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Vol. II. SOURCES AND MIGRATION OF HIGHWAY RUNOFF POLLUTANTS - METHODS

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FINAL REPORT

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16. Abstract

The overall objectives of this research were to identify the sources of highway pollutants, and to determine their deposition and accumulation within the highway system and subsequent removal from the highway system to the surrounding environment. Included in this report are the details of monitoring site selection and field monitoring procedures. Data collected at four sites included atmospheric deposition and removal, saltation, highway surface loads, runoff quantity and quality, groundwater percolation, soil and vegetation, traffic characteristics, highway maintenance, climatological data and source investigative studies.

This document is the second volume of a report entitled "Sources and Migration of Highway Runoff Pollutants." The titles of the volumes of this report are:

FHWA/RD		SUBTITLE
Vol. I 84/057	Volume I	Sources and Migration of Highway Runoff Pollutants - Executive Summary
Vol. II 84/058	Volume II	Sources and Migration of Highway Runoff Pollutants - Methods
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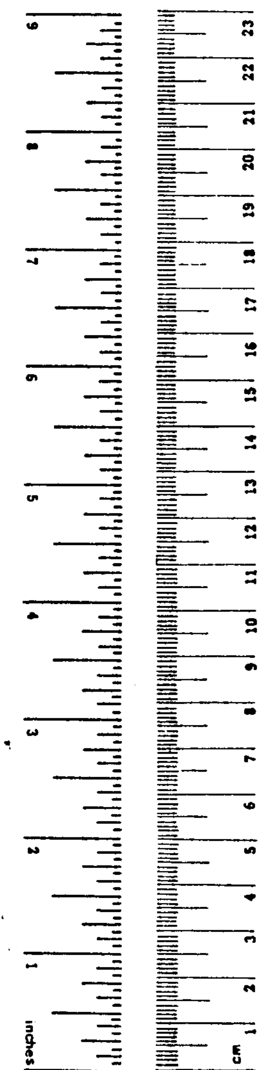
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
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cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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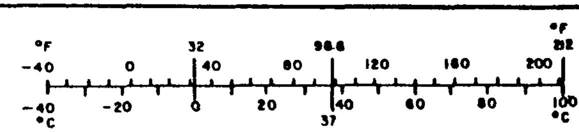
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECTION I
INTRODUCTION

The highway system is a potential source of a wide variety of possible pollutants to surrounding surface and subsurface waters through the mechanisms of the natural hydrologic cycle. Thus, consideration of the effects of a highway system on the environment plays an increasingly important role in the planning, design, construction, and operation of a transportation system. Highway systems are not unique as a potential contributor of pollutants to the surrounding environment. In addition to point sources, highway runoff and other urban land runoff sources are now considered potential sources of pollutional materials. Environmental quality can be preserved only by considering and controlling, if necessary, pollution emanating from each of these sources. The National Environmental Policy Act (NEPA) of 1969, Public Law 91-190, further strengthens this contention. This law mandates that, for all federal projects affecting the environment, all government agencies shall utilize a systematic, interdisciplinary approach which will insure integrated use of the natural and social sciences and the environmental design arts in planning and decision making. The Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500, sets a national goal of restoring and maintaining chemical, physical, and biological integrity of our water resources. In addition, many States have either already enacted or are in the process of enacting legislation similar to NEPA that may be more stringent than the Federal laws in controlling various point and nonpoint discharges.

The Federal Highway Administration (FHWA), charged with the responsibility of protecting the environment from pollution from highway sources, has approached the problem in a multiphase research effort having the following objectives:

Phase 1: Identify and quantify the constituents of highway runoff.

Phase 2: Identify the sources and the migration paths of these pollutants from the highways to the receiving water.

Phase 3: Analyze the effects of these pollutants in the receiving waters.

Phase 4: Develop the necessary abatement/treatment methodology for objectionable constituents.

The Phase 1 study whose objective was to identify and quantify the constituents of highway runoff has been completed, and the results have been reported in a six-volume document series entitled "Constituents of Highway Runoff." Individual report titles for this six-volume series are as follows:

Volume I: State-of-the-Art Report on Highway Runoff Constituents

Volume II: A Procedural Manual for Monitoring of Highway Runoff

Volume III: Predictive Procedure for Determining Pollutant Characteristics in Highway Runoff

Volume IV: Characteristics of Runoff from Operating Highways. Research Report

Volume V: Highway Runoff Data Storage Program and Computer User's Manual

Volume VI: Executive Summary

This research deals with the Phase 2 objective. The Phase 2 research was conducted to identify the sources of highway pollutants, and to investigate their deposition and accumulation within the highway system and subsequent removal from the highway system to the surrounding environment. The purpose of this research was to identify opportunities to practice pollution mitigation. In order to accomplish these Phase 2 objectives, a literature search and field monitoring program were conducted. The field monitoring program was divided into two categories as follows:

1. Source investigative studies
2. Migration studies

Sources of many highway pollutants were found during the Phase 1 study (State-of-the-Art Report on Highway Runoff Constituents) to be adequately documented in the literature, while further investigation was required for others, including pathogenic indicator bacteria, asbestos and polychlorinated biphenyls (PCB's). Significant data were collected with respect to presence and quantification of these constituents in highway runoff during the Phase 1 study; however, there remained a gap in the understanding of the origin and fate of these constituents within the highway environment. Source investigative studies were conducted in an attempt to fill those gaps. This information would be valuable in developing control and mitigation measures, by defining points at which abatement strategies can be effectively applied.

Pollutants which accumulate on highway surfaces originate from the highway itself, highway use, maintenance, and ambient atmospheric deposition. Pollutants accumulate within the highway system between major removal events, such as runoff and highway sweeping, when deposition exceeds removal rates. Monitoring was conducted at all sites to evaluate the qualitative and quantitative aspects of background pollutant loading to the highway system, pollutants originating from the highway system, and the mechanism of pollutant dispersion within and transport out of the highway system. Studies were also conducted to determine the fate of these pollutants after they are deposited in areas adjacent to the highway. Soils, vegetation and groundwater seepage were monitored as part of these studies.

In this report, the highway system is defined as the paved highway surface and associated drainage scheme. For curb and gutter drainage design, the highway system would include the paved highway surface and sewer system. For a flush shoulder drainage design, the highway system would include the paved highway surface, shoulder, and that part of the unpaved right-of-way which transports the paved runoff.

SECTION II
MONITORING SITE SELECTION

SITE SELECTION CRITERIA

Monitoring site selection was considered to be a critical task since the data collected from these sites form the very basis for deriving the conclusions and findings of the study. The following criteria were applied to the selection of the monitoring sites:

1. Adjacent land usage
2. Traffic characteristics
3. Precipitation characteristics and geographic location
4. Drainage area and highway design characteristics
5. Pavement characteristics
6. Logistical characteristics

Adjacent Land Usage

The adjoining land use activity near a highway system was considered to have a significant influence on the transport of pollutants onto the highway system. Both rural and urban environments exhibit different land use features for the study of the sources and migration of pollutants within a highway system. Feedback from FHWA and various State Highway Departments, as well as the results of FHWA's study on the constituents of highway runoff (1), indicated that potential pollution problems are much more severe in urban areas due to high traffic volumes, curb and gutter drainage designs which transport pollutant loads directly to receiving water bodies, and pollutant deposition due to atmospheric fall out. Therefore, selection of urban sites would be necessary to meet study objectives. However, representation of rural site(s) was also considered necessary for the study program. This monitoring strategy, selection of urban and rural sites, would allow comparisons between the two extremes in pollution potential.

Traffic Characteristics

Results of FHWA's study on the constituents of highway runoff (1) recommended selection of urban sites with average daily traffic (ADT) volumes greater than 85,000 vehicles per day. However, it was considered desirable to select sites representing a wide variation in ADT volume.

The minimum desirable ADT for a rural site was established at 20,000 vehicles per day. FHWA's study on the constituents of highway runoff (2) indicated that sites with traffic less than 20,000 vehicles per day have highway surface pollutant loads too small to effectively monitor the mechanisms and pathways of pollutant transport.

Various other traffic characteristics that were considered in site selection were:

1. Vehicular mix (percentage trucks/cars)
2. Congestion factors (braking), ramps, weaving
3. Level of service factors - numbers of lanes, variations in traffic flow
4. Vehicle speed

Precipitation Characteristics and Geographic Location

The form of precipitation, i.e., rainfall or snow, can have a significant effect on highway runoff. It was desired to have two sites having significant snowfall while at least one site with minimum or no snowfall. The amounts and patterns of precipitation variation were studied for potential sites from historical climatological data records published by National Oceanic and Atmospheric Administration (NOAA). Sites were selected to represent as wide a variation in geographical distributions as possible in order to provide a broad character to the study findings.

Drainage Area and Highway Design Characteristics

The most important consideration in site selection criteria for this phase of study was to find well-defined drainage areas for the paved and unpaved areas within the same highway system. Such segregated drainage areas do not normally exist in as-built drainage systems. Special modifications are required in most cases to provide separation. The segregated drainage system is desirable to facilitate the study of origin and migration of pollutants within the highway right-of-way. Even though larger highway drainage areas were considered desirable for suitably studying the origin, migration, and fate of pollutant movement, such highway drainage areas are difficult to isolate and/or segregate for extended highway lengths. Typical highway drainage areas considered for site selection were generally in the range of 1000 to 2000 ft (305 to 610 m) in length and encompassed an approximate area of 4 to 8 acres (1.2 to 3.2 ha).

Another important consideration made in site selection was to ensure that selected sites would not be flooded due to surcharge or high water from respective receiving water streams during flood periods. Consideration was also given to highway design features to ensure selection of typical highway sections across the country. Some of the design features considered in site selection were:

Highway grade	- At least one site with 2 to 3 percent slope
Type of drainage system	- Curb and gutter, and flush shoulder type

Roadway alignment - Straight highway lengths were considered desirable to facilitate monitoring and data interpretation. Also highway surface pollutant studies (sweeping/flushing studies) would be impossible to perform at intersections or extremely curved sections of highways due to safety and logistic considerations.

Type of highway section	- Cut, fill and at grade
Median barrier characteristics	- No barrier, GM barrier, etc.
Right-of-way characteristics	- Type of cover (vegetative types)
	- Soil Types
	- Slopes
	- Maintenance practices

Pavement Characteristics

Drainage areas with at least 40 to 80 percent impervious areas were considered desirable for selection based on FHWA's Phase 1 study recommendations. Sites selected should represent a wide range of pervious/impervious pavement characteristics within the above recommended range.

The type of pavement surface material, i.e., bituminous or portland cement concrete can also affect the quantity or quality of pollutants from a highway system. Both were included for monitoring sites. Age of pavement and pavement maintenance practices can also have a significant effect on the accumulation and dispersion of pollutants within a highway system. Sites which were newly paved or had pavements exhibiting excessive wear, were not selected for monitoring.

Logistical Considerations

These considerations included several miscellaneous items such as:

1. Segregation of pervious and impervious runoff areas

   One of the most important considerations in site selection was the ability to segregate the runoff emanating from the pervious and impervious areas. This usually required significant field modifications. Permission and cooperation of the local highway departments was necessary for such work prior to the selection of a potential site.

2. Accessibility

   All selected sites were to be accessible to operating personnel both in terms of convenience and safety for installing, monitoring, and servicing the instrumentation. Monitoring sites were to be as vandalism proof as possible. For this reason, all instrumentation was kept in locked monitoring sheds, and signs were posted around the monitoring areas informing the public about the pollution abatement research study.

3. Power

The availability of line electricity was considered desirable. However, since most of the monitoring instrumentation could be operated with batteries, this consideration was not critical in site selection.

4. Construction activity

It was emphasized and carefully checked during site selection procedure that no major construction activity (other than routine repairs) was planned on the site drainage area or its vicinity during the study period. Such activity can significantly affect the type and level of pollutants discharged from a highway system. Frequent contacts were maintained with the state and/or local highway planning and maintenance personnel to avoid any surprises during the course of the study.

5. Sweeping/flushing studies

Sweeping/flushing studies were conducted at selected sites to develop information on the accumulation of pollutants on the paved highway surface, as well as the magnitude of pollutant loadings and their dispersion within areas adjacent to the highway. These studies were conducted at each site for a minimum of once every three months and a maximum of once per month. It was estimated that such studies would require closing one or two traffic lanes for about one to two hours each time. Permission and cooperation of local highway departments and agencies responsible for traffic control were necessary for such work prior to selection of a potential site.

DESCRIPTION OF SELECTED SITES

Four highway sites were selected around the country based on the site selection criteria discussed above. These sites were located in Milwaukee, WI; Harrisburg, PA; Sacramento, CA; and Efland, NC (Figure 1). Among the selected sites, Milwaukee, WI and Sacramento, CA sites were located in urban areas while the Harrisburg, PA and Efland, NC sites were located in rural areas. Field modifications were required at all sites except the Efland site to enable segregation and monitoring of runoff from paved and unpaved areas. A summary of the characteristics of the selected sites is shown in Table 1.

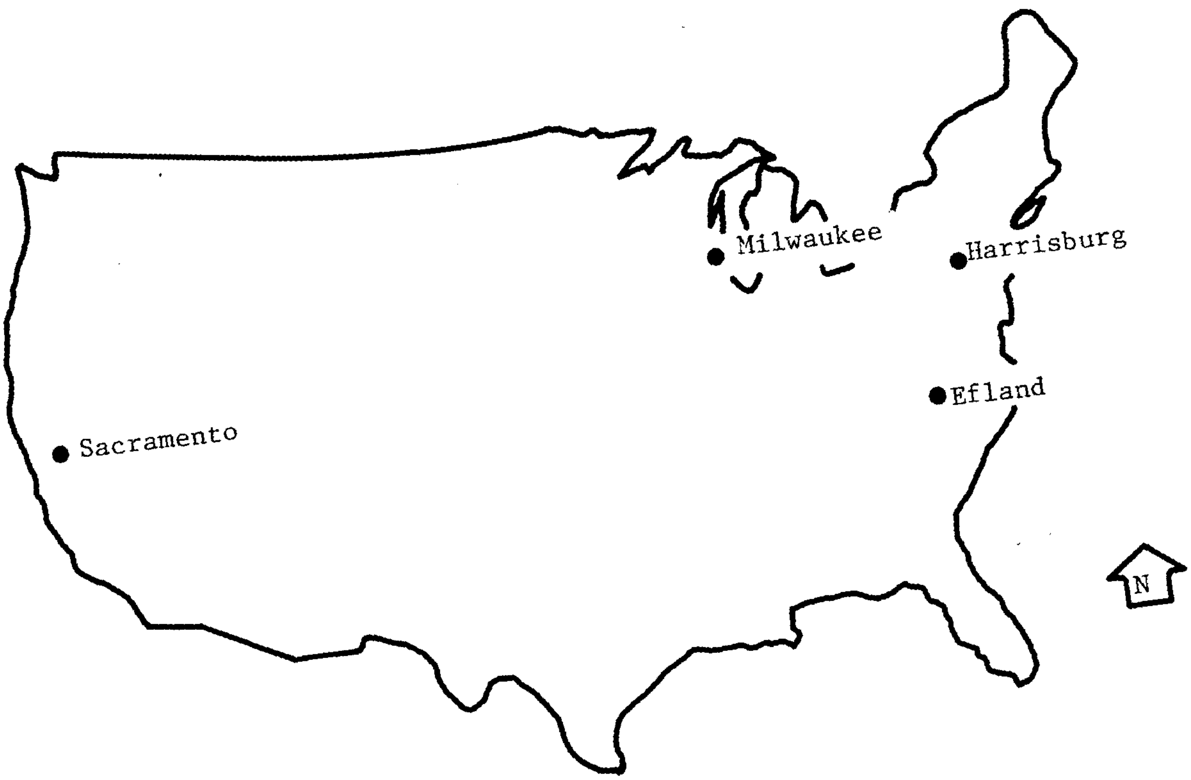


Figure 1. Selected site locations.

Table 1. Characteristics of selected sites.

Location	Type	ADT, vehicles/day	Precipitation in./year: Total	Precipitation in./year: Snowfall	Drainage area, acres: Total	Drainage area, acres: Paved	% Paved	Surface type	Hwy. length, ft	Number of travel lanes	Type of section	Curb/barrier
Milwaukee, Wisconsin I-94	Urban	116,000	30	45	7.60	4.90	64	Asphalt	1,373	8	Cut/fill	yes
Sacramento, California Hwy. 50	Urban	85,900	17	0	2.45	2.01	82	Concrete	1,400	8	At grade	yes
Harrisburg, Penn. I-81	Rural	27,800	38	35	2.81	1.05	45	Concrete	1,345	4	Cut/ At grade	no
Efland, North Carolina I-85	Rural	25,000	41	9	2.49	1.27	51	Asphalt	1,025	4	At grade	no

Metric conversion units: 1 inch = 2.54 cm, 1 ft = 0.305 m; 1 acre = 0.405 ha.

The ADT at these sites varied from a low of 25,500 vehicles per day at Efland to a high of 116,000 vehicles per day at Milwaukee.

I-94 - Milwaukee, Wisconsin

This site is located on the east/west lanes of I-94 and extends from just west of the 35th Street overpass to just east of the bridge which crosses the Menomonee River and Milwaukee Road railroad right-of-way (Figures 2 and 3). The length of the monitored area is 0.26 miles (0.42 km) and covers a total area of 7.6 acres (3.1 ha). Of the total area, 4.9 acres (1.98 ha) or 64 percent are paved and 2.7 acres (1.09 ha) or 36 percent are unpaved.

Figure 4 shows a cross sectional drawing of the highway within the monitored area. This portion of the highway is eight lanes wide with the curb lane in each direction (east and west) being used as an acceleration/deceleration lane for the on and off ramps in each direction. The on and off ramps are located just outside the boundary lines of the monitored area. The median barrier between the east and westbound lanes of the highway is of the G.M. type and is made out of concrete. The paved surface of all lanes consists of a three-inch bituminous layer over a nine- inch concrete base. Both east and westbound lanes are bounded on the outside by an asphalt distress lane and associated mountable curb. The average daily traffic through the monitored area was 116,000 vehicles per day during the monitoring period (1978-80).

The site is characterized as "urban" by both the adjacent land use activity and the type of drainage system design. Due to site modifications, the unpaved (pervious) area drainage and the paved (impervious) area drainage systems were separated with the resultant runoff being diverted to two different collection points for monitoring (Figures 5 through 8). The paved area has all of its runoff channeled through inlets near the median barrier on the inside lanes and through inlets located in the roadway near the mountable curb on the outside lanes (Figure 6). All the runoff thus collected is channeled underground through two main sewers, one an 18-in sewer and the other a 24-in sewer. At the junction of these two sewers a 27-in (67.5-cm) trunk sewer begins and it is in this 27-in (67.5-cm) sewer where all paved surface runoff monitoring is done. Access to the 27-in (67.5-cm) trunk sewer is through a manhole. Figure 3 shows the inlet points, minor sewers, and the main truck sewer that routes the runoff to the monitoring point.

