&EPA Characterization of PM-10 Emissions from Antiskid Materials Applied to Ice- and Snow-Covered Roadways - Phase II

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National Risk Management Research Laboratory

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

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 identifying the resuspension of antiskid materials from urban paved roads as an important emission source. In this study, a field sampling program was conducted on 47th Street in Kansas City, Missouri, during February and March of 1993 to quantify the PM-10 emissions associated with the use of rock salt (NaCl) for ice and snow control. A baseline test was conducted in September of 1993. The emissions were determined using the exposure profiling technique. The measured emission factors spanned the following ranges:

- Total PM-10: 0.2 to 1.7 g/VKT (winter tests); 3.9 to 4.9 g/VKT (September test)
- PM-10 lead: $7.5 (10)^{-5}$ to $4.5 (10)^{-4}$ g/VKT (winter tests)
- PM-10 NaCl: 0.014 to 0.039 g/VKT (winter tests)

The wintertime emission factors for total PM-10 determined in this study were about an order of magnitude lower than the wintertime factors measured in the 1992 Duluth Study, which utilized a 90% sand 10% salt antiskid material. The studies concluded the sand from the antiskid material mixture that remained after the road had dried, constituted most of the silt loading, and PM-10 emission impact. Whereas the rock salt was removed from the road mostly in the melting slush and contributed only a few percent to the residual silt loading.

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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 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 certain antiskid materials, especially low durability abrasives, can create a temporary, but substantial, increase in the amount of fine particles on the paved 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 emissions 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 under dry conditions at eight sites, ranging from a freeway to a rural town road (Cowherd and Englehart 1984).

According to EPA's publication, *Compilation of Air Pollutant Emission Factors* (AP-42), the quantity of dust emissions from vehicle traffic on a paved roadway (per vehicle kilometer of travel—VKT) may be estimated using the following empirical expression (EPA 1985):

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

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/m²)

More recently, a revised emission factor model for predicting the PM-10 emissions from paved roads has been incorporated into the 5th edition of AP-42 (EPA 1995). This model is expressed as:

$$E = 4.6 \left(\frac{sL}{2}\right)^{0.65} \left(\frac{W}{3}\right)^{1.5} \tag{1-2}$$

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/m²)
W = average weight (tons) of the vehicles traveling on the road

The total loading (excluding litter) shown in the above equations is measured by sweeping and vacuuming lateral strips of a known area from each active travel lane. The silt fraction is determined by measuring the proportion of loose dry road dust that passes a 200-mesh screen, using a modified version of ASTM Method C 136 (ASTM 1993). Silt loading is the product of total loading and silt content. Average vehicle weight is determined from observations of the mix of traffic on the road of interest.

In a recent EPA study, 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 which produce lower road surface silt loadings and PM-10 emissions (Kinsey et al., 1990). Although that program provided guidance for the selection of antiskid materials, no direct information was developed regarding (a) the actual PM-10 emissions related to their use, (b) the changes in surface silt loading resulting from such application, or (c) the degree of control actually achieved by compliance with the

material selection criteria developed in the study. Therefore, field testing was needed to evaluate the applicability of the current emission factor equations (Eqs. 1-1 and 1-2) for predicting the PM-10 emissions resulting from the use of antiskid materials.

To address the above need, a field testing program was performed by Midwest Research Institute (MRI) during February and March of 1992 in Duluth, Minnesota (Kinsey, 1993). During these tests, the PM-10 emissions from a four-lane divided highway were determined using exposure profiling. Sampling was conducted during a total of three test periods following two minor storm events.* Moderate quantities of a sand-salt mixture (90% sand/10% rock salt) were applied to the road during each storm. The PM-10 emission factors developed in this study are shown in Table 1-1.

TABLE 1-1. EMISSION FACTORS DEVELOPED DURING 1992 DULUTH TESTING PROGRAM[a]

Run No.	Array No.	No. of vehicle passes	PM-10 emission factor (g/VKT)
AY-3	D-1	1,175	3.91
	D-4	983	10.6
AY-4	D-1	220	1.44
AY-5	D-4	650	2.29

[a] From Kinsey (1993).

Due to the unfavorable wind conditions during the mandatory testing periods following these storm events, the accuracy of the emission factors shown in Table 1-1 may vary by as much as an order of magnitude from the "true" PM-10 emissions from the test road. Additional measurements were needed, therefore, to supplement the results of the 1992 study, especially for deicing chemicals. This is the primary purpose of the work reported here.

In the current program, source testing was conducted during two separate time periods. The first testing phase, conducted in February and March of 1993, was devoted to the characterization of emissions from a paved road after the application of a common deicer (rock salt) consisting primarily of sodium chloride for ice and snow

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* Note that the winter of 1992 was very mild and lacked major storm events.

PM-10 emissions from the same road without the influence of the deicing chemical. The results of these tests are provided in the following sections and are compared to the Duluth experimental data obtained in 1992.

The remainder of this report is structured as follows: Section 2 describes the test 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 degrees 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, although most previous MRI tests of dust emissions from paved roadways were performed during warm, dry weather, the present study required testing in cold, wet conditions. The adverse weather conditions complicated both the deployment and operation of the sample collection equipment. Second, most 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, it was decided that one of four local sites (Table 2-1) currently active in another EPA-sponsored project should be used for emission testing. Although these sites had been selected for determining seasonal variations in surface silt loading, suitability for possible source testing also was considered during site selection. As such, each location provided (a) good orientation with respect to ambient winds, (b) lack of major obstructions in the prevailing wind direction, and (c) safe and easy access for installation and removal of sampling equipment. In addition, each of the sites were located near MRI's main laboratory in Kansas City, Missouri, which would substantially reduce logistical problems and response time after a storm event.

Table 2-1. DESCRIPTION OF CANDIDATE TEST SITES

Site No. 1: 47th Street (also known as Brush Creek) between Rockhill Road and Oak Street. This section of Brush Creek is a 6-lane road that is divided by a wide median. Sampling would take place approximately 385 ft west of the intersection with Rockhill Road.

Site No. 2: Paseo at 72nd Street. This location is a 4-lane boulevard also divided by a median. Sampling would take place about 100 ft south of the intersection with 72nd Street.

Site No. 3: Highway 71, in front of Mason Land Reclamation. This is a 2-lane (one-way) frontage road that is very heavily travelled due to road construction in the area. Sampling would take place approximately 20 ft north of the entrance to Mason Land Reclamation.

Site No. 4: 63rd Street (just east of Burns and McDonnell). This is an undivided 4-lane street with a very high traffic volume. Sampling of the emissions from all 4 lanes would be necessary. The sampling area starts approximately 150 ft west of the intersection at Manchester and 63rd Street.

From the four candidate sites, 47th Street between Rockhill Road and Oak Street was finally selected for emission testing (Figure 2-1). This particular road is a six-lane arterial maintained as part of Kansas City's boulevard system. The site was suitable for a number of reasons, including its orientation with respect to either northerly or southerly ambient winds, good cooperation by the local transportation agency (City of Kansas City, Parks and Recreation Department), and a desirable traffic volume during daylight hours.

A few shortcomings were noted, however, with respect to the source testing that took place at the 47th Street site. Although most of these problems were not unique to 47th Street, they did substantially influence the tests conducted.

First, because of the unusually high amount of precipitation occurring during each winter storm, snow was cast by the plows into relatively high piles near the curb of the test road. When ambient temperatures rose above freezing after the storm, the snow melt would flow directly onto the road surface, keeping it wet for long periods of time. Because it had previously been established that emission testing should be conducted only under dry pavement conditions, opportunities for source sampling were severely curtailed at ambient temperatures above the freezing point.

Second, the major intersections located on each end of the test section were controlled by traffic signals. These signals typically caused the vehicles to either accelerate or decelerate as they passed the sampling equipment. Moreover, this effect was influenced day to day by weather conditions. A relatively consistent vehicle speed is desirable during source testing to assure reproducible effects of traffic on road surface conditions.

Finally, a major construction project for flood control was located about two blocks south of the test site. Fugitive dust generated from this project had the potential to influence the measurements made during southerly wind conditions; however, the wet conditions that existed during most of the testing program are believed to have reduced the impact of construction dust emissions to a negligible level. Nonetheless, heavy trucks exiting the project did substantially influence the results of the September testing by increasing the surface silt loading as described in Section 4 below.
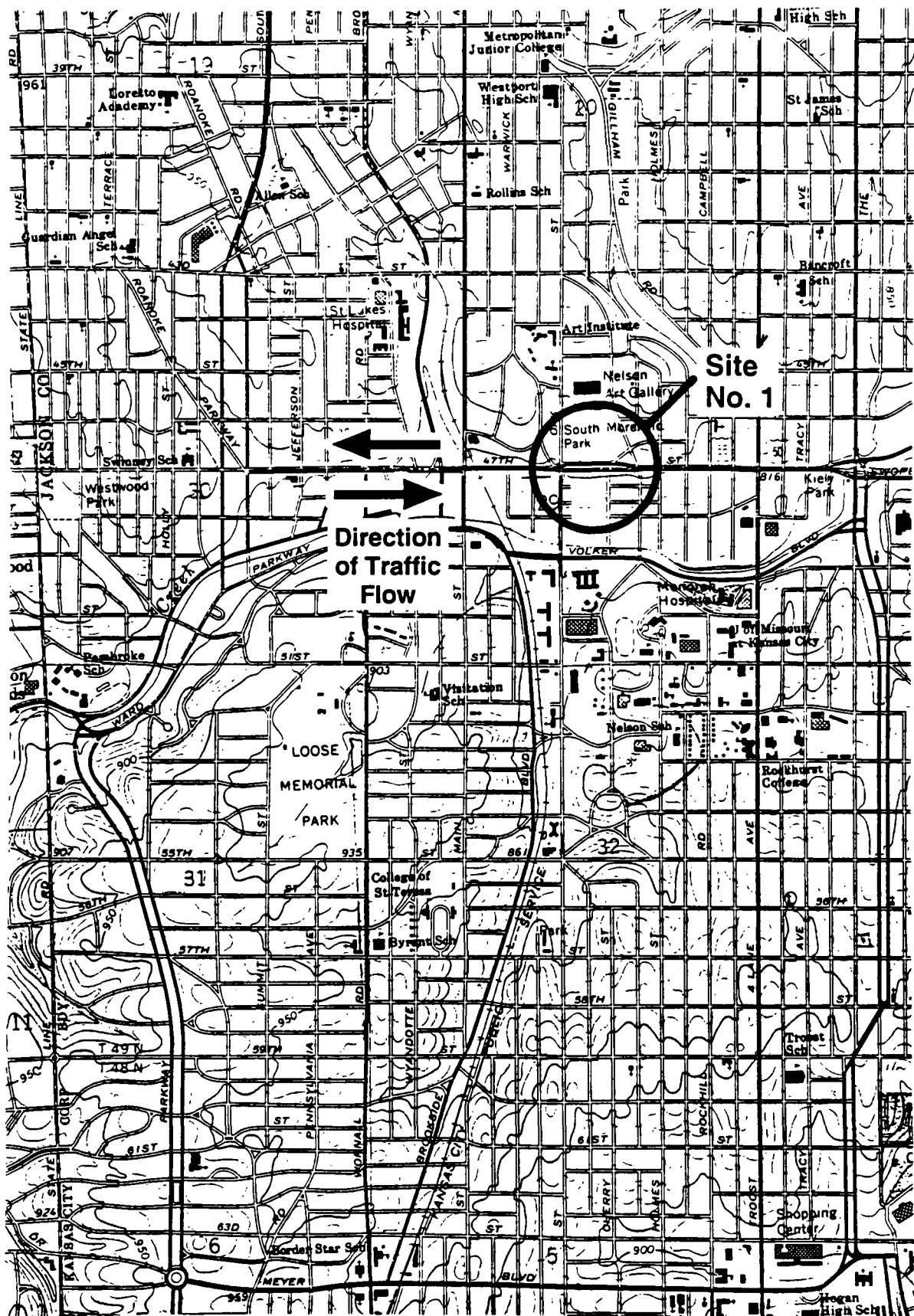
Figure 2-1. Location of 47th Street test site.

SECTION 3

OVERALL STUDY DESIGN

The source-directed field sampling conducted in this study employed the "exposure profiling" approach to quantify source emission contributions. This section describes the overall study design, including the procedures used for sample collection, chemical analysis, ancillary sample collection, and emission factor calculations.

3.1 GENERAL AIR SAMPLING EQUIPMENT AND TECHNIQUES

As indicated above, the "exposure profiling" technique was used for particulate source testing. This method 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, which uses a mass flux measurement scheme similar to EPA Method 5 (EPA, 1994a) for stack testing, does not require an 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 1986 EPA collaborative study (Pyle and McCain 1986).

For measurement of particulate emissions from moving point sources (roads), vertical networks of samplers (Figures 3-1a and 3-1b) were positioned downwind and upwind from the edge of the road. The downwind distance of 5 m was far enough from the road's edge that sampling interferences due to traffic-generated turbulence were usually minimal, but close enough to the source that the vertical plume extent could be adequately characterized with a maximum sampling height of about 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 usually affect sampling, and (b) a brief
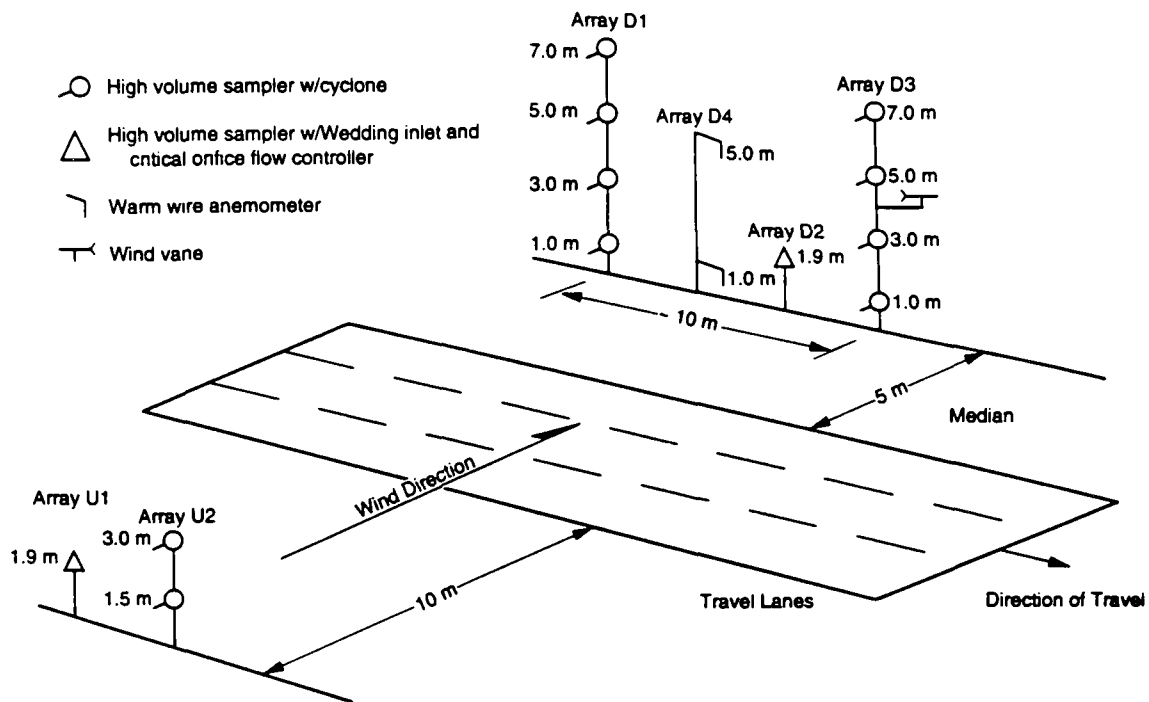
Figure 3-1a. Sampler deployment scheme for winter tests (all horizontal dimensions nominal).
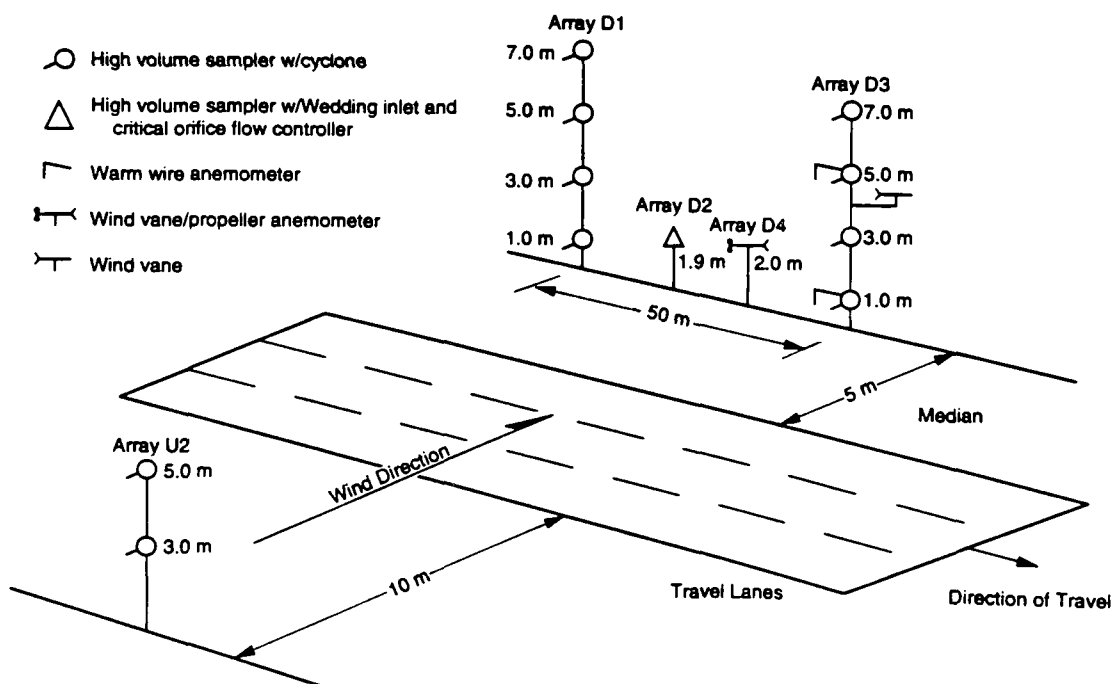
Figure 3-1b. Sampler deployment scheme for September tests (all horizontal dimensions nominal).

reversal did 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 mass flux (i.e., due to the source).

