United States
Environmental Protection
Agency

EPA-600/7-84-077

July 1984

EPA

Research and Development

PAVED ROAD

PARTICULATE EMISSIONS

Source Category Report

Prepared for

Office of Air Quality Planning and Standards

Prepared by

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

EPA REVIEW NOTICE

EPA-600/7-84-077
July 1984

PAVED ROAD PARTICULATE EMISSIONS

Source Category Report

by

Chatten Cowherd, Jr. and Phillip J. Englehart
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

EPA Contract 68-02-3158, Task 19

EPA Project Officer: Dale L. Harmon
Industrial Environmental Research Laboratory
Research Triangle Park, North Carolina 27711

Prepared for:

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

PREFACE

This report was prepared for the Environmental Protection Agency's Industrial Environmental Research Laboratory under EPA Contract No. 68-02-3158, Technical Directive No. 19. Dale L. Harmon was the project officer and William B. Kuykendal was the task manager for the preparation of this report. Dennis C. Drehmel and William B. Kuykendal served as technical project officers for the field testing portion of the study.

CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

Traffic-entrained particulate from paved roads has been identified as a major cause of nonattainment of air quality standards for total suspended particulates (TSP) in urban areas.[1] Therefore, the quantification of this source is necessary to the development of effective strategies for the attainment and maintenance of the TSP standards, as well as the anticipated standard for inhalable particulate.

Based on previous limited field testing of this source,[2] suspended particulate emissions have been found to vary in direct proportion to traffic volume and surface loading of fines on the traveled portion of the street. Measured emission factors for street particulate reentrainment added to vehicle exhaust have been found to be an order of magnitude larger than the factors for vehicle exhaust alone.[3]

This document presents the results of an expanded measurement program to develop particulate emission factors for paved roads. The emission sampling procedure used in this program provided emission factors for the following particle size ranges:

IP = Inhalable particulate matter consisting of particles equal to or smaller than 15 μm in aerodynamic diameter

PM-10 = Particulate matter consisting of particles equal to or smaller than 10 μm in aerodynamic diameter

FP = Fine particulate matter consisting of particles equal to or smaller than 2.5 μm in aerodynamic diameter

Results are presented for winter testing in the Kansas City, Missouri area and spring testing in areas of St. Louis, Missouri and Granite City, Illinois. These results are used as a basis for the derivation of a matrix of emission factors for specific road categories and particle size ranges.

The presentation of this report is organized in the following sequence:

Section 2 - Background Information
Section 3 - Sampling Site Selection
Section 4 - Sampling Equipment
Section 5 - Sampling and Analysis Procedures
Section 6 - Test Results
Section 7 - Test Data Reduction and Analysis
Section 8 - Conclusions and Recommendations
Appendix A - Emission Factor Calculation Procedure
Appendix B - Correction Parameters Calculation Procedures
Appendix C - Proposed AP-42 Section

2.0 BACKGROUND INFORMATION

This section reviews published background information on the dynamics of the paved roadway dust emissions problem.

2.1 STREET DUST COMPOSITION

In a comprehensive study of runoff from street surfaces as a source of water pollution,[4] 81 samples were taken from streets in 12 cities by vacuum sweeping and/or flushing. The samples were dry sieved and chemically analyzed to determine composition. The major constituent of street surface contaminants was consistently found to be mineral-like matter similar to common sand and silt. Typically, 78% of the material was located within 6 in. from the curb and 88% within 12 in. from the curb. The silt content of the material (particles smaller than 75 micrometers (μm) in diameter) fell in the 5 to 15% range reported elsewhere[5-7] for surface dust from paved streets and parking lots and from gravel roads and parking lots. In addition, it was found that 5.9% of the material was less than 43 μm in size. The silt size fraction, which is readily suspendable in the atmosphere, was found to contain more than proportional amounts of the total heavy metals and pesticides.

In a study which entailed a comprehensive review on the topic of reentrained dust from paved streets,[8] 129 samples of street surface materials were taken in Kansas City and Cincinnati by means of broom sweeping and subsequent vacuuming. The samples were weighed and analyzed by microscopy to determine the particle size distribution. The results of the sample analyses showed that approximately 9.5% of the paved road surface material was less than 44 μm in size.

2.2 STREET DUST LOADINGS

Table 1 summarizes the results of field measurements of surface loadings at sites in 12 cities.[4] In addition to land use characteristics, dust loadings were found to depend on:

- Time elapsed since the last cleaning by mechanical means or by substantial rainfall (exceeding 0.5 in. accumulation).

- Street surface characteristics: asphalt streets had loadings that were 80% higher than concrete-surfaced streets; and streets in fair-to-poor condition had loadings about twice as high as streets in good-to-excellent condition.

- Public works practices: average loadings were reduced by regular street cleaning (as reflected by lower values for commercial areas), and loadings were increased during winter in areas where sand and salt were applied.

Although traffic speed and density were believed to be important factors, effects of these parameters could not be separated from more dominant factors such as land use.

2.3 DEPOSITION AND REMOVAL PROCESSES

On the average, vehicular carry-out from unpaved areas (unpaved roads and parking lots, construction sites, demolition sites) may be the largest source of dust on paved streets.[8] Maximum carry-out occurs in wet weather when dust emissions from open sources are at a minimum. In a study conducted in the Seattle area,[7,9] a car driven at 10 miles/hr on a wet gravel road collected approximately 80 lb of mud on tires and underbody, and carry-out on tires from a wet unpaved parking lot averaged about 3/4 lb/vehicle.

TABLE 1. CONTAMINANT LOADINGS ON URBAN STREET SURFACES[4]

Land use	Mean initial accumulation rate (lb/mile/day)	Loading intensity (lb/curb mile)[a]			
		Minimum	Maximum	Numerical mean	Weighted mean
Residential	373				1,200
Low/old/single		120	1,900	850	
Low/old/multi		31	1,300	890	
Med/new/single		180	1,200	430	
Med/old/single		260	1,900	-	
Med/old/multi		140	6,900	1,400	
Industrial	447				2,800
Light		260	12,000	2,600	
Medium		280	1,300	890	
Heavy		240	12,000	3,500	
Commercial	226				290
Central business district		60	1,200	290	
Shopping center		63	640	290	
Overall	348				1,500

[a] There are 2 curb miles per street mile.

An American Public Works Association study[10] found that 10.2 lb of dust under 1/8 in. in size comes onto each 100 ft of curbless paved road in Chicago each day; this amount is cut by a factor of four if curbs are added.

As evidence of the importance of the carry-out process, a positive correlation has been observed between TSP concentration and the occurrence of precipitation several days before sampling, i.e., after sufficient time for the carry-out residue to dry out.[11]

In addition to vehicular carry-out, other potentially significant sources of street dust are:

- Water and wind erosion from adjacent exposed areas (sparsely vegetated land, unpaved parking lots, etc.).
- Motor vehicle exhaust, lubricant leaks, and tire and brake wear.
- Truck spills.
- Street repair.
- Winter sanding and salting.
- Atmospheric dustfall.
- Vegetation and litter.

Table 2 presents typical annualized deposition and removal rates for street surface material estimated by one study.[8] The values were derived by applying assumptions to data found in other literature sources. One assumption was that the typical street has four lanes, is 50 ft wide, and has an average daily traffic volume of 10,000 vehicles.

TABLE 2. ESTIMATED DEPOSITION AND REMOVAL RATES

Deposition process	Typical rate (lb/curb-miles/day)	Removal process	Typical rate (lb/curb-miles/day)
Mud and dirt carry-out	100	Reentrainment	100
		Displacement	40
Litter	40	Wind erosion	20
Biological debris	20	Rainfall runoff	50
Ice control compounds	20		
Dustfall	10	Sweeping	35
Pavement wear and decomposition	10		
Vehicle-related (including tire wear)	17		
Spills	< 2		
Erosion from adjacent areas	20		

In a recent field study of street surface contaminants in the Washinton, D.C. area,[12] roadway deposition of traffic-related materials was found to be directly proportional to the traffic volume, at a rate of about 10^{-3} lb/vehicle-mile. The rate appeared to be independent of the loading already present.

However, the accumulation of materials on the roadway has been found to level off within a period of 3 to 10 days after a rain storm or street cleaning.[4,12] This leveling off occurs when traffic-related removal rates, which increase with loading intensity, balance traffic-related deposition rates. The equilibrium is established more rapidly with increasing traffic speed.

2.4 TRAFFIC-GENERATED EMISSIONS

Few data on directly measured dust emissions from paved streets are available in the literature. An isolated study of dust emissions from a paved road in the Seattle area yielded an emission factor of 0.83 lb/vehicle-mile at 20 mph.[7,9] The test road was noticeably dusty and had no curbs or street cleaning program; it was located adjacent to gravel roads and unpaved parking lots from which dirt was tracked. Dust emissions generated by vehicular traffic with average daily traffic exceeding 200 vehicles was estimated to equal the amount removed by sweeping every 2 weeks.[9]

A single-valued emission factor of 3.7 g/vehicle-kilometer for dust entrainment from paved roads was developed from another field study.[8] Emission measurements were obtained using the upwind-downwind technique with four high-volume samplers, one located 10 m upwind, with the remaining three located at 10, 20, and 30 m downwind. Thirty-five successful tests were completed. It was determined through microscopy that 78% (by weight) of the emissions consisted of particulate less than 30 μm in size. Also through optical microscopy it was found that 59% of the particulate collected was mineral matter while 40% consisted of combustion products. It was also concluded in this study that particulate emissions from a street are proportional to traffic volume but independent of street surface dust loading.

In a third field study quantitative emission factors for dust entrainment from paved urban roads were developed using exposure profiling.[2] Field testing was conducted at three representative sites in the Kansas City area. At one location, controlled amounts of pulverized top soil and gravel fines were applied to the road surface. Eight tests were performed at the artificially loaded site, and five tests were made at a different site under actual traffic conditions. Emissions were found to vary directly with traffic volume and surface loading of silt (fines). The dust emission factor for normally loaded urban streets ranged from 1 to 15 g/vehicle-kilometer, depending on land use. Approximately 90% of the emissions (by weight) were found to be less than 30 μm in Stokes diameter and 50% less than 5 μm in Stokes diameter, based on a particle density of 2.5 g/cm^3.

3.0 SAMPLING SITE SELECTION

Eight candidate sampling areas in Kansas, Missouri and Illinois were designated by the Environmental Protection Agency (EPA) as representative sites for the field study. As indicated in Table 3, these areas represent a range of typical road, traffic, geographical, and environmental conditions within residential, commercial, and industrial land uses. Each sampling area contained a TSP monitoring site providing historical air quality data. In 1975, ambient TSP concentrations in the candidate sampling areas ranged from annual geometric means of 52 $\mu g/m^3$ at Brauer School, Wyandotte County, Kansas, to 157 $\mu g/m^3$ at 2001 East 20th, Granite City, Illinois.

3.1 SITE PRESURVEYS

Before going to the field, liaison was established with the appropriate state and local environmental and transportation authorities. Support data were compiled for each proposed sampling area to aid in careful site selection. This information included local street maps, topographic maps, street maintenance and traffic data, and 1976 microinventories supplied by EPA. Based on this research, previous Midwest Research Institute (MRI) road dust sampling experience, and EPA recommendations, presurvey data requirements were developed. Table 4 identifies specific field data that were obtained during the presurveys for use in final sampling site selection.

It was decided to presurvey two or three sites within each sampling area to provide roadway orientations suitable for sampling under various wind direction ranges. Similarly, street segments were surveyed where minimum obstruction to wind flow existed to provide a wide spread of wind fetch corresponding to acceptable sampling conditions.

TABLE 3. GENERAL SAMPLING AREAS DESIGNATED BY EPA

Sampling area					Annual geometric mean TSP concentrations (μg/m³)		
Presurvey identification	Name	Address of associated Hi-Vol	SAROAD identification	Hi-Vol currently operational	1974	1975	1976
1	321 Delaware	321 Delaware, Tonganoxie, Kansas	17-2000-001-F01	No	82	90	107
2	Brauer School	K-7 and Leavenworth Road, Wyandotte County, Kansas	17-3840-008-H01	No	45	52	-
3	Baltimore and Miami	Baltimore and Miami, Kansas City, Kansas	17-1800-002-H01	No	107	110	-
4	Shreve and I-70	Shreve and I-70, St. Louis, Missouri	26-4280-061	Yes	111	105	96
5	River des Peres	E. of Sulpher, between Manchester and I-44, St. Louis, Missouri	26-4280-062	Yes	-	90	-
6	15th and Madison	15th and Madison, Granite City, Illinois	14-2960-10	Yes	-	137	154
6	2001 E. 20th	2001 E. 20th, Granite City, Illinois	14-2960-09	Yes	158	157	205
7	23rd and Madison	23rd and Madison, Granite City, Illinois	14-2960-07	Yes	93	105	122

TABLE 4. FIELD DATA REQUIREMENTS FOR EACH SAMPLING SITE PRESURVEY

1. Accurate location of each presurvey site on street and topographic map

2. Location of site with respect to reference Hi-Vol monitor.

3. Primary land use in the surrounding area.

4. Street information including:

   - Direction of travel
   - Number of travel and parking lanes
   - Presence of curbs and sidewalks
   - Street surface composition
   - Street surface roughness (qualitative - smooth, medium, rough)

5. Road maintenance information including:

   - Cleaning activities and frequency
   - Winter snow mitigation procedures

6. Street surface particulate loading in curb area, parking lanes, and travel lanes (qualitative - light, medium, heavy)

7. Detailed sketch of the road dimensions.

8. Detailed sketch of surrounding area including:

   - Topography
   - Buildings (type, dimensions, address)
   - Open areas (use, dimensions)
   - Street names and locations
   - Fences, trees, billboards, and other miscellaneous information

9. A 15 to 30 min traffic count by vehicle type.

10. A photographic survey including views of:

    - The sampling street (both directions)
    - The sampling set-up area
    - The fetch area
    - The road surface (travel lane and curb area)

Seven sites in Areas 1, 2, and 3 (identified in Table 1) were surveyed on August 2 and 3, 1979. An additional 11 sites were surveyed in Areas 4, 5, 6, and 7 on August 7 and 8, 1979. The 2001 East 20th location and the 15th and Madison location in Granite City, Illinois were combined into one sampling area (Area 6) because of their proximity.

A wide variety of road and traffic characteristics were found in the areas presurveyed. Equivalent hourly traffic volume ranged from 36 vehicles at Site 2A to 2,944 vehicles at Site 5A. Road width varied from 22 ft at Site 1C to 216 ft at Site 2B. Both asphalt and concrete street surfaces, curbed and uncurbed, were included. Qualitative evaluation of street surface conditions indicated that the surfaces ranged from smooth to rough, and that surface particulate loadings varied from light to heavy in comparison with typically observed loadings.

3.2 SITE SELECTION

Three major criteria were used to determine the suitability of each candidate site for sampling of road dust emissions by the exposure profiling technique.[6]

1. Adequate space for sampling equipment,

2. Sufficient traffic and/or surface dust loading so that adequate mass would be captured during a reasonable sampling time period, and

3. A wide range of acceptable wind directions.

3.2.1 Adequate Space

Adequate space for equipment deployment and easy accessibility to the area is required for road dust sampling. All of the 18 candidate paved road sites were chosen so as to provide necessary space, as well as accessibility for the setup of all sampling equipment and to ensure the safety of the sampling crew.

3.2.2 Adequate Mass Catch

To provide for accurate determination of the dust emission rate from exposure profiling data, at least 5 mg of sample should be collected by each profiling head. Particulate concentration and sampling time must be sufficient to provide the 5 mg weight gain under isokinetic sampling conditions. This requirement is the most difficult to achieve for the highest sampling head (located at 4 m above ground) because of the significant decrease in particulate concentration with height.

An empirical relationship between sampler catch and traffic volume obtained in MRI's previous testing of traffic entrained dust emissions is illustrated in Figure 1. Assuming a typical silt loading (excluding curbs) of 5 kg/km, approximately 3,600 vehicle passes are required to collect 5 mg of sample (above background) on the top sampler; for roads with heavier loadings, fewer passes are required.

Roads with light traffic are excluded from consideration because (a) it is not possible to collect sufficient sample mass within an acceptable sampling period (4 to 6 hrs), and (b) such roads probably do not contribute substantially to total emissions of traffic entrained dust in urban areas. In any case, the emission factor equations developed in this study are expressed in terms of emissions per unit of traffic volume (Kg/VKT); therefore these equations should be applicable regardless of traffic density.

3.2.3 Adequate Traffic Volume

During the presurvey of each candidate testing site, traffic was counted visually during a 15 to 40 min period. These traffic counts were then converted to an average hourly count (AHT) by simple linear extrapolation in time.

