the silt loadings on US 53 tended to be relatively low, as is typical for high-speed roadways. Also, the northbound lanes (which received the abrasive/salt mixture) tended to have generally higher silt loadings as compared to the southbound lanes (which received straight rock salt). In both cases, the loadings generally dropped off fairly rapidly after a storm event, which was also verified by on-site observation.

Using the silt-loading data shown in Table 4-7, PM-10 emission factor estimates were calculated for the various samples using the AP-42 predictive model provided previously as Eq. 1-1. Emission factors were predicted for both northbound and southbound lanes in terms of g/VKT. The results of these calculations are shown in Table 4-8.

As indicated by Table 4-8, the predicted emission factors were generally low, ranging from less than 1 to a maximum of 4 g/VKT. The highest emission factors (resulting from the highest silt loadings) were for samples collected from the northbound lanes after a fairly major storm event occurring on February 24, 1992. After that time, the predicted emissions generally dropped to ≤ 1 g/VKT until the next storm in early April. This decrease in loading would be expected due to the effects of traffic, which tends to reestablish a silt-loading "equilibrium" on the road surface after external influences (e.g., the application of antiskid material) have been eliminated.

TABLE 4-7. RESULTS OF ROAD SURFACE SAMPLING[a]

Date	Lane sampled	Sample bag No.	Road surface area sampled		Sample mass (g)	Total surface loading		Silt content (wt %)	Road surface silt loading	
			ft^2	m^2		oz/yd^2	g/m^2		oz/yd^2	g/m^2
2/26	NB-Driving	9017	576	53.5	336.8	0.186	6.30	16.5	0.0307	1.04
	NB-Passing	9019	576	53.5	114.4	0.0628	2.13	23.5	0.0148	0.501
	SB-Driving	9711-23	576	53.5	306.5	0.169	5.73	9.23	0.0156	0.529
	SB-Passing	9711-22	576	53.5	104.4	0.0575	1.95	13.9	0.00799	0.271
2/28	NB-Driving	9012	576	53.5	147.1	0.0811	2.75	12.4	0.0101	0.341
	NB-Passing	9010	576	53.5	1.4	0.0008	0.0262	N/A	0.0008	0.0262[b]
	SB-Driving	9013	576	53.5	130.0	0.0717	2.43	18.3	0.0131	0.445
	SB-Passing	9011	576	53.5	204.1	0.113	3.82	7.74	0.00870	0.295
3/2	NB-Driving	9016	576	53.5	92.3	0.0510	1.73	4.05	0.00206	0.0701
	NB-Passing	9022	576	53.5	113.3	0.0625	2.12	3.12	0.00195	0.0661
	SB-Driving	9020	576	53.5	23.1	0.0127	0.432	8.85	0.00112	0.0382
	SB-Passing	9021	576	53.5	162.0	0.0894	3.03	4.03	0.00360	0.122
3/11	NB-Driving	9008	576	53.5	45.5	0.0251	0.850	23.5	0.00590	0.200
	NB-Passing	9014	576	53.5	63.3	0.0348	1.18	13.9	0.00484	0.164
	SB-Driving	9015	576	53.5	114.0	0.0628	2.13	9.77	0.00613	0.208
	SB-Passing	9018	576	53.5	112.0	0.0616	2.09	16.9	0.0104	0.354
3/19	NB-Driving	63	575	53.4	2.3	0.00127	0.0431	N/A	0.00127	0.0431[b]
4/1	NB-Driving	62	1,150	107	76.0	0.0209	0.710	11.1	0.00233	0.0788
	NB-Passing	119	1,150	107	157.9	0.0437	1.48	10.6	0.00460	0.156
4/22	NB-Driving	74	646	60.0	44.0	0.0216	0.733	8.43	0.00183	0.0618
	NB-Passing	75	646	60.0	314.0	0.154	5.23	10.4	0.0160	0.544
	NB-Turning	61	53.3	4.95	1107.1	6.61	224	4.96	0.327	11.1
4/24	NB-Driving	98	648	60.2	181.1	0.0885	3.00	4.97	0.00442	0.150
	NB-Passing	96	648	60.2	161.2	0.0790	2.68	4.96	0.00392	0.133
	SB-Driving and passing	93	1,300	121	65.7	0.0160	0.543	9.68	0.00156	0.0526

[a] Calculations to three significant figures.

[b] Assumed to be 100% silt.

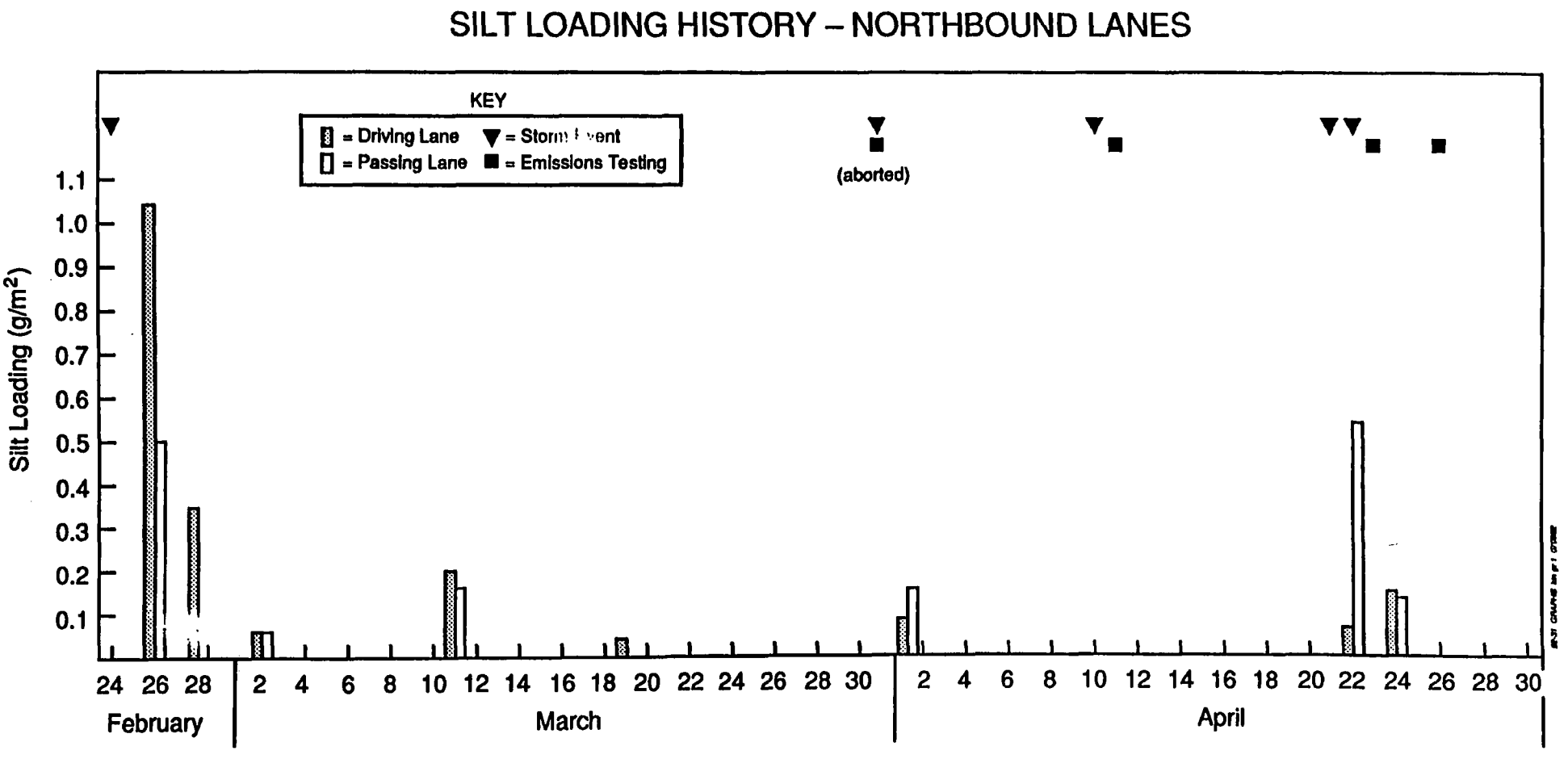

Figure 4-1. Silt-loading history for northbound lanes (sand/salt mix).