The unpaved area has been modified with a series of ditches which allow all runoff to collect at a central point for monitoring. This series of channels is depicted in Figures 6 through 8. The central point (Figure 3) where all overland runoff collects is the control section for a 12-in (30-cm) "V" notch weir.

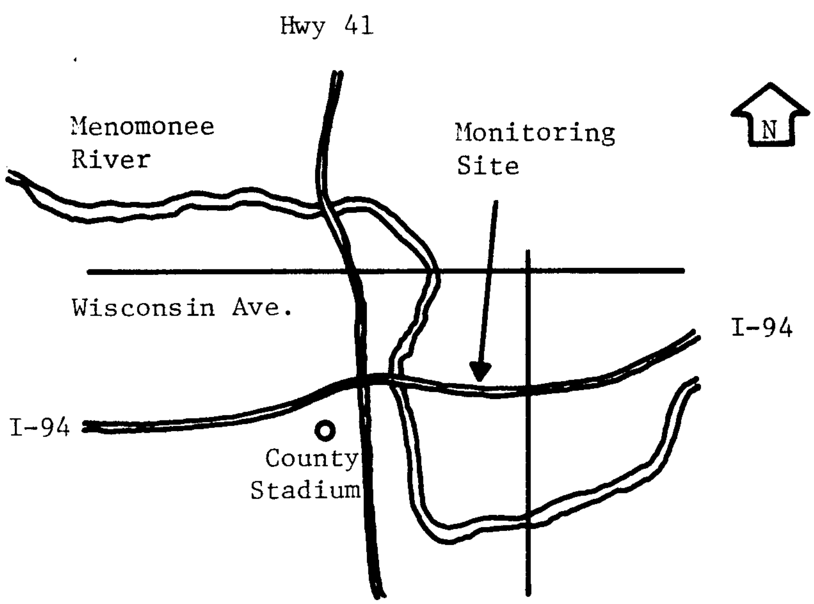


Figure 2. Location of Milwaukee I-94 Site.

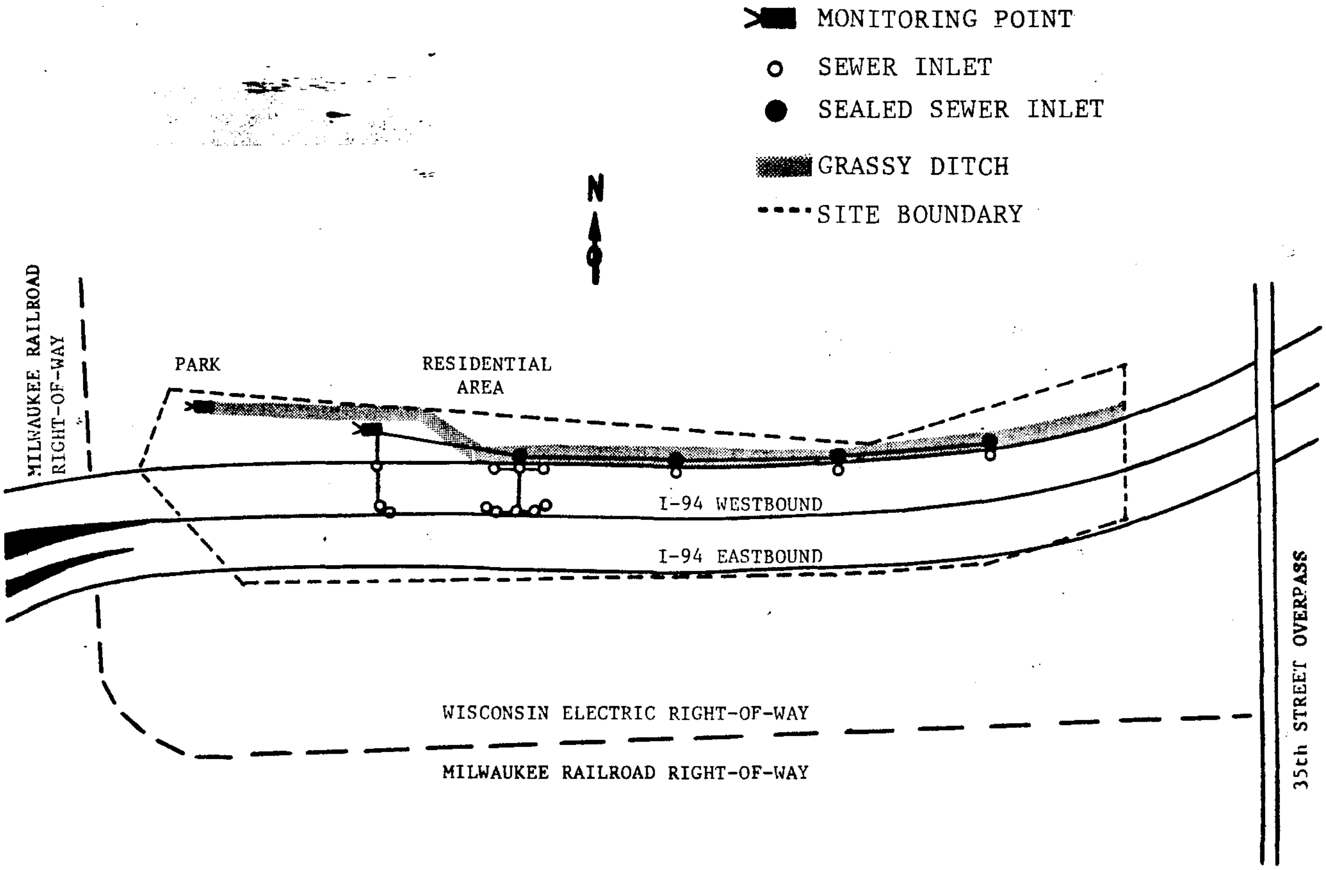


Figure 3. Schematic drainage plan - Milwaukee I-94 site.

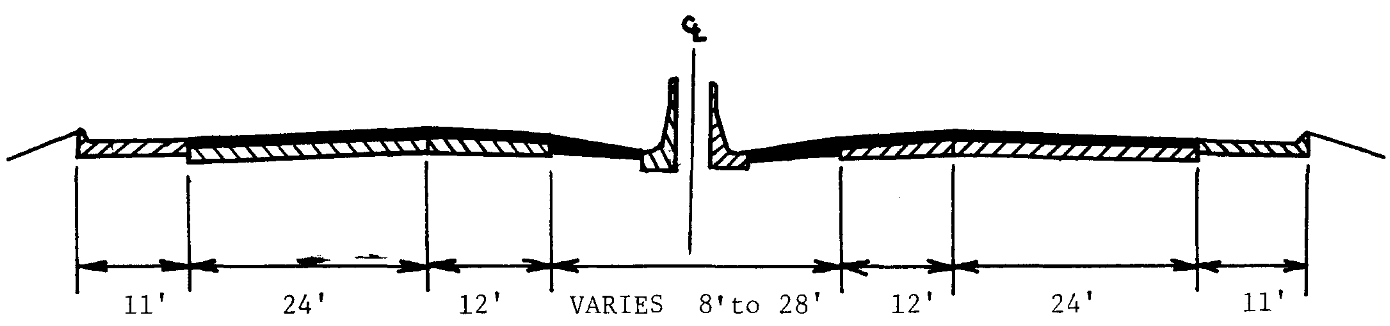


Figure 4. Typical cross section - Milwaukee I-94 site.

Figure 5. Sealing inlets in the unpaved area - Milwaukee I-94 site.

Figure 6. Cut section drainage ditch diverting unpaved runoff to a central monitoring point - inlets are sealed and sodding has begun (foreground).

Figure 7. Pipe installation carrying unpaved runoff from the cut section to the drainage ditch in the fill section.

Figure 8. Drainage ditch in the fill section carrying unpaved runoff to the central monitoring point (background).

Hwy 50 - Sacramento, California

This monitoring site is located on U.S. Route 50 in the westbound lanes between Watt and Howe Avenues in the City of Sacramento (Figures 9 and 10). The length of the monitored area is 1400 ft (424 m) and covers a total area of 2.45 acres (1.0 ha). Of the total area, 2.01 acres (0.9 ha) or 85 percent are paved and 0.44 acres (0.1 ha) or 15 percent are unpaved.

Figure 11 shows a cross sectional drawing of the highway within the monitored area. It is an eight-lane highway with concrete travel lanes, bituminous flush shoulders and a grassy right-of-way. The roadway grade is relatively flat. The east and westbound lanes are separated by a sheet metal barrier anchored in the ground with steel supports. Average daily traffic monitored through the site during the study period was 85,900 vehicles per day.

The site is characterized as "urban" by the adjacent land use activity. The site right-of-way on both sides of the highway is bounded by residential areas including several parks. A bituminous berm was constructed on the edge of the paved shoulder by CALTRAN (California Department of Transportation) personnel to completely segregate runoff from paved and unpaved areas (Figure 12). This construction modification converted the site to a modified "curb/gutter" drainage design instead of the original "flush shoulder" type.

I-81 - Harrisburg, Pennsylvania

This site is located five miles northeast of Harrisburg on I-81 (Figure 13). This section of highway was built around 1970-72. The site is characterized as "rural" based on adjoining landuse activity (Figure 14). The drainage design is "flush shoulder" with no curbs and gutters (Figure 15). The site drainage area of interest to this study consists of the paved area of northbound lanes and associated unpaved right-of-way areas. The surface type is concrete. The roadway grade is relatively steep at 2.76 percent along with steep right-of-way slopes (between 2:1 and 6:1). Monitored area length is 1,345 ft (410 m) and covers a total area of 1.92 acres (0.8 ha). Of the total area, 1.05 acres (0.5 ha) or 55 percent are paved and 0.87 acres (0.3 ha) or 45 percent are unpaved. Average daily traffic monitored through the site during the study period was 27,800 vehicles per day. A typical highway section is shown in Figure 16. Drainage is collected at inlets located in grassy rights-of-way and routed by storm sewers to an open area outfall.

This site required some field drainage modifications by Penn DOT (Pennsylvania Department of Highways) in order to achieve segregated runoff monitoring from the paved and unpaved areas. These modifications consisted of closing four inlets and installation of a half-cut PVC pipe (12-inch dia.) as shown in Figures 17 and 18.

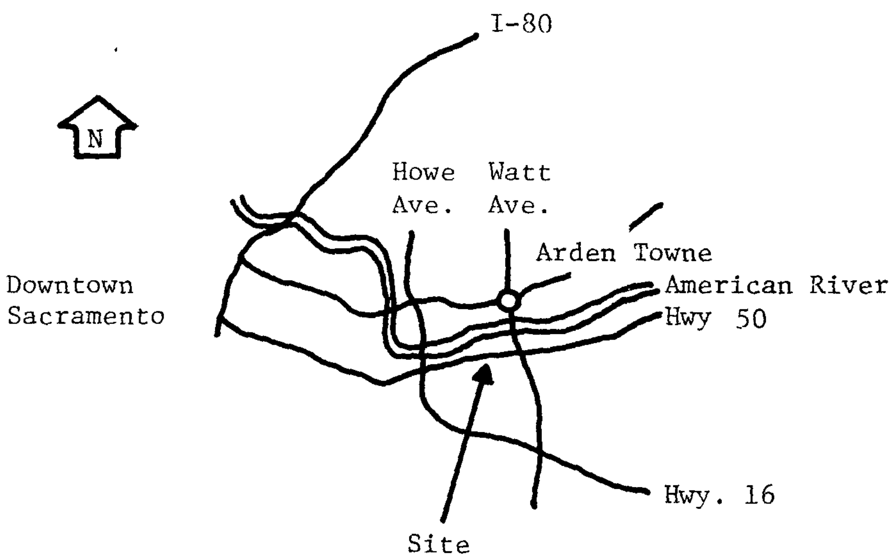


Figure 9. Location of Sacramento Hwy 50 site

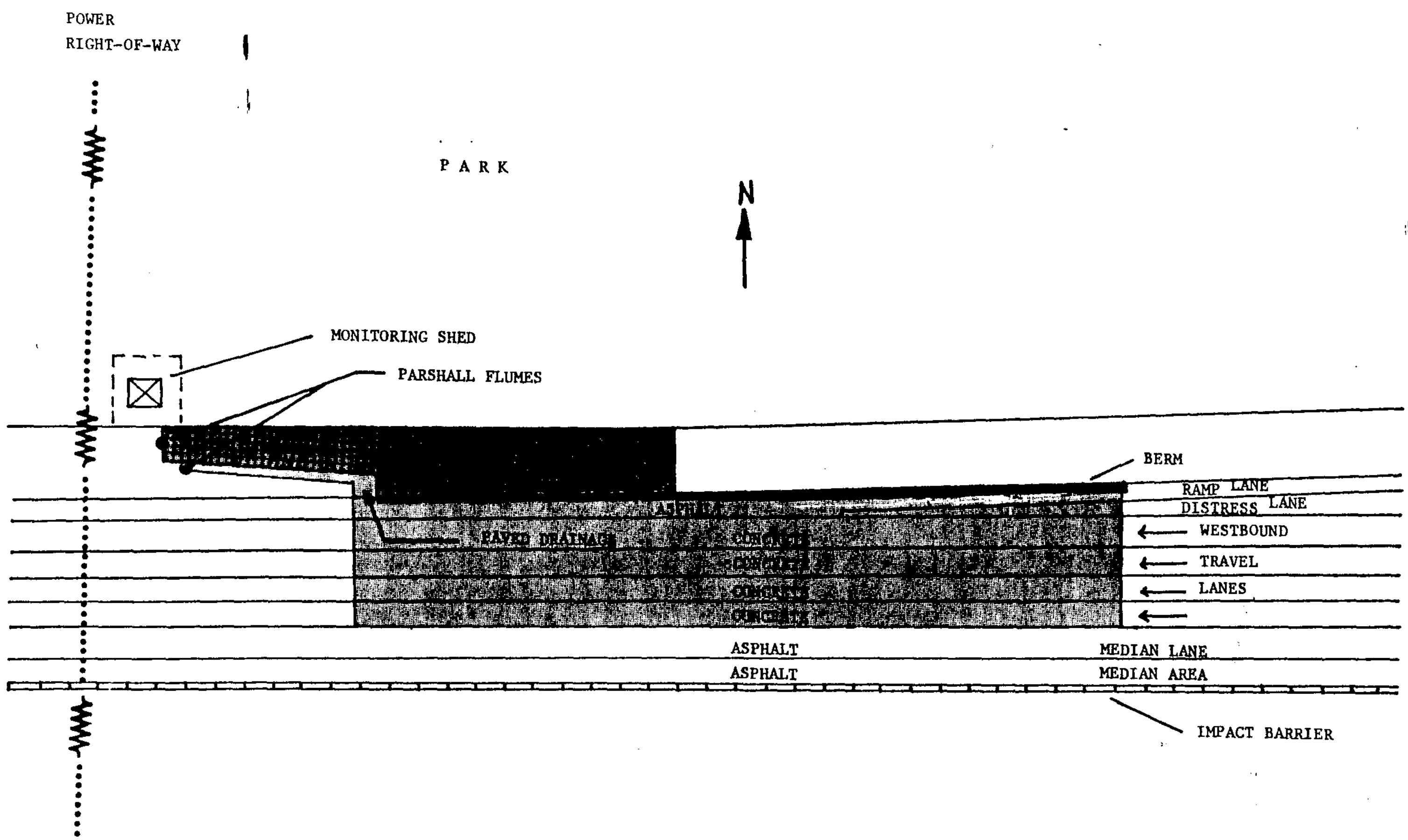


Figure 10. Schematic drainage plan - Sacramento Hwy 50 site.

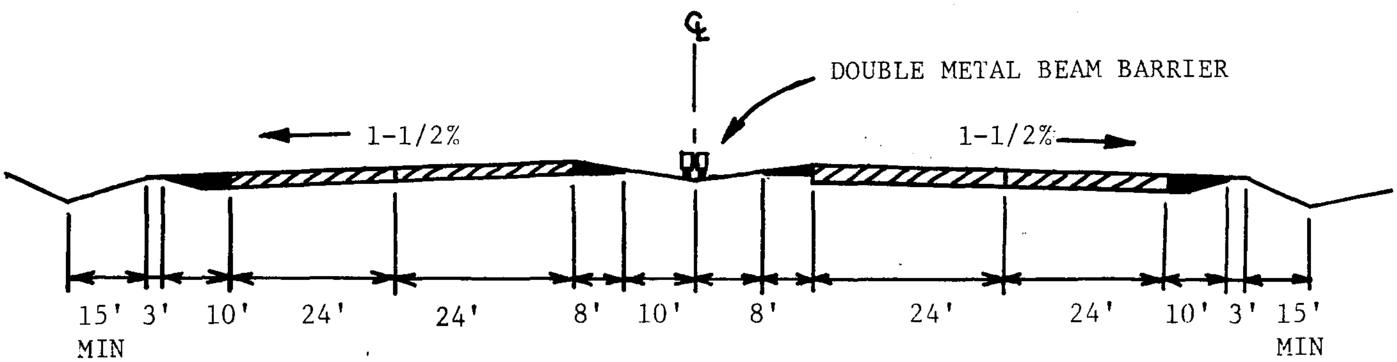


Figure 11. Typical cross section - Sacramento Hwy 50 site.

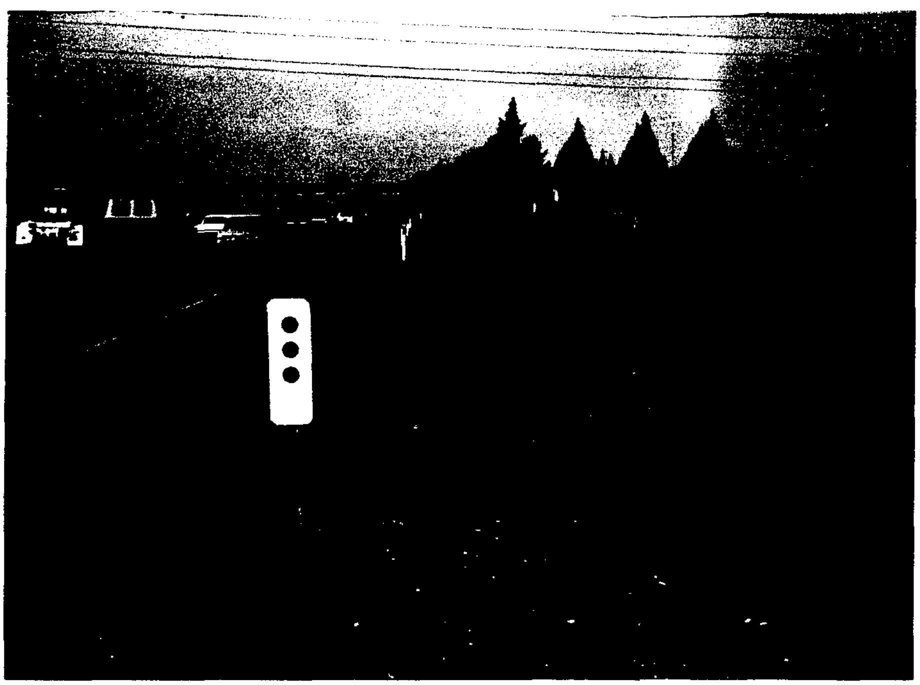


Figure 12. Drainage scheme - Sacramento Hwy 50 site.