As shown in Tables 3-1a and 3-1b, the equipment deployment scheme made use of three downwind vertical sampling arrays, D1 through D3. Downwind arrays D1 and D3 (as well as upwind array U2) made use of high-volume (hi-vol) air samplers equipped with cyclone preseparators and critical orifice flow controllers. Arrays D2 and U1 used hi-vols equipped with Wedding PM-10 inlets and critical orifice flow controllers.

During the winter tests, the two vertical profiler arrays (D1 and D3) were located about 10 m apart. As such, the resultant profiling data can be considered as duplicate measurements of the same emissions. In the case of the September test, the two profilers were located a considerable distance from each other and thus represent independent measures of road emissions.

For each profiling trailer (e.g., Array D1 and D3), PM-10 samples were collected at four downwind measurement heights. Also, during the winter tests, concentrations of lead (Pb), sodium (Na^+), and chloride (Cl^-) were determined in the PM-10 samples collected at each height for one profiler array per test. The PM-10 (and lead measurements) made by the two Wedding reference instruments were used for comparison against data collected by the hi-vol/cyclone samplers.

The primary air sampling device in this program was a standard hi-vol air sampler fitted with a Sierra Model 230CP cyclone preseparator (Figure 3-2). The cyclone exhibits an effective 50% cutoff aerodynamic diameter (D_{50}) of approximately 10 microns (μm) 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) mounted at two heights. The vertical profile of wind speed was determined using data from these sensors, assuming a logarithmic distribution. Horizontal wind direction was also monitored by a wind vane at a single height, with 5-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.

TABLE 3-1a. SAMPLER DEPLOYMENT FOR WINTER TESTS

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

[a] Lead analysis by EPA Method 239.1 (EPA 1983a) (inductively coupled plasma atomic absorption spectroscopy).

[b] Lead analysis by EPA Method 200.9 (EPA 1994b) (graphite furnace atomic absorption spectroscopy).

TABLE 3-1b. SAMPLER DEPLOYMENT FOR SEPTEMBER TEST

Sampler array ID	No. of instruments	Measurement height(s) (meters)	Type of sampler or instrument	Parameter(s) measured
U2	2	3, 5	Hi-vol + cyclone	PM-10
D1, D3	4	1, 3, 5, 7	Hi-vol + cyclone	PM-10
D2	1	2	Hi-vol + Wedding inlet	PM-10
D3	1	4	Wind vane	Wind direction
D3	2	1, 5	Warm wire anemometer	Wind velocity
D4	1	3	Wind vane/propeller anemometer	Wind velocity and direction

Cyclone

Back-up Filter
Holder

0   5
Scale - Inches
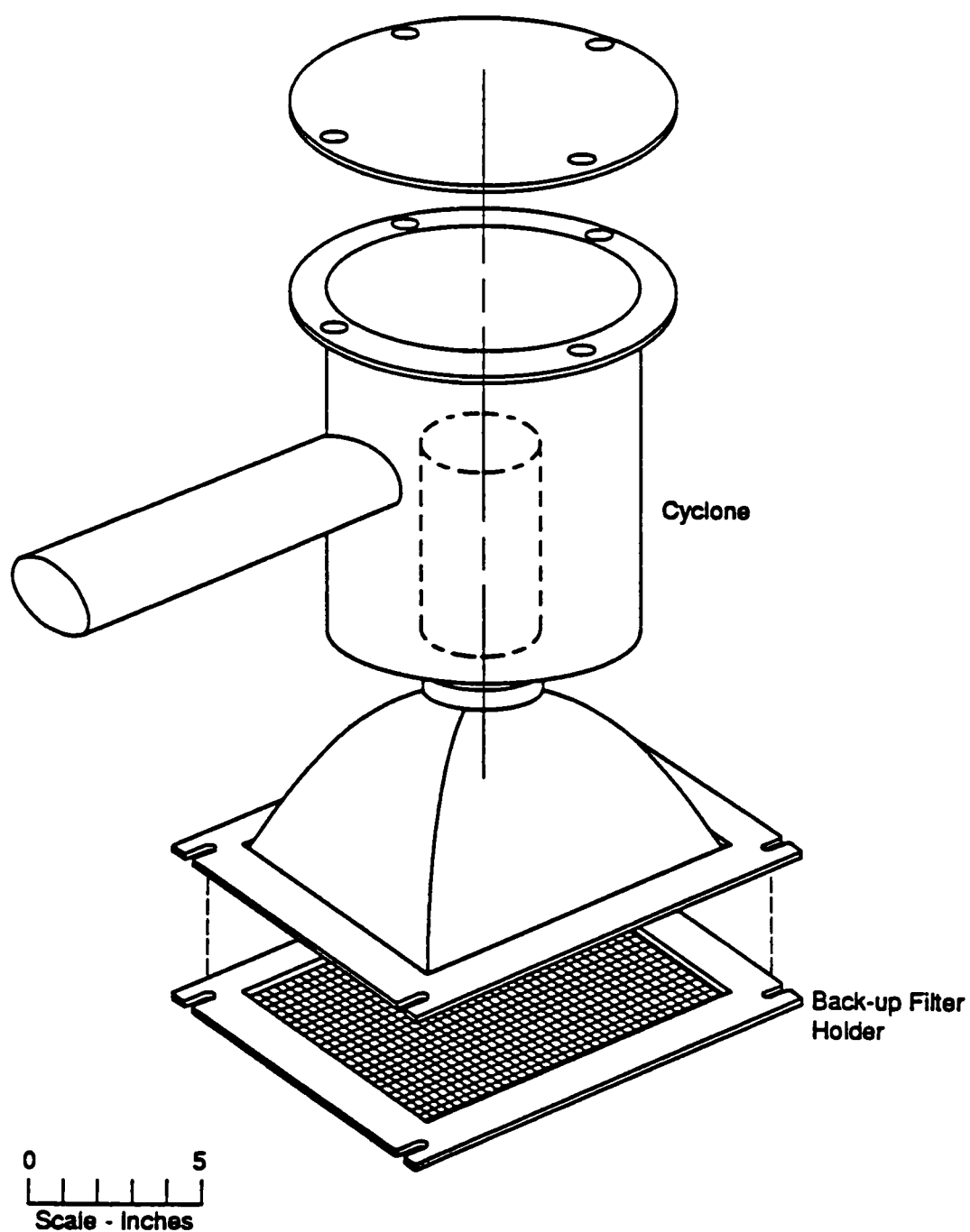
Figure 3-2. Diagram of high-volume cyclone sampler.

3.2 TESTING PROCEDURES

3.2.1 Preparation of Sample Collection Media

Particulate samples were collected on either Type AH grade glass fiber or QM-A microquartz 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 a second analyst reweighed them as a precision check. If a filter could not pass audit limits, the entire lot was reweighed. Ten percent (10%) 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 10% field blanks was collected for QC purposes (von Lehmden and Nelson, 1977). This procedure involved handling at least one 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. During 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 from the local U.S. Weather Service office. If conditions were considered acceptable, the sampling equipment was prepared for testing. Pretest preparations included calibration checks 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.

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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	For tare weights, conduct a 100% audit. Reweigh tare weight of any filters that deviate by more than ±1.0 mg. 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.
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 field blanks (see text).

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

Activity	QC check/requirement
Hi-vol air samplers	Single point calibration check using calibration orifice upon arrival at test site for comparison against standard table.
Orifice and electronic calibrator	Calibrate against displaced volume test meter annually.
Warm wire anemometers	Calibrate annually in standard wind tunnel.

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

- Air samples—Start/stop times, wind speed profiles, flow rates, and wind direction relative to the roadway perpendicular (5-min average). (See Table 3-4 for QC procedures.)

- Traffic count by vehicle type and speed.

- General meteorology—Wind speed, wind direction, temperature, and barometric pressure.

MRI has developed criteria for suspending or terminating a source test, which are presented in Table 3-5. With the exception of criterion 3 for the first and last test conducted (BC-1) and (BC-12), all of the criteria listed in Table 3-5 were met during the sampling program.

3.2.3   Sample Handling and Analysis

To prevent particulate losses, the exposed media were carefully transported at the end of each run to MRI's main laboratory. In the laboratory, exposed filters 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 from the winter tests were extracted and chemically analyzed by an outside laboratory to determine the concentration of Cl^-, Na^+, and/or Pb in selected PM-10 samples collected in the program (see Table 3-1a). The analytical procedures, and associated QA/QC, used for this purpose are described below.

TABLE 3-4. QUALITY CONTROL PROCEDURES FOR SAMPLING EQUIPMENT

Activity	QC check/requirement[a]
Maintenance	Check motors, gaskets, timers, and flow measuring devices prior to testing.
Operations	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] "Mean" denotes a 5- to 15-min average.

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.

3.3.1 Chloride Analysis

Selected filter samples were extracted following the 40 *CFR* 50, Appendix G, procedure (EPA 1994c) and analyzed for Cl^- using EPA Method 300.0 (EPA 1983b). 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 selected filter samples also was determined in the program. The filters were first extracted using the 40 *CFR* 50, Appendix G, procedure and then analyzed by EPA Method 273.1 (EPA 1983c). These techniques consist 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

Selected filters were analyzed for Pb content using the 40 *CFR* 50, Appendix G, extraction procedure (EPA 1994c), followed by either EPA Method 239.1 (EPA 1983a), or EPA Method 200.9 (EPA 1994b) for analysis. These techniques consist of sample extraction using dilute nitric acid, followed by either inductively coupled plasma (ICP) or graphite furnace atomic absorption (GFAA) 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.

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* Note that the samples from the two Wedding samplers (Arrays U1 and D2) were analyzed by the EPA Method 239.1, and the samples from the profilers (Arrays U2, D1, and D3) were analyzed using the EPA Method 200.9. This was the result of a problem at the subcontractor laboratory where the filter extracts from Arrays U1 and D2 were analyzed by ICP instead of GFAA and inadvertently discarded after analysis. In the case of the profiler filter extracts, the same samples analyzed for Cl^- were also used for the determination of lead content by GFAA.

3.4 ANCILLARY SAMPLE COLLECTION AND ANALYSIS

The types of ancillary samples and information collected were divided into two broad categories: antiskid materials and roadway surface samples, and 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 of the antiskid material applied to the road (winter testing only) and the dust on the road surface were obtained. 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 deicing chemical (rock salt or NaCl) applied during the study, appropriate material samples were collected and analyzed for silt content. Grab samples were taken from the stockpiled material distributed by the spreader trucks. The standard MRI procedures used for the collection and analysis of stockpile samples are provided in Appendix A.

To further characterize the deicing compound, the percent insoluble matter was determined using ASTM Method E 534 (ASTM 1991). This property was determined to be a good general indicator of overall silt production potential as determined in the laboratory study described earlier (Kinsey et al., 1990).

3.4.1.2 Road Surface Sampling and Analysis—
Surface sampling was conducted on both the westbound and eastbound lanes of 47th Street during the course of the program. The specific procedures used to collect and analyze paved road surface samples to determine silt loading are described in Appendix A.

In addition, ASTM Method E 534 (ASTM 1991) was used to determine the water insoluble fraction of the silt determined by dry sieving. This property was used as an indirect indicator of residual salt remaining on the road surface.

3.4.2 Source Activity Monitoring

Vehicle-related parameters were obtained using a combination of manual and automated counting techniques. Pneumatic tube axle counters were used to acquire 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 allowed the accuracy of the axle counter to be assessed. A radar gun was used during selected tests to determine the average speed of vehicles passing the sampler array.

Detailed information was collected by the Kansas City Parks and Recreation Department (KCP&R) personnel on the weather and condition of the pavement during the course of each winter storm and the types and amounts of deicing chemical applied. Although MRI was not directly responsible for collecting these data, this information was used to supplement the data obtained on source activity. MRI did, however, perform a gravimetric calibration of a typical spreader used by KCP&R to determine the equivalent amount of salt applied to the road from the data provided. Additional surface sampling was conducted at various points in time under a companion study, which was used to develop a silt-loading "history" of the test road. Sample forms completed by KCP&R personnel are included in Appendix B.

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:

$$C = 10^3 \frac{m}{Qt} \qquad (3\text{-}1)$$

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:

$$C_i = \frac{m_i}{Qt} \qquad (3\text{-}2)$$

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 inHg).

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:

$$IFR = \frac{Q}{aU} \qquad (3\text{-}3)$$

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 typically accepted 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 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:

$$E_{10} = 10^{-7} \times CUt \qquad (3\text{-}4)$$

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 repre-sents 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:

$$I = \int_O^H E_{10} \, dh \qquad (3\text{-}5)$$

where: I = integrated PM-10 (or compound-specific) exposure (m-mg/cm^2)
E_{10} = PM-10 (or compound-specific) 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 from 1 m to H using Simpson's approximation.

3.5.2 PM-10 Emission Methodology

The emission model for PM-10 generated by vehicular traffic on roadways, 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 also can be generated for NaCl and Pb by substituting the appropriate integrated exposure into the above calculation.

SECTION 4

FIELD SAMPLING PROGRAM

This section discusses the results of both the winter and September 1993 phases of the field-sampling program conducted on 47th Street.

4.1   SOURCE DESCRIPTION AND ACTIVITY

As stated in Section 2.2, the test site used in the experimental program was located on 47th Street between Oak Street and Rockhill Road in Kansas City, Missouri. This street has six lanes, which are used by commuter traffic to and from a major shopping and business area of the city at an approximate volume of 30,000 vehicles per day. Data collected during field sampling showed that essentially all of the traffic consisted of two-axle, light-duty vehicles traveling at an average speed of 46 km/h (29 mph). Surface loadings, determined both visually and by sampling, were generally very low, with nominal silt loadings in the range of 0.2 g/m^2.

During the winter tests, exposure profiling was performed after three storm events occurring on: February 15 and 16; February 25; and March 18 and 19, 1993. After the February 15 and 16 storm, three tests were attempted with two of these being complete runs. For the February 25 storm, one complete test was performed. During this particular test, however, the road surface was initially damp and later became wet with snow melt. Therefore, these particular data were not included in the emission factor calculations. (Note that this run sampled fine salt spray produced by passing vehicles and **not** particulate matter in the traditional sense.) Finally, an additional test was completed after the March 18 and 19 storm. A summary of the test conditions for each winter sampling period is provided in Table 4-1a.

During the first storm, approximately 5 in of snow fell on 47th Street during a 36-h period. Five applications of rock salt were applied to the road during the course

of 29 h, totaling 886 kg/lane-km (3,100 lb/lane-mi). During the February 25 storm, a total of 11 in of snow fell over a 24-h period. In this case, five applications of rock salt were applied during a period of 16 h, totaling 886 kg/lane-km (3,100 lb/lane-mi). Finally, during the last storm tested on March 18 and 19, a 1-in snowfall occurred during a 36-h period. During the final storm, only one application of rock salt was applied to 47th Street, totaling 177 kg/lane-km (620 lb/lane-mi).

