EPA-450/3-77-027

QUANTIFICATION OF DUST ENTRAINMENT FROM PAVED ROADWAYS

by

Chatten Cowherd, Jr., Christine M. Maxwell, and Daniel W. Nelson

Midwest Research Institute
425 Volker Blvd.
Kansas City, Missouri 64110

Contract No. 68-02-1403
Task Order No. 25

EPA Project Officer: Charles Mann

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

July 1977

This report is issued by the Environmental Protection Agency to report technical data of interest to a limited number of readers. Copies are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations - in limited quantities - from the Library Services Office (MD-35), Research Triangle Park, North Carolina 27711; or, for a fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

This report was furnished to the Environmental Protection Agency by the Midwest Research Institute, 425 Volker Blvd., Kansas City, Missouri 64110, in fulfillment of Contract No. 68-02-1403, Task Order No. 25. The contents of this report are reproduced herein as received from the Midwest Research Institute. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency. Mention of company or product names is not to be considered as an endorsement by the Environmental Protection Agency.

Publication No. EPA-450/3-77-027

ACKNOWLEDGEMENTS

This report was prepared for the Environmental Protection Agency's Office of Air Quality Planning and Standards under EPA Contract No. 68-02-1403 (Task 25). Mr. Charles O. Mann served as EPA Project Officer.

The program was conducted in MRI's Environmental and Materials Sciences Division under the supervision of Dr. Larry J. Shannon, Director. Dr. Chatten Cowherd, Jr., was the Principal Investigator for MRI. Dr. Cowherd was assisted by Ms. Christine Maxwell, Mr. Daniel Nelson, Mr. Nicholas Stich, Mr. Thomas Cuscino, and several members of MRI's Environmental Measurements Section.

Approved for:

MIDWEST RESEARCH INSTITUTE

L. J. Shannon, Director
Environmental and Materials
Sciences Division

July 19, 1977

CONTENTS

FIGURES

FIGURES (concluded)

TABLES

TABLES (Concluded)

ABSTRACT

This report presents the results of a field testing program to develop emission factors for fugitive dust entrainment from paved urban roads. Substantial evidence has been compiled which indicates that dust emissions from city streets are a major cause of nonattainment of national air quality standards for total suspended particulates (TSP). Therefore, the quantification of this source is necessary to the development of effective attainment and maintenance strategies.

Field testing was conducted at 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. The basic measurements consisted of isokinetic exposure and concentration profiles of airborne dust, particle size distributions, dust deposition profiles, surface dust loading, and traffic characteristics. In addition, conventional high-volume samplers were used to determine attenuation of TSP concentration with distance from the source.

Emissions are found to vary directly with traffic volume and surface loading of silt (fines). The dust emission factor for normally loaded urban streets ranges from 1 to 15 g/vehicle-km, depending on land use. Approximately 90% of the emissions (by weight) is less than 30 μm in diameter and 50% less than 5 μm in diameter.

INTRODUCTION

In a number of metropolitan areas of the country failure to attain national primary air quality standards for total suspended particulates (TSP) has spurred a detailed reexamination of the nature of the urban TSP problem. While TSP control strategy development has routinely included an analysis of the contributions of conventional point and area sources superimposed on a constant "background" concentration, adequate consideration has not been given to the contributions of local open dust sources and advection from both confined and fugitive sources in adjacent regions.

Microscopic analysis of filters from urban air sampling stations where measured TSP levels are routinely higher than expected has yielded conclusive evidence that dust emissions from paved streets are a major cause of the nonattainment of the primary standard.[1,2] Although emissions from paved streets are generated primarily by vehicular traffic, appreciable emissions are added when the wind velocity exceeds the erosion threshold value of about 13 miles/hr, i.e., the observed limit of the ventilation flushing effect.[3] Figure 1 presents a diagram of particulate transfer processes occurring on urban streets.

Following a review of the published results of previous investigations on the subject, this report presents the results of a field testing program conducted by Midwest Research Institute to develop quantitative emission factors for dust entrainment from paved urban roads. Specific items discussed include field test sites, field measurements, calculation procedures, test results and the relationship of resultant emission factors to traffic volume and street surface dust loadings. Appendix A presents the results of a separate series of field studies to determine particle size distributions of atmospheric dust generated by traffic on unpaved roads.

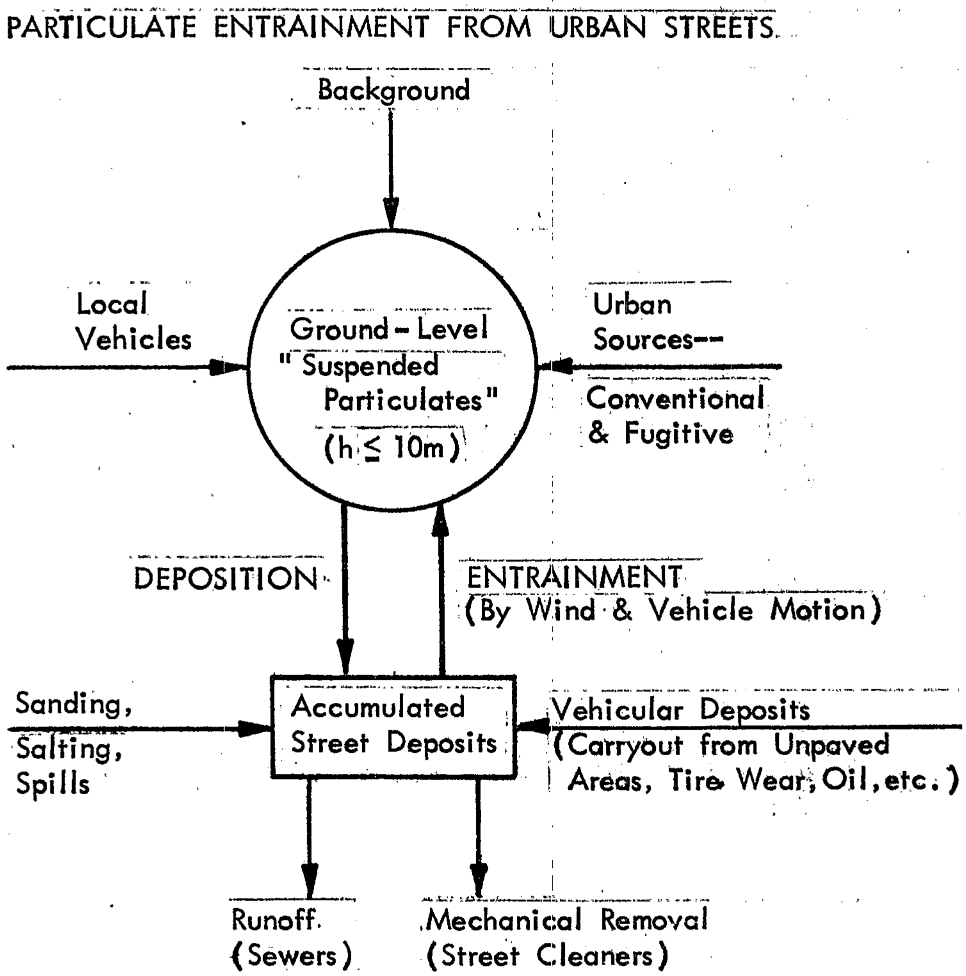


Figure 1. Diagram of Street Surface/Atmospheric Exchange of Particulate Matter

BACKGROUND

In a comprehensive study of runoff from street surfaces as a source of water pollution,[4] 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[3,5,6] for surface dust from paved streets and parking lots and from gravel roads and parking lots. However, the silt size fraction, which is readily suspendable in the atmosphere, was found to contain a substantially larger than proportional percentage of the total heavy metals and pesticides.

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.

Table 1. CONTAMINANT LOADINGS ON 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		60	1,200	290	
district		63	640	290	
Shopping center					
Overall	348				1,500

a/ There are 2 curb miles per street mile.

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.

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. 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[6,7] 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.

An American Public Works Association study[8] 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.[9]

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, tire and brake wear.
- Truck spills.
- Street repair.
- Winter sanding and salting.
- Atmospheric dustfall.
- Vegetation and litter.

In a recent field study of street surface contaminants in the Washington, D.C. area,[10] 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.[4,10] 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.

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.[6,7] 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.[7]

In less populated areas of the country, particularly those areas with a dry, windy climate, the advective portion of urban TSP originates largely from wind erosion of land with sparse vegetation, including tilled cropland. Whenever the wind velocity exceeds the critical wind erosion threshold and the exposed soil is sufficiently dry, wind forces cause soil movement by three distinct mechanisms--surface creep, saltation (jumping), and suspension.

Although the total erosion of soil by wind has been studied in detail and quantitatively related to soil, field, and wind properties, comparatively little is known about the proportion of suspended particulate generated by wind erosion. Up to now, TSP generation by wind erosion has been estimated by assuming that a fixed percentage of the total erosion, as quantified by the Wind Erosion Equation,[11] is transported as suspended particulate. This factor has ranged from 2.5 to 10%.[12,13]

An analysis of quantitative emissions of suspended dust generated by wind erosion is presented in Appendix B. A mathematical expression, similar to the Wind Erosion Equation, is derived which incorporates experimental measurements of vertical fluxes of fine particles from wind eroding fields.

The remainder of this report describes a program of field testing of fugitive dust emissions from paved roadways and the derivation of emission factors from test results.

FIELD TEST SITES

Three sites in the Kansas City area were selected for measurement of fugitive emissions from paved roadways. Two of the sites (37th Street and Fairfax Trafficway) were on four-lane arterial streets in areas where attainment of particulate standards has been a problem. The 37th Street test roadway passes through an old residential neighborhood interspersed with light-to-medium industrial activity. Medium industry surrounds the Fairfax Trafficway test site. The test pavement along 37th Street test was concrete, but Fairfax Trafficway was surfaced with asphalt; both streets were bordered by unpaved parking areas. The Stillwell site, a local four-lane street in an undeveloped area of a new industrial park, was chosen for testing with artifically loaded surface materials. Table 2 summarizes the characteristics of each test site.

Table 2. TEST SITE CHARACTERISTICS

Site	37th Street	Stillwell	Fairfax Trafficway
Location	Leeds Fire Station No. 26 6402 E. 37th Street Kansas City, Missouri	Stillwell Avenue between Topping Avenue and Southern Road Kansas City, Missouri	Fire Station No. 15 5200 Fairfax Kansas City, Kansas
Land use	Residential (medium industry nearby)	Industrial park	Medium industry
Average daily traffic	7,870	Light	8,360
Street characteristics			
• Orientation	East-west	East-west	North-south
• Surface type	Concrete	Asphalt, artificially loaded	Asphalt
• Surface condition	Fair	Excellent	Good
• Curbed	Yes	Yes	Yes
Ventilation	Partially restricted	Open	Partially restricted
Air sampling station			
• Operating Agency	Kansas City, Missouri	-	Kansas City, Kansas-Wyandotte County Health Department
• Geometric mean TSP ($\mu g/m^3$)			
1972	86	-	96
1973	101	-	86
1974	87	-	75
MRI runs	1-6	7-14	15-16

FIELD MEASUREMENTS

Field testing of dust emissions from paved roads was conducted at the 37th Street site in September and October 1975, at the Stillwell Avenue site in October and November 1975, and at the Fairfax Trafficway site in March 1976. To the extent possible, emission sampling was restricted to periods with moderate crosswinds, 3 or more days after significant rainfall (accumulation exceeding 0.5 in.).

Table 3 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.

Sampling Equipment

The primary tool for quantification of emission rate was the MRI exposure profiler (see Figure 2), which was developed under EPA Contract No. 68-02-0619.[5,16] The profiler (modified for this study) consists of a portable tower (4 m height) with four sampling heads. Each sampling head was operated as a directional exposure sampler (with automatic separation of settleable dust), i.e., in the "exposure mode" illustrated in Figure 2.

In addition to airborne dust passage (exposure), fugitive dust parameters that were measured included suspended dust concentration, particle size distribution and deposition (dustfall). Conventional high-volume filtration units were operated at breathing height (2 m above ground) upwind and downwind of the test street. Deposition rates were measured with dustfall buckets at ground level and elevated locations downwind of the street.

A Sierra Instruments high-volume parallel-slot cascade impactor with a 40 cfm flow controller was used to measure particle-size distribution at 2 m above ground along side of the exposure profiler. The impactor unit was equipped with a Sierra cyclone preseparator to remove coarse particles which otherwise would tend to bounce off of the glass fiber impaction substrates, causing fine particle measurement bias. By means of a pivotal bearing and wind vane, the cyclone sampling intake was directed into the wind, resulting in isokinetic sampling for a wind speed of 10 mph.

TABLE 3

FIELD MEASUREMENTS--PAVED ROADS

Test Parameter	Units	Sampling Mode	Measurement Method
1. Meteorology			
a. Wind speed	mph	Continuous	Recording instrument at "background" station; sensors at reference height
b. Wind direction	deg	Continuous	
c. Cloud cover	%	Single	Visual observation
d. Temperature	°F	Single	Sling psychrometer
e. Relative humidity	%	Single	Sling psychrometer
2. Road Surface			
a. Pavement type	--	Composite	Observation (photographs)
b. Surface condition	--	Composite	Observation
c. Dust loading	g/m^2	Multiple	Dry vacuuming
d. Dust texture	% silt	Multiple	Dry sieving
3. Vehicular Traffic			
a. Mix	--	Multiple	Observation (car, truck, number of axles, etc.)
b. Count	--	Cumulative	Automatic counters
4. Suspended Dust			
a. Exposure (versus height)	mg/cm^2	Integrated	Isokinetic high-volume filtration (MRI method)
b. Mass size distribution	µm	Integrated	High-volume cascade impaction
c. Downwind concentration	$\mu g/m^3$	Integrated	High-volume filtration (EPA method[14])
d. Background concentration	$\mu g/m^3$	Integrated	High-volume filtration (EPA method[15])
e. Duration of sampling	min	Cumulative	Timing
5. Deposition			
a. Surface (versus distance from curb)	$g/m^2/veh$	Integrated	Dustfall buckets (ASTM method[15])
b. Elevated	$g/m^2/veh$	Integrated	Dustfall buckets (ASTM method[15])

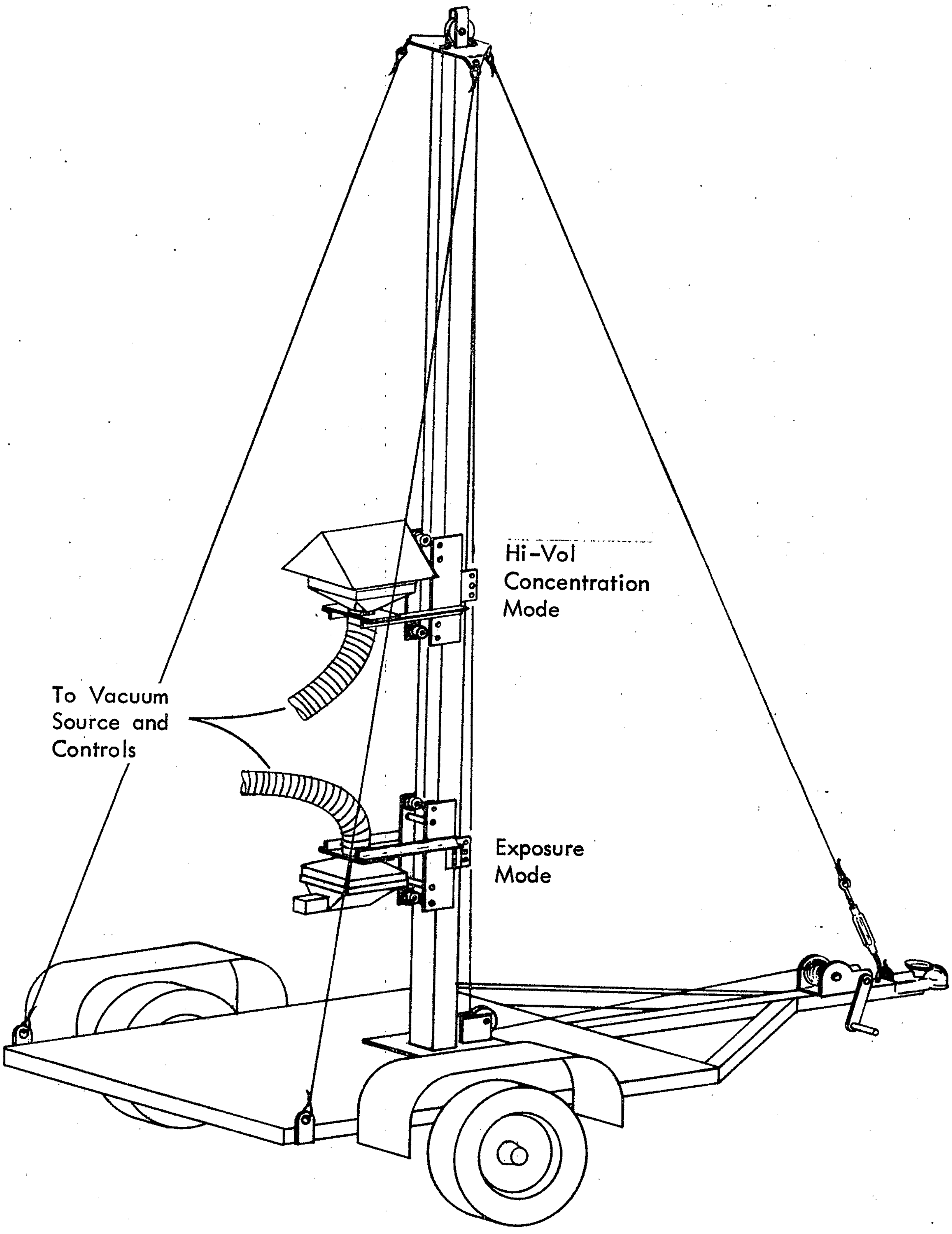


Figure 2. MRI Exposure Profiler (with illustrations of sampling modes)

Other types of parameters that were measured during each test included prevailing meteorology and vehicular traffic. Wind speed and direction were monitored with a recording wind instrument. Traffic counters were used to record traffic volume during each test at the 37th Street and Fairfax sites, while manual counts were made during the tests at the Stillwell site.

Figures 3 through 7 show the locations of sampling instruments at the 37th Street, Stillwell, and Fairfax sites. Distances from curbings are specified.

<u>Tests with Artificial Loading</u>

As indicated previously, the Stillwell site was selected for testing of emissions from an artificially loaded test strip. This necessitated closing the street to normal traffic for a period of 3 weeks.

On October 21, 1975, a salt/sand spreader was used to spread pulverized topsoil over an 85 m test strip; on October 30, 1975, limestone gravel fines were spread on a 105 m test strip. Four runs were conducted with each material, the loading being reduced for each successive run. No rainfall occurred during either series of runs. Prior to application of the gravel fines, the road was cleaned with wet brushing equipment.