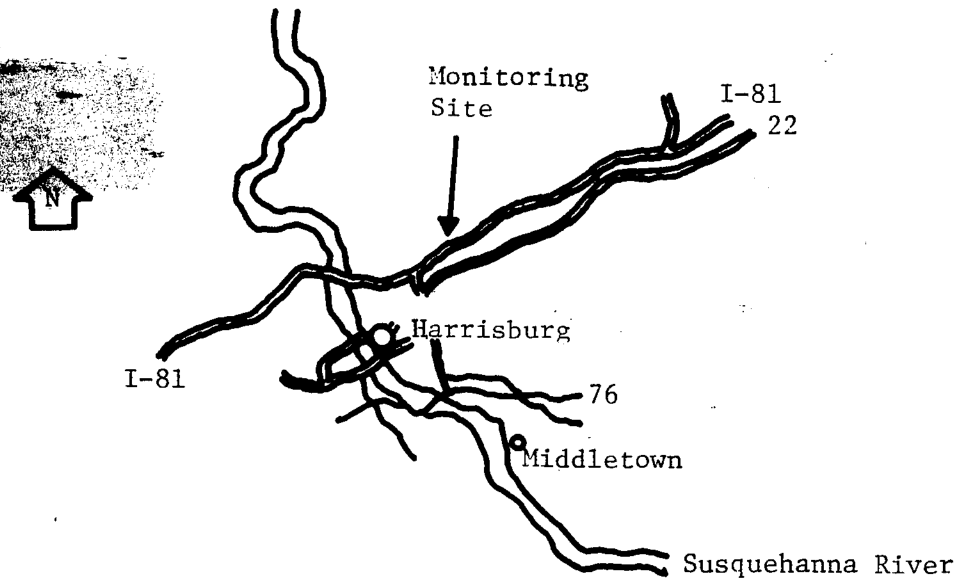


Figure 13. Location of Harrisburg I-81 Site.

Figure 14. Rural site - I-81, Harrisburg, PA.

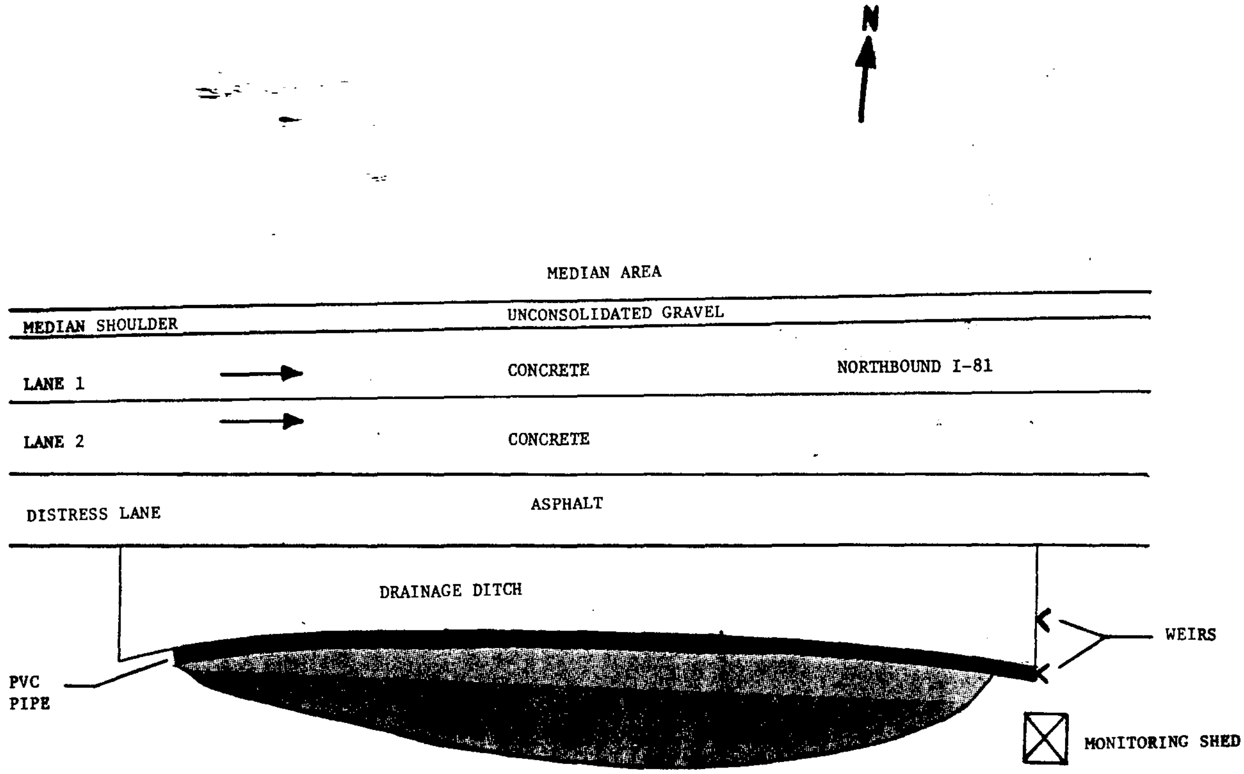


Figure 15. Schematic drainage plan - Harrisburg I-81 site.

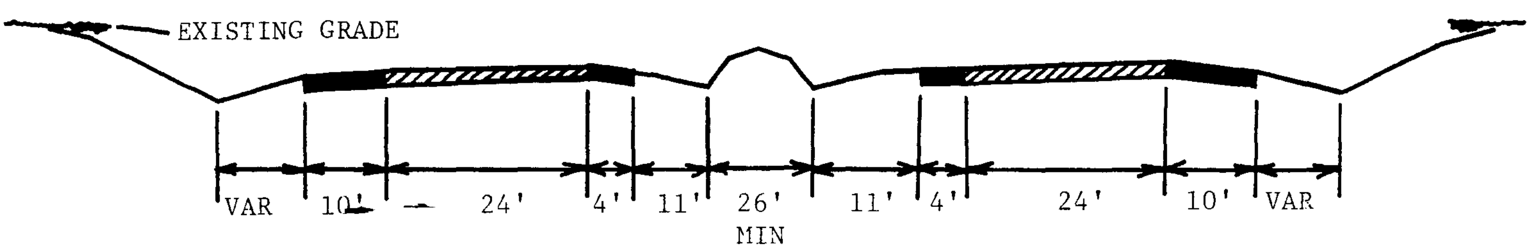


Figure 16. Typical cross section - Harrisburg I-81 site.

Figure 17. Drainage scheme - Harrisburg I-81 site.

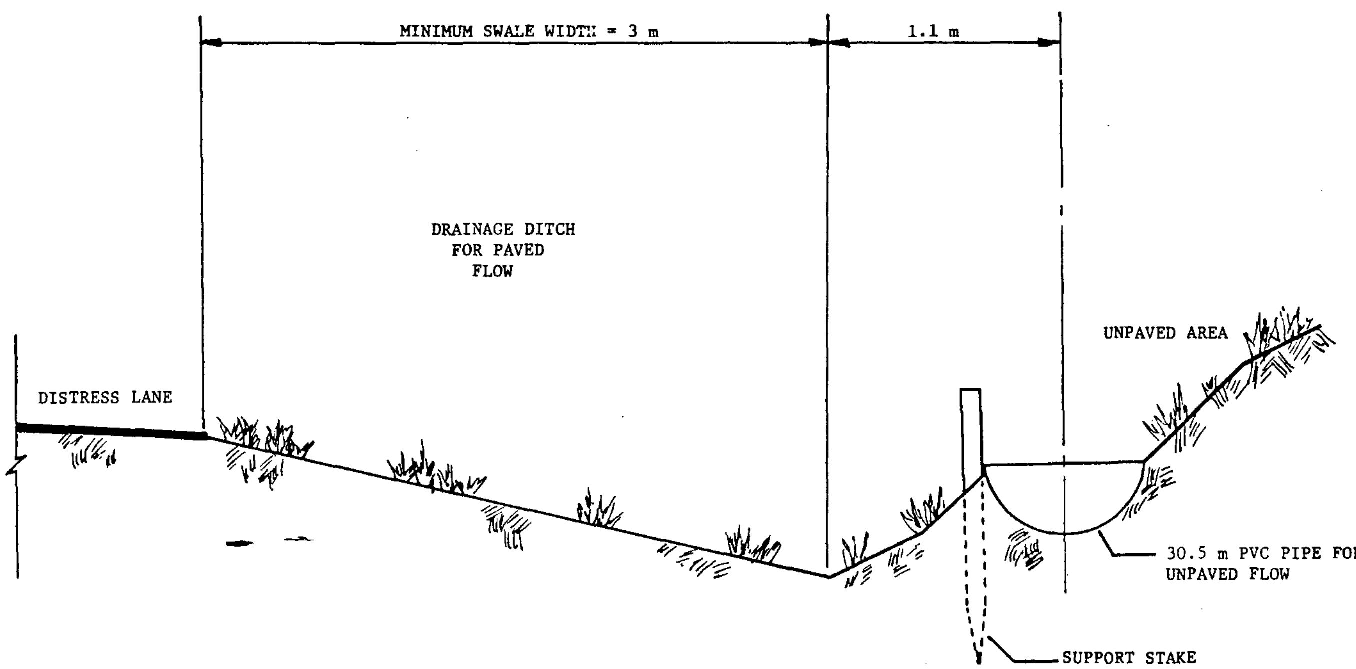


Figure 18. Drainage scheme cross section - Harrisburg I-81 site.

After selection of the I-81 site had been completed and monitoring had begun, it was discovered that significantly lower flows were being monitored at the paved area runoff monitoring station than originally anticipated. Investigation of this problem revealed that there exists a gravel subbase underneath the soil cover next to the shoulder through which some of the highway surface runoff seeps into the ground. This surface water seepage into the ground reduces the amount of runoff to the monitoring location. However, site monitoring was continued because such a situation is a practical reality, and the objective of the study is to monitor runoff in an existing drainage situation. Study objectives do not require collection of all surface runoff, and hence, no changes in this respect were made at this site.

I-85 - Efland, North Carolina

This site is located on I-85 near Efland in the piedmont region of North Carolina (Figure 19). The site is characterized as "rural" based upon adjoining land use activity (Figure 20). I-85 is a four-lane divided highway (Figure 21) with an average daily traffic of 25,500 vehicles per day. It has asphalt-paved travel lanes, and a stone and asphalt aggregate pavement on the distress and median shoulders. Figure 22 shows a typical cross section of the highway which has a flush shoulder drainage design. The travel lanes are crowned in the center for drainage. The grassy median between the median lanes is approximately 32 ft (10 m) wide and has inlet drains. These inlets are connected by a 15-in (38-cm) concrete pipe which outlets to a grass ditch adjacent to the distress lane (Figure 21).

The drainage area monitored is 1,025 ft (313 m) long with 1.27 acres (0.51 ha) of pavement and 1.22 acres (0.49 ha) of grassy areas. The area contributing to the monitoring point (Figure 21) includes all northbound lanes of I-85, and one travel and median lane of the southbound lanes of I-85. The site is located just west of the rest areas on the northbound and southbound lanes (Figure 20).

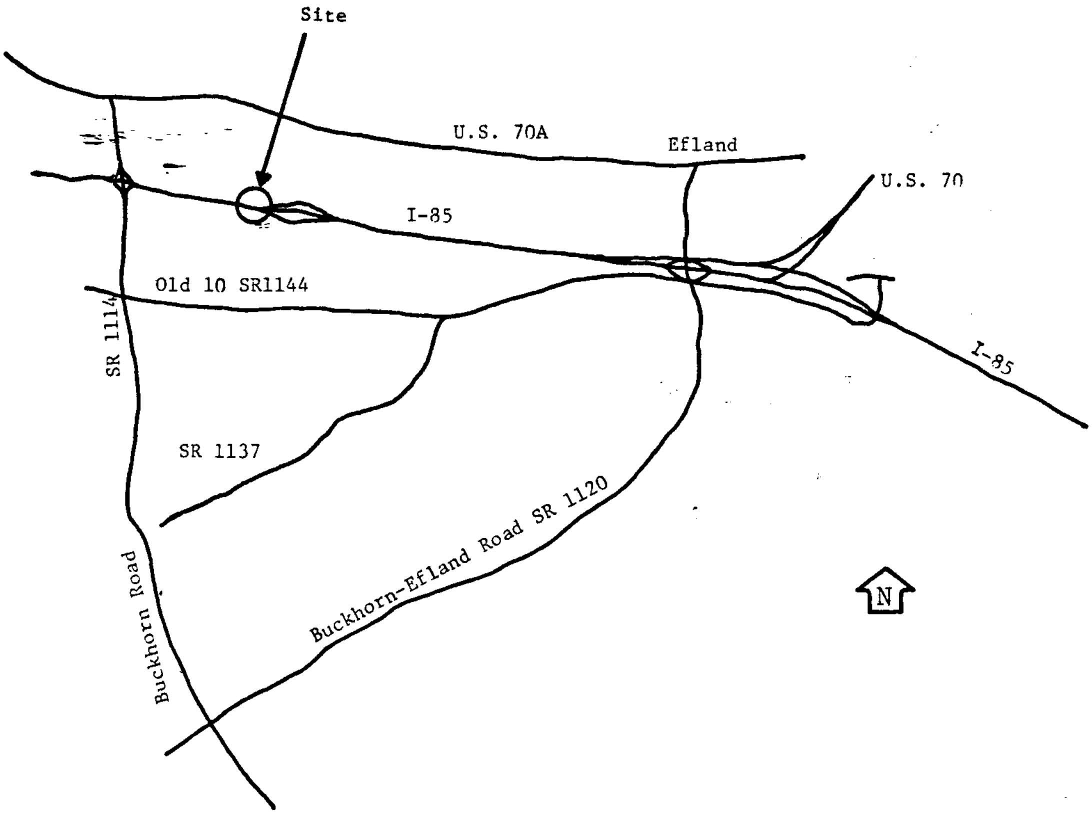


Figure 19. Location of Efland I-85 site.

Figure 20. Rural site - Efland I-85.

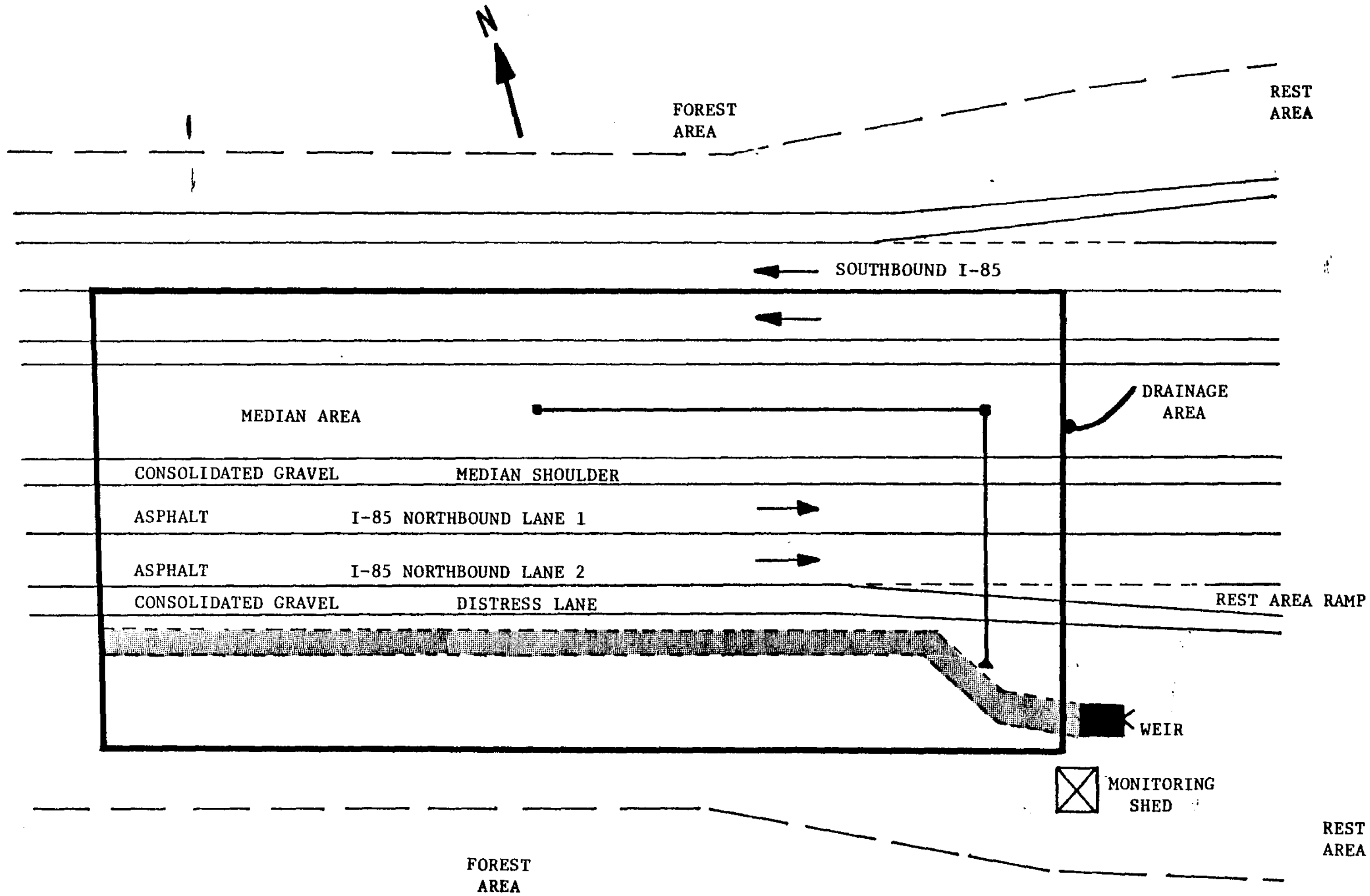


Figure 21. Schematic drainage plan - Efland I-85 site.