In September 1993, one successful test was performed 2 days after a major rain storm. During this test, 47th Street was used by heavy vehicle traffic exiting the flood control project located south of the test site. The heavy trucks exiting the project tracked out mud and dirt, causing a substantial increase in the silt loading measured on the road surface as compared to the winter testing. This increase in silt loading was reflected in the measured PM-10 emissions provided below. A summary of the September test is shown in Table 4-1b. (Note that the two profiling towers should be considered independently and not as collocated measurements.)

The rock salt application rates used by KCP&R during the winter testing are fairly typical of most other transportation agencies as determined in a previous survey conducted by MRI (see Table 4-2). Further, most of the material applied was either eliminated with the snow melt or sprayed into the air as droplets by passing vehicles. Thus, the dry surface loadings observed after a storm were generally very low.

4.2 EXPOSURE PROFILING RESULTS

Summaries of the exposure profiling tests conducted on 47th Street were provided previously in Tables 4-1a and 4-1b. 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.

4.2.1 PM-10 Sampling Results

The results of the gravimetric analyses performed on the filter samples collected in the field are summarized in Tables 4-3a and 4-3b for the winter and September tests, respectively. Using the raw data provided in Tables 4-3a and 4-3b, the measured (i.e., blank-corrected) PM-10 concentrations were determined for the various sampling locations using the calculation scheme outlined in Section 3.5.

TABLE 4-1a. SUMMARY OF WINTER SOURCE TESTS

Test ID	Date of test	Sampler array	Operating period		Mean wind speed (m/s)[a]		Mean wind direction (degrees)[a]	Total vehicle passes during test period	Total deicer applied to roadway (kg/lane-km)
			Start time (h)	Stop time (h)	1.0-m height	5.0-m height			
BC-1	2/17/93	U1	1142	1645	–	–	–	3807	886[b]
		U2	1142	1645	–	–	–	3807	886[b]
		D1	1335	1635	1.8	3.0	315	2245	886[b]
		D2	1228	1635	1.7	3.0	315	3061	886[b]
		D3	1227	1536[c]	1.7	3.0	312	2342	886[b]
BC-2	2/18/93	U1	1555	1658	1.0	1.5	–	–	886[b]
		U2	1555	1658	1.0	1.5	–	–	886[b]
	(blanks)	D1,2,3	–	–	–	–	–	–	
BC-3	2/19/93	U1	0842	1412	–	–	–	4518	886[b]
		U2	0842	1412	–	–	–	4518	886[b]
		D1	0947	1357	3.4	3.9	200	3577	886[b]
		D2	1004	1405	3.4	3.9	200	3552	886[b]
		D3	1004	1405	3.4	3.9	200	3552	886[b]
BC-4[d]	2/28/93	U1	1009	1400	–	–	–	1760	886[b]
		U2	1009	1400	–	–	–	1760	886[b]
		D1	0958	1258	1.7	2.6	161	1371	886[b]
		D2	0958	1258	1.7	2.6	161	1371	886[b]
BC-5	3/20/93	U1	1010	1600	–	–	–	4655	177[e]
		U2	1010	1600	–	–	–	4655	177[e]
		D1	1053	1525	1.1	1.9	11	3617	177[e]
		D2	1055	1528	1.1	1.9	11	3639	177[e]
		D3	1055	1528	1.1	1.9	11	3639	177[e]

[a] Average of 5-min integration periods.

[b] Five passes of 177 kg/lane-km (620 lb/lane-mi) of 100% rock salt (NaCl).

[c] Samplers at 1- and 3-m were down for approximately 25 min.

[d] D3 did not run during this test. Road was wet during the entire test period; therefore this run is referred to as "salt spray" test.

[e] One pass of 177 kg/lane-km (620 lb/lane-mi) of 100% rock salt (NaCl).

TABLE 4-1b. SUMMARY OF SEPTEMBER SOURCE TESTS

| Test ID | Date of test | Sampler array | Operating period | | Mean wind speed (m/s)[a] | | Mean wind direction (degrees)[a] | Total vehicle passes during test period |
			Start time (h)	Stop time (h)	1.0-m height	5.0-m height		
BC-12	9/16/93	U2	1005	1156	–	–	–	–
		D1	1034	1155	1.0	1.2	140	969
		D2	1034	1155	1.0	1.2	140	969
		D3	1029	1152	1.1	1.3	144	1,016
BC-13 (blanks)	9/17/93	All	–	–	–	–	–	–

[a] Average of 5-min integration periods.

TABLE 4-2. AASHTO GUIDELINES FOR CHEMICAL APPLICATION RATES (Kinsey et al., 1990)

Weather conditions			Application rate (pounds of material per mile of two-lane road or two lanes of divided)			
Temperature	Pavement conditions	Precipitation	Low- and high-speed multilane divided	Two- and three-lane primary	Two-lane secondary	Instructions
30°F and above	Wet	Snow	300 salt	300 salt	300 salt	Wait at least 0.5 h before plowing
		Sleet or freezing rain	200 salt	200 salt	200 salt	Reapply as necessary
25°-30°F	Wet	Snow or sleet	Initial at 400 salt; repeat at 200 salt	Initial at 400 salt; repeat at 200 salt	Initial at 400 salt; repeat at 200 salt	Wait at least 0.5 h before plowing; repeat
		Freezing rain	Initial at 300 salt; repeat at 200 salt	Initial at 300 salt; repeat at 200 salt	Initial at 300 salt; repeat at 200 salt	Repeat as necessary
20°-25°F	Wet	Snow or sleet	Initial at 500 salt; repeat at 250 salt	Initial at 500 salt; repeat at 250 salt	1,200 of 5:1 sand/salt; repeat same	Wait about 0.75 h before plowing; repeat
		Freezing rain	Initial at 400 salt; repeat at 300 salt	Initial at 400 salt; repeat at 300 salt		Repeat as necessary
15°-20°F	Dry	Dry snow	Plow	Plow	Plow	Treat hazardous areas with 1,200 of 20:1 sand/salt
	Wet	Wet snow or sleet	500 of 3:1 salt/calcium chloride	500 of 3:1 salt/calcium chloride	1,200 of 5:1 sand/salt	Wait about 1 h before plowing; continue plowing until storm ends; then repeat application
Below 15°F	Dry	Dry snow	Plow	Plow	Plow	Treat hazardous area with 1,200 of 20:1 sand/salt

TABLE 4-3a. RESULTS OF GRAVIMETRIC ANALYSES FOR WINTER TESTS[a]

Test ID No.	Array ID No.	Sampling height (m)	Filter ID No.	Filter tare weight (mg)	Filter final weight (mg)	Weight difference (mg)
BC-1	U1	1.9	9311003	3300.30	3305.55	5.25
(2/17/93)	U2	1.5	9311001	3290.35	3295.20	4.85
		3.0	9311002	3303.10	3305.90	2.80
	D1	1.0	9311004	3298.55	3302.70	4.15
		3.0	9311005	3298.95	3301.60	2.65
		5.0	9311006	3281.00	3282.45	1.45
		7.0	9311007	3291.90	3293.50	1.60
	D2	1.9	9311008	3290.65	3295.55	4.90
	D3	1.0	9311009	3304.65	3304.90	0.25
		3.0	9311010	3308.85	3310.30	1.45
		5.0	9311011	3311.20	3313.90	2.70
		7.0	9311012	3306.30	3308.85	2.55
BC-2	U1	1.9	9311015	3252.50	3253.90	1.40
(2/18/93)	U2	1.5	9311013	3281.05	3282.00	0.95
		3.0	9311014	3249.55	3250.20	0.65
	D1 (blanks)	1.0	9311016	3239.00	3237.80	-1.20
		3.0	9311017	3291.35	3290.70	-0.65
		5.0	9311018	3298.30	3298.15	-0.15
		7.0	9311019	3305.10	3304.60	-0.50
	D2 (blank)	1.9	9311020	3319.40	3319.55	0.15
	D3 (blanks)	1.0	9311021	3312.60	3313.15	0.55
		3.0	9311022	3308.85	3308.95	0.10
		5.0	9311023	3300.00	3300.10	0.10
		7.0	9311024	3312.00	3311.55	-0.45
BC-3	U1	1.9	9311027	3302.90	3310.35	7.45
(2/19/93)	U2	1.5	9311025	3329.00	3335.65	6.65
		3.0	9311026	3316.00	3321.00	5.00

(Continued)

TABLE 4-3a (Continued)

Test ID No.	Array ID No.	Sampling height (m)	Filter ID No.	Filter tare weight (mg)	Filter final weight (mg)	Weight difference (mg)
	D1	1.0	9311028	3287.80	3295.80	8.00
		3.0	9311029	3297.55	3304.10	6.55
		5.0	9311030	3290.85	3295.50	4.65
		7.0	9311031	3307.70	3312.15	4.45
	D2	1.9	9311032	3300.10	3307.85	7.75
	D3	1.0	9311033	3293.65	3312.55	18.90
		3.0	9311034	3306.00	3312.85	6.85
		5.0	9311035	3301.20	3306.30	5.10
		7.0	9311036	3317.35	3322.10	4.75
BC-4[b]	U1	1.9	9311039	3296.40	3304.50	8.10
(2/28/93)	U2	1.5	9311037	3314.65	3321.50	6.85
		3.0	9311038	3302.70	3308.55	5.85
	D1	1.0	9311045	3348.00	3354.45	6.45
		3.0	9311046	3321.80	3327.30	5.50
		5.0	9311047	3311.45	3316.95	5.50
		7.0	9311048	3322.20	3327.15	4.95
	D2	1.9	9311044	3349.15	3355.35	6.20
BC-5	U1	1.9	9311051	3339.40	3353.30	13.90
(3/20/93)	U2	1.5	9311049	3314.85	3328.00	13.15
		3.0	9311050	3309.00	3321.25	12.25
	D1	1.0	9311040	3301.75	3317.00	15.25
		3.0	9311041	3303.85	3316.25	12.40
		5.0	9311042	3291.40	3302.70	11.30
		7.0	9311043	3330.10	3340.75	10.65
	D2	1.9	9311056	3322.70	3338.15	15.45
	D3	1.0	9311055	3337.95	3352.25	14.30
		3.0	9311054	3332.95	3345.05	12.10
		5.0	9311053	3332.85	3344.05	11.20
		7.0	9311052	3336.80	3347.40	10.60

[a] Includes all samples collected. All filters are Type AH glass fiber.

[b] Array D3 did not run during salt spray test.

TABLE 4-3b. RESULTS OF GRAVIMETRIC ANALYSES FOR SEPTEMBER TEST

Test ID No.	Array ID No.	Sampling height (m)	Filter ID No.	Filter tare weight (mg)	Filter final weight (mg)	Weight difference (mg)
BC-12 (9/16/93)	U2	3	9311119	3329.10	3332.55	3.45
		5	9311120	3321.25	3324.00	2.75
	D1	1	9311111	3320.50	3345.25	24.75
		3	9311112	3333.45	3343.10	9.65
		5	9311113	3347.85	3353.15	5.30
		7	9311114	3344.30	3347.65	3.35
	D2[a]	1.9	9312002	4320.55	4330.30	9.75
	D3	1	9311115	3355.00	3373.80	18.80
		3	9311116	3344.25	3357.30	13.05
		5	9311117	3354.25	3361.30	7.05
		7	9311118	3342.80	3347.75	4.95
BC-13 (9/17/93) (blanks)	U2	3	9311121	3328.35	3329.05	0.70
		5	9311122	3318.55	3320.00	1.45
	D1	1	9311130	3313.70	3313.60	−0.10
		3	9311129	3334.95	3334.20	−0.75
		5	9311128	3337.85	3337.80	−0.05
		7	9311127	3329.55	3329.40	−0.15
	D2[a]	1.9	9312003	4323.15	4323.55	0.40
	D3	1	9311126	3335.20	3335.30	0.10
		3	9311125	3339.50	3339.75	0.25
		5	9311124	3341.35	3341.35	0
		7	9311123	3337.00	3337.30	0.30

[a] Microquartz filter media. All others are Type AH glass fiber filters.

In these calculations, the net sample weight for each filter was first determined by subtracting the respective average filter blank value (from Tests BC-2 and BC-13, respectively) from the gross weight difference (Tables 4-3a and 4-3b). 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 Tables 4-4a and 4-4b for the winter and September tests, respectively, along with any comments relevant to the experimental data.

Using the data shown in Tables 4-4a and 4-4b, net (i.e., upwind-corrected) PM-10 concentrations were calculated at each height by subtracting the average of the upwind concentrations determined by Array U2. Using these net concentrations, the net PM-10 exposure was calculated for each sampler 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 Tables 4-5a and 4-5b for the winter and September tests, respectively, with a sample calculation for Test BC-5 provided in Appendix C.

Several factors should be noted with regard to the experimental results. First, the net (i.e., upwind corrected) PM-10 concentrations measured during the winter testing were generally low, whereas those measured in September were relatively high. Net concentrations ranging from approximately 0 to 15 $\mu g/m^3$ for most samplers in the winter tests (Table 4-5a) were, in many cases, only slightly above background. Higher net concentrations were obtained in September, however, substantially improving the reliability of the data.

Another factor involves the exposure profiles themselves. As indicated by Table 4-5a, in two out of the three winter tests conducted (Tests BC-1 and BC-5), the profiles are essentially flat (i.e., show little difference with height) over the first 7 m of the plume. Further, in the case of Test BC-1, only a 5-m plume height was estimated from the exposure data with corresponding wind speeds ranging from 1.8 to 3.3 m/s. Exposure profiles of this type are generally indicative of poor plume definition because of low emission impact (above background) during sample collection. The lack of a well-defined plume (and associated exposure profile) adversely affected the quality of the winter emission factors shown in Table 4-5a. No such problems were observed during the September testing.

TABLE 4-4a. SUMMARY OF EXPERIMENTAL RESULTS FOR WINTER TESTS

Test ID	Test date	Array ID No.	Sampling height (m)	Net filter weights (mg)			Sampler flow rate (std m³/min)	Sampling time (min)	Measured PM-10 concentration (μg/m³)	Comments/problems
				Gross catch	Blank correction	Blank-corrected[a]				
BC-1	2/17/93	U1	1.9	5.25	0.15	5.10	1.26	303	13.36	Wind integrator inoperable. Wind data collected manually. W-bound lanes tested. Test did not meet QA.
		U2	1.5	4.85	-0.28	5.13	1.28	303	13.23	
			3.0	2.80	-0.28	3.08	1.24	303	8.20	
		D1	1.0	4.15	-0.28	4.43	1.27	180	19.38	
			3.0	2.65	-0.28	2.93	1.26	180	12.92	
			5.0	1.45	-0.28	1.73	1.28	180	7.51	
			7.0	1.60	-0.28	1.88	1.25	180	8.36	
		D2	1.9	4.90	0.15	4.75	1.32	247	14.57	
		D3	1.0	0.25	-0.28	0.53	1.27	164[b]	2.54	Array D3 void due to malfunction of two bottom samplers.
			3.0	1.45	-0.28	1.73	1.27	164[b]	8.31	
			5.0	2.70	-0.28	2.98	1.26	189	12.51	
			7.0	2.55	-0.28	2.83	1.27	189	11.79	
BC-2	2/18/93	U1	1.9	1.40	0.15	1.25	1.25	63	15.87	Test aborted due to poor wind direction—blank run.
		U2	1.5	0.95	-0.28	1.23	1.26	63	15.50	
			3.0	0.65	-0.28	0.93	1.22	63	12.10	
	(blanks)	D1,3	–	-0.275 (avg)	–	–	–	–	–	–
		D2	–	0.15	–	–	–	–	–	–

(Continued)

TABLE 4-4a (Continued)