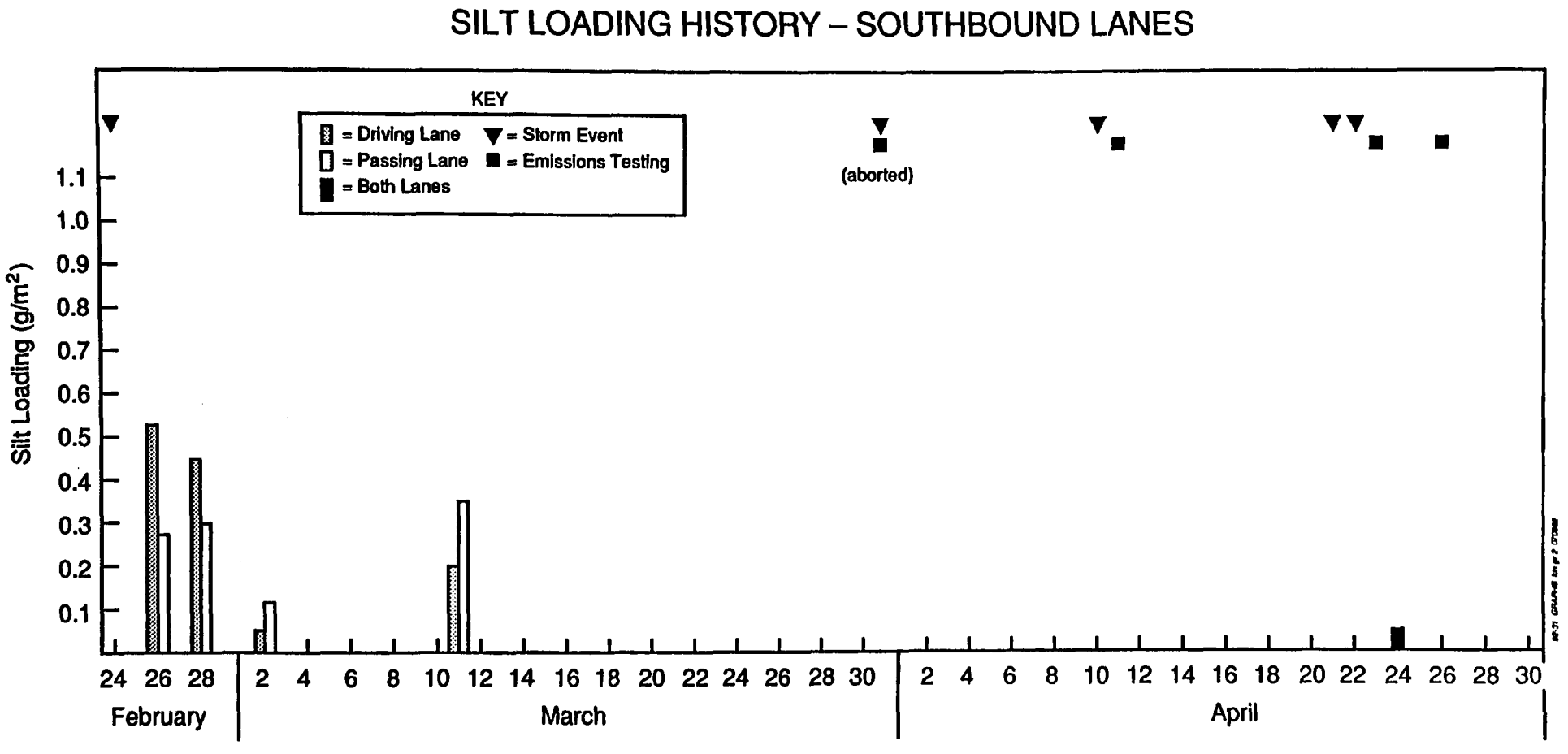

Figure 4-2. Silt-loading history for southbound lanes (rock salt only).

TABLE 4-8. PREDICTED PM-10 EMISSION FACTORS FOR MEASURED SURFACE SILT LOADINGS[a]

Date	Lane sampled	Road surface silt loading (g/m^2)	Predicted PM-10 emission factor (g/VKT)
2/26	NB—Driving	1.04	4.10
	NB—Passing	0.501	2.28
	SB—Driving	0.529	2.38
	SB—Passing	0.271	1.39
2/28	NB—Driving	0.341	1.68
	NB—Passing	0.0262	0.215
	SB—Driving	0.445	2.08
	SB—Passing	0.295	1.50
3/2	NB—Driving	0.0701	0.473
	NB—Passing	0.0661	0.452
	SB—Driving	0.0382	0.291
	SB—Passing	0.122	0.738
3/11	NB—Driving	0.200	1.10
	NB—Passing	0.164	0.935
	SB—Driving	0.208	1.13
	SB—Passing	0.354	1.73
3/19	NB—Driving	0.0431	0.321
4/1	NB—Driving[b]	0.0788	0.520
	NB—Passing[b]	0.156	0.900
4/22	NB—Driving[b]	0.0618	0.428
	NB—Passing[b]	0.544	2.44
4/24	NB—Driving	0.150	0.870
	NB—Passing	0.133	0.790
	SB—Driving and Passing	0.0526	0.376

[a] PM-10 emission factors predicted using Eq. 1-1 and silt loadings shown in Table 4-7.

[b] Loadings measured after application of antiskid material.

As also shown, the estimated emission factors (Table 4-8) are of the same approximate magnitude as the test results provided in Table 4-4. This lends some additional credibility to the data obtained by exposure profiling in the current study.

4.5 DISCUSSION OF RESULTS

As shown by the above test results, the measured emission factors varied from 1 to 11 g/VKT for the three tests conducted. The data were not sufficient, however, to develop any specific correlation between the measured emission factors and source parameters such as quantity of antiskid material applied, time since application, and silt loading. The only general observation that can be made from the data is that the PM-10 emissions appear to increase with the amount of antiskid material applied during the two storms tested (i.e., the emission factors for Test AY-3 are higher than for Tests AY-4 and AY-5). (Also note that Test AY-5 had the most acceptable wind conditions of the three tests conducted and thus represents the most reliable emission factor determined in the study.) Otherwise, the results do not seem to follow a consistent relationship. A major cause for the lack of association was the marginal test conditions discussed above.

A comparison of the measured emission factors (Table 4-4) with those predicted by the current AP-42 equation (Table 4-8) also yields some interesting results. With only a relatively few exceptions, most of the measured factors are higher than those which would be predicted from silt-loading values alone. In the case of the test (i.e., northbound) lanes themselves, the measured factors either equal or exceed the lane average emissions predicted by the AP-42 equation, except for the February 26 samples that were collected after a fairly major storm. This suggests that the application of antiskid material results in a short-term increase in PM-10 emissions from the roadway in an amount greater than that which would be predicted by silt loading alone. Although no definitive assessment of this increase can be made based on available data, the PM-10 emissions could be almost a factor of three higher (i.e., 11 vs. 4 g/VKT) than would be predicted from the silt loading. This proportional increase in emissions is considerably higher than the precision factor of approximately 2 for the current AP-42 predictive equation and thus worthy of further study (Cowherd and Englehart, 1984). Therefore, a more explicit evaluation is needed to determine the exact extent of the emissions increase due to the application of antiskid material to paved roadways.

SECTION 5

QUALITY ASSURANCE

An independent evaluation of the field and analytical activities on this work assignment was performed by the Midwest Research Institute Quality Assurance Manager (QAM). The evaluation procedure included the review of the field and analytical data. The field work was performed by Midwest Research Institute and the elemental analyses were conducted by Galbraith Laboratories, Inc., Knoxville, Tennessee.

5.1 PERFORMANCE AUDIT

The analytical laboratory, through its internal quality control program, analyzed replicate performance samples using a NIST standard reference material (SRM 1643c) for lead. The results for the performance audit samples were 99.4% and 102.8%. The precision for the performance audit samples, calculated as a percent range, was 3.36%. These results are within the data quality objectives as stated in the Quality Assurance Project Plan (QAPjP). In addition to the performance audit samples, the laboratory analyzed quality control samples (method spikes) prepared at a theoretical concentration of 2.0 µg/mL for each analyte. The average results for the method spikes were 101% for the sodium analyses, 103% for the chlorine analyses, and 108% for the lead analyses.

5.2 DATA AUDIT

Two data audits were performed for this work assignment, one on the field data and the second on the analytical data. A summary of the audit findings are given in the following subsections.

5.2.1 Field Data

The sampling procedures followed in this field testing program were subject to quality assurance/quality control (QA/QC) guidelines. As a part of this program, quality assurance audits were performed to demonstrate that the measurements were made within acceptable control conditions for particulate source sampling and to assess the reliability of the field data with respect to the established criteria. The use of specially-designed reporting forms for sampling and quality control data obtained in the field aided in the auditing procedure.

Two source activity factors pointed out by the Work Assignment Leader (and mentioned previously in this report) that had major effects on the quality of the field data collected were the atypical amount of antiskid material applied by MnDOT and the antiskid material itself. These are discussed in Sections 4.1 and 4.4.1.

