No. FHWA/RD-81/045

CONSTITUENTS OF HIGHWAY RUNOFF

Vol. IV. Characteristics of Runoff from Operating Highways. Research Report

February 1981

Final Report

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Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Environmental Division
Washington, D.C. 20590

FOREWORD

This report is composed of six volumes: Volume I documents the constituents of highway stormwater runoff and their pollutional effects; Volume II contains detailed procedures for conducting a monitoring and analysis program for highway runoff pollutant data; Volume III describes a simple predictive procedure for estimating runoff quantity and quality from highway systems; Volume IV is the research report discussing research approach and findings; Volume V contains the computer user's manual for a highway runoff data storage program and Volume VI is an executive summary. The report will be of interest to planners, designers and researchers involved in evaluation of highway stormwater runoff contributions to non-point sources of water pollution.

Research in Water Quality Changes due to Highway Operations is included in the Federally Coordinated Program of Highway Research and Development as Task 3 of Project 3E, "Reduction of Environmental Hazards to Water Resources Due to the Highway System". Mr. Byron N. Lord is the Project and Task Manager.

Sufficient copies of the report are being distributed to provide a minimum of one copy to each FHWA Regional office, Division office and State highway agency. Direct distribution is being made to the Division offices.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

NOTICE

Technical Report Documentation Page

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16. Abstract

This report relates to the identification and quantification of the constituents of highway runoff. It includes the details of monitoring site selection, field monitoring procedures, analysis of accumulated data, conclusions, significant findings and limitations. A total of 159 storm events were monitored at six sites between Spring of 1976 to September, 1977. The data were evaluated for: rainfall/runoff relationships; highway runoff pollutants loadings and variations with time; differences in pollutant characteristics from paved and non-paved areas; correlation of pollutants amongst measured parameters as well as with highway operation related factors. This is the fourth volume of a six volume document series. The titles of the volumes of this report are:

FHWA-RD-	Subtitle	
81/042	Vol. I	State-of-the-Art Report
81/043	Vol. II	Procedural Manual for Monitoring of Highway Runoff
81/044	Vol. III	Predictive Procedure for Determining Pollutant Characteristics in Highway Runoff
81/045	Vol. IV	Characteristics of Runoff from Operating Highways. Research Report.
81/046	Vol. V	Highway Runoff Data Storage Program and Computer User's Manual
81/047	Vol. VI	Executive Summary

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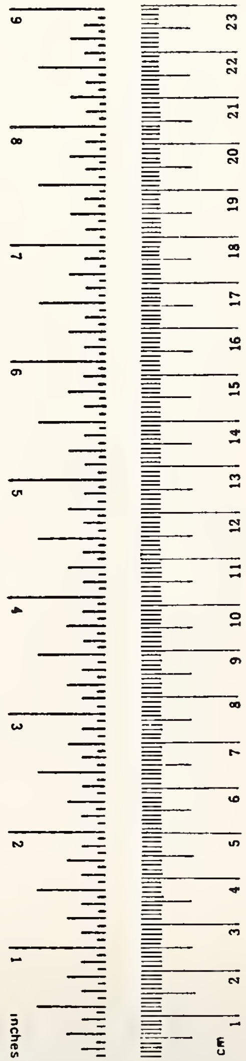
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

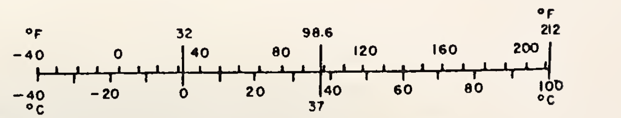
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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		
mm	millimeters	0.04	inches	in
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
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ACKNOWLEDGEMENTS

Acknowledgement is given to numerous State highway and U.S. Geological Survey representatives as well as individual experts who provided assistance during the progress of the study and preparation of the final report. It is not possible to name all who participated in this research study and therefore only a few key agencies and persons are listed below.

The following State highway agencies provided technical assistance, sites for field investigations, traffic and maintenance data:

Colorado State Department of Highways
Louisiana Department of Transportation and Development
Pennsylvania Department of Transportation
Tennessee Department of Transportation
Wisconsin Department of Transportation

District offices of the U.S. Geological Survey in Colorado, Pennsylvania, Tennessee and Wisconsin provided technical assistance in equipment installation and site operation.

Review and assistance in the preparation of the final reports was provided by: Richard Howell, California Department of Transportation and Roderick Moe, Texas State Department of Highways and Public Transportation.

In addition to those agencies and individuals acknowledged above, sincere appreciation is expressed for the work of Frank K. Stovicek, (deceased), FHWA, Office of Research who thoroughly reviewed the final report.

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. Highway runoff along with other urban land runoff (nonpoint sources) are now considered as possible additional sources (in addition to point 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:

1. Identify and quantify the constituents of highway runoff.
2. Identify the sources and the migration paths of these pollutants from the highways to the receiving water.
3. Analyze the effects of these pollutants in the receiving waters.
4. Develop the necessary abatement/treatment methodology for objectionable constituents.

An extensive literature review was conducted at the beginning of this study to prepare a State-of-the-Art Report. This report was then updated throughout the conduct of the Phase I research and an updated version is being published as the Volume I of a six volume document series that describe the results of the Phase I research and is titled, "Constituents of Highway Runoff". Furthermore, a Procedural Manual has been written for use by state highway personnel which contains detailed procedures for establishing and conducting a monitoring program. This manual constitutes Volume II of the above mentioned document series. Volume III, "Predictive Procedure for Determining Pollutant Characteristics in Highway Runoff" utilizes the accumulated data to formulate a highway pollutant accumulation and wash-off model. The model is designed as a means to assist the highway designer in writing environmental impact statements. Volume IV, "Characteristics of Runoff from Operating Highways Research Report", provides a complete documentation of all work performed under this project including details of site selection, field monitoring, data analysis, conclusions and significant findings. Volume V presents the details of the computer program developed for the handling and storage of data generated during this study. The sixth volume is an executive summary of the entire project under Contract No. DOT-FH-11-8600.

The titles of the various reports comprising this six volume document series which relates to the objective No. 1 of the FHWA research program are:

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:	Constituents of Highway Runoff - An Executive Summary.

This report constitutes the Volume IV of the above described document series.

SECTION II
MONITORING SITE SELECTION

SITE SELECTION CRITERIA

The selection of monitoring sites was considered to be a very critical task since the data collected from these sites were to form the basis for the development of much of the predictive procedure, as well as the overall conclusions and findings of the study. Since the possible locations of monitoring sites were almost unlimited, the following criteria were applied to the selection of the monitoring sites:

1. Adjacent land usage and airborne particulates fallout.
2. Traffic characteristics.
3. Precipitation characteristics and geographic location.
4. Drainage area and highway design characteristics.
5. Pavement characteristics.
6. Logistical considerations.
7. Receiving water characteristics.

A brief discussion of these parameters for site selection follows:

1. Adjacent Land Usage and Airborne Particulates Fallout

The adjoining land use activity near a highway system can have significant influence on the transport of pollutants onto the highway system. Both rural and urban areas can exhibit peculiar features such as widely varying airborne particulate fallouts and traffic characteristics. For this study, it was planned to select a minimum of one rural, one suburban and two or three urban sites in order to represent the general spectra of highway systems. Also, feedback received from various State Highway Departments indicated that potential pollution problems would be more severe in urban areas while some representation of rural areas must be included in the study program.

2. Traffic Characteristics

It was desired to select sites representing a wide variation in average daily traffic (ADT) volumes. The desired range of ADT values for the selected sites was:

Less than 20,000 ADT
20,000 to 35,000 ADT
35,000 to 50,000 ADT

50,000 to 80,000 ADT
Greater than 80,000 ADT

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

Vehicular mix (car and truck mix)
Congestion factors (braking), ramps, weaving
Level of service factors - Number of lanes, variations in traffic flow
Vehicular Speed

3. Precipitation Characteristics and Geographic Location

The form of precipitation, i.e., rainfall or snow, can have significant effect on highway runoff. At least two sites were planned to have significant snowfall while at least one site was planned to have 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 wide variation in geographical locations in order to provide a broad character to the study findings.

4. Drainage Area and Highway Design Characteristics

The most important consideration in the site selection criteria was to find sites having well defined drainage areas with minimum influence from nonhighway land use activities. Large, highway drainage areas were considered desirable for suitably characterizing the overall constituents of highway runoff leaving highway drainage systems. Such highway drainage areas are difficult to isolate because of extraneous drainage additions along various points in many of the existing drainage systems. Typical highway drainage areas considered for site selection were generally in the range of 2,000 to 3,000 ft (610 m to 915 m) in length and encompassed an approximate area of 8 to 10 acres (3.2 to 4.0 ha).

Another important consideration made in the site selection was to ensure that the 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 various highway design features to ensure selection of typical highway sections across the country. Some of the design features considered in site selection were:

Vertical alinement of the roadway - Elevated, ground level or depressed sections.

Highway grades
Type of drainage system - curb & gutter or flush shoulder type
Type of highway section - straight sections, intersections
Median barrier characteristics
Right-of-way characteristics - Type of cover
Maintenance practices such as grass mowing, herbicide use and irrigation practices
Slope

5. Pavement Characteristics

It is important to know the relative degree of pervious and impervious areas within a highway drainage area because of potential impact on highway runoff. It was desired to select sites representing a wide range of pervious/impervious pavement characteristics.

The type of pavement surface i.e., bituminous or concrete may also affect the quantity or quality of pollutants discharged from a highway system. Both types of pavement surfaces were included for monitoring sites. The age of pavement and the pavement maintenance practices can also have significant effect on the accumulation of pollutants on highways. Most selected sites were desired to have a typical surface condition with respect to wear and tear of the roadway.

6. Logistical Considerations

These considerations included several miscellaneous items such as:

a. Accessibility - All selected sites were to be accessible to operating personnel both in terms of convenience and safety for installing, as well as 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 about the pollution abatment research study.

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

c. Construction Activity - It was emphasized and carefully checked during site selection procedure that no major construction activity 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. In this respect 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. However, in spite of this, some construction activity occurred near two of the selected sites but the frequent contacts with highway agencies enabled the study participants to take steps to minimize the impacts of such construction activity.

7. Receiving Water Characteristics

The ideal location of a monitoring site for highway runoff impact studies would be on a stream where the upstream samples above the selected monitoring point were not contaminated by other nonmonitored discharges. In this way, heavy metal loads and other sensitive parameters could be attributed more easily to the highway runoff. Also, the monitored reach of the receiving stream should be free from overland inflows or withdrawals.

However, it was recognized that it might be difficult to find sites fulfilling this tall order, therefore, it was decided to rank receiving water considerations at the lowest hierarchy.

DESCRIPTION OF SELECTED SITES

Seven highway sites were selected around the country based on the site selection criteria discussed above. Three of the selected sites were located in Milwaukee, WI and one each in Harrisburg, PA, Nashville, TN, Denver, CO, and Baton Rouge, LA. However, no significant data could be collected at the Baton Rouge, LA site because of various problems and the operations were discontinued at this site during 1977. Therefore, site descriptions and evaluations are presented only for the six other sites throughout this report.

Among the three sites in Milwaukee, WI, the largest site was located on state Hwy. 45 and had a drainage area of 106 acres (42.9 ha). Two typical photographs of this highway are shown in Figure 1. The other two Milwaukee sites were significantly smaller in size (less than 3.0 acres area) but were selected for the investigation of runoff from an all paved (impervious) area site located on interstate I-794 (Figure 2) and an all pervious (unpaved) area site located on an inlet on Hwy. 45 (Figure 3).

Harrisburg, PA was the only site located in a rural environment among the selected sites (Figure 4). All the other sites were located in urban/suburban environments (Figure 5 and 6). The locations of the monitoring points for all of these sites, either in the sewer, or at the outfall, were such that the runoff from the entire upstream drainage area could be monitored. A summary of the important characteristics of the selected sites is shown in Table 1. The average, daily traffic at these sites varied from a low of 24,000

Figure 1. Typical photographic view, (looking north) Hwy. 45 site, Milwaukee, Wisconsin.

View looking west

View looking east

Figure 2. Typical photographic views, I-794 Milwaukee, Wisconsin.

View looking east

Figure 3. Typical photographic view, Hwy. 45 grassy site, Milwaukee, Wisconsin.

View looking north

View looking south

Figure 4. Typical photographic views, I-81 site, Harrisburg, Pennsylvania.