Test ID	Test date	Array ID No.	Sampling height (m)	Net filter weights (mg)			Sampler flow rate (std m³/min)	Sampling time (min)	Measured PM-10 concentration (µg/m³)	Comments/problems
				Gross catch	Blank correction	Blank-corrected[a]				
BC-3	2/19/93	U1	1.9	7.45	0.15	7.30	1.21	330	18.28	Winds from S to S-SW during test period. E-bound lanes tested. Test terminated when lanes became wet. Average vehicle speed was 31 mph.
		U2	1.5	6.65	−0.28	6.93	1.23	330	17.07	
			3.0	5.00	−0.28	5.28	1.19	330	13.45	
		D1	1.0	8.00	−0.28	8.28	1.21	250	27.37	
			3.0	6.55	−0.28	6.83	1.22	250	22.39	
			5.0	4.65	−0.28	4.93	1.21	250	16.30	
			7.0	4.45	−0.28	4.73	1.22	250	15.51	
		D2	1.9	7.75	0.15	7.35	1.27	241	24.01	
		D3	1.0	18.90	−0.28	19.20	1.21	241	65.84	
			3.0	6.85	−0.28	7.13	1.21	241	24.45	
			5.0	5.10	−0.28	5.38	1.22	241	18.30	
			7.0	4.75	−0.28	5.03	1.20	241	17.39	
BC-4	2/28/93	U1	1.9	8.10	0.15	7.95	1.26	231	27.31	Salt spray test. Data were not used for emission factor calculations. E-bound lanes tested.
		U2	1.5	6.85	−0.28	7.13	1.21	231	25.51	
			3.0	5.85	−0.28	6.13	1.19	231	22.30	
		D1	1.0	6.45	−0.28	6.73	1.22	180	30.65	
			3.0	5.50	−0.28	5.78	1.21	180	26.54	

(Continued)

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TABLE 4-4a (Continued)

Test ID	Test date	Array ID No.	Sampling height (m)	Net filter weights (mg) Gross catch	Net filter weights (mg) Blank correction	Net filter weights (mg) Blank-corrected[a]	Sampler flow rate (std m³/min)	Sampling time (min)	Measured PM-10 concentration (µg/m³)	Comments/problems
			5.0	5.50	−0.28	5.78	1.21	180	26.54	
			7.0	4.95	−0.28	5.23	1.21	180	24.01	
		D2	1.9	6.20	0.15	6.05	1.22	180	27.55	
BC-5	3/20/93	U1	1.9	13.90	0.15	13.80	1.24	350	31.80	W-bound lanes tested. Average vehicle speed was 27 mph.
		U2	1.5	13.15	−0.28	13.43	1.24	350	30.94	
			3.0	12.25	−0.28	12.53	1.21	350	29.59	
		D1	1.0	15.25	−0.28	15.53	1.25	272	45.68	
			3.0	12.40	−0.28	12.68	1.24	272	37.59	
			5.0	11.30	−0.28	11.58	1.24	272	34.33	
			7.0	10.65	−0.28	10.93	1.25	272	32.15	
		D2	1.9	15.45	0.15	15.30	1.29	273	43.44	
		D3	1.0	14.30	−0.28	14.76	1.24	273	43.60	
			3.0	12.10	−0.28	12.38	1.24	273	36.57	
			5.0	11.20	−0.28	11.48	1.23	273	34.19	
			7.0	10.60	−0.28	10.88	1.25	273	31.88	

[a] Corrected by average field blank values from Test BC-2, Arrays D1, D2, and D3, as indicated.

[b] Samplers off for approximately 25 min. Run time estimated by field personnel.

TABLE 4-4b. SUMMARY OF EXPERIMENTAL RESULTS FOR SEPTEMBER TEST (BC-12)

Test date	Array ID No.	Sampling height (m)	Net filter weights (mg) Gross catch	Net filter weights (mg) Blank correction	Net filter weights (mg) Blank-corrected[a]	Sampler flow rate (std m³/min)	Sampling time (min)	Measured PM-10 concentration (μg/m³)
9/16/93	U2	3	3.45	−1.08	2.37	1.18	111	18.09
		5	2.75	−1.08	1.67	1.18	111	12.75
	D1	1	24.75	0.05	24.80	1.19	81	257.3
		3	9.65	0.05	9.70	1.19	81	100.6
		5	5.30	0.05	5.35	1.19	81	55.50
		7	3.35	0.05	3.40	1.18	81	35.57
	D2	1.9	9.75	−0.40	9.35	1.19	81	97.00
	D3	1	18.80	0.05	18.85	1.18	83	192.5
		3	13.05	0.05	13.10	1.19	83	132.6
		5	7.05	0.05	7.10	1.18	83	72.49
		7	4.95	0.05	5.00	1.16	83	51.93

[a] Corrected by average field blank values from Test BC-13 as indicated.

TABLE 4-5a. RESULTS OF PM-10 EMISSION FACTOR CALCULATIONS FOR WINTER TESTS[a]

Run No.	Array No.	Sampler height (m)	Net PM_{10} concentration (μg/std m^3)[b]	Wind speed (m/s)	Net PM_{10} exposure ($\mu g/cm^2$)[c]	Integrated exposure (m-$\mu g/cm^2$)[d]	No. of vehicle passes	Measured PM_{10} emission factor (g/VKT)[e]
BC-1	D1	1	8.66	1.8	16.8	44.5	2245	0.20
(2/17/93)		3	2.20	(2.6)	6.18			
		5	0.0	3.0	0.0			
		7	0.0	(3.3)	0.0			
BC-3	D1	1	12.11	3.4	61.8	224	3577	0.63
(2/19/93)		3	7.13	(3.8)	40.6			
		5	1.04	3.9	6.08			
		7	0.25	(4.1)	1.54			
	D3	1	50.58	3.4	249	606	3552	1.7
		3	9.19	(3.8)	50.5			
		5	3.04	3.9	17.1			
		7	2.13	(4.1)	12.6			
BC-5	D1	1	15.41	1.1	27.7	135	3617	0.37
(3/20/93)		3	7.32	(1.7)	20.3			
		5	4.06	1.9	12.6			
		7	1.88	(2.1)	6.44			
	D3	1	13.33	1.1	24.0	118	3639	0.32
		3	6.30	(1.7)	17.5			
		5	3.92	1.9	12.2			
		7	1.61	(2.1)	5.53			

[a]   ( ) indicates inter/extrapolated value.

[b]   Net concentration calculated as difference between average upwind concentration and downwind concentration at each sampler height.

[c]   Rounded to three significant figures.

[d]   Integration scheme assumes constant exposure from 0 to 1 m height with Simpson's approximation used for integration between 1 m and effective plume height (H). H assumed to be 5 m for Test BC-1 and 9 m for all other tests.

[e]   Rounded to two significant figures.

TABLE 4-5b. RESULTS OF PM-10 EMISSION FACTOR CALCULATIONS FOR SEPTEMBER TEST[a]

Run No.	Array No.	Sampler height (m)	Net PM$_{10}$ concentration (μg/std m^3)[b]	Wind speed (m/s)	Net PM$_{10}$ exposure (μg/cm^2)[c]	Integrated exposure (m-μg/cm^2)[d]	No. of vehicle passes	Measured PM$_{10}$ emission factor (g/VKT)[e]
BC-12 (9/16)	D1	1	241.9	1.0	118	381	969	3.9
		3	85.18	(1.1)	45.5			
		5	40.08	1.2	23.4			
		7	20.15	(1.2)	11.8			
	D3	1	177.1	1.1	97.0	497	1016	4.9
		3	117.2	(1.3)	75.9			
		5	57.07	1.3	37.0			
		7	36.51	(1.4)	25.5			
		(9)	16.00	(1.5)	12.0			

[a] ( ) indicates inter/extrapolated value.

[b] Net concentration calculated as difference between average upwind concentration (Array U2) and downwind concentration at each sampler height.

[c] Rounded to three significant figures.

[d] Integration scheme assumes constant exposure from 0 to 1 m height with Simpson's approximation used for integration between 1 m and effective plume height (H). H assumed to be 9 m for Array D1 and 11 m for Array D3.

[e] Rounded to two significant figures.

Several observations also can be made about the emission factors themselves. First, the emission factors calculated in Table 4-5a appear to be unusually precise in one of the two tests (BC-5) where collocated profiler data were available. A more typical degree of precision was observed, however, in the other test (BC-3).

Second, during the first winter storm tested (Tests BC-1 and BC-3), the emissions appear to increase substantially (a factor of 3 to 8) with time (i.e., the emission factor for Test BC-1 is lower than that for Test BC-3). This would suggest that the flushing action of the snowmelt causes the road to be initially "clean" after the storm (i.e., a low silt loading), but the road becomes increasingly "dirty" as deposition from vehicles increases the surface silt loading.

Third, the two emission factors obtained immediately after the storm in Test BC-5 are slightly higher than those measured previously in Test BC-1, even though much less salt was applied to the road. These data indicate that factors other than salt application rate (e.g., overall surface silt loading) are better indicators of PM-10 emission potential.

Finally, the emission factors determined in September (Test BC-12) are substantially larger than even the highest value obtained in the winter (Test BC-3). The increase in emissions between the two data sets varies from about a factor of 2.5 to more than an order of magnitude. This trend is explainable based on increases in surface silt loading as discussed in Section 4.4 below.

4.2.2 Results of Chemical Analyses

As mentioned in Section 3.3, selected filters (including blank filters) from each of the winter tests were submitted for chemical analysis of Pb, Na^+, and Cl^- content. The concentration of lead in the PM-10 samples was determined both upwind and downwind of the road by two different methods. In the first method, filters from the two Wedding samplers (Arrays U1 and D2) were acid extracted and analyzed by ICP. In the second technique, filters from one profiler array (as well as Array U2) for each test were acid extracted and analyzed by GFAA (see Section 3.3). Since none of the filters analyzed by the ICP method were above the instrumental detection limit, only the results of the lead analyses conducted by GFAA will be presented here. These data are summarized in Table 4-6.

Test ID No.	Array ID No.	Sampling height (m)	Filter ID No.	Results of chemical analysis (ppm)[b]	Mass used in chemical analysis (mg)[c]	Mass of analyte on filter (mg)[d]	Blank-corrected sample weight (mg)[e]
BC-1	U2	1.5	9311001	3.87	1715.32	0.006638	0.006230
2/17/93		3.0	9311002	0.63	1614.28	0.001017	0.000609
	D1	1.0	9311004	0.63	1706.53	0.001075	0.000667
		3.0	9311005	0.45	1719.36	0.000774	0.000366
		5.0	9311006	0.34	1769.49	0.000602	0.000194
		7.0	9311007	0.48	1672.21	0.000803	0.000395
BC-2	U2	1.5	9311013	0.29	1567.14	0.000454	0.000046
2/18/93		3.0	9311014	0.29	1646.66	0.000478	0.000070
(blanks)	D1	1.0	9311016	0.23	1602.11	0.000368	–
		3.0	9311017	0.46	1077.13	0.000495	–
		5.0	9311018	< 0.23	1640.08	< 0.000377	–
		7.0	9311019	< 0.23	1711.99	< 0.000394	–
BC-3	U2	1.5	9311025	0.58	1694.16	0.000983	0.000575
2/19/93		3.0	9311026	0.49	1684.37	0.000825	0.000417
	D3	1.0	9311033	0.97	1667.18	0.001617	0.001209
		3.0	9311034	0.60	1712.44	0.001027	0.000619
		5.0	9311035	0.39	1668.99	0.000651	0.000243
		7.0	9311036	0.39	1330.53	0.000519	0.000111
BC-4	U2	1.5	9311037	0.33	1677.60	0.000554	0.000146
2/28/93		3.0	9311038	0.53	1152.42	0.000611	0.000203
	D1	1.0	9311045	0.53	1630.45	0.000864	0.000456
		3.0	9311046	0.41	1621.77	0.000665	0.000257
		5.0	9311047	0.40	1647.18	0.000659	0.000251
		7.0	9311048	0.35	1847.93	0.000647	0.000239

(Continued)

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TABLE 4-6 (Continued)

Test ID No.	Array ID No.	Sampling height (m)	Filter ID No.	Results of chemical analysis (ppm)[b]	Mass used in chemical analysis (mg)[c]	Mass of analyte on filter (mg)[d]	Blank-corrected sample weight (mg)[e]
BC-5	U2	1.5	9311049	3.49	1620.17	0.005654	0.005246
3/20/93		3.0	9311050	3.69	1248.12	0.004606	0.004198
	D1	1.0	9311040	4.82	1645.88	0.007933	0.007525
		3.0	9311041	3.53	1652.82	0.005834	0.005426
		5.0	9311042	3.67	1693.67	0.006216	0.005808
		7.0	9311043	3.34	1678.21	0.005605	0.005197

[a] Results for one downwind profiler array and upwind Array U2 for each test conducted. Originally, filters from the two Wedding instruments (Arrays U1 and D2) were to be analyzed for Pb by GFAA. However, due to an error at the subcontractor laboratory, these samples were analyzed by ICP and the extracts discarded. Therefore, the same extracts used for chloride were analyzed for lead using GFAA, and the results are reported in this table.

[b] Parts per million by weight. 1 μg/g = 1 ppm.

[c] Mass of filter and PM-10 sample. The filter was divided in half with one half used for chloride and lead analysis.

[d] Not blank corrected.

[e] Blank correction value = 0.000408 mg from Test BC-2, Array D1 applied to analyte mass in previous column.

In the case of sodium and chloride, filter sets from one downwind profiler array for each test (and Array U2) 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 Tables 4-7 and 4-8 for sodium and chloride, respectively.

To obtain the equivalent amount of NaCl contained on each filter analyzed, an ion balance was conducted using a 1:1 molar ratio of Na^+ to Cl^-. In this evaluation, the blank-corrected weight of both analytes (Tables 4-7 and 4-8) were used to calculate the stoichiometric quantity of NaCl present in the sample mass. If an insufficient amount of either ion was present to achieve a suitable balance, it was assumed that no NaCl was present in the PM-10 sample collected. The results of the ion balance calculations performed in the study are shown in Table 4-9.

As indicated in Table 4-9, minor quantities of NaCl were found in most samples collected, with the exception of Test BC-4. As mentioned previously, Test BC-4 was conducted under wet pavement conditions and thus measured fine salt spray instead of solid PM-10. For this reason, the data from Test BC-4 were not used in the derivation of PM-10 emission factors for NaCl as described below.

Using the data shown in Tables 4-6 and 4-9, compound-specific PM-10 emission factors were calculated for both Pb and NaCl. The same calculation procedure outlined previously for total PM-10 (see Sections 3.5 and 4.2.1) was used for this purpose.

In both cases, the concentration determined at each measurement height was calculated using the appropriate blank-corrected sample weight and the sampler operating data shown in Table 4-4a. Net concentrations of both analytes were then calculated by subtracting the average upwind value, and the applicable emission factor was obtained by integration of the net exposures. The compound-specific PM-10 emission factors determined in this manner are shown in Tables 4-10 and 4-11 for Pb and NaCl, respectively.

TABLE 4-7. RESULTS OF CHEMICAL ANALYSES FOR SODIUM ION (WINTER TESTS)

Test ID No.	Array ID No.	Sampling height (m)	Filter ID No.	Results of chemical analysis (ppm)[a]	Mass used in chemical analysis (mg)[b]	Mass of analyte on filter (mg)[c]	Blank-corrected sample weight (mg)[d]
BC-1	U2	1.5	9311001	209	1340.27	0.28012	0.0
2/17/93		3.0	9311002	336	1689.58	0.56770	0.19330
	D1	1.0	9311004	275	1592.44	0.43792	0.06352
		3.0	9311005	326	1581.19	0.51547	0.14107
		5.0	9311006	321	1512.22	0.48542	0.11102
		7.0	9311007	270	1619.52	0.43727	0.06287
BC-2	U2	1.5	9311013	188	1713.76	0.32219	0.0
2/18/93		3.0	9311014	237	1602.28	0.37974	0.00534
(blanks)	D1	1.0	9311016	205	1633.36	0.33484	–
		3.0	9311017	257	1632.01	0.41943	–
		5.0	9311018	254	1655.76	0.42056	–
		7.0	9311019	203	1589.88	0.32275	–
BC-3	U2	1.5	9311025	238	1639.99	0.39032	0.01592
2/19/93		3.0	9311026	286	1634.02	0.46733	0.09293
	D3	1.0	9311033	397	1642.12	0.65192	0.27752
		3.0	9311034	246	1598.08	0.39313	0.01873
		5.0	9311035	237	1634.73	0.38743	0.01303
		7.0	9311036	240	1989.39	0.47745	0.10305
BC-4	U2	1.5	9311037	285	1641.63	0.46786	0.09346
2/28/93		3.0	9311038	233	1596.26	0.37193	0.0
	D1	1.0	9311045	253	1721.69	0.43559	0.06119
		3.0	9311046	244	1703.75	0.41572	0.04132
		5.0	9311047	227	1665.68	0.37811	0.00371
		7.0	9311048	296	1475.73	0.43682	0.06242

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TABLE 4-7 (Continued)

Test ID No.	Array ID No.	Sampling height (m)	Filter ID No.	Results of chemical analysis (ppm)[a]	Mass used in chemical analysis (mg)[b]	Mass of analyte on filter (mg)[c]	Blank-corrected sample weight (mg)[d]
BC-5	U2	1.5	9311049	259	1707.53	0.44225	0.06785
3/20/93		3.0	9311050	222	1564.74	0.34737	0.0
	D1	1.0	9311040	331	1670.59	0.55297	0.17857
		3.0	9311041	269	1662.55	0.44723	0.07283
		5.0	9311042	251	1605.52	0.40299	0.02859
		7.0	9311043	352	1660.59	0.58453	0.21013

[a] Parts per million by weight. 1 ppm = 1 μg/g.