The quality control criteria established for this program are given in Table 3-3, "Quality Control Procedures for Sampling Flow Rates," and Table 3-4, "Quality Control Procedures for Sampling Equipment." During this work assignment, the calibration of the equipment was checked by the field personnel to ensure that the equipment was properly calibrated.

The criteria used to define the unacceptable conditions for the collection of reliable test data are given in Table 3-5, "Criteria for Suspending or Terminating a Test." Because of the mild winter in Duluth, adherence to the criteria for suspending the test was not always followed. However, each decision to conduct sampling was discussed in advance with the EPA project officer. The reliability of the data collected during these periods needs to be carefully reviewed with respect to the conditions at the time of the tests.

5.2.2 Laboratory Data

A data audit was conducted to evaluate the analytical data generated. The quality of the analytical data was evaluated against the QA indicators for the measured data presented in the QAPjP, the analytical methodology, and the project Standard Operating Procedures (SOPs).

The samples (filters) were initially analyzed using MRI SOP EET-610 to determine the weight change between prefield weights and postfield weights. The samples were equilibrated for 24 h in a clean, controlled temperature and humidity room. The filters were analyzed as described in the SOP and were within the data quality indicators as given in the SOP and the QAPjP.

The air samples analyzed for lead were digested using EPA SW-846 Method 3050 and analyzed using EPA 600 Series Method 239.2. The air samples analyzed for sodium and chloride were extracted using the leaching procedure described in 40 *CFR* 50, Appendix G. The analytical procedure used for chlorine was EPA Series 600 Method 300.1; Method 273.1 was used for sodium. The procedures were followed as described, and the associated quality control data met the measurement requirements of the analytical procedures and the QAPjP.

5 DATA ASSESSMENT

Although the analytical data generated met the quality control criteria established for this work assignment, the field data were affected by environmental factors, many of which were beyond the control of the Work Assignment Leader.

Since the samples were collected under environmental conditions that did not meet all of the applicable quality control criteria, the quality of the data was adversely affected. Because there was a failure of field equipment that resulted in the loss of samples, the completeness of the sample collection process also affected the reliability of the data. Therefore, the data generated for this work assignment should be considered only as an estimation of PM-10 emissions from the roadway.

5.4 REPORT REVIEW

The document was reviewed for consistency in reporting the analytical data, and the report was found to reflect the analytical data generated for this activity.

SECTION 6

STUDY CONCLUSIONS

The following conclusions were reached as a result of the current study:

1. Because the measurements conducted were performed under difficult environmental conditions that did not meet all of the applicable QC criteria for exposure profiling, data quality was adversely affected.

2. Although the emission factors determined in the program ranged from 1 to 11 g/VKT for the three tests conducted, these values should be used with extreme caution due to the lack of suitable test conditions during sample collection and resulting poor data quality.

3. The contribution of both particulate lead (Pb) and sodium chloride (NaCl) to the total PM-10 emissions from the road did not appear to be significant based on the limited chemical analyses performed in the program.

4. The dry silt loadings determined on US 53 tended to: (a) be relatively low; and (b) drop off rapidly after a storm event which is typical of high-speed roadways. The amount of silt available for resuspension was also found to be very low due to the minimal application of antiskid material during the experimental program.

5. Emission factors determined in the program were generally higher than those predicted by the current AP-42 equation, based on road surface silt loading. The magnitude of this increase could not be definitively determined from available data, but it may be almost a factor of 3.

SECTION 7

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APPENDIX A

MATERIAL SAMPLING AND ANALYSIS

APPENDIX A

MATERIAL SAMPLING AND ANALYSIS

A.1 SAMPLING PROCEDURES FOR ANTISKID MATERIALS

For stockpiled antiskid materials, the following steps were used to collect each sample:

1. Sketch plan and elevation views of the pile to be sampled. Indicate if any portion is inaccessible. Use the sketch to plan where the N increments will be taken by dividing the perimeter into N-1 roughly equivalent segments.

   a. For a large pile, collect a minimum of 10 increments as near to the mid-height of the pile as practical.

   b. For a small pile, a sample should consist of a minimum of 6 increments evenly distributed among the top, middle, and bottom.

   "Small" or "large" piles, for practical purposes, may be defined as those piles which can or cannot, respectively, be scaled by a person carrying a shovel and pail.

2. Collect material with a straight-point shovel or a small garden spade. Take increments from the portions of the pile which most recently had material added and removed. Collect the material with a shovel to a depth of 10 to 15 cm (4 to 6 in). Do not deliberately avoid larger pieces of aggregate present on the surface. Store the increments in a clean, labeled container of suitable size (such as a metal or plastic 19-L [5-gal] bucket) with a sealable polyethylene liner.

3. Record the required information on the sample collection sheet (Figure A-1). Note the space for deviations from the summarized method.

The sample mass collected should be at least 5 kg (10 lb). When most materials are sampled with 10 increments, a sample of at least 23 kg (50 lb) is typical. Note that storage pile samples usually require splitting to a size more amenable to moisture and silt analysis.

For the abrasive/salt mixture, grab samples were collected directly from the rear of the distributor truck while the vehicle was stationary. Samples were collected from

SAMPLING DATA FOR STORAGE PILES

Date Collected _____ Recorded by _____

Type of material sampled _____

Sampling location* _____

METHOD:

1. Sampling device: pointed shovel (hollow sampling tube if inactive pile is to be sampled)
2. Sampling depth:
   For material handling of active piles: 10-15 cm (4-6 in)
   For material handling of inactive piles: 1 m (3 ft)
   For wind erosion samples: 2.5 cm (1 in) or depth of the largest particle (whichever is less)
3. Sample container: bucket with a sealable liner
4. Gross sample specifications:
   For material handling of active or inactive piles: minimum of 6 increments with total sample weight of 5 kg (10 lb) [10 increments totalling 23 kg (50 lb) are recommended]
   For wind erosion samples: Minimum of 6 increments with total sample weight of 5 kg (10 lb)

Refer to procedure described in Section 4 of "Open Source PM-10 Method Evaluation" for more detailed instructions.

Indicate any deviations from the above: _____

SAMPLING DATA COLLECTED:

Sample No.	Time	Location* of Sample Collection	Device Used S/T **	Depth	Mass of Sample

* Use code given on plant or area map for pile/sample identification. Indicate each sampling location on map.

Figure A-1. Example data form for storage piles.

as many loads as possible with the samples split (if required) prior to laboratory analysis. The following describes the sample splitting procedure used.

The main principle in sizing the laboratory sample for subsequent silt analysis is to have sufficient coarse and fine portions to be representative of the material and to allow sufficient mass on each sieve so that the weighing is accurate. A laboratory sample of 400 to 1,600 g is recommended because of the scales normally available (1.6 to 2.6 kg capacities). A larger sample than this amount may produce "screen blinding" for the 20 cm (8 in) diameter screens normally available for silt analysis. Screen blinding can also occur for small samples of finer texture. Finally, the sample mass should be such that it can be spread out in a reasonably sized drying pan to a depth of < 2.5 cm (1 in).

Two methods are recommended for sample splitting—riffles and coning and quartering. Since a riffle was used in the current study, only this procedure is described.

Figure A-2 shows two riffles for sample division. Riffle slot widths should be at least three times the size of the largest aggregate in the material being divided. The following quote from ASTM Standard Method D2013-72 describes the use of the riffle (ASTM, 1977).

> "Divide the gross sample by using a riffle. Riffles properly used will reduce sample variability but cannot eliminate it. Riffles are shown in Figure A-2. Pass the material through the riffle from a feed scoop, feed bucket, or riffle pan having a lip or opening the full length of the riffle. When using any of the above containers to feed the riffle, spread the material evenly in the container, raise the container, and hold it with its front edge resting on top of the feed chute, then slowly tilt it so that the material flows in a uniform stream through the hopper straight down over the center of the riffle into all the slots, thence into the riffle pans, one-half of the sample being collected in a pan. Under no circumstances shovel the sample into the riffle, or dribble into the riffle from a small-mouthed container. Do not allow the material to build up in or above the riffle slots. If it does not flow freely through the slots, shake or vibrate the riffle to facilitate even flow (ASTM, 1977)."