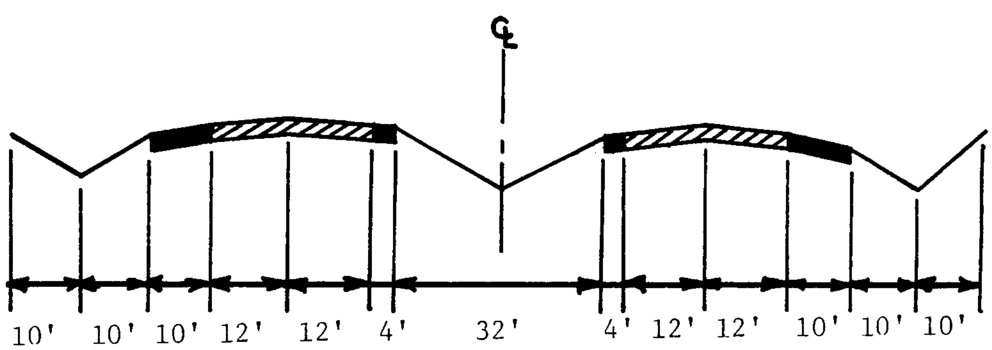


Figure 22. Typical cross section - Efland I-85 site.

SECTION III
MONITORING PROGRAM

The overall objectives of the field monitoring program were to identify the sources of highway pollutants, and to investigate their deposition and accumulation within the highway system (paved highway surface and associated drainage scheme) and subsequent removal from the highway system to the surrounding environment. In order to accomplish these objectives, the field monitoring program was divided into two categories as follows:

1. Source investigative studies
2. Migration studies

For these studies, standard methods (3) were used wherever possible.

SOURCE INVESTIGATIVE STUDIES

Sources of many highway pollutants were found to be adequately documented in the literature (4) while further investigation was required for others, including pathogenic indicator bacteria, asbestos and PCB's. As part of FHWA's study on the constituents of highway runoff (1), significant data were collected with respect to presence and quantification of highway runoff constituents; however, there remained a gap in the understanding of the origin and fate of these constituents within the highway environment. The purpose of the source investigative studies was to fill those gaps.

Because of the detailed nature of the source investigative studies, the majority of the monitoring was conducted at the Milwaukee I-94 site. Close proximity of the monitoring equipment to the Rexnord Laboratory provided better control of sampling and analysis techniques, as well as changes in strategy based upon unexpected results.

Bacteriological Studies

The principal objective of the bacteriological studies was to investigate the origin, movement and fate of pathogenic indicator bacteria in highway runoff. These studies also attempted to identify potential aerial sources of pathogenic indicator bacteria, to detect them in roadway sweepings and to determine their survival in highway dust and dirt over time. Bacteriological investigations included the following studies:

1. Detection of airborne bacteria.

2. Detection in runoff from paved and unpaved areas.

3. Detection and fate on roadway surfaces.

4. Survival within a sewer system.

Detection of Airborne Bacteria--

Bulk precipitation (wet and dry depositions) samples were collected at the Milwaukee I-94 site and analyzed for total coliform (TC), fecal coliform (FC) and fecal streptococci (FS). Three separate samples were collected for periods of three days, seven days and fifteen days. These collection intervals were used to identify the optimum collection period. Sterile collection buckets containing sterile phosphate buffer solution were installed approximately 15 ft (4.6 m) high on a power pole adjacent to the highway. In addition to bacterial analyses, each sample was analyzed for total particulate matter. Bacterial counts could then be related to monitored bulk precipitation rates (total particulate matter due to wet and dry deposition). A precipitation sample (wet deposition only) was also collected for bacteriological analysis.

In addition, ambient air near the bacterial bulk precipitation installation was sampled using a sterile glass impinger designed for bacteriological studies. The ambient air sample was obtained on the same day the three-day bacterial sample was collected. A vacuum of 20 in (50.8 cm) Hg was applied to the impinger for 23 minutes per sample as described in the instructions supplied with the instrument. Total volume of air drawn through the impinger per sample was approximately 10 ft (0.28 m). Bacterial counts could then be related to total air volume.

Detection in Runoff from Grassy and Paved Areas--

Grab samples obtained from the paved areas at the Milwaukee, Sacramento, and Harrisburg monitoring sites were analyzed for FC and FS. Paved and grassy area samples collected at the Milwaukee, I-94 site were analyzed for TC, FC, and FS. Samples were collected in sterilized glass bottles.

Detection in Runoff from Grassy and Paved Areas--

This study was conducted to provide some insight into the fate (die-off or multiplication) of enteric bacteria associated with highway surface debris. Dry roadway debris was collected from a section of median lane at the Milwaukee I-94 site, two feet by fifteen feet (0.6 m by 4.67 m). An aliquot of the collected material was passed through a 100-mesh sieve. The "as received" material and sieved material were immediately analyzed in duplicate for fecal coliforms to obtain initial coliform counts on the "as received" material and to determine if enteric bacteria tend to be associated more with the coarse debris (as received) or fine debris (less than 100 mesh). The dry material was suspended in sterile buffer solution using a vigorous shaking environment. Following a short period of settling, a FC analysis was performed on the supernatant liquid.

The "as received" material was placed in 100-ml glass beakers to a depth of approximately one cm, and stored on the flat roof of the Rexnord single story building. Five of the beakers were placed in an area exposed to sunlight for most of the day, whereas the other five beakers were placed in a shaded area on the roof. The beakers were covered with a piece of plexiglass set on a steep slope with sufficient clearance above the beakers to allow free air movement (Figure 23). With this arrangement, rainwater was kept out of the beakers, a condition which was verified by observing the beaker contents following rainfall events. At time intervals of 2, 4, 7, 11, 21, 35, and 49 days, aliquots were taken from each of the ten beakers and subjected to fecal coliform analysis. Fate of the enteric bacteria under the two environmental conditions over the 49-day period could then be determined.

Survival Within A Sewer System--

A study was also conducted to obtain information regarding a hypothesis that a moist storm sewer conduit which is periodically "seeded" with roadway surface debris containing enteric bacteria can provide an environment that would keep these organisms viable for long periods and even possibly provide an environment that would promote their reproduction. To test this hypothesis, storm water entering two gutter-line inlets at the Milwaukee, I-94 site was sampled at different times during two rainfall events. Samples were also obtained from the outfall of the storm sewer which conveys the storm runoff from the two inlets. This outfall is approximately 130 ft (40 m) from the inlets, and the conduit is buried for the entire distance. Qualitative comparisons between inlet and outfall enteric bacteria could then be made, indicating whether or not these organisms are viable or even reproducing in the conduit system between storm events. To verify this hypothesis a bacteriological sample was obtained from stagnant water in the conduit after an extended dry day period.

Asbestos Studies

During FHWA's study on highway runoff constituents (1), asbestiform fibers were not detected in nineteen highway runoff samples from the Milwaukee, Harrisburg and Denver sites, while some chrysotile asbestiform material was detected in two samples from Nashville, Tennessee. However, most of the monitoring points in that study (1) were significantly distant from the roadway surface, and this may have had some effect on the results. Findings of Jacko and Ducharme (5) suggested that asbestiform material should be present in detectable quantities within the highway system. Therefore, in order to establish the source and fate of asbestiform material, the following parameters were sampled during the source investigative studies:

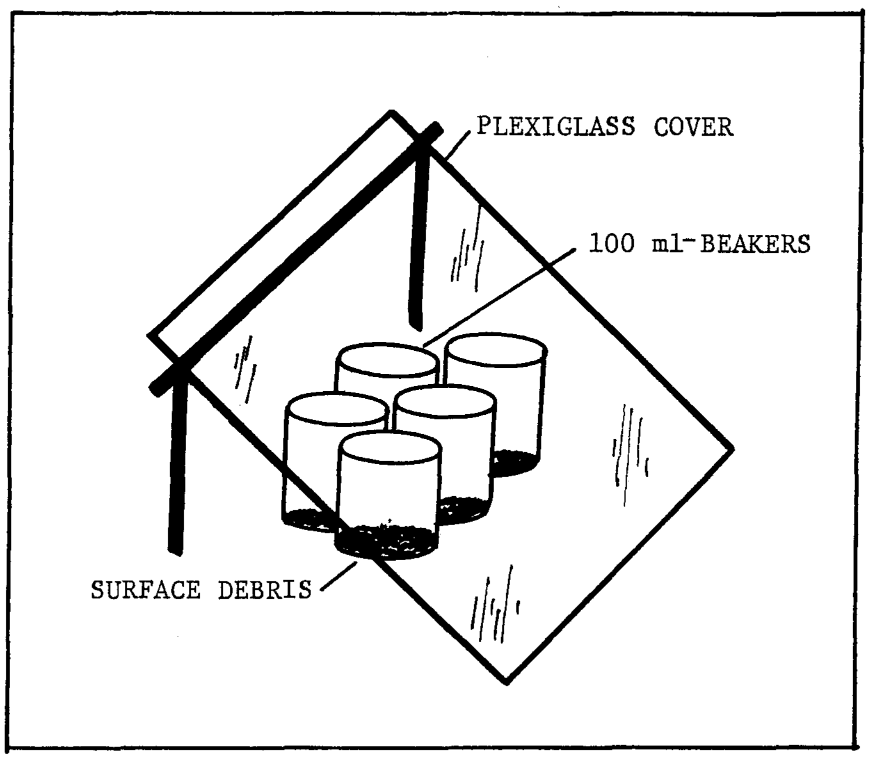


Figure 23. Apparatus to study the fate of enteric bacteria associated with highway surface debris.

1. Ambient air
2. Precipitation
3. Highway surface debris
4. Runoff
5. Bulk precipitation

An exit ramp at the Milwaukee I-94 site was used for the asbestos studies. The exit ramp drainage system is segregated from the highway and is characterized by significant clutching and braking action. Based upon the geology of the area, this site should not contain any rock formation such as serpentine rock that may contribute chrysotile or any other form of asbestiform material.

Ambient Air--

A Cahill impactor was used to detect asbestos in ambient air. Air was drawn through the impactor for eight hours. A membrane filter was used because fibers from glass fiber filters cause interferences in the detection of asbestos fibers. Ambient air samples were collected adjacent to the road surface at the top of the exit ramp where most of the braking and clutching activity occurs and where prevailing winds should provide the greatest probability for asbestos detection.

Precipitation--

A precipitation sample was collected using plastic funnels manifolded to a plastic collection bottle. The precipitation sample was collected near the point of ambient air collection.

Highway Surface Debris--

Highway surface debris near the two inlets on the exit ramp were sampled for asbestos. A six- by twelve-foot (1.8- x 3.7-m) area around each inlet was swept, dry vacuumed and flushed. A composite sample for each inlet was made from these ~~three~~ fractions.

Runoff--

Runoff samples were collected at each of the two inlets on the exit ramp. A composite sample for each inlet was analyzed for asbestos.

Bulk Precipitation--

The atmosphere can be conceptualized as a temporary holding area or collective source of pollutants originating from many point sources. Atmospheric deposition or bulk precipitation (rainfall and dustfall) is the mechanism which transports pollutants from the atmosphere to a specified area such as a section of highway. Bulk precipitation data were collected to establish if the atmosphere is a source of asbestos to the highway. A bulk precipitation sample was collected adjacent to the road surface at the top of the exit ramp. Filtered distilled water was used for collection in lieu of tap water which may contain asbestos fibers (6). Bulk precipitation was collected for a two-week period.

Polychlorinated Biphenyl (PCB) Studies

During FHWA's study on highway runoff constituents (1), PCB's were found to be prevalent in highway runoff at low concentrations. PCB's were further investigated as a part of this study to establish their possible source and fate within the highway system. The following parameters were sampled during the source investigative studies:

1. Precipitation
2. Paved and unpaved runoff
3. Soil/vegetation
4. Highway surface debris

Except for localized loading sources (faulty transformers, accidental spills, etc.), the major source of PCB's to the highway system may be precipitation (7). For this reason, rainfall samples were collected at all three monitoring sites and analyzed for PCB content.

PCB analyses were performed on highway surface debris collected at the Milwaukee I-94 site to determine surface loading values. Composite samples for selected runoff events from the paved and unpaved areas at this site were also analyzed for PCB content. Data for the paved and unpaved area were collected to evaluate any PCB contributions from the soil and vegetative cover. To support this data, soil and associated vegetation samples from the unpaved area were analyzed for PCB content.

Precipitation samples were collected in aluminum baking pans and transferred to glass sample bottles immediately following each storm. Grab samples were obtained at the Milwaukee I-94 site for selected runoff events and composited prior to analysis. Highway surface debris was collected by sweeping and flushing a 50-ft (15-m) test section in the distress and median lanes at the Milwaukee I-94 site. All liquid samples were collected in hexane-rinsed aluminum or glass containers which were covered with aluminum foil until used (8).

MIGRATION STUDIES

Data were collected at all monitoring sites to evaluate the qualitative and quantitative aspects of background pollutant loading to the highway system, pollutants originating from the highway system, and the mechanism of pollutant dispersion within and transfer out of the highway system. Measurement of variables which affect pollutant deposition, accumulation and removal were also measured to facilitate data evaluation. These variables are traffic characteristics, maintenance activities, and climatic conditions. Field studies were conducted at each of the four sites for a minimum twelve-month period to evaluate seasonal effects on these processes. Field monitoring can be categorized as follows:

1. Atmospheric deposition
2. Total suspended particulates
3. Saltation
4. Highway surface loads monitored through sweeping/flushing studies
5. Runoff quantity and quality
6. Groundwater percolation monitored by lysimeters
7. Soil and vegetation studies
8. Traffic characteristics
9. Highway maintenance data
10. Climatological data

All sites were instrumented for monitoring precipitation, dustfall, saltation, runoff quantity and quality, groundwater percolation and the climatological variables of wind speed, wind direction, and temperature. The selection of monitoring equipment was based on cost, availability, applicability, and most important, its reliability from prior experience. Monitoring equipment was maintained and operated by Rexnord EnviroEnergy Technology Center (EETC) personnel at the Milwaukee, WI site. Monitoring stations were maintained and operated by U.S. Geological Survey personnel in Harrisburg, PA and Raleigh, NC, and by the California Department of Transportation (CALTRANS) personnel in Sacramento, CA. However, monitoring operations at all sites were coordinated by Rexnord EETC personnel. Soil, vegetation, and sweeping/flushing studies were also performed by Rexnord EETC personnel at all sites. Details of the monitoring instrumentation, equipment installation, operation, and maintenance are delineated below. For an elaborate discussion on evaluating highway runoff, procedures for establishing and conducting a monitoring program and evaluating the collected data, the reader is referred to a manual prepared during FHWA's Phase I study, "Volume II, Procedural Manual for Monitoring of Highway Runoff" (9).

Meteorological Parameters

Meteorological data were collected on site to correlate atmospheric deposition patterns to meteorological events. All sites were equipped with a Meteorology Research, Inc. (MRI) Mechanical Weather Station Model 1071 (Figure 24) which recorded wind direction, wind speed, and temperature. Each weather

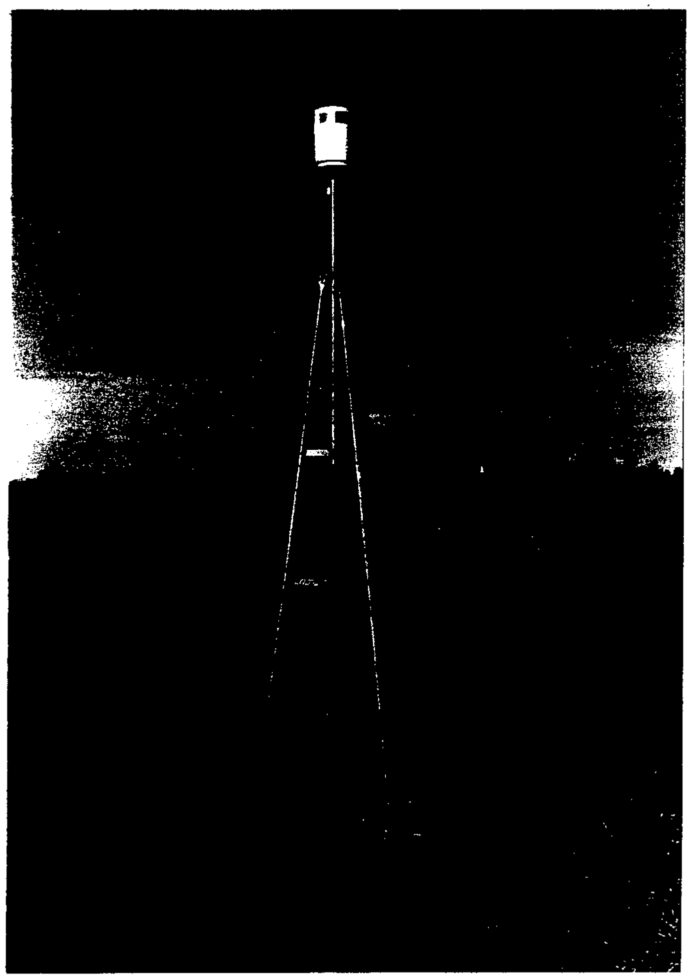


Figure 24. MRI mechanical weather station.

station was mounted on a 13-ft (4-m) tower and located a minimum of 150 ft (45.7 m) from the paved highway to eliminate bias in the meteorological data due to vehicular turbulence, especially from trucks. The weather station was capable of recording continuous meteorological data for 32 days.

On-site meteorological data were supplemented by monthly climatological data sheets obtained from the National Climatic Center in Ashville, North Carolina. These climatological data sheets provided data on temperature, wind direction, and wind speed.

Precipitation

A weighing type, 8-day (24-hour rotation) mechanical wind precipitation gauge (Figure 25) from Belfort Instrumentation Company (Model No. 5-780) was installed at all sites to measure precipitation (rainfall and snowfall) quantity. In addition, a 6-hour rotation precipitation gauge was installed at the Milwaukee I-94 site to determine the precision of precipitation quantity measurements. These gauges provided continuous data on total precipitation and precipitation intensity. Precipitation gauges were installed in accordance with the manufacturers' instructions, in the immediate vicinity of site areas to facilitate time synchronization between precipitation and runoff measurements. During winter monitoring periods, the precipitation gauge housings were lined with heat tape to prevent mechanical parts (including clock mechanism) from freezing. Antifreeze was also added to precipitation gauge collection buckets to prevent ice formation. On-site precipitation data were supplemented by monthly climatological data sheets obtained from the National Climatic Center in Ashville, North Carolina.

Background precipitation quality samples (snowfall and rainfall) were obtained at each site to establish the background level of atmospheric pollutants reaching the highway system through precipitation wash-out. Polyethylene dustfall buckets were used to obtain precipitation quality samples. A standard method of precipitation collection for quality analyses is not used or recognized by the National Weather Service or U.S. Geological Survey (personal communications with those agencies). Precipitation collection using plastic buckets is described by Galloway and Likens (10).