View looking east

View looking west

Figure 5. Typical photographic views, I-40 site, Nashville, Tennessee.

View looking north

View looking south

Figure 6. Typical photographic views, I-25 site, Denver, Colorado.

Table 1. Characteristics of selected sites.

Location	Type	ADT	Precipitation in./yr Total	Snowfall	Drainage area, acres Total	Paved	% Paved	Surface type	Highway length, ft	# of lanes	Type of selection	Curb/barrier	Outfall/manhole size, in.
Milwaukee, WI I-794	Urban	53,000	30	40-60	2.1	2.1	100	Concrete	813	8	Elevated	Yes	24
Milwaukee, WI Hwy. 45	Urban	85,000	30	40-60	106.0	33.0	31	Concrete	9,500	6	Cut & Fill	Yes	72
Milwaukee, WI Hwy. 45	Urban	85,000	30	40-60	2.5	0.0	0	Grass cover	500	-	Fill	-	15
Harrisburg, PA I-81	Rural	24,000	40	20-30	18.5	5.0	27	Concrete	2,000	6	Fill	No	36
Nashville, TN I-40	Urban	88,000	55	1-20	55.6	20.5	37	Concrete	6,290	6	Cut	Yes	48
Denver, CO I-25	Urban	149,000	20	60-100	35.3	13.2	37	Asphalt	3,600	10	Fill	No	30

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

at the Harrisburg site to a high of 149,000 at the Denver, CO site. Total precipitation variation was between 20 and 60 inches (50-152 cm) per year, with wide variations in rainfall and snowfall patterns. For example, snowfall varied from nearly insignificant amounts at Nashville to as high as 100 inches (254 cm) at Denver, CO. Also, there were significant variations in the magnitude and type of drainage areas for the various sites. The all-paved I-794 site had a drainage area of only 2.1 acres (0.85 ha) while the Hwy. 45 site drained an area of 106 acres (42.9 ha). The unpaved or the all-grassy area site had a drainage area of 2.5 acres (1.0 ha). Various other features of the selected sites pertaining to surface type, length, number of lanes, type of section, curb/barrier existence and the size of the monitoring sewer are also shown in this table.

Additional descriptions for the six selected sites along with drainage plans and typical highway sections follow.

I-794, Milwaukee, WI

This site is the east extension of I-94 and is a bridge structure in downtown Milwaukee near Lake Michigan. It is an eight lane elevated section with all the drainage conveyed to the Milwaukee River through a separate and isolated 24 in. (61 cm) storm sewer. Drainage is conveyed to the sewer by means of inlets and downspouts. The site section extends from east of 6th Street to west of 3rd Street. It is a 813 ft (248m) long 2.1 acres (0.85 ha) section and had a ADT of 53,000 for 1976-77. A schematic drainage plan of this site is shown in Figure 7 and a typical section is shown in Figure 8.

It is an entirely (100%) paved (concrete) urban site with significant industrial activity surrounding it. Because of its location on an elevated bridge deck, it is not influenced by drainage from any right-of-way areas with soil or vegetative cover. This site was considered ideal for the purposes of developing the predictive model through monitoring of pollutant accumulations and wash-off from the paved areas without influence of right-of-way areas. The roadway has 27 inch (0.7 m) high concrete barriers with guard rails and a grade of 1.94%.

Milwaukee area has about 30 in. (76 cm) of total precipitation (including snowfall in water equivalents) per year and approximately 40 to 60 in. (102 to 152 cm) of snow (as snowfall) each year. Salt is used to melt snow and ice and a bare pavement snow removal policy is generally maintained throughout the winter season.

Hwy. 45, Milwaukee, WI

This site is located on Hwy. 45 (I-894 by-pass) extending from Bluemound Road northwest to the bridge over Underwood Creek just east of

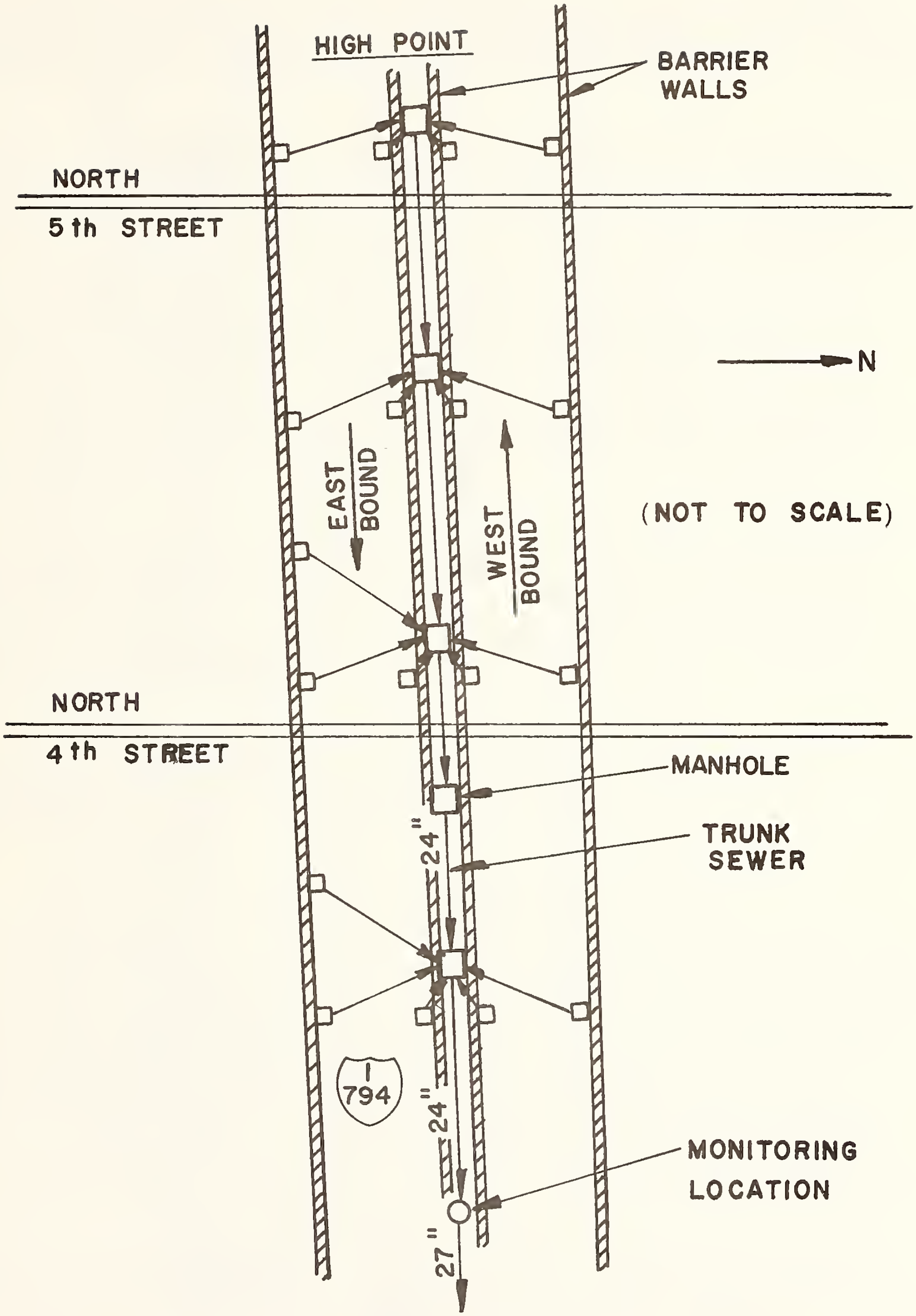


Figure 7. Schematic drainage plan, I-794, Milwaukee, WI

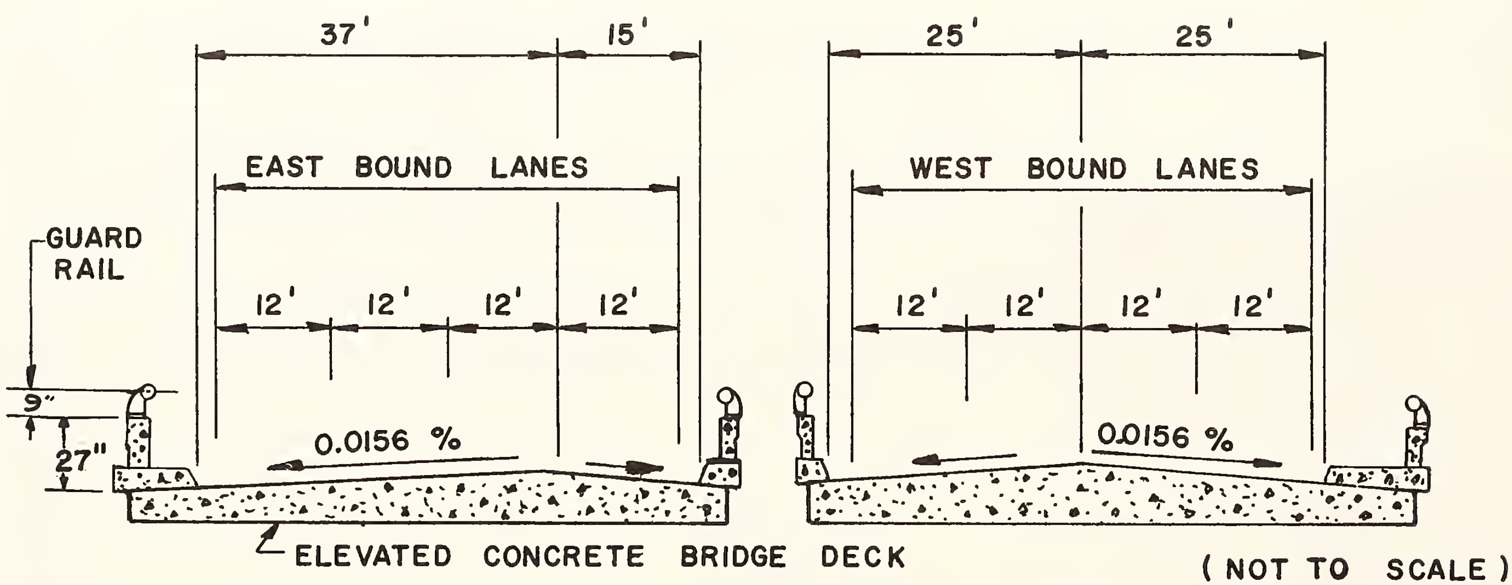


Figure 8. Typical cross section, I-794, Milwaukee, WI

Hwy. 100 in Milwaukee, WI. It is a 6 lane freeway with concrete pavement located in a suburban area. New concrete barriers were added in the median on this freeway during 1975 as safety improvements. Average daily traffic during 1976-77 was 85,000.

The site is characterized as "urban" both by adjoining land use activity, as well as the type of drainage system design. A schematic drainage of the site is shown in Figure 9 and a typical section is shown in Figure 10. This is the largest of the 6 sites encompassing 106 acres (42.9 ha). Nearly 70 acres (28.4 ha), 66% of the total area, is within the highway right-of-way area while 36 acres (14.6 ha), 34% is off-site area, consisting predominantly of grassy land adjoining the highway right-of-way. The selected highway section is 9,500 ft (2.9 km) long and has 33.0 acres (13.4 ha), 31% of the total drainage area, as impervious (paved) area. Within the 9,500 ft (2.9 km) section, the freeway has ground level (at grade), depressed (below grade) and elevated (above grade) roadway sections. Roadway grades vary from 0.5% to 2.98%.

Pavement drainage is to inlets in the median adjacent to the concrete barrier and inlets in the mountable curb. Grass areas are drained by grass lined ditches to inlets on the outer edges of the roadway. All inlets are connected by laterals to a trunk sewer which drains the entire 106 acre (42.9 ha) area into Underwood Creek. The creek then joins the Menomonee River.

Monitoring location was a large and deep junction chamber manhole for this trunk sewer. Trunk sewer pipe size was 72 in. (1.8 m) at the manhole which was the last manhole before the outfall of the trunk sewer into Underwood Creek.

Hwy. 45 Grassy Site, Milwaukee, WI

The site is located near the on-ramp from Bluemound Road to the southbound freeway (Hwy. 45) and is within the right-of-way of the Hwy. 45 site as shown in Figure 9. It is an all-pervious (unpaved) area grassy site having a total drainage area of 2.5 acres (1.0 ha). This site was added about midway through the study in an attempt to characterize differences between runoff quality and quantity from pervious and imprevious areas. A schematic drainage plan of the site is shown in Figure 11. The length of the freeway adjacent to the ramp is about 500 ft (152.5 m) and the traffic volume for this site was the same as for Hwy. 45 (ADT = 85,000).