In order to evaluate each site with respect to the requirement of 3,600 vehicle passes in a 4-hr test period, it was necessary to convert the observed AHT into an equivalent 4-hr count. This was accomplished by using reported data on the diurnal variation of hourly traffic in Detroit, Chicago,

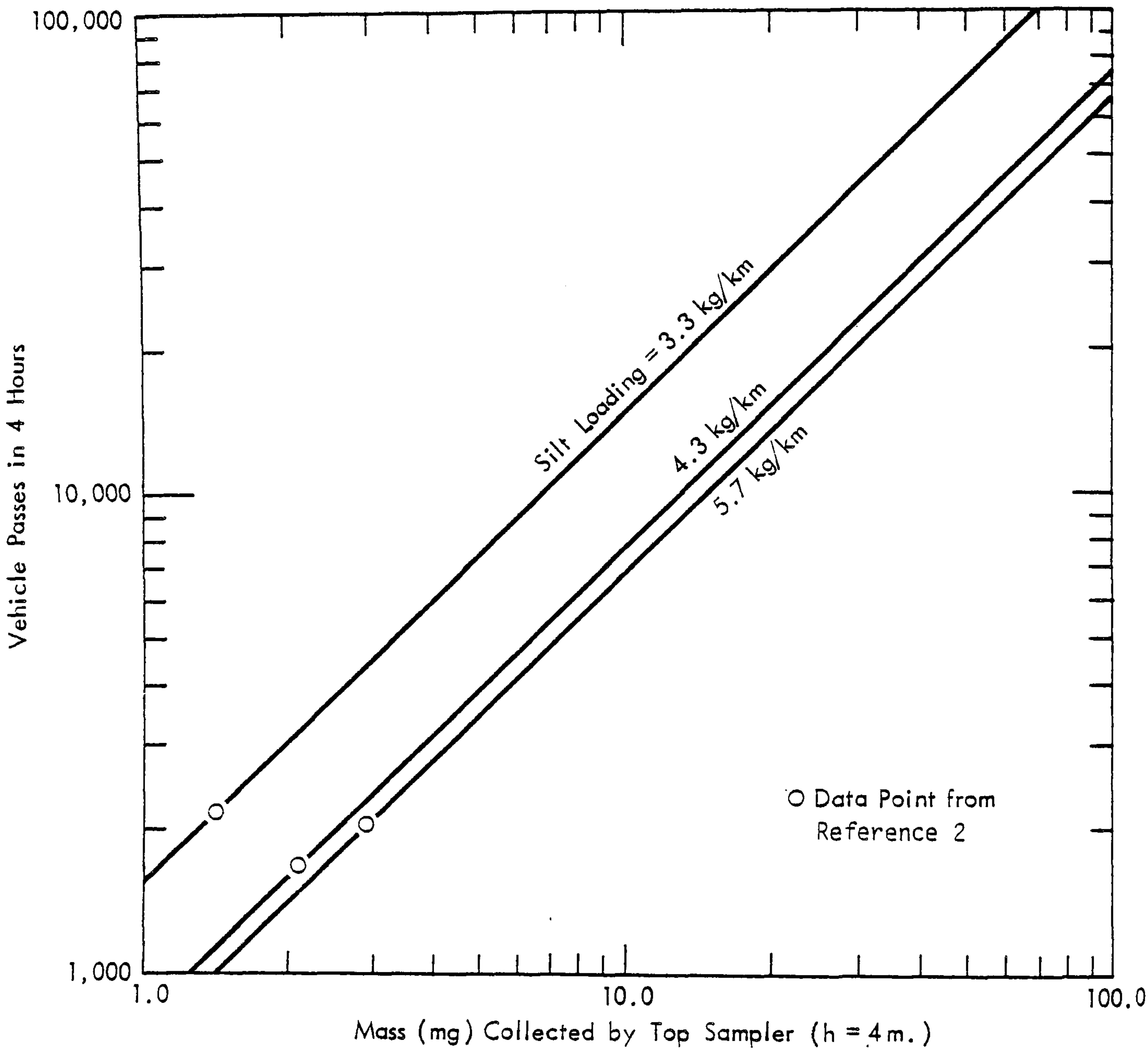


Figure 1. Empirical relationship between sampler catch and traffic volume.

Pittsburgh, and Toronto.[13] In order to maximize the projected vehicle count, it was assumed that testing would be conducted between 3:30 PM and 7:30 PM which encompasses the evening traffic peak. After analysis of the collected data, eleven of the eighteen site candidates met the traffic requirement and were eligible for selection.

3.2.4 Acceptable Wind Directions

Wind directions that would successfully transport the traffic entrained dust from paved streets to the exposure profiler depend on the following factors:

- Street Orientation - the mean (15-min average) direction of the wind must lie within 45 degrees of the perpendicular to the road.

- Wind Fetch - the wind flowing toward the test roadway should not be blocked by obstacles on the upwind side.

In order to evaluate the candidate sites for the wind fetch requirement, the arc of wind direction for which the wind would flow freely between the two nearest upwind obstacles (houses, buildings, or trees) was calculated as follows:

$$\theta = \arctan \frac{b}{2a}$$

where θ represents the half angle of the arc, b is half the distance between the two blocking obstacles (fetch), and a is the perpendicular distance from the line joining the rear corners of the obstacles to the proposed location of the profiler (5 m from the downwind edge of the roadway.) Figure 2 illustrates these parameters.

3.2.5 Summary of Selection Criteria

Selection criteria for sampling sites included, in descending order of importance:

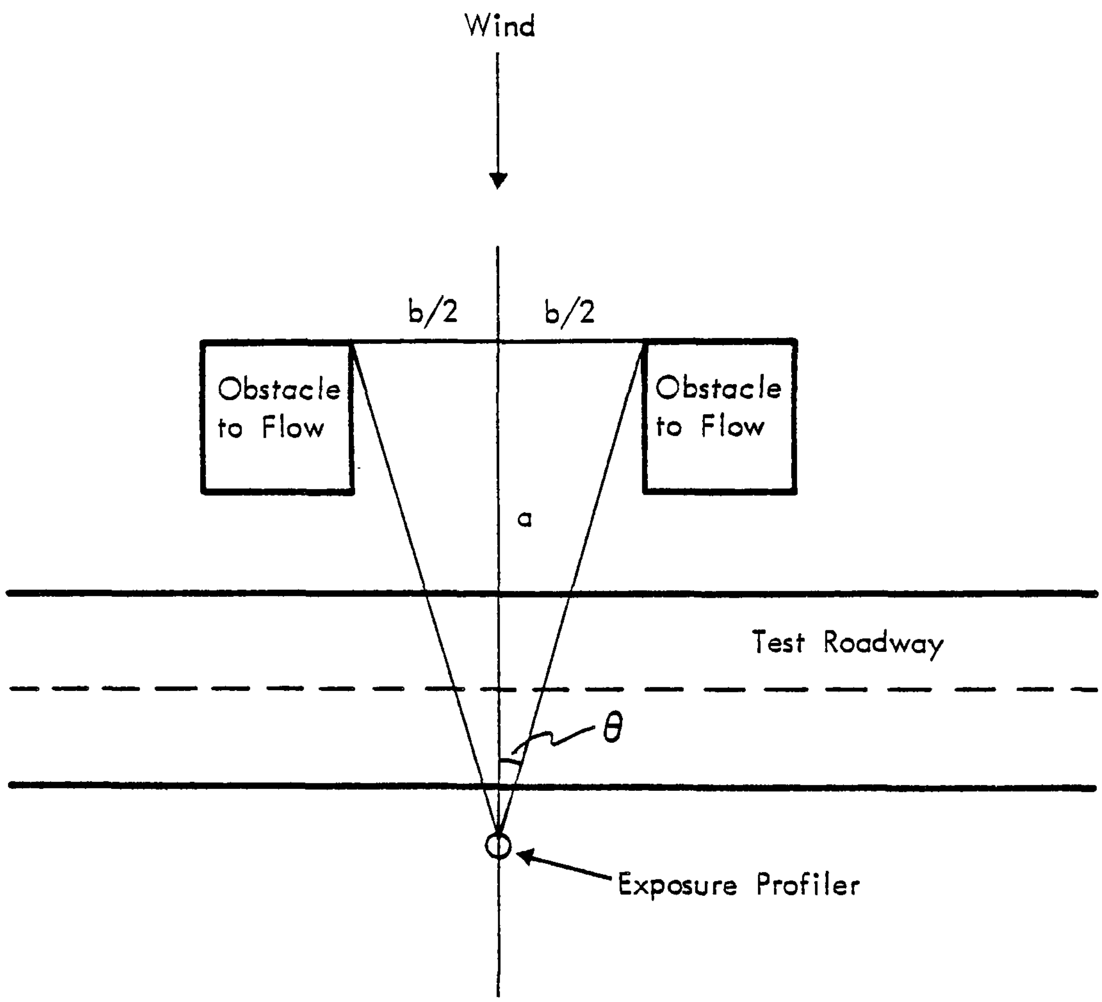


Figure 2. Parameters for calculations of angle of unobstructed wind flow.

- Adequate space - for operation of equipment and for safety of crew.

- Adequate mass - as determined by number of vehicle passes in a 4-hr test period.

- Wind direction - range of unobstructed wind directions.

A summary of the selection criteria as applied to each site, is shown in Table 5. It should be noted that accessibility was determined during the presurveys, and all candidates were assured of this.

Suitability was determined by an examination of all criteria, and ratings were assigned as follows: (A = primary choice, B = alternate choice, C = emergency choice, R = rejected). Those sites designated A or B were selected to be considered for source testing. It should be noted that sampling sites 1A and 1C were considered primary because it was desirable to sample at rural locations. These sites were easily accessible to the sampling crew so that a longer sampling period was possible.

TABLE 5. APPLICATION OF SELECTION CRITERIA TO CANDIDATE SAMPLING SITES

Site	Traffic count (peak 4 hr)[a]	Curbed	Street particulate loading	Adequate sample mass	Wind direction versatility[b]	Suitability for testing[c]
1-A	Low	Yes	Moderate	No	N/20°	P[d]
1-B	Low	Yes	Moderate	No	E/40°	R
1-C	Low	No	Moderate	No	W/90°	P[d]
2-A	Low	No	Moderate	No	N/90°, S/90°	R
2-B	High	No	Light	Yes	W/90°, E/90°	P
3-A	High	Yes	Light	Yes	W/70°, E/60°	P
3-B	Low	Yes	Moderate	No	N/40°, S/20°	R
4-A	Medium	Yes	Moderate	Yes	W/50°, E/70°	P
4-B	Low	Yes	Moderate	No	WNW/90°	R
5-A	High	Yes	Light	Yes	N/90°, S/90°	P
5-B	Medium	Yes	Moderate	Yes	N/90°	S
5-C	High	Yes	Light	Yes	ESE/20°	E
6-A	Medium	Yes	Moderate	Yes	NE/40°	P
6-B	Medium	Yes	Moderate	Yes	SE/20°	E
6-C	Medium	Yes	Heavy	Yes	ESE/40°	P
7-A	Low	Yes	Moderate	No	SE/40°	R
7-B	Medium	One side	Moderate	Yes	NNW/40°, SE/90°	P
7-C	Low	One side	Heavy	No	ENE/70°	S

[a] Four-hour traffic count: low = 1,000 to 4,000; medium = 4,000 to 8,000; high = > 8,000.

[b] Centerline directions and ranges of unobstructed wind flow.

[c] P = prime site; S = alternate site; E = emergency site; R = rejected site.

[d] Sampling will be attempted for periods longer than 4 hr (see text).

4.0 SAMPLING EQUIPMENT

A variety of sampling equipment was utilized in this study to measure particulate emissions, roadway surface particulate loadings, and traffic characteristics.

Table 6 specifies the kinds and frequencies of field measurements that were conducted during each run. "Composite" samples denote a set of single samples taken from several locations in the area; "integrated" samples are those taken at one location for the duration of the run.

4.1 AIR SAMPLING EQUIPMENT

The primary tool for quantification of emissions was the MRI exposure profiler, which was developed under EPA Contract No. 68-02-0619.[6] The profiler (Figure 3) consists of a portable tower (4 to 6 m height) supporting an array of four sampling heads. Each sampling head is operated as an isokinetic total particulate matter exposure sampler directing passage of the flow stream through a settling chamber (trapping particles larger than about 50 µm in diameter) and then upward through a standard 8 in. by 10 in. glass fiber filter positioned horizontally. Sampling intakes are pointed into the wind, and sampling velocity of each intake is adjusted to match the local mean wind speed, as determined prior to each test. Throughout each test, wind speed is monitored by recording anemometers at two heights, and the vertical wind profile of wind speed is determined by assuming a logarithmic distribution. Normally, the exposure profiler is positioned at a distance of 5 m from the downwind edge of the road.

TABLE 6. FIELD MEASUREMENTS

Test Parameter	Units	Sampling Mode	Measurement/Instrument method	Manufacturer/Model
1. Meteorology				
a. Wind speed	m/s	continuous	warm wire anemometer	Kurz Model 410
b. Wind direction	deg	continuous	wind vane	Wong Eco-System III
c. Cloud Cover	%	single	visual observation	-
d. Temperature	°C	single	sling psychrometer	Taylor cat. no. 146-761
e. Relative humidity	%	single	sling psychrometer	Taylor cat. no. 146-761
2. Road Surface				
a. Pavement type	-	composite	observation	-
b. Surface condition	-	composite	observation	-
c. Particulate loading	g/m^2	multiple	dry vacuuming	Hoover, Model S2015 Quick Broom
d. Particulate texture	% silt	multiple	dry sieving	Forney, Inc., LA-410 Sieve Shaker
3. Vehicular Traffic				
a. Mix	-	multiple	observation	-
b. Count	-	cumulative	pneumatic tube axle counters	Streeter Amet, J R trafficounter, Model No. 160
4. Atmospheric Particulate				
a. Total particulate	mass conc. ($\mu g/m^3$)	integrated	Iso-kinetic profiler	MRI developed under EPA Contract No. 68-02-0619
b. Total suspended particulate	mass conc. ($\mu g/m^3$)	integrated	Hi-Volume sampler	Sierra Instruments, Inc., Model 305
c. Inhalable particulate	mass conc. ($\mu g/m^3$)	integrated	size selective inlet	Andersen Samplers, Inc., Model 7000
d. Inhalable particulate	mass size dist. (μg)	integrated	slotted high-volume cascade impactor	Sierra Instruments, Inc., Model 230

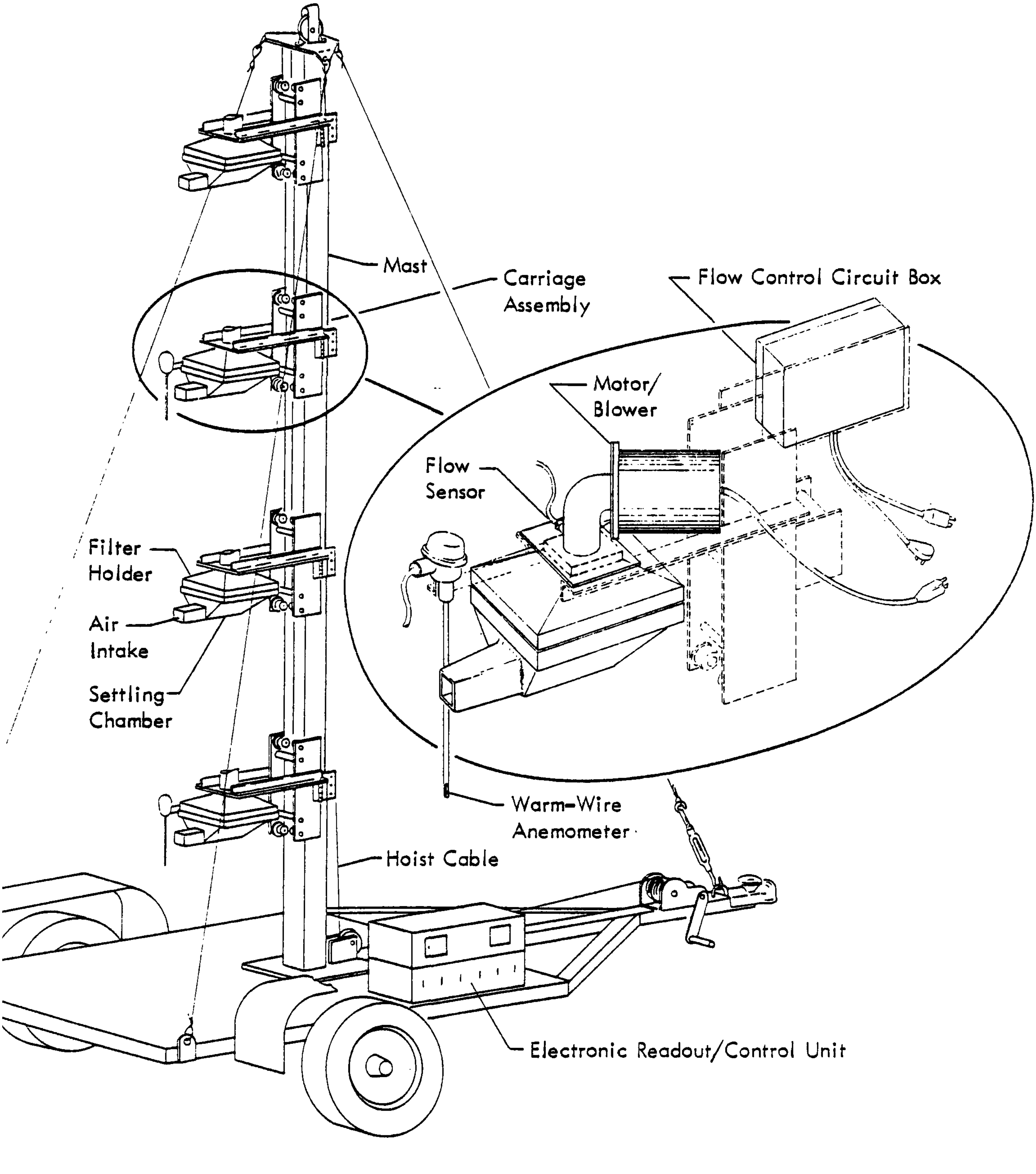


Figure 3. MRI exposure profiler.

The recently developed EPA version of the size selective inlet (SSI) for the high volume air sampler was used to determine the IP concentrations. To obtain the particle size distribution of IP, a high-volume parallel-slot cascade impactor (CI) with greased substrates was positioned beneath the SSI. This five stage cascade impactor has, at a flow rate of 40 SCFM, 50% efficiency cutpoints at 7.2, 3.0, 1.5, 0.95, and 0.49 μm aerodynamic diameter.

The cascade impactors were used in conjunction with the SSI's for two reasons. First, the 15 μm cutpoint for inhalable particulate (IP) was not well established as a standard at the time of this study. With the use of the cascade impactor data, alternate cutpoints for IP could be determined. The second reason for using the cascade impactors was to obtain a fine particle (FP) cutpoint of 2.5 μm.

Other air sampling instrumentation used included standard high-volume air samplers to measure total suspended particulate matter (TSP) consisting of particles smaller than about 30 μm in aerodynamic diameter.

Three variations of air sampling equipment deployment were used in this study. The deployment used in the winter testing (Kansas City area) is shown in Figure 4. The two deployments of sampling equipment for the spring testing (St. Louis/Granite City areas) are shown in Figures 5 and 6.

The basic downwind equipment included an exposure profiling sampling system with four sampling heads positioned at 1- to 4-m heights. In addition, size selective inlets fitted with high-volume cascade impactors were placed at 1- and 3-m heights to determine the respective IP and FP mass fractions of the total particulate emissions. A standard high-volume air sampler was also operated at a height of 2 m.

Optional equipment operated downwind in the winter testing included a 1-m high size-selective inlet, fitted with a cascade impactor with ungreased substrates. No optional equipment was operated downwind in the St. Louis testing.