Immediately before and after each run at the Stillwell site, composite samples of in-place road dust were removed from 1-ft wide lateral strips of road surface. First, loose material was manually swept from the 15-in. curbing areas and then from the rest of the strip and placed in polyethylene bags. This step was followed by dry vacuuming of the strip. Samples were returned to MRI for determination of mass and texture.

Traffic at Stillwell was provided by test vehicles which traveled back and forth over the test strip at a speed of 30 mph. Each of the four traffic lanes was utilized to the same extent during a run. Vehicle spacing was maintained to minimize vehicle interaction effects.

<u>Sample Handling and Analysis</u>

At the end of each run, the collected samples of dust emissions were carefully transferred to protective containers within the MRI instrument van, to prevent dust losses. High-volume filters (from the MRI exposure profiler and from standard high-volume units) and impaction substrates were folded and placed in individual envelopes. Dust that collected on the interior surfaces of each exposure probe was rinsed with distilled water into separate glass jars. The contents of the deposition samplers were also rinsed into glass jars. Dust was transferred from the cyclone precollector in a similar manner.

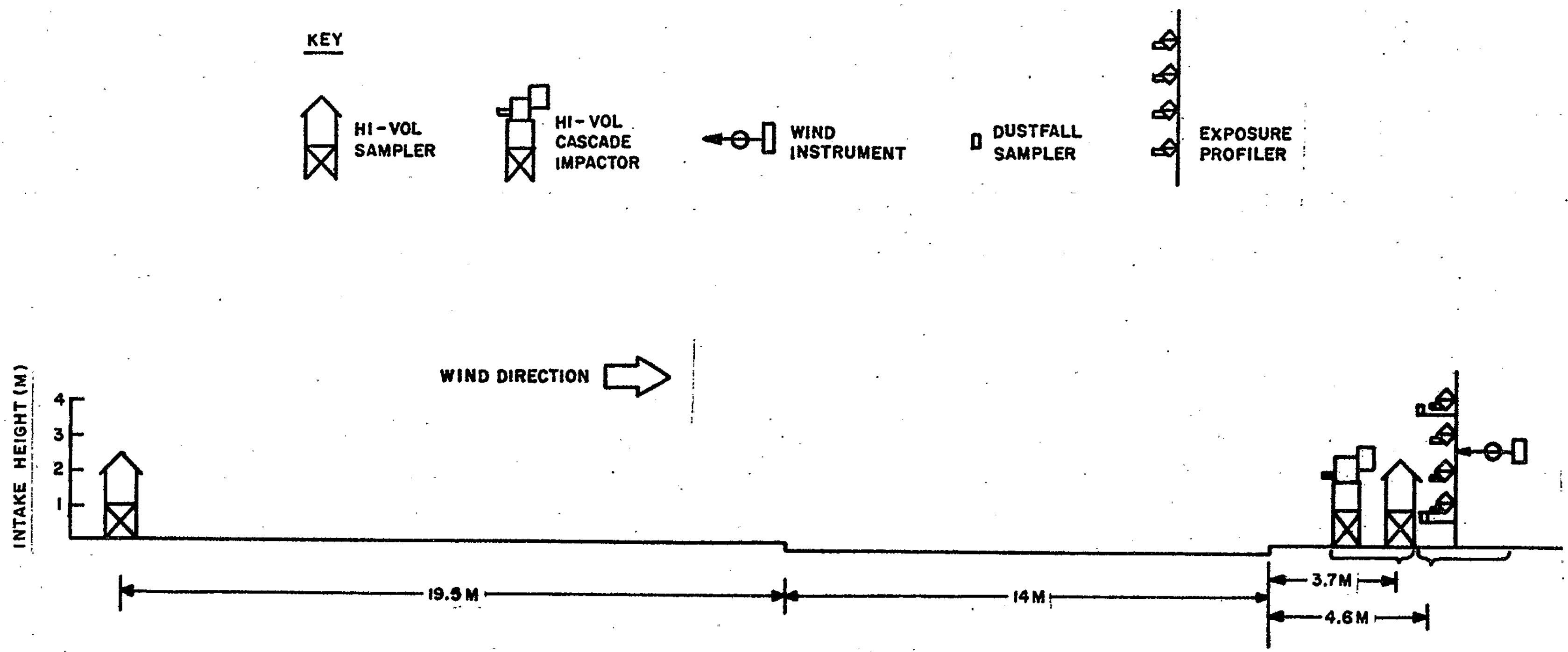


Figure 3. Location of Sampling Instruments at 37th Street Site--South Wind

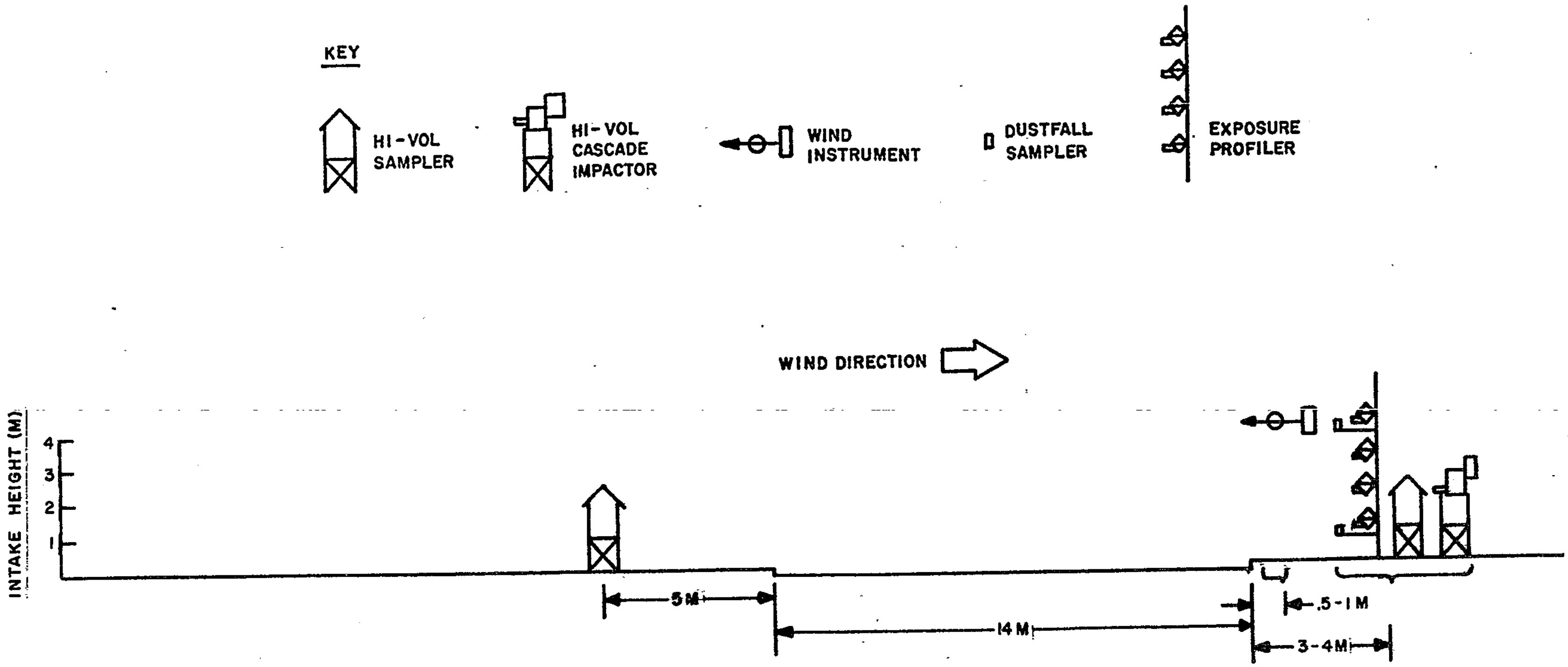


Figure 4. Location of Sampling Instruments at 37th Street Site--North Wind

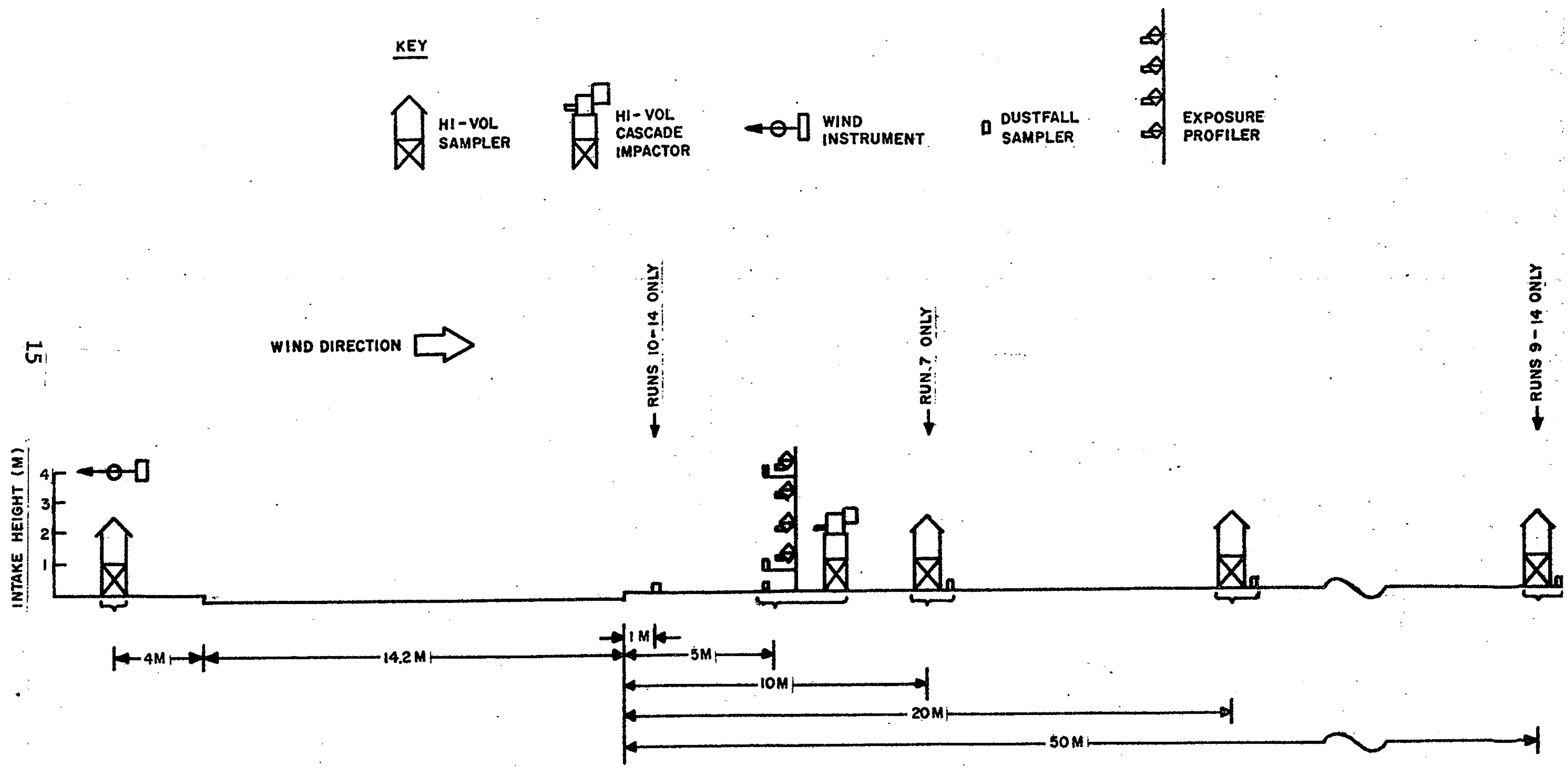


Figure 5. Location of Sampling Instruments at Stillwell Site--North or South Wind

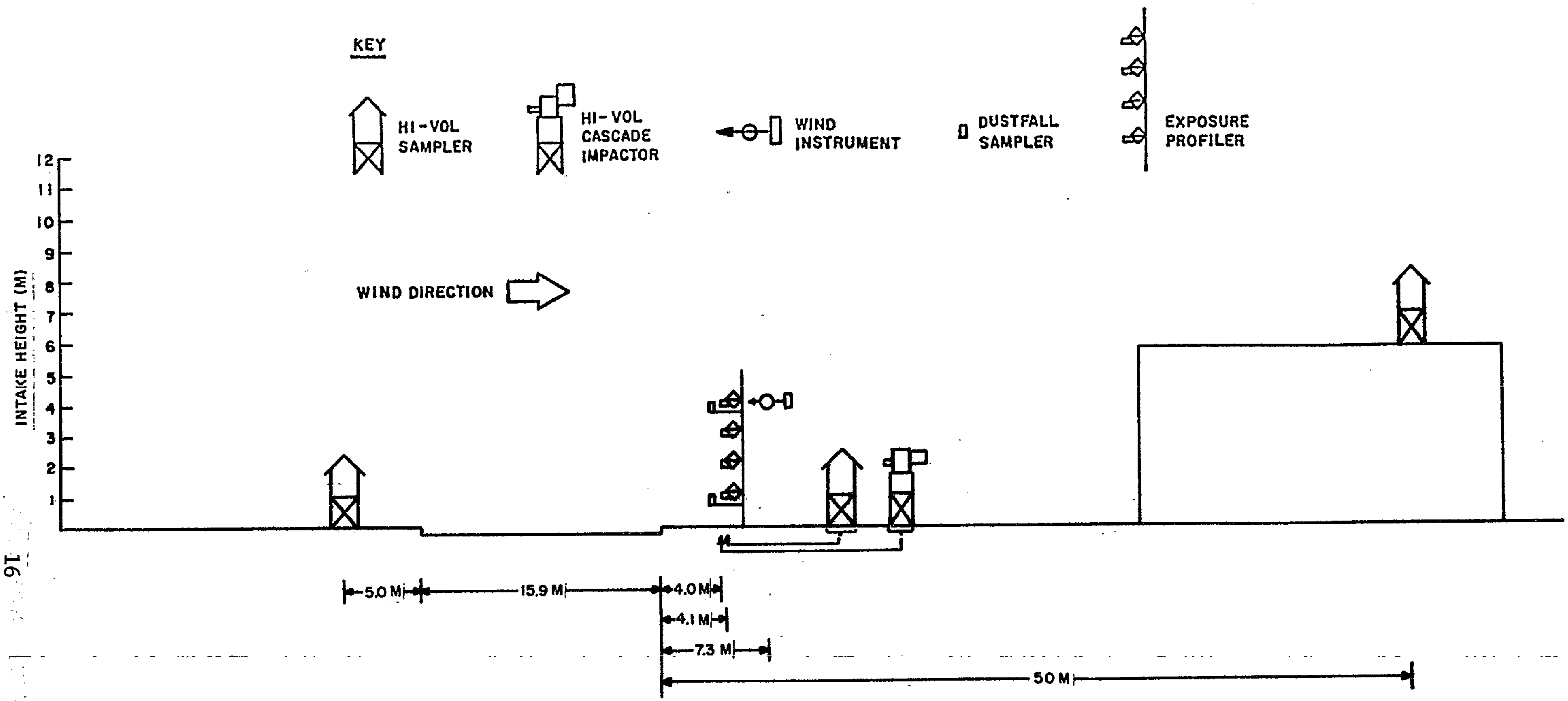


Figure 6. Location of Sampling Instruments at Fairfax Trafficway--Side View

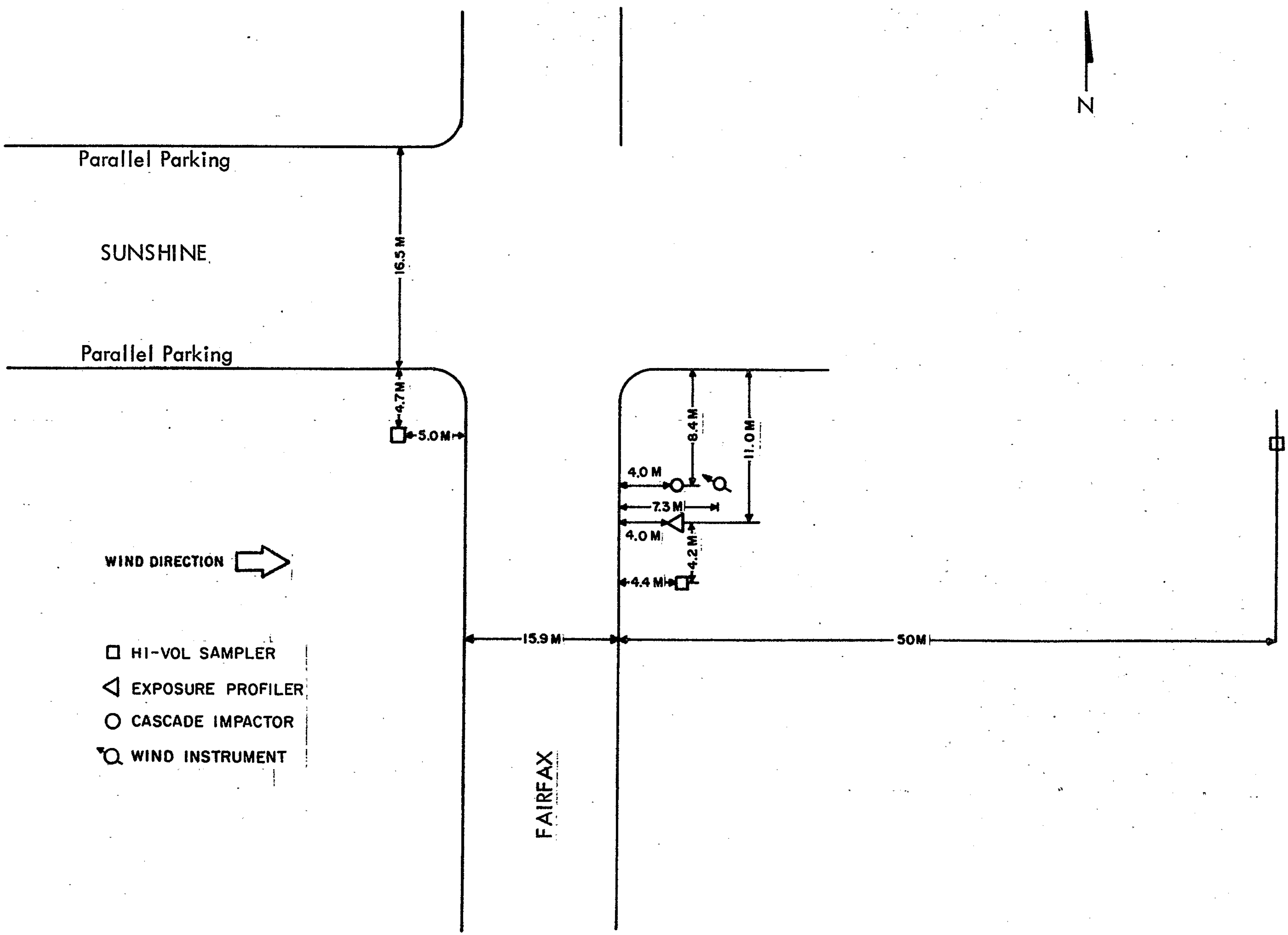


Figure 7. Location of Sampling Instruments at Fairfax Trafficway--Overhead View

Dust samples from the field tests were returned to MRI and analyzed gravimetrically in the laboratory. Glass-fiber filters and impaction substrates were conditioned at constant temperature and relative humidity for for 24 hr prior to weighing (the same conditioning procedure used before taring). Water washes from the exposure profiler intakes, cyclone precollector and dustfall buckets were filtered, after which the tared filters were dried, conditioned at constant humidity, and reweighed.