Twelve plastic buckets, 8 in (20 cm) in diameter, collect the minimum sample required for complete analysis (1000 ml) for a 0.10 in (0.25 cm) rainfall. Dustfall buckets were acid-washed with 6N hydrochloric acid and rinsed with distilled water (10) until flush water pH was the same as the distilled water used (usually five rinsings). To avoid contamination, the buckets were tightly covered, and those covers were removed shortly before the precipitation event.

Ground snow samples were obtained at the Milwaukee and Harrisburg sites to obtain the following information:

Figure 25. Belfort Instrument Company precipitation gauge used during study.

1. Determine the pollutant load in ground snow (winter buildup) available for spring runoff and percolation through the soil profile.

2. Assess pollutant buildup in ground snow with distance from the highway.

Ground snow samples were obtained from transects spanning the highway right-of-way. Background samples were also obtained. Sample plot size varied with snow depth in order to obtain a sufficient sample for analysis. The snow was collected in plastic buckets which were acid-washed with 6N hydrochloric acid and rinsed with distilled water. Snow samples were melted at room temperature and submitted for analysis.

Bulk Precipitation

Bulk precipitation data (rainfall plus dustfall) were collected at each site to establish the background level of pollutants reaching the highway system through atmospheric deposition. Each background bucket was elevated a minimum of 8 ft (2.4 m) above ground, with a minimum of 4 ft (1.2 m) above any surface such as a roof (11). Bulk precipitation collectors were located such that higher objects, including billboards, buildings, etc., were not more than 30° from the horizontal, i.e., a line drawn from the sampling bucket to the nearest edge of the highest point on any structure should form not more than a 30° angle with the horizontal (12). Background bulk precipitation stations were located a minimum of 200 ft (61 m) from the edge of the paved highway surface.

Bulk precipitation data were also collected at each site to determine the level of pollutants leaving the highway through atmospheric processes. To establish the pattern of atmospheric deposition by highway-generated pollutants, bulk precipitation collectors were placed along a transect crossing the highway right-of-way including the unpaved areas on either side of the paved surface. Collectors were also positioned along the length of the highway to determine lateral variations. The initial sampling scheme (number of buckets and placement) used at each site was based upon site characteristics (predominant wind direction, topography, average daily traffic, vegetation cover, vandalism potential, etc.). Wherever necessary, initial sampling schemes were adjusted based upon preliminary data collection results. Schematics showing collector installations at the four monitoring sites are presented in Volume III, the research report.

Ground level buckets were used at all sites to determine the quantity of total particulate matter (TPM) transport from the paved highway surface to areas adjacent to the highway through the atmosphere by blow-off due to wind and vehicular turbulence. Studies were conducted at the Milwaukee I-94 and Efland I-85 sites to determine the amount of saltating particles [particles bouncing off the highway surface within the height interval of 30 in (76 cm)] entering ground level dustfall buckets close to the highway. The 1978-79 Milwaukee and 1981-82 Efland monitoring schemes included buckets elevated 30 in (76 cm) from the ground or pavement to the top lip of the bucket. The difference between the loading values for ground level buckets and elevated buckets would be due to saltation.

Bulk precipitation collectors used met ASTM requirements and consisted of a deep taper polyethylene bucket, 8 in (20.3 cm) in diameter and 10 in (24.4 cm) deep, supported in a bird ring (Figure 26). An Aerochem Metrics Model 30 wet/dry collector was used to collect background bulk precipitation data at the Efland I-85 site. Each bucket, including the background bucket, was filled with approximately one liter of solution. During summer months, the solution consisted of 0.5 grams cupric sulfate pentahydrate per liter of distilled water to prevent algal growth. During winter months, approximately one liter of fifty percent methanol was used to prevent freezing. Solution was added as needed during the sampling period to compensate for evaporation. Rubber mesh screens were secured over bucket openings to prevent insects and large debris from falling into the solution. When buckets were changed, the mesh screens were sprayed with distilled water to wash off all clinging particulates. Vegetation immediately surrounding a bulk precipitation collector was periodically trimmed so that the vegetation never exceeded the bucket top.

Intensive atmospheric deposition studies were performed at the Milwaukee I-94 site prior to equipment installation at other sites. The primary goals of these intensive studies were to:

1. Refine data acquisition methods and procedures including the establishment of sampling frequency.

2. Determine which pollutants act as "tracers" for other pollutants.

3. Determine the precision of the atmospheric deposition data collected.

4. Evaluate results to facilitate the formulation of sampling schemes at other sites.

To meet these objectives, several sampling schemes (number, position, and height of buckets) were utilized at the Milwaukee I-94 site. Multiple buckets were also installed at many sampling points to determine monitoring precision. Schematics showing these sampling schemes are presented in Volume III, the research report.

Suspended Particulates

The objective of this study was to determine the amount of total suspended particulates (TSP) generated by the highway. A Sierra Instruments Model "Ultra-Vol" 3 flow-controlled high-volume sampling station with Model 310 flow rate controller was utilized to sample TSP at the Milwaukee I-94 site. High-volume samplers were installed at five locations; two

Figure 26. Bulk precipitation collector with bird ring support.

edge-of-pavement stations, two edge-of-right-of-way stations and a background station. To determine the amount of TSP generated by the highway, TSP concentrations obtained at each of the five stations for a 24-hour period were applied to a Gaussian dispersion model for a line source. However, the high-volume sampling results were difficult to interpret because model parameters such as wind speed and stability varied significantly during a 24-hour period. At best, only a gross approximation of TSP generated by the highway could be calculated. A better approximation could be obtained only if hourly TSP and meteorological data were obtained. However, the time and cost involved in changing high-volume sampler filter pads every hour, analyzing each filter pad, and interpreting hourly meteorological data was prohibitive. High-volume sampling was discontinued at the Milwaukee I-94 site when it became apparent that 24-hour sampling periods provided data that could not be used to determine the amount of TSP generated by the highway. Approximately four months of TSP data were collected at the Milwaukee I-94 site and sampling at other sites was never attempted.

As a result of the TSP sampling performed at the Milwaukee I-94 site, an analytical technique was developed to analyze for metals collected on the high-volume sampler filter pads. Previously, a strip was cut from the filter pad, digested, and analyzed for metals content. Total metal content on the entire filter pad (516 cm^2) was then calculated based upon the results of the subsampled strip (40 cm). However, even with the use of a template, accurately cutting each strip to a uniform area (40 cm) was time-consuming and prone to error. Instead of strips, circles (19.3 cm) were punched from the high-volume sampler filter pads using a plastic cylinder with sharp edges. Table 2 presents the results of lead analyses performed on five different filter pads by removing a strip (40 cm) and three circles (each/19.3 cm). The low standard deviations for the three circles indicate that the circle method provides a uniform subsampled area and that lead is uniformly distributed over the entire high-volume pad. The circles are easier to digest and this fact may account for the slightly higher values obtained using the circle methods. In summary, an accurate, reproducible filter sample which is easy to digest can be cut quickly and easily using a punch.

Saltation

Saltating particles are sand-sized particles injected into the atmosphere by vehicular turbulence. The objective of this study was to determine the magnitude of saltation transport relative to the level of pollutants leaving the highway through atmospheric deposition. The "saltation catchers" used in this study are modified versions of the Bagnold catchers developed by Midwest Research Institute (13) and described by Dr. D. Gillette (11 and 14). Each saltation catcher consists of a plastic bucket (filled with approximately one liter of solution) fitted with a 28.5-in (72.4-cm) high piece of PCB pipe (6-in I.D. [15.2 cm]) with a 1-in (2.54-cm) wide vertical sampling slot 19 in. (48.2 cm) high (Figure 27). The slot is perpendicular to the highway-paved surface (Figure 28) and captures saltating particles (movement by a series of pumps) with the height interval at 12 to 30 in (30.5 to 76.2 cm). Capture efficiency of this device is approximately fifty percent (15). A saltation

Table 2. Comparison of lead content using the circle versus strip method of subsampling high volume filter pads.

	Lead Concentration, $\mu g/m^3$		
Filter pad #	Circle Mean[1]	Standard Deviations	Strip
1	1.36	0.01	1.26
2	3.52	0.06	3.26
3	1.37	0.02	1.32
4	0.57	0.00	0.56
5	0.90	0.04	0.87

[1] Circle mean represents an average of three values.

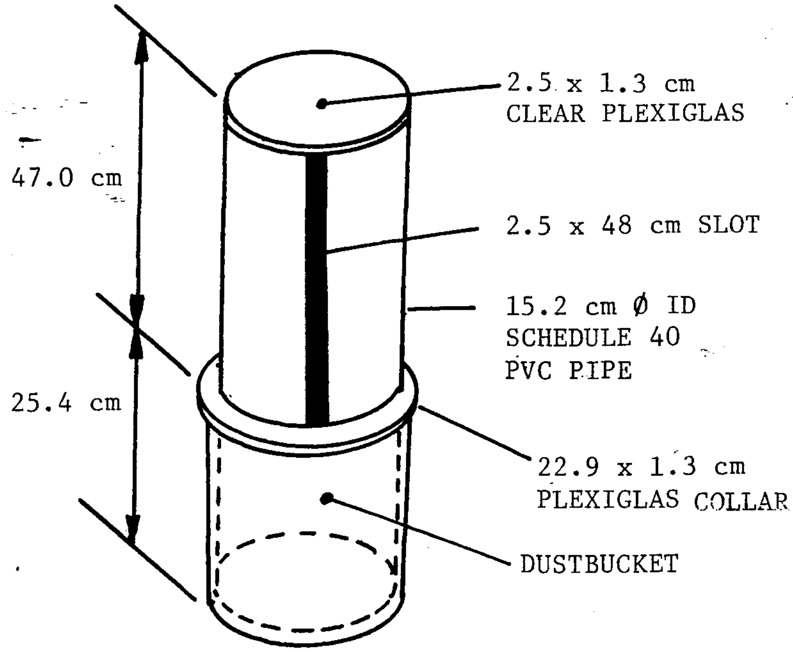


Figure 27. Saltation catcher schematic.

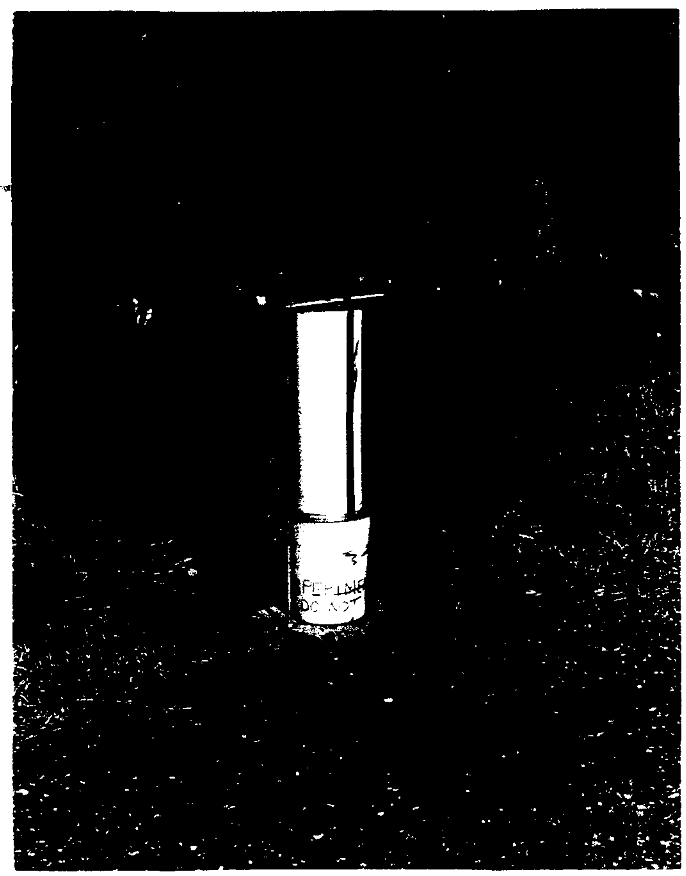


Figure 28. Saltation catcher installation.

catcher is placed at the shoulder of the road, no further than 32.8 ft (10 m) away (13).

Sweeping/Flushing

In order to understand the processes of highway pollutant deposition and removal, it was necessary to characterize highway surface pollutants. Sweeping/flushing studies were performed to define highway surface pollutant load, composition, and distribution. To characterize highway surface pollutant load, test sections of highway surface were sampled at each monitoring site as follows:

1. Removal of gross material (very large litter such as hub caps, tire fragments, etc.)

2. Sweeping where heavy highway surface loads existed

3. Flushing

In each test section, any gross material was first removed and bagged for subsequent identification and weighing. If the pollutant load was heavy, the test section was then handswept for dry solids using a stiff-bristled push broom (Figure 29). The dust and dirt was swept into a pile and picked up using a two-inch (5.1-cm) paint brush and dust pan (Figure 30). All test sections were flushed to remove the small sized particles and water-soluble pollutants (Figure 31). Dry solids obtained by sweeping the highway surface were passed through a U.S.A. No. 6 sieve (3.35 mm) (16). Particles larger than 3.35 mm were defined as litter and particles less than 3.35 mm were defined as total solids. Constituent analyses were performed on the total solids fraction and flush sample.

The techniques used to characterize pollutants on city streets by collection of flush water impounded within a damming system (16, 17) were not feasible for this study because rural highway sites had flush shoulder drainage designs and all sites had multiple travel lanes which had to be individually sampled. Instead, flushing studies were performed using a Model RV-17C Rinse 'n' Vac carpet cleaner (Figure 32). The wand on the Rinse 'n' Vac machine contains the apparatus for both applying the flush water and capturing the sample (Figure 33). The flushing and capturing process could, therefore, occur simultaneously, eliminating the need for an elaborate damming system. Each Rinse 'n' Vac was equipped with a three-gallon (11 liter) stainless steel collection container and flush water container (Figure 33). Many carpet cleaners were considered for use in this study, but after careful examination, the Rinse 'n' Vac appeared best suited for use in this study. Features considered included tank capacity, overall size and weight of machine, cost, suction power, maintenance requirements, durability, and composition of parts which would come in contact with flush water and sample.

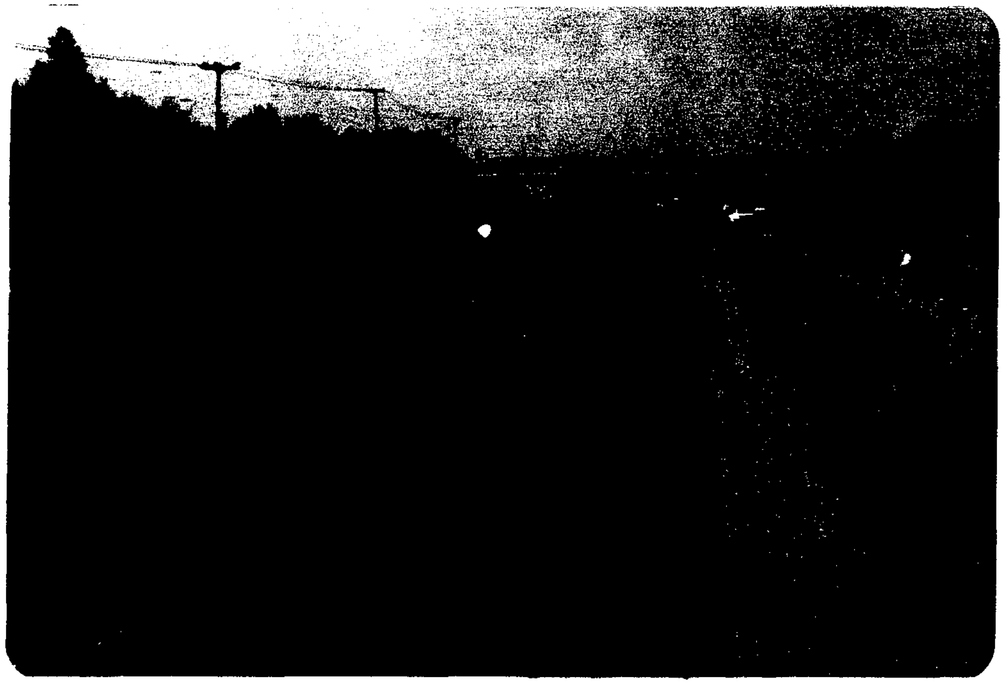


Figure 29. Sweeping the highway surface.

Figure 30. Collecting the dust and dirt sample.

Figure 31. Flushing the highway surface.

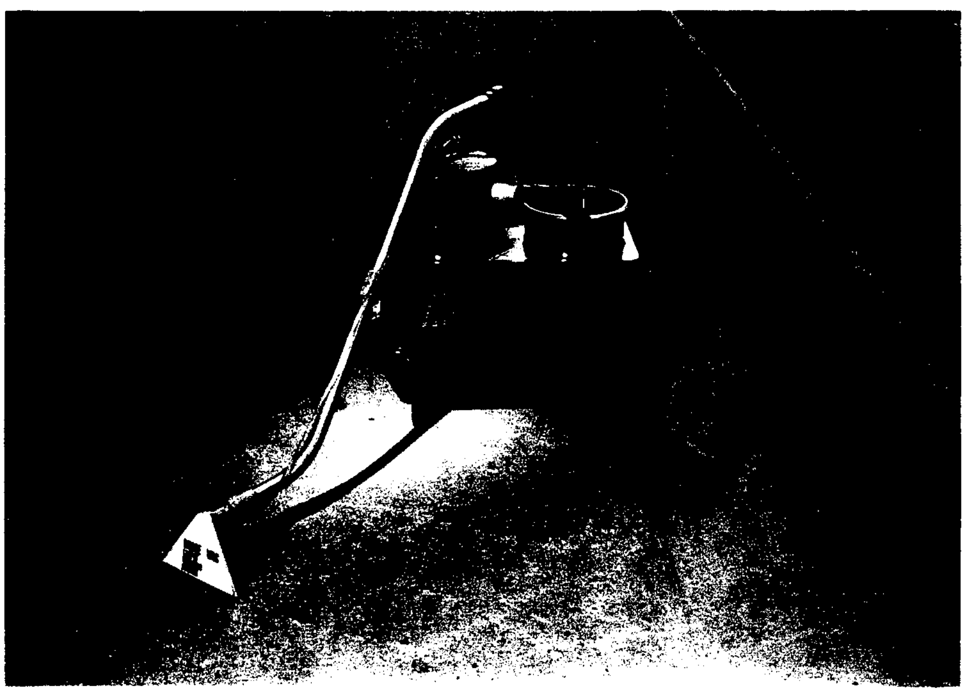


Figure 32. Rinse 'n' Vac machine.