Runoff monitoring was conducted at a shallow inlet near the Hwy. 45 on-ramp as shown in Figure 11. This site has a shallow cut slope of about 3.2% from the high point at 97th Street to the low point monitoring location near the ramp. Grades for the curved ramp ditches extending from both sides of the low point inlet vary from 1.4% to 3.3%. The grass area within the site area is not mowed except for an 8 ft (2.4 m) strip along Hwy. 45. The storm sewer at

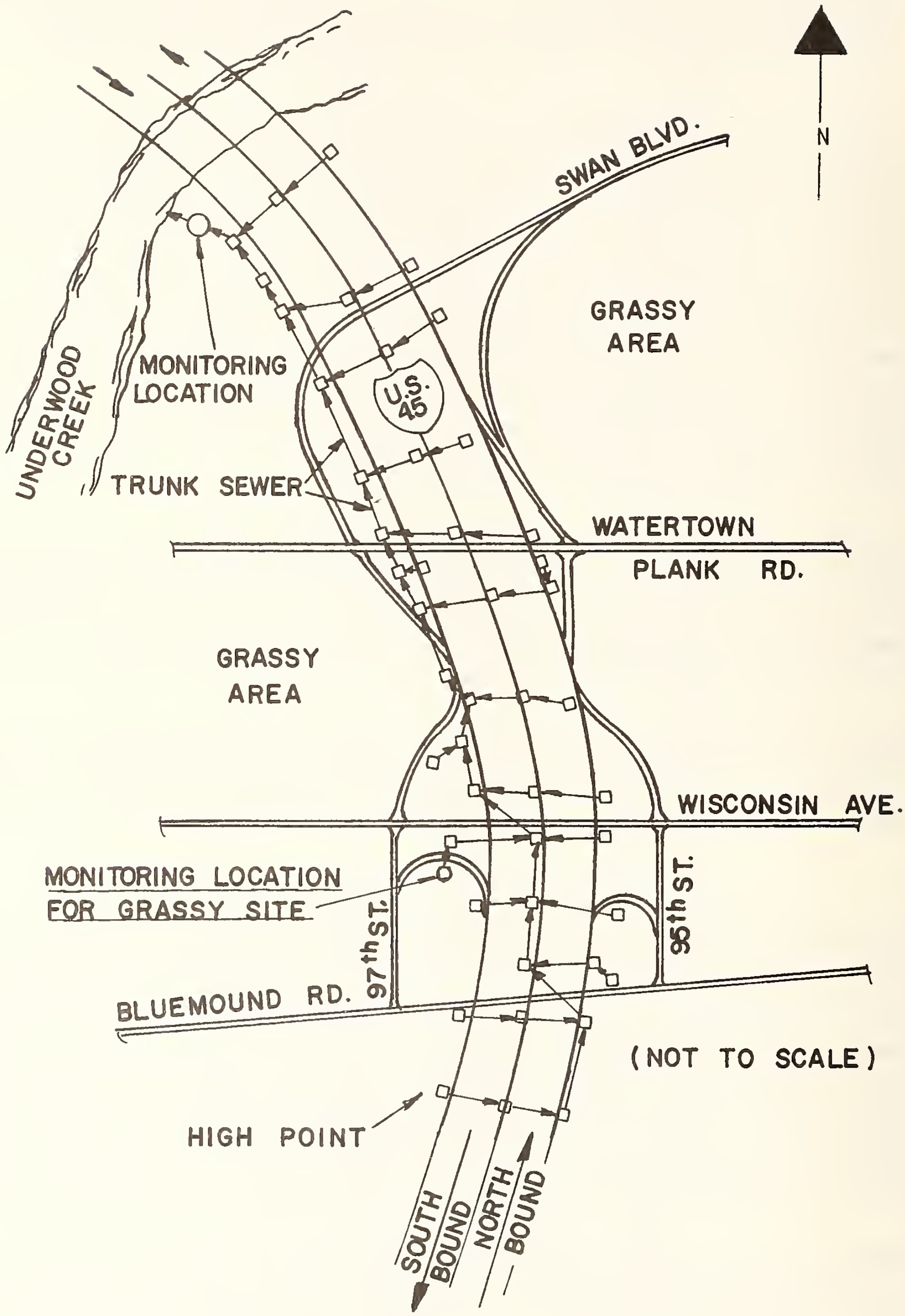


Figure 9. Schematic drainage plan, Hwy. 45, Milwaukee, WI

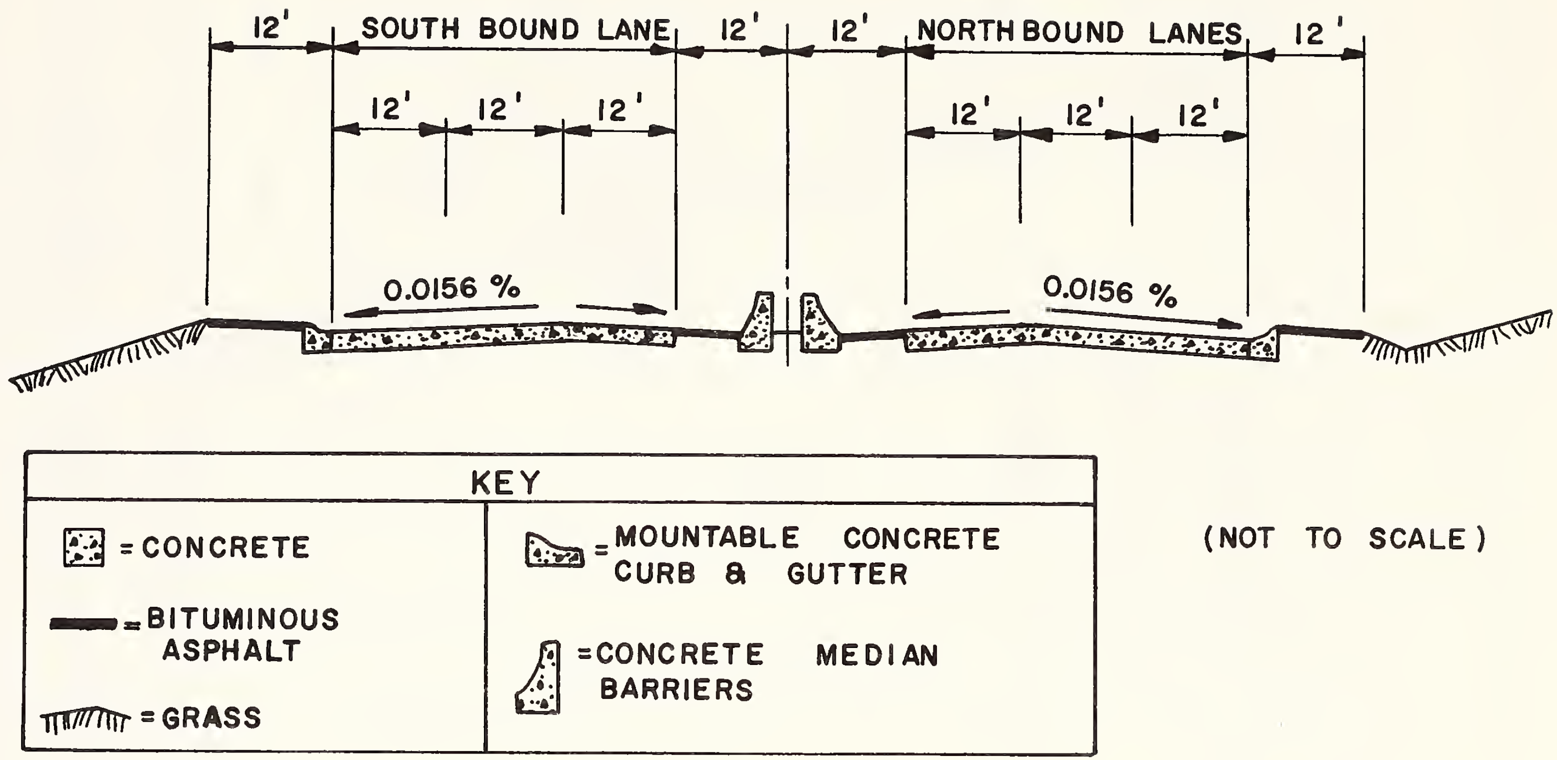


Figure 10. Typical cross section, Hwy. 45, Milwaukee, WI

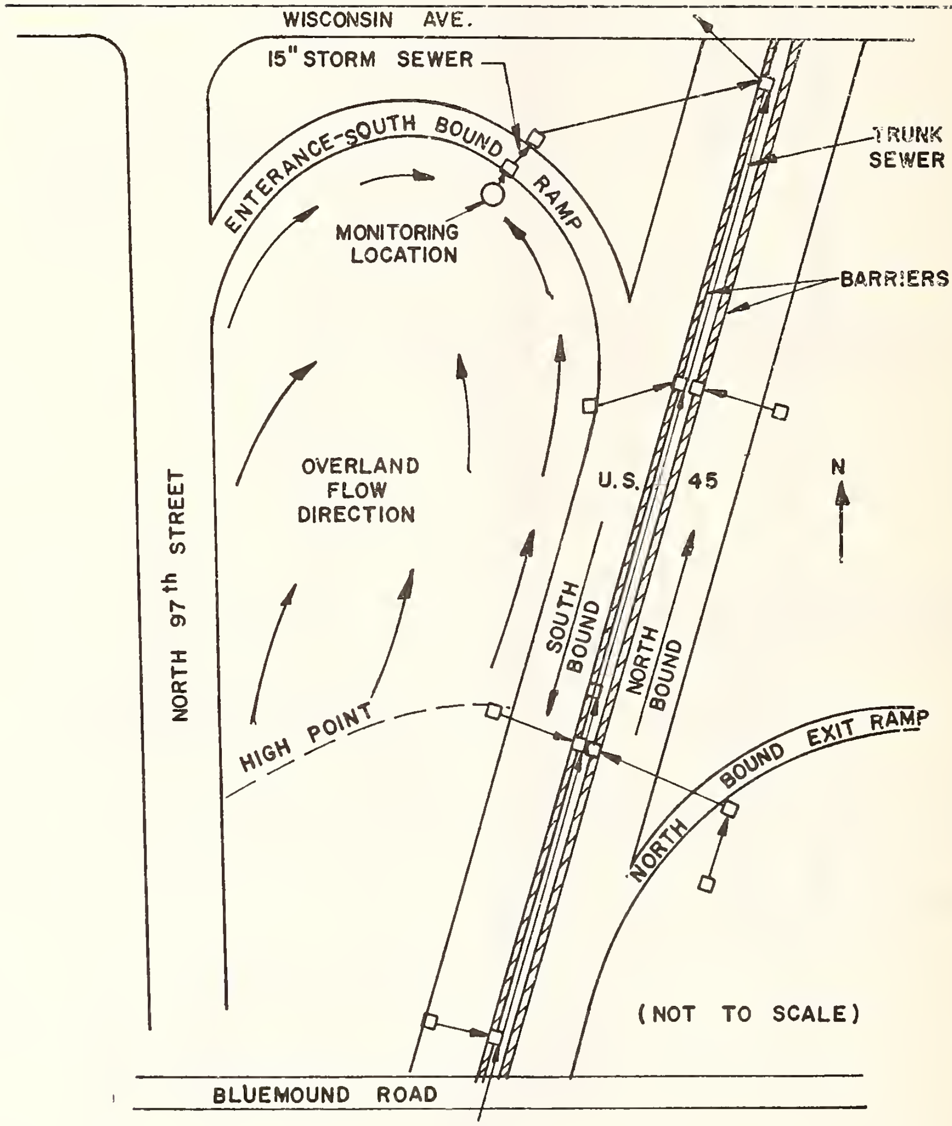


Figure 11. Schematic drainage plan, Hwy. 45 grassy site, Milwaukee, WI

the monitoring point is a 15 in. (38 cm) diameter concrete sewer.

I-81, Harrisburg, PA

This site is located on Interstate 81 in Cumberland County near Enola, PA. The site is characterized as rural based on adjoining land use activity. It is a new highway. Construction began in the fall of 1972 and the highway was opened to traffic on September 11, 1975. The site area spans on both sides of Wertzville diamond interchange (intersection of I-81 and state route 944), between stations 475 and 491 for the southbound lanes and stations 483 and 496 for the northbound lanes. At the interchange, I-81 passes under Wertzville Road (Rt. 944). The 1976-77 ADT for the site was 24,000.