Samples of road dust from Stillwell were dried and screened to determine the weight fraction passing a 200-mesh screen, which corresponds to a 74 μm particle size. A conventional shaker was used for this purpose.

CALCULATION PROCEDURES

Dust entrainment from a paved roadway may be quantified by measuring the total passage of airborne dust (after subtraction of background) at some distance downwind of the roadway. Total dust passage (per unit length of roadway) is determined by integration of vertically distributed measurements of exposure obtained with the MRI exposure profiler (described earlier). Exposure is defined as the horizontal flux of airborne dust (mass of sampling intake area per time) integrated over the time of measurement.

Isokinetic Corrections

If it is necessary to sample at a nonisokinetic flow rate (for example, to obtain sufficient sample under light wind conditions), the following multiplicative factors should be used to correct measured exposures and concentrations to corresponding isokinetic values:

	Fine Particles ($d < 5\ \mu m$)	Coarse Particles ($d > 50\ \mu m$)
Exposure Multiplier	U/u	1
Concentration Multiplier	1	u/U

where u = sampling intake velocity at a given elevation
U = wind velocity at same elevation as u
d = aerodynamic (equivalent sphere) particle diameter

For a particle-size distribution containing a mixture of fine, intermediate, and coarse particles, the isokinetic correction factor is an average of the above factors, weighted by the relative proportion of coarse and fine particles. For example, if the mass of fine particles in the distribution equals twice the mass of the coarse particles, the weighted isokinetic correction for exposure would be

$$1/3\ [2(U/u) + 1]$$

Particle Size Distribution

As stated above, a cyclone preseparator was used in conjunction with a high-volume cascade impactor to measure airborne particle size distribution. The purpose of the preseparator was to remove coarse particles which otherwise would tend to bounce through the impactor to the back-up filter, thereby causing fine-particle-measurement bias.

Although the cyclone precollector was designed by the manufacturer to have a 50% cutoff diameter of 7.6 μm (particle density of 2.5 g/cm^3), laboratory calibration of the cyclone, reported in May 1976, indicated the effective cutoff diameter to be 3.5 μm. Because this value overlapped the cutoff diameter of the first impaction stage (6.4 μm), it was decided to add the first stage catch to the cyclone catch, in calculating the particle size distribution.

As indicated by the simultaneous measurement of airborne particle-size distribution, one impactor being used with a precollector and a second without a precollector, the cyclone precollector is very effective in reducing fine particle measurement bias. However, the following observations indicate that additional correction for coarse particle bounce is needed:

1. There is a monotonic decrease in collected particulate weight on each successive impaction state, followed by a several-fold increase in weight collected by the back-up filter.

2. Because the assumed value (0.2 μm) for the effective cutoff diameter of the glass fiber back-up filter fits the progression of cutoff diameters for the impaction stages, the weight collected on the back-up filter should follow the particulate weight progression on the impactor stages.

The excess particulate on the back-up filter is postulated to consist of coarse particles that penetrated the cyclone (with small probability) and bounced through the impactor.

To correct the measured particle size distribution for the effects of residual particle bounce, the following procedure was used:

1. The calibrated cutoff diameter for the cyclone preseparator was used to fix the upper end of the particle-size distribution.

2. At the lower end of the particle-size distribution, the particulate weight on the back-up filter was reduced to fit the particulate weight distribution of the impactor stages, thereby extending the monotonic decrease in particulate weight observed on the impactor stages).

One effect of these corrections was to reduce substantially the mass median diameter determined for a given field test site.

TEST RESULTS

37th Street Site

Table 4 gives information on the time of each run, prevailing meteorological conditions, and vehicular traffic for three of six runs at the 37th Street site. Wind conditions during Runs 1, 2 and 4 were not acceptable for test purposes. Figure 8 shows the variation of traffic flow for each run, and Table 5 gives a typical vehicle mix observed over a period of 75 min.

Because of the combination of relatively low airborne dust concentrations and low wind speeds, it was necessary to obtain profiler samples at highly over-isokinetic sampling rates. Based on the adjusted aerodynamic particle size distributions (solid lines) shown in Figure 9, measured exposures and concentrations were corrected to corresponding isokinetic values, as described under Calculation Procedures.

Table 6 gives the results of exposure and concentration measurements at the 37th Street site. Vertical profiles of isokinetic concentration at 3 to 5 m downwind from the edge of the roadway are shown in Figure 10. For a sampling height of 2 m, there is good agreement between the profiler measurements and standard hi-volume measurements of particulate concentration obtained at approximately the same distance downwind.

Stillwell Avenue Site

Table 7 gives information on the time of each run, prevailing meteorological conditions, and controlled vehicular traffic at the Stillwell site. The vehicle mix for each test is given in Table 8.

Figures 11 and 12 show the aerodynamic particle size distributions for Stillwell. The adjusted distributions (solid lines) were used to calculate isokinetic correction factors. Results of Run 7 are suspect because of sampler overloading.

Table 4. EMISSIONS TEST PARAMETERS (37th Street)

Run	Date	Time: Start	Time: Finish	Duration of exposure sampling (min)	Ambient temperature (°F)	Wind: Speed (mph)	Wind: Direction[a/] (°)	Wind direction angle to perpendicular (°)	Drift distance correction factor[b/]	Cloud cover (%)	Pasquill stability[c/]	No. of passes
3	9/17/75	1115	1545	270	68	2.0	140	40	1.31	85	B	1,880
5	9/23/75	1500	1930	270	78	3.0	340	20	1.06	<5	B-C	2,260
6	10/9/75	1400	1830	270	75	2.5	340	20	1.06	0	B-C	2,440

a/ Magnetic reading.

b/ Ratio of actual drift distance to the perpendicular distance from the road.

c/ Pasquill Stability Classes:[17/]
A = Extremely unstable
B = Unstable
C = Slightly unstable
D = Neutral
E = Slightly stable
F = Stable to extremely stable

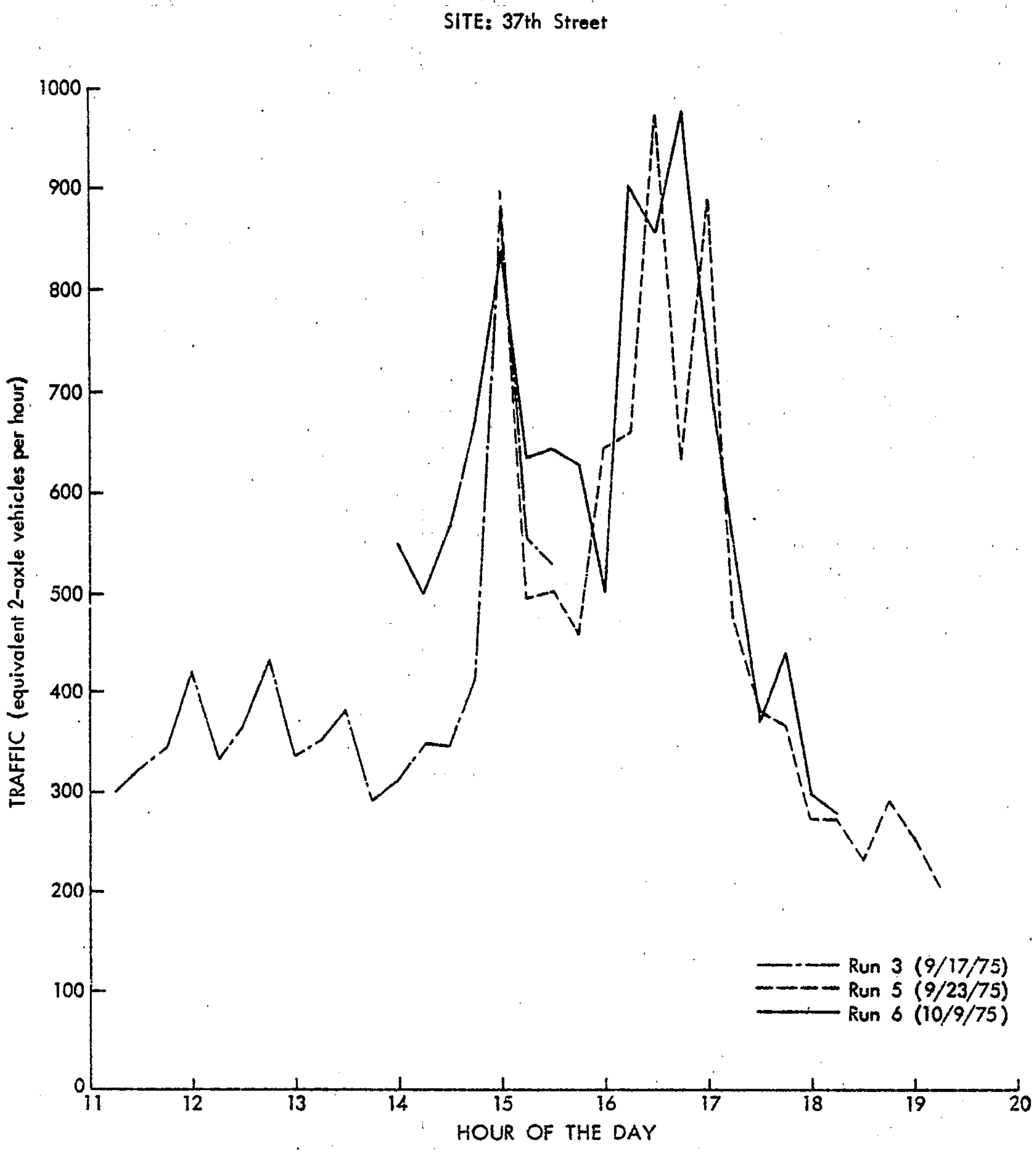


Figure 8. Traffic Flow (37th Street)

Table 5. VEHICLE MIX (37th Street)

Observation period: 1445 to 1600[a/]

Vehicle type	No. of axles	No. of vehicle passes	Percentage of total
Car	2	472	70.0
Bus	2	21	3.1
Pick-up truck	2	123	18.2
Small cargo truck	2	45	6.7
Tractor trailers	6	11	1.6
Other	2	3	0.4
Total		675	

Note: Run: 6
Sampling Period: 1400 to 1830
No. of Vehicle Passes: 2440 (2-axle equivalent)

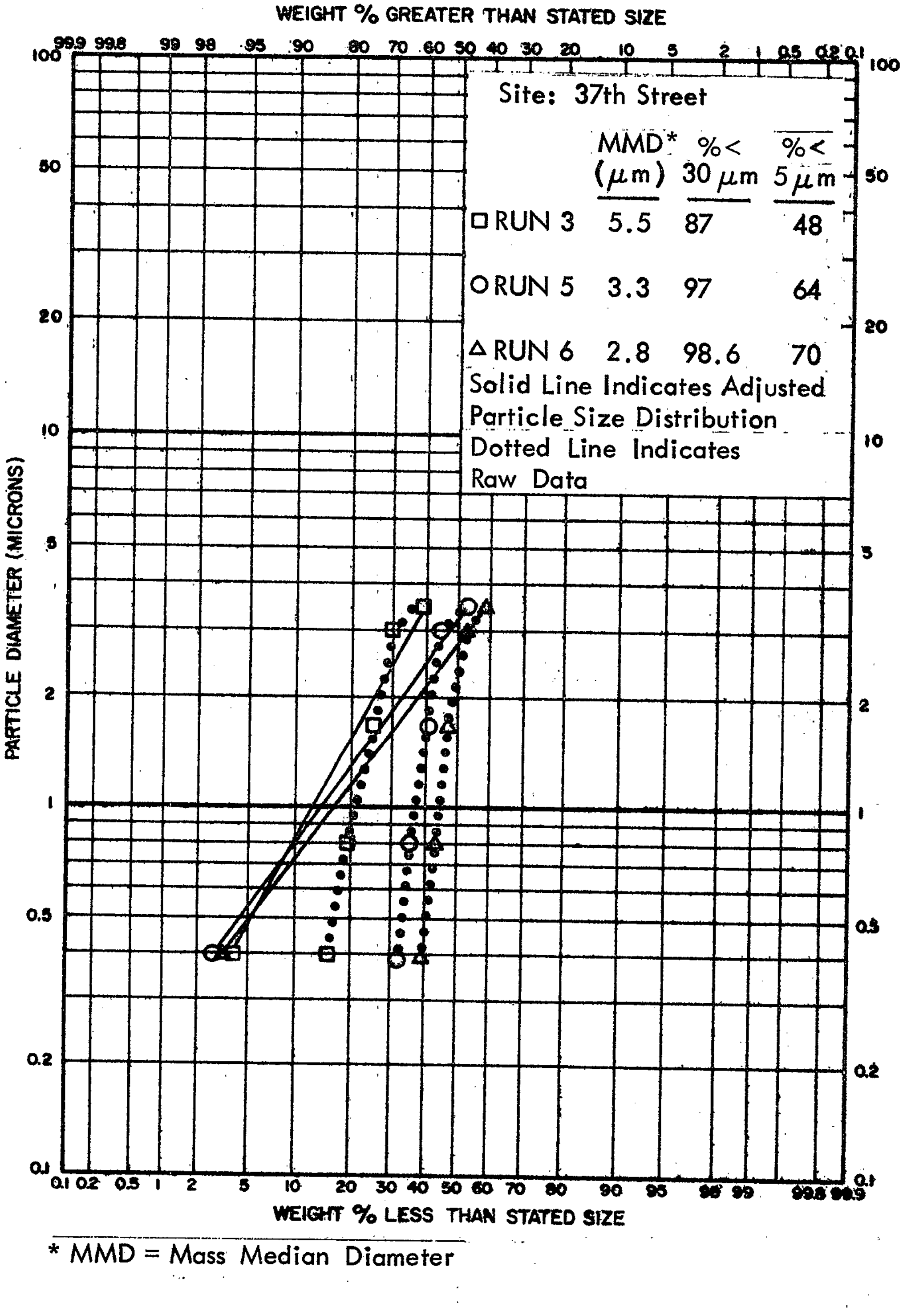


Figure 9. Airborne Particle Size Distributions (37th Street)

Table 6. SUSPENDED PARTICULATE CONCENTRATION AND EXPOSURE MEASUREMENTS (37th Street)

	Particulate concentration ($\mu g/m^3$) at 2 m above ground						
		Downwind, including background					
		Profiler[a]				Isokinetic ratio for profiler,	Integrated exposure[a]
Run	Background	Total	≤ 30 μm	Standard Hi-Vol	Cascade Impactor	u/U	(lb/vehicle-mile)
3	155	295	257	271	164	7.5	0.015
5	130	293	284	281	207	5.0	0.020
6	137	261	257	250	230	6.0	0.012

a/ Isokinetic--correction factor = 1.0.

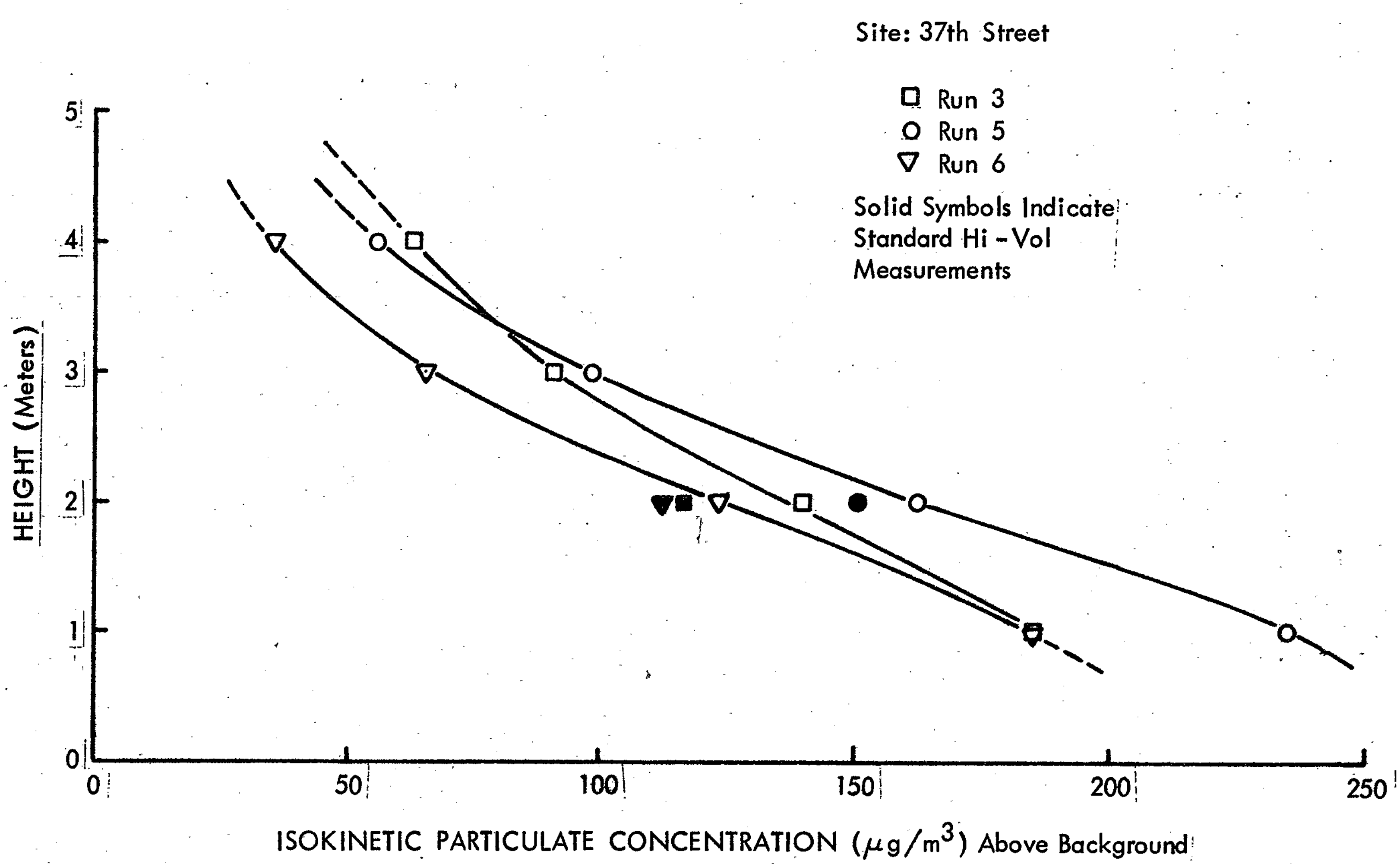


Figure 10. Vertical Profiles of Particulate Concentration (37th Street)