[b] Mass of filter and PM-10 sample. The filter was divided in half with one half used for sodium.

[c] Not blank-corrected.

[d] Average blank correction = 0.37440 mg from Test BC-2, Array D1 applied to analyte mass in previous column.

TABLE 4-8. RESULTS OF CHEMICAL ANALYSES FOR CHLORIDE ION (WINTER TESTS)

Test ID No.	Array ID No.	Sampling height (m)	Filter ID No.	Results of chemical analysis (ppm)[a]	Mass used in chemical analysis (mg)[b]	Mass of analyte per filter (mg)[c]	Blank-corrected sample weight (mg)[d]
BC-1	U2	1.5	9311001	18	1715.32	0.03088	-0-
2/17/93		3.0	9311002	20	1614.28	0.03229	0.00046
	D1	1.0	9311004	118	1706.53	0.20137	0.16954
		3.0	9311005	66	1719.36	0.11348	0.08165
		5.0	9311006	38	1769.49	0.06724	0.03541
		7.0	9311007	28	1672.21	0.04682	0.01499
BC-2	U2	1.5	9311013	20	1567.14	0.03134	-0-
2/18/93		3.0	9311014	19	1646.66	0.03129	-0-
(blanks)	D1	1.0	9311016	18	1602.11	0.02884	–
		3.0	9311017	27	1654.92	0.04468	–
		5.0	9311018	14	1640.08	0.02296	–
		7.0	9311019	18	1711.99	0.03082	–
BC-3	U2	1.5	9311025	22	1694.16	0.03727	0.00544
2/19/93		3.0	9311026	24	1684.37	0.04042	0.00859
	D3	1.0	9311033	91	1667.18	0.15171	0.11988
		3.0	9311034	48	1712.44	0.08220	0.05037
		5.0	9311035	17	1668.99	0.02837	-0-
		7.0	9311036	18	1330.53	0.02395	-0-
BC-4	U2	1.5	9311037	16	1677.60	0.02684	-0-
2/28/93		3.0	9311038	< 20	1709.41	< 0.03419	-0-
	D1	1.0	9311045	47	1630.45	0.07663	0.04480
		3.0	9311046	15	1621.77	0.02433	-0-
		5.0	9311047	15	1647.18	0.02471	-0-
		7.0	9311048	16	1847.93	0.02957	0.0

(Continued)

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TABLE 4-8 (Continued)

Test ID No.	Array ID No.	Sampling height (m)	Filter ID No.	Results of chemical analysis (ppm)[a]	Mass used in chemical analysis (mg)[b]	Mass of analyte per filter (mg)[c]	Blank-corrected sample weight (mg)[d]
BC-5	U2	1.5	9311049	20	1620.17	0.03240	0.00057
3/20/93		3.0	9311050	44	1755.74	0.07725	0.04542
	D1	1.0	9311040	65	1645.88	0.10698	0.07515
		3.0	9311041	69	1652.82	0.11404	0.08221
		5.0	9311042	46	1693.67	0.07791	0.04608
		7.0	9311043	23	1678.21	0.03860	0.00677

[a] Parts per million by weight. 1 ppm = 1 µg/g.

[b] Mass of filter and PM-10 sample. The filter was divided in half with one half used for chloride and lead.

[c] Not blank-corrected.

[d] Blank correction value = 0.03183 mg from Test BC-2, Array D1 applied to analyte mass in previous column.

TABLE 4-9. RESULTS OF ION BALANCE FOR NaCl (WINTER TESTS)[a]

Test ID No.	Array ID No.	Sampling height (m)	Filter ID No.	Cl⁻ blank-corrected weight (mg)	Na⁺ blank-corrected weight (mg)	Equivalent mass of NaCl based on ion balance (mg)
BC-1	U2	1.5	9311001	-0-	-0-	-0-
2/17/93		3.0	9311002	0.00046	0.19330	0.00076
	D1	1.0	9311004	0.16954	0.06352	0.16158
		3.0	9311005	0.08165	0.14107	0.13456
		5.0	9311006	0.03541	0.11102	0.05836
		7.0	9311007	0.01499	0.06287	0.02471
BC-3	U2	1.5	9311025	0.00544	0.01592	0.00898
2/19/93		3.0	9311026	0.00859	0.09293	0.01417
	D3	1.0	9311033	0.11988	0.27752	0.19756
		3.0	9311034	0.05037	0.01873	0.04765
		5.0	9311035	-0-	0.01303	-0-
		7.0	9311036	-0-	0.10305	-0-
BC-4	U2	1.5	9311037	-0-	0.09346	-0-
2/28/93		3.0	9311038	< 0.00236	-0-	-0-
	D1	1.0	9311045	0.04480	0.06119	0.07384
		3.0	9311046	-0-	0.04132	-0-
		5.0	9311047	-0-	0.00371	-0-
		7.0	9311048	-0-	0.06242	-0-
BC-5	U2	1.5	9311049	0.00057	0.06785	0.00095
3/20/93		3.0	9311050	0.04542	-0-	-0-
	D1	1.0	9311040	0.07515	0.17857	0.12385
		3.0	9311041	0.08221	0.07283	0.13549
		5.0	9311042	0.04608	0.02859	0.07272
		7.0	9311043	0.00677	0.21013	0.01116

[a]   Stoichiometric quantity of NaCl in sample mass using minimum quantity of either Na⁺ or Cl⁻ to achieve a 1:1 molar balance.

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TABLE 4-10. COMPOUND-SPECIFIC PM-10 EMISSION FACTOR CALCULATIONS FOR LEAD (Pb)

Run No.	Array No.	Sampler height (m)	Measured lead concentration (μg/std m^3)	Net lead concentration (μg/std m^3)	Wind speed (m/s)[a]	Net lead exposure (μg/cm^2)[b]	Integrated exposure (m-μg/cm^2)[c]	No. of vehicle passes	Lead emission factor (g/VKT)[d]
BC-1	D1	1.0	0.00292	-0-	1.8	-0-	–	2245	Nil
(2/17/93)		3.0	0.00161	-0-	(2.6)	-0-		–	
		5.0	0.00084	-0-	3.0	-0-		–	
		7.0	0.00176	-0-	(3.3)	-0-		–	
BC-3	D3	1.0	0.00415	0.00291	3.4	0.0143	0.0266	3552	7.5 (10)$^{-5}$
(2/19/93)		3.0	0.00212	0.00088	(3.8)	0.00102		–	
		5.0	0.00083	-0-	3.9	-0-		–	
		7.0	0.00038	-0-	(4.1)	-0-		–	
BC-5	D1	1.0	0.02213	0.01113	1.1	0.0200	0.155	3617	4.3 (10)$^{-4}$
(3/20/93)		3.0	0.01609	0.00509	(1.7)	0.0141		–	
		5.0	0.01722	0.00622	1.9	0.0193		–	
		7.0	0.01529	0.00429	(2.1)	0.0147		–	

[a] ( ) indicates inter/extrapolated value.

[b] Rounded to three significant figures.

[c] Plume height (H) assumed to be 5 m for Test BC-3 and 11 m for Test BC-5.

[d] Includes only Pb found in particles $\leq$ 10 μm in aerodynamic diameter. Rounded to two significant figures.

Run No.	Array No.	Sampler height (m)	Measured NaCl concentration (μg/std m^3)	Net NaCl concentration (μg/std m^3)*	Wind speed (m/s)[a]	Net NaCl exposure (μg/cm^2)[b]	Integrated exposure (m-μg/cm^2)[c]	No. of vehicle passes	NaCl emission factor (g/VKT)[d]
BC-1	D1	1.0	0.70682	0.70581	1.8	1.37	8.83	2245	0.039
(2/17/93)		3.0	0.59330	0.59229	(2.6)	1.66			
		5.0	0.25330	0.25229	3.0	0.817			
		7.0	0.10982	0.10881	(3.3)	0.388			
BC-3	D3	1.0	0.67748	0.64802	3.4	3.19	7.28	3552	0.021
(2/19/93)		3.0	0.16340	0.13394	(3.8)	0.736			
		5.0	-0-	-0-	3.9	-0-			
		7.0	-0-	-0-	(4.1)	-0-			
BC-5	D1	1.0	0.36426	0.36316	1.1	0.652	5.22	3617	0.014
(3/20/93)		3.0	0.40171	0.40061	(1.7)	1.11			
		5.0	0.21561	0.21451	1.9	0.665			
		7.0	0.03282	0.03172	(2.1)	0.109			

[a] ( ) indicates inter/extrapolated value.

[t] Rounded to three significant figures.

[c] Plume height (H) assumed to be 9 m for Tests BC-1 and BC-5 and 5 m for Test BC-3.

[d] Includes only NaCl found in particles ≤ 10 μm in aerodynamic diameter. Rounded to two significant figures.

As observed from Tables 4-10 and 4-11, the emission factors calculated for Pb and NaCl are generally very low. In the case of Pb, the emission factors are negligible as compared to total PM-10 (Table 4-5a). The emission factors for NaCl, on the other hand, are substantially higher, but still only represent about 1% to 4% of the total PM-10 emitted from the road in two of the three tests conducted. These results indicate that the contribution of both analytes to the total PM-10 emissions is minor.

4.3   RESULTS OF ANCILLARY SAMPLING AND ANALYSIS

4.3.1   Antiskid Material Samples

A sample of rock salt was collected from the KCP&R storage pile according to the procedures outlined in Appendix A. This sample was split and analyzed for silt content and percent insoluble matter. The analytical results obtained for the antiskid material samples collected are summarized in Table 4-12.

In previous research conducted by MRI, a preliminary selection criterion of < 2% insoluble matter was established by Kinsey et al. (1990) for chloride-based deicing compounds. As noted from Table 4-12, the average insoluble content of the salt samples analyzed was only slightly above the 2% value and thus considered acceptable.

TABLE 4-12. PROPERTIES OF ROCK SALT SAMPLES
COLLECTED FROM KCP&R STOCKPILE

Material property	Measured value
Silt content (wt. %)[a]	1.6
Percent insoluble matter (wt. %)	2.3[b]

[a] Percent of material less than 200 mesh or 75 μm in physical diameter.

[b] Average of triplicate samples.

4.3.2 Road Surface Sampling

Road surface sampling was performed throughout the period that field testing was attempted. Samples were collected and analyzed to determine silt loading, using the procedures outlined in Appendix A, and percent insoluble matter using ASTM Method E 534 (ASTM 1991). Surface samples were collected from both the eastbound and westbound lanes near the air sampling site. The silt-loading values and percent insolubles obtained from the various samples collected are shown in Table 4-13 for the winter tests and for the September tests.

As shown from the surface sampling results in Table 4-13, the silt loadings measured in the study varied considerably during the course of the study around a typical value of about 0.2 g/m^2. The highest silt-loading value was measured in September as part of Test BC-12.

Except for the two samples collected in January, the insoluble matter found in the silt fell within a fairly narrow range of 91% to 98% (i.e., 2% to 9% water soluble fraction) regardless of time of year. Assuming that all of the water soluble fraction consists of rock salt, these results would suggest that, except during the especially heavy salt application periods in January, very little residual NaCl is normally present in the silt on the road surface. Thus the application of rock salt for ice and snow control should not substantially affect PM-10 emissions from the road.

Using the data provided in Table 4-13, a "silt-loading history" was developed for the entire period that samples were collected. This history is provided in Figures 4-1a and 4-2b for the winter and summer months, respectively. Also shown in Figure 4-1a and Figure 4-1b are the days when source testing took place, and on Figure 4-1a the occurrence of snowstorm events. Rainstorm event records for the period shown in Figure 4-1b are not currently available.

Finally, PM-10 emission factor estimates were also calculated from the silt-loading data shown in Table 4-13 using the existing AP-42 predictive model provided previously as Eq. (1-1). For comparison, similar calculations were performed utilizing the new emission factor model shown as Eq. (1-2). Emission factors were predicted for eastbound and westbound lanes, as applicable, in units of grams per vehicle kilometer traveled (g/VKT).

TABLE 4-13. RESULTS OF ROAD SURFACE SAMPLING

Date	Lane sampled[a]	Sample bag no.	Road surface area sampled ft^2	Road surface area sampled m^2	Sample mass (g)[b]	Total surface loading lb/lane-mi[c]	Total surface loading g/m^2	Silt content (wt %)[d]	Percent H$_2$O insolubles in silt (wt. %)[e]	Road surface silt loading lb/lane-mi[c]	Road surface silt loading g/m^2
12/23/92	WB	107	2800	260	380.9	19.1	1.47	1.50	93.9	0.287	0.0221
01/06/93	WB	97	2800	260	496.6	24.8	1.91	13.1	68.3	3.24	0.250
01/15/93	WB	89	2700	251	540.1	27.9	2.15	9.89	62.4	2.76	0.213
01/26/93	WB	86	2700	251	426.3	22.0	1.70	13.7	96.1	3.02	0.233
02/18/93	EB	43	2583	240	1325.1	71.6	5.52	1.1	91.4[f]	0.787	0.0607
03/07/93	WB	58	2800	260	378.2	18.8	1.45	27.9	97.5	5.25	0.405
03/20/93	WB	–	1396	130	559.5	55.8	4.30	12.8	92.4[f]	7.13	0.550
6/10/93	WB	53	2800	260	287.7	14.4	1.11	9.11	96.7	1.30	0.100
9/15/93	EB	32	530	49.3	134.1	35.3	2.72	8.56	96.9[g]	3.02	0.233
9/16/93	EB	35	722	67.2	1215.8	235	18.1	7.93	97.9[g]	18.7	1.44

[a] WB = westbound lanes; EB = eastbound lanes.

[b] Sample mass = total net loading.

[c] Calculated assuming a 12-ft lane width. 1 g/m^2 = 12.97 lb/lane-mi.

[d] Silt = % < 200 mesh or 75 μm physical diameter determined by dry sieving.

[e] Percent of silt mass which is not soluble in water. Used as an indirect indicator of residual NaCl on road surface.

[f] Average of triplicate analyses.

[g] Average of duplicate analyses.

SILT LOADING HISTORY (WINTER)
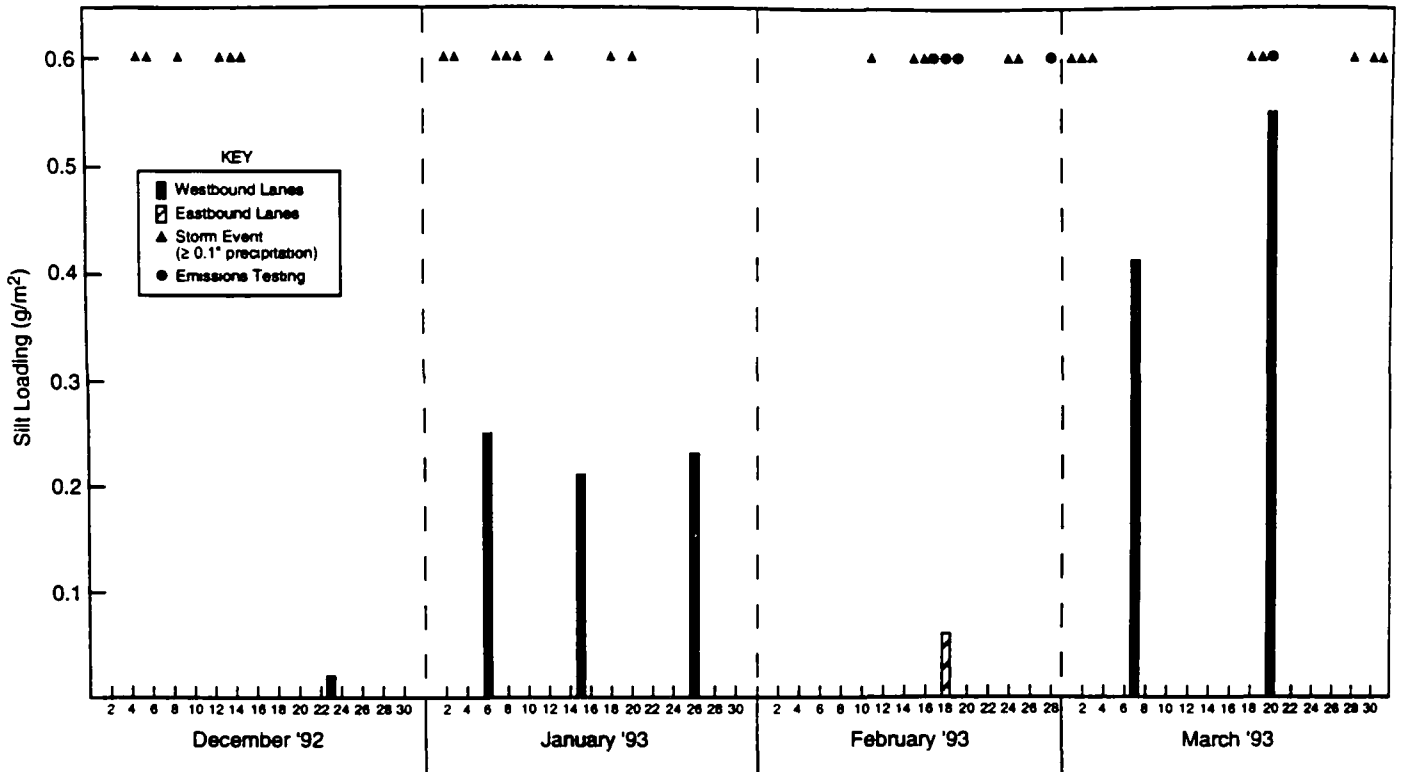
Figure 4-1a. Silt-loading history for the winter months of 1993.