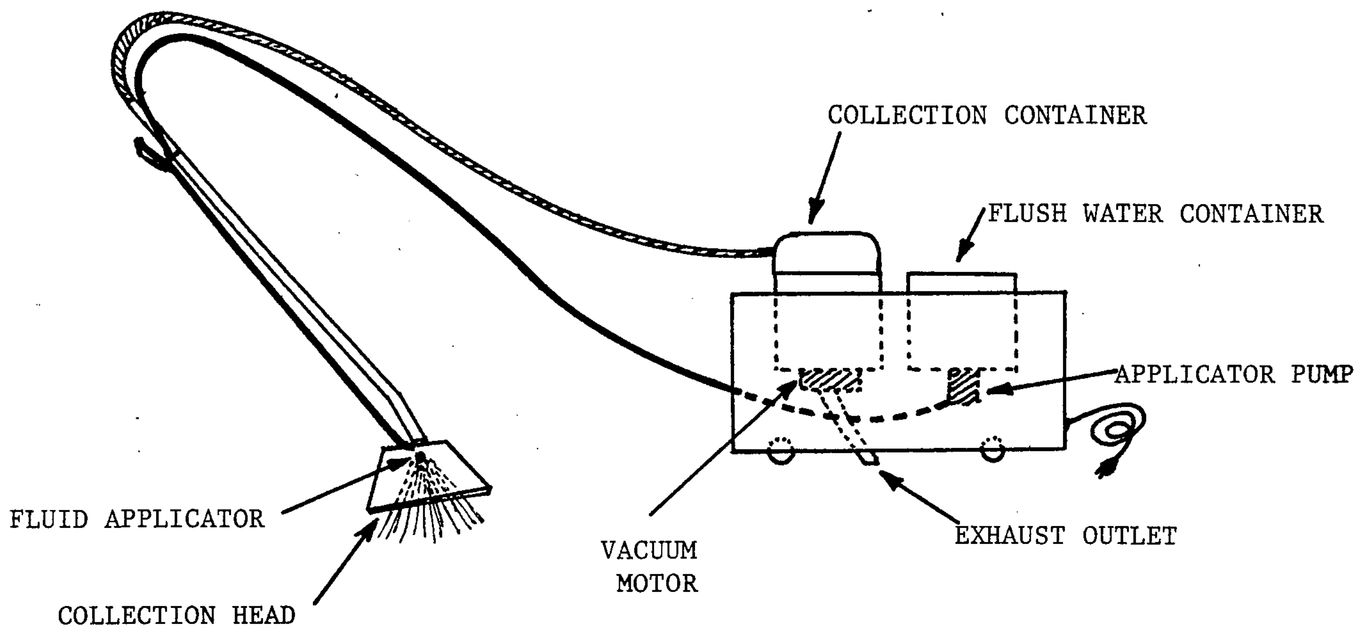


Figure 33. Schematic of Rinse 'n' Vac machine.

Prior to the field studies performed under this task, the following preliminary studies were conducted in Milwaukee:

1. Metals contamination from the Rinse 'n' Vac
2. Recovery of dust and dirt by the Rinse 'n' Vac
3. Determination of optimum test area size

Two tests were conducted to determine if metals contamination (iron, copper, chromium, zinc, cadmium, lead, and nickel) occurs from the operation of the Rinse 'n' Vac machine itself. First, the flush water application system (flush water container, applicator pump, tubing and spray nozzle) of the Rinse 'n' Vac machine (Figure 33) was tested for metals contamination by pumping one gallon (3.8 liters) of distilled water through the system for twenty minutes. The selected metals were not detectable in the resulting sample. Next, the collection system (collection head, hosing, and collection container) of the Rinse 'n' Vac (Figure 33) was tested for metals by pumping 2 gallons (7.6 liters) of distilled water through the system six times. Only iron, 0.24 mg/l, was detectable in the resulting sample. Considering that the collection water was cycled six times, and that the concentration of iron in subsequent field samples was in the range of tens to hundreds of milligrams per liter, the contamination of iron is insignificant.

A preliminary study was also conducted to determine the efficiency of the Rinse 'n' Vac machine to pick up dust and dirt. The Rinse 'n' Vac machine used in this recovery study was carefully cleaned and dried. A sample of dust and dirt was collected in the Rexnord EETC parking lot by dry vacuuming. The oven-dry weight of this sample was 28.150 grams. This sample was spread on a 82 ft (7.5-m) section of concrete floor which had been swept, dry vacuumed and flushed. The test area containing the sample dust and dirt was first dry vacuumed and then wet vacuumed (flushed). Particulate matter exhausted by the Rinse 'n' Vac machine during dry vacuuming was collected by attaching a hose to the exhaust outlet and running the hose into a bucket of distilled water. After wet vacuuming, the collection system was rinsed with distilled water. The results of this study appear in Table 3. The majority of the sample, 83.8 percent, was recovered by dry vacuuming, while wet vacuuming accounted for an additional 8.7 percent. The rinse water recovered another 5.6 percent which indicated that thorough rinsing of the collection system would be necessary during the subsequent field studies. Only 0.6 percent of the sample was recovered in the exhaust water. Overall, approximately 99 percent of the original sample was recovered.

Table 3. Results of the recovery study.

Component	Weight of recovered material, grams	Recovery of original sample %
Dry vacuum	235.90	83.8
Wet vacuum	24.45	8.7
Rinse water	16.77	5.6
Exhaust water	1.65	0.6
Total	278.77	99.0

Preliminary sweeping/flushing studies were conducted on September 26 and October 31, 1978 at the Milwaukee I-94 site to define the minimum test area size which would provide a representative sample of the highway surface load. Factors which were considered in determining test area size included:

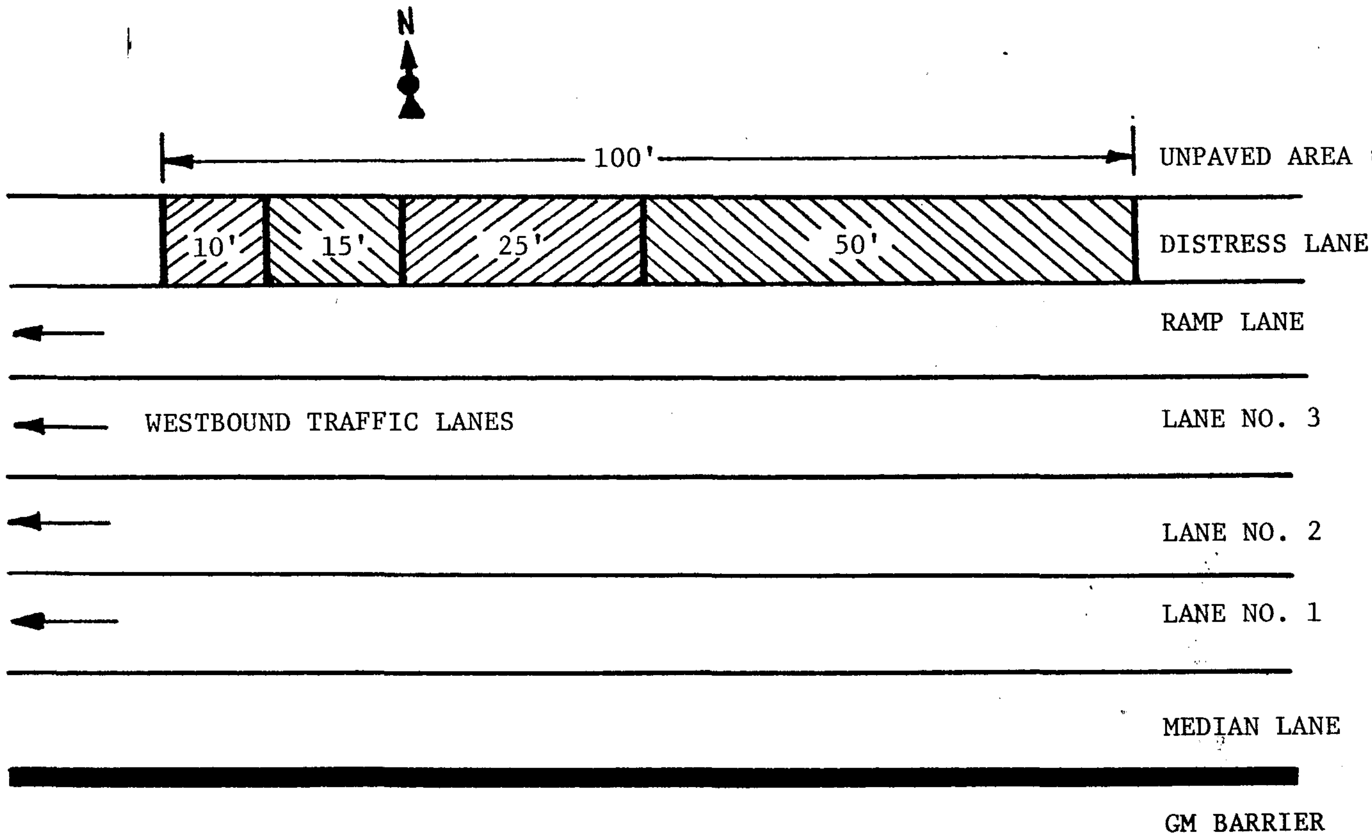
1. Obtaining representative data
2. Safety
3. Logistics
4. Time constraints

The test area must be of sufficient size so that the data collected is representative of the highway section being monitored. Suggested curb lengths for sampling street surface contaminants varied from 25 to 100 ft (7.6 to 30.5 m) (16, 17). However, any decrease in sampling area greatly increases the safety factor by decreasing both the logistical problems (quantity of flush water required, number of field personnel required, etc.) and sampling time.

To determine the test area size, 100 ft (30.5 m) of distress lane were divided into four sections; 10 ft (3.0 m), 15 ft (4.6 m), 25 ft (7.6 m) and 50 ft (15.2 m) (Figure 34). Data obtained by sampling these four sections permitted a comparison of variability between the sample sections and the variability of each section to the total 100-ft (30.5-m) section. The study to define test area size was conducted in the distress lane because this lane had the potential for greatest variability of surface load due to the presence of warning groove strips, which should effectively trap highway surface material (Figure 35). The test area size selected as representative for the distress lane should, therefore, be representative for other lanes. The 15-ft (4.6-m) and 50-ft (15.2-m) test sections contained warning groove strips.

The results of these two studies appear in Tables 4 and 5. The data presented in these tables allow a comparison of highway surface load between the four test sections and a comparison of each test section to the entire 100-ft (30.5-m) section. Data from the two studies show that the 10-ft (3.0-m) and 25-ft (7.6-m) sections generally had the lowest surface loads. Presumably, this reflects the absence of warning groove strips in these test sections. For the September 26, 1978 study, the data show that surface loadings for the 50-ft (15.2-m) section are most comparable to the entire 100-ft (30.5-m) section, while for the October 31, 1978 study, both the 15-ft (4.6-m) and ~~50-ft~~ (15.2-m) sections are most comparable. These results indicate that the representative test area must contain a warning strip and that the 50-ft (15.2-m) section contains enough area of grooved warning strip and smooth-paved surface to best represent the entire 100 ft (30.5 m) of distress lane. For these reasons, a 50-ft (15.2-m) test section was used in all subsequent sweeping/flushing studies.

From these preliminary studies, it was also determined that sampling a 50-ft (15.2-m) section required a two-man team with two Rinse 'n' Vac machines. With this arrangement, each section required from 30 to 60 minutes



Metric units: To convert ft to m multiply by 0.3048.

Figure 34. Schematic of the Milwaukee I-94 site showing test sections used to define test area size.

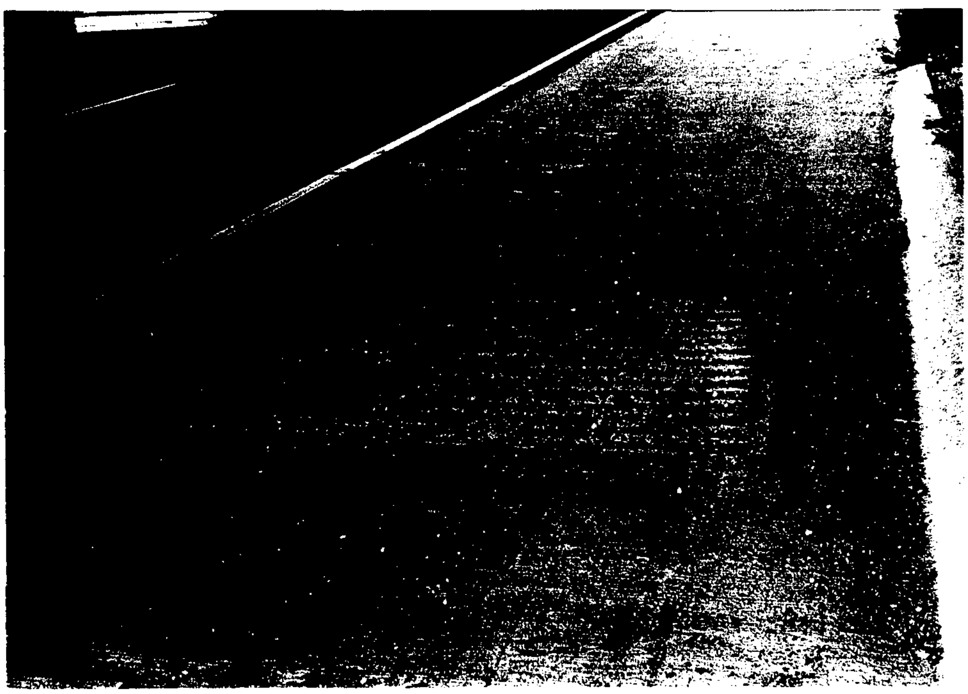


Figure 35. Highway surface load trapped in warning groove strips of the distress lane - Milwaukee I-94 site.

Table 4. Results of the September 26, 1978 sweeping/flushing study conducted to determine representative test area size - Milwaukee I-94 site.

	Distress lane test section, lb/mi[a]				
Parameter	10 ft	15 ft	25 ft	50 ft	100 ft
Gross material[b]	75.9	141	240	73.1	125
Litter[c]	79.4	367	131	204	198
TS[d]	173	730	304	462	434
TVS	10.6	25.8	15.3	18.0	17.7
BOD_5	0.626	0.798	0.587	0.557	0.608
TOC	1.81	4.75	3.30	3.69	3.56
COD	6.19	19.0	12.7	13.5	13.4
Pb	1.32	5.12	2.70	2.35	2.75
Zn	0.176	0.605	0.254	0.335	0.339
Fe	15.9	68.3	29.4	29.8	34.1
Cr	0.007	0.084	0.025	0.029	0.034
Cu	0.108	0.231	0.078	0.147	0.138
Cd	0.005	0.004	0.003	0.003	0.003
Ni	0.014	0.083	0.023	0.029	0.034
As x 10^{-3}	0.436	1.05	0.242	0.538	0.531
Hg x 10^{-3}	0.066	0.000	0.029	0.030	0.029
NO_2+NO_3	0.024	0.020	0.019	0.019	0.020
TKN	0.117	0.326	0.127	0.184	0.187
TPO_4	0.053	0.278	0.176	0.153	0.167
Cl	1.28	1.17	1.39	1.31	1.30
Oil & grease	0.600	3.22	0.939	1.50	1.53

[a] One direction-total of wet and dry fractions.

[b] Gross material is defined as very large litter which can be picked up by hand (hub caps, tire fragments, etc.).

[c] Litter is defined as particles larger than 3.35 mm not including gross material.

[d] Total solids are defined as particles less than 3.35 mm.

Metric units: To convert lb/mi to kg/km multiply by 0.2819.
To convert ft to m multiply by 0.3048.

Table 5. Results of the October 31, 1978 sweeping/flushing study conducted to determine representative test area size - Milwaukee I-94 site.

Parameter	Distress lane test section, lb/mi[a] 10 ft	15 ft	25 ft	50 ft	100 ft
Gross material[b]	168	152	123	129	135
Litter[c]	119	526	193	518	398
TS[d]	292	1060	407	1030	811
TVS	16.3	49.6	19.7	41.9	35.2
TOC	6.78	7.04	4.80	11.6	8.83
COD	14.2	24.9	11.1	30.6	23.3
Pb	2.27	4.93	3.06	7.36	5.45
Zn	0.367	1.09	0.402	0.929	0.770
Fe	18.6	70.7	33.7	74.1	58.3
Cr	0.025	0.189	0.035	0.021	0.050
Cu	0.166	0.636	0.182	0.308	0.314
Cd	0.002	0.005	0.002	0.005	0.004
Ni	0.085	0.081	0.032	0.060	0.059
As x 10^{-3}	0.754	1.18	1.68	1.51	1.83
Hg x 10^{-3}	0.036	0.061	0.054	0.269	0.154
NO_2+NO_3	0.018	0.018	0.021	0.020	0.020
TKN	0.208	0.399	0.244	0.472	0.380
TPO_4	0.392	0.373	0.118	0.364	0.308
Cl	2.75	4.78	2.89	5.40	4.45
Oil & grease	1.64	6.18	2.74	5.26	4.44
Rubber	1.10	4.86	0.178	0.479	1.12

[a] One direction-total of wet and dry fractions.

[b] Gross material is defined as very large litter which can be picked up by hand (hub caps, tire fragments, etc.).

[c] Litter is defined as particles larger than 3.35 mm not including gross material.

[d] Total solids are defined as particles less than 3.35 mm.

Metric Units: To convert lb/mi to kg/km multiply by 0.2819.
To convert ft to m multiply by 0.3048.

to complete sampling. The amount of flush water required for each section varied with the highway surface involved, but generally, 30 to 45 liters were required to flush the test section and to flush the Rinse 'n' Vac collection system.

Prior to an actual sweeping/flushing study, arrangements were made with local Department of Highway personnel to control traffic and cone off the test areas being studied.

Runoff Quantity and Quality

Quantity and quality of runoff from the paved, as well as the unpaved area at each site were monitored at separate points in order to establish the overall fate of pollutants leaving the highway drainage system. Monitoring of the paved and unpaved areas was segregated to determine pollutant loadings leaving the highway drainage system and to develop insights into the hydraulics of pollutant movement and strengths at various points in the drainage scheme. Two types of drainage systems were monitored: flush shoulder (Harrisburg and Efland) and curb and gutter (Milwaukee and Sacramento). Monitoring strategies at these sites are discussed in Section II of this report.

All sites were equipped with automatic water sampling and flow measurement equipment.

Flow Measurement--

Two components were required for the measurement of flow in an open channel:

1. A calibrated device which is inserted in a channel such that the resultant water level can be related to discharge.
2. A level sensing instrument which measures the water level upstream of the calibrated device.

V-notch weirs, combination weirs, Palmer-Bowlus flumes and Parshall flumes were used as calibrated devices for this study. Selection of the calibrated device and level-sensing instrument was based upon site characteristics, and the preference and experience of site-operating personnel. A calibrated device and associated level sensing instrument was installed at the paved and unpaved monitoring point at each site (Table 6). In addition to the Palmer-Bowlus flume installed at the paved monitoring point at the Milwaukee I-94 site, a V-notch weir was installed downstream of the flume to measure small flows associated with a base flow which occurred during the 1979-80 winter/spring monitoring season.