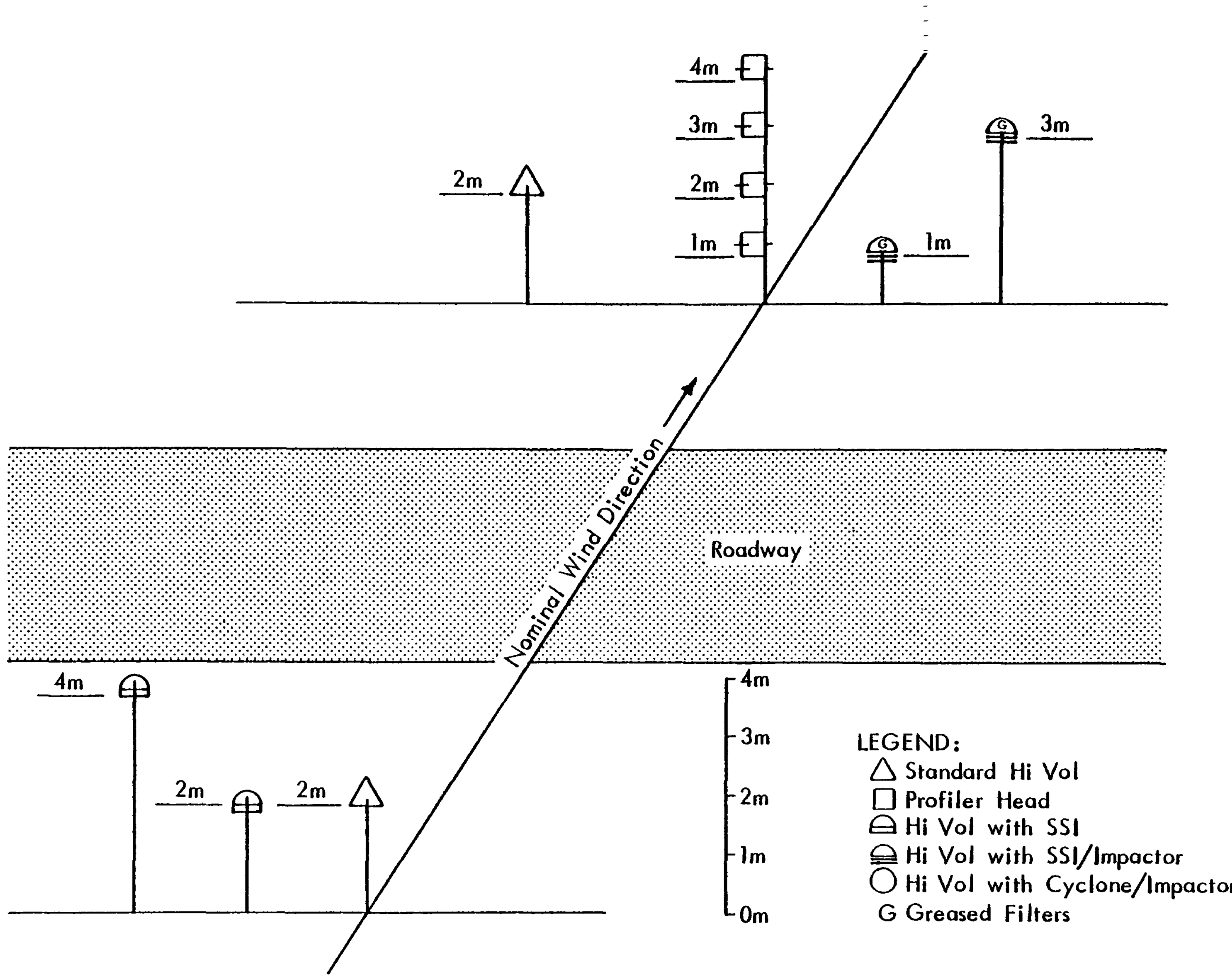


Figure 4. Sampling equipment deployment for winter testing in Greater Kansas City Area.

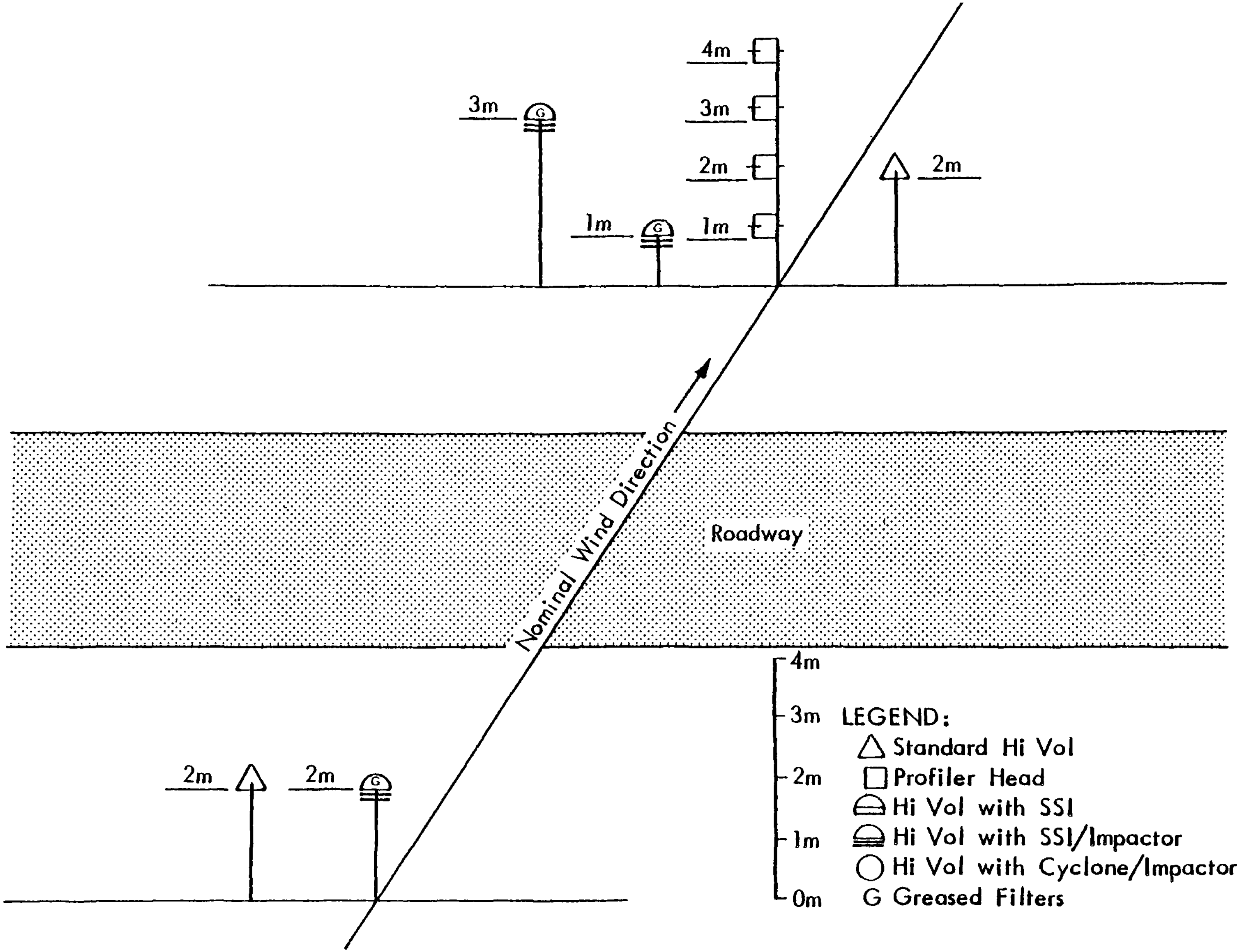


Figure 5. Sampling equipment deployment "A" for spring testing in Greater St. Louis Area.

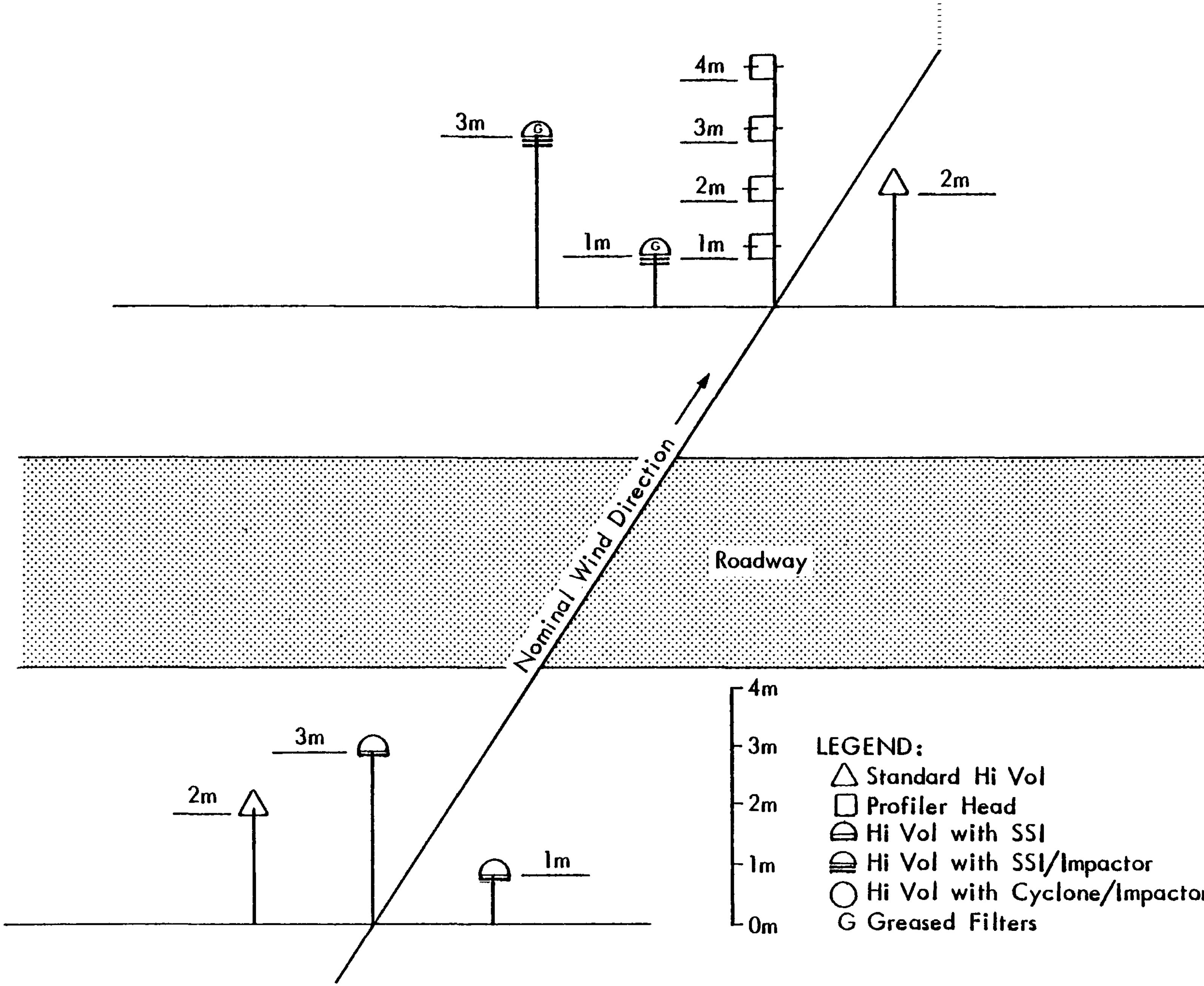


Figure 6. Sampling equipment deployment "B" for spring testing in Greater St. Louis Area.

The basic upwind equipment included SSIs and a standard high-volume air sampler. In the Kansas City testing, two SSIs at heights of 2 and 4 m were used to obtain the IP concentration of upwind particulate matter. In the St. Louis testing, the primary upwind equipment included a high-volume air sampler and an SSI/CI with greased substrates. For the secondary deployment array, two SSIs were used to obtain the vertical distribution of IP.

4.2 ROADWAY DUST SAMPLING EQUIPMENT

Samples of the dust found on the roadway surface were collected during the source tests. In order to collect this surface dust, it was necessary to close each traffic lane for a period of approximately 15 min. Normally, an area that was 3 m by the width of a lane was sampled. For each test, collection of material from all travel lanes and curb areas (extending to about 25-30 cm from the curbing) was attempted. A hand held portable vacuum cleaner was used to collect the roadway dust. The attached brush on the collection inlet was used to abrade surface compacted dust and to remove dust from the crevices of the road surface. Vacuuming was preceded by broom sweeping if large aggregate was present.

4.3 VEHICLE CHARACTERIZATION EQUIPMENT

The characteristics of the vehicular traffic during the source testing, were determined by both automatic and manual means. The vehicular characteristics included: (a) total traffic count, (b) mean traffic speed, and (c) vehicle mix.

Total vehicle count was determined by using pneumatic-tube counters. In order to convert the axle counts to total vehicles, visual 1-min vehicle mix summaries were tabulated every 15 min during the source testing. The vehicle mix summaries recorded vehicle type, number of vehicle axles and number of vehicle wheels. From this information, the total axle counts were corrected to the total number of vehicles by type.

The speed of the traveling vehicles was determined by noting the posted speed limits of the roadway test section. As a check against this determination method, speeds of the vehicles were determined through the occasional use of a hand-held radar gun.

The weights of the vehicle types were estimated by consulting (a) automobile literature concerning curb weights of vehicles and (b) distributors of medium duty and semi-trailer type trucks as to their curb weights.

(This page intentionally blank)

5.0 SAMPLING AND ANALYSIS PROCEDURES

The sampling and analysis procedures employed in this study were subject to the Quality Control guidelines summarized in Tables 7 to 10. These procedures met or exceeded the requirements specified by EPA.[14,15]

As part of the QC program for this study, routine audits of sampling and analysis procedures were performed. The purpose of the audits was to demonstrate that measurements were made within acceptable control conditions for particulate source sampling and to assess the source testing data for precision and accuracy. Examples of items audited include gravimetric analysis, flowrate calibration, data processing, and emission factor calculation. The mandatory use of specially designed reporting forms for sampling and analysis data obtained in the field and laboratory aided in the auditing procedure. Further detail on specific sampling and analysis procedures are provided in the following sections.

5.1 PREPARATION OF SAMPLE COLLECTION MEDIA

Particulate samples were collected on type A slotted glass fiber impactor substrates and on Type AE (8 x 10 in.) glass fiber filters. To minimize the problem of particle bounce, the glass fiber cascade impactor substrates were greased. The grease solution was prepared by dissolving 140 g of stopcock grease in one liter of reagent grade toluene. No grease was applied to the borders and backs of the substrates. The substrates were handled, transported and stored in specially designed frames which protected the greased surfaces.

TABLE 7. QUALITY CONTROL PROCEDURES FOR SAMPLING FLOW RATES

Activity	QC check/requirement
Calibration	
• Profilers, hi-vols, and impactors	Calibrate flows in operating ranges using calibration orifice every two weeks at each regional site prior to testing.
Single-point checks	
• Profilers, hi-vols, and impactors	Check 25% of units with rotameter calibration orifice or electronic calibrator once at each site prior to testing (different units each time). If any flows deviate by more than 7%, check all other units of same type and recalibrate non-complying units. (See alternative below.)
• Alternative	If flows cannot be checked at test site, check all units every two weeks and recalibrate units which deviate by more than 7%.
Orifice calibration	Calibrate against displaced volume test meter annually.

TABLE 8. QUALITY CONTROL PROCEDURES FOR SAMPLING MEDIA

Activity	QC check/requirement
Preparation	Inspect and imprint glass fiber media with ID numbers.
Conditioning	Equilibrate media for 24 hr in clean controlled room with relative humidity of less than 50% (variation of less than ± 5%) and with temperature between 20° ± and 25°C (variation of less than ± 3%).
Weighing	Weigh hi-vol filters and impactor substrates to nearest 0.1 mg.
Auditing of weights (Tare and Final)	Independently verify weights of 10% of filters and substrates (at least 4 from each batch). Reweigh batch if weights of any hi-vol filters (8 x 10 in.) or substrates deviate by more than ± 1.0 and ± 0.5 mg respectively.
Correction for handling effects	Weigh and handle at least one blank for each 1 to 10 filters or substrates 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.

TABLE 9. QUALITY CONTROL PROCEDURES FOR SAMPLING EQUIPMENT

Activity	QC check/requirements
Maintenance	
· All samplers	Check motors, gaskets, timers, and flow measuring devices at each regional site prior to testing.
Equipment siting	Separate colocated samplers by 3 to 10 equipment widths.
Operation	
· Timing	Start and stop all samplers during time spans not exceeding 1 min.
· Isokinetic sampling (profilers only)	Adjust all sampling intake orientations whenever mean (15 min. average) wind direction changes by more than 30 degrees.
	Adjust all sampling rates whenever mean (15 min average) wind speed approaching samplers changes by more than 20%.
· Prevention of static mode deposition	Cap sampler inlets prior to and immediately after sampling.

TABLE 10. QUALITY CONTROL PROCEDURES FOR DATA PROCESSING AND CALCULATIONS

Activity	QA check/requirements
Data recording	Use specially designed data forms to assure all necessary data are recorded. All data sheets must be initialed and dated.
Calculations	Independently verify 10% of calculations of each type. Recheck all calculations if any value audited deviates by more than ± 3%.

Prior to the initial weighing, the greased substrates and filters were equilibrated for 24 hr at constant temperature and humidity in a special weighing room. During weighing, the balance was checked at frequent intervals with standard weights to assure accuracy. The substrates and filters remained in the same controlled environment for another 24 hr, after which a second analyst reweighed them as a precision check. Substrates or filters that could not pass audit limits were discarded. Ten percent of the substrates and filters taken to the field were used as blanks. Paper bags for the vacuum cleaner were conditioned and tared in a similar manner.

5.2 PRE-TEST PROCEDURES/EVALUATION OF SAMPLING CONDITIONS

Prior to equipment deployment, a number of decisions were made as to the potential for acceptable source testing conditions. These decisions were based on forecast information obtained fom the local U.S. Weather Service office. A specific sampling location was identified based on the prognosticated wind direction. Sampling would ensue only if the wind speed forecast was between 4 and 20 mph. Sampling was not planned if there was a high probability of measurable precipitation (normally > 20%) or if the road surface was damp.

If conditions were considered acceptable, the sampling equipment was transported to the site, and deployment was initiated. This procedure normally took 1 to 2 hr to complete. During this period, the samples of the road surface particulate were collected at a location within 100 m of the air sampling site. For a 4-lane roadway, the collection of road surface particulate samples required approximately 1 hr to complete.