SILT LOADING HISTORY (SUMMER)
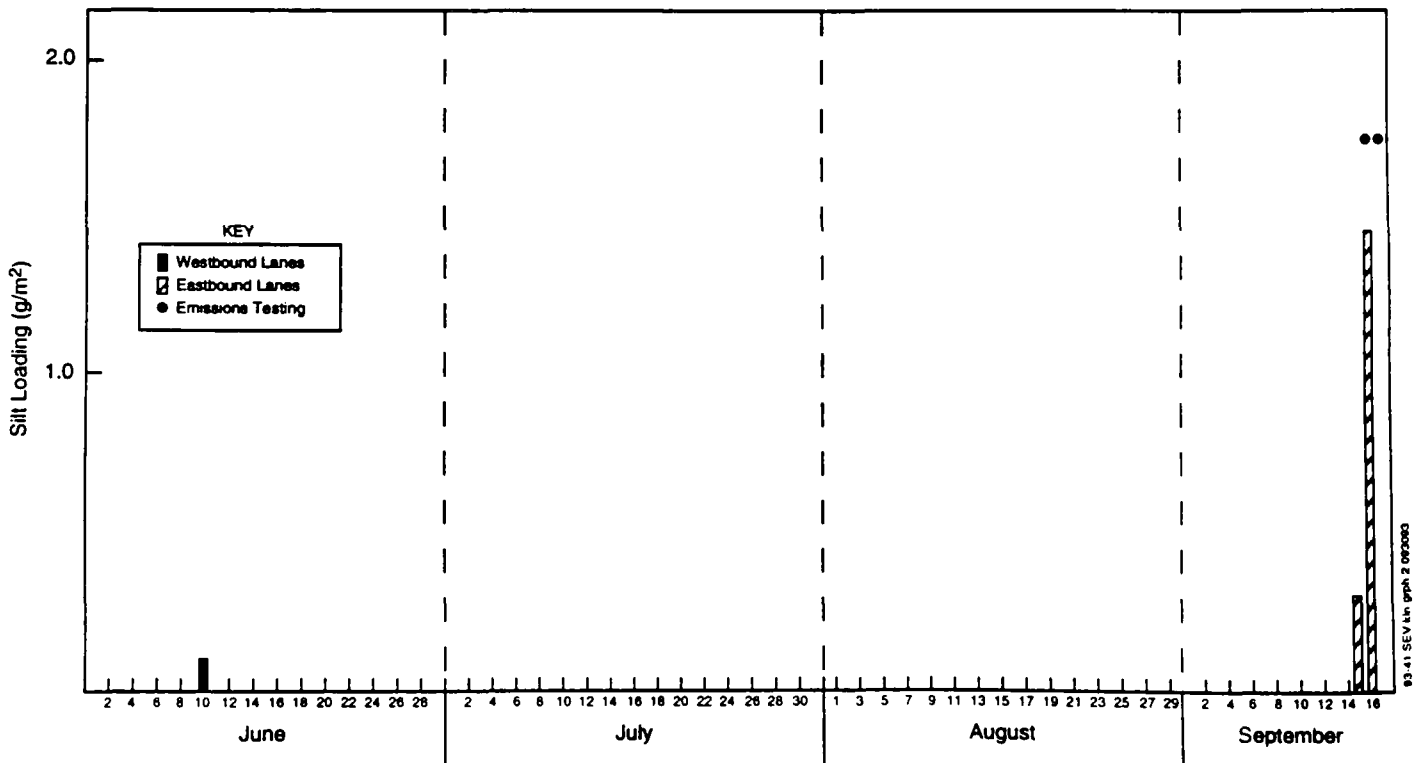
Figure 4-1b. Silt-loading history for the summer months of 1993.

The results of these calculations are shown in Table 4-14 for the winter and summer months, respectively. A similar comparison performed using the Duluth silt loading data collected by Kinsey (1993) is shown in Table 4-15.

As indicated by Table 4-14, the emission factors predicted from the existing AP-42 equation (Eq. 1-1) are about twice as large as the paired values calculated using the new emission factor model (Eq. 1-2) except for the summer measurements when heavier vehicles were observed. As shown in Table 4-15, the sets of emission factors obtained from the 1992 Duluth silt-loading data using the two predictive equations are in close agreement due to a greater proportion of heavier vehicles. It is also interesting to note that the emission factors predicted from the silt-loading data using the new model are within the same general range as the measured emission factors shown previously in Tables 4-5a and 4-5b. This lends additional credibility to the exposure-profiling results obtained in the current study.

4.4   DISCUSSION OF RESULTS

As shown by the above results, the PM-10 emission factors determined from the wintertime test data (Table 4-5a) are not related to the amount of NaCl applied to the road surface during each storm tested. This is consistent with the fact that NaCl constitutes only a minor portion of the surface silt loading. The NaCl apparently goes into solution and is largely removed from the road surface before it dries. This negates an earlier assumption that much of the NaCl dries as a film on the road surface and is subsequently resuspended by traffic (Grelinger et al., 1988).

The wintertime surface silt loading consists largely of insoluble matter (Table 4-13) **not** derived directly from the chemical deicer (rock salt) but instead from other types of materials. The origin of this loading may be related to pavement wear and "potholing," which could be an indirect result of the deicing chemical used (Kinsey et al., 1990).

TABLE 4-14. PREDICTED PM-10 EMISSION FACTORS FROM MEASURED SURFACE SILT LOADINGS

Date	Lane sampled[a]	Road surface silt loading (g/m^2)[b]	Predicted PM-10 emission factor: OLD EQ. (g/VKT)[c]	Predicted PM-10 emission factor: NEW EQ. (g/VKT)[d]
12/23/92	WB	0.0221	0.188	0.134
01/06/93	WB	0.250	1.31	0.648
01/15/93	WB	0.213	1.15	0.584
01/26/93	WB	0.233	1.24	0.619
02/18/93	EB	0.0607	0.422	0.258
03/07/93	WB	0.405	1.93	0.886
03/20/93	WB	0.550	2.46	1.08
6/10/93	WB	0.100	0.629	0.656
9/15/93	EB	0.233	1.24	1.14
9/16/93	EB	1.44	5.31	3.72

[a] WB = westbound lanes; EB = eastbound lanes.

[b] From Table 4-13a.

[c] Calculated from surface silt loading using Eq. (1-1).

[d] Calculated from silt loading and average vehicle weight using Eq. (1-2). Average vehicle weight was 2 tons (1.82 Mg) based on observations made in the field.

TABLE 4-15. PREDICTED PM-10 EMISSION FACTORS FROM MEASURED
SURFACE SILT LOADINGS (1992 Duluth data)

Date	Lane sampled[a]	Road surface silt loading (g/m^2)[b]	Predicted PM-10 emission factor: OLD EQ. (g/VKT)[c]	Predicted PM-10 emission factor: NEW EQ. (g/VKT)[d]
02/26/92	NB-Driving	1.04	4.10	3.01
	NB-Passing	0.501	2.28	1.87
	SB-Driving	0.529	2.38	1.93
	SB-Passing	0.271	1.39	1.26
02/28/92	NB-Driving	0.341	1.68	1.46
	NB-Passing	0.0262	0.215	0.275
	SB-Driving	0.445	2.08	1.73
	SB-Passing	0.295	1.50	1.33
03/2/92	NB-Driving	0.0701	0.473	0.521
	NB-Passing	0.0661	0.452	0.501
	SB-Driving	0.0382	0.291	0.351
	SB-Passing	0.122	0.738	0.747
03/11/92	NB-Driving	0.200	1.10	1.03
	NB-Passing	0.164	0.935	0.905
	SB-Driving	0.208	1.13	1.06
	SB-Passing	0.354	1.73	1.49
03/19/92	NB-Driving	0.0431	0.321	0.380
04/1/92	NB-Driving	0.0788	0.520	0.562
	NB-Passing	0.156	0.900	0.876
04/22/92	NB-Driving	0.0618	0.428	0.480
	NB-Passing	0.544	2.44	1.97
04/24/92	NB-Driving	0.150	0.870	0.854
	NB-Passing	0.133	0.790	0.790
	SB-Driving and Passing	0.0526	0.376	0.432

[a] NB = northbound lanes; SB = southbound lanes.

[b] From Table 4-7 of Kinsey (1993).

[c] Calculated from silt loading using Eq. (1-1).

[d] Calculated from silt loading and average vehicle weight using Eq. (1-2). Average vehicle weight assumed to be 3 tons (2.72 Mg) based on observations made in the field.

A comparison of the results of the 1992 Duluth emission study and that of the current work is also of interest. As can be observed from Table 1-1, the PM-10 emission factors measured in 1992 for a sand/salt mixture are substantially higher than those determined after the application of rock salt in the present study, (Table 4-5a) by as much as an order of magnitude. These data would indicate that the application of antiskid abrasives is of far greater concern in the control of PM-10 emissions from paved roads than is the case for chloride deicers. It is recommended, therefore, that the guidelines developed by the American Association of State Highway and Transportation Officials (AASHTO), shown in Table 4-1, be used to minimize the amount of abrasives used for ice and snow control and the resulting PM-10 emissions (Kinsey et al., 1990).

Finally, a comparison of the measured PM-10 emission factors with those predicted by Eq. (1-2) from the silt-loading data yields some interesting results. As shown in Figures 4-2a and 4-2b, the measured emission factors agree well with the predicted values, taking into account the confidence interval associated with Eq. (1-2). The 1 σ confidence interval for Eq. (1-2), which is a good measure of its average uncertainty of prediction, is a factor of 4.2. The calculated ratios of predicted to measured emissions are shown in Table 4-16.

TABLE 4-16. RATIO OF PREDICTED TO MEASURED PM-10 EMISSIONS

Date	Run No.	Array No.	Measured silt loading (g/m²)	Measured PM-10 emission factor (g/VKT)	Predicted PM-10 emission factor (g/VKT)	Ratio of predicted to measured emissions
2/17	BC-1	D1	0.061[a]	0.20	0.26	1.3
3/20	BC-5	D1	0.55	0.37	1.08	2.9
		D3		0.32		3.4
9/16	BC-12	D1	1.44	3.9	3.7	0.95
		D3		4.9		0.76

[a] Determined on 2/18/93.
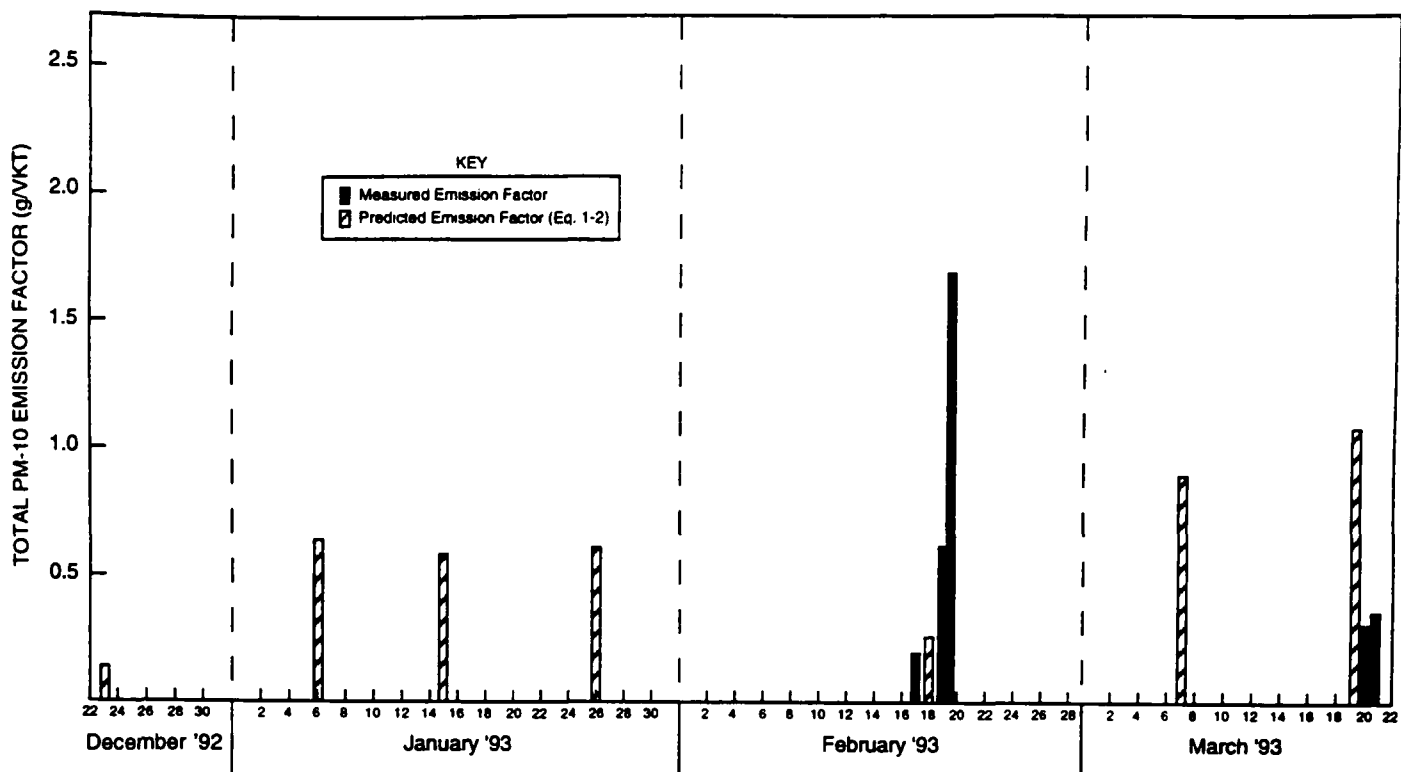
Figure 4-2a. Comparison of measured vs. predicted emission factors (Eq. 1-2) for winter months.
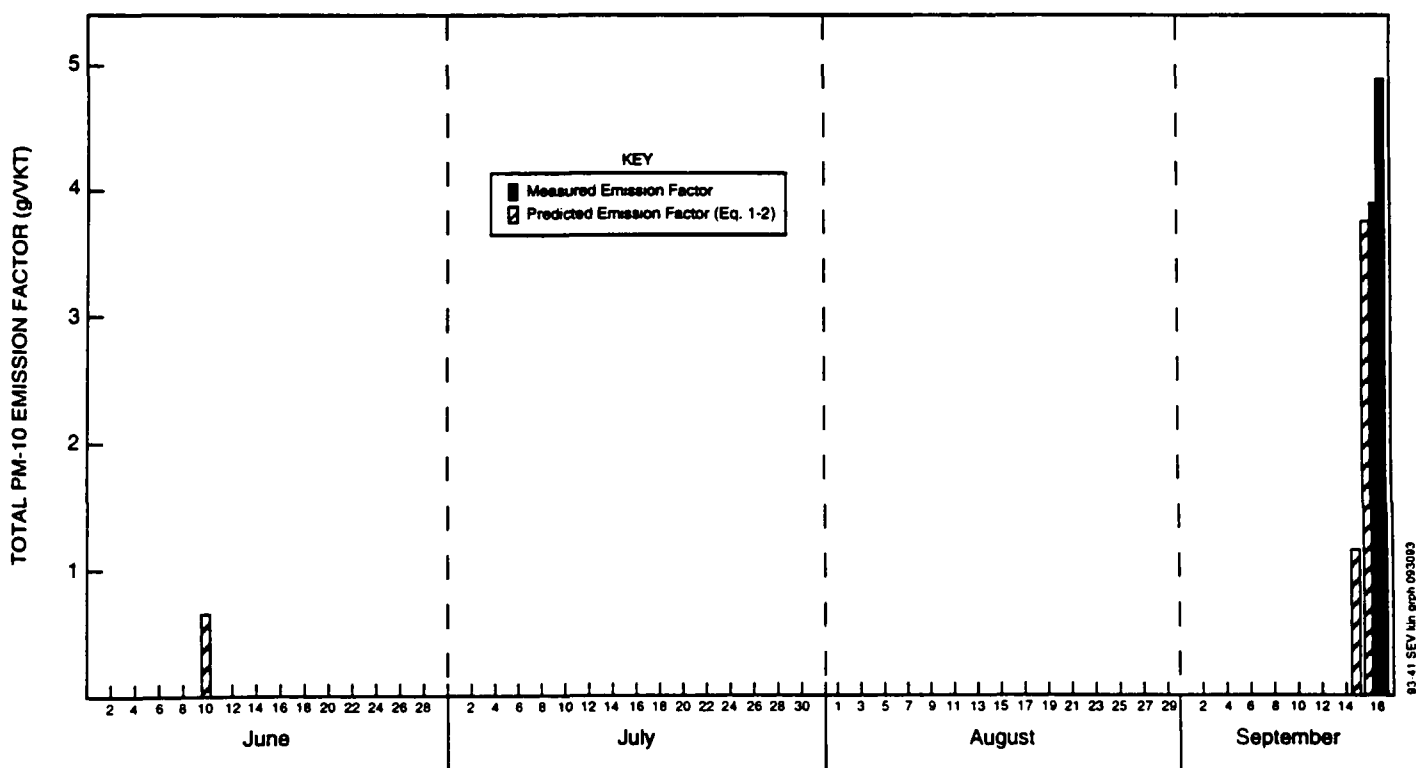
Figure 4-2b. Comparison of measured vs. predicted emission factors (Eq. 1-2) for summer months.