The total drainage area is 18.5 acres (7.5 ha), almost all of which is within the highway right-of-way. The off-site drainage to the monitoring point is very minimal. A schematic drainage plan is shown in Figure 12. One full ramp and portions of three other ramps along with a portion of the Wertzville road bridge are included in the site drainage area. The paved areas total 5.0 acres (2.0 ha) accounting for 27% of the total area. This is a 6 lane concrete pavement highway with 6 to 8 ft (1.8 to 2.4 m) wide bituminous flush shoulders approximately 2000 ft (610 m) long. A typical highway section is shown in Figure 13. It has no median barriers.

Drainage is collected at inlets located in the grass lined ditches and routed by means of storm sewers to a 36 in. (0.91 m) culvert outfall into an existing ditch which drains to a tributary of Conodquinet Creek. Separate grass lined ditches drain both outer edges of the roadway and the wide median into the creek tributary. Roadway grades are 0.5%.

Harrisburg has about 35 to 45 in. (89 to 114 cm) of total precipitation (including snowfall in water equivalents) per year and 20 to 30 in. (51 to 76 cm) of snow (as snowfall) each year. Salt and sand are applied on the site section only under icy and hazardous road travel conditions. No salt is used for smaller snowfalls when hazardous driving conditions are not expected.

I-40, Nashville, TN

This site is located on Interstate I-40 in Nashville, TN and encompasses the I-40/I-70 interchange to just east of Brown Creek (Hwy. stations 435 to 373). The selected highway section is a 6 lane depressed (below grade) urban freeway. It is a 6,200 ft (1.9 km) long section with concrete pavement and curbs. 1976-77 ADT was 88,000 with a higher than average percentage of truck traffic: approximately 12% of the ADT. Total drainage area of the site is 55.6 acres (22.5 ha) of which 42.1 acres (17.0 ha) are within the highway right-of-way, 13.5 acres (5.5 ha) are off-site consisting predominantly of grassy

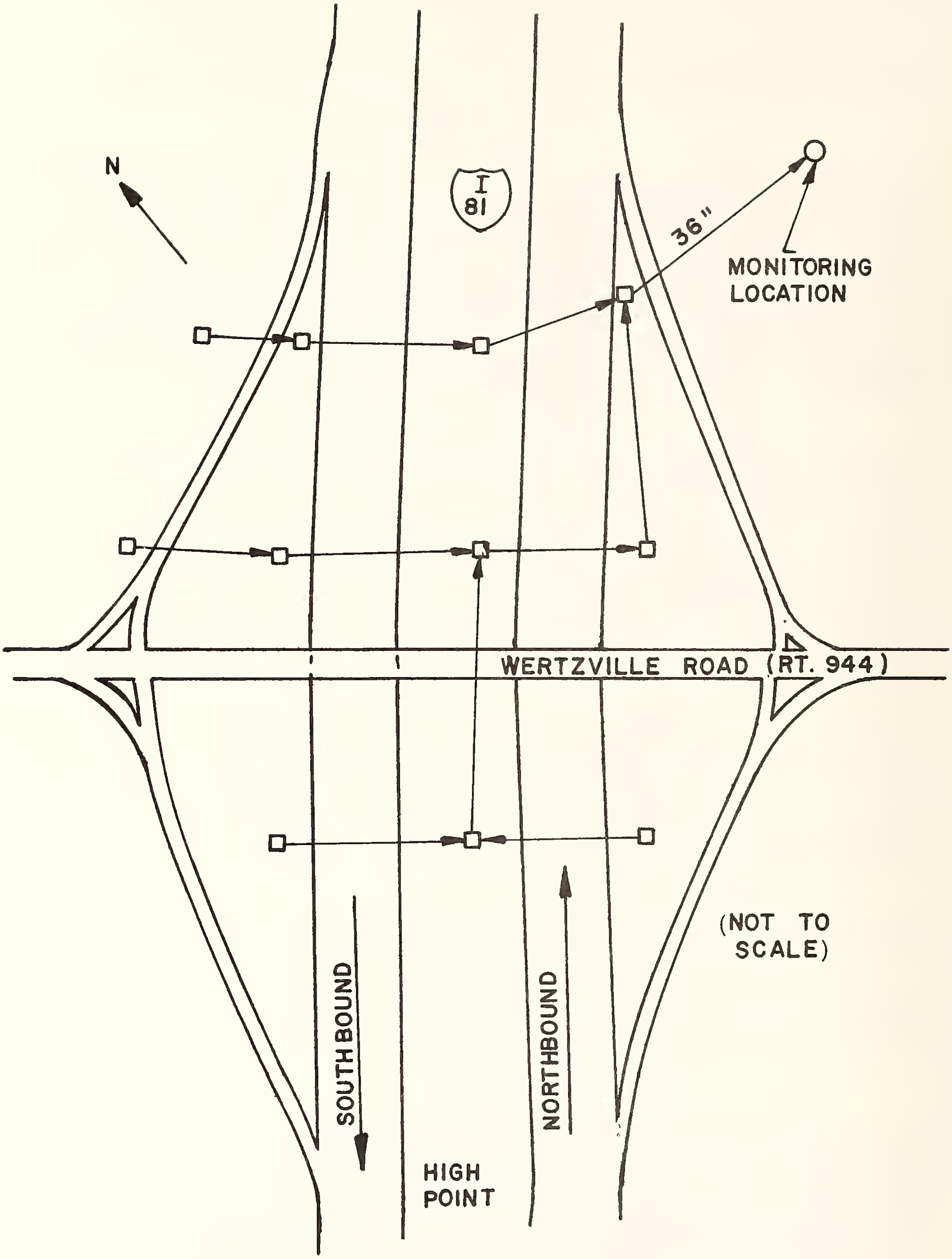


Figure 12. Schematic drainage plan, I-81 site, Harrisburg, Pennsylvania.

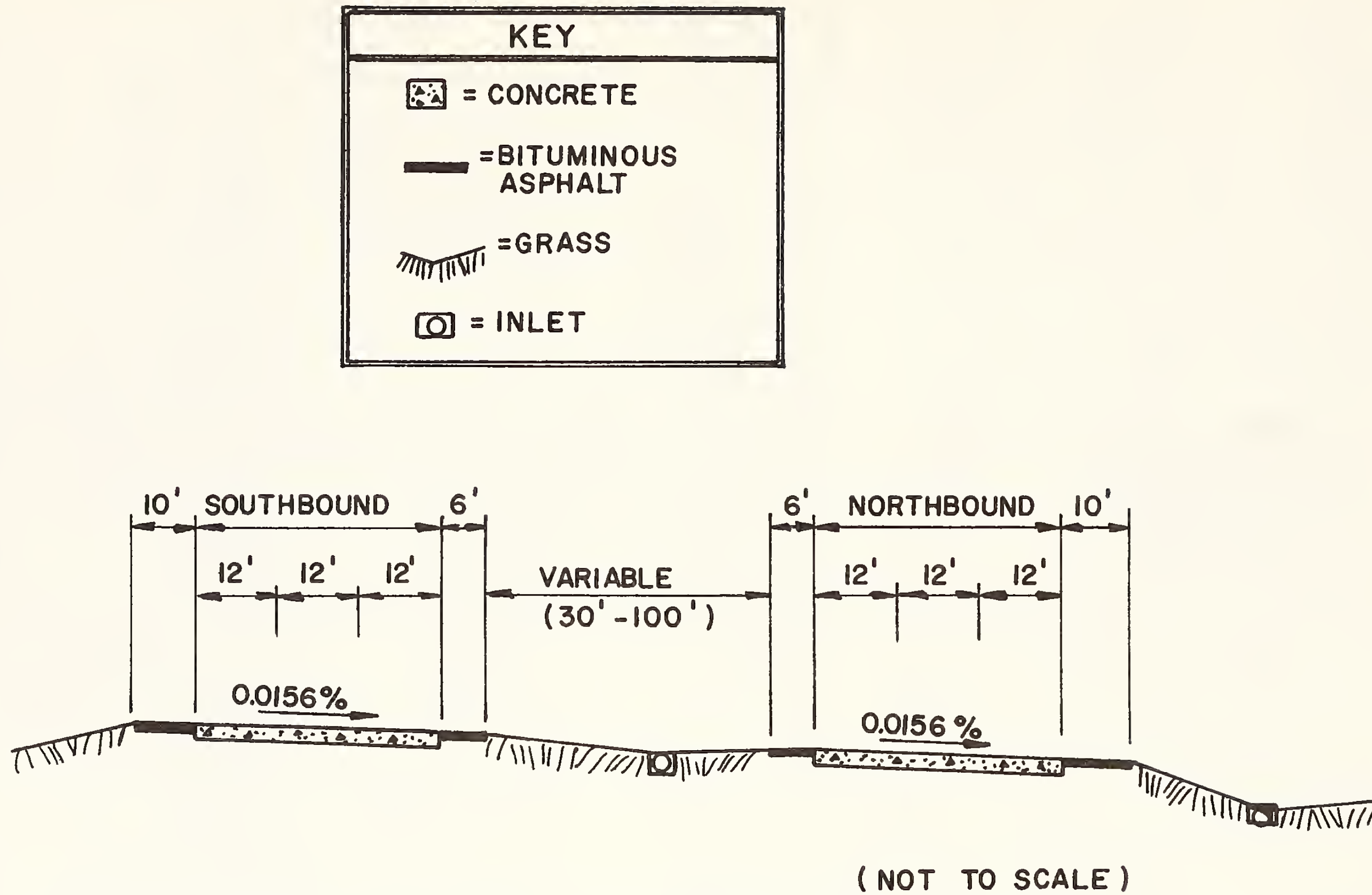


Figure 13. Typical cross section, I-81 site, Harrisburg, Pennsylvania

areas of cemeteries and private residences adjoining the highway right-of-way. Twenty and a half acres (8.3 ha) are paved (impervious) areas constituting 37% of the total drainage area. Included in the paved area is concrete pavement, asphalt shoulders, and approximately one acre (0.4 ha) of rock cut (see photo Figure 5).

The site is characterized "urban" by adjoining land use activity as well as the high volume of traffic (88,000 ADT). The freeway section has standard 12 ft (3.7 m) lanes, mountable concrete curbs and gutter in the median and outside edges of the roadway traffic lanes, and 6 ft to 8 ft (1.8 to 2.4 m) asphalt shoulders. Concrete gutters for drainage are placed in the shoulder areas of cut, both in the standard grass covered cut areas and in the rock cut areas. Roadway grades along the length of the highway section vary from 0.5% to 4.0%. A schematic drainage plan of the site is shown in Figure 14 and typical cross sections for the normal and rock cut portions of the site are shown in Figure 15.

Nashville has a yearly rainy season in winter and spring, with total precipitation (inclusive of snowfall water equivalents) of about 50 to 60 inches (127 to 152 cm) and 1 to 20 inches (2.5 to 50.8 cm) of snow as snowfall. Salt is used for icy conditions. The storm sewer in the manhole being monitored is 48 inches (1.2 m) in diameter. The runoff from the site is discharged to Brown's Creek.

I-25, Denver, CO

This site is located on Interstate route I-25 in Denver, CO and extends from just south of fully directional interchange with I-70 to Fox Street. 1976-1977 ADT was 149,000. The selected section is a 3,600 ft (1,098 m) long, 10 lane, urban freeway. Denver is the only site having asphalt pavement. Total drainage area of the site is 35.3 acres (14.3 ha). Of the total drainage area, 27.8 acres (11.3 ha), 79%, is within the highway right-of-way while 7.5 acres (3.0 ha), 21%, is off-site area. The off-site area consists predominantly of grass covered land. Total paved area is 13.2 acres (5.3 ha), 37% of the total drainage area. The site is characterized as urban by adjoining land use activity as well as the high volume of traffic (149,000 ADT). A schematic drainage plan for the site is shown in Figure 16. The stormwater runoff from both the north and southbound lanes is carried in a 30 in. (0.76 m) storm sewer running through the median. The runoff is ultimately discharged to South Platt River about 2 miles (3.2 km) from the site.