A.2 ANALYSIS OF ANTISKID MATERIAL SAMPLES

All antiskid materials were oven dried to determine moisture content prior to silt analysis. The following procedure was used for this purpose:

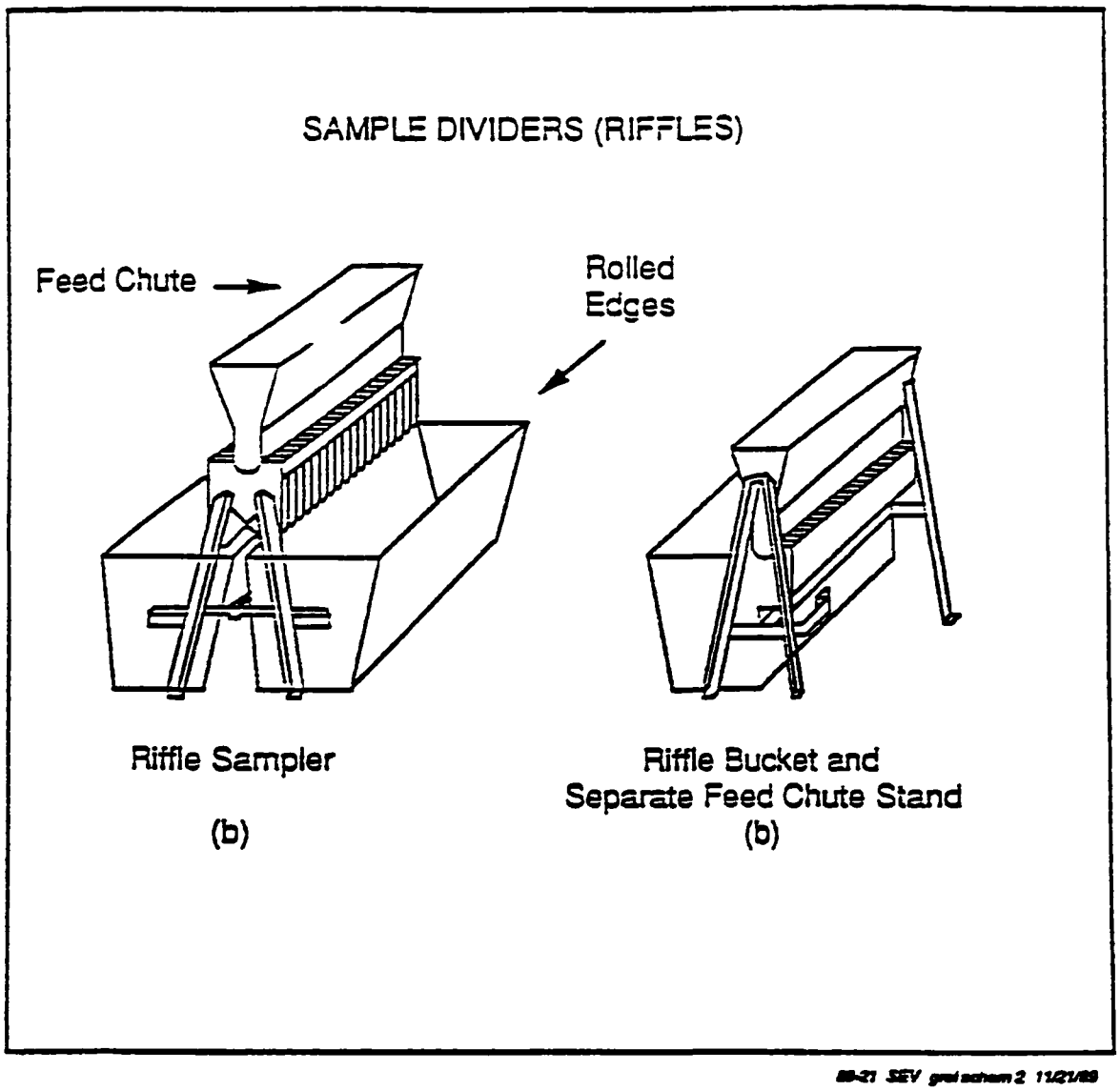

Figure A-2. Sample riffle dividers.

1. Preheat the oven to approximately 110°C (230°F). Record oven temperature.

2. Record the make, capacity, and smallest division of the scale.

3. Weigh the empty laboratory sample containers which will be placed in the oven to determine their tare weight. Weigh containers with the lids on if they have lids. Record the tare weight(s). Check zero before each weighing.

4. Weigh the laboratory sample(s) in the container(s). For materials with high moisture content, ensure that any standing moisture is included in the laboratory sample container. Record the combined weight(s). Check zero before each weighing.

5. Place sample in oven and dry overnight. Materials composed of hydrated minerals or organic material like coal and certain soils should be dried for only 1½ h.

6. Remove sample container from oven and (a) weigh immediately if uncovered, being careful of the hot container; or (b) place the tight-fitting lid on the container and let cool before weighing. Record the combined sample and container weight(s). Check zero reading on the balance before weighing.

7. Calculate the moisture as the initial weight of the sample and container minus the oven-dried weight of the sample and container divided by the initial weight of the sample alone. Record the value.

8. Calculate the sample weight to be used in the silt analysis as the oven-dried weight of the sample and container minus the weight of the container. Record the value. (See Figure A-3.)

A.3 PAVED ROAD SURFACE SAMPLING

In comparison to unpaved road sampling, planning for a paved road sample collection exercise necessarily involves greater consideration as to types of equipment to be used. Specifically, provisions must be made to accommodate the characteristics of the vacuum cleaner chosen. For example, paved road samples are collected by cleaning the surface using a vacuum cleaner with "tared" (i.e., weighed before use) filter bags. "Stick broom" vacuums use relatively small, lightweight filter bags, while bags for "industrial-type" vacuums are bulky and heavy. Stick brooms are thus well suited for collecting samples from lightly loaded road surfaces because the mass collected is usually several times greater than the bag tare weight. On the other hand, the larger industrial-type vacuum bags are not only easier to use on heavily loaded

MOISTURE ANALYSIS

Date: _____

By: _____

Sample No: _____
Material: _____

Split Sample Balance:
Make _____
Capacity_____
Smallest Division _____

Total Sample Weight: _____
(Excl. Container)
Number of Splits: _____

Split Sample Weight (before drying)
Pan + Sample: _____
Pan: _____
Wet Sample: _____

Oven Temperature: _____
Date In _____ Date Out _____
Time In _____ Time Out _____
Drying Time _____

Sample Weight (after drying)
Pan + Sample: _____
Pan: _____
Dry Sample: _____

MOISTURE CONTENT:
(A) Wet Sample Wt. _____
(B) Dry Sample Wt. _____
(C) Difference Wt. _____

$\frac{C \times 100}{A}$ = _____ % Moisture

Figure A-3. Example moisture analysis form.

roads but also can be more readily used to aggregate incremental samples from several road surfaces. In this study, an industrial-type vacuum cleaner was used.

The following steps describe the collection method used for the individual samples collected:

1. Ensure that the site offers an unobstructed view of traffic and that sampling personnel are visible to drivers. If the road is heavily traveled, use one crew member to "spot" and route traffic safely around another person collecting the surface sample (increment). (Note that a vehicle-mounted arrow board was also used in the study as an extra safety precaution.)

2. Using string or other suitable markers, mark the sampling width across the road. (WARNING: Do not mark the collection area with a chalk line or in any other method likely to introduce fine material into the sample.) The widths may be varied between 0.3 m (1 ft) for visibly dirty roads and 3 m (10 ft) for clean roads. When using an industrial-type vacuum to sample lightly loaded roads, a width greater than 3 m (10 ft) may be necessary to meet sample specifications unless increments are being combined.

3. If large, loose material is present on the surface, it should be collected with a whisk broom and dustpan. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i.e., not from berms or any "mounds" along the road centerline). On roads with painted side markings, collect material "from white line to white line" (but avoid any centerline mounds). Store the swept material in a clean, labeled container of suitable size (such as a metal or plastic 19 L [5 gal] bucket) with a sealable polyethylene liner. Increments of the same sample may be mixed within the container.

4. Vacuum sweep the collection area using a portable vacuum cleaner fitted with an empty tared (i.e., preweighed) filter bag. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i.e., not from berms or any "mounds" along the road centerline). On roads with painted side markings, collect material "from white line to white line" (but avoid centerline mounds). The same filter bag may be used for different increments for one sample. For heavily loaded roads, more than one filter bag may be required for a sample (increment).

5. Carefully remove the bag from the vacuum sweeper and check for tears or leaks. If necessary, reduce samples from broom sweeping to a size amendable for analysis (see Section A.1). Seal broom-swept material in

a clean, labeled plastic jar for transport (alternatively, the swept material may be placed in the vacuum filter bag). Fold the unused portion of the filter bag, wrap a rubber band around the folded bag, and store the bag for transport.

6. Record the required information on the sample collection sheet (Figure A-4).

Broom-swept samples (if collected) should be at least 400 g (1 lb) for silt and moisture analysis (see Section A.2). The vacuum-swept sample should be at least 200 g (0.5 lb); in addition, the exposed filter bag weight should be at least 3 to 5 times greater than the weight of the empty filter bag. Additional increments should be taken until these sample mass goals have been achieved.