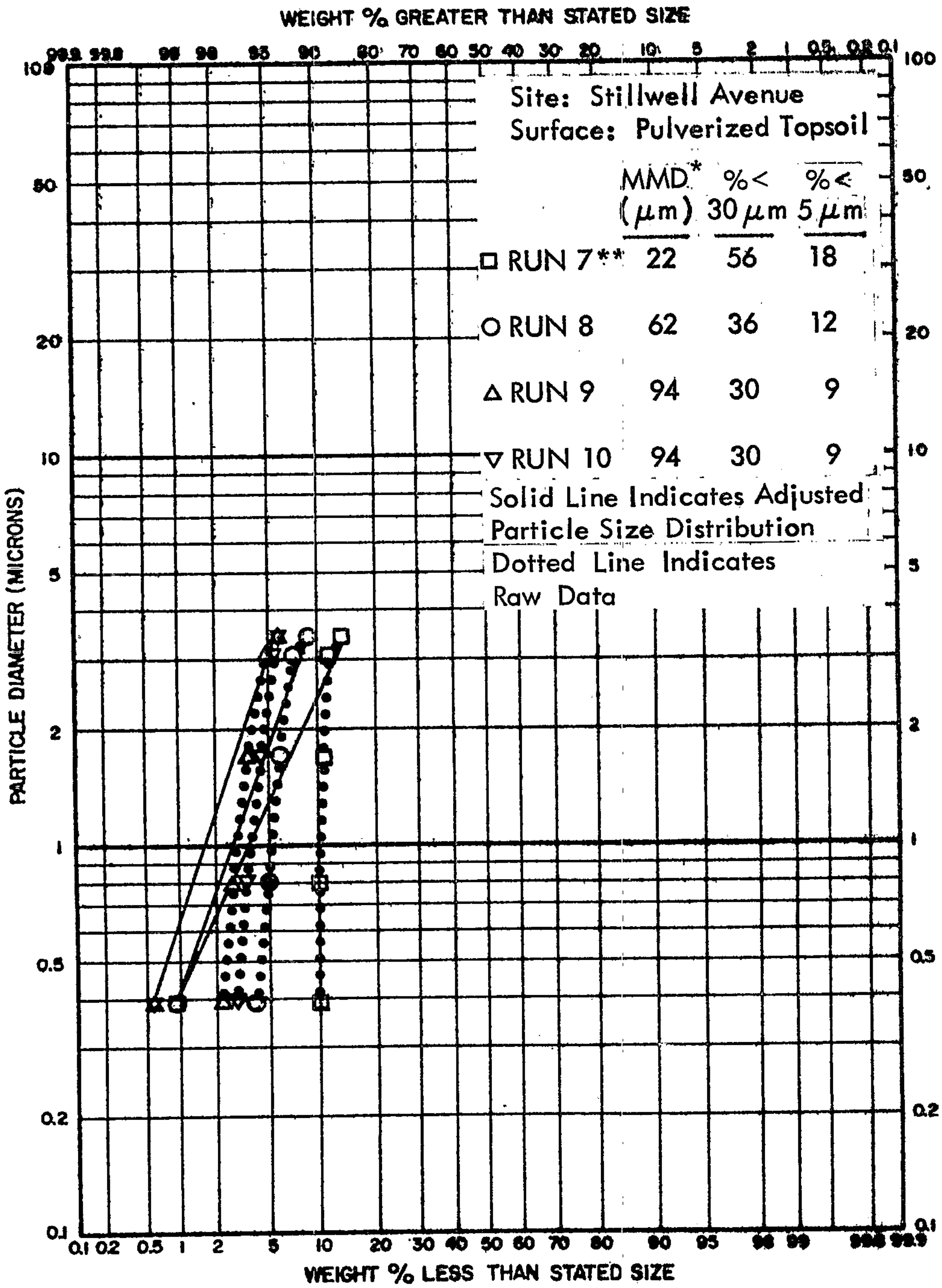
Table 7. EMISSIONS TEST PARAMETERS (Stillwell)

Run	Date	Time		Duration of exposure sampling (min)	Ambient temperature (°F)	Wind		Wind direction angle to perpendicular (°)	Drift distance correction factor[b]	Cloud cover (%)	Pasquill stability[c]	No. of passes
		Start	Finish			Speed (mph)	Direction[a] (°)					
7	10/21/75	1615	1651	36	69	4.0	170	10	1.02	0	B	214
8	10/22/75	1106	1136	30	70	10.5	210	50	1.56	40	C	100
9	10/22/75	1302	1344	30	78	12.0	200	40	1.31	40	C	150
10	10/22/75	1441	1551	60	75	13.0	190	30	1.15	50	D	200
11	10/30/75	1313	1348	35	69	9.5	180	20	1.06	0	B-C	100
12	10/30/75	1525	1610	30	72	10.0	180	20	1.06	0	C	200
13	10/31/75	1110	1203	50	71	17.0	210	50	1.56	20	D	250
14	11/13/75	1255	1430	90	42	7.0	310	30	1.15	< 5	C	600

a/ Magnetic reading.
b/ Ratio of actual drift distance to perpendicular distance from the road.
c/ Pasquill Stability Classes:[17/] A = Extremely unstable
B = Unstable
C = Slightly unstable
D = Neutral
E = Slightly stable
F = Stable to extremely stable

Table 8. VEHICLE MIX (Stillwell)

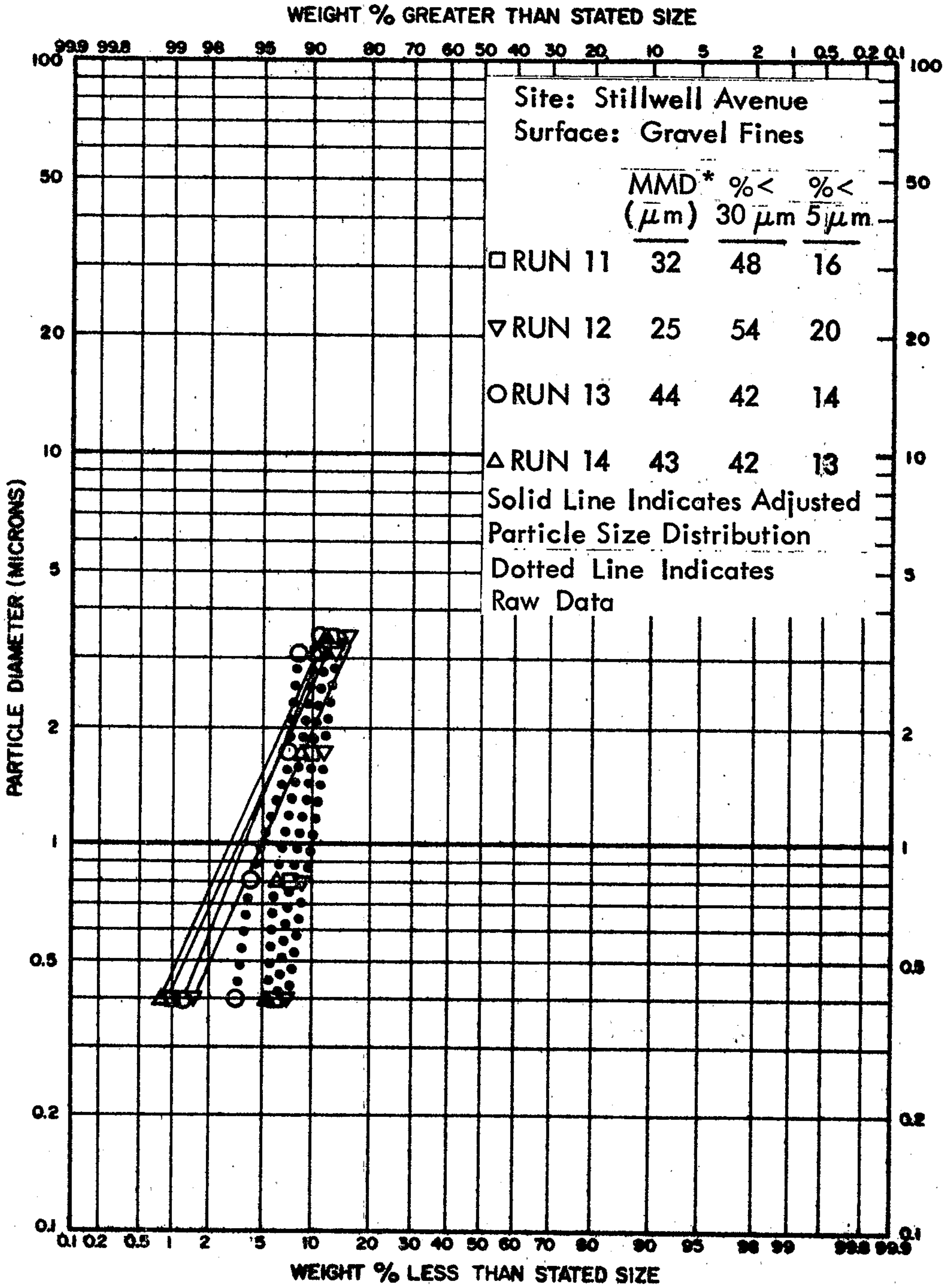
Run	Number of vehicle passes: Passenger car	Station wagon	Van/truck	Total
7	108	54	52	214
8	65	0	35	100
9	112	0	38	150
10	145	0	55	200
11	75	25	0	100
12	94	54	52	200
13	102	0	148	250
14	275	191	134	600



* MMD = Mass Median Diameter

** Sampler Overloaded on Run 7

Figure 11. Airborne Particle Size Distributions (Stillwell-Pulverized Topsoil)



* MMD = Mass Median Diameter

Figure 12 - Airborne Particle Size Distributions
(Stillwell-Gravel Fines)

Table 9 gives the results of exposure and concentration measurements at the Stillwell site. Vertical profiles of isokinetic concentration measured at 5 m downwind of the roadway are shown in Figures 13 and 14.

Downwind distributions of unit dust deposition as a function of mean drift time are shown in Figures 15 and 16. Mean drift time equals drift distance divided by mean wind speed; for example, a drift time of 1 sec represents a distance of 4.5 m for a wind speed of 10 mph (4.5 m/sec). As indicated, the deposition intensity decays rapidly over the first few seconds of drift time.

Table 10 summarizes measurements of loading intensity and silt content of pulverized topsoil and gravel fines which were artificially applied to the test strip. As expected, loadings decayed with traffic (and wind erosion during periods between tests); surface material tended to be depleted much more rapidly in the traveled areas than along the curbs.

Fairfax Trafficway

Table 11 gives information on the time of each run, prevailing meteorological conditions, and vehicular traffic for the runs at the Fairfax site. Figure 17 shows the variation of traffic flow for each run, and Table 12 gives a typical vehicle mix observed over a period of 10 min.

Based on the adjusted aerodynamic particle size distributions (solid lines) shown in Figure 18, measured exposures and concentrations were corrected to corresponding isokinetic values, as described under Calculation Procedures.

Table 13 gives the results of exposure and concentration measurements at the Fairfax site. There is fairly good agreement between the profiler measurement of particulate concentration for particles less than 30 μm in diameter, and the standard hi-vol measurement of particulate concentration, obtained at about the same distance downwind. The complexity of this site is evidenced by the high background concentrations, possibly due to interference from Sunshine (see Figure 7).

Comparative Particle Size Distributions

Table 14 compares particle-size distributions of atmospheric dust generated by vehicular traffic on paved and unpaved roads. (Testing results for paved roads are presented in Appendix A.) With the exceptions of Run Nos. 7 and 23, for which samplers were overloaded, particle-size data are consistent from site to site. Emissions from dirt roads or paved roads with topsoil loading exhibit the largest mass median diameter, while dust entrainment from normal city streets consists of the smallest particles. For emissions from unpaved roads and heavily loaded paved roads, there is a consistent ratio (approximately 0.3) between fine particles (less than 5 μm in diameter) and particles less than 30 μm in diameter, the effective cutoff diameter of the standard hi-vol sampler.

Table 9. SUSPENDED PARTICULATE CONCENTRATION AND EXPOSURE MEASUREMENTS (Stillwell)

	Particulate concentration (mg/m^3) at 2 m above ground								
		Downwind, excluding background							
					Standard Hi-Vol				
		Profiler[a]						Isokinetic ratio for profiler,	Integrated exposure[a]
Run	Background	Total	≤ 30 μm	Cascade impactor	10 m Downwind	20 m Downwind	50 m Downwind	u/U	(lb/vehicle-mile)
7	0.136	145	81.2	64.8	38.6	28.9	-	2.5	34.7
8	0.200	25.8	9.3	17.6	-	5.88	-	1.14	26.7
9	0.200	13.9	4.2	13.6	-	3.26	3.06	1.17	12.2
10	0.200	5.61	1.7	7.01	-	2.45	1.32	1.15	6.93
11	0.083	15.3	7.3	6.95	-	4.51	2.59	1.58	10.0
12	0.083	14.2	7.7	8.87	-	8.41	4.48	1.50	6.75
13	0.193	5.52	2.3	5.43	-	3.35	2.19	0.88	5.31
14	0.031	2.43	1.0	1.06	-	0.896	0.283	1.43	1.05

a/ Isokinetic.

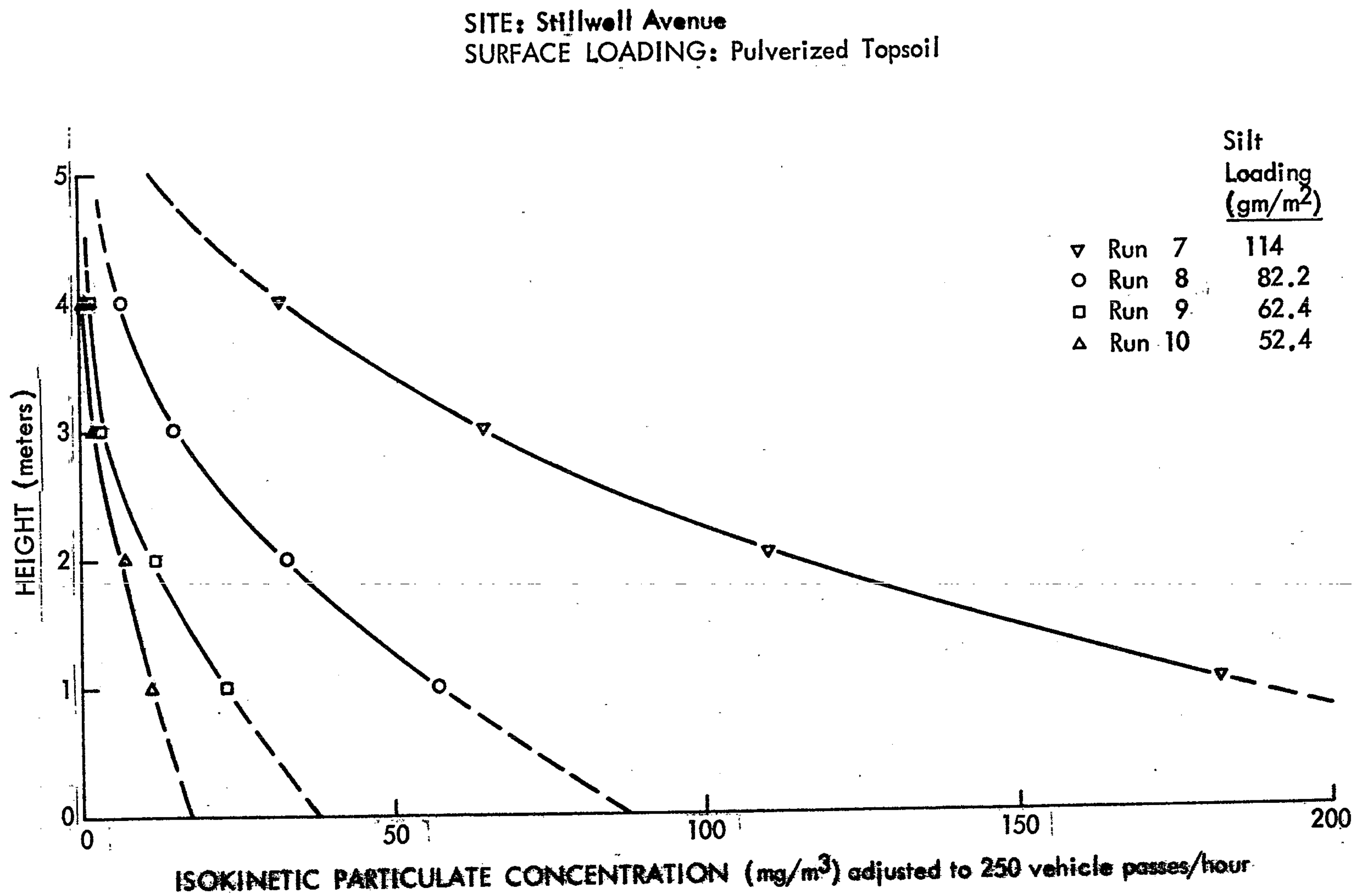


Figure 13. Vertical Profiles of Particulate Concentration (Stillwell-Pulverized Topsoil)