I-25 was originally constructed with 6 lanes, but has been reconstructed to 10 lanes to accommodate higher volumes of traffic. The northbound lane has mountable curb in the median for normal superelevated (banked) sections. The southbound superelevated section has a flush shoulder with a low side gutter for drainage of the paved roadway area and shoulder area. The outside lane is an acceler-

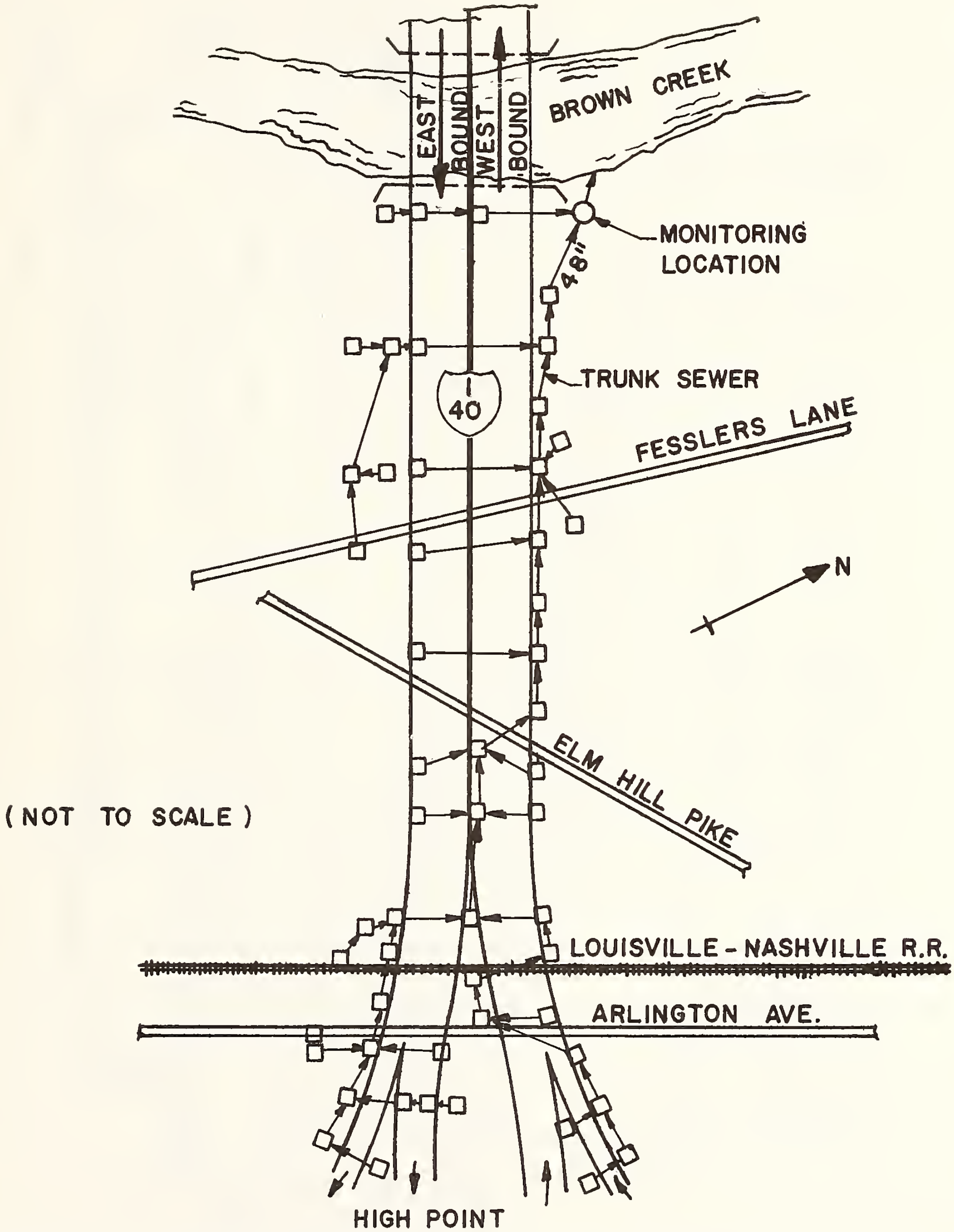


Figure 14. Schematic drainage plan, I-40 site, Nashville, TN

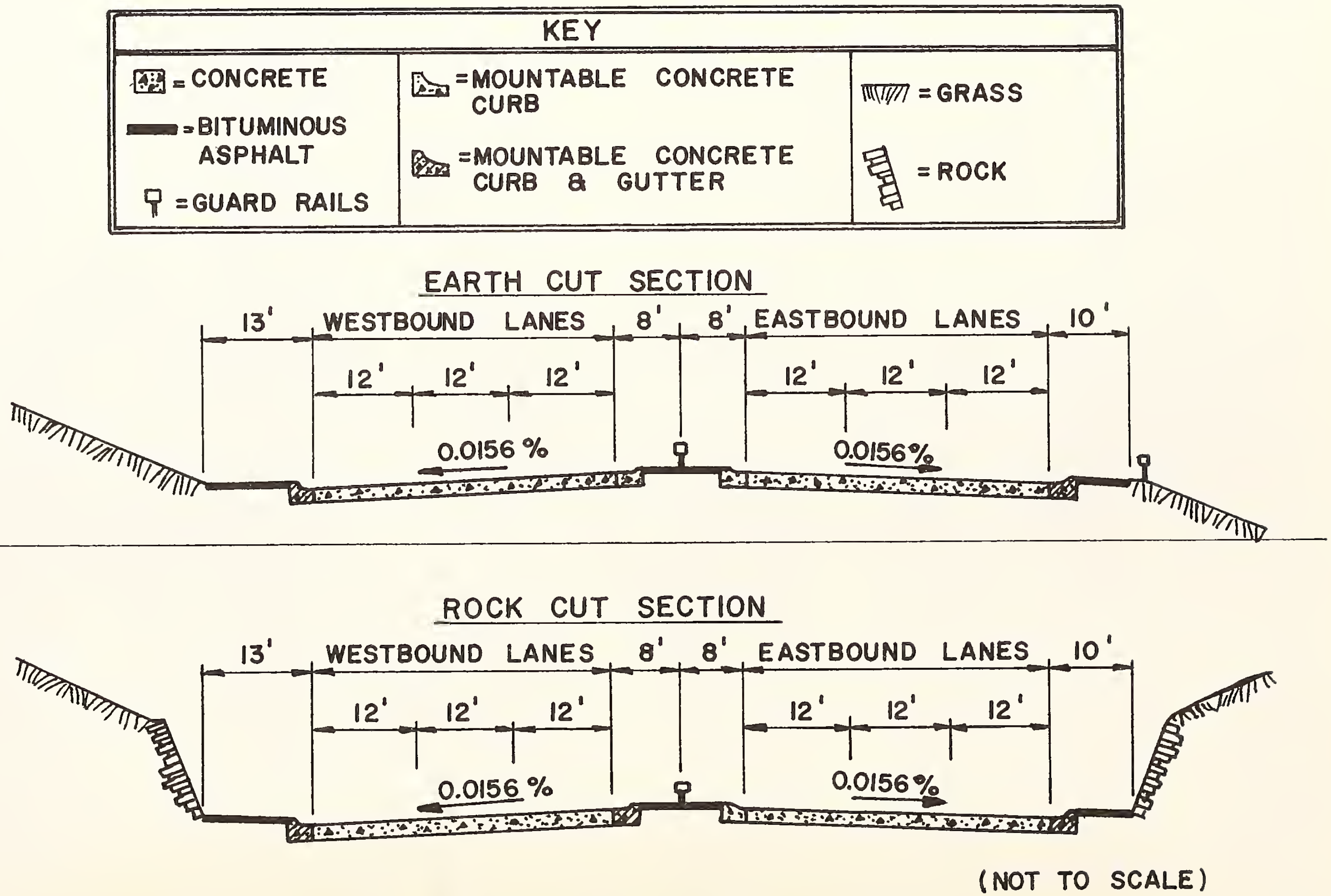


Figure 15, Typical cross sections, I-40 site, Nashville, TN

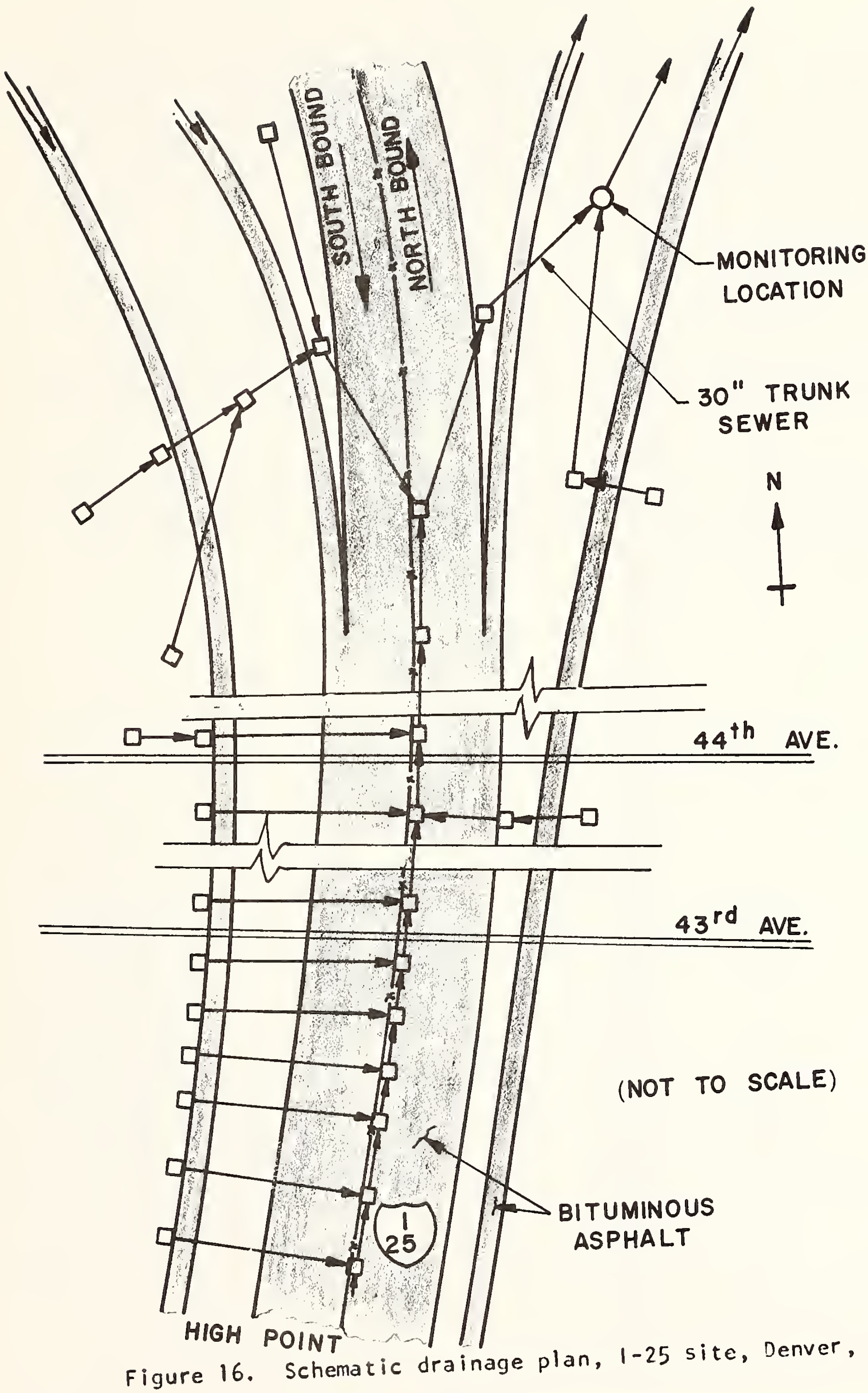


Figure 16. Schematic drainage plan, I-25 site, Denver, CO

ation and deceleration lane between the I-70 interchange ramps at Fox Street. At the I-70 interchange, the 2 outside lanes are dropped and the freeway becomes 8 lanes. Standard curb and gutters are placed in the outside freeway lanes and the left side of the ramp lane to provide separation between the freeway and the 2 ramps. Freeway grades vary from 0.10% to 0.40%. A typical section is shown in Figure 17.

Denver receives about 15 to 25 in. (38 to 63.5 cm) of total precipitation (including snowfall as water equivalents) annually and 60 to 100 in. (152-254 cm) of snow as snowfall. Sand and salt are used for control of snow and ice. The site also contains a permanent sprinkler system to provide water for landscaping maintenance during periods of dry weather.