Table 6. Flow measuring devices and recording instrumentation used at each site.

Site	Calibrated device	Level sensing instrument type and manufacturer
Milwaukee I-94 Paved runoff	Palmer-Bowlus flume	Bubbler tube recorder Instrumentation Specialties Company
		Bubbler tube recorder Bristol Div., Acco Inc.
Paved baseflow	90°V-notch weir	Bubbler tube recorder Bristol Div., Acco Inc.
Unpaved runoff	90°V-notch weir	Bubbler tube recorder Bristol Div., Acco Inc.
		Bubbler tube recorder Instrument Specialties Company
Harrisburg I-81 Paved runoff	90°V-notch weir	Mechanical float recorder Leupold-Stevens Company
Unpaved runoff	90°V-notch weir	Mechanical float recorder Leupold-Stevens Company
Sacramento Hwy. 50 Paved runoff	Parshall flume	Bubbler tube recorder Instrumentation Specialties Company
Unpaved runoff	Parshall flume	Bubbler tube recorder Instrumentation Specialties Company
Efland I-85	Combination weir	Automatic digital recorder Fischer-Porter Company

Installation and calibration of V-notch weirs and Palmer-Bowlus flumes is described in detail in the Procedural Manual developed during FHWA's study on highway runoff constituents (9). Installation and calibration of Parshall flumes at the Sacramento Hwy 50 site were performed by the California Department of Transportation (CALTRANS).

Level-sensing instrumentation was installed at all sites in accordance with the manufacturer's instructions. At the Milwaukee I-94 site, the paved monitoring point was instrumented with both a Bristol recorder (Figure 36) and an ISCO Model 1700 flow meter with Model 1710 printer and Model 1720 chart recorder (Figure 37) (Table 6) to compare flow volumes measured by these two devices. Both are bubbler tube devices which use a compressed gas supply to pressurize a bubbler tube in the flow channel. A rise in flow causes a proportional change in pressure in the tube which is recorded as flow height. Bristol recorders were used extensively during FHWA's Phase I study (Constituents of Highway Runoff). ISCO level-sensing instrumentation, which was not available at the start of the Phase I study, was purchased for this study (Phase II) because of the following advantages over the Bristol instrumentation:

1. Self-contained pressurized gas supply. The Bristol recorder required a large nitrogen cylinder as the pressurized gas supply.

2. Electronic circuitry for quick response to decreasing flows.

3. An integration system which automatically calculates flow volume. The Bristol records only a flow height trace which then has to be manually converted to flow volume.

For 55 runoff events at the Milwaukee I-94 site from summer monitoring periods in 1978 and 1979, calculated flow from Bristol charts totalled 185,117 ft^3 (5243 m^3) while the ISCO integrator totalled flow at 194,855 ft^3 (5518 m^3), approximately a five percent difference.

The same comparison between Bristol and ISCO level-sensing equipment was to be made at the Milwaukee I-94 site unpaved monitoring point (Table 6). However, the ISCO equipment malfunctioned during the 1979 spring monitoring period and all flows were calculated based upon Bristol flow charts. For the 1980 spring monitoring period, the Bristol had to be used to record paved area base flow through the 90^{o} V-notch weir (Table 6) and all unpaved flow volumes were recorded by the ISCO equipment.

At the time of equipment installation at the Sacramento Hwy 50 site, ISCO marketed a new level-sensing system, the Model 1870 (Figure 38). The Model 1870 combined the Model 1700 flow meter and Model 1720 chart recorder into a single unit. The Model 1870 also integrates flow digitally with a plug-in module whose electronic circuitry is user-specified for the calibrated device used to measure flow (weirs, flumes, or other devices). The Model 1700 used

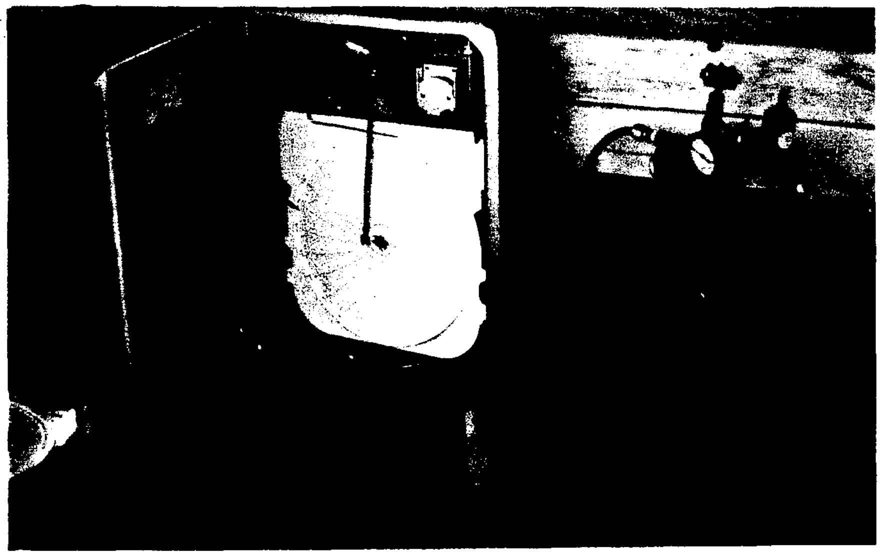


Figure 36. Bristol recorder.

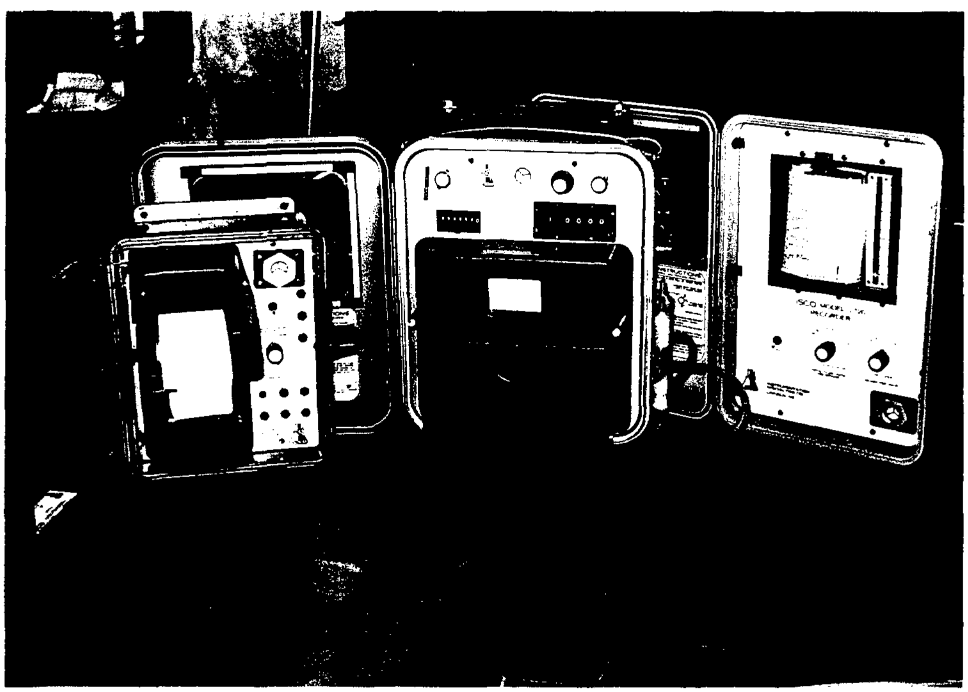


Figure 37. ISCO Model 1700 flow meter with Model 1710 printer and Model 1720 chart recorder.

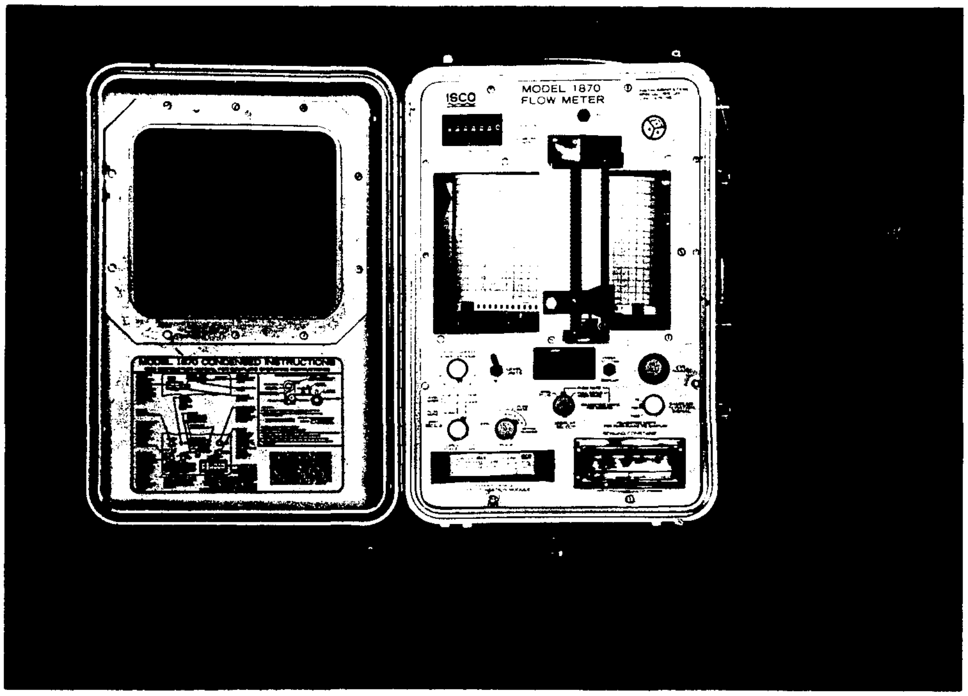


Figure 38. ISCO Model 1870 flow meter and chart recorder.

an optical disk system. A Model 1870 was used at each monitoring point (paved and unpaved) at the Sacramento Hwy 50 site.

Figures 39 through 42 show photographs of the flow measuring equipment at various sites.

Water Quality Sampling--

Water quality sampling was conducted at all sites using Instrument Specialty Company (ISCO) water quality samplers (Models 1392 and 1680). A typical ISCO sampler is shown in Figure 43. ISCO samplers are self-contained portable units capable of taking 28 discrete samples. These samplers can be operated using either AC or DC power sources. Sampling may be time-or flow-proportioned.

Samples collected by the ISCO can be analyzed individually and/or they can be composited proportional to flow into a single sample that represents the entire runoff event. Selected discrete samples were analyzed to determine changes in pollutant strength with flow time. Analysis of flow-proportional composite samples from the paved and unpaved areas provided information on the total pollutant load leaving these areas during a runoff event. At sites where ISCO Model 1700 or 1870 level-sensing equipment was installed, ISCO water quality samplers were set in the flow proportional sampling mode. Because the Model 1700 or 1870 automatically integrates flow volume, a sample could be obtained for a specified unit of flow volume in cubic feet or cubic meters. A composite sample could then be obtained by simply combining an equal volume of each discrete sample. Where Bristol or Leupold-Stevens recorders were installed, ISCO samplers had to be set in the time mode. Volume of discrete sample used to make a composite sample is then based upon volume of flow calculated for the time interval between discrete samples as discussed in "Procedural Manual for Monitoring Highway Runoff" (9).

At each paved monitoring point, two ISCO water quality samplers were used. If ISCO level-sensing equipment was used, one sampler was set in the flow mode and one was set in the time mode. Sampling time intervals depended upon the anticipated characteristics of the storm event to be sampled. Samples from the flow mode sampler were used for the composite sample and samples from the time mode sampler used for discrete analyses. If ISCO level sensing equipment was not used, both samplers were set in the time mode, each using different sampling time intervals. Depending upon storm characteristics, samples were then chosen from the two sample sets for compositing and/or discrete analysis. At each unpaved monitoring point, one ISCO sampler was used because of the small flow volumes normally obtained from these areas. Mode of sampling depended upon the type of level-sensing equipment used.

Figure 39. V-notch weir - unpaved area Milwaukee I-94 site.

Figure 40. Palmer-Bowlus flume - paved area sewer at Milwaukee I-94 site.

Figure 41. Parshall flume - Sacramento Hwy. 50 site.

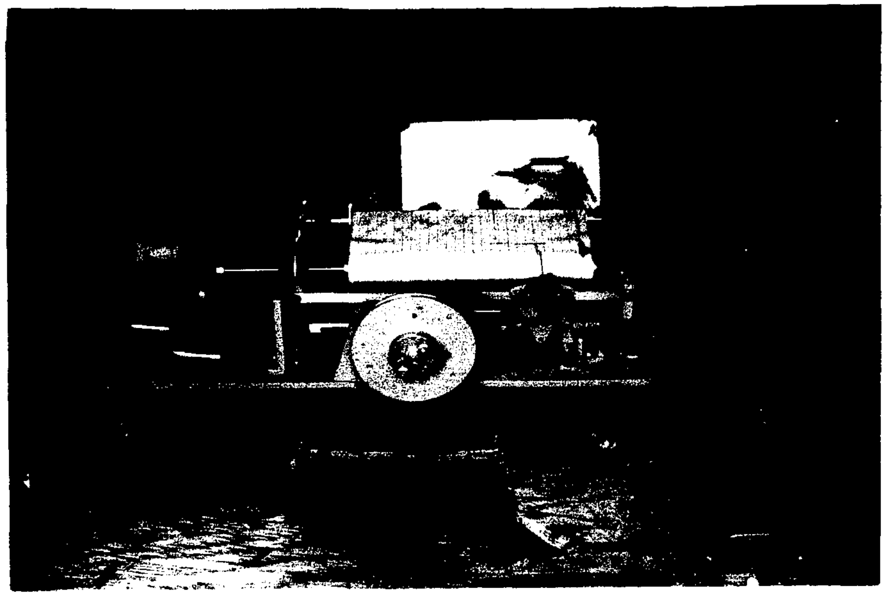


Figure 42. Leupold-Stevens mechanical float recorder.

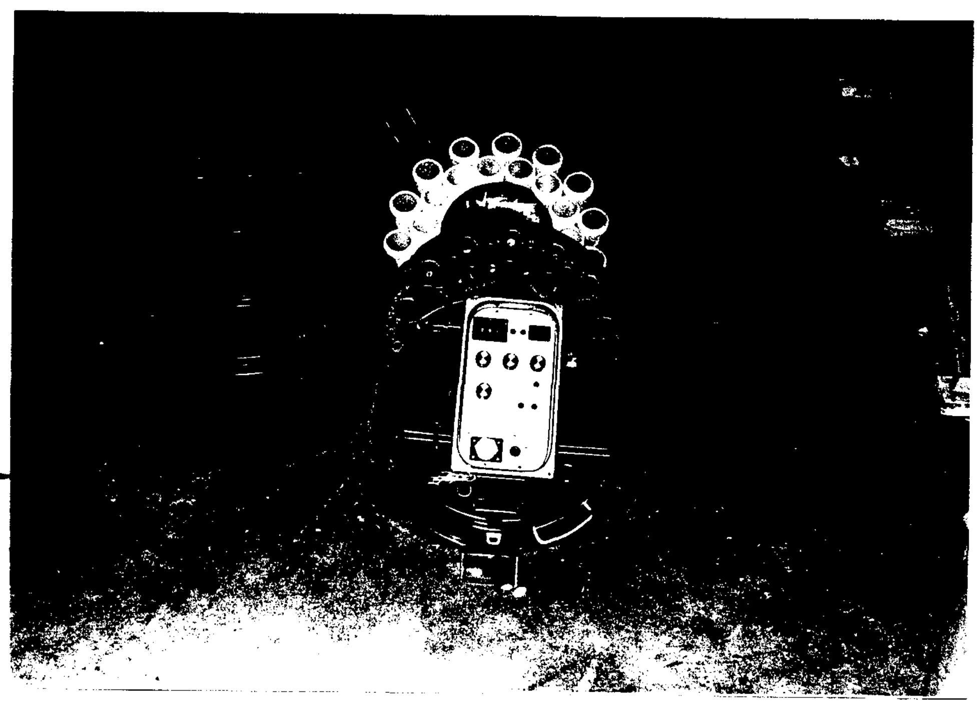


Figure 43. ISCO water quality sampler.

The sampler intake lines were installed in accordance with the manufacturer's instructions with respect to the maximum allowable suction tube lengths (20 ft or 6.1 m) and pumping heads (20 ft or 6.1 m). Gravity drainage of the intake lines was provided in all cases to protect from ice build-up in lines during freezing weather. Sampling intakes were placed behind the weir and flumes where maximum turbulence was experienced during runoff periods and were installed at points approximately one-third the estimated water depth from the bottom of the sewer or channel. At each monitoring location all equipment was kept inside a locked shed to protect the instrumentation from inclement weather, as well as from any vandalism. Monitoring sheds were heated with an electric or gas heater during extremely cold weather periods at various sites to protect the instrumentation and lines from freezing.

Samples for certain parameters required special attention and handling. Bacteriological samples, for example, required sterilized sample bottles and sterile handling techniques to avoid contamination. These samples were, therefore, collected manually in separate sterile bottles. Samples for oil and grease, pesticides/herbicides, and PCB's required glass bottles because of possible absorption of these pollutants by plastic containers. These samples were usually collected manually in separate glass bottles.

During the 1979-80 winter monitoring season, data were collected at the Milwaukee I-94 site to develop a sodium and chloride mass balance. A V-notch weir, sensitive to low flow, was installed downstream from the Palmer-Bowlus flume prior to the 1979-80 winter monitoring season to obtain detailed base flow data. Conductivity was continuously monitored using a Beckmen Strip Chart Conductivity Recorder. A minimum of one base flow grab sample was obtained each week during the winter season and analyzed for sodium chloride and conductivity. This data provided sodium and chloride to conductivity ratios. These ratios, the continuous conductivity measurements, base flow measurements and the monitoring of all snowmelt and storm-related runoff events along with de-icing agent application data for the Milwaukee I-94 site supplied by WI DOT provided the basis for developing a sodium and chloride mass balance for the 1979-80 winter season.

Groundwater Percolation

Soil water studies using zero tension lysimeters were performed in the unpaved areas at all monitoring sites. Zero tension lysimeters, designed by Jordan (18), collect soil water as it percolates down through the soil profile. Each lysimeter consists of a stainless steel trough with a 12 in long by 2.1 in wide (30.5 x 5.4 cm) collection surface (Figure 44). Within the trough are two parallel strainless steel rods in slight contact with an overlying mesh screen which has a thin layer of fiberglass wool (0.15 to 0.30 cm thick) to keep soil from falling into the trough (Figure 45). The rods in contact with the mesh screen negate surface tension of water percolating through the screen and provide effective capillary drainage (zero tension lysimeter).