SECTION 5

QUALITY ASSURANCE

An independent evaluation of the field and analytical activities on this work assignment was performed by the Senior Quality Assurance Officer (QAO). The evaluation procedure included a 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 quality control samples prepared at a theoretical concentration of 2.0 μg/mL for each analyte. The average results for the method spikes were 98.5% for the sodium analyses, 105% for the chlorine analyses, and 99.3% 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.

Three source activity factors pointed out by the Work Assignment Leader (and mentioned previously in this report) that had an effect on the quality of the field data collected were: the atypical amount of precipitation received during the test period and the existence of a major earth-moving project close to the field-sampling location. These are discussed in Sections 2.2 and 4.2.1.

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 prior to sampling 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 adverse meteorological conditions, sampling activity for BC-2 (February 18) did not meet the criterion for wind direction. The data from activity BC-4 (February 25) were not used in the calculations for the emission factors because melting precipitation caused salt spray during this test instead of PM-10 emissions.

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 and postfield weights. The samples were equilibrated for 24 h in a clean room that had controlled temperature and humidity. 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 samples (filters) analyzed for Na^+ and Cl^- were extracted using the leaching procedure described in 40 *CFR* 50, Appendix G (EPA 1994c). The analytical procedure used for Cl^- was EPA Series 600 Method 300.0 (EPA 1983b); EPA Method 273.1 (EPA 1983c) was used for Na^+. The samples (filters) analyzed for Pb were subjected to using EPA Series 600 Method 200.9 (EPA 1994b). The procedures were followed as described, and the associated quality control data met the measurement requirements of the analytical procedures and the QAPjP.

5.3   DATA ASSESSMENT

Although the analytical data generated met the quality control criteria established for this work assignment, field data collection was made more difficult by environmental factors, many of which were beyond the control of the Work Assignment Leader, because of the limited sampling windows.

Since the samples were collected under environmental conditions that did not meet all of the applicable quality control criteria, some of the data may have been affected. The sampling activities for BC-1 (February 17) lost some data for one tower (D3) due to a generator malfunction. The sampling data from BC-4 activities (February 25) were not used for the emission factor calculations because of wet pavement conditions.

Although an error in the method used by the analytical laboratory for the analysis of lead and the premature disposal of the lead extracts provided sufficient data to calculate an emission factor for this analyte. However, as discussed by the Work Assignment Leader, the amount of both salt and lead found in the samples has resulted in emission contributions that are just above background levels and should be considered negligible.

5.4   REPORT REVIEW

During a review for consistency in reporting the analytical data, 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. The wintertime PM-10 emission factors determined in this study of the effects of a chemical deicer (NaCl) were generally low, ranging from 0.2 to 1.7 g/VKT. In contrast, the wintertime emission factors measured in the earlier Duluth study of the effects of antiskid abrasives were about an order of magnitude higher. Thus the use of antiskid abrasives is much more significant than the chemical deicer, in terms of PM-10 emission impact.

2. Rather than increasing the surface silt loading, NaCl aids in cleaning the road by forming slush which is either picked up on vehicle underbodies, cast aside, or removed as runoff. Little NaCl is left in the residual silt loading once the road surface has dried.

3. The measured PM-10 emission factors are unrelated to the amount of NaCl applied to the road, primarily because the NaCl constitutes only a minor portion of the surface silt loading. Rather, insoluble materials from other sources (possibly including pavement deterioration enhanced by the NaCl) drives the PM-10 emission rate.

4. The compound-specific PM-10 emission factors for Pb and NaCl, as determined in the winter testing, ranged from $7.5 (10)^{-5}$ to $4.5 (10)^{-4}$ g/VKT and 0.014 to 0.039 g/VKT, respectively. Due to the low magnitude of these emission factors, the contributions of both analytes to the total PM-10 emissions from the road can be considered negligible.

5. The PM-10 emission factor equation found in the 5th edition of AP-42 is a reliable tool for predicting emission rates from measured wintertime silt loading. The uncertainty in the predictions is well within the previously determined reliability of the equation.

SECTION 7

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APPENDIX A

MATERIAL SAMPLING AND ANALYSIS

A.1 SAMPLING AND PREPARATION PROCEDURES

For the stockpiled rock salt, the following steps were used to collect a representative sample for analysis:

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. The following sample splitting procedure was 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.

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.

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

The antiskid material sample collected from the KCP&R stockpile was split and analyzed for both silt content and percent insoluble matter. Silt content was determined using the procedure outlined in Section A.4 below. ASTM Method E 534 was used to determine percent insolubles in the salt sample collected.

SAMPLE DIVIDERS (RIFFLES)

Feed Chute →

Rolled
Edges

Riffle Sampler

(b)

Riffle Bucket and
Separate Feed Chute Stand

(b)

89-21 SEV grai schem 2 11/21/89
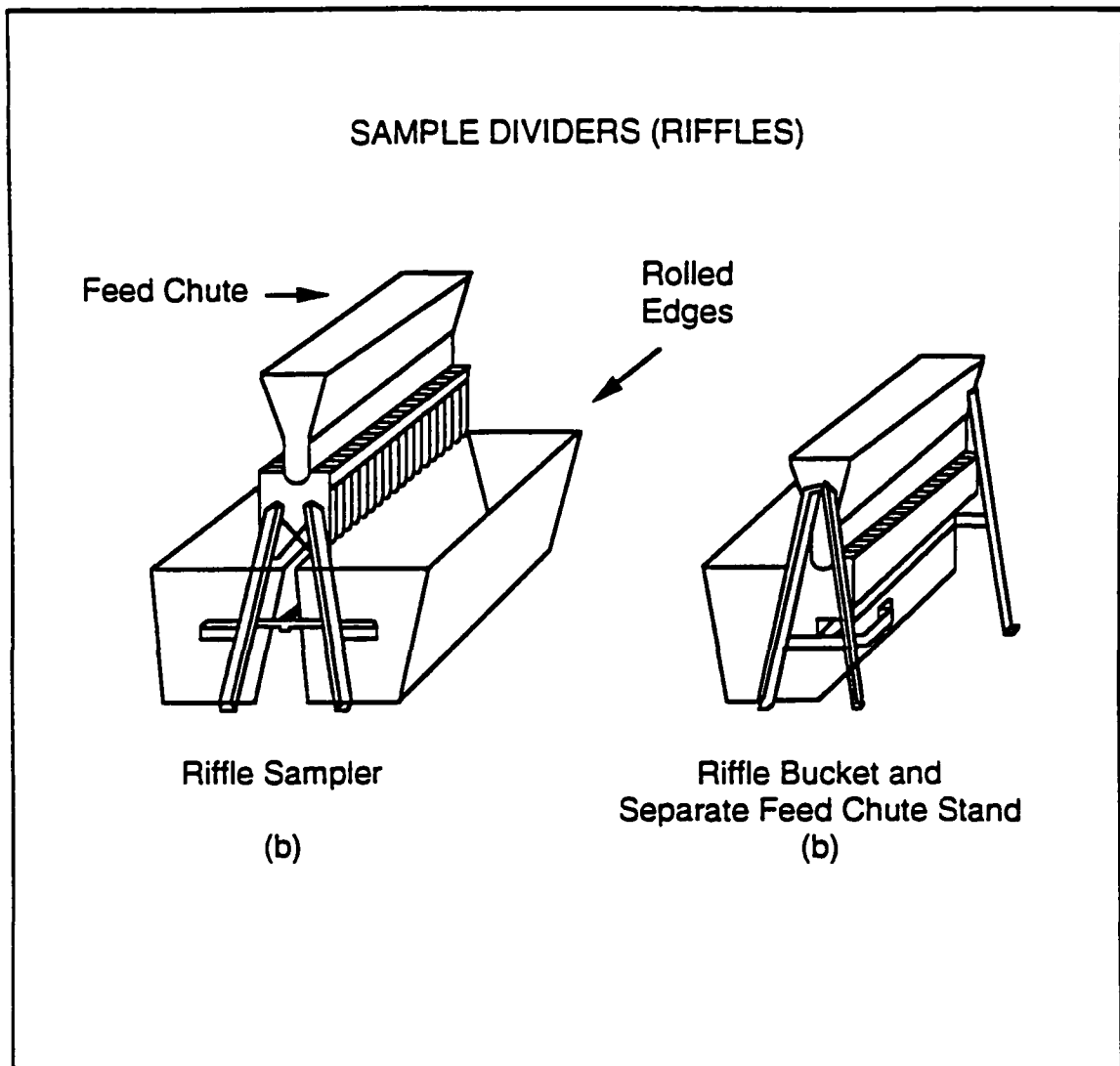
Figure A-2. Sample riffle dividers.

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 roads but also can be more readily used to aggregate incremental samples from several road surfaces. In this study, both types of vacuums were 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: <u>Do not mark the collection area with a chalk line or in any other method likely to introduce fine material into the sample.</u>) 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: <u>Collect material only from the portion of the road over which the wheels and carriages routinely travel</u> (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: <u>Collect material only from the portion of the road over which the wheels and carriages routinely travel</u> (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-3).

SAMPLING DATA FOR PAVED ROADS	
Date Collected_____	Recorded by _____

Sampling location* _____

Surface type (e.g., asphalt, concrete, etc.) _____ No. of lanes _____

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 at least 3 to 5 times greater than the empty bag tare weight.

Refer to procedure described in Appendix C-1 and C-2 of AP-42 (EPA, 1995) for more detailed instructions.

Indicated any deviations from the above; _____

SAMPLING DATA COLLECTED

Sample No.	Vacuum bag		Surface area sampled	Time	Mass of broom-swept sample[a]
	ID	Tare weight (g)			

[a] Enter "0" if not broom sweeping is performed.

Figure A-3. Example data form for paved roads.

Broom-swept samples (if collected) should be at least 400 g (1 lb) for silt and moisture analysis. 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. No broom-swept material was collected in the program.

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: $\frac{3}{8}$ 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 other sizes 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.

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-4).

ASTM E534 was also used to determine the percent insoluble matter in the silt samples obtained by dry sieving.

SILT ANALYSIS

Date: _____   Recorded by: _____

Sample No.: _____   Sample weight (after drying)
Material: _____   Pan + Sample: _____
                                      Dry sample: _____
                                      Final weight: _____

Split Sample Balance:
Make_____ $\% \ silt = \dfrac{Net \ Weight < 200 \ mesh}{Total \ Net \ Weight} \ x \ 100 = \_\_\_\_\_\%$
Capacity_____
Smallest Division_____

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-4. Example data form for silt analysis.

APPENDIX B

EXAMPLE DATA FORMS USED FOR MONITORING SITE CONDITIONS

OPERATOR ACTIVITY LOG (TEST SECTION)

Name of Operator: _R. Griffin / F. McClain_   Truck I.D. No. _217_

Location of Highway: _87th Brush Creek_

Spreader Make and Model _Fairway_   Type of Spreader Control _Hydraulic_

1 Date	2 Treatment Start Time	3 Type of Material Applied	4 Pump/or Conveyor Auger Settings	5 Spinner Setting	6 Pass No.	7 Lane Being Treated¹	8 Method of Treatment²	9 Approx. Speed (mph)	10 Comments or General Weather/Pavement Conditions
2/24	8:50 PM	Rock-Salt	10	11	1	D.L./P.L.	C	15	Light Snow
2/24	9:35 PM	" "	10	"	2	D.L./P.L.	C	15	" "
2/25	1:40 PM	Rock-Sait	10	11	3	DL/PL	C	15	HEAVY SNOW
2/26	2:30 AM	Rock-Salt	10	11	4	DL/PL	C	15	SNOW PACKED ROADS
2/26	10:30	Rock-Salt	10	11	5	DL/PL	C	15	SLUSH ON Rds Some Snow PACK

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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B-2

OPERATOR ACTIVITY LOG (TEST SECTION)

Name of Operator: _Fred McClain_   Truck I.D. No. _217_

Location of Highway: _42 st Brush Creek_

Spreader Make and Model _Fontaine_   Type of Spreader Control _Hydraulic_

1 Date	2 Treatment Start Time	3 Type of Material Applied	4 Pump/or Conveyor-Auger Settings	5 Spinner Setting	6 Pass No.	7 Lane Being Treated[1]	8 Method of Treatment[2]	9 Approx. Speed (mph)	10 Comments or General Weather/Pavement Conditions
3/19	12:25	Rock/Salt	10	11		DL/PL	C	15	Freezing Rain

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.

B-3

OPERATOR ACTIVITY LOG (TEST SECTION)

Name of Operator: **FRED MCCLAIN** Truck I.D. No. **317**

Location of Highway: **Brush Creek Blvd - Broadway to Paseo**

Spreader Make and Model **Fontane / AC 2450** Type of Spreader Control **Hydralic**

1 Date	2 Treatment Start Time	3 Type of Material Applied	4 Pump or Conveyor Auger Settings	5 Spinner Setting	6 Pass No.	7 Lane Being Treated¹	8 Method of Treatment²	9 Approx. Speed (mph)	10 Comments or General Weather/Pavement Conditions
1/1/93	1:30 AM	ROCK SALT	10	11	1	E+W LANES (CL)	C	8	ICE GLAZE
1/2/93	2:00 PM	" "	"	"	2	"	"	"	" "
1/3/93	3:00 AM	" " "	"	"	3	"	"	15	" "

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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OPERATOR ACTIVITY LOG (TEST SECTION)

Name of Operator: A. Campbell / B. McRoy   Truck I.D. No. 337

Location of Highway: Brush Creek Blvd - Broadway to Paseo

Spreader Make and Model: Fontane   Type of Spreader Control: hydralic

1 Date	2 Treatment Start Time	3 Type of Material Applied	4 Pump/or Conveyor-Auger Settings	5 Spinner Setting	6 Pass No.	7 Lane Being Treated[1]	8 Method of Treatment[2]	9 Approx. Speed (mph)	10 Comments or General Weather/Pavement Conditions
1/7	1:30 PM	Rock Salt	10	11	1	DL PL	C	15	Preparation for Ice + snow
1/7	7:30 PM	Rock Salt	10	11	2	DL PL	C	15	" " "
1/8	4:00 AM	Rock Salt	10	11	3	DL/PL	C	15	" "

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.