A.4 ANALYSIS PROCEDURES FOR PAVED ROAD SAMPLES

Paved road samples are not normally oven dried because vacuum filter bags are used to collect the samples. After the sample has been recovered by dissection of the bag, it is combined with any broom-swept material for silt analysis. The following procedure was used for sample analysis.

For the paved road samples, the broom-swept particles and the vacuum-swept dust are individually weighed on a beam balance. The broom-swept particles are weighed in a container. The vacuum-swept dust is weighed in the vacuum bag, which was tared prior to sample collection. After weighing the sample to calculate total surface dust loading on the traveled lanes, broom-swept particles and the vacuum-swept dust are combined. The composite sample is usually small and probably will not require splitting in preparation for sieving. The following steps were followed to analyze the resulting surface sample:

1. Select the appropriate 20 cm (8-in) diameter, 5 cm (2-in) deep sieve sizes. Recommended U.S. Standard Series sizes are: 3/8 in, No. 4, No. 40, No. 100, No. 140, No. 200, and a pan. Comparable Tyler Series sizes can also be utilized. The No. 20 and the No. 200 are mandatory. The others can be varied if the recommended sieves are not available or if buildup on one particular sieve during sieving indicates that an intermediate sieve should be inserted.

2. Obtain a mechanical sieving device such as vibratory shaker or a Roto-Tap without the tapping function.

3. Clean the sieves with compressed air and/or a soft brush. Material lodged in the sieve openings or adhering to the sides of the sieve should be removed (if possible) without handling the screen roughly.

SAMPLING DATA FOR PAVED ROADS

Date Collected _____ Recorded by _____

Sampling location* _____ No. of Lanes _____

Surface type (e.g., asphalt, concrete, etc.) _____

Surface condition (e.g., good, rutted, etc.) _____

* Use code given on plant or road map for segment identification. Indicate sampling location on map.

METHOD:

1. Sampling device: portable vacuum cleaner (whisk broom and dustpan if heavy loading present)
2. Sampling depth: loose surface material (do not sample curb areas or other untravelled portions of the road)
3. Sample container: tared and numbered vacuum cleaner bags (bucket with sealable liner if heavy loading present)
4. Gross sample specifications: Vacuum swept samples should be at least 200 g (0.5 lb), with the exposed filter bag weight should be at least 3 to 5 times greater than the empty bag tare weight.

Refer to procedure described in Section 3 of "Open Source PM-10 Method Evaluation" for more detailed instructions.

Indicate any deviations from the above: _____

SAMPLING DATA COLLECTED:

Sample No.	Vacuum Bag		Surface Area Sampled	Time	Mass of Broom-Swept Sample +
	ID	Tare Wgt (g)			

+ Enter "0" if no broom sweeping is performed.

Figure A-4. Example data form for paved roads.

4. Obtain a scale (capacity of at least 1,600 g or 100 lb) and record make, capacity, smallest division, date of last calibration, and accuracy.

5. Weigh the sieves and pan to determine tare weights. Check the zero before every weighing. Record weights.

6. After nesting the sieves in decreasing order with pan at the bottom, transfer dried laboratory sample (preferably immediately after moisture analysis, as applicable) into the top sieve. The sample should weigh between ~ 400 and 1,600 g (0.9 to 3.5 lb). This amount will vary for finely textured materials; 100 to 300 g may be sufficient when 90% of the sample passes a No. 8 (2.36 mm) sieve. Brush fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.

7. Place nested sieves into the mechanical sieving device and sieve for 10 min. Remove pan containing minus No. 200 and weigh. Repeat the sieving in 10-min intervals until the difference between two successive pan sample weighings (where the tare weight of the pan has been subtracted) is less than 3.0%. Do not sieve longer than 40 min.

8. Weigh each sieve and its contents and record the weight. Check the zero reading on the balance before every weighing.

9. Collect the laboratory sample and place the sample in a separate container if further analysis is expected.

10. Calculate the percent of mass less than the 200 mesh screen (75 μm physical diameter). This is the silt content (see Figure A-5).

SILT ANALYSIS

Date _____
Sample No: _____
Material: _____

Split Sample Balance:
Make _____
Capacity _____
Smallest Division _____

By _____
Sample Weight (after drying)
Pan + Sample: _____
Pan: _____
Dry Sample: _____

Final Weight: _____

$$\% \text{ Silt} = \frac{\text{Net Weight } <200 \text{ Mesh}}{\text{Total Net Weight}} \times 100 = _____\%$$

SIEVING

Time: Start:	Weight (Pan Only)
Initial (Tare):	
20 min:	
30 min:	
40 min:	

Screen	Tare Weight (Screen)	Final Weight (Screen + Sample)	Net Weight (Sample)	%
3/8 in.				
4 mesh				
10 mesh				
20 mesh				
40 mesh				
100 mesh				
140 mesh				
200 mesh				
Pan				

Figure A-5. Example silt analysis form.

APPENDIX B

MODIFICATIONS TO ASTM METHODS FOR LA ABRASION LOSS AND VICKERS HARDNESS

APPENDIX B

MODIFICATIONS TO ASTM METHODS FOR LA ABRASION LOSS AND VICKERS HARDNESS

Modifications made to ASTM Methods C 131 and E 384 for the analysis of antiskid abrasives are shown in Tables B-1 and B-2, respectively.

TABLE B-1. MODIFICATIONS TO ASTM METHOD C 131-89 FOR AGGREGATE MATERIAL < 2.36 mm

The standard ASTM methodology should be used with the following modifications:

5. Apparatus

5.4.1 The weight of the test sample placed in the Testing Machine shall be 5,000 ± 10 g along with a charge of six (6) standard spheres.

8. Procedure

8.1 Split the sample into two equal fractions according to Method C 702. Sieve the first fraction according to the procedure outlined in Table A and record the results. Weigh the charge of spheres to be introduced into the testing machine and record the results.

8.2 Place the second sample fraction (as received) and the charge in the Los Angeles testing machine and rotate the machine at a speed of 30 to 33 rpm for 500 revolutions. After the prescribed number of revolutions, discharge the material from the machine, separate the charge, and sieve the sample material using the procedure shown in Table A. Record the results.

TABLE A. SAMPLE SIEVING PROCEDURE

1. Select the appropriate 8-in diameter, 2-in deep sieve sizes. Recommended U.S. Standard Series sizes are 3/8 in, No. 4, No. 20, No. 40, No. 100, No. 140, No. 200, and a pan. Comparable Tyler Series sizes can also be utilized. The No. 20 and the No. 200 are mandatory. The others can be varied if the recommended sieves are not available or if buildup on one particular sieve during sieving indicates that an intermediate sieve should be inserted.
2. Obtain a mechanical sieving device such as vibratory shaker or a Roto-Tap.
3. Clean the sieves with compressed air and/or a soft brush. Material lodged in the sieve openings or adhering to the sides of the sieve should be removed (if possible) without handling the screen roughly.
4. Obtain a scale (capacity of at least 1,600 g) and record make, capacity, smallest division, date of last calibration, and accuracy (if available).
5. Tare sieves and pan. Check the zero before every weighing. Record weights.
6. After nesting the sieves in decreasing order with pan at the bottom, dump dried laboratory sample (probably immediately after moisture analysis) into the top sieve. Brush fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.
7. Place nested sieves into the mechanical device and sieve for 20 min. Remove the pan containing the minus No. 200 fraction and weigh. Replace pan beneath the sieves and sieve for another 10 min. Remove pan and weigh. When the differences between two successive pan sample weighings (where the tare of the pan has been subtracted) is less than 3.0%, the sieving is complete.
8. Weigh each sieve and its contents and record the weight. Check the zero before every weighing.
9. Collect the laboratory sample and place the sample in a separate container if further analysis is expected.

Table B-1 (Continued)

9. Calculation

9.1 Determine the abrasion loss as a percentage using the following equation:

$$aL = \frac{S_i - S_f}{S_i} \times 100$$

where:

aL	=	LA abrasion loss (weight percent)
S_i	=	Weight percent of material > 200 mesh (75 µm) in original sample
S_f	=	Weight percent of material > 200 mesh (75 µm) in sample after exposure in Los Angeles Testing Machine

Table B-2. MODIFICATIONS TO ASTM E 384-89 TO INCORPORATE FINE AGGREGATE MATERIALS

The standard ASTM methodology should be used with the following modifications:

7. Test Specimens

7.1 Mount each aggregate sample in an appropriate epoxy resin mold. Grind and polish the surface of the mold according to standard techniques.