5.3 AIR SAMPLING

Once the source testing equipment was set up and filters put in place, air sampling commenced. Information recorded for each test included: (a) exposure profiler - start/stop times, wind speed profiles and sampler flow rates (determined every 15 min) and wind direction (relative to roadway perpendicular); SSI/CIs, Hi-Vols - start/stop times, and sampler flow rates, (c) vehicle traffic - total count, vehicle mix count, and speed; and (d) general meteorology - wind speed and direction, temperature, relative humidity and solar radiation.

Sampling usually lasted 4 to 6 hr. Occasionally, sampling was interrupted due to occurrence of unacceptable meteorological conditions and then restarted when suitable conditions returned. Table 11 presents the criteria used for suspending or terminating a source test.

The upwind-background samplers were normally operated concurrent with the downwind samplers. Care was taken to position the upwind samplers away from any influencing particulate emission source.

5.4 SAMPLE HANDLING AND ANALYSIS

To prevent particulate losses, the exposed media were carefully transferred at the end of each run to protective containers within the MRI instrument van. Exposed filters and substrates were placed in individual glassine envelopes and numbered file folders and then returned to the MRI laboratory. Particulate that collected on the interior surfaces of each exposure probe was rinsed with distilled water into separate glass jars.

TABLE 11. CRITERIA FOR SUSPENDING OR TERMINATING AN EXPOSURE PROFILING TEST

A test will be suspended or terminated if:[a]

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

2. Mean wind speed during sampling moves outside the 4 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 more than 20% of the sampling time.

4. Mean wind direction during sampling shifts by more than 30 degrees from profiler intake direction.

5. Mean wind speed approaching profiler sampling intake is less than 80% or greater than 120% of intake speed.

6. Daylight is insufficient for safe equipment operation.

7. Source condition deviates from predetermined criteria (e.g., occurrence of truck spill).

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

When exposed substrates and filters (and the associated blanks) were returned from the field, they were equilibrated under the same conditions as the initial weighing. After reweighing, 10% were audited to check precision.

The vacuum bags were weighed to determine total net mass collected. Then the dust was removed from the bags and was dry sieved. The screen sizes used for the dry sieving process were the following: 3/8 in., 4, 10, 20, 40, 100, 140, and 200 mesh. The material passing a 200 mesh screen is referred to as silt content.

5.5 EMISSION FACTOR CALCULATION

The primary quantities used in obtaining emission factors in this study were the concentrations measured by the size selective inlet/cascade impactor sampler combinations. This combination not only provides a reliable cut point for 15 μm but also permits the determination of concentrations in other particle size ranges. The MRI exposure profiler collects total particulate matter and enables one to determine the plume height. A knowledge of the vertical distributions of plume concentration is necessary in the numerical integration required to calculate emission factors. The emission factor calculation procedure is presented in Appendix A.

6.0 TEST RESULTS

6.1 TEST SITE CONDITIONS

As indicated in Table 12, the winter testing was conducted during the months of February and March 1980 at three sites in the Kansas City area: 7th Street in Kansas City, Kansas; Volker Boulevard/Rockhill Road in Kansas City, Missouri, and 4th Street in Tonganoxie, Kansas. The spring testing (Table 13) was conducted during the month of May 1980, at two sites in St. Louis (I-44 and Kingshighway) and at three closely spaced sites in Granite City, Illinois.

The sites where source testing occurred can be classified into four land use categories, based upon source parameters such as road type, vehicle mix, and vehicle speed. The categories are: commercial/industrial; commercial/residential; expressway, and rural town. Much of the data presented in the following sections is broken out according to these categories.

Table 14 presents an evaluation of the source tests according to established QA criteria. Seven of the nine Kansas City tests (Runs M-1, -2, -3, -6, -7, -8, and -9) met all of the QA criteria, while only three of the ten tests conducted in the St. Louis, Granite City area (Runs M-11, -12, and -15) met the QA criteria. The spring testing, in particular, was hampered by unseasonably light wind conditions as wind speed for four of the ten tests did not meet the minimum wind speed criterion of 4 mph.

The results of the ten runs which met the QA criteria were used as input to Multiple Linear Regression (MLR) analysis (see Section 7.0). These runs are subsequently referred to as the "MLR" data set.

TABLE 12. WINTER TEST SITE CONDITIONS (Kansas City Area Paved Roads)

			Profiler Operation			Ambient Temperature		Wind Speed		Number of Vehicle Passes			Mean Vehicle Speed	
Run	Site	Date	Start Time	Stop Time	Sampling Duration	°C	°F	m/sec	mph	Cars/ Vans	Light Trucks	Heavy Trucks	mph	kph
M-1	7th Street	2/7/80	13:08	15:08	120	-2.0	28	3.3	7.4	1,932	359	336	30	48
M-2	7th Street	2/11/80	14:21	15:47	86	-2.8	27	2.9	6.5	1,952	107	107	30	48
M-3	7th Street	2/12/80	10:54	12:54	120	-2.5	28	3.5	7.8	1,848	120	176	30	48
M-4	Volker Boulevard	2/26/80	11:22	15:22	240	3.5	38	3.5	7.8	2,732	31	0	35	56
M-5	Volker Boulevard	2/27/80	10:35	14:21	226	11.5	53	1.0	2.2	2,419	54	0	35	56
M-6	Rockhill Road	2/28/80	10:19	15:00	281	1.8	35	2.5	5.6	3,672	32	0	30	48
M-7	Volker Boulevard	3/5/80	11:30	15:41	251	-5.0	23	2.4	5.4	3,017	57	17	35	56
M-8	Tonganoxie - 4th St.	3/6/80	11:17	17:02	345	10.0	50	2.1	4.7	1,936	39	0	20	32
M-9	7th Street	3/10/80	10:30	12:51	136	10.0	50	3.3	7.4	2,705	270	273	30	48

TABLE 13. SPRING TEST SITE CONDITIONS (St. Louis Area Paved Roads)

Run	Site	Date	Profiler Operation: Start Time	Profiler Operation: Stop Time	Profiler Operation: Sampling Duration	Ambient Temperature °C	Ambient Temperature °F	Wind Speed m/sec	Wind Speed mph	Number of Vehicle Passes: Cars/ Vans	Number of Vehicle Passes: Light Trucks	Number of Vehicle Passes: Heavy Trucks	Mean Vehicle Speed mph	Mean Vehicle Speed kph	Sampling Equipment Configuration
M-10	I-44, Hampton by Sublette	5/7/80	11:30	14:32	182	15.5	60	1.3	2.9	9,595	458	1,095	55	89	A
M-11	I-44, Hampton by Sublette	5/8/80	9:42	12:43	181	13.3	56	3.9	8.7	9,563	520	1,016	55	89	A
M-12	I-44, Hampton by Sublette	5/8/80	15:27	17:57	150	18.3	65	2.1	4.7	7,751	850	1,211	55	89	B
M-13	Kingshighway and Penrose Park	5/9/80	11:16	14:30	194	15.5	60	1.2	2.7	5,000	40	150	35	56	A
M-14	Kingshighway and Penrose Park	5/11/80	9:20	12:18	178	12.7	55	4.1	9.2	3,800	30	110	35	56	A
M-15	Kingshighway and Penrose Park	5/13/80	13:46	16:01	135	24.9	77	5.1	11.4	3,900	30	110	35	56	B
M-16	I-44, Hampton by Sublette	5/14/80	10:18	14:32	254	21.1	70	1.8	4.0	13,200	1,010	1,220	55	89	A
M-17	24th and Madison, Granite City	5/15/80	12:23	14:53	150	23.8	75	1.8	4.0	3,390	-	-	30	48	A
M-18	24th and Madison, Granite City	5/15/80	16:19	19:11	172	23.8	75	2.3	5.1	3,670	-	-	30	48	A
M-19	Benton Road and Oregon, Granite City	5/19/80	9:45	17:53	488	21.1	70	1.2	2.7	5,500	300	-	30	48	A
M-20	Benton Road and Nameok, Granite City	5/21/80	10:00	10:20	Test Aborted - light and variable winds										

TABLE 14. ACCEPTABLE TESTS FOR MLR

Criteria	Run Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
. Mean angle of wind direction and profiler orientation less than 20°.	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes
. Mean angle of profiler orientation and roadway less than 45°.	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
. Adequate sampling wind speed conditions, greater than 4 mph.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
. Acceptable background particle concentration relative to downwind samplers	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Results are not based on average emissions data of other test runs.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Acceptable test for MLR	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	No	No	No	No

6.2 STREET SURFACE PARTICULATE LOADINGS

During each emissions sampling run and at other times when emissions sampling was not being conducted, samples of street surface particulate were collected to determine total particulate loadings and silt percentages. The silt percentage corresponds to that fraction of the surface sample < 75 μm in equivalent physical diameter. As shown in Table 15, silt loadings on active travel lanes ranged from about 0.022 g/m^2 on a freeway (I-44) to more than 2.5 g/m^2 on a lightly traveled rural road in Tonganoxie. As expected, loadings in curb areas substantially exceeded loadings in travel lanes. The range of day-to-day variations in loadings at a given site was generally within a factor of 2. Higher loadings tended to occur after a precipitation event.

6.3 AIRBORNE PARTICULATE CONCENTRATIONS

Table 16 lists the upwind and downwind particulate mass concentrations for the various particle size fractions measured during the field program. These concentration data were collected under a broad range of environmental conditions, some of which did not meet the QA criteria established for a valid profiling test (see page 40). The latter data are included in Table 16 because they reflect the air quality impact of the roadway under meteorological conditions which occur a significant portion of the time. Also shown in this table is the effective plume height found by extrapolating the upper net (i.e., due to the source) TP concentrations to a value of zero.

Table 17 provides a summary of the mass fraction ratios. As indicated, the IP concentration measured downwind of the test road segment was found to decrease with height. The mean ratio of downwind IP to TSP concentration (2 m) was 0.45 (σ = 0.14), and the corresponding mean upwind ratio was 0.54 (σ = 0.18). This indicates that background TSP, although lower in concentration , contains a higher percentage of IP. Similar differences are also evident in the mean upwind versus downwind < 10 μm to TSP ratios and FP to TSP ratios.

TABLE 15. PAVED ROAD SURFACE DUST LOADINGS

Test site by land use category	Date	Run	No. of traffic lanes	Average lane width (m)	Average lane width (ft)	Total loading: Curb (gr/ft^2)	Total loading: Curb (g/m^2)	Total loading: Travel lanes (gr/ft^2)	Total loading: Travel lanes (g/m^2)	Silt Content (%): Curb	Silt Content (%): Travel lanes
COMMERCIAL/INDUSTRIAL											
7th Street	2/11/80	M-1	4	3.4	11	203	142	6.2	4.3	15.7	10.7
7th Street	2/12/80	M-2	4	3.4	11	a	a	6.1	4.2	a	6.2
7th Street	2/12/80	M-3	4	3.4	11	a	a	6.0	4.2	a	3.5
7th Street	2/22/80	-	4	3.4	11	5,670	3,160	7.7	5.4	8.7	11.9
7th Street	3/03/80	-	4	3.4	11	-	-	4.5	3.1	-	5.5
7th Street	3/10/80	M-9	4	3.4	11	-	-	3.4	2.4	-	12.2
COMMERCIAL/RESIDENTIAL											
Volker Boulevard	2/13/80	-	4	2.7	9		a	3.1	2.2	a	5.9
Volker Boulevard	2/26/80	M-4	4	2.7	9	2,590	1,810[b]	3.3	2.3	12.3	18.8
Volker Boulevard	2/27/80	M-5	4	2.7	9	3,640	2,540[b]	6.7	4.7	13.7	21.4
Volker Boulevard	3/03/80	-	-	2.7	9	-	-	3.2	2.2	-	20.2
Volker Boulevard	3/05/80	-	4	2.7	9	-	-	3.8	2.6	-	22.7
Volker Blvd. (2 blks. E of prev. site)	3/05/80	-	4	2.7	9	1,330	929[b]	9.8	6.8	11.3[b]	20.7
Rockhill Road	2/28/80	M-6	4	2.7	9	910	635[b]	4.7	3.3	21.2	21.7
Kingshighway and Penrose Park	5/09/80	M-13	2	3.4	11	41.3	28.8	1.12	0.8	8.2	13.7
Kingshighway and Penrose Park	5/11/80	M-14	2	3.4	11	-	-	-	-	-	-
Kingshighway and Penrose Park	5/13/80	M-15	2	3.4	11	-	-	0.81	0.6	2.6	8.1
24th and Madison, Granite City	5/15/80	M-17	4	3.0	10	-	-	20.3	14.2	-	5.7
24th and Madison, Granite City	5/15/80	M-18	4	3.0	10	560	391[b]	14.8	10.3	12.5[b]	7.1
Benton Road and Oregon	5/19/80	M-19	2	3.0	10	168	117[b]	15.4	10.8	15.5[b]	8.6
20th Street (E. of Steel Plant)	5/21/80	-	4	2.7	9	245	171	20.3	14.2	13.2	6.7
EXPRESSWAY											
I-44, Hampton by Sublette	5/07/80	M-10	8	3.6	12	-	-	-	-	-	-
I-44, Hampton by Sublette	5/08/80	M-11	8	3.6	12	-	-	-	-	-	-
I-44, Hampton by Sublette	5/08/80	M-12	8	3.6	12	-	-	-	-	-	-
I-44, Hampton by Sublette	5/14/80	M-16	8	3.6	12	-	-	-	-	-	-
I-44, Hampton by Sublette	5/21/80	-	8	3.6	12	-	-	0.07	0.05	-	46.0
RURAL TOWN											
Tonganoxie - 4th St. (W of Church St.)	3/16/80	-	2	3.0	10	-	-	322.0	224.8	-	9.6
Tonganoxie - 4th St. (W of Church St.)	3/17/80	-	2	3.0	10	-	-	238.0	166.2	-	6.9
Tonganoxie - 4th St. (3 blocks W of previous site)	3/06/80	M-8	2	3.0	10	-	-	24.5	17.1	-	14.5
Tonganoxie - 4th st. (3 blocks W of previous site)	3/17/80	-	2	3.0	10	-	-	35.7	24.9	-	7.4
Tonganoxie - Main Street	3/06/80	-	2	3.0	10	-	-	13.3	9.3	-	11.0
Tonganoxie - Main Street	3/17/80	-	2	3.0	10	-	-	14.7	10.3	-	41.1

[a] Curb area wet.
[b] Average of two samples.

TABLE 16. PARTICULATE CONCENTRATIONS AND PLUME HEIGHT

Run number	Upwind concentration (μg/m³) IP (2 m)	≦10 μm (2 m)	FP (2 m)	TSP (2 m)	Downwind concentration (μg/m³) IP (1 m/3 m)	≦10 μm (1 m/3 m)	FP (1 m/3 m)	TSP (2 m)	IP (2 m)	Downwind plume height (m)
COMMERCIAL/INDUSTRIAL										
M-1	19	-	-	120	146/108	124/94	68/60	490	368	8.5
M-2	12	-	-	46	35/33	33/31	28/23	68	124	10[b]
M-3	35	-	-	77	93/62	79/60	44/40	88	183	8.1
M-9	65	-	-	128	207/106	169/86	77/31	400	437	8.5
COMMERCIAL/RESIDENTIAL										
M-4	37	-	-	65	37/32	31/27	17/11	76	85	4.6
M-5	83	-	-	99	110/95	98/85	55/46	190	248	6.1
M-6	57	-	-	78	69/71	63/63	41/38	127	138	7.2
M-7	31	-	-	42	154/70	130/61	57/26	190	210	5.7
M-13	60	54	33	79	80/71	70/63	42/39	164	199	10[b]
M-14	37	31	16	80	34/38	28/34	15/22	118	184	7.1
M-15	59[a]	-	-	161	100/13	89/10	56/6	200	242	6.0
M-17	65	60	39	98	64/61	56/53	39/35	180	228	6.5
M-18	75	68	47	113	92/85	82/74	51/48	187	230	6.0
M-19	47[a]	-	-	72	57/50	51/42	33/31	109	112	10[b]
EXPRESSWAY										
M-10	83	70	34	131	121/110	104/100	53/50	275	323	4.0
M-11	71	63	40	154	99/83	86/75	51/46	233	322	4.5
M-12	65[a]	-	-	198	96/79	84/70	55/45	228	161	4.8
M-16	42	38	24	67	71/63	65/56	44/37	128	191	5.8
RURAL TOWN										
M-8	62	-	-	100	171/125	140/109	59/49	348	387	8.5

- No data collected

a Represents the average of 1 and 3 meter measurements.

b Assumed value.

TABLE 17. SUMMARY OF PARTICULATE SIZE RATIOS

Statistical parameter	Upwind					Downwind				
	IP/TSP	≤10 μm/TSP	FP/TSP	≤10 μm/IP	FP/IP	IP/TSP	≤10 μm/TSP	FP/TSP	≤10 μm/IP	FP/IP
$\bar{x}$	0.54	0.54	0.33	0.88	0.53	0.45	0.40	0.24	0.87	0.52
σ	0.15	0.11	0.090	0.034	0.085	0.14	0.13	0.092	0.028	0.098
RSD	0.28	0.20	0.27	0.039	0.16	0.31	0.32	0.38	0.032	0.19
n	19	7	7	7	7	19	19	19	19	19

The FP to IP mean ratio measured downwind was 0.52 (σ = 0.098) while the mean upwind ratio was 0.53 (σ = 0.085). This finding implies that there is no significant enrichment of fine particles attributable to the paved road source.

6.4 EMISSION FACTORS

Tables 18 and 19 present for each test the calculated emission factors (IP, < 10 µm, and FP) and corresponding source characterization parameters which are thought to affect the intensity of emissions from paved roads. Appendix A describes the procedures used to calculate the emission factors from field testing data.

Tables 20 and 21 summarize, by land use category and test series quality, the emission factor and associated parameter data. As can be seen, the smallest emission factors were measured in the freeway category which also had the lowest surface silt loadings. The highest emission factor was measured in the rural town category which showed a correspondingly high surface silt loading.

Intercomparison of emission factors by land-use category indicates that relative to the mean expressway IP emissions: (a) mean commercial/residential IP emissions were approximately 10 times larger; (b) commercial/industrial emissions were approximately 20 times larger; and (c) the rural town roadway produced IP emissions that were roughly 60 times larger. Relative to mean expressway silt loading: (a) the silt loading for commercial/residential roadways was approximately 25 times higher; (b) the silt loading for commercial/industrial roadways was roughly 15 times higher; and (c) silt loading on the rural town roadway was approximately 115 times higher.