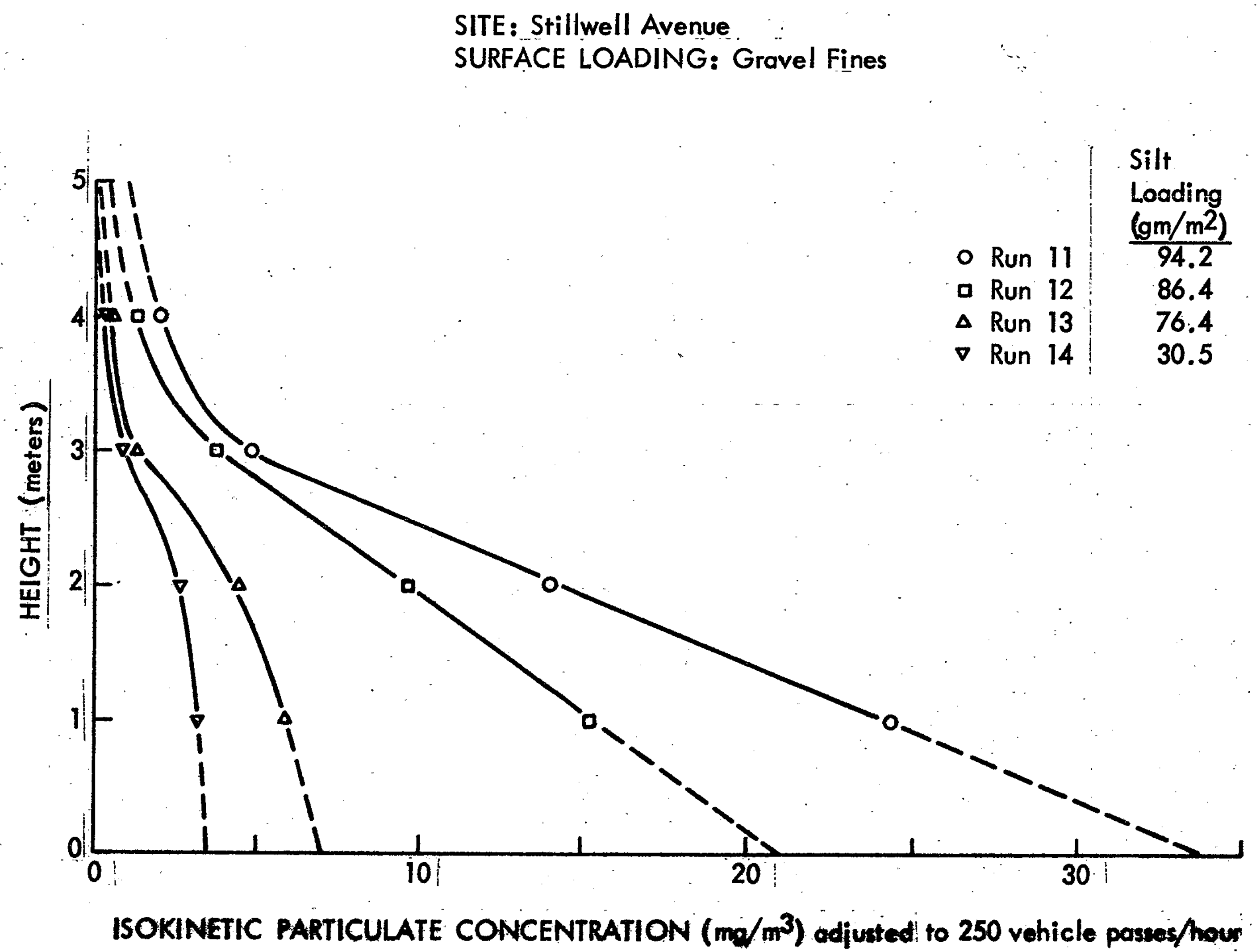


Figure 14. Vertical Profiles of Particulate Concentration (Stillwell-Gravel Fines)

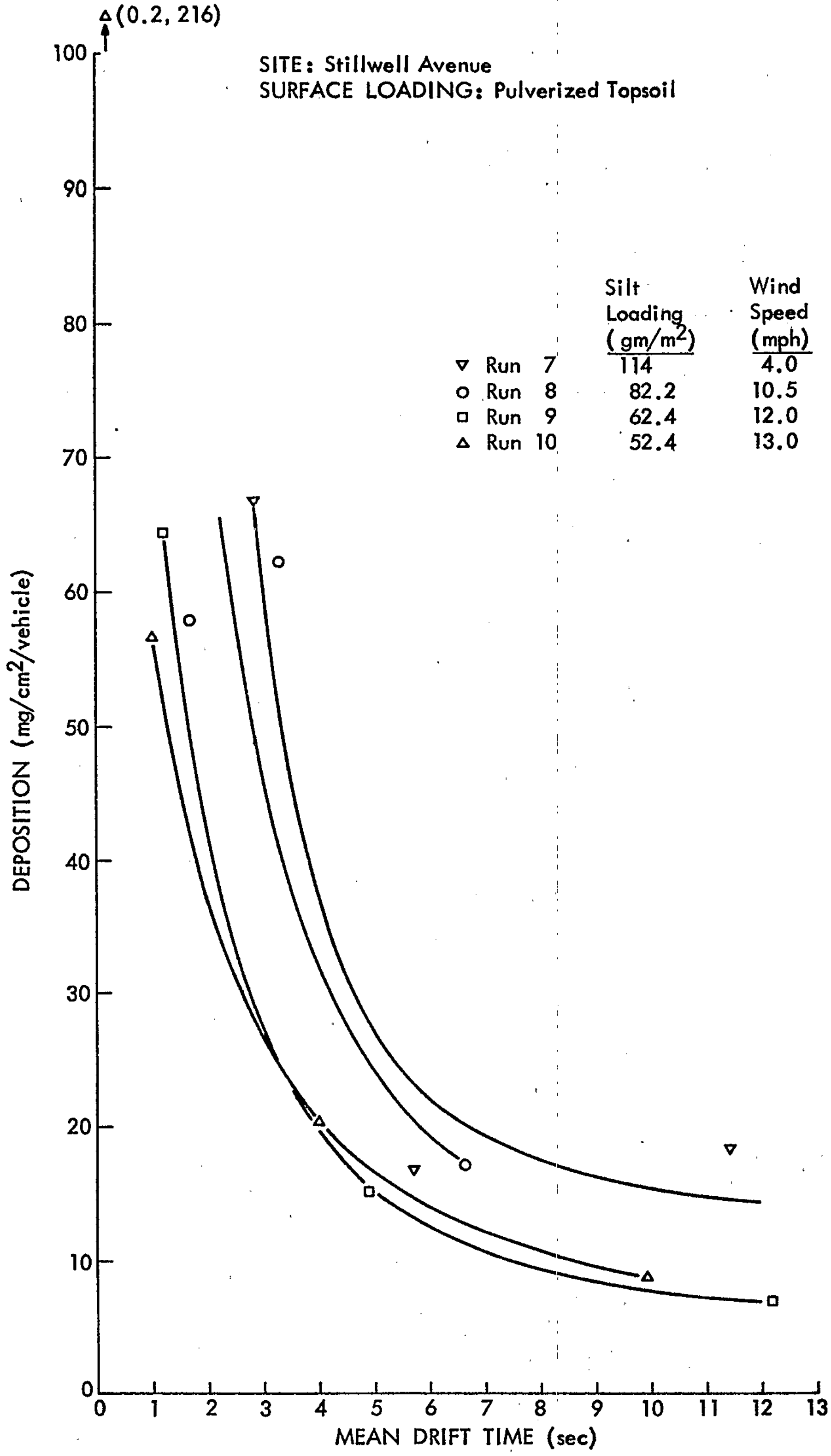


Figure 15. Downwind Distribution of Dust Deposition (Stillwell-Pulverized Topsoil)

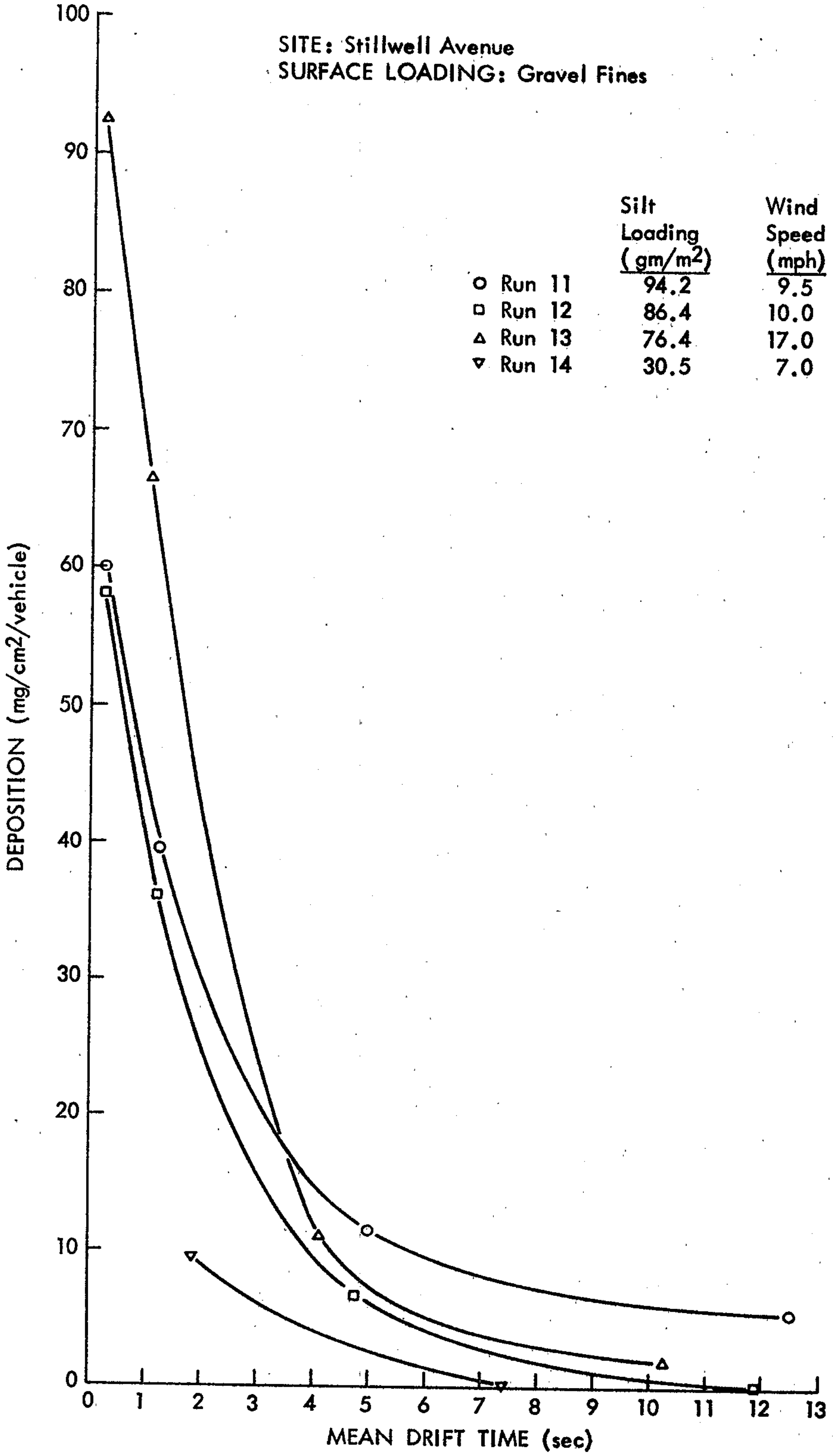


Figure 16. Downwind Distributions of Dust Deposition (Stillwell-Gravel Fines)

Table 10. SURFACE LOADING INTENSITIES AND SILT CONTENT (Stillwell)[a/]

Run	Seed material[c/]	Total loading[b/] Intensity (kg/km)	Total loading Intensity (lb/mile)	Total loading % along curbs	Loading excluding curbs Intensity (kg/km)	Loading excluding curbs Intensity (lb/mile)	Loading excluding curbs Intensity (g/m^2)	Loading excluding curbs % Silt	Silt loading excluding curbs (kg/km)	Silt loading excluding curbs (lb/mile)	Silt loading excluding curbs (g/m^2)
7	S	9,010	31,900	20	7,210	25,600	506	22	1,620	5,740	114
8	S	6,650	23,600	47	3,480	12,300	245	34	1,170	4,150	82
9	S	5,410	19,200	63	1,990	7,060	140	45	880	3,120	62
10	S	4,340	15,400	81	810	2,870	57	92	750	2,660	52
11	G	11,560	41,000	27	8,450	30,000	594	16	1,340	4,750	94
12	G	12,370	43,900	33	8,270	29,300	582	15	1,220	4,330	86
13	G	11,870	42,100	39	7,270	25,800	513	15	1,090	3,860	76
14	G	6,960	24,700	73	1,890	6,700	133	23	440	1,560	30

a/ Average of measurements taken before and after each run.
b/ Mass of dust on the entire width of the road.
c/ S = pulverized topsoil; G = gravel.

Table 11. EMISSIONS TEST PARAMETERS (Fairfax Trafficway)

Run	Date	Time		Duration of exposure sampling (min)	Ambient temperature (°F)	Wind		Wind direction angle to perpendicular (°)	Drift distance correction factor[b]	Cloud cover (%)	Pasquill stability[c]	No. of passes
		Start	Finish			Speed (mph)	Direction[a] (°)					
15	3/16/76	1330	1730	240	40	7.1	290	20	1.06	5	C	3791
16	3/24/76	1200	1600	240	66	7.3	280	10	1.02	< 5	B-C	4146

a/ Magnetic reading.
b/ Ratio of actual drift distance to perpendicular distance from the road.
c/ Pasquill Stability Classes: A = Extremely unstable
B = Unstable
C = Slightly unstable
D = Neutral
E = Slightly stable
F = Stable to extremely stable

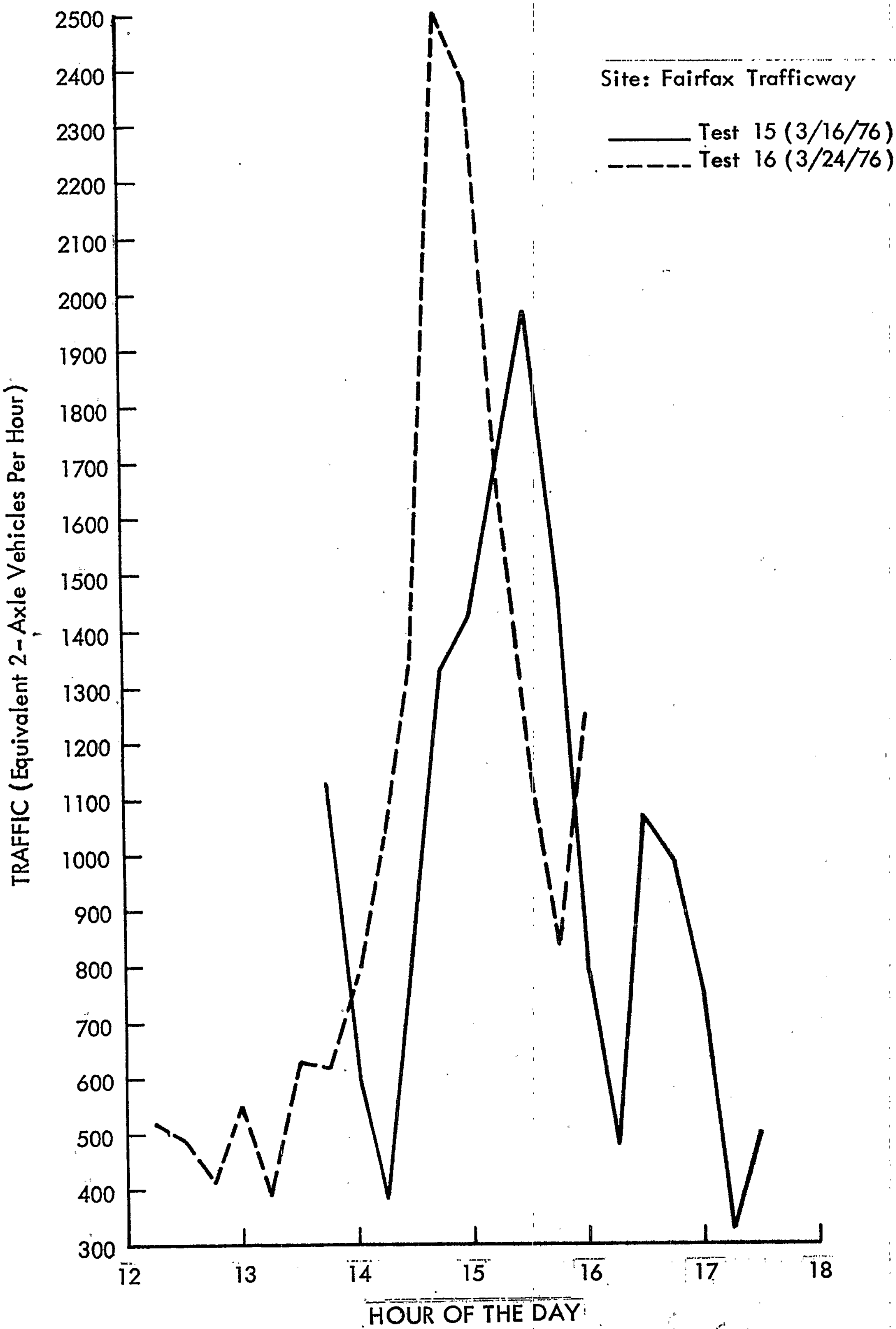


Figure 17. **Traffic Flow (Fairfax Trafficway)**

Table 12. VEHICLE MIX (Fairfax Trafficway)

Observation Period: 1447 to 1457

Vehicle type	No. of axles	No. of vehicle passes	Percentage of total
Car	2	229	70.7
Pick-up truck	2	71	21.9
Small cargo truck	2	13	4.0
Tractor trailers	6	11	3.4
Total		324	

Note: Run: 15
Sampling Period: 1330 to 1730
No. of Vehicle Passes: 3791 (2-axle equivalent)

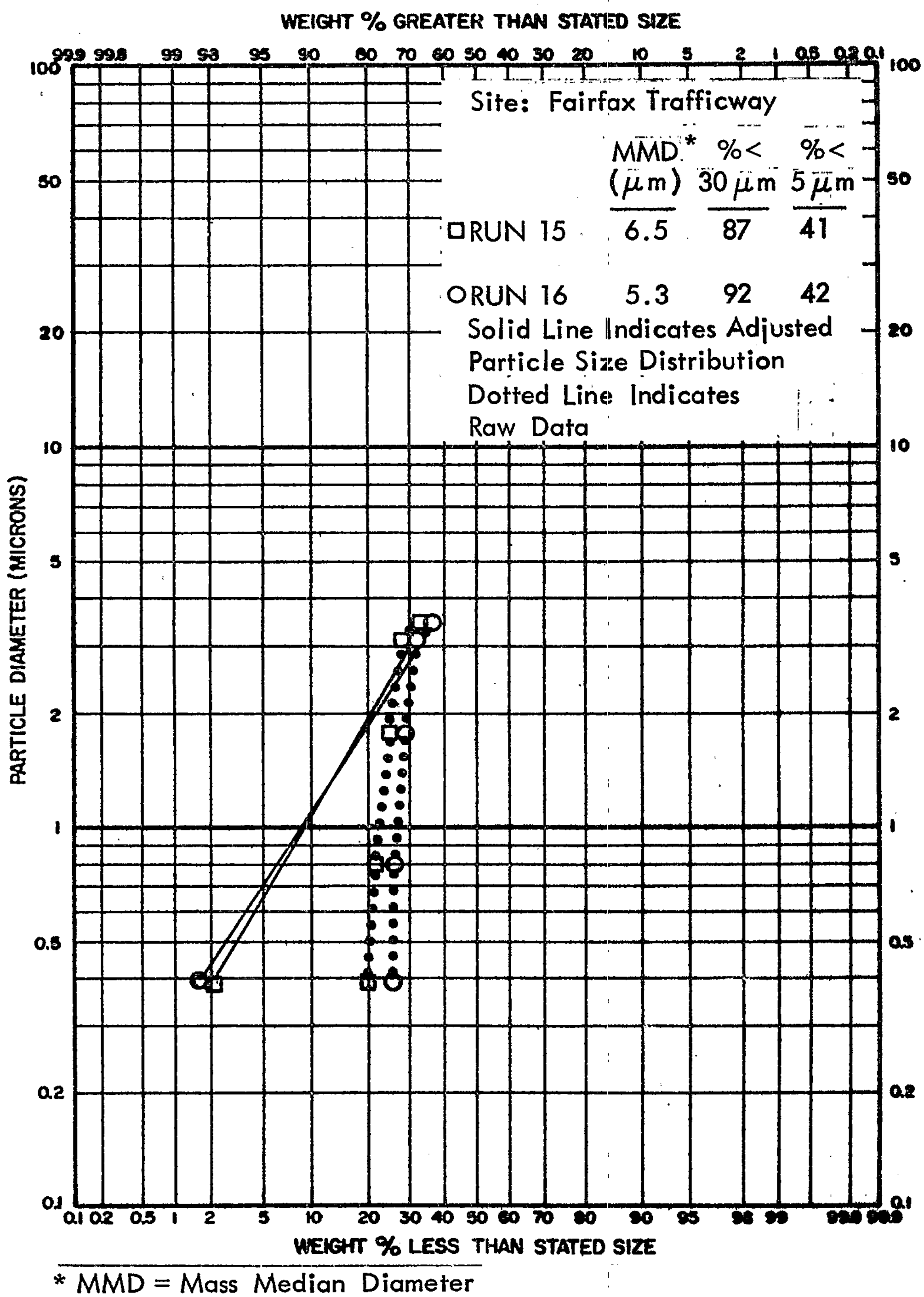


Figure 18. Airborne Particle Size Distribution (Fairfax Trafficway)

Table 13. SUSPENDED PARTICULATE CONCENTRATION AND EXPOSURE MEASUREMENTS (Fairfax Trafficway)

	Particulate concentration ($\mu g/m^3$) at 2 m above ground						Isokinetic ratio for profiler	Integrated exposure
		Downwind, including background						
		Profiler[a]			Standard Hi-Vol			
					4.4 m	50 m		
Run	Background	Total	< 30 μm	Sierra	Downwind	Downwind	u/U	(lb/vehicle-mile)
15	268	336	292	234	398	137	1.41	0.019
16	288	327	301	232	362	245	1.64	0.010

a/ Isokinetic.