8. Procedure

8.1 Select at least four (4) particles from each mold for analysis. The particles should be representative of the bulk material present in the specimen. Variations in reflectance, polishing hardness, color, and anisotropism should be noted and particles excluded which do not represent the bulk of the material present. For materials of greatly varied lithologic character, particles with different lithology should be selected which represent the entire sample.

8.2 Delete

8.4.7 Measure a total of five (5) indentations on each of the four particles selected for analysis to obtain a total of 20 indentations for each polished section. Read the two diagonals of the indentation to within 0.25 µm or 0.4%, whichever is larger, and determine the average of the diagonal lengths. For materials with very low reflectance values (e.g., calcite, quartz, etc.), indentation measurements should be performed using an appropriate microscope equipped with dark field illumination or other special types of lighting arrangements.

8.4.8 Indentations which exhibit obvious problems shall not be measured. (For example, an indentation that shows cracks at its edge.) Instead, repeat the indentation elsewhere on the same particle or select another representative particle from the same polished section.

8.5.2 Compute the mean HV for the polished section by calculating the Vickers hardness number for each of the 20 indentations from the equation given in Section 4.3.1.1 or from the information given in Table 2. Average the 20 measurements to obtain the mean for the sample. To obtain the hardness number from the table, read the HV (1 g_f) corresponding to the average of the two measured diagonal lengths (in micrometers) and multiply by the test load in grams-force.

APPENDIX C

EXAMPLE DATA FORMS USED IN SHRP PROJECT H-208A FOR MONITORING SITE CONDITIONS

WEATHER AND PAVEMENT CONDITION LOG

NAME: Ed Fleege AGENCY: Minnesota

Date	Time	Type of Precipitation: Drizzle	Rain	Fr. Rain	Sleet	Lt. Snow	Snow	Blowing Snow	None	Section Observed: Test	Control	Location (Route and Milepost)	Lane No. and Direction	Type of Pavement*	Observed Pavement Condition: Wheel Track: Dry	Wet	Slush	Snow	Ice	Snow/Ice Pack	Other	Outside Wheel Track: Dry	Wet	Slush	Snow	Ice	Snow/Ice Pack	Other	Friction Value
4/10/92	08:15						X				X	TH 53 & Jct CR 889	NB - Driving	PCC					X							X			0.13
	08:24						X				X	TH 53 MP 15.5	NB - Driving	PCC					X							X			0.16
	08:27						X				X	TH 53 MP 16.0	NB - Driving Right behind sanding	PCC					X							X			0.23
	08:33					X					X	TH 53 MP 18.7	NB - Driving Air Temp 27.0 Before Sanding	PCC					X							X			0.12
	08:38					X					X	TH 53 MP 20.8	NB - Driving Air Temp 27.0 After Sanding	PCC					X							X			0.21
	08:53					X					X	TH 53 MP 21.2	NB - Driving After Sanding	PCC		X	X							X					
	08:55					X					X	TH 53 MP 22.0	NB - Driving After Sandy	PCC		X	X							X					0.24
	08:57					X					X	TH 53 MP 22.5	NB - Passing	PCC				X							X				0.18
4/10/92	09:00					X					X	TH 53 MP 22.5	NB - Driving	PCC		X	X							X					0.24

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* Indicate as either PCC, DGA, or OAG. PCC=Portland Cement Concrete; DGA=Dense Graded Asphalt; OGA=Open Graded Asphalt

November 21, 1991

91 69 SEV weath/pave log 120291

Anti-Icing Operation Aborted

Date _____

Time _____

OPERATOR ACTIVITY LOG (CONTROL SECTION)

STATE OF Minnesota

Name of Operator: Jim Syrna Truck I.D. No. 85246

Location of Highway: Hwy 53 N.B. Pike Lake to Canyon

Spreader Make and Model _____ Type of Spreader Control _____

Was spreader calibrated prior to use (Yes or No): _____ If so, when: _____

Date	Treatment Start Time	Type of Material Applied	Pump/or Conveyor/Auger Settings	Spreader Setting	Lane Mix[1]	Lane Being Treated[1]	Method of Treatment[2]	Approx. Speed (mph)	Comments or General Weather/Pavement Conditions
4/10/92	0830	SAND/salt winter mix	800	2.5	1	NB D+P	P+C	25	Snow + compaction icy
4/10/92	1050	SAND/SALT winter mix	400	1	2	NB D	P+C	25	Wet
4/10/92	1100	SAND/SALT winter mix	400	1	2	NB P	P+C	25	Slushy
4/10/92	1500	SAND/SALT winter mix + 10% salt	600	2	3	NB D+P	P+C	25	Snow + Slush
4/10/92	1800	SAND/SALT winter mix + 10%	600	2	4	NB D+P	P+C	25	Snow + Slush midway Rd. to Caribou Lake Rd

1 Indicate DL, CL, PL, DL + CL, or CL + PL. DL = Driving Lane; CL = Center Lane; PL = Passing Lane; DL + CL = Driving and Passing Lanes; or CL + PL = Center Lane and Passing Lanes.

2 Indicate P, C, A, S, P+C, or P + A. P = Plowing; C = Chemical; A = Abrasives; S = Sweeping; P+C = Plowing + Chemical treatment; or P + A = Plowing + Abrasives.

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December 3 1-61 OPACT03

Page ___ of ___

SOBO/CORALBA DATA RECORDING FORM 2

Name: Ed Fleege Agency: Minnesota Date: 4-10-92

Time: 08:48 Hours Test Location: TH 53 NB Mile Point 21.1

General Weather Condition: Snowing

General Pavement Condition: _____

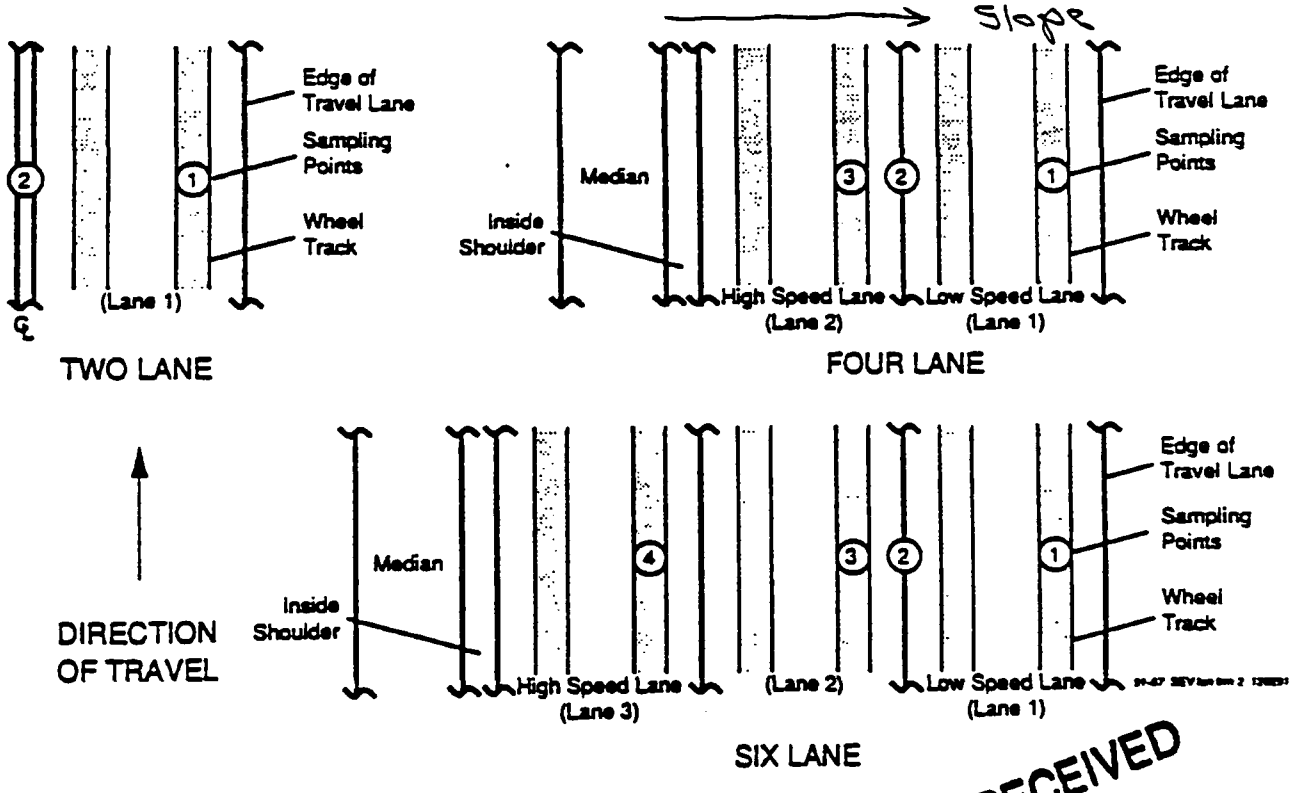
Type of Pavement: ____ Open Graded Asphalt ____ Dense Graded Asphalt X Concrete