TABLE 18. PAVED ROAD EMISSION FACTORS[a]

Run No.	Site	Inhalable particulate emission factor (g/VKT)	Inhalable particulate emission factor (lb/VMT x 10^4)[b]	≤ 10 μm particulate emission factor (g/VKT)	≤ 10 μm particulate emission factor (lb/VMT x 10^4)[b]	Fine particulate emission factor (g/VKT)	Fine particulate emission factor (lb/VMT x 10^4)[b]
COMMERCIAL/INDUSTRIAL							
M-1	7th Street	3.52	125.0	3.10	110.0	1.78	63.2
M-2	7th Street	1.01	35.7	0.96	34.0	0.86	30.4
M-3	7th Street	2.39	84.8	2.20	78.1	1.54	52.0
M-9	7th Street	2.80	99.3	2.01	71.2	1.14	40.5
COMMERCIAL/RESIDENTIAL							
M-4	Volker Boulevard	0.19	6.7	0.11	4.0	c	c
M-5	Volker Boulevard	0.47	16.8	0.43	15.3	0.16	5.6
M-6	Rockhill Road	0.93	32.9	0.86	30.4	0.59	20.9
M-7	Volker Boulevard	3.30	117.0	2.62	92.8	1.04	36.8
M-13	Kingshighway and Penrose Park	0.22	7.8	0.19	6.8	0.11	4.0
M-14	Kingshighway and Penrose Park	0.93	33.0	0.85	30.1	0.62	22.0
M-15	Kingshighway and Penrose Park	1.01	35.8	0.91	32.3	0.62	22.0
M-17	Granite City, 24th and Madison	1.92	68.0	1.64	58.2	c	c
M-18	Granite City, 24th and Madison	0.32	11.4	0.23	8.0	0.052	1.9
M-19	Granite City, Benton Road and Oregon	0.16	5.8	0.11	3.9	d	d
EXPRESSWAY							
M-10	I-44, Hampton by Sublette	0.12	4.1	0.11	3.9	0.063	2.3
M-11	I-44, Hampton by Sublette	0.22	7.8	0.20	7.0	0.097	3.4
M-12	I-44, Hampton by Sublette	0.059	2.1	0.052	1.9	0.039	1.4
M-16	I-44, Hampton by Sublette	0.16	5.8	0.15	5.3	d	d
RURAL TOWN							
M-8	Tonganoxie, 4th Street	8.77	311.0	6.96	247.0	1.42	50.4

[a] Emission factors for < 10 and FP require use of interpolated concentrations.

[b] To convert these factors to lb/VMT multiply by 10^{-4}.

[c] Downwind and upwind concentrations were equal.

[d] Data gaps preclude the determination of an emission factor.

TABLE 19. SOURCE CHARACTERIZATION PARAMETERS

Run number	Site	Silt loading (g/m²)	Silt loading (gr/ft²)	Mean vehicle speed (kph)	Mean vehicle speed (mph)	Mean vehicle weight (Mg)	Mean vehicle weight (tons)
COMMERCIAL/INDUSTRIAL							
M-1	7th Street	0.46	0.66	48	30	5.1	5.6
M-2	7th Street	0.26	0.37	48	30	3.4	3.8
M-3	7th Street	0.15	0.21	48	30	4.1	4.5
M-9	7th Street	0.29	1.41	48	30	3.7	4.1
COMMERCIAL/RESIDENTIAL							
M-4	Volker Boulevard	0.43	0.61	56	35	1.9	2.1
M-5	Volker Boulevard	1.00	1.43	56	35	2.0	2.2
M-6	Rockhill Road	0.68	0.97	48	30	1.9	2.1
M-7	Volker Boulevard	0.59	0.84	56	35	2.1	2.3
M-13	Kingshighway and Penrose Park	0.11	0.16	56	35	2.4	2.7
M-14	Kingshighway and Penrose Park	0.079	0.11	56	35	2.4	2.7
M-15	Kingshighway and Penrose Park	0.047	0.067	56	35	2.4	2.7
M-17	Granite City, 24th and Madison	0.83	1.19	48	30	1.8	2.0
M-18	Granite City, 24th and Madison	0.73	1.04	48	30	1.8	2.0
M-19	Granite City, Benton Road and Oregon	0.93	1.33	48	30	2.2	2.4
EXPRESSWAY							
M-10	I-44, Hampton by Sublette	0.022	0.031	89	55	4.1	4.5
M-11	I-44, Hampton by Sublette	0.022	0.031	89	55	4.4	4.8
M-12	I-44, Hampton by Sublette	0.022	0.031	89	55	3.4	3.8
M-16	I-44, Hampton by Sublette	0.022	0.031	89	55	3.9	4.3
RURAL TOWN							
M-8	Tonganoxie, 4th St.	2.50	3.58	32	20	2.0	2.2

TABLE 20. SUMMARY OF PAVED ROAD EMISSION FACTORS

Land use category	Test series quality	Test numbers	IP emission factor			≤10 μm emission factor			FP emission factor		
			$\bar{x}$ (g/VKT)	σ (g/VKT)	RSD/RD[a]	$\bar{x}$ (g/VKT)	σ (g/VKT)	RSD/RD[a]	$\bar{x}$ (g/VKT)	σ (g/VKT)	RSD/RD[a]
Commercial/ Industrial	All tests	M-1, 2, 3, 9	2.43	1.06	0.44	2.07	0.88	0.42	1.31	0.40	0.30
	MLR tests	M-1, 2, 3, 9	2.43	1.06	0.44	2.07	0.99	0.42	1.31	0.40	0.30
Commercial/ Residential	All tests	M-4, 5, 6, 7, 13, 14, 15, 17, 18, 19	0.94	0.99	1.05	0.80	0.80	1.01	0.46	0.36	0.79
	MLR tests	M-6, 7, 15	1.75	1.35	0.77	1.46	1.00	0.68	0.75	0.25	0.34
Expressway	All tests	M-10, 11, 12, 16	0.14	0.069	0.50	0.13	0.062	0.48	0.66	0.029	0.44
	MLR tests	M-11, 12	0.14	0.12	1.16	0.12	0.10	1.16	0.068	0.041	0.85
Rural Town	All tests	M-8	8.77	-	-	6.96	-	-	1.42	-	-
	MLR tests	M-8	8.77	-	-	6.96	-	-	1.42	-	-

[a] RSD (relative standard deviation) calculated when more than two data points are present.

RD (relative deviation) = $\frac{\Sigma \left| \bar{x} - x_i \right|}{\bar{x}}$ calculated when two data points are present.

TABLE 21. SUMMARY OF SOURCE CHARACTERIZATION PARAMETERS

Land use category	Test series quality	Test numbers	Silt loading $\bar{x}$ (g/m^2)	Silt loading σ (g/m^2)	Silt loading RSD/RD[a]	Vehicle speed $\bar{x}$ (kph)	Vehicle speed σ (kph)	Vehicle speed RSD/RD[a]	Vehicle weight $\bar{x}$ (Mg)	Vehicle weight σ (Mg)	Vehicle weight RSD/RD[a]
Commercial/ Industrial	All runs	M-1, 2, 3, 9	0.29	0.13	0.45	48	-	-	4.1	0.75	-
	MLR runs	M-1, 2, 3, 9	0.29	0.13	0.45	48	-	-	4.1	0.75	-
Commercial/ Residential	All runs	M-4, 5, 6, 7, 13, 14, 15, 17, 18, 19	0.54	0.36	0.67	53	4.2	0.079	2.1	0.25	0.12
	MLR runs	M-6, 7, 15	0.44	0.34	0.77	53	4.6	0.087	2.1	0.25	0.12
Expressway	All runs	M-10, 11, 12, 16	0.022	-	-	89	-	-	4.0	0.42	-
	MLR runs	M-11, 12	0.022	-	-	89	-	-	3.9	0.71	0.26
Rural Town	All runs	M-8	2.5	-	-	32	-	-	2.0	-	-
	MLR runs	M-8	2.5	-	-	32	-	-	2.0	-	-

[a] RSD (relative standard deviation) calculated when more than two data points are present.

RD (relative deviation) = $\frac{\Sigma\left|\bar{x} - x_i\right|}{\bar{x}}$ calculated when two data points are present.

(This page intentionally blank)

7.0 MULTIPLE REGRESSION ANALYSIS

7.1 INTRODUCTION

Stepwise Multiple Linear Regression (MLR) was the method used to evaluate independent variables for possible use as correction factors in a predictive emission factor equation. It is available as a computer program in the Statistical Package for the Social Sciences (SPSS).[17] The MLR program outputs of interest in evaluating the data sets for the paved road source tests are the multiple regression coefficient, significance of the variable, and reduction in relative standard deviation due to each variable. Further information on MLR can be found elsewhere.[16-18]

It is desirable to have correction factors in the emission factor equations multiplicative rather than additive; consequently all independent and dependent variable data are transformed to natural logarithms before being entered in the MLR program.

The stepwise regression program: (a) selects the potential correction factor that is the best predictor of IP emission factors; (b) changes the dependent variable values to reflect the impact of this independent variable; and, (c) repeats this process with remaining potential correction factors until all have been used in the MLR equation or until no improvement in the predictive equation is obtained by adding another variable. Not all variables included in the MLR equation are necessarily selected as correction factors.

The steps followed in developing correction factors are listed below:

1. Create a data array of all monitored independent variables with corresponding emissions measurements.

2. Input these data into the MLR program using a COMPUTE statement to transform both independent and dependent variables to their natural logarithms.

3. From the summary statistics, find variables that have a significance less than 0.05. These are definite correction factors.

4. Next, evaluate those variables with a significance of 0.05 to 0.20. If any of these variables are judged to be pertinent independent variables they may also be included as correction factors.

5. Determine the form of the emission factor equation, exclusive of the coefficient (base emission factor).

6. Assume typical values for the correction parameters.

7. Calculate adjusted emission factors at the average conditions for all the correction parameters, using the relationships established in the emission factor equation.

8. Determine the geometric mean for the adjusted data set. This mean is the base emission factor or coefficient in the emission factor equation.

9. Finalize the emission factor equation as the base emission factor times each correction parameter normalized to average conditions.

10. Determine the precision factor for the emission factor equation.

7.2 ANALYSIS AND RESULTS

The independent variables evaluated initially as possible correction factors were silt loading (g/m^2), total loading (g/m^2), average vehicle speed, (Kph), and average vehicle weight (Mg). The rationale for including measures of roadway particulate loading stems from findings of an earlier MRI program[3] which indicated that the magnitude of roadway emissions was directly related to variations in surface loadings. The vehicle parameters--mean weight and speed--were included largely by analogy to MRI's unpaved road equation,[19] although it was recognized that the dust generation mechanism for paved roads may differ from that for unpaved roads. The moisture content of the road surface particulate was not included as a correction parameter because of the difficulty of collecting a sample without altering its moisture content.

The correlation matrix associated with a preliminary MLR analysis of the entire data set is shown in Table 22. Examination of the matrix indicated that all the independent variables except vehicle weight were highly intercorrelated. Although the stepwise algorithm would include vehicle speed first in a predictive equation, silt loading and total loading show essentially the same correlation with IP emissions ($r \cong 0.60$). In other words, the variables represent a common set of source conditions--either low vehicle speed, high surface loadings and emissions or high vehicle speed, low loadings and emissions.

The decision was made to use silt loading rather than total loading or vehicle speed in the development of the emission factor equation from the "MLR" data set. This decision was based on the perception that (a) silt loading is the most physically plausible indicator of the magnitude of IP emissions, and (b) it will yield more reproducible results in independent applications than total loading, a parameter which can be biased by the presence of macro size particles (i.e., gravel).

TABLE 22. CORRELATION MATRIX FOR ENTIRE DATA SET (n = 19)

	e_{IP}	Silt loading	Total loading	Vehicle speed	Vehicle weight
IP Emission factor (e_{IP})	1.0	0.56	0.63	-0.74	0.02
Silt loading		1.0	0.94	-0.86	-0.62
Total loading			1.0	-0.94	-0.56
Vehicle speed				1.0	0.48
Vehicle weight					1.0

The correlation matrix associated with the "MLR" data set is presented in Table 23. Including silt loading as the primary predictor effectively precludes total loading or vehicle speed from entering the equation. This follows from the high intercorrelations (multicollinearity) mentioned above. Examination of the regression statistics indicated that inclusion of vehicle weight as a second correction parameter could not be justified.

TABLE 23. CORRELATION MATRIX FOR "MLR" DATA SET (n = 10)

	e_{IP}	Silt loading	Total loading	Vehicle speed	Vehicle weight
IP Emission factor (e_{IP})	1.0	0.85	0.91	-0.89	-0.08
Silt loading		1.0	0.92	-0.89	-0.46
Total loading			1.0	-0.97	-0.31
Vehicle speed				1.0	0.37
Vehicle weight					1.0

The raw MLR equation for the "MLR" data set , as output from the SPSS package is as follows:

$$e_{IP} = 4.37\ (sL)^{0.8} \qquad (1)$$

where:

e_{IP} = IP emission factor expressed in grams per vehicle kilometer traveled (g/VKT)

sL = Silt loading of road surface particulate matter expressed in grams per square meter (g/m^2).

This equation explains 73% of the variation in the emission factors. As noted earlier, the "MLR" data set does contain data from all the land use categories sampled during the field program.

Equation 2 presents the comparable predictive IP emission factor equation normalized to a typical value for silt loading:

$$e_{IP} = 2.54\ \left(\frac{sL}{0.5}\right)^{0.8} \qquad (2)$$

The normalization procedure consists of steps 6 through 10 as outlined in Section 7.1 (p. 52).

Table 24 presents the predicted versus measured IP emission factors, and provides a comparative statistic--the ratio of predicted to measured emission factors for each test. The same information is presented graphically by land use category in Figure 7. As can be seen, there is considerable variation between predicted and measured emission factors, both overall and within individual categories. The only discernible predictive bias appears in the commercial/industrial subset where the tendency appears to be for the emission factor equation to underpredict observed emissions.

TABLE 24. PREDICTED VERSUS OBSERVED IP EMISSION FACTORS

Land use category		IP Emission factor (g/VKT)		
		Observed	Predicted	Ratio[a]
Commercial/ industrial				
	M-1	3.52	2.37	0.67
	M-2	1.01	1.51	1.50
	M-3	2.39	0.970	0.41
	M-9	2.80	1.64	0.58
Commercial/ residential				
	M-6	0.928	3.25	3.50
	M-7	3.30	2.90	0.88
	M-15	1.01	0.384	0.38
Expressway				
	M-11	0.222	0.209	0.94
	M-12	0.0589	0.209	3.55
Rural town				
	M-8	8.77	9.20	1.05

[a] Predicted divided by observed.

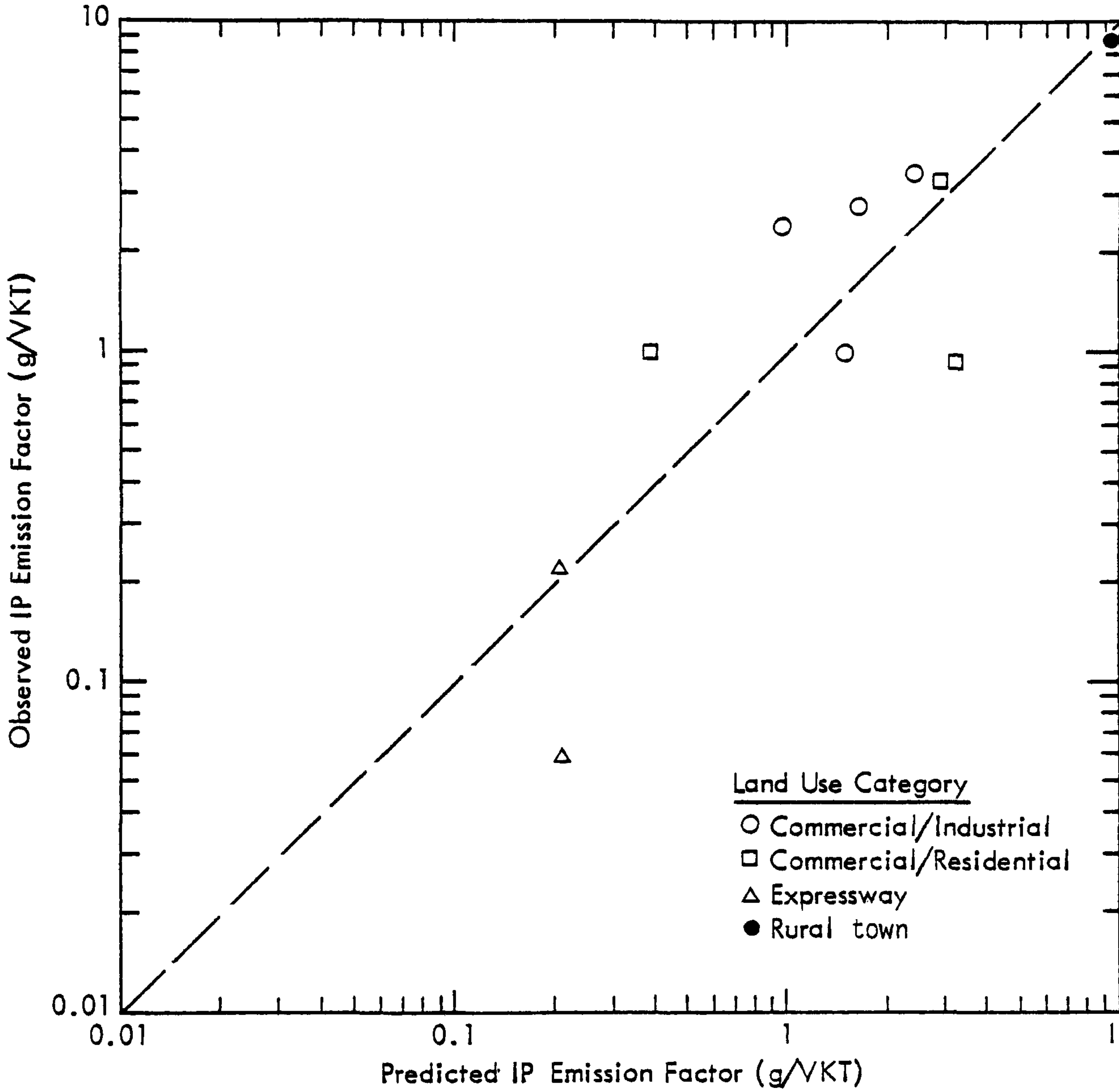


Figure 7. Predicted versus observed IP emission factors by land use category.