Table 14. COMPARATIVE PARTICLE SIZE DATA

Run	Site	Surface	MMD[a] (μm)	Weight % ≤ 30 μm	Weight % ≤ 5 μm	Fine particle ratio[b]
3	37th Street	-	5.5	87	48	0.55
5	37th Street	-	3.3	97	64	0.66
6	37th Street	-	2.8	99	70	0.71
7[c]	Stillwell	Pulverized topsoil	22	56	18	0.32
8	Stillwell	Pulverized topsoil	62	36	12	0.33
9	Stillwell	Pulverized topsoil	94	30	9	0.30
10	Stillwell	Pulverized topsoil	94	30	9	0.30
11	Stillwell	Gravel fines	32	48	16	0.33
12	Stillwell	Gravel fines	25	54	20	0.37
13	Stillwell	Gravel fines	44	42	14	0.33
14	Stillwell	Gravel fines	43	42	13	0.31
15	Fairfax	-	6.5	87	41	0.47
16	Fairfax	-	5.3	92	42	0.46
20	207th Street	Gravel (unpaved)	13	69	29	0.42
21	207th Street	Gravel (unpaved)	19	62	20	0.32
22	207th Street	Gravel (unpaved)	24	54	20	0.37
23[c]	167th Street	Dirt (unpaved)	11	78	27	0.35
24	167th Street	Dirt (unpaved)	84	30	7	0.23
25	167th Street	Dirt (unpaved)	66	35	10	0.29

a/ MMD = Mass Median Diameter

b/ $\text{Ratio} = \frac{\text{Weight \%} \leq 5\ \mu m}{\text{Weight \%} \leq 30\ \mu m}$

c/ Sampler overloaded

Computed Emission Factors

The environmental impact of dust emission from unpaved roads varies greatly with particle size. Large particles (d > 75 μm) drift short distances from the road during the settling process, and create mainly a nuisance problem. On the other hand, fine particles (d < 5 μm), which represent a potential health hazard and which effectively reduce atmospheric visibility, may remain suspended for long periods of time and be dispersed over distances of regional scale. Thus, it is imperative that emission factors be developed for specific particle-size ranges.

The upper particle-size limit for total suspended particulates is about 30 μm for a particle density of 2 to 2.5 g/cm^3. This is the effective cutoff diameter for the capture of fugitive dust by a standard high-volume filtration sampler.[5]

The total emission factor for fugitive dust from a test road is equal to the vertically integrated exposure divided by the number of vehicle passes. This excludes particles which settle out between the edge of the street and the exposure profiler. Emission factors for specified size ranges are calculated by multiplying the total factor by the measured (isokinetic) fraction of particles in the particular size range of interest. Computed emission factors for the 37th Street, Stillwell, and Fairfax sites are presented in Tables 15 through 17, respectively.

Table 15. EMISSION FACTORS (37th Street)

	Measured emission factor[a/]					
	(g/vehicle-km)			(lb/vehicle-mile)		
Run	Total	≤ 30 μm	≤ 5 μm	Total	≤ 30 μm	≤ 5 μm
3	4.2	3.7	2.0	0.015	0.013	0.007
5	5.6	5.4	3.7	0.020	0.019	0.013
6	3.4	3.3	2.3	0.012	0.012	0.008

a/ Isokinetic.

Table 16. EMISSION FACTORS (Stillwell)

	Measured emission factor[a/]					
	(kg/vehicle-km)			(lb/vehicle-mile)		
Run	Total	≤ 30 μm	≤ 5 μm	Total	≤ 30 μm	≤ 5 μm
7	9.8	5.5	1.8	34.7	19.4	6.2
8	7.5	2.7	0.90	26.7	9.6	3.2
9	3.4	1.0	0.31	12.2	3.7	1.1
10	1.9	0.59	0.17	6.9	2.1	0.62
11	2.8	1.4	0.45	10.0	4.8	1.6
12	1.9	1.0	0.27	6.8	3.7	0.95
13	1.5	0.62	0.21	5.3	2.2	0.74
14	0.31	0.13	0.039	1.1	0.46	0.14

a/ Isokinetic.

Table 17. EMISSION FACTORS (Fairfax Trafficway)

Run	Measured emission factor[a/] (g/vehicle-km) Total	≤ 30 μm	≤ 5 μm	(lb/vehicle-mile) Total	≤ 30 μm	≤ 5 μm
15	5.4	4.8	2.3	0.019	0.017	0.008
16	2.8	2.6	1.2	0.010	0.0092	0.0042

a/ Isokinetic.

CORRECTIONS TO EMISSION FACTORS

As indicated in Figure 19, a nearly linear relationship between the computed total emission factor and the measured silt loading for silt loadings (excluding curbs) below about 20 g/m^2 (280 kg/km or 1,000 lb/mile) can be assumed for the Stillwell site. Based on this representation of the data, the following functional relationship is proposed:

$$e = KLs$$

where
- e = Emission factor (kg/vehicle-km)
- K = Proportionality constant ($vehicle^{-1}$)
- L = Surface loading excluding curbs (kg/km)
- s = Silt content of the surface material (fraction)

The curb area extended 15 in. from the curb toward the center of the street.

Computed total K-values for Stillwell are given in Table 18. These values, which are based on total silt loading excluding curbs (Ls), apply to the loading range normally observed on urban streets (Ls $<$ 280 kg/km or 1,000 lb/mile). Table 18 also shows the K-values as a function of particle-size for 37th Street and Fairfax Trafficway, based on the uniform application of the average total K-value for Stillwell Avenue.

To check the consistency of the emissions data between sites, the average total K-value determined for Stillwell was used to calculate the silt loading excluding curbs for 37th Street and Fairfax, yielding the results shown in Table 19. As indicated in Table 19, the calculated silt loadings for 37th Street and Fairfax compare well with the silt loadings found by Sartor and Boyd[4/] based on the assumption that the 10% of the total loading between curb areas has a 10% silt content.

As a further check on the validity of these factors, a comparison may be made with the factors of 1 to 3 x 10^{-5} per axle estimated in a previously cited study of contaminant loadings on paved urban streets.[10/] Assuming two axles per vehicle and 10% silt in the surface material, these estimated factors are transformed to 20 to 60 x 10^{-5} $vehicle^{-1}$.

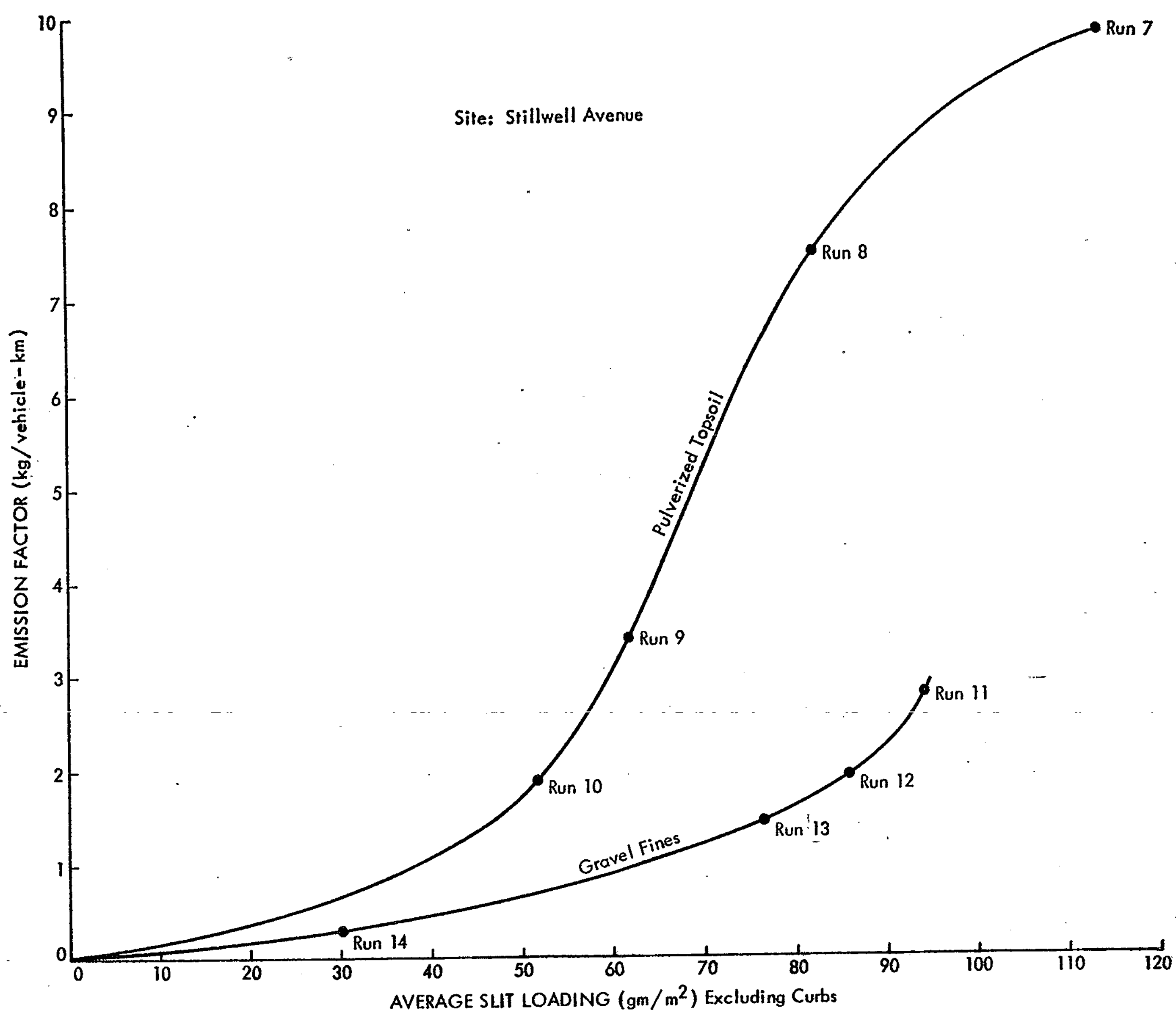


Figure 19. Emission Factor Versus Average Silt Loading (Stillwell)

Table 18. EMISSION PROPORTIONALITY FACTORS

Site	K-Factor (x 10^5) Total	$\leq$ 30 µm	$\leq$ 5 µm
Stillwell Avenue			
Pulverized topsoil	125	a/	a/
Gravel fines	71	a/	a/
Average	98		
37th Street			
Run 3	98	85	47
Run 5	98	95	63
Run 6	98	97	69
Average	98	96	60
Fairfax Trafficway			
Run 15	98	85	40
Run 16	98	90	41
Average	98	87	40
Average K-Factor b/	98	91	50

a/ Stillwell entrained dust size distributions are not representative of paved urban roadways (see Table 14).

b/ Average of 37th Street average and Fairfax Trafficway average.

Table 19. COMPARISON OF CALCULATED VERSUS PROBABLE SURFACE LOADINGS

Site	Silt loading excluding curbs (kg/km)	
	Calculated using $K = 98 \times 10^{-5}$	Sartor and Boyd[a/]
37th Street		residential-low/old/single
Run 3	4.3	4.8
Run 5	5.7	4.8
Run 6	3.5	4.8
Fairfax Trafficway		industrial-medium
Run 15	5.5	5.0
Run 16	2.9	2.5[a/]

a/ Table 1 gives loading intensities measured by Sartor and Boyd for various land uses.

b/ Assuming half the normal loading following thorough street cleaning on the day prior.

The time-average silt loading on a paved street is a complicated function of traffic-related and other parameters as discussed earlier. Perhaps these are best related to land use, as given in Table 1. To the extent that traffic-related deposition is the major source of surface material, emissions become independent of traffic speed after the deposition-reentrainment equilibrium is reached.

Therefore, in calculating an emission factor for dust emissions from paved roadways, with the equation $e = KLs$, the following parameter values should be used (based on the data in Table 18):

e = Calculated emission factor (kg/vehicle-km)
K = 98×10^{-5} vehicle^{-1} for total emissions
91×10^{-5} vehicle^{-1} for particles < 30 μm in diameter
50×10^{-5} vehicle^{-1} for particles < 5 μm
L = Surface loading excluding curbs (kg/km) estimated as a function of land use (Table 1)
s = Silt content of the surface material (10%)

Table 20 shows calculated emission factors as a function of land use, based on 10% (the noncurb portion) of the surface loadings given in Table 1 and a 10% silt content.

Table 20. EMISSION FACTORS FOR MAJOR LAND USE CATEGORIES

Emission factor units	Land use	Calculated emission factors: Total		< 30 μm		< 5 μm	
		Mean[a]	Range	Mean[a]	Range	Mean[a]	Range
g/vehicle-km	Residential	6.6	0.2-38	6.2	0.16-35	3.4	0.09-19
	Industrial	15	1.3-66	14	1.2-62	7.9	0.68-34
	Commercial	1.6	0.33-6.6	1.5	0.31-6.2	0.79	0.17-3.4
	Overall	8.3		7.7		4.2	
lb/vehicle-mile	Residential	0.024	0.0006-0.14	0.022	0.0006-0.13	0.012	0.0003-0.069
	Industrial	0.055	0.0047-0.24	0.051	0.0044-0.22	0.028	0.0024-0.12
	Commercial	0.0057	0.0012-0.024	0.005	0.0011-0.022	0.0028	0.0006-0.012
	Overall	0.029		0.027		0.015	

a/ Weighted over several cities according to land use percentages.

REFERENCES

1. Harrison, P. R., "Considerations for Siting Air Quality Monitors in Urban Areas," Paper No. 73-161, presented at the 65th Annual Meeting of the Air Pollution Control Association, Miami Beach, Florida, June 18 to 22, 1972.

2. Harrison, P. R., R. Draftz, and W. H. Murphy, "Identification and Impact of Chicago's Ambient Suspended Dust," paper submitted to Atmospheric Environment (1974).

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

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. Cowherd, C., Jr., K. Axetell, Jr., C. M. Guenther, and G. A. Jutze, "Development of Emission Factors for Fugitive Dust Sources," EPA Publication No. EPA-450/3-74-037, June 1974.

6. 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.

7. 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.

8. American Public Works Association, "Water Pollution Aspects of Urban Runoff," APWA, Chicago, pp. 171-175 (1969).

9. 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).

10. 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.

11. Woodruff, N. P., and F.H. Siddoway, "A Wind Erosion Equation," Soil Science Society of America Proceedings, 29(5):602-608, September to October 1965.

12. "Investigation of Fugitive Dust Emissions Impact in Designated Air Quality Control Regions," Final Report, EPA Contract No. 68-02-044 (Task 9), prepared by PEDCo-Environmental Specialists, Inc., May 1973.

13. Amick, R. S., K. Axetell, Jr., and D. M. Wells, "Fugitive Dust Emission Inventory Techniques," Paper No. 74-58, presented at the 67th Annual Meeting of the Air Pollution Control Association, Denver, Colorado, June 9 to 13, 1974.

14. "Reference Method for the Determination of Suspended Particulates in the Atmosphere (High Volume Method)," Federal Register, 36:28, Appendix B, 22388-22390, November 25, 1971.

15. "Standard Method for Collection and Analysis of Dustfall," ASTM Method D 1739-62.

16. Cowherd, C., Jr., J. H. Southerland, and C. O. Mann, "Development of Emission Factors for Fugitive Dust Sources," Paper No. 74-81, Air Pollution Control Association, Denver, Colorado, June 1974.

17. Pasquill, F., "The Estimation of the Dispersion of Windborne Materials," Meteorol. Mag., 90:1063 (1961).

18. Gillette, G. A., "Production of Fine Dust by Wind Erosion of Soil: Effect of Wind and Soil Texture," paper presented at the 1974 Symposium of Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants, at Battelle Pacific Northwest Laboratories, Richland, Washington, September 1974.

19. Thornthwaites, C. W., "Climate of North America According to a New Classification," Geograph. Rev., 21:633-655 (1931).

APPENDIX A

PARTICLE SIZE DISTRIBUTIONS OF ATMOSPHERIC DUST FROM UNPAVED ROADS

This Appendix presents the results of a separate series of field studies to determine particle-size distributions of atmospheric dust generated by vehicular traffic on unpaved roads. Field tests were conducted in an agricultural area (Southern Johnson County, Kansas) characterized by relatively flat, open terrain. Testing at the gravel road site (207th Street) took place in September 1976, and testing at the dirt road site (167th Street) in October 1976.

Figures A-1 through A-4 show the layout of sampling equipment used for each run. As in the case of paved roads, the primary device for measurement of particle-size distribution was a Sierra Instruments high-volume cascade impactor equipped with a cyclone preseparator.