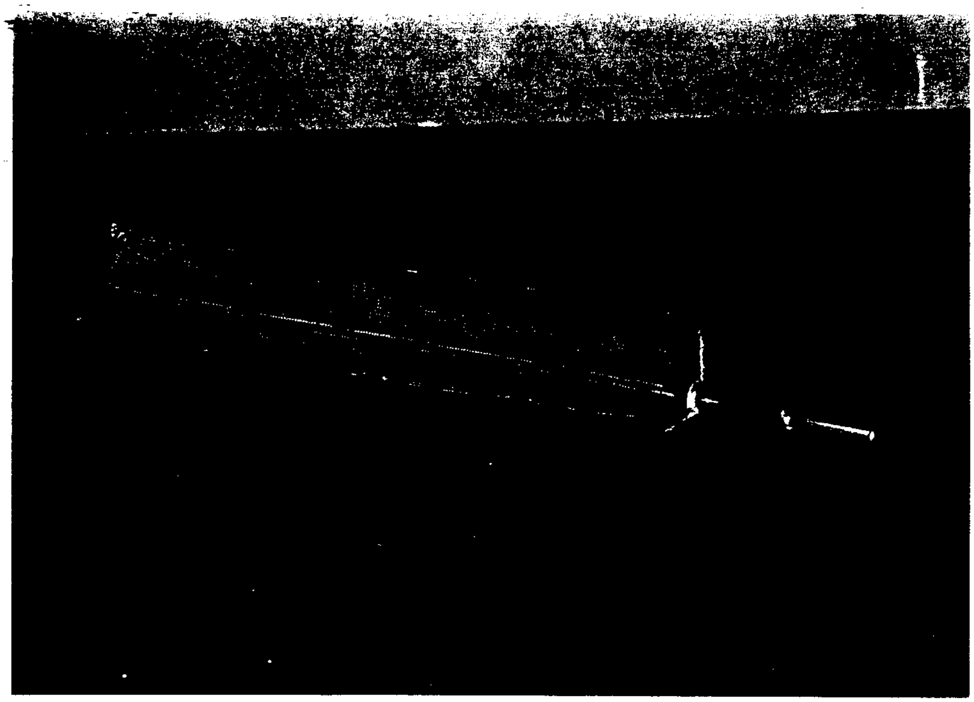


Figure 44. Zero tension lysimeter.

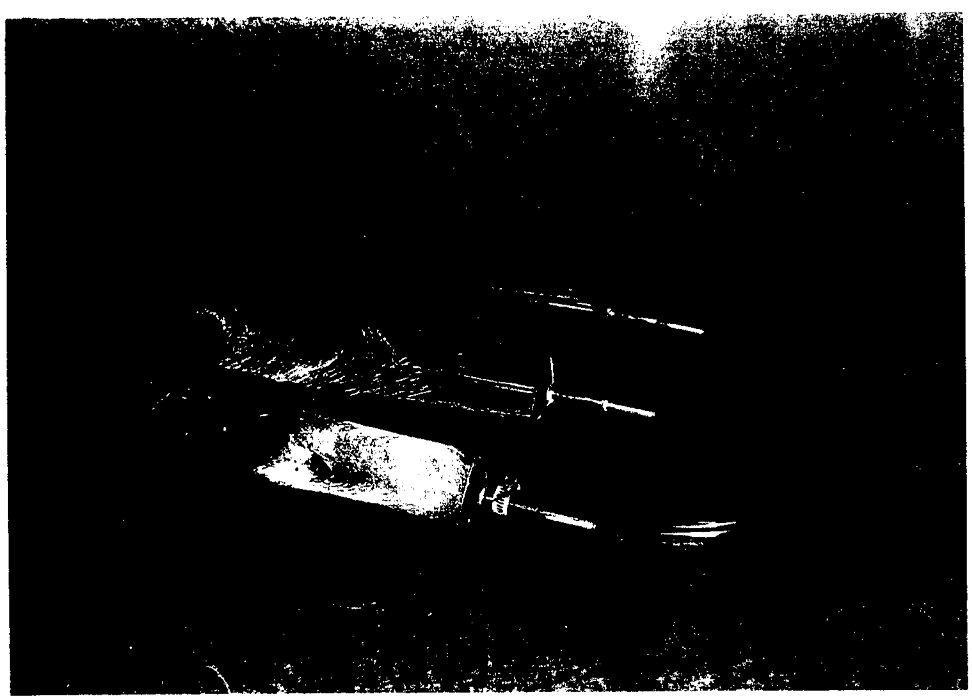


Figure 45. Various stages of packing a lysimeter.

Figure 45 presents a schematic of the lysimeter installations used in this study. Each installation consisted of a lysimeter, collection pit housing a collection bottle, and a piece of tygon tubing connecting the lysimeter to the collection bottle. The collection pit consisted of a five-gallon (19 liter) plastic bucket with lid (Figure 46). At sites with good drainage (Milwaukee and Sacramento) the bottom of each bucket was cut out to keep the pit drained of any rainwater which might enter the pit. At Harrisburg and Efland, where groundwater seepage into the pit became a problem, a completely sealed system had to be used. Lysimeters were installed by cutting the topsoil mat on three sides, folding the mat back, digging a depression in the soil substrate, inserting the packed lysimeter into the substrate depression and replacing the mat. The mat was then tamped down to ensure close contact between the topsoil layer and lysimeter. The lysimeter and tubing channel sloped slightly downward toward the collection pit to allow complete drainage of the lysimeter.

After installation, several heavy rains occurred before soil water was collected for analysis. This allowed the soil system to physically recover from the disturbance and ensured that the lysimeter was in close contact with the soil. Soil water samples were usually collected four or more hours after completion of a storm event when the percolation process was complete.

Lysimeters installed just beneath the topsoil layer (major rooting zone) provided estimates of the loss of various chemical constituents from the highway system due to groundwater percolation. Since plant roots are the major mechanism for "pumping" chemical constituents back to the surface, chemical constituents leaving the rooting zone are essentially lost to the surface system.

Soils

The objective of the soil studies was to determine pollutant loads in soils adjacent to highways and to evaluate their effects on plant uptake, and on runoff and groundwater seepage characteristics. Soil cores were obtained along a transect perpendicular to the paved highway surface at selected distances to define the pattern of contaminant accumulation in the soils with distance from the paved surface. The number of cores obtained and the distance between cores varied according to site characteristics. Soil core sampling included background samples as points for comparison to highway-influenced samples. Cores were taken with a 2.5 in (6.4 cm) I.D. stainless steel corer (Figure 47) to a depth of 1 ft (30.5 cm), and each core was divided into a topsoil and substrate sample. Topsoil and substrate layers of each soil core were separated and analyzed (physical and chemical analyses) as individual samples to quantify contaminant storage and migration within the right-of-way soil profile.

The accumulation of highway-related metals from atmospheric deposition should be reflected in the surface soil layer of areas adjacent to the

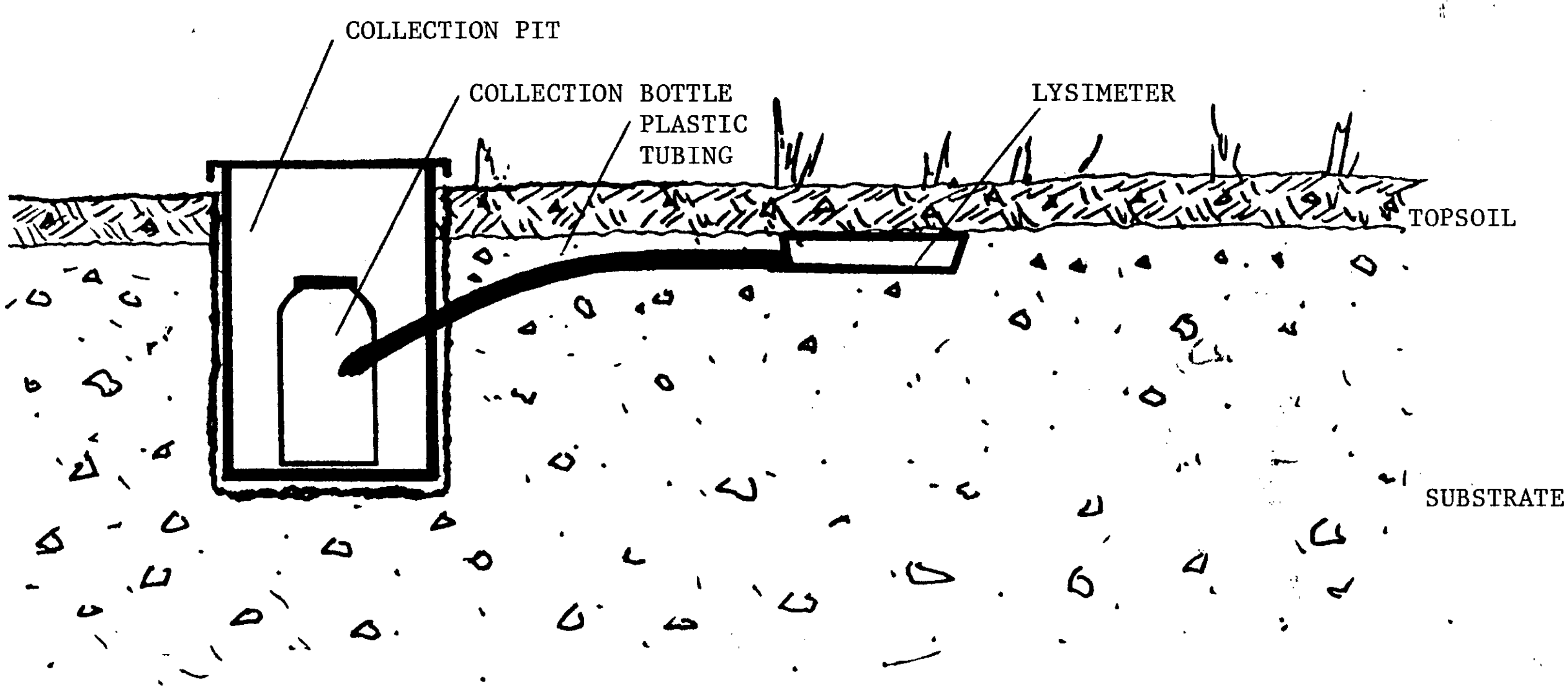


Figure 46. Lysimeter installation schematic.

Figure 47. Soil core sampler.

highway. To support the bulk precipitation data collected at the four monitoring sites and to better define the impacted areas, the top centimeter of soil was sampled along a transect crossing the right-of-ways at each site monitored including the unpaved areas on either side of the highway, and the unpaved median areas at Efland and Harrisburg. A circular plastic template 3.5 in (9 cm) in diameter was used to precisely define the sample area at each sampling point. The plastic template was embedded several centimeters into the soil and the top one centimeter of soil was carefully removed. Lead, zinc, iron, copper, chromium, cadmium, and nickel analyses were performed on each sample.

Vegetation

Vegetation studies were performed to determine pollutional load held by the vegetation in temporary storage. Vegetation was sampled from plots whose size varied 3 to 11 sq ft (0.25 to 1 m) depending on the density of the vegetative cover (19 through 22). A vegetation sample was obtained at each soil core sampling location. Vegetation samples were divided into above ground, litter, and below ground components with chemical and physical analyses being performed on each component. Above ground vegetation was obtained by clipping all vegetation within the sample plot to ground level (Figure 48). The litter fraction (dead vegetation not yet decomposed to soil) was then removed. Below ground vegetation was obtained by removing the sod layer within the plot (Figure 49) and carefully separating as much soil from the below ground vegetative structures as possible. Samples were prepared for analyses by oven drying all plant tissue at 75 ^{o}C. until a constant weight was obtained, usually 48 hours. Prior to oven drying, all root samples were washed with cold water to remove any clinging soil particles. Oven dried weights were recorded as biomass values. The oven-dried material was ground using a 20-mesh sieve in a Wiley mill and stored in air tight jars (canning jars) until chemical analyses were performed.

SAMPLE HANDLING AND LABORATORY ANALYSES

Analytical determinations for all constituents except pH, bacteria, rubber, asbestos, and selected soils analyses were performed at the Rexnord EETC Laboratory in Milwaukee, WI. At sites outside Milwaukee, pH was measured by local monitoring personnel, while bacteriological analyses were performed by USGS personnel in Harrisburg, PA and Efland, NC, and Morse Laboratories, Inc. in Sacramento, CA. For the Milwaukee site, pH and bacteriological analyses were performed by the EETC laboratory. Asbestos and rubber analyses at the Milwaukee site were made by McCrone Associates of Chicago, Illinois. Soil analyses, excluding metals, were performed by the Soil and Plant Analysis Laboratory, University of Wisconsin. Soil metals analyses were performed at the EETC laboratory.

Samples from sites outside Milwaukee were air freighted or express mailed to Rexnord in ice-packed coolers for analysis. Once at the EETC laboratory, all samples were assigned separate sample identification numbers which were

Figure 48. Sampling above-ground vegetation.

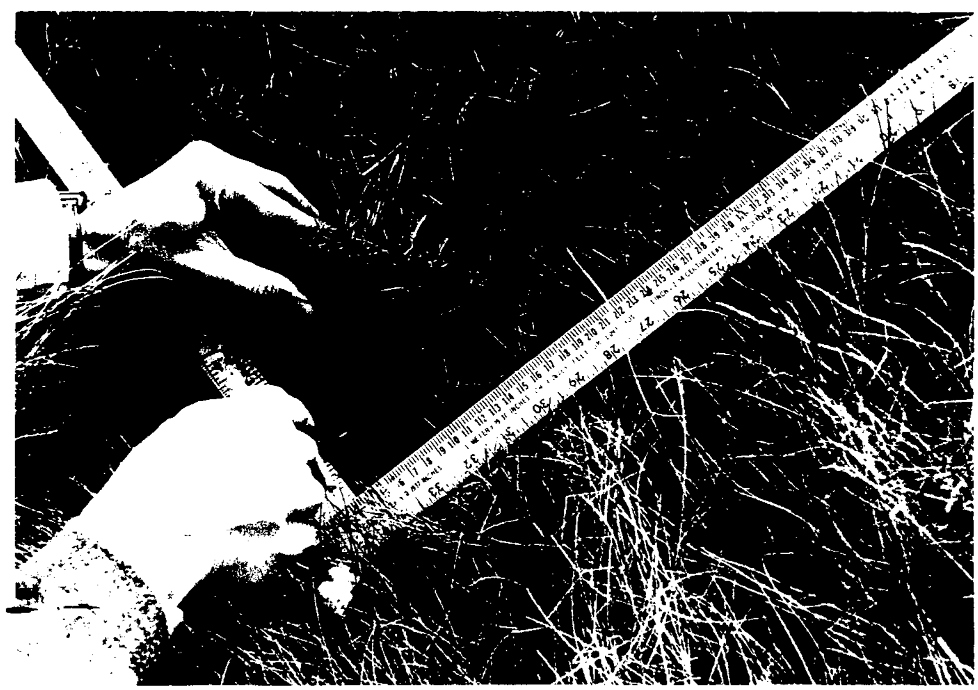


Figure 49. Sampling below ground vegetation.

logged into a laboratory book along with corresponding information about the samples with respect to location, date, time of sampling and type of sample.

All samples were analyzed by methods approved for use in the National Pollutant Discharge Elimination System (NPDES) as recommended in Federal Register 38, 199, 28758-60 (October 16, 1973) and Federal Register 44, 244, 75029-52 (December 18, 1979), and according to accepted Standard Methods of Water and Wastewater Analyses (3) or EPA-approved procedures (23, 24). An in-house quality control program was used to assure the validity and accuracy of the analytical determinations performed by the EETC laboratory. This program included analysis of quality control samples provided by EPA. A listing of samples, typical detection limits and methods used appears in Table 7. During the 1981 monitoring season, samples with sufficient volume were concentrated before metals analysis, increasing the detection limit by a factor of ten.

Traffic Characteristics

Traffic counts were obtained to correlate the processes of highway pollutant deposition, accumulation, and removal with traffic characteristics. The Milwaukee I-94 and Sacramento Hwy 50 sites had permanent automatic traffic counters located on or near the site. Temporary traffic counters were installed at the Harrisburg I-81 site by the Pennsylvania Department of Transportation and at the Efland I-85 site by the North Carolina Department of Transportation under contract from the Federal Highway Administration. Traffic data at all sites were provided by the respective State highway departments.

Highway Maintenance Data

All roadway/right-of-way maintenance data for various sites were provided by the respective State highway department similar to the traffic data. The following maintenance data were requested from these highway departments:

1.	Road cleaning	technique, date, and total amount removed
2.	Roadside mowing	technique and date
3.	Herbicide spraying	type of herbicide, application date and methods, rate of application, and total amount used
4.	Fertilizer	type, spreading technique, total amount used, and date of application

Table 7. Analytical methods.

Parameter	Analytical method reference	Typical detection limits, mg/l
Total solids	3, 23, 24	1
Suspended solids	3, 23, 24	1
Volatile solids	3, 23, 24	1
Volatile fraction of above	3, 23, 24	1
Lead	3, 23, 24	0.1
Zinc	3, 23, 24	0.01
Iron	3, 23, 24	0.1
Chromium	3, 23, 24	0.02
Copper	3, 23, 24	0.02
Cadmium	3, 23, 24	0.02
Nickel	3, 23, 24	0.05
Mercury	3, 23, 24	0.0002
Arsenic	3	0.01
Sodium	23, 24	0.1
Calcium	23, 24	0.1
Magnesium	23, 24	0.01
Potassium	23, 24	0.1
Aluminum	3, 23, 24	0.1
Chlorides	23, 24	1
Sulphate	23, 24	1
Total phosphorus	3, 23, 24	0.01
Total Kjeldahl nitrogen	3, 23, 24	1
Nitrate, nitrite nitrogen	3, 23, 24	0.01
Total organic carbon	3, 23, 24	1
Chemical oxygen demand	3, 23, 24	6
Biological oxygen demand	23, 24	2
pH	23, 24	
Oil and grease	3, 23, 24	1
Pesticides	8	0.0001
Polychlorinated biphenyl (PCB)	8	0.00005
Asbestos	25	
Rubber	26	0.1%
Bacteria	3	
Soils analyses (excluding metals)	27	

5. Road sanding/salting — date and time of application, type, mix, rate of application, number of applications, and quantity applied

6. Road repair, lane marking, painting, or other road improvement items performed.

7. Accident and spill data that may be pertinent to the study

DATA HANDLING AND STORAGE

The large volume of data generated from the monitoring activities were cataloged and stored on the in-house Hewlett Packard 9845B computer. Data could then be readily accessed for unit conversions, statistical analysis, and report writing. The HP 9845B has graphic capabilities which allowed visual display during data analyses including scatter plots, modeling, and sensitivity analysis.

Data collected as a part of this study is available to interested parties on magnetic tape through the Federal Highway Administration. The tape is IBM-specific Fortran (ANSI FORTRAN IV).

SECTION IV

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