The site was monitored at a manhole where the storm sewer was 30 in. (0.76 m) in diameter. The manhole is located in the southeast part of the interchange, and is adjacent to the north to west ramp and between that ramp and the north to east ramp.

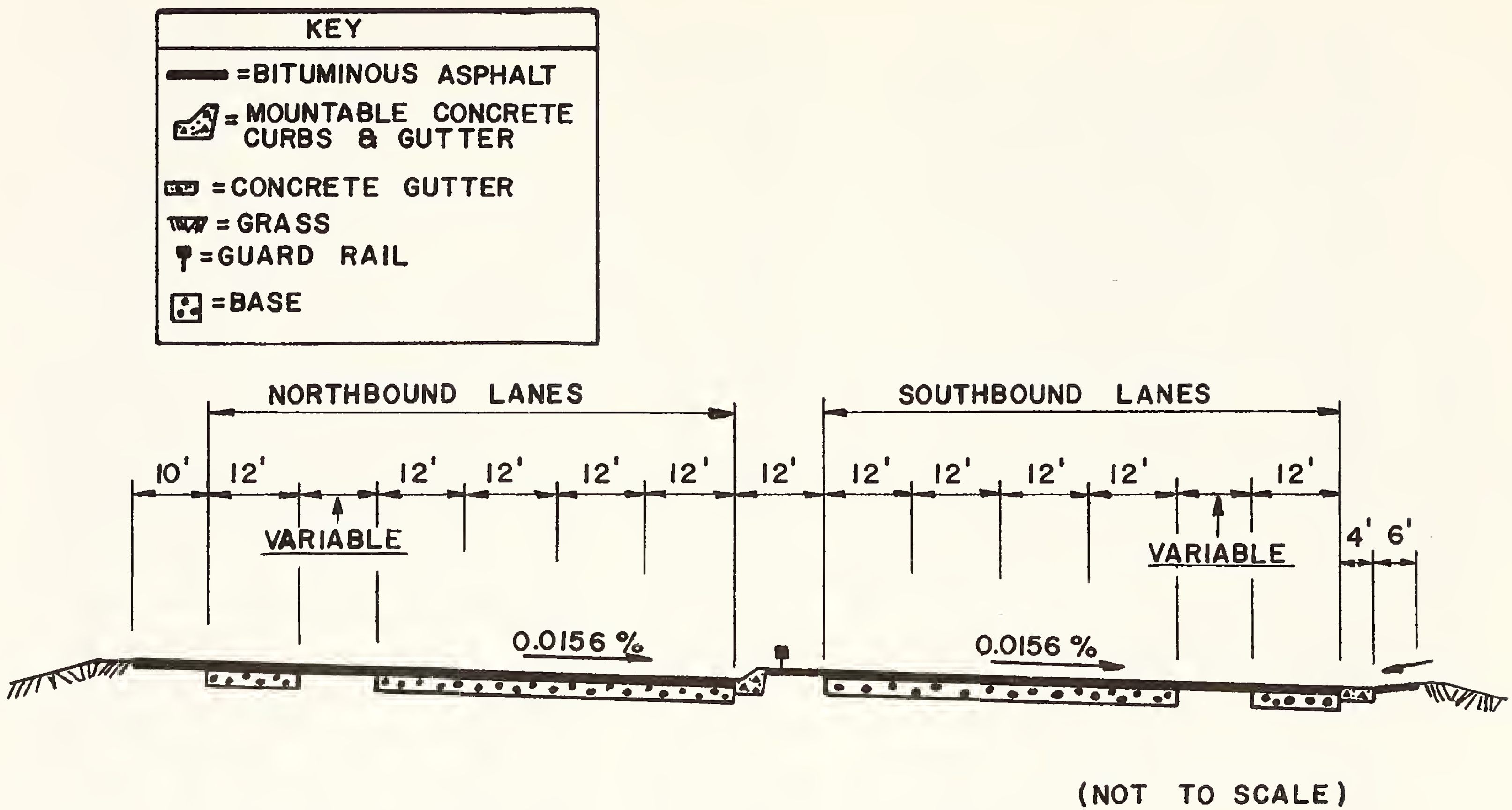


Figure 17. Typical cross section, I-25 site, Denver, CO

SECTION III
MONITORING PROGRAM

Monitoring of storm events was conducted for a minimum 12 month period at each site. This time frame allowed for a study of variations in pollutant characteristics due to seasonal changes and produced between 16 and 30 storm events at each site. A fairly wide variation in rainfall intensities, rainfall durations and prestorm conditions (i.e., the number of dry days) was encountered during the study period. Close contacts with local weather forecasters and the National Weather Service were maintained to choose storms of varying intensity and duration as far as possible. Initially, storm events were monitored at a frequency of not exceeding once per week to obtain preliminary data. Later, attempts were made to monitor all storm events, back to back, between two large storm events of sufficient total volume (>1.0 in. (2.54 cm)) and of sufficient intensity (minimum 0.5 in. (1.27 cm) per hour)) for obtaining the necessary pollutant build-up and wash-off data for the predictive model.

DATA COLLECTION

In order to suitably characterize highway runoff, it was necessary to collect data for not only the volume and concentration of pollutants emanating from a highway system, but also the variables which affect the accumulation of pollutants at the monitoring site. Therefore, the following types of data were collected at all the monitoring sites:

1. Traffic characteristics.
2. Highway maintenance data.
3. Precipitation data.
4. Air particulate fallout (dustfall) data.
5. Runoff quantity and quality data.

Traffic Characteristics

The collection of traffic counts is important for correlation of the runoff pollutants with traffic characteristics. Also, periodic vehicle classification counts were considered necessary to record any changes in vehicular mix due to seasonal variations. All selected study sites except the I-81 Harrisburg, PA site had permanent automatic traffic counters located on or near the site. Temporary traffic counters were installed at the Harrisburg site by the Pennsylvania Department of Transportation under contract from the Federal Highway Administration. The necessary 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 departments similar to the traffic data. The following maintenance data were requested from these highway departments. However, only limited maintenance data were recorded and were available from various highway departments as discussed later in Section IV.

- -Road cleaning: technique, dates, time, frequency and duration along with best estimates of the total amount removed.
- -Roadside mowing and/or weed cutting: technique, dates and time, frequency and duration.
- -Herbicide spraying: type of herbicide, application date and method, rate of application and total amount used.
- -Sprinkler irrigation: frequency, duration and estimate of water usage.
- -Fertilizer: type, spreading, total amount used and dates of application.
- -Road sanding/salting: date and time of application, type, mix, and rate of application, number of applications, and total amounts used.
- -Any road repair, lane marking, painting or other road improvement items performed.
- -Accident and spill data that may be pertinent to the study.

Precipitation, Dustfall and Runoff Data

All sites were instrumented for the monitoring of precipitation, dustfall, runoff flow volume and sampling of runoff quality. The monitoring equipment was maintained and operated by Envirex personnel at all the three sites in Milwaukee. For the sites away from Milwaukee the monitoring stations were maintained and operated by the U.S. Geological Survey personnel in Harrisburg, PA; Nashville, TN; and Denver, CO; through separate cooperative agreements with the Federal Highway Administration. However, all monitoring operations at all sites were coordinated by Envirex personnel. The specific details of the monitoring instrumentation, equipment installation, operation and maintanance are delineated below.

MONITORING EQUIPMENT

The selection of monitoring equipment was based on cost, availability, applicability and most important, its reliability from prior experience. In the following section, only the specifics of the equipment used and field operations for this study are presented. For a more elaborate discussion of the equipment selection criteria, equipment installation, maintenance and operations, the reader is referred to Volume II - Procedural Manual for Monitoring of Highway Runoff (1).

Precipitation Measurement

Due to the time variable nature of precipitation events, continuous recording type precipitation gauges were utilized at all sites. A weighing type, 8-day mechanical-wind precipitation gauge (Figure 18) from Belfort Instrument Company (Model No. 5-780) was used at all sites except Nashville where a Leupold Stevens A-71 combination flow recorder and raingauge was utilized. These gauges provided the necessary data on the precipitation intensities, as well as the total amount. The precipitation gauges were installed in accordance with the manufacturer's instructions, in the immediate vicinity of site areas to facilitate time synchronization of the rainfall measurements with the flow measurements and sampling equipment. Such equipment synchronization was considered extremely important in determining the lag time from rainfall to runoff and in the determination of pollutant discharge patterns as related to rainfall.

Generally the precipitation gauges were installed at the monitoring site either at the point of flow measurement or in the immediate vicinity. However, a problem was experienced in relating the rainfall to runoff data at the Nashville, TN site due to such installation. In this case, the precipitation gauge was located at the monitoring outlet which was approximately one mile (1.6 km) downstream of the starting point of the drainage area under study. The rainfall showers occurring in this area were intense but widely scattered and localized. This resulted in certain periods of runoff at the monitoring point without any corresponding rainfall activity being recorded at the raingauge. As a result, significant differences in total rainfall vs. runoff data were experienced. In order to alleviate this situation, a second raingauge was installed at the upstream end of the drainage area for this site.

On-site precipitation data were supplemented by official climatological data for each site by obtaining monthly data sheets through the National Climatic Center in Asheville, NC. These climatological data sheets also provided data on temperature, wind and several other meteorological parameters for the cities in which the sites were located.

Air Particulate Fallout (Dustfall) Measurements

Dustfall measurements were made at each site to assess the effects of adjoining land use activity on the accumulation of pollutants on the highway surface on a qualitative basis. Generally, three dustfall buckets were placed in each site to obtain representative samples except the Hwy. 45 grassy site and the I-794 site in Milwaukee where only one and two buckets, respectively, were considered necessary because of the smaller size of these two sites. The dustfall containers were obtained from the Research Appliance Company of Allison Park,

Figure 18. Belfort Instrument Company precipitation gauge used during study.

PA. The dustfall stations were erected in accordance with the recommended ASTM method (8-10 ft or 2.4-3.0 m above ground) (2). A typical dustfall station is shown in Figure 19. The collected dust contents were analyzed after each storm or once per month, whichever occurred first.

Runoff Monitoring

It was considered important to automate the sampling, flow measurement, and recording equipment because of the time variable nature of rainfall related storm events and the need to monitor runoff throughout the event.

Equipment may become out-of-phase (unsynchronized) due to mechanical error (clock drive slippage, etc) or operator error. This may result in an undefined lag between clocks in the sampling device and the flow recorder, therefore, true flow values corresponding to the discrete samples cannot be determined. Pollutant discharge calculations or flow compositing of samples with such data will be erroneous. Such errors were significantly minimized by carefully synchronizing the monitoring equipment during routine maintenance. Furthermore, an "event marker" was used on the flow recorders to record on the runoff hydrograph the times at which the water quality samples were taken. Several different types of event markers used in this study have been described in detail in the Procedural Manual (1).

In addition, a pocket-size electronic pager was used at most sites to facilitate storm response by operating personnel. The pager was carried by the person on storm response call at all times. When precipitation started, a 24 hour security guard would call the pager number. A beep tone then sounded on the pager to alert the person on call of a potential storm event. Close contacts were maintained by the monitoring personnel with local weather services so as to better anticipate and plan operations for the approaching storm events.