This tendency may be the result of a combination of the high percentage of heavy-duty vehicles (~ 20%) coupled with vehicle idle, acceleration, and deceleration typically associated with proximity to traffic lights. The latter condition normally produces a significant increase in the exhaust emissions component, which would not be incorporated in the silt loading model.

7.3 COMPARATIVE EVALUATION

The emission factor equation predicts the "MLR" series test data with a precision factor of 2.0. The precision factor (f) for an emission factor is defined such that the 68% confidence interval for a predicted value (P) extends from P/f to Pf. The precision factor is determined by exponentiating the standard deviation of the differences (standard error of the estimate) between the natural logarithms of the predicted and observed emission factors.

The precision factor may be interpreted as a measure of "average" error in predicting IP emissions from the regression equation. Assuming that the actual IP emission factors are log normally distributed about the regression line, it can be stated that approximately 68% of the predictions are within a factor of 2. The effective outer bounds of predictability are determined by exponentiating twice the standard error of the estimate. The resultant estimate of predictive accuracy, in this case 4.0, then encompasses approximately 95% of the predictions.

To put the precision factor of the IP predictive emission factor equation emission factor into perspective, two comparisons were undertaken utilizing the single-value emission factor found in the current AP-42 manual.[3] However, before valid comparisons could be made, it was necessary to convert the AP-42 single value factor which represents TSP emissions, to an approximate IP emission factor.

This was accomplished by multiplying the AP-42 value by 0.4 which is the mean ratio of net IP (downwind minus upwind) to net TSP concentrations as determined from the data collected in this study. This ratio may be expressed as follows:

$$\frac{\sum_{1}^{n} \frac{(IP_{Down} - IP_{Up})}{(TSP_{Down} - TSP_{Up})}}{n}$$

Because this ratio reflects net emissions, that is, the emissions directly attributable to the source, it is preferable to one based on sizing information given in AP-42 which describes emissions due to both source and background. As noted in AP-42, the latter information will be biased toward small particle sizes.

The first comparison involved the calculation of a precision factor for the AP-42 data set. The resulting value of 2.1 is a measure of the ability of the single-value factor to represent the 40 pieces of data which were averaged originally to produce the AP-42 factor. The second comparison involved the calculation of a precision factor using the single value AP-42 factor to represent the "MLR" data set, as collected in this study. This comparison yielded a precision factor of 4.4.

The precision factors and the range of the data values (emission factors) upon which they are based, are presented graphically in Figure 8. The ideal model has a precision factor of 1.0, implying that each predicted value is identical to the corresponding observed value, over an infinite range of emission factors. The most important conclusion that can be drawn from Figure 8 is that the emission factor equation, though far from ideal, does predict IP emissions more accurately over a much greater range of values than does the AP-42 single-value factor over a considerably smaller range of data values corresponding to the AP-42 data set. Furthermore, application of the single-value AP-42 factor to represent the wide range of IP emissions from paved roads as measured during this program, yields a

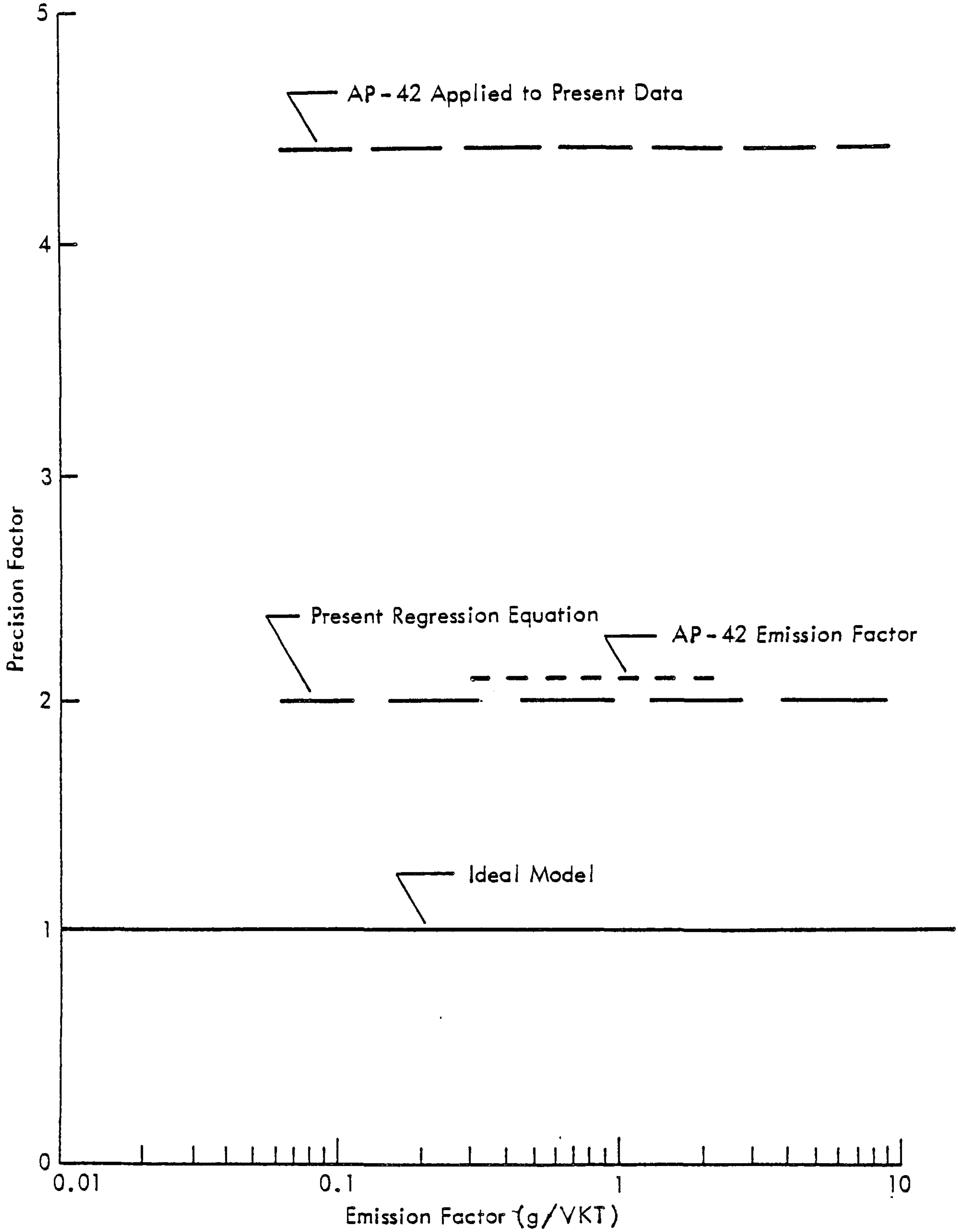


Figure 8. Comparison of emission factor models.

precision factor which is more than double (4.4 versus 2.0) that associated with the predictive equation. This ability of the predictive equation to more accurately represent variations in IP emissions is directly attributable to the relatively strong relationship between roadway surface silt loading and IP emissions.

7.4 EXTENSION OF THE PREDICTIVE EQUATION TO DIFFERENT PARTICLE SIZE FRACTIONS

The particle sizing data obtained from the SSI/CI combinations was also used to develop emission factors and predictive emission factor equations for the ≦ 10 μm and FP particle size fractions. These analyses used the same procedure as that applied in developing the equation for IP (see Section 7.1). Derivation of TSP emission factors for use in developing a predictive equation required different initial calculations, since only two TSP samplers (one upwind, one downwind) were operated during the measurement phase of the program. In essence, the initial calculation involved multiplication of the IP emission factor for each run in the "MLR" series data set by the corresponding net ratio of TSP to IP concentration as measured by appropriate samplers (see Figures 4 to 6). This procedure assumes that the TSP/IP ratio is constant over the vertical extent of the plume.

The general form of the emission factor equation applicable to all particle size fractions, is as follows:

$$e = k \left(\frac{sL}{0.5}\right)^{P} \qquad \text{(metric)} \qquad (3)$$

$$e = K \left(\frac{sL}{0.7}\right)^{P} \qquad \text{(English)} \qquad (4)$$

The base emission factor coefficients (k, K), exponent (P), and precision factor for each size fraction are listed in Table 25. For the metric equation, silt loading is expressed as grams per square meter; silt loading for the English equation is expressed as grains per square foot.

TABLE 25. PAVED ROAD EMISSION FACTOR EQUATION PARAMETERS (by particle size fraction)

Particle size fraction	k (g/VKT)	K (lb/VMT)	P	Precision factor[a]
TSP	5.87	0.0208	0.9	2.4
IP	2.54	0.0090	0.8	2.0
≦ 10 μm	2.28	0.0081	0.8	2.2
FP	1.02	0.0036	0.6	2.2

[a] Represents the interval encompassing 68% of the predicted values.

It should be noted that the tendency for the power term in the equation to increase with larger particle size fraction is generally consistent with MRI's previous paved road equation in which silt loading to the 1.0 power was employed to account for variations in TSP emissions.

7.5 EMISSIONS INVENTORY APPLICATIONS

For the majority of emissions inventory applications involving urban paved roads, actual measurements of silt loading will probably not be made. Therefore, in order to facilitate the use of the previously described equations, it is necessary to characterize silt loadings according to a parameter(s) more readily available to persons developing emissions inventories. After examination and analysis of silt loading and traffic data collected during relevant MRI sampling programs, as well as surface loading data gathered in connection with an extensive study of urban water pollution, the decision was made to characterize variations in silt loading based upon a roadway classification system. The roadway classification system developed by MRI for this purpose is presented in Table 26.

TABLE 26. PAVED ROADWAY CLASSIFICATION

Roadway type	Average daily traffic (ADT)	No. of lanes
Freeway/expressway	> 50,000	≥ 4
Major street/highway	> 10,000	≥ 4
Collector street	500-10,000	2[a]
Local street	< 500	2[b]

[a] Total roadway width ≧ 32 ft.

[b] Total roadway width < 32 ft.

This system generally corresponds to the functional classification systems employed by transportation agency personnel; and thus the data necessary for emissions inventory--number of road miles per road category and traffic counts--should be easily estimated. It should be noted that in some situations it may be necessary to combine this silt loading information with sound engineering judgment in order to approximate the loadings for roadway types not specifically included in Table 26.

It should be recalled from Section 2.0 that traffic volume is not the only factor affecting roadway silt loadings. For all roadways that provide access to immediately adjacent areas, land use, particularly as it relates to the potential for mud and dirt "tracking," is important. Silt loadings may also be affected by street surface type and condition, the presence or absence of curb, as well as public works practices and season of the year. However, given the present data base, it is not possible to incorporate relationships between these factors and silt loadings in a manner applicable to the majority of emissions inventories.

The data base made up of 44 samples collected and analyzed according to the procedures outlined in Sections 4.2 and 5.4 may be used to characterize the silt loadings for each roadway category. These samples, obtained during MRI field sampling programs over the past 3 years, represent a broad range of urban land use and roadway conditions. Geometric means for this data set are broken out by sampling location (i.e., city) and roadway category in Table 27.

TABLE 27. SUMMARY OF TYPICAL SILT LOADINGS (g/m^2) FOR URBAN PAVED ROADWAYS[a] BY CITY

	Roadway category							
	Local		Collector		Major		Overall	
City	$\bar{X}g$[b]	n	$\bar{X}g$	n	$\bar{X}g$	n	$\bar{X}g$	n
Baltimore[c]	1.42	2	0.72	4	0.39	3	0.68	9
Buffalo[d]	1.41	5	0.29	2	0.24	4	0.56	11
Granite City (Ill.)[e]	-	-	-	-	0.82	3	0.82	3
Kansas City[e]	-	-	2.11	4	0.41	13	0.60	17
St. Louis[e]	-	-	-	-	0.16	3	0.16	3

a Freeway/expressway loading measurement (0.022 g/m^2) from Table 19 not included.

b $\bar{X}g$'s are geometric means based on the corresponding n sample size.

c Reference 20.

d Reference 21.

e From this report.

The sampling locations can be considered representative of most large urban areas in the United States with the possible exception of those located in the Southwest. Except for the collector roadway category, the overall mean silt loadings do not vary greatly from city to city, though the St. Louis mean for major roads is somewhat lower than the other four cities. The substantial variation within the collector roadway category is probably attributable to the deposition effects of land use associated with the specific sampling locations. It should also be noted that an examination of data collected at three cites in Montana during early spring, indicates that winter road sanding may produce loadings five to six times higher than the means of the loadings given in Table 27 for the respective road categories.[22]

Typical silt loadings by roadway category (from Table 27) are as follows:

- Local streets 1.41 g/m²
- Collector streets 0.92 g/m²
- Major streets and highways 0.36 g/m²
- Expressways/freeways 0.022 g/m²

It should be noted that regression analysis indicates a significant ($\alpha = 0.01$) relationship between silt loading and traffic volume of the following form.

$$sL = 21.3\ (ADT)^{-0.41}$$

This equation explains 35% of the sample variation.

Table 28 presents the emission factors broken out by roadway category and particle size. These were obtained by inserting the typical silt loadings of each roadway category into the emission factor equations found in Section 7.4, Table 25. These emission factors can be utilized directly for emission inventory purposes. It is important to note that the current AP-42 paved road emission factors[3] for TSP agree quite well with those developed in this study. For example, those cited in connection with MRI's previous testing[2] were conducted at two roadway sites in the major street and highway category. Those tests yielded a mean TSP emission factor of 4.3 g/VKT versus 4.4 g/VKT as determined from the data presented here.

TABLE 28. RECOMMENDED EMISSION FACTORS FOR SPECIFIC ROADWAY CATEGORIES AND PARTICLE SIZE FRACTIONS

Roadway category	Emission factor by particle size fraction							
	TSP		≦ 15 μm		≦ 10 μm		≦ 2.5 μm	
	g/VKT	lb/VMT	g/VKT	lb/VMT	g/VKT	lb/VMT	g/VKT	lb/VMT
Local	15	0.053	5.8	0.021	5.2	0.018	1.9	0.0067
Collector	10	0.035	4.1	0.015	3.7	0.013	1.5	0.0053
Major street and highway	4.4	0.016	2.0	0.0071	1.8	0.0064	0.84	0.0030
Freeway/ Expressway	0.35	0.0012	0.21	0.00074	0.19	0.00067	0.16	0.00057

(This page intentionally blank)

8.0 SUMMARY AND CONCLUSIONS

The purpose of this study was to quantify inhalable particulate emissions generated by traffic entrainment of paved road surface particulate matter. Paved road source testing was performed at sites representative of significant emission sources within a broad range of urban land-use categories.

The measured inhalable particulate emission factors ranged from 0.06 to 8.77 g/VKT. Lowest mean emissions were measured for the "Expressway" use category; highest mean emissions were measured for the "Rural Town" use category. Approximately 90% of the IP emissions consisted of particles smaller than 10 µm in aerodynamic diameter, and approximately 50% of the IP emission consisted of particles smaller than 2.5 µm in aerodynamic diameter.

Correlation analysis of IP emissions with parameters characterizing the source conditions showed the existence of a relatively strong positive relationship between intensity of emissions and roadway surface silt loading. This confirms the findings of earlier testing.[2] Based on regression analysis of a subset of acceptable ("MLR") test runs, the following predictive IP emission factor equation was developed:

$$e_{IP} = 2.54 \left(\frac{sL}{0.5}\right)^{0.8} \qquad (5)$$

where e_{IP} = Inhalable particulate emission factor (g/VKT).

sL = Road surface silt loading (g/m^2).

This predictive equation has an associated precision factor of 2.0 in relation to the "MLR" data set. By way of comparison, the AP-42 single-value factor (corrected to represent IP emissions) has a precision factor of 2.1 for its data set and a precision factor of 4.4 for the "MLR" data set, which spans a much larger range of values than the AP-42 data set. Therefore the predictive equation, though far from ideal, does represent IP emissions more accurately over a much larger range of values than does the AP-42 single-value factor. This fact is directly attributable to the relationship of IP emissions to silt loading.

Extension of the regression analysis to include emission factor equations for other particle size fractions--FP, < 10 μm, and TSP--yielded a set of equations in which the power term for silt loading increased with larger particle size fraction. This result is generally consistent with MRI's previous paved road equation in which silt loading to the 1.0 power was employed to account for variations in TSP emissions.

To facilitate the use of these particle size specific equations in the development of emission inventories, a classification system of mean or typical silt loadings as a function of roadway category was derived. These mean silt loadings were then inserted into the respective emission factor equations. The resultant emission factors for specific roadway category and particle size fractions can be utilized directly for emissions inventory purposes. By accounting for variations in silt loading, these emission factors are significantly more reliable than an overall average emission factor in developing components of an urban paved road emission inventory.

9.0 REFERENCES

1. Lynn, D. L., G. Deane, R. Galkiewicz, R. M. Bradway, and F. Record. National Assessment of Urban Particulate Problem. Volume I - Summary of National Assessment. U.S. Environmental Protection Agency, Publication No. EPA 450/3-76-024, July 1976.

2. Cowherd, C., Jr., C. M. Maxwell, and D. W. Nelson. Quantification of Dust Entrainment From Paved Roadways. U.S. Environmental Protection Agency, Publication No. EPA-450/3-77-027, July 1977.

3. Compilation of Air Pollutant Emission Factors, Third Edition, U.S. Environmental Protection Agency, Publication No. AP-42, August 1977.

4. Sartor, J. D., and G. B. Boyd. Water Pollution Aspects of Street Surface Contaminants. U.S. Environmental Protection Agency, Publication No. EPA-R2-72-081, November 1972.

5. Abel, M. P. The Impact of Refloatation on Chicago's Total Suspended Particulate Levels. Master's Thesis, Purdue University, August 1974.

6. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther, and G. Jutze. Development of Emission Factors for Fugitive Dust Sources. Final Report, Midwest Research Institute for U.S. Environmental Protection Agency, Publication No. EPA-450/3-74-037, NTIS No. PB 238262/AS, June 1974.

7. Roberts, J. W., A. T. Rossano, P. T. Bosserman, G. C. Hofer, and H. A. Watters. The Measurement, Cost and Control of Traffic Dust and Gravel Roads in Seattle's Duwamish Valley. Paper No. AP-72-5, Presented at the Annual Meeting of the Pacific Northwest International Section of the Air Pollution Control Association, Eugene, Oregon, November 1972.