Gravel Road Results

Table A-1 gives information on the time of each run, prevailing meteorological conditions and vehicular traffic for the three runs at the 207th Street site. Table A-2 gives the vehicle mix for each run. Measured particulate concentrations are listed in Table A-3.

Figure A-5 shows the aerodynamic particle size distributions measured downwind of the test gravel road. The solid lines are the distributions adjusted to eliminate bias caused by residual coarse particle bounce, following the procedure outlined in the body of this report.

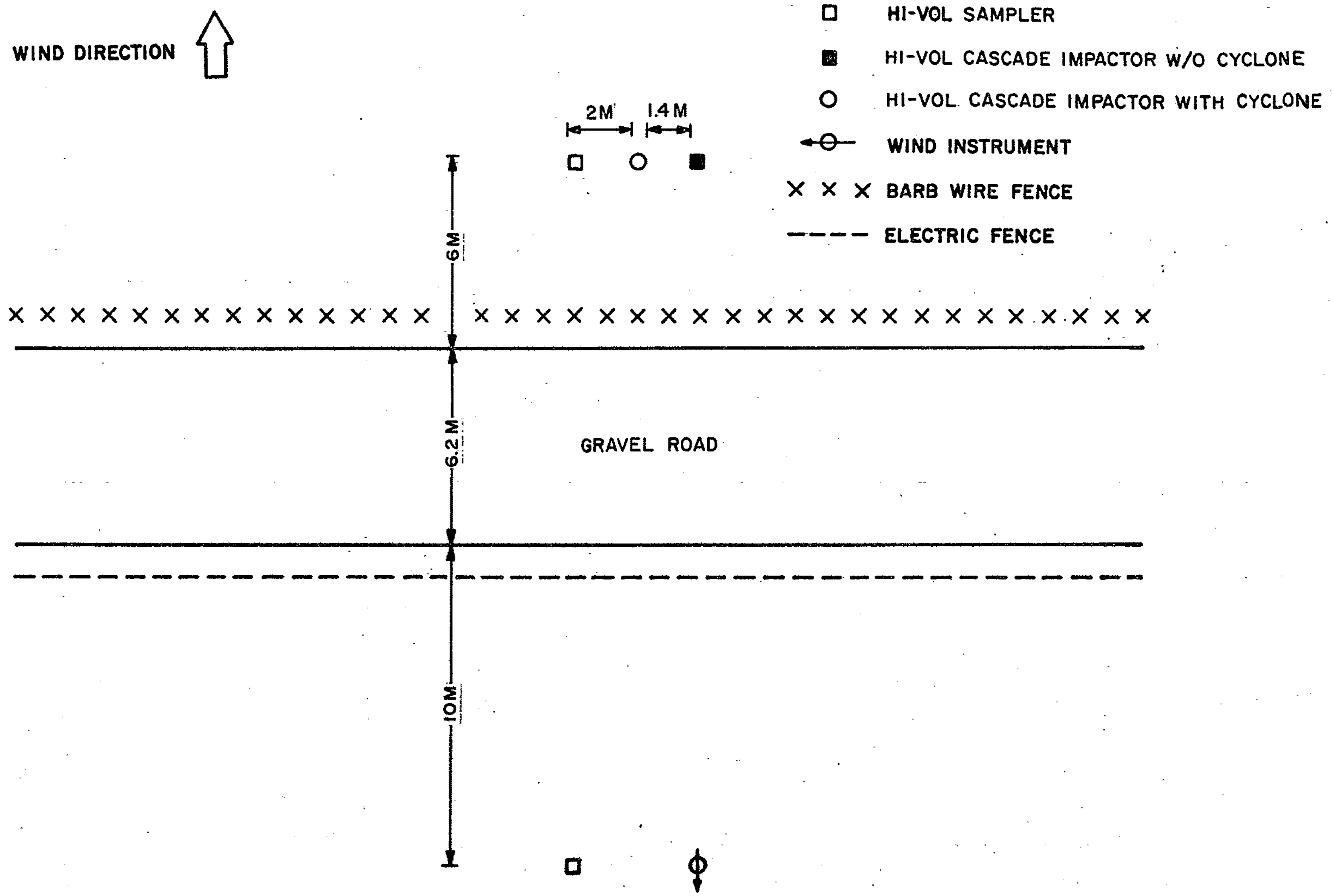


Figure A-1. Location of Sampling Instruments at 207th Street Site--South Wind

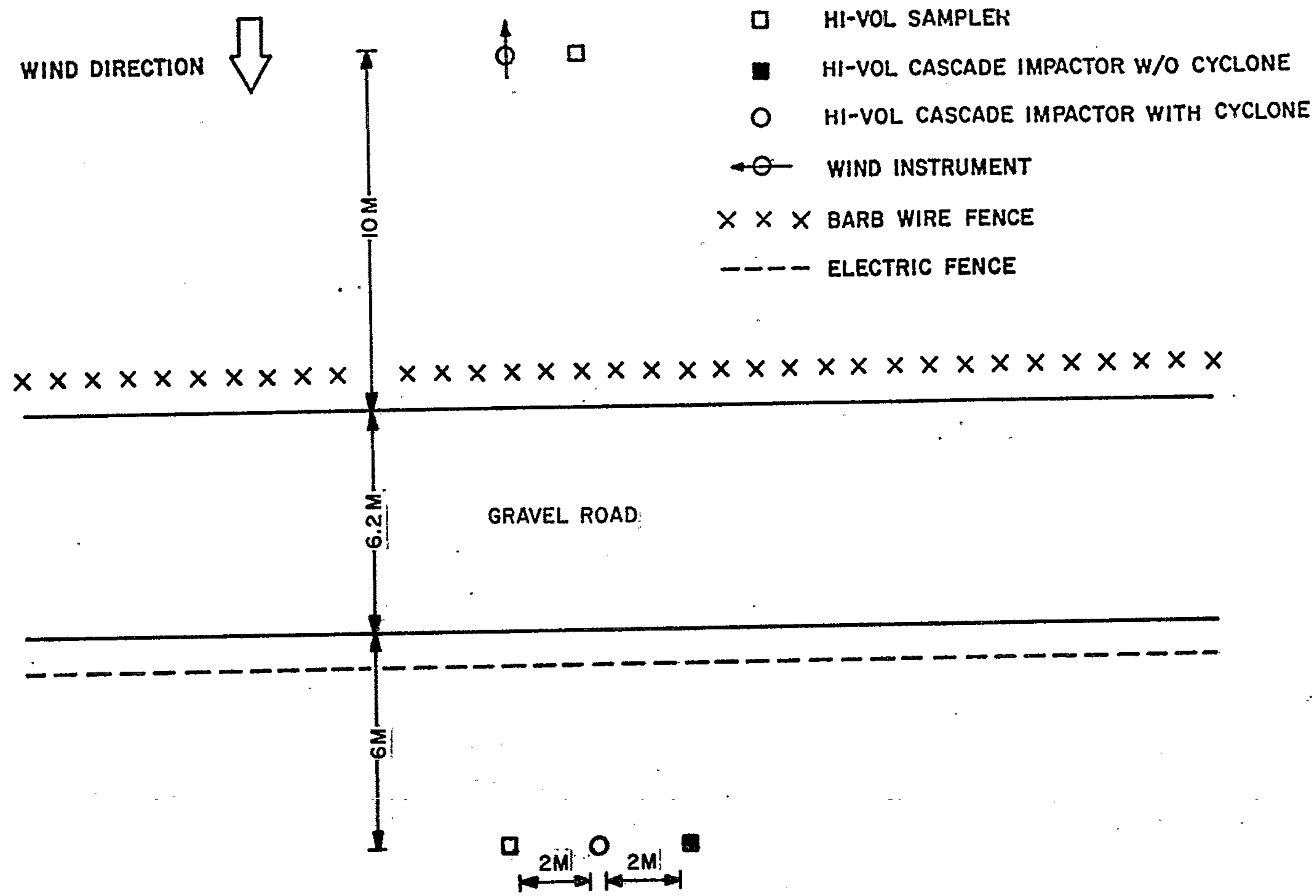


Figure A-2. Location of Sampling Instruments at 207th Street Site--North Wind

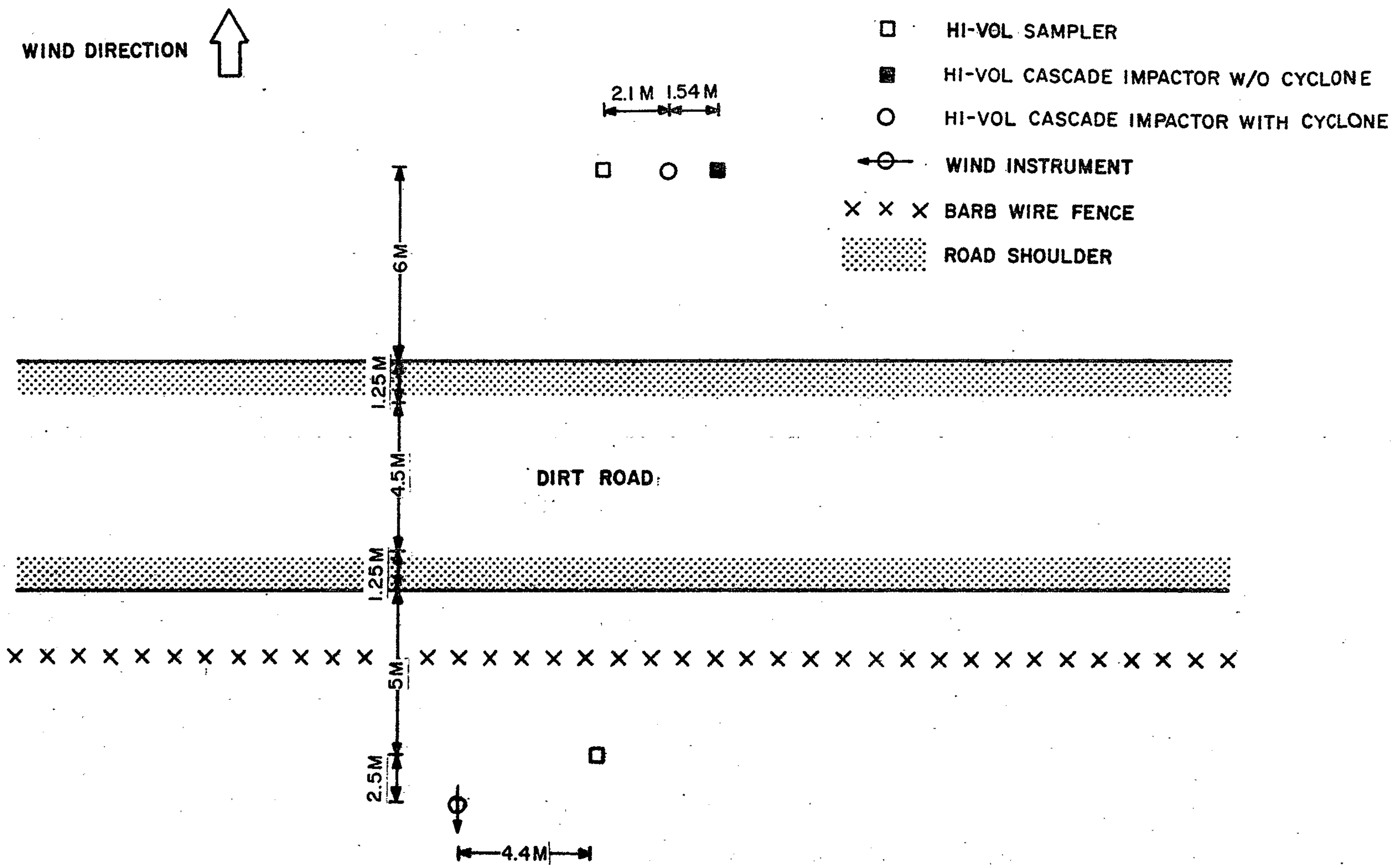


Figure A-3. Location of Sampling Instruments at 167th Street--South Wind

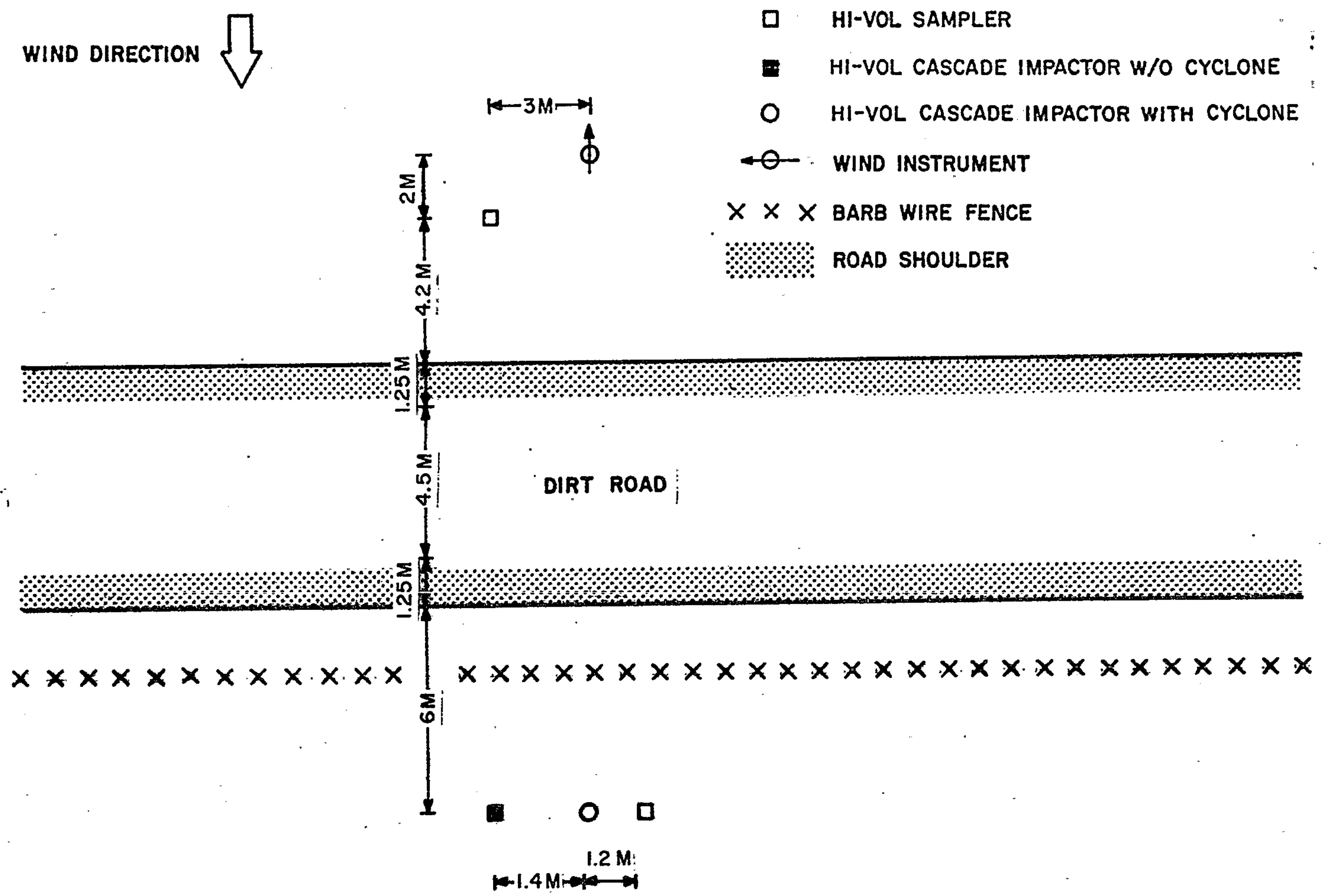


Figure A-4. Location of Sampling Instruments at 167th Street--North Wind

Table A-1. EMISSIONS TEST PARAMETERS (207th Street)

Run	Date	Time		Duration of exposure sampling (min)	Ambient temperature (°F)	Wind		Wind direction angle to perpendicular (°)	Drift distance correction factor[b]	Cloud cover (%)	Pasquill[c] stability	No. of passes
		Start	Finish			Speed (mph)	Direction[a] (°)					
20	9/8/76	1206	1233	27	84	3.3	260	80	5.76	50	B	102
		1250	1313	23	84	5.9	240	60	2.00	50	B	
21	9/9/76	1050	1135	45	71	16	20	20	1.06	10	D	106
22	9/9/76	1300	1345	45	73	16	355	5	1.00	10	D	100

a/ Magnetic reading.

b/ Ratio of actual drift distance to the perpendicular distance from the road.