Flow Measurement

Two components are 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 and Palmer-Bowlus (PB) flumes were used as the calibrated device for this study. The use of one device over the other was generally based upon the preference and experience of the site operating personnel. Similarly, a variety of level sensing instru-

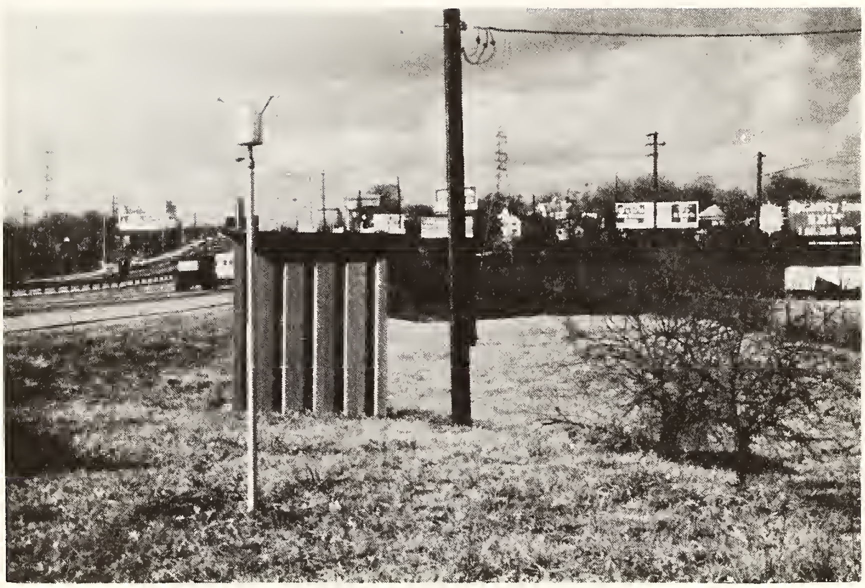


Figure 19. Typical dustfall bucket station, I-40, Nashville, Tennessee.

ments were used at the various sites as shown below:

Site	Calibrated device	Level sensing instrument type and manufacturer
I-794, Milwaukee	P-B flume	Bubbler tube recorder Bristol Division, Acco Inc.
Hwy. 45, Milwaukee	P-B flume	Bubbler tube recorder Bristol Division, Acco Inc.
Hwy. 45-Grassy Site, Milwaukee	90° V-notch weir	Bubbler tube recorder Bristol Division, Acco Inc.
I-81, Harrisburg	90° V-notch weir	Mechanical float recorder Leupold-Stevens Co.
I-40, Nashville	P-B flume	Bubbler tube recorder Scientific Instruments Co.
I-25, Denver	120° V-notch weir	Digitalized bubbler tube recorder Scientific Instruments Co.

All of the weirs and flumes were cast in-situ either in concrete or built out of plywood. Discharges over the V-notch weirs were calculated using the general equation:

$$Q = \frac{2.49\ H^{2.5}}{\tan \emptyset}$$

Where, Q = Discharge, cubic feet per second
H = Head, ft
$\emptyset$ = Angle of notch for the weir in use

The rating of the P-B flumes was done, in consultation with the Madison, Wisconsin office of the U.S. Geological Survey using the trial and error procedure described in Appendix A of the Procedural Manual (1). The level sensing instrumentation was installed in accordance with the manufacturer's instructions. Figures 20 through 23 show photographs of the flow measuring equipment at various sites.

Water Quality Sampling

Runoff sampling was conducted at all sites with Instrument Specialty Company (ISCO) water quality samplers (Models 1392 and 1680). A typical ISCO sampler is shown in Figure 24. The ISCO sampler is a self-contained portable unit capable of taking 28 discrete samples. The sampler can be operated using batteries or line electricity.

Figure 20. V-notch weir(90°), Hwy. 45 grassy site, Milwaukee, Wisconsin.

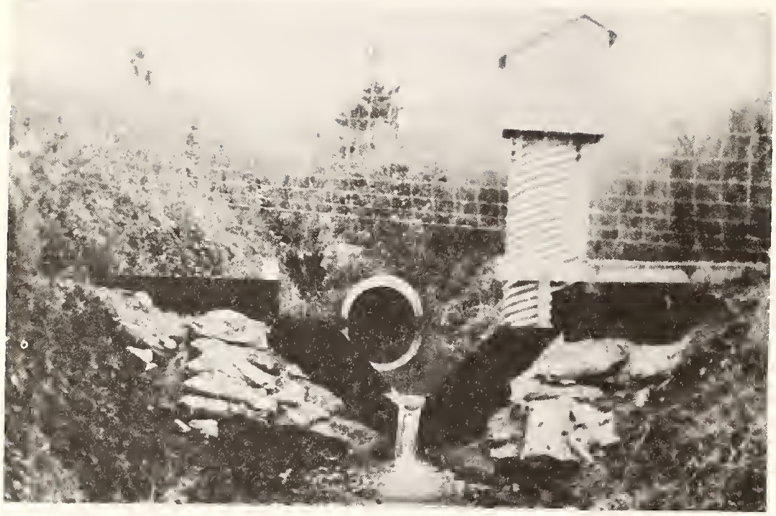
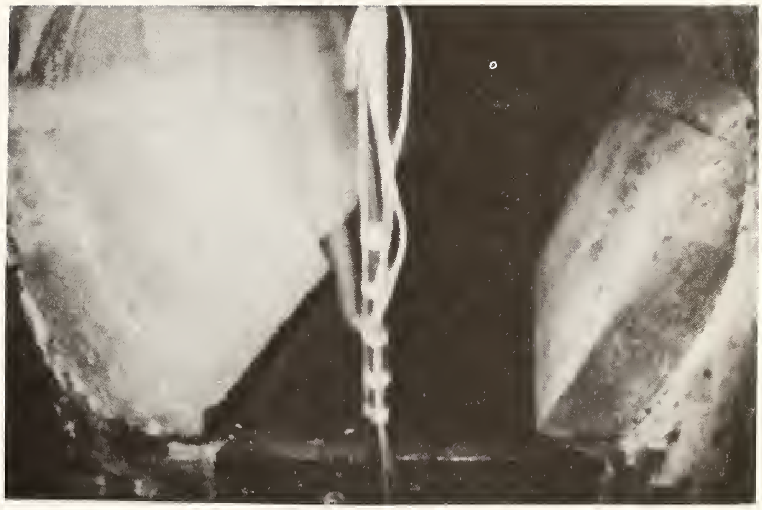


Figure 21. V-notch weir (90°) and typical USGS flow monitoring station, I-81 site, Harrisburg, Pennsylvania.



NOTE: Object in the middle of the picture is a plexiglass tube designed for obtaining a representative sample during a high flow.

Figure 22. Palmer-Bowlus flume, Hwy. 45, Milwaukee, Wisconsin.

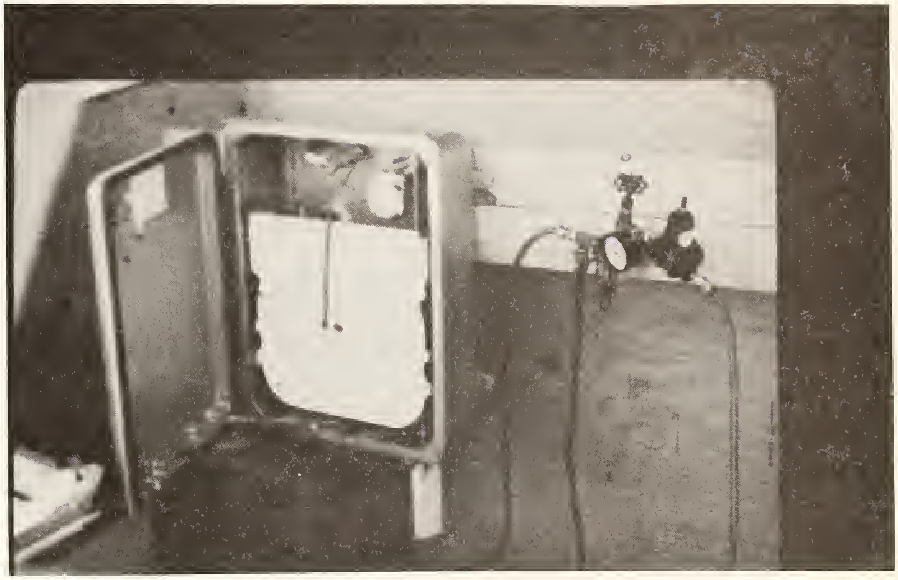


Figure 23. Bubbler type level sensing recorder (Bristol Div., ACCO Co), Hwy. 45, Milwaukee, Wisconsin.

Figure 24. Typical ISCO Model No. 1680 water quality sampler used in this study.

Sampling may be time or flow proportioned. Sample sizes between 40 ml to 450 ml may be selected for discrete samples. The two models, 1392 and 1680, used in the study represent the same basic sampler unit with the 1680 units being the updated version of the older 1392 model. The 1680 model provided several additional desirable sampling features. Most important of these features was that the 1680 model can be used for any time interval between 1 and 999 minutes. The minimum time interval on the 1392 model is 15 minutes on standard units, but could be bought with 10 minutes interval features with special order instructions. A peristaltic pump is utilized on the samplers for pumping the runoff samples from the flow stream to the sample bottles. After each sample, the pump reverses the flow direction to air purge the intake tube and minimize cross contamination between samples.

Two ISCO samplers were utilized at each site to collect discrete samples at intervals of 5 and 15 minutes most of the time. The sampling intervals were adjusted to desired levels (as high as 60 minutes) during longer storm events. Also, sampling frequencies were adjusted to 2-3 minutes and 10-12 minutes for the all-paved area I-794 site in Milwaukee because of the short response time (time of concentration) between rainfall and runoff.

For automated operations, the samplers were wired into the flow recorder through a contact closure that was activated when a preset liquid level was reached. This arrangement enabled the collection of runoff samples at the very beginning of a runoff event when monitoring personnel could not reach the site in time.

The sampler intake lines were installed in accordance with the manufacturer's instruction 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. In the case of Hwy. 45, Milwaukee and I-40, Nashville sites, the P-B flumes were built at the end of a pipe where the runoff had a freefall of about four ft (1.2 m) or more downstream of the flume. In these cases, a mixing box was placed downstream of the flume which in turn had the runoff falling into it, thereby providing good turbulent conditions for obtaining samples. The sampler intakes were placed in these boxes. 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, require 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 require glass bottles because of possible absorption of these pollutants by plastic containers. These samples were, therefore, collected manually in separate glass bottles.

MONITORING OPERATIONS

The monitoring operations are divided into the following separate tasks:

Prestorm operations	Storm related operations
Poststorm operations	Routine maintenance

Prestorm operations consisted of planning for an anticipated storm event. Regular contacts were made with the local offices of the National Weather Service to get an idea about the intensity and pattern of the expected rainfall event to determine if it would cause a runoff event. The field operations coordinator would then notify laboratory personnel of the anticipated storm event in order to have necessary preparations made for conducting those analyses that needed to be performed immediately. Similarly, other field monitoring personnel were alerted and briefed about the various operational tasks that may have been planned for that specific storm event. In most cases, these special monitoring instructions related to the operation of instrumentation, the number of samples to be collected and any special manual grab samples that might be required.

Every effort was made by storm response personnel to reach the site prior to the start of an event. However, within practical limitations, it was suggested that an operator should reach the site within 30 minutes of the start of a storm event. The operator upon receiving the signal from the electronic pager went to the site for most storm events. Upon reaching the site and studying the flow meter chart, the final decision was made by the operator with regards to the special sampling needs, frequency of sampling, etc. If the storm event was <u>not</u> to be used for data collection because of insufficient rainfall or other reasons, any collected samples were dumped and the instrumentation was reset in proper order for recording the next storm event. However, if the storm event <u>was</u> to be used for data collection, the following was done:

1. If the operator reached the site prior to the start of a storm event, a one gallon (3.785 ℓ) prestorm sample was manually collected in a glass bottle from either the stagnant pool of water behind the weir or flume or from the flow of water in the sewer (if any because of groundwater infiltration or snowmelt, etc.).

2. The automatic start-up system for the ISCO samplers was disconnected to enable flexibility of manual operation with regard to sampling frequency.

3. The flow recorder chart time was checked by the operator against his own watch (several operator's watches were maintained at standard time in accordance with the local telephone company time) and any discrepancies were recorded. Any corrections were noted on the chart either at the beginning of a storm event or at the end of the storm event, if the flow was already on the rise.

4. Once the flow started to increase in the channel the two samplers were started manually. One set of samples was taken immediately and then the samplers were set to take samples once every five minutes (model 1680 ISCO) and once every 15 minutes (model 1392 ISCO). The time at which each sampler took its first sample was also noted on the field data sheet. This enabled the determination of the time at which each subsequent sample was taken.

5. Started manual collection of desired special samples at the desired frequency (generally between 10 to 60 minutes).

6. Ensured proper sample collection and equipment operation through the duration of the storm. If the storm event was expected to last for a long duration (say greater than 4 to 6 hours), the ISCO sampler frequency was adjusted according to the judgement of the operator. If necessary and possible, collected samples were taken out of the ISCO samplers and new sampling bottles were substituted to enable sampling of longer duration storms.

At the end of a storm event, pertinent data sheets and log books were filled out and any special observations about the storm event were recorded. Instrumentation was then reset for the next storm event. When the storm was over, another one gallon (3.785 ℓ) grab sample was collected in a glass bottle similar to the prestorm sample. This sample was designated as the poststorm sample. For additional details on monitoring procedures, refer to Section V of Procedural Manual (1).

At the end of a storm event, either on the same or the next day, samples were collected from the dustfall buckets. The empty buckets were then recharged with fresh water and placed back in service. The collected dustfall samples were sent to the Envirex laboratory for total solids analysis.