8. Axetell, K., and J. Zell. Control of Reentrained Dust from Paved Streets. EPA Publication No. EPA-907/9-77-007, August 1977.

9. Roberts, J. W., H. A. Watters, C. A. Margold, and A. T. Rossano. Cost and Benefits of Road Dust Control in Seattle's Industrial Valley. Paper No. 74-83, Presented at the 67th Annual Meeting of the Air Pollution Control Association, Denver, Colorado, June 9 to 13, 1974.

10. American Public Works Association. Water Pollution Aspects of Urban Runoff, APWA, Chicago, 1969. pp. 171-175.

11. Hanna, T. R., and T. M. Gilmore. Applicability of the Mass Concentration Standards for Particulate Matter in Alaskan Areas. Alaska Department of Environmental Conservation, Juneau, Alaska, 1973.

12. Shaheen, D. G. Contribution of Urban Roadway Usage to Water Pollution. U.S. Environmental Protection Agency, Publication No. EPA-600/2-75-004, March 1975.

13. Transportation and Traffic Engineering Handbook. Institute of Traffic Engineers. Prentice-Hall, Inc., London, 1976. pp. 162-163.

14. Quality Assurance Handbook for Air Pollution Measurement Systems. Volume II - Ambient Air Specific Methods. U.S. Environmental Protection Agency, Publication No. EPA 600/4-77-027a, May 1977.

15. Ambient Monitoring Guidelines for Prevention of Significant Deterioration. U.S. Environmental Protection Agency, Publication No. EPA 450/2-78-019, May 1978.

16. Draper, N. R. and H. Smith. Applied Regression Analysis. John Wiley and Sones, New York, 1965.

17. Nie, N. H., et al. Statistical Package for the Social Sciences, Second Edition. McGraw-Hill, Inc., New York, 1975.

18. Snedecor, G. W. Statistical Methods. Fourth Edition. The Iowa State College Press, Ames, Iowa, 1946.

19. Cowherd, C., Jr., R. Bohn, and T. Cuscino, Jr. Iron and Steel Plant Open Source Fugitive Emission Evaluation. Final Report, Midwest Research Institute for U.S. Environmental Protection Agency, Publication No. EPA-600/2-79-103, May 1979.

20. Cuscino, T., Jr. Total Suspended Particulate Matter Analysis in Baltimore, Maryland. State of Maryland, Baltimore, Maryland, October 1981.

21. Bohn, R. Evaluation of Open Dust Sources in the Vicinity of Buffalo, New York. EPA Contract No. 68-02-2545, Assignment 1, Environmental Protection Agency, New York, New York, March 1979.

22. Bohn, R. Update and Improvement of the Emission Inventory for MAPS Study Areas. State of Montana, Helena, Montana, August 1979.

APPENDIX A

EMISSION FACTOR CALCULATION PROCEDURES

INTRODUCTION

This appendix describes the calculation of particulate emission factors from exposure profiling data. The example calculation presented here is based on actual data obtained from an exposure profiling test (M-3) performed at the 7th Street site in Kansas City, Kansas on February 12, 1980.

The following definitions for particulate matter will be used in this appendix:

TP Total airborne particulate matter.

IP Inhalable particulate matter consisting of particles smaller than 15 μm in aerodynamic diameter.

PARTICULATE CONCENTRATION

The concentration of airborne particulate matter measured by an air sampler is given by

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

Where C = particulate concentration (μg/m³)

m = particulate sample weight (mg)

Q = sampler flow rate (m³/hr)

t = duration of sampling (hr)

The specific particulate matter concentrations from the various particulate catches are as follows:

Size range	Particulate catches
TP	Profiler filter and intake catches
IP	Size Selective Inlet (SSI) filter and impactor substrate catches

The measured IP concentrations for the sample test are found in Table A-1.

TABLE A-1. INHALABLE PARTICULATE CONCENTRATIONS FOR RUN M-3

Height (m)	Location	Total sample mass (mg)	Sample flow rate (m^3/hr)	Sampling duration (min)	Measured IP concentration (μg/m^3)
1.0	Downwind	12.75	68.0	120	93.8
2.0	Upwind	5.25	68.0	130	35.6
3.0	Downwind	8.45	68.0	120	62.1
4.0	Upwind	4.45	68.0	130	30.2

To be consistent with the National Ambient Air Quality Standard for TSP, all concentrations are adjusted to standard conditions (25°C and 760 mm of Hg).

ISOKINETIC FLOW RATIO

The isokinetic flow ratio (IFR) is defined only for a directional sampler. It is the ratio of intake air speed to the mean wind speed approaching the sampler. It is given by

$$IFR = \frac{Q}{aU} \qquad (2)$$

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

This ratio is of interest in the sampling of TP, since isokinetic sampling assures that particles of all sizes are sampled without bias. For Run M-3, the profiler IFRs at 1.0, 2.0, 3.0, and 4.0 m heights were 0.98, 0.96, 0.96, and 0.96, respectively. The profiler was the only directional sampler used in this study.

PARTICLE SIZE DISTRIBUTIONS

The particle size distribution at a given height is determined using concentration measurements from the profiler head (or Hi-Vol for upwind distributions) and the SSI/cascade impactor at the same height and at the same distance from the source. The determination of concentrations corresponding to particulate fractions < 10 µm and < 2.5 µm requires an interpolation of the particle size-mass distribution. In this study, a spline fit of the natural logarithms of the SSI/cascade impactor data was used to determine these concentrations. The downwind particle size data for Run M-3 are plotted on log-probability paper in Figures A-1 and A-2.

NET IP EXPOSURES

The upwind IP concentrations from Table A-1 are averaged to produce a representative upwind (uniform) concentration. This value is subtracted from the downwind concentrations at each height to obtain net IP concentrations (i.e., due to vehicular traffic on the road). The net concentrations are used to produce net exposure values at each downwind sampling height by the expression.

$$E = 10^{-7} C\ U\ t \qquad (3)$$

where
- E = net IP exposure (mg/cm^2)
- C = net IP concentration ($\mu g/m^3$)
- U = mean wind speed (m/s)
- t = duration of sampling (s)

Exposure represents the net mass flux of airborne particulate matter at the downwind sampling point, integrated over the time of sampling, or equivalently, the total net particulate mass passing through a unit area normal to the mean wind direction during the test. Net IP concentrations and exposures for the sample test are presented in Table A-2. The sample test lasted 120 min.

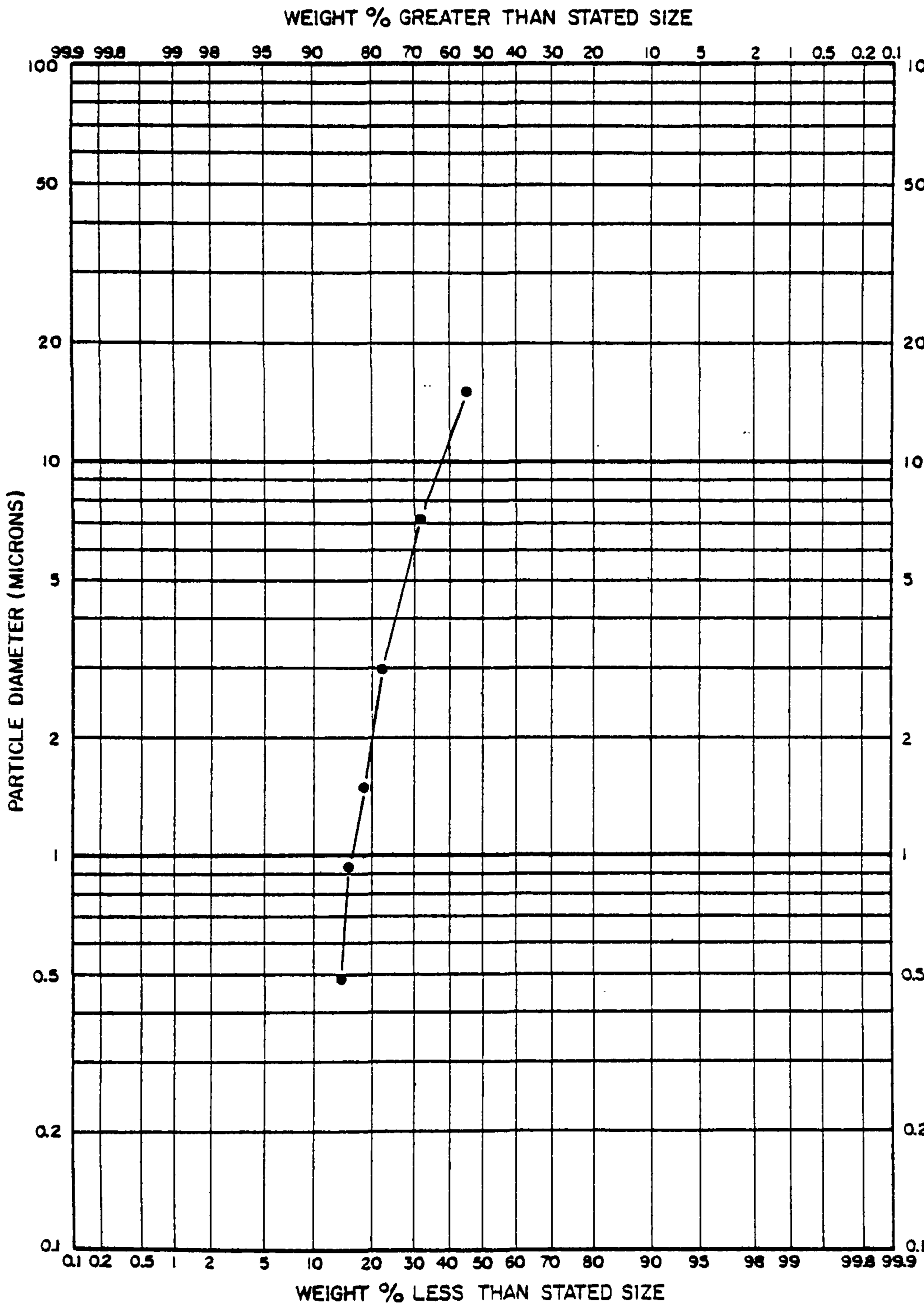


Figure A-1. Downwind particle size distribution measured at a height of 1 m for Run M-3.

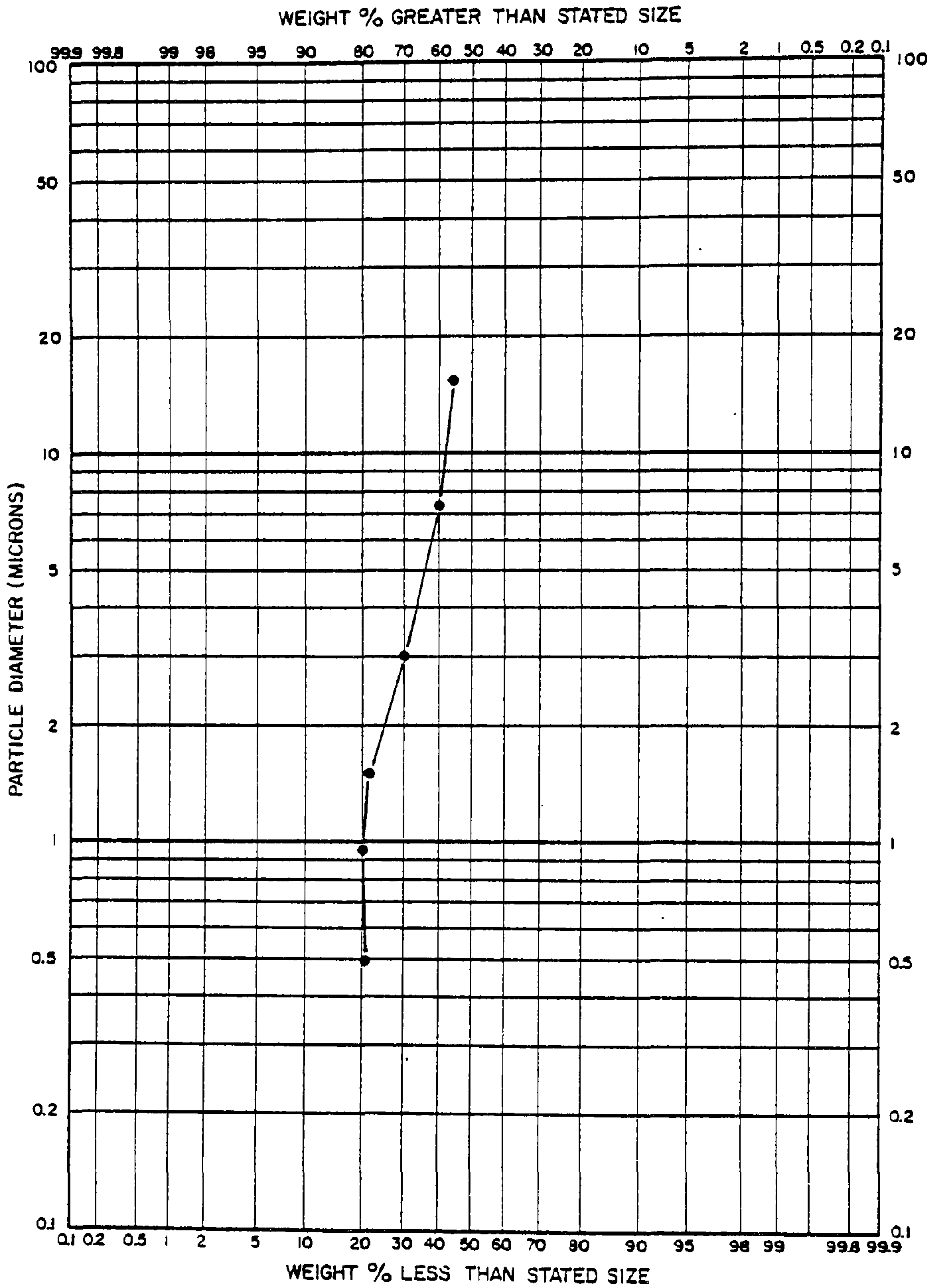


Figure A-2. Downwind particle size distribution measured at a height of 3 m for Run M-3.

TABLE A-2. NET INHALABLE CONCENTRATIONS AND EXPOSURES

Height (m)	Concentration ($\mu g/m^3$) Downwind	Upwind	Net	Wind speed (m/s)	Net IP exposure (mg/cm^2)
1.0	93.8	32.9	60.9	2.78	0.122
3.0	62.1	32.9	29.2	3.48	0.0732

EXPOSURE PROFILE

Typically the (net) exposure values decrease with increasing height in the plume. If exposure is mathematically integrated over the vertical extent of the plume, then the quantity obtained represents the total passage of airborne particulate matter due to the source, per unit length of roadway. This quantity is called the integrated exposure A and is found by:

$$A = \int_0^H E \, dh \qquad (4)$$

where:
A = integrated IP exposure ($m\text{-}mg/cm^2$)
E = net IP exposure (mg/cm^2)
h = height (m)
H = vertical extent of plume above ground (m)

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 vertical extent of the plume where the net concentration equals zero. Because exposure increases sharply over the first few centimeters of plume height, the value of exposure at the ground level is set equal to the value at a height of 1 m.

The vertical extent of the plume is found by linear extrapolation of the uppermost net TP concentrations to a value of zero. Net TP concentrations are found by subtracting the upwind TSP concentration from the downwind profiler concentration. In the case of Run M-3, Table 16 of the text shows that a plume height value of 8.1 m was found by extrapolation. For cases in which extrapolation was not possible, a plume height of 10 m was used.

Linear interpolation is used to generate the intermediate exposure values (at 1 m intervals) needed for the Simpson's rule integration of A. Because Simpson's Rule requires an odd number of equally spaced points, additional points are added (if needed) by setting exposures of heights greater than H equal to zero. From the data presented in Table A-2, the exposure profile of Figure A-3 is thus obtained.

Application of Simpson's rule to perform the integration in Eq. (4) for Run M-3 yields:

$$A = \frac{h}{3} (E_0 + 4E_1 + 2E_2 + 4E_3 + 2E_4 + 4E_5 + 2E_6 + 4E_7 + 2E_8 + 4E_9 + E_{10}) \quad (5)$$

where:
A = Integrated IP exposure (m-mg/cm^2)
E_i = Net IP exposure at i m above ground (mg/cm^2)
h = Distance between exposure values (i.e., 1 m)
E_0 = Net IP exposure at ground level = E_1

When the values from Figure A-3 are substituted into Eq. (5), it is found that the integrated exposure for Run M-3 equals 0.512 m·mg/cm^2).

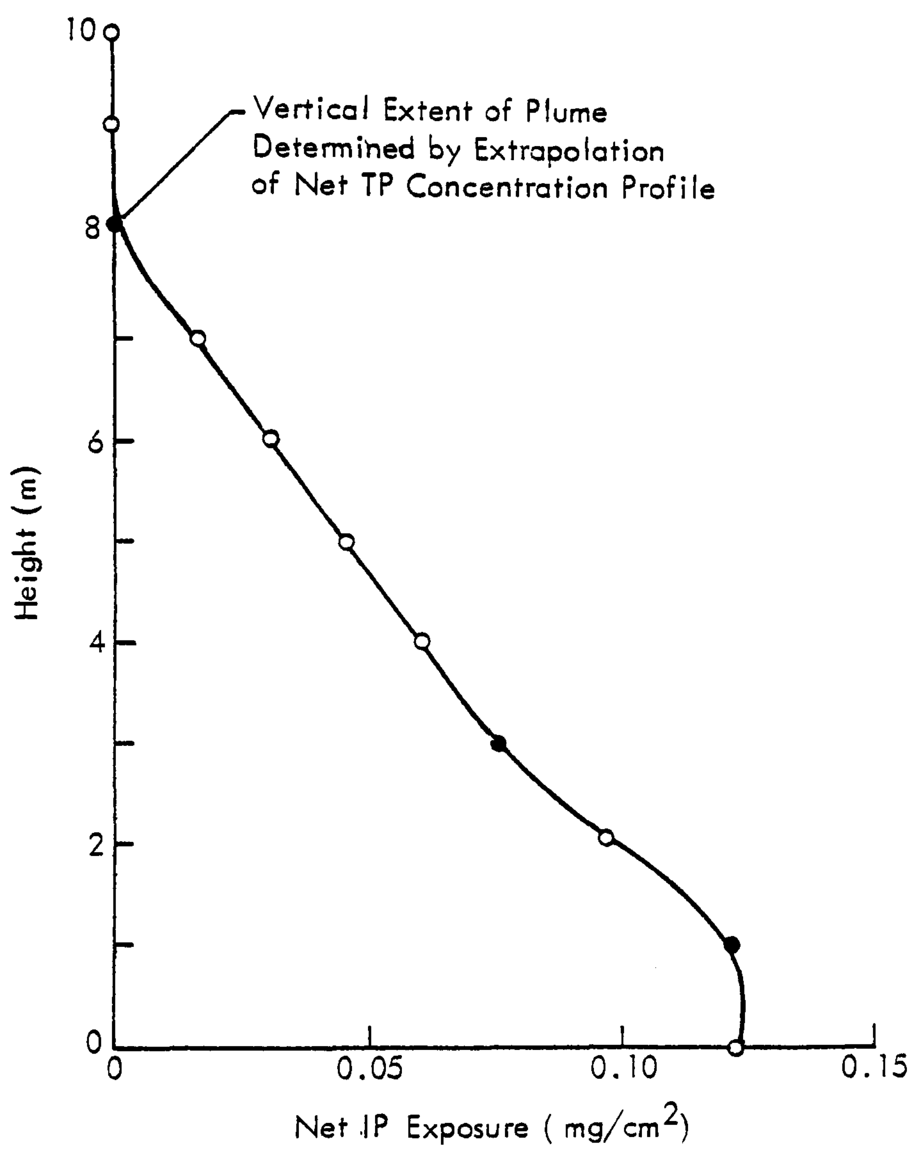


Figure A-3. Exposure profile for Run M-3.