No. of Lanes 2 Direction of Travel: Test Section _____ Control Section NB

Direction of Cross Slope: _____

Test Location Relative to Nearest RWIS Site: _____

TEST SECTION			CONTROL SECTION			COMMENTS
Sampling Point	Scale Factor	Sobo Reading	Sampling Point	Scale Factor	Sobo Reading	
1			1	0.1	5	wet
2			2	0.1	15	icy
3			3	0.1	13	snow
4			4			
5			5			
Coralba Reading: Lane 1: ____; Lane 2: ____; Lane 3: ____			Coralba Reading: Lane 1: 0.21; Lane 2: ____; Lane 3: ____			



SAMPLING POINTS FOR DIFFERENT ROAD CONFIGURATIONS

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APPENDIX D

SAMPLE CALCULATIONS

MIDWEST RESEARCH INSTITUTE

PROJECT DEVELOPMENT SKETCH

MRI-18

TITLE Sample Calculations for Test AP-5, Array D4

PROJECT NO. 9801-12 DRAWN _____ APPR. JSK DATE 9/30/92

1. Calculate measured PM-10 concentration (C) at each sampling height from Tables 4-2 and 4-3 using Eq. 3-1:

- Avg. blank correction (Array D3) $= \frac{0.80 + 1.60 + (-8.70)}{3}$ mg

$= -2.10$ mg

For 1-m sampler: subtract avg blank correction from gross catch

$(4.85 + 2.10)\text{ mg} \times 1{,}000 \frac{\mu g}{mg} \times \frac{1\text{ min}}{0.948\text{ m}^3} \times \frac{1}{220\text{ min}} = 33.3 \frac{\mu g}{m^3}$ PM-10

For 3-m sampler: same as above

$(3.85 + 2.10)\text{ mg} \times 1{,}000 \frac{\mu g}{mg} \times \frac{1\text{ min}}{1.21\text{ m}^3} \times \frac{1}{220\text{ min}} = 22.4 \frac{\mu g}{m^3}$ PM-10

For 5-m sampler: same as above

$(3.15 + 2.10)\text{ mg} \times 1{,}000 \frac{\mu g}{mg} \times \frac{1\text{ min}}{1.14\text{ m}^3} \times \frac{1}{220\text{ min}} = 20.9 \frac{\mu g}{m^3}$ PM-10

For 7-m sampler: same as above

$(3.50 + 2.10)\text{ mg} \times 1{,}000 \frac{\mu g}{mg} \times \frac{1\text{ min}}{1.19\text{ m}^3} \times \frac{1}{220\text{ min}} = 21.4 \frac{\mu g}{m^3}$ PM-10

2. Correct measured PM-10 concentrations for background (upwind):

MIDWEST RESEARCH INSTITUTE

PROJECT DEVELOPMENT SKETCH

MRI-18

TITLE Page 2 of Sample Calculations

PROJECT NO. _____ DRAWN _____ APPR. _____ DATE _____

— Linear regression of measured upwind concentrations (internal calc. program)

Measured concentrations = 13.3 $\frac{\mu g}{m^3}$ @ 1.5-m & 14.6 $\frac{\mu g}{m^3}$ @ 3-m

Resulting regression equation: PM-10 conc = 12 + 0.87 (height)

* For 1-m sampler: PM-10 conc. = 12 + 0.87 (1m) = 12.9 $\frac{\mu g}{m^3}$

* For 5-m sampler: PM-10 conc. = 12 + 0.87 (5m) = 16.4 $\frac{\mu g}{m^3}$

* For 7-m sampler: PM-10 conc. = 12 + 0.87 (7m) = 18.1 $\frac{\mu g}{m^3}$

— Net PM-10 concentrations:

* For 1-m sampler: (33.3 − 12.9) $\frac{\mu g}{m^3}$ = 20.4 $\frac{\mu g \text{ PM-10}}{m^3}$

* For 3-m sampler: (22.4 − 14.6) $\frac{\mu g}{m^3}$ = 7.8 $\frac{\mu g \text{ PM-10}}{m^3}$

* For 5-m sampler: (20.9 − 16.4) $\frac{\mu g}{m^3}$ = 4.5 $\frac{\mu g \text{ PM-10}}{m^3}$

* For 7-m sampler: (21.4 − 18.1) $\frac{\mu g}{m^3}$ = 3.3 $\frac{\mu g \text{ PM-10}}{m^3}$

3. Inter/extrapolate wind velocities at 3- & 7-m heights: assume straight log profile from measured velocities

MIDWEST RESEARCH INSTITUTE

PROJECT DEVELOPMENT SKETCH

MRI-18

TITLE Page 3 of Sample Calculations

PROJECT NO. _____ DRAWN _____ APPR. _____ DATE _____

Using log velocity from attached plot:

* At 3-m height: $3.9 \frac{mi}{hr} \times \frac{1\ hr}{3{,}600\ sec} \times 5{,}280\ \frac{ft}{mi} \times \frac{1\ m}{3.28\ ft} = 1.7 \frac{m}{sec}$

* At 7-m height: $4.7 \frac{mi}{hr} \times \frac{1\ hr}{3{,}600\ sec} \times 5{,}280\ \frac{ft}{mi} \times \frac{1\ m}{3.28\ ft} = 2.1 \frac{m}{sec}$

4. Calculate net PM-10 exposure (E_{10}) using Eq. 3-4 for each sampler height:

* For 1-m height: $20.4 \frac{\mu g}{m^3} \times 1.4 \frac{m}{sec} \times 220\ min \times 60 \frac{sec}{min} \times \frac{1\ m^2}{10^4\ cm^2} = 37.7 \frac{\mu g}{cm^2}$

* For 3-m height: $7.8 \frac{\mu g}{m^3} \times 1.7 \frac{m}{sec} \times 220\ min \times 60 \frac{sec}{min} \times \frac{1\ m^2}{10^4\ cm^2} = 17.5 \frac{\mu g}{cm^2}$

* For 5-m height: $4.5 \frac{\mu g}{m^3} \times 1.9 \frac{m}{sec} \times 220\ min \times 60 \frac{sec}{min} \times \frac{1\ m^2}{10^4\ cm^2} = 11.3 \frac{\mu g}{cm^2}$

* For 7-m height: $3.3 \frac{\mu g}{m^3} \times 2.1 \frac{m}{sec} \times 220\ min \times 60 \frac{sec}{min} \times \frac{1\ m^2}{10^4\ cm^2} = 9.14 \frac{\mu g}{cm^2}$

5. Perform one-dimensional integration of net exposures according to Eq. 3-5 using Simpson's Approximation extrapolated to 9-m plume height as shown by:

$$I_T = I_1 + I_2 = \int_1^9 E\, dh + \int_0^1 E\, dh$$

$$\cong \frac{h}{3}(1E_1 + 4E_3 + 2E_5 \ldots + 1E_n) + 1(E_1)$$

MRI Project No. 9801-12

Run No. A1-5

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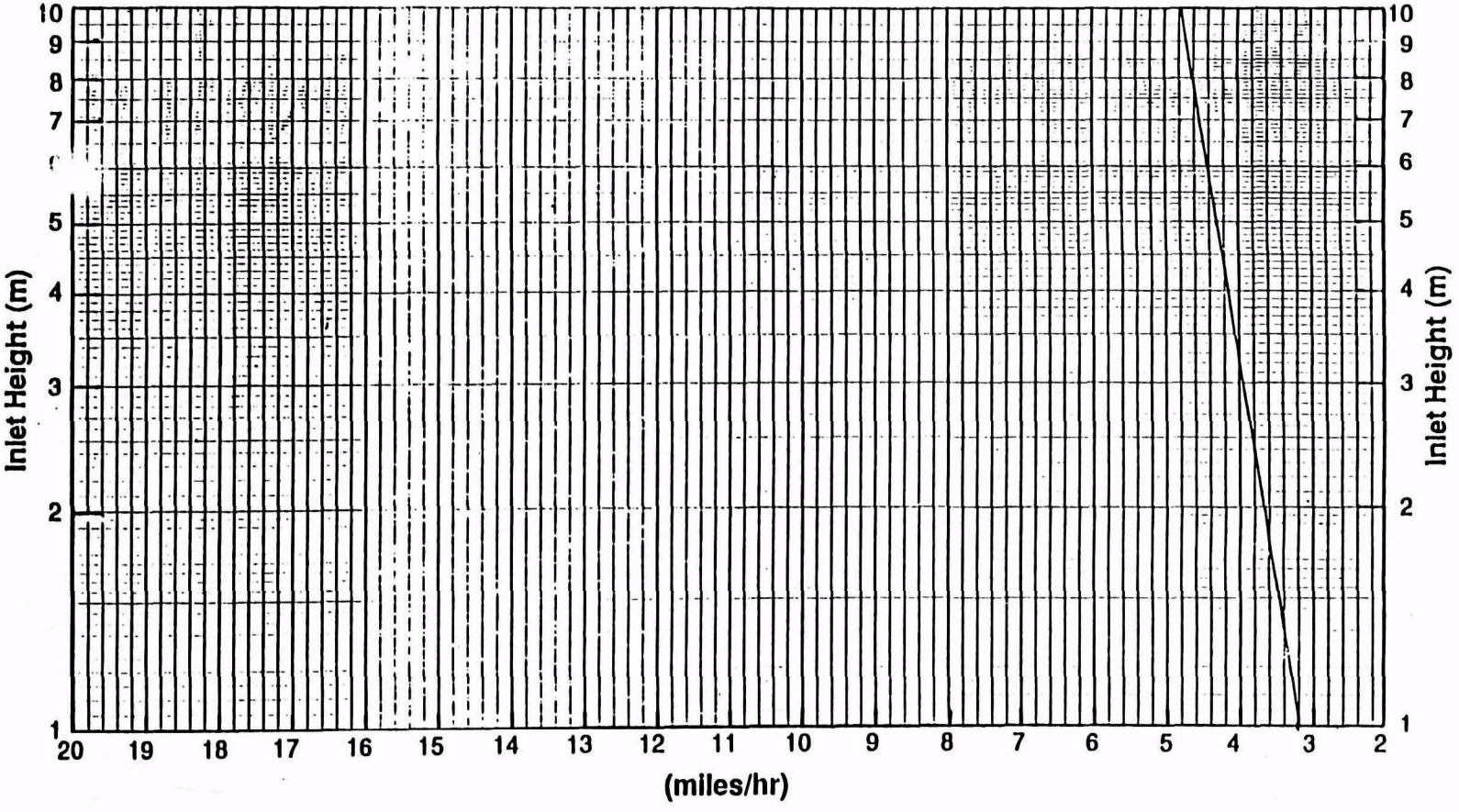
Fugitive Dust Emission Test
Total Test Avg.
Velocity Profile

Date 5/19/92

Recorded by JSK



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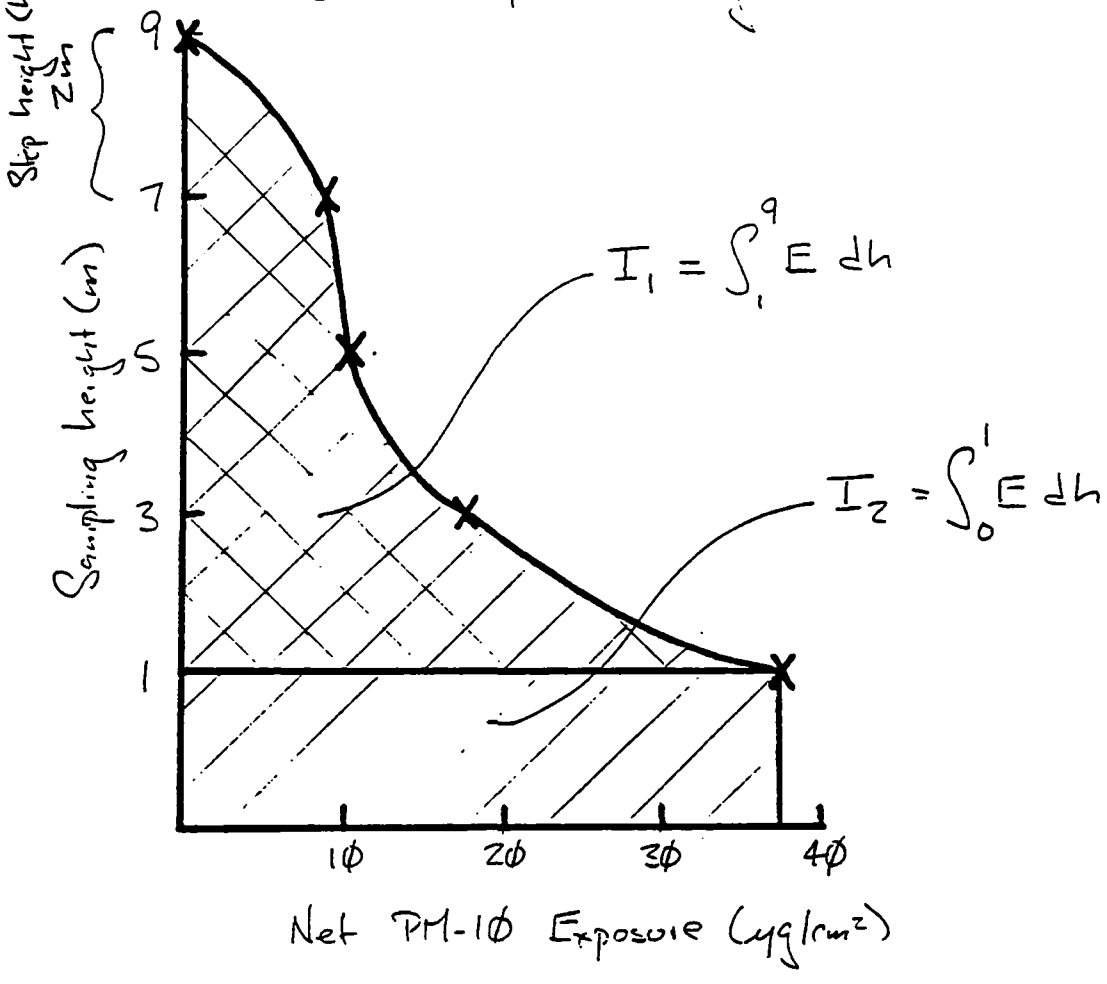
Graphically, the above integration extrapolated to 0 exposure @ 9-m plume height is illustrated as:



Integrating the net PM-10 exposures to obtain I_1 using Master Library Program No. 10 written for the TI-59 Programmable Calculator and combining with integrated exposure at 1-m gives:

$$I_T = I_1 + I_2 = (111.2 + 37.7) = 148.9 \text{ m}\cdot\mu g/cm^2$$

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6. Calculate PM-10 emission factor using Eq. 3-6:

$$e = 145 \frac{\cancel{\mu g}}{\cancel{cm^2}} \times \frac{1}{650 \text{ veh.}} \times \frac{1 \text{ gm}}{10^6 \cancel{\mu g}} \times 100 \frac{\cancel{cm}}{\cancel{m}} \times \frac{10^5 \cancel{cm}}{1 \text{ km}}$$

$$= 2.29 \text{ g/veh. km}$$

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/R-93-019	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Characterization of PM-10 Emissions from Antiskid Materials Applied to Ice- and Snow-Covered Roadways		5. REPORT DATE January 1993
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7. AUTHOR(S) John S. Kinsey		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Midwest Research Institute 425 Volker Boulevard Kansas City, Missouri 64110-2299		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-DO-0137, Tasks 12 and 71
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15. SUPPLEMENTARY NOTES AEERL project officer is Charles C. Masser, Mail Drop 62, 919/541-7586.

16. ABSTRACT The report gives results of a field program to establish a predictive model for PM-10 (particulate matter with diameters = or < 10 micrometers) emissions. (NOTE: Several areas of the U.S. in violation of the National Ambient Air Quality Standard for PM-10 have conducted studies that have identified the resuspension of antiskid material applied to paved roads as an important source of PM-10. The application of antiskid materials creates a temporary but substantial increase in the amount of fine particulate on the road surface over and above that which is normally present. Measured emission data are lacking for all types of antiskid materials.) A source-oriented emissions sampling procedure was conducted on a section of US 53 just west of Duluth, MN, during March/April 1992. The measured emission factors varied from 1 to 11 g/VKT (vehicle kilometer traveled) for the three tests conducted. The data were not sufficient, however, to develop any specific correlation between the measured emission factors and source parameters. The only general observation made was that PM-10 emissions appear to increase with the amount of antiskid material applied. A comparison of measured emission factors with those predicted by an EPA compilation of air pollutant emission factors indicated that most of the measured factors are higher than those predicted from silt-loading.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Deicers	Pollution Control	13B 01C, 08L
Particles	Stationary Sources	14G
Mathematical Models	Particulate	12A
Skid Resistance	Antiskid Material	13L
Pavements		
Abrasives		11K

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	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

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