SAMPLE CUSTODY, HANDLING AND ANALYTICAL DETERMINATIONS

The analytical determinations for all constituents except pH, bacteria and asbestos were done at the Envirex laboratory in Milwaukee, WI. The pH and bacteria analyses for sites outside Milwaukee were done by the local USGS personnel in Harrisburg, Nashville, and Denver, respectively. For the Milwaukee sites, these analyses were performed at the Envirex laboratory. The asbestos analyses were made by McCrone Associates of Chicago, IL.

Envirex laboratory personnel were alerted via phone by field monitoring personnel about an impending storm event as well as immediately after completion of the monitoring of a storm event. Laboratory personnel then took immediate steps to prepare for the receipt and processing of the anticipated number of samples. All discrete samples collected via the two ISCO samplers along with the manually collected samples for oil and grease and pesticides/PCB's were air freighted to Envirex in ice-packed coolers for analysis. Envirex personnel then picked up the samples from the airport to further save on the lead time prior to the analyses. Once in the Envirex laboratory, all samples were assigned separate sample identification numbers. These numbers were logged in a separate laboratory book along with corresponding information about the respective samples with respect to location, date of storm, time of sampling and type of sample.

These samples were then manually composited in the laboratory by Envirex personnel in proportion to flow rate. A detailed description of the sample compositing procedure used in this study is included in the Procedural Manual (1). A flow-composited sample of approximately 2 liters was prepared for most storm events. When sharp hydrograph peaks did not permit preparation of a 2 liter sample volume, a proportionately lesser volume of flow-composited sample was prepared. The flow-composited samples permitted calculation of the total pollutant loadings for each storm event. In addition, individual discrete samples were selected for analysis for selected parameters, primarily metals and solids. A listing of the analytical determinations performed on the flow-composited, as well as the discrete samples is presented in Table 2. However, significant flexibility was maintained in the numbers and types of analyses performed to enable evaluation of unusual situations. Among the listed parameters in Table 2, pH, BOD_5 and coliform analyses,

Table 2. Parameters analyzed during this study on composite and discrete samples.

	Discrete samples	
Flow-composite sample	ISCO sampler	Manual[a]
Total solids	Total solids	Oil and grease
Total volatile solids[a]	Suspended solids	Total coliform
Suspended solids	Volatile suspended solids[a]	Fecal coliform
Volatile suspended solids	TOC	Fecal Streptococus
BOD_5 and BOD_{20}[a]	Lead	
TOC	Zinc	
COD	Iron	
Total PO_4	Chloride[a]	
Kjeldahl nitrogen	pH	
$NO_3 + NO_2$		
Lead		
Zinc		
Iron		
Copper		
Chromium		
Cadmium		
Mercury		
Chloride		
pH		
Asbestos		
PCB's[a]		
Pesticides/herbicides[a]		

[a]Analyzed for selective events only.

were performed on an immediate basis (within 4 to 16 hours of sampling). Samples for other analytical determinations were refrigerated in a walk-in cooler and analyses were undertaken within the next few days. Chlorides were run on discrete samples only for those storm events when road salting for deicing was used. Selected pesticide/herbicide analyses were made only in those seasons when application of these materials was made on the highway right-of-way.

Laboratory Analysis Procedures

All samples were analyzed by methods approved for use in the National Pollutant Discharge Elimination System (NPDES) as recommended in the Federal Register, 38, 199, 28758-60 (October 16, 1973) and according to accepted Standard Methods (3) of water and wastewater analyses or EPA approved procedures (4, 5). Some of the modifications and/or variations utilized for the analysis of PCB and chlorinated hydrocarbons are described in Appendix A. Also included in this appendix are the methods of analysis for asbestos determinations performed by McCrone Associates of Chigago, IL. An in-house quality control program was used to assure the validity and accuracy of the analytical determinations performed by Envirex. This program included the analysis of quality control samples provided by EPA.

DATA HANDLING AND STORAGE

The large volume of data generated from the monitoring locations were cataloged and stored in a computer using a data storage program developed for this purpose. A detailed description of the data storage program along with input and output examples is included in Volume V of this project document Series (6). This program allows the project team to assess the results of the monitoring program at a particular site on a storm by storm basis. Input to the program include total rainfall, rain duration, quantity and quality of flow at selected time intervals, dustfall data and site characteristics (drainage area and average daily traffic). The program uses this data to generate a matrix of results for each site which can then be used for correlation of various parameters for use in the development of the predictive model. Another output option of the program is the graphical representation of rainfall, flow, pollutant concentration and pollutant loadings. Typical graphical outputs of this program are shown in Figures 25 through 28. These plots can then be used to trace the response of each site to individual rainfall events both hydraulically and qualitatively.

To obtain metric units of cm/hr, multiply in./hr by 2.54

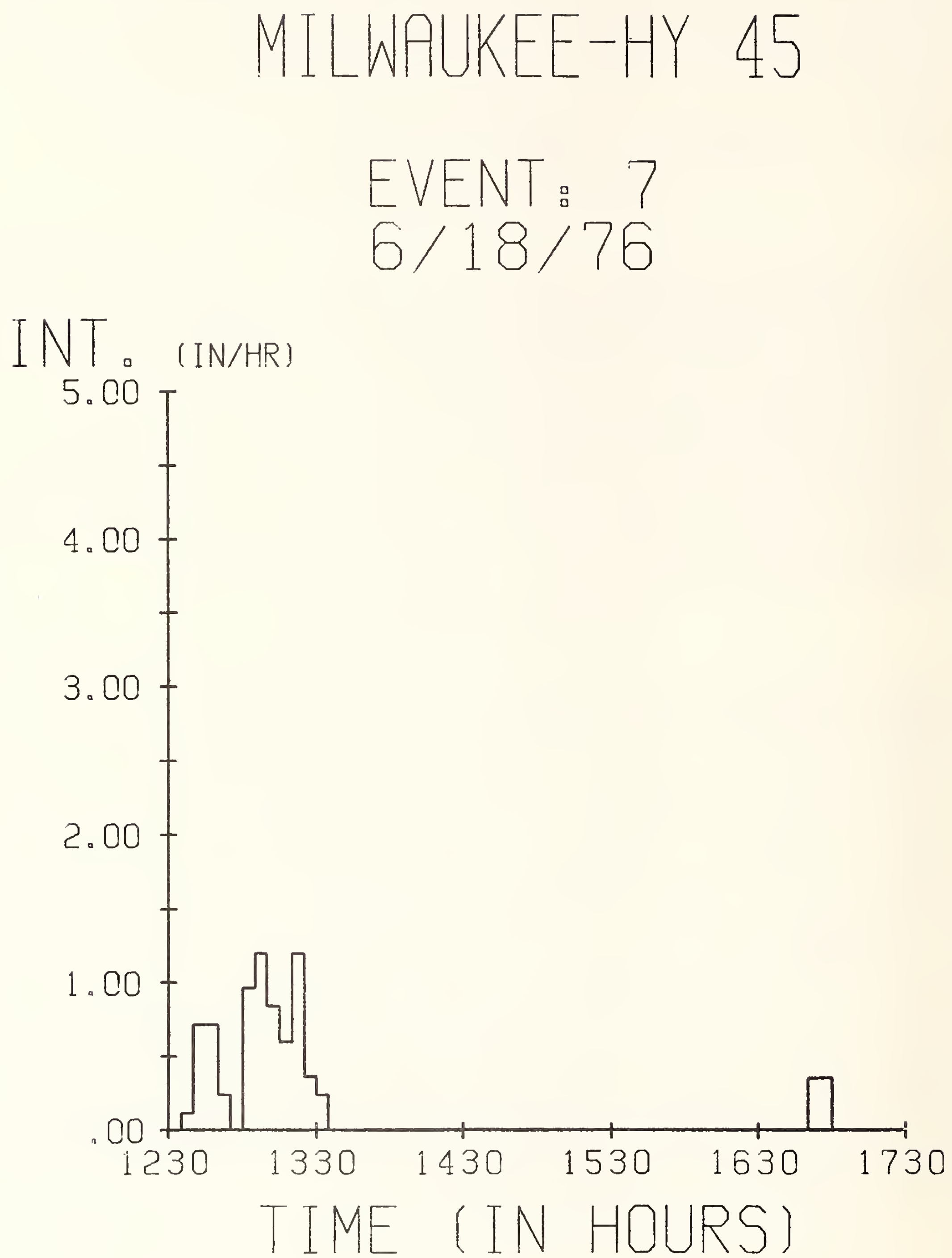


Figure 25. Typical graphical computer output - rainfall data.

To obtain metric units of m^3/sec, multiply cfs by 0.028.

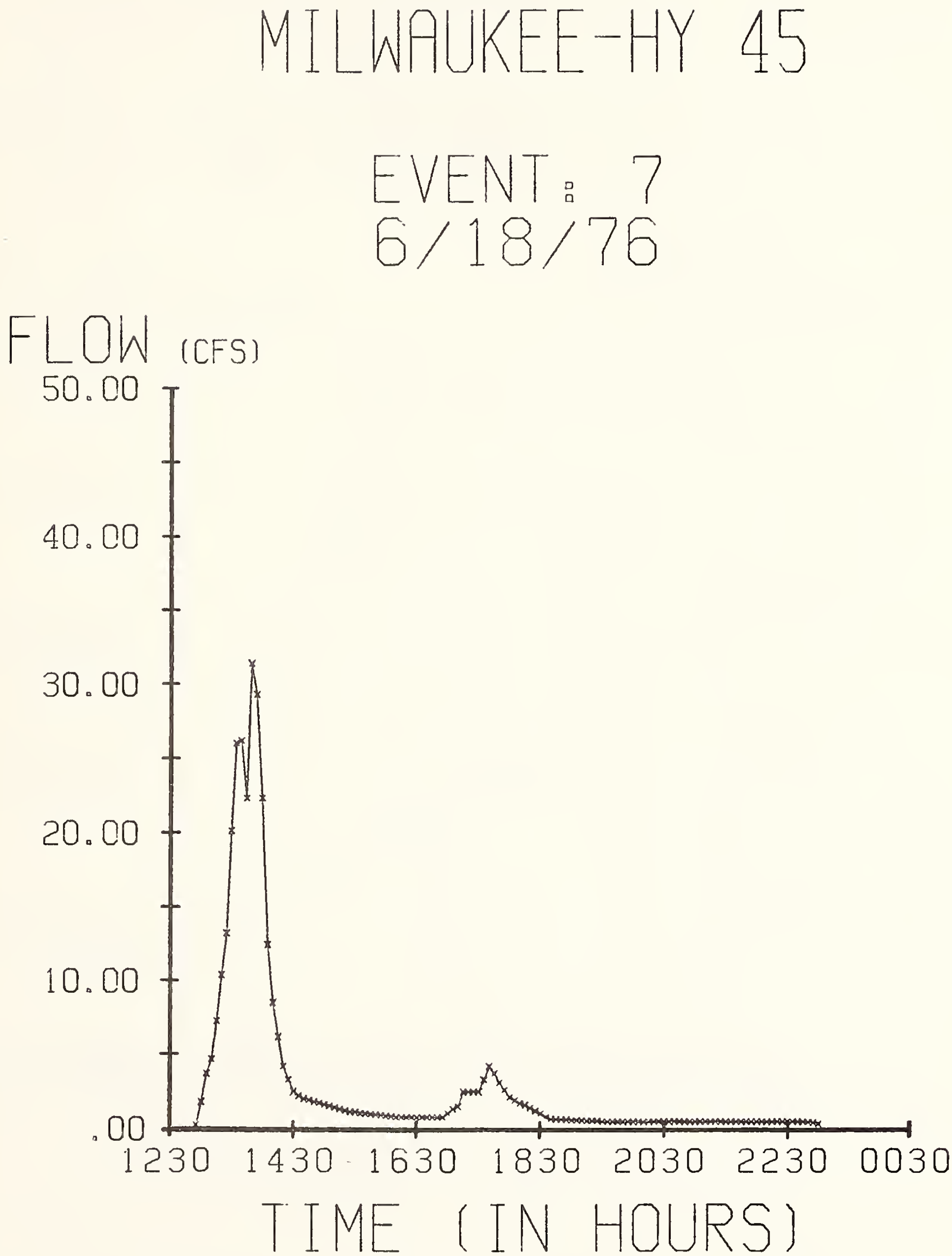


Figure 26. Typical graphical computer output - flow data.