OPERATOR ACTIVITY LOG (TEST SECTION)

Name of Operator: _Q Washington / F. McCLAIN_   Truck I.D. No. _337_

Location of Highway: _Brush Creek Blvd - Broadway to Paseo_

Spreader Make and Model _Fuitace_   Type of Spreader Control _Hydralic_

1 Date	2 Treatment Start Time	3 Type of Material Applied	4 Pump/or Conveyor-Auger Settings	5 Spinner Setting	6 Pass No.	7 Lane Being Treated[1]	8 Method of Treatment[2]	9 Approx. Speed (mph)	10 Comments or General Weather/Pavement Conditions
1/8	8:00 PM	Rock salt	10	11	1	D.L./PL.	C	15	melt snow
1/9	2:00 AM	ROCK SALT	10	11	2	DL/PL	C	15	melt snow
1/10	3:00 AM	ROCK SALT	10	11	3	DL/PL	C	15	melt snow
1/10	8:00 AM	Rock SALT	10	11	4	DL/PL	C	15	melt snow
1/10	10:30 AM	Rock SALT	10	11	5	DL/PL	C	15	melt snow
1/10	4:00 AM	Rock SALT	10	11	6	DL/PL	C	15	thin layer snow

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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OPERATOR ACTIVITY LOG (TEST SECTION)

Name of Operator: _A. Campbell_   Truck I.D. No. _337_

Location of Highway: _Brush Creek Blvd Broadway to Paseo_

Spreader Make and Model _____   Type of Spreader Control _Hydraulic_

1 Date	2 Treatment Start Time	3 Type of Material Applied	4 Pump/or Conveyor-Auger Settings	5 Spinner Setting	6 Pass No.	7 Lane Being Treated[1]	8 Method of Treatment[2]	9 Approx. Speed (mph)	10 Comments or General Weather/Pavement Conditions
1/19/93	9.00	Rock-Salt	10	11		DL/PL	C	15	Preparation for Freezing Rain + snow
1/19/93	11.30	" "	10	11		"	C	15	" " " "
1/19/93	4:00/A.M.	" "	10	11		DL/PL	C	15	melt ice

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.

OPERATOR ACTIVITY LOG (TEST SECTION)

Name of Operator: F. MCCLAIN   Truck I.D. No. 317

Location of Highway: 47th St. Rockhill to OAK

Spreader Make and Model Fontane   Type of Spreader Control Hydralic

1 Date	2 Treatment Start Time	3 Type of Material Applied	4 Pump or Conveyor Auger Settings	5 Spinner Setting	6 Pass No.	7 Lane Being Treated[1]	8 Method of Treatment[2]	9 Approx. Speed (mph)	10 Comments or General Weather/Pavement Conditions
2/14/93	4:00 AM	SAlt	6	11	1	CL	C	15	dry ROAds
2/14/93	1:00 PM	SAlt	6	11	2	CL	C	15	2" Snow
2/15/93	7:00 PM	SAlt	6	1.1	3	CL	P+C	15	4" Snow
2/16/93	2:00 AM	SAlt	6	11	4	CL	P+C	15	4"-5" Snow
2/16/93	9:00 AM	SAlt	6	11	5	CL	C	15	Slush

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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OPERATOR ACTIVITY LOG (TEST SECTION)

Name of Operator: _R. GRIFFIN / F. McCLAIN_   Truck I.D. No. _217_

Location of Highway: _97ᵗʰ Brush Creek_

Spreader Make and Model _Fairace_   Type of Spreader Control _Hydraulic_

1 Date	2 Treatment Start Time	3 Type of Material Applied	4 Pump/or Conveyor-Auger Settings	5 Spinner Setting	6 Pass No.	7 Lane Being Treated[1]	8 Method of Treatment[2]	9 Approx Speed (mph)	10 Comments or General Weather/Pavement Conditions
2/24	6:30 PM	Rock-Salt	10	11	1	D.L./P.L.	C	15	Light Snow
2/24	8:35 PM	" "	10	"	2	D.L./P.L	C	15	" "
2/25	1:40 PM	ROCK-SALT	10	11	3	DL/PL	C	15	HEAVY SNOW
2/26	2:30 AM	Rock-SALT	10	11	4	DL/PL	C	15	SNOW PACKED ROADS
2/26	10:30 AM	Rock-SALT	10	11	5	DL/PL	C	15	SLUSH ON RDS. Some Snow PACK

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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APPENDIX C

SAMPLE CALCULATIONS

1. Calc. measured PM-10 concentration (C) at each sampler height using Equation (3-1) and Tables 4-2 & 4-13:

Average blank correction $= \dfrac{(-1.2 - 0.65 - 0.15 - 0.50 + 0.55 + 0.10 + 0.10 - 0.45)}{8}$
(Test BC-2)

$$= -0.28 \text{ mg}$$

For 1-m sampler: subtract blank from gross catch & calc. C

$$C = (15.25 + 0.28) \text{ mg} \times 10^3 \frac{\mu g}{mg} \times \frac{1 \text{ min}}{1.25 \text{ m}^3} \times \frac{1}{272 \text{ min}} = 45.68 \text{ }\mu g/m^3$$

For 3-m sampler:

$$C = (12.40 + 0.28) \text{ mg} \times 10^3 \frac{\mu g}{mg} \times \frac{1 \text{ min}}{1.24 \text{ m}^3} \times \frac{1}{272 \text{ min}} = 37.59 \text{ }\mu g/m^3$$

For 5-m sampler:

$$C = (11.30 + 0.28) \text{ mg} \times 10^3 \frac{\mu g}{mg} \times \frac{1 \text{ min}}{1.24 \text{ m}^3} \times \frac{1}{272 \text{ min}} = 34.33 \text{ }\mu g/m^3$$

For 7-m sampler:

$$C = (10.65 + 0.28) \text{ mg} \times 10^3 \frac{\mu g}{mg} \times \frac{1 \text{ min}}{1.25 \text{ m}^3} \times \frac{1}{272 \text{ min}} = 32.15 \text{ }\mu g/m^3$$

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

— Calc. average upwind concentration:

$$\frac{30.94 + 29.59}{2} \text{ }\mu g/m^3 = 30.27 \text{ }\mu g/m^3$$

— Net PM-10 concentrations:

* For 1-m sampler: $(45.68 - 30.27) \frac{\mu g}{m^3} = 15.41 \, \mu g/m^3$

* For 3-m sampler: $(37.59 - 30.27) \frac{\mu g}{m^3} = 7.32 \, \mu g/m^3$

* For 5-m sampler: $(34.33 - 30.27) \frac{\mu g}{m^3} = 4.06 \, \mu g/m^3$

* For 7-m sampler: $(32.15 - 30.27) \frac{\mu g}{m^3} = 1.88 \, \mu g/m^3$

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

Using log velocity from this plot

MRI Project No. 9802-71	MIDWEST RESEARCH INSTITUTE Fugitive Dust Emission Test	Date 7/19/93
Run No. BC5 (UL, DL)	Velocity Profile	Recorded by AC

1m 2.4mph   1.9m 3.2
5m 4.3 mph   3m   3.7
              7m   4.7

C-3
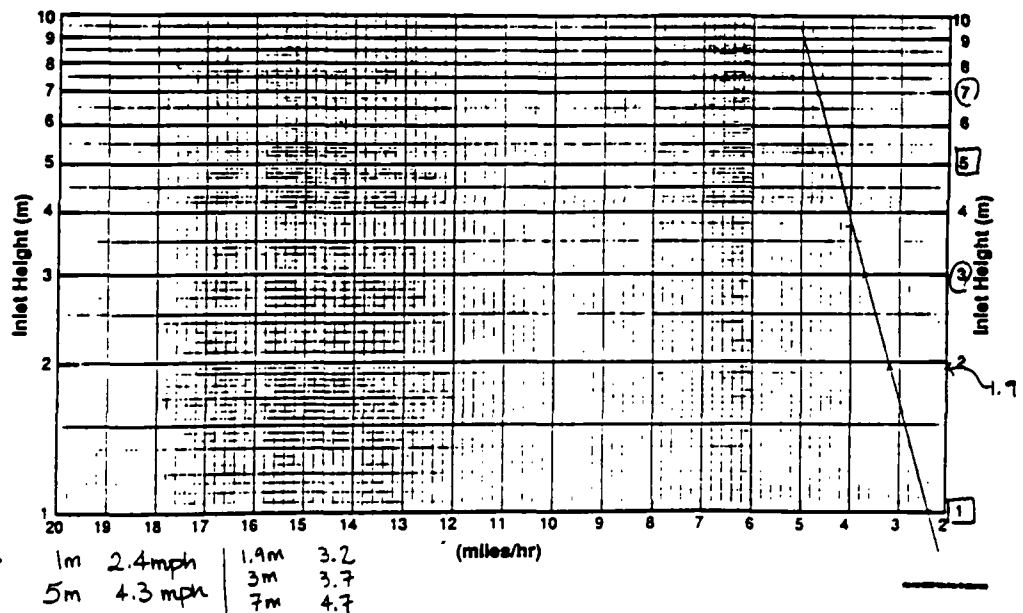
* At 3-m height: $3.7 \frac{mi}{hr} \times \frac{1 \, hr}{3600 \, sec} \times 5280 \frac{ft}{mi} \times \frac{1 \, m}{3.28 \, ft} = 1.7 \, m/sec$

* At 7-m height: $4.7 \frac{mi}{hr} \times \frac{1 \, hr}{3600 \, sec} \times 5280 \frac{ft}{mi} \times \frac{1 \, m}{3.28 \, ft} = 2.1 \, m/sec$

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

* For 1-m height: $15.44 \frac{\mu g}{m^3} \times 1.1 \frac{m}{sec} \times 272 \, min \times 60 \frac{sec}{min} \times \frac{1 \, m^2}{10^4 \, cm^2} = 27.66 \frac{\mu g}{cm^2}$

* For 3-m height: $7.32 \frac{\mu g}{m^3} \times 1.7 \frac{m}{sec} \times 272 \, min \times 60 \frac{sec}{min} \times \frac{1 \, m^2}{10^4 \, cm^2} = 20.31 \frac{\mu g}{cm^2}$

* For 5-m height: $4.06 \frac{\mu g}{m^3} \times 1.9 \frac{m}{sec} \times 272 \, min \times 60 \frac{sec}{min} \times \frac{1 \, m^2}{10^4 \, cm^2} = 12.59 \frac{\mu g}{cm^2}$

* For 7-m height: $1.88 \frac{\mu g}{m^3} \times 2.1 \frac{m}{sec} \times 272 \, min \times 60 \frac{sec}{min} \times \frac{1 \, m^2}{10^4 \, cm^2} = 6.4 \frac{\mu g}{cm^2}$

5. Estimate plume height from net PM-10 concentrations:

Linear regression of upper two net concentrations (internal calculator program)

$$h_{5-7} = 8.7 - 0.92 \, (conc.) \implies H = 8.7 \, m$$

Linear regression of upper three net concentrations

$$h_{3-7} = 8.2 - 0.73 \, (conc.) \implies H = 8.2 \, m$$
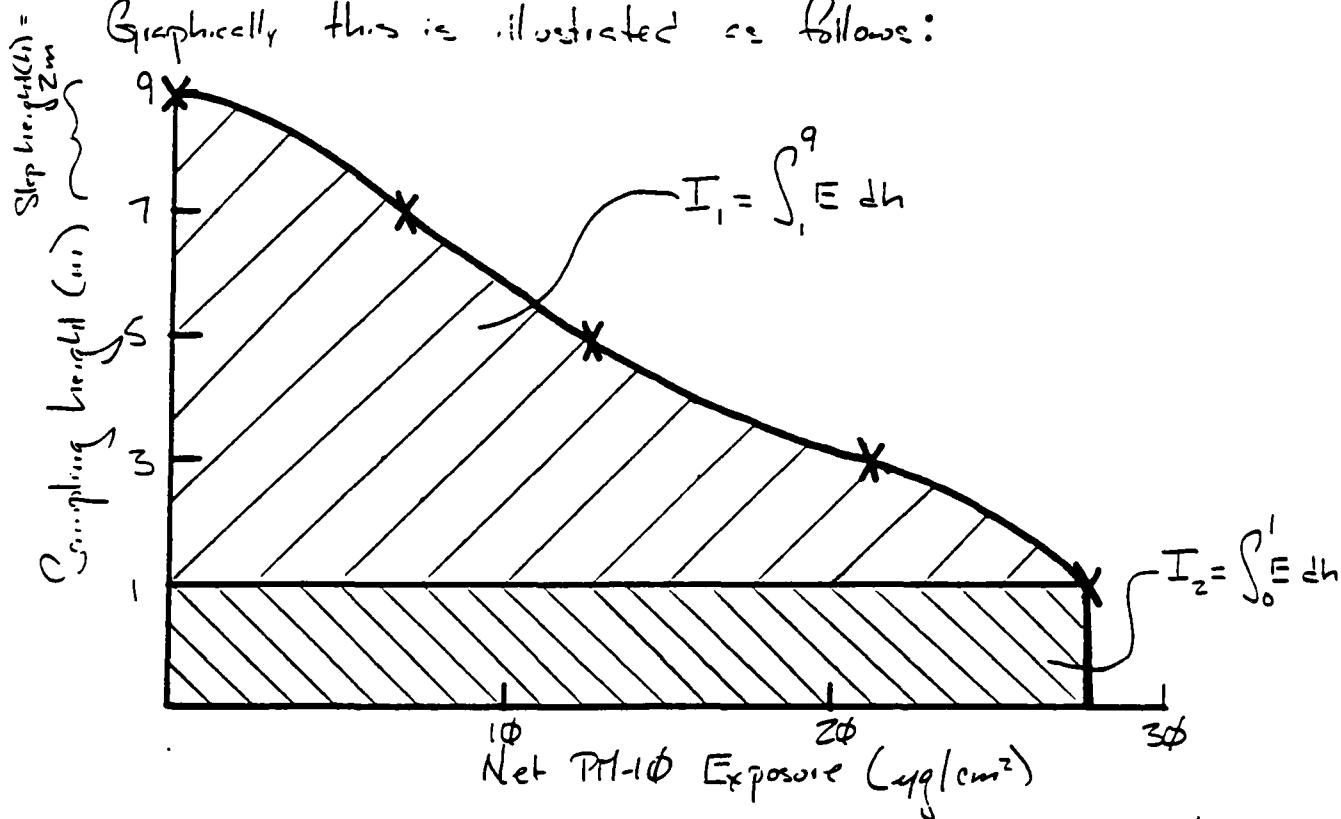
From above → assume H = 9 for integration purposes

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

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

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

Graphically this is illustrated as follows:

$$I_1 = \int_1^9 E\,dh$$

$$I_2 = \int_0^1 E\,dh$$

Sampling height (m) — Step height(h) = 2m

Net PM-10 Exposure ($\mu g/cm^2$)

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

$$I_T = I_1 + I_2 = (107 + 27.7) = 134.7 \ \mu g\cdot m/cm^2$$

7. Calculate PM-10 emission factor using I_T and Eq. (3-6):

$$e = 135 \frac{\mu g \cdot \text{yr}}{\text{?}^2} \times \frac{1 \text{ test}}{3617 \text{ veh.}} \times \frac{1 \text{ gm}}{10^6 \text{ } \mu g} \times 100 \frac{\text{cm}}{\text{yr}} \times \frac{10^5 \text{ cm}}{1 \text{ km}}$$

$$= 0.373 \text{ g/VKT}$$

THIS COMPLETES THE SAMPLE CALCULATION!

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

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4. TITLE AND SUBTITLE	5. REPORT DATE August 1995
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7. AUTHOR(S) John S. Kinsey	8. PERFORMING ORGANIZATION REPORT NO. MRI-OPPT/R71-01

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15. SUPPLEMENTARY NOTES APPCD project officer is Charles C. Masser, Mail Drop 62, 919/541-7586. Report EPA-600/R-93-019 (NTIS PB93-150209) is the Phase I report.

16. ABSTRACT The report gives results of field sampling on 47th Street in Kansas City, Missouri, during February and March 1993 to quantify the PM-10 emissions associated with the use of rock salt (NaCl) for ice and snow control. A baseline test was conducted in September 1993. The emissions were determined using exposure profiling. The measured emission factors spanned the following ranges, in grams per vehicle kilometers traveled (g/KVT): (1) total PM-10--0.2 to 1.7 (winter tests), and 3.9 to 4.9 (September test); (2) PM-10 lead--7.5×10 to the -5 to 4.5×10 to the -4 (winter tests); and (3) PM-10 NaCl--0.014 to 0.039 (winter tests). The winter emission factors for total PM-10 determined in this study were about an order of magnitude lower than those measured in a 1992 Duluth study, which utilized a 90% sand/10% salt antiskid material. The studies concluded that the sand from the antiskid material mixture that remained after the road had dried, constituted most of the silt loading and, therefore, the PM-10 emission impact. The rock salt, removed from the road mostly in the melting slush, contributed only a few percent to the residual silt loading.

17.		KEY WORDS AND DOCUMENT ANALYSIS	
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