INHALABLE PARTICULATE EMISSION FACTORS

The emission factor for IP generated by vehicular traffic on the paved road is given by

$$e = 10^4 \frac{A}{N} \qquad (6)$$

where
- e = IP emission factor (g/VKT)
- A = integrated IP exposure ($m \cdot mg/cm^2$)
- N = number of vehicle passes

Note that the leading term of Eq. (6) is a conversion factor. The IP emission factor for Run M-3 is 2.39 g/VKT based on 2,144 vehicle passes during the 120 min sampling period. To convert g/VKT to lb/VMT, multiply by 0.00355.

OTHER EMISSION FACTORS

Particulate emission factors for other size ranges are found in a manner analogous to that described above for IP. The concentrations for the other size ranges are determined using the sizing information presented earlier. Once the net concentrations are obtained, the exposure values and emission factors are found in the same manner as those for IP.

APPENDIX B

CORRECTION PARAMETER CALCULATION PROCEDURES

Silt loading is calculated as the product of total loading and fractional silt content. The total loading is simply the mass of street surface particulate sample divided by the surface area from which the sample was obtained. The tare weights of sample containers are subtracted from the total weights to obtain the sample weights. Table B-1 gives the procedure for determination of silt content.

Mean vehicle weight is the arithmatic average of the weights of vehicles passing over the test road segment during the emissions sampling period. Vehicle weights are assigned to vehicle types as described in the body of this report.

TABLE B-1. SILT ANALYSIS PROCEDURES

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

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

3. Clean the sieves with dry 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 (3.5 lb)) and record make, capacity, smallest division, date of last calibration, and accuracy.

5. Tare sieves and pan. Check the zero before every weighing. Record weights.

6. After nesting the sieves in order from the largest to the smallest openings with pan at the bottom, dump dried laboratory sample (immediately after drying) into the top sieve. The sample should weigh between 800 and 1,600 g (1.8 and 3.5 lb).[a] Brush fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.

7. Place nested sieves into the mechanical device and sieve for 10 min. Remove pan containing minus 200 mesh and weigh. Replace pan beneath the sieves and sieve for another 10 min. Remove pan and weigh. When the difference between two successive pan sample weighings spaced 10 min apart (where the tare of the pan has been subtracted) is less than 3.0%, the sieving is complete. Do not sieve longer than 40 min.

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

9. Calculate the percent of mass passing the 200 mesh screen (75 μm physical diameter). This is the silt content.

[a] This amount will vary for the finer textured materials; 100 to 300 g may be sufficient when 90 percent of the sample passes a No. 8 (2.36 mm) sieve.

APPENDIX C

PROPOSED AP-42 SECTION

The reader is cautioned that this proposed AP-42 section is subject to probable change resulting from internal EPA reviews before it is published in AP-42.

11.2.5 PAVED URBAN ROADS

General - Various field studies have indicated that dust emissions from paved streets are a major component of the material collected by high volume samplers.[1] Reentrained traffic dust has been found to consist primarily of mineral matter similar to common sand and soil, mostly tracked or deposited onto the roadway by vehicle traffic itself. Other particulate matter is emitted directly by the vehicles from, for example, engine exhaust, wear of bearings and brake linings, and abrasion of tires against the road surface. Some of these direct emissions may settle to the street surface, subsequently to be reentrained. Appreciable emissions from paved streets are added by wind erosion when the wind velocity exceeds a threshold value of about 20 km/hr (13 mi/hr).[2] Figure 11.2.5-1 illustrates particulate transfer processes occurring on urban streets.

Emission Factors and Correction Parameters - Dust emission rates may vary according to a number of factors. The most important are thought to be traffic volume and the quantity and particle size of loose surface material on the street. As shown in Figure 11.2.5-1, various activities add or remove street surface material. On a normal paved street, an equilibrium is reached whereby the accumulated street deposits are maintained at a relatively constant level. On average, vehicular carryout from unpaved areas may be the largest single source of street deposit. Accidental spills, street cleaning and rainfall are activities that disrupt the street loading equilibrium, usually for a relatively short duration.

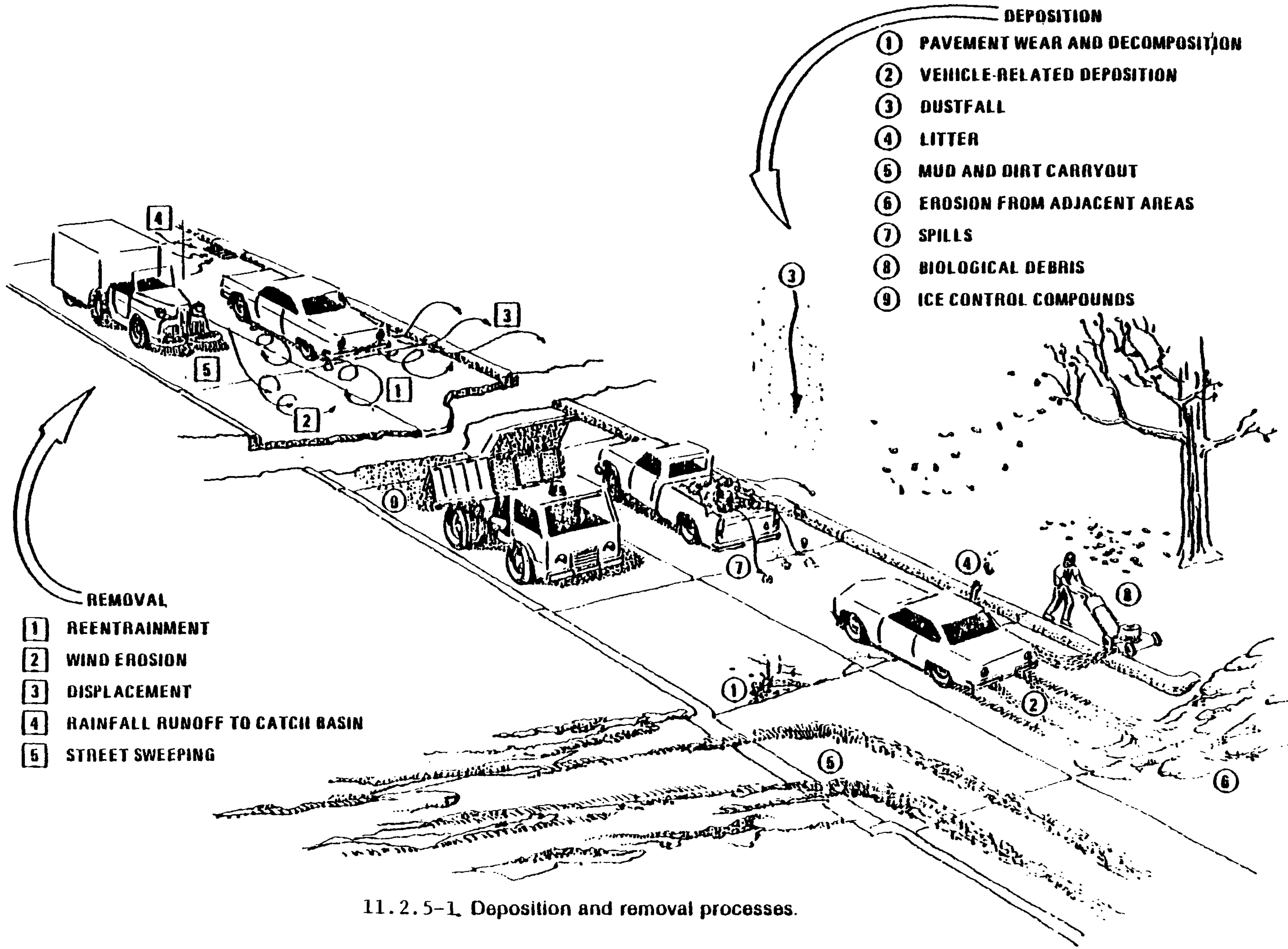
The lead content of fuels also becomes a part of reentrained dust from vehicle traffic. Studies have found that, for the 1975-76 sampling period, the lead emission factor for this source was approximately 0.03 gram per vehicle mile. With the reduction of lead in gasoline and the use of catalyst equipped vehicles, the lead factor for reentrained dust was expected to drop below 0.01 grams per mile by 1980.[3]

The quantity of dust emissions of vehicle traffic on a paved roadway per vehicle kilometer of travel may be estimated using the following empirical expression[4]:

$$e = k\left(\frac{sL}{0.5}\right)^{p}$$

where: e = particulate emission factor (g/VKT)
L = total road surface dust loading (g/m^2)
s = surface silt content, fraction of particles < 75 μm diameter (American Association of State Highway Officials)
k = base emission factor (g/VKT)
p = exponent (dimensionless)

The total loading (excluding litter) is measured by sweeping and vacuuming lateral strips of 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 the ASTM-C-136 method. Silt loading is the product of total loading and silt content.



11.2.5-1. Deposition and removal processes.

The base emission factor coefficients (k) and exponents (p) in the equation for each size fraction are listed in Table 11.2.5-1. Total suspended particulate (TSP) denotes that particle size fraction of airborne particulate matter that would be collected by a standard high volume sampler.

TABLE 11.2.5-1. Paved Urban Road Emission Factor Equation Parameters[a]

Particle Size Fraction[b]	k (g/VKT)	p
TSP	5.87	0.9
≤ 15 μm	2.54	0.8
≤ 10 μm	2.28	0.8
≤ 2.5 μm	1.02	0.6

[a] Reference 4. See p. 11.2.5-1 for equation.
[b] Aerodynamic diameter. TSP is total suspended particulate.

Microscopic analysis indicates the origin of material collected on high volume filters to be about 40 weight percent combustion products and 59 percent mineral matter, with traces of biological matter and rubber tire particles. The small particulate is mainly combustion products, while most of the large material is of mineral origin.[5]

Emissions Inventory Applications[4] - For most emissions inventory applications involving urban paved roads, actual measurements of silt loading will probably not be made. Therefore, to facilitate the use of the previously described equation, it is necessary to characterize silt loadings according to parameters readily available to persons developing the inventories. It is convenient to characterize variations in silt loading with a roadway classification system, and this is presented in Table 11.2.5-2. This system generally corresponds to the classification systems used by transportation agencies, and thus the data necessary for an emissions inventory - number of road miles per road category and traffic counts - should be easy to obtain. In some situations it may be necessary to combine this silt loading information with sound engineering judgment in order to approximate the loadings for roadway types not specifically included in Table 11.2.5-2.

A data base of 44 samples analyzed according to consistent procedures may be used to characterize the silt loadings for each roadway category.[4] These samples, obtained during recent field sampling programs, represent a broad range of urban land use and roadway conditions. Geometric means for this data set are given by sampling location and roadway category in Table 11.2.5-3.

TABLE 11.2.5-2. Paved Urban Roadway Classification[a]

Roadway Category	Average Daily Traffic (ADT)	Lanes
Freeways/expressways	> 50,000	≥ 4
Major streets/highways	> 10,000	≥ 4
Collector streets	500 - 10,000	2[b]
Local streets	< 500	2[c]

[a] Reference 4.
[b] Road width ≧ 32 ft.
[c] Road width < 32 ft.

TABLE 11.2.5-3. Summary of Silt Loadings (sL) for Paved Urban Roadways[a]

City	Roadway Category							
	Local Streets		Collector Streets		Major Streets/ Highways		Freeways/ Expressways	
	$\bar{X}_g$ (g/m²)	n	$\bar{X}_g$ (g/m²)	n	$\bar{X}_g$ (g/m²)	n	$\bar{X}_g$ (g/m²)	n
Baltimore	1.42	2	0.72	4	0.39	3	-	-
Buffalo	1.41	5	0.29	2	0.24	4	-	-
Granite City (IL)	-	-	-	-	0.82	3	-	-
Kansas City	-	-	2.11	4	0.41	13	-	-
St. Louis	-	-	-	-	0.16	3	0.022	1
All	1.41	7	0.92	10	0.36	26	0.022	1

[a] Reference 4. $\bar{X}_g$ = geometric mean based on corresponding n sample size.

These sampling locations can be considered representative of most large urban areas in the United States, with the possible exception of those in the Southwest. Except for the collector roadway category, the mean silt loadings do not vary greatly from city to city, though the St. Louis mean for major roads is somewhat lower than those of the other four cities. The substantial variation within the collector roadway category is probably attributable to the effects of land use around the specific sampling locations. It should also be noted that an examination of data collected at three cities in Montana during early spring indicates that winter road sanding may produce loadings five to six times higher than the means of the loadings given in Table 11.2.5-3 for the respective road categories.[5]

Table 11.2.5-4 presents the emission factors by roadway category and particle size. These were obtained by inserting the above mean silt loadings into the equation on page 11.2.5-1. These emission factors can be used directly for many emission inventory purposes. It is important to note that the paved road emission factors for TSP agree quite well with those developed from previous testing of roadway sites in the major street and highway category, yielding mean TSP emission factors of 4.3 g/VKT (Reference 6) and 2.6 g/VKT (Reference 7).

TABLE 11.2.5-4. Recommended Particulate Emission Factors for Specific Roadway Categories and Particle Size Fractions

Roadway Category	Emission Factor (by particle size fraction)			
	TSP	≤ 15 μm	≤ 10 μm	≤ 2.5 μm
	g/VKT (lb/VMT)	g/VKT (lb/VMT)	g/VKT (lb/VMT)	g/VKT (lb/VMT)
Local streets	15 (0.053)	5.8 (0.021)	5.2 (0.018)	1.9 (0.0067)
Collector streets	10 (0.035)	4.1 (0.015)	3.7 (0.013)	1.5 (0.0053)
Major streets/ highways	4.4 (0.016)	2.0 (0.0071)	1.8 (0.0064)	0.84 (0.0030)
Freeways/ expressways	0.35 (0.0012)	0.21 (0.00074)	0.19 (0.00067)	0.16 (0.00057)

References for Section 11.2.5

1. D. R. Dunbar, Resuspension of Particulate Matter, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1976.

2. M. P. Abel, "The Impact of Refloatation on Chicago's Total Suspended Particulate Levels", Purdue University, Purdue, IN, August 1974.

2. M. P. Abel, "The Impact of Refloatation on Chicago's Total Suspended Particulate Levels", Purdue University, Purdue, IN, August 1974.

3. C. M. Maxwell and D. W. Nelson, A Lead Emission Factor for Reentrained Dust from a Paved Roadway, EPA-450/3-78-021, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1978.

4. C. Cowherd, Jr., et al., Paved Road Particulate Emissions, EPA Contract No. 68-02-3158, Midwest Research Institute, Kansas City, MO, April 1982.

5. R. Bohn, Update and Improvement of the Emission Inventory for MAPS Study Areas, State of Montana, Helena, MT, August 1979.

6. C. Cowherd, Jr. et al., Quantification of Dust Entrainment from Paved Roadways, EPA 450/3-77-027, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1977.

7. K. Axetell, and J. Zell, Control of Reentrained Dust from Paved Streets, EPA Contract No. 68-02-1375, PEDCo Environmental, Inc. Cincinnati, OH, July 1977.

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

1. REPORT NO. EPA-600/7-84-077	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Paved Road Particulate Emissions--Source Category Report		5. REPORT DATE July 1984
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Chatten Cowherd, Jr. and Phillip J. Englehart		8. PERFORMING ORGANIZATION REPORT NO. 4892-L
9. PERFORMING ORGANIZATION NAME AND ADDRESS Midwest Research Institute, 425 Volker Boulevard, Kansas City, Missouri 64110		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-3158, Task 19
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 1/80 - 4/84
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer W.B. Kuykendal is no longer with the Laboratory; for report details, contact Dale L. Harmon, Mail Drop 61, 919/541-2429.

16. ABSTRACT The report gives results of extensive field tests to develop emission factors for particulate emissions generated by traffic entrainment of paved road surface particulate matter. Emission factors were developed for the following particle size ranges: < or = 30, 15, 10, and 2.5 micrometer aerodynamic diameter. Sites tested represented commercial/industrial, commercial/residential, expressway, and rural town land-use categories. The measured inhalable particulate (IP--< or = 15 micrometer aerodynamic diameter) emission factors ranged from 0.06 to 8.8 g/VKT (vehicle km traveled). Lowest emissions were measured for the expressway category; highest emissions were measured for the rural town category. About 90% of the IP emissions consisted of particles < or = 10 micrometers in aerodynamic diameter, and about 50% of the IP emissions consisted of particles < or = 2.5 micrometers in aerodynamic diameter. Using roadway surface silt loading as the basis, predictive emission factor equations for each particle size range were derived. To facilitate the use of these particle-size-specific equations in developing emission inventories, a classification system was derived of mean or typical silt loadings as a function of roadway category. These mean silt loadings were then inserted into the respective emission factor equations for specific roadway categories and particle size fractions.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Pavements	Stationary Sources	
Roads	Particulate	
Particles	Emission Factors	14G
Dust	Silt Loading	11G
Silts		

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 97
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)