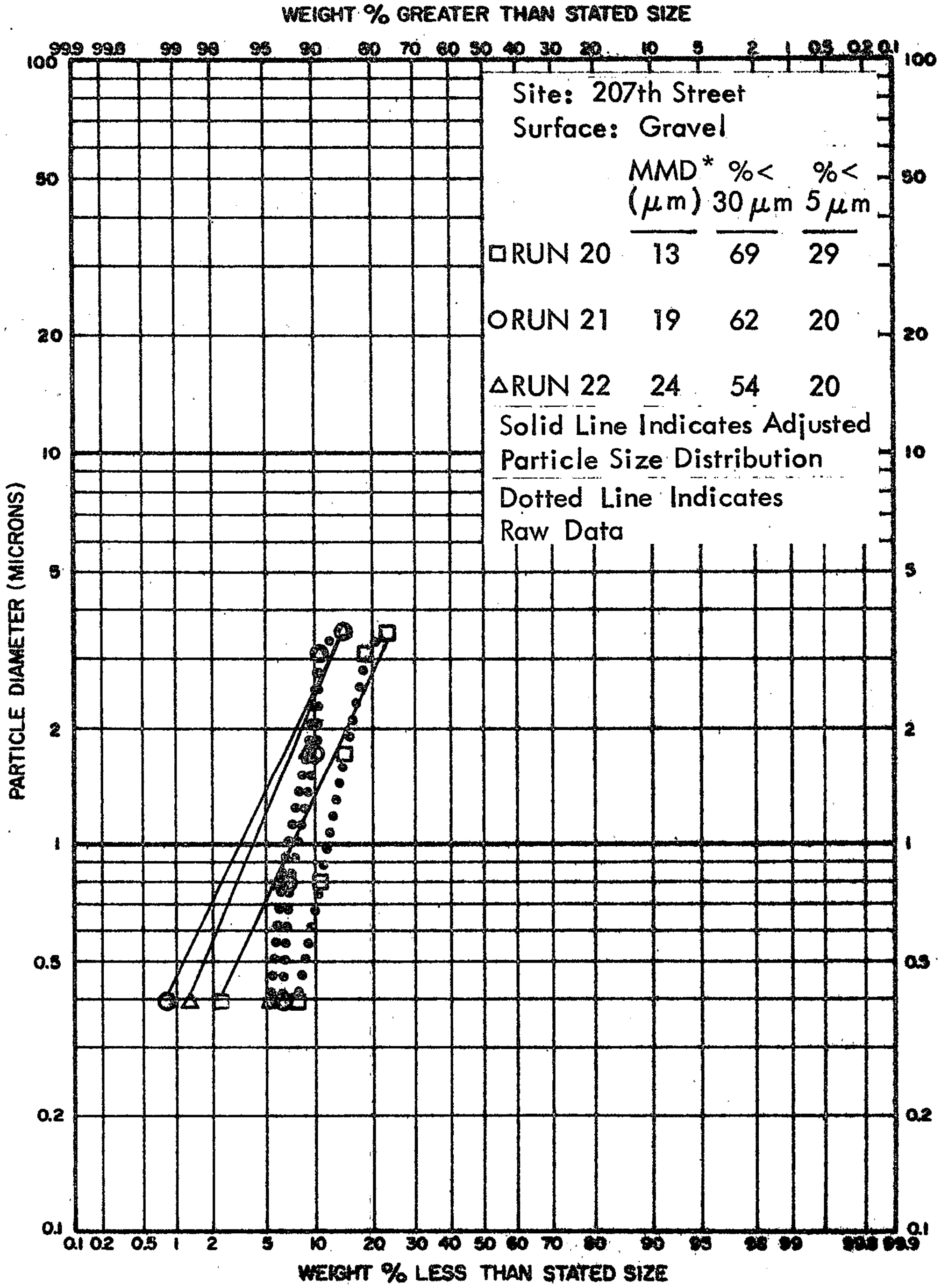
c/ Pasquill Stability Classes: A = Extremely unstable
B = Unstable
C = Slightly unstable
D = Neutral
E = Slightly stable
F = Stable to extremely stable

Table A-2. VEHICLE MIX (207th Street)

Run	No. of vehicle passes		
	Passenger car	Van/truck	Total
20	52	54	106
21	50	50	100
22	50	50	100

Table A-3. SUSPENDED PARTICULATE CONCENTRATIONS AT 207th STREET

Run	Particulate concentration ($\mu g/m^3$ at 2 m above ground		
		Downwind, excluding background	
	Background	Cascade impactor with cyclone	Standard Hi-Vol
20	1,484	3,250	4,958
21	76	2,486	3,258
22	18	3,127	3,790



* MMD = Mass Median Diameter

Figure A-5. Airborne Particle Size Distributions (207th Street-Gravel)

Dirt Road Results

Table A-4 gives information on the time of each run, prevailing meteorological conditions and vehicular traffic for the three runs at the 167th Street site. Table A-5 gives the vehicle mix for each run. Measured particulate concentrations are listed in Table A-6.

Figure A-6 shows the aerodynamic particle size distributions measured downwind of the test dirt road. The solid lines are the distributions adjusted to eliminate bias caused by residual coarse particle bounce, following the procedure outlined in the body of this report.

Table A-4. EMISSIONS TEST PARAMETERS (167th Street)

Run	Date	Time Start	Time Finish	Duration of exposure sampling (min)	Ambient temperature (°F)	Wind Speed (mph)	Wind Direction[a] (°)	Wind direction angle to perpendicular (°)	Drift distance correction factor[b]	Cloud cover (%)	Pasquill[c] stability	No. of passes
23	10/14/76	1230	1325	55	58	6.5	200	20	1.06	10	B	100
24	10/14/76	1440	1505	25	59	7	200	20	1.06	10	B	50
25	10/15/76	1115	1140	25	42	12.2	336	24	1.09	0	C	50

a/ Magnetic reading.
b/ Ratio of actual drift distance to the perpendicular distance from the road.
c/ Pasquill Stability Classes: A = Extremely unstable
B = Unstable
C = Slightly unstable
D = Neutral
E = Slightly stable
F = Stable to extremely stable

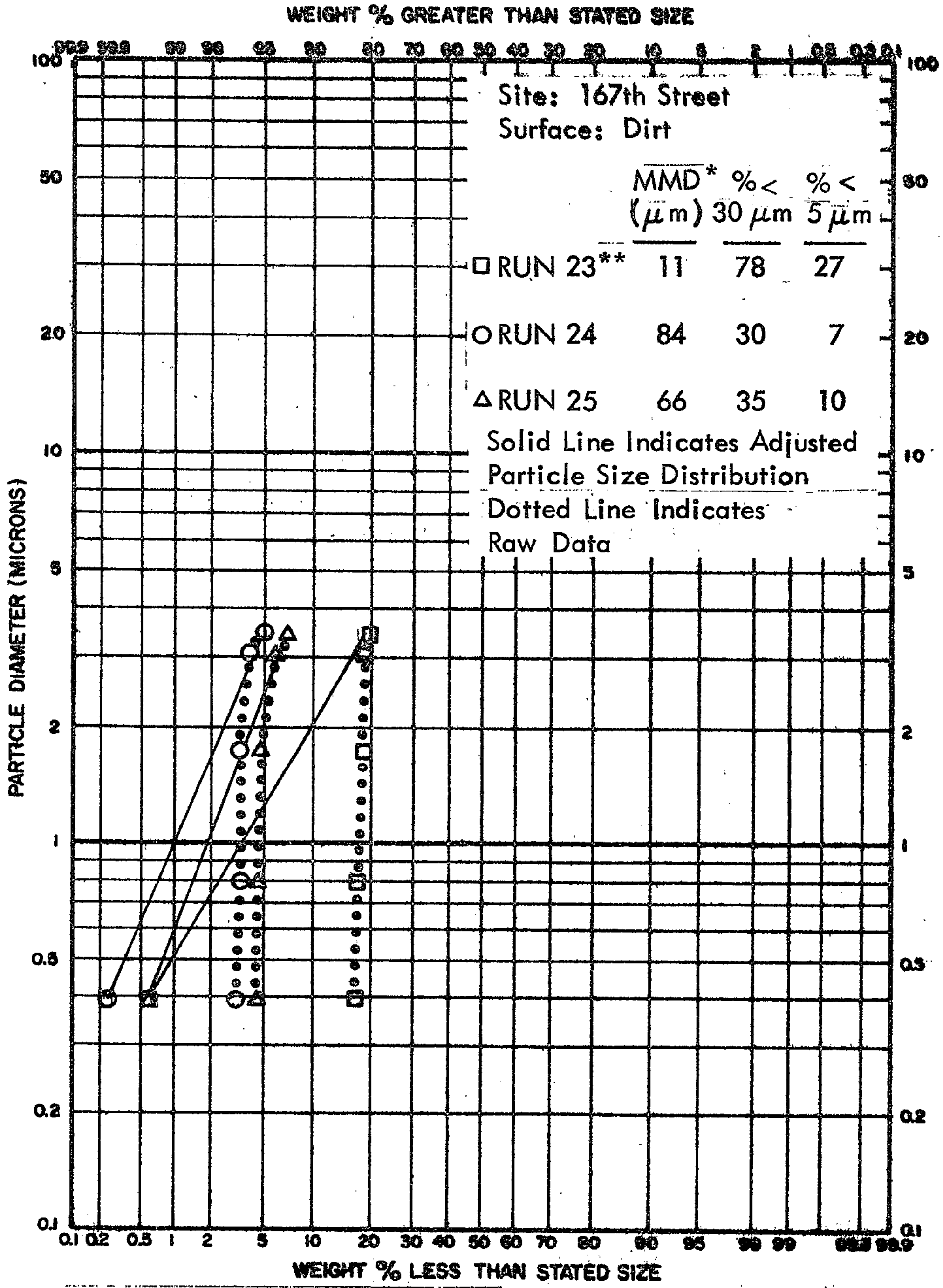
Table A-5. VEHICLE MIX (167th Street)

Run	Passenger car	Van/Truck	Total
23	50	50	100
24	25	25	50
25	25	25	50

Table A-6. SUSPENDED PARTICULATE CONCENTRATIONS AT 167th STREET

	Particulate concentration ($\mu g/m^3$) at 2 m above ground			
		Downwind, excluding background		
			Standard Hi-Vol	
Run	Background	Cascade impactor with cyclone	With Cascade impactor	Without Cascade impactor
23	218[a/]	12,658	7,565	10,120
24	218[a/]	13,062	6,784	11,058
25	191	5,383	-	6,348

a/ Average over both Runs 23 and 24.



* MMD = Mass Median Diameter

** Sampler Overloaded on Run 7

Figure A-6. Airborne Particle Size Distribution (167th Street-Dirt)

APPENDIX B

ESTIMATION OF SUSPENDED PARTICULATE EMISSIONS GENERATED BY WIND EROSION

Recently Gillette[18/] measured vertical fluxes of suspended dust smaller than 20 μm in diameter generated by wind eroding fields in West Texas. As expected, emissions increased sharply with increasing friction velocity, above the threshold value of about 25 cm/sec. In addition, the vertical flux was significantly higher for one of eight soils which had a substantially higher content of silt (particles between 2 and 50 μm in diameter). This finding confirmed Gillette's previously developed theory that the generation of suspended dust by wind erosion is a function of the silt content of the eroding soil, in addition to the total rate of wind erosion.

The Wind Erosion Equation[11/] relates the total rate of wind erosion to the following field and climatic parameters:

- Soil erodibility - potential annual loss rate for a wide, unsheltered, isolated field with a bare, smooth surface.
- Ridge roughness - a function of ridge (clod) height and spacing.
- Climate factor - contains in addition to wind speed, Thornthwaites Precipitation-Evaporation Index[19/] as a measure of average soil moisture content.
- Vegetative cover - expressed as equivalent small grain stubble.
- Field length - distance along which erosion builds to its maximum (equilibrium) value.

Soil erodibility for various soil texture classes[5] is given in Table B-1. Erodibility is related to the percentage of erodible dry aggregates (particles smaller than 0.84 mm in diameter) in the surface soil.

Table B-1. SOIL ERODIBILITY FOR VARIOUS SOIL TEXTURAL CLASSES

Predominant soil textural class	Erodibility, I (tons/acre/year)
Sand[a]	220
Loamy sand[a]	134
Sandy loam[a]	86
Clay	86
Silty clay	86
Loam	56
Sandy clay loam[a]	56
Sandy clay[a]	56
Silt loam	47
Clay loam	47
Silty clay loam	38
Silt	38

a/ Very fine, fine, or medium sand.

Figure B-1 shows a map of P-E values for the United States.[5] These values were calculated from annual precipitation and temperature data, using the relationship developed by Thornthwaite.[19]

THORNTHWAITE'S PRECIPITATION - EVAPORATION INDEX

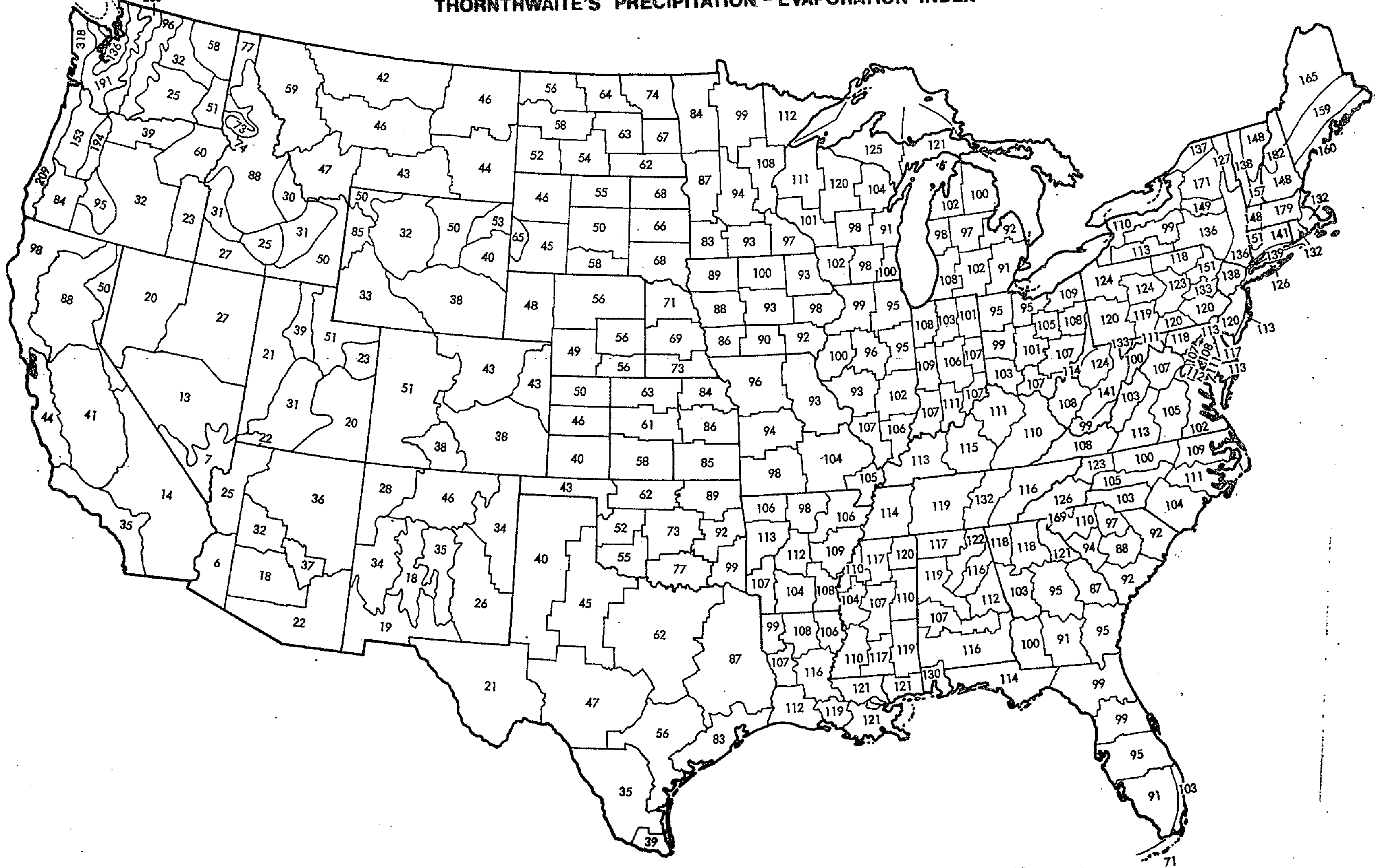


Figure B-1. Map of PE Values for State Climatic Division 5/

The reduction in wind erosion due to vegetative cover[11] is given in Figure B-2. The conversion of measured residue density to equivalent flat small-grain stubble is described elsewhere.[11] Typical values of equivalent vegetative cover for common field crops[5] are given in Table B-2.

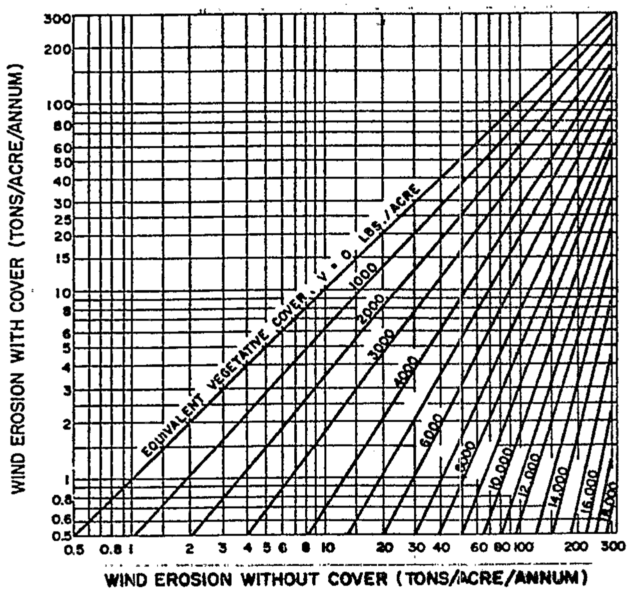


Figure B-2. Mitigative Effect of Vegetative Cover

Based on the above information, the following equation is proposed for the calculation of emissions of suspended dust (particles smaller than 30 µm in diameter) from wind erosion:

$$E = 0.0089 \frac{esr'}{(PE/50)^2} f$$

where E = Emissions of suspended dust in tons/acre/year

e = Soil erodibility in tons/acre/year

s = Silt content of surface soil in percent

Table B-2. VALUES OF EQUIVALENT VEGETATIVE COVER FOR COMMON FIELD CROPS

Crop	V (lb/acre)
Alfalfa	3,000
Barley	1,100
Beans	250
Corn	500
Cotton	250
Grain Hays	1,250
Oats	1,250
Peanuts	250
Potatoes	400
Rice	1,000
Rye	1,250
Safflower	1,500
Sorghum	900
Soybeans	250
Sugar beets	100
Vegetables	100
Wheat	1,350

f = Fraction of time wind exceeds the threshold value for wind erosion (12 mph)

r = Mitigative fractional reduction in wind erosion due to vegetative cover, calculated from Figure B-2.

PE = Thornthwaite's Precipitation-Evaporation Index

The proportionality constant in the above equation was derived from the previously cited field measurements.[18/] The soil erosion parameters for the test field were as follows:

Silt content = 8.5%

Potential erodibility = 100 tons/acre/year

Ridge roughness = 2.5 cm

Precipitation-Evaporation Index = 40

Vegetative cover = 33 lb/acre

Field length = 1.6 km

The above value for ridge roughness is an average value for a plowed field, and the vegetative cover is negligible. In addition, a factor of 0.85 has been inserted into the proportionality constant to reflect a typical field length of 2/3 km.

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

1. REPORT NO. EPA-450/3-77-027	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Quantification of Dust Entrainment from Paved Roadways		5. REPORT DATE July 1977
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Chatten Cowherd, Jr., Christine M. Maxwell, Daniel W. Nelson		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Midwest Research Institute, 425 Volker Boulevard, Kansas City, Missouri 64110		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-1403, Task Order 25
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina 27711		13. TYPE OF REPORT AND PERIOD COVERED Final-July 1975 to June 1977
		14. SPONSORING AGENCY CODE 200/04
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

This report presents the results of a field testing program to develop emission factors for fugitive dust entrainment from paved urban roads. Substantial evidence has been compiled which indicates that dust emissions from city streets are a major cause of nonattainment of national air quality standards for total suspended particulates (TSP). Therefore, the quantification of this source is necessary to the development of effective attainment and maintenance strategies.

Field testing was conducted at 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. The basic measurements consisted of isokinetic exposure and concentration profiles of airborne dust, particle size distributions, dust deposition profiles, surface dust loading, and traffic characteristics. In addition, conventional high-volume samplers were used to determine attenuation of TSP concentration with distance from the source.

Emissions are found to vary directly with traffic volume and surface loading of silt (fines). The dust emission factor for normally loaded urban streets ranges from 1 to 15 g/vehicle-km, depending on land use. Approximately 90% of the emissions (by weight) is less than 30 μm in diameter and 50% less than 5 μm in diameter.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Emission Factors Paved Roads Fugitive Dust Particulates Sampling Techniques		

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 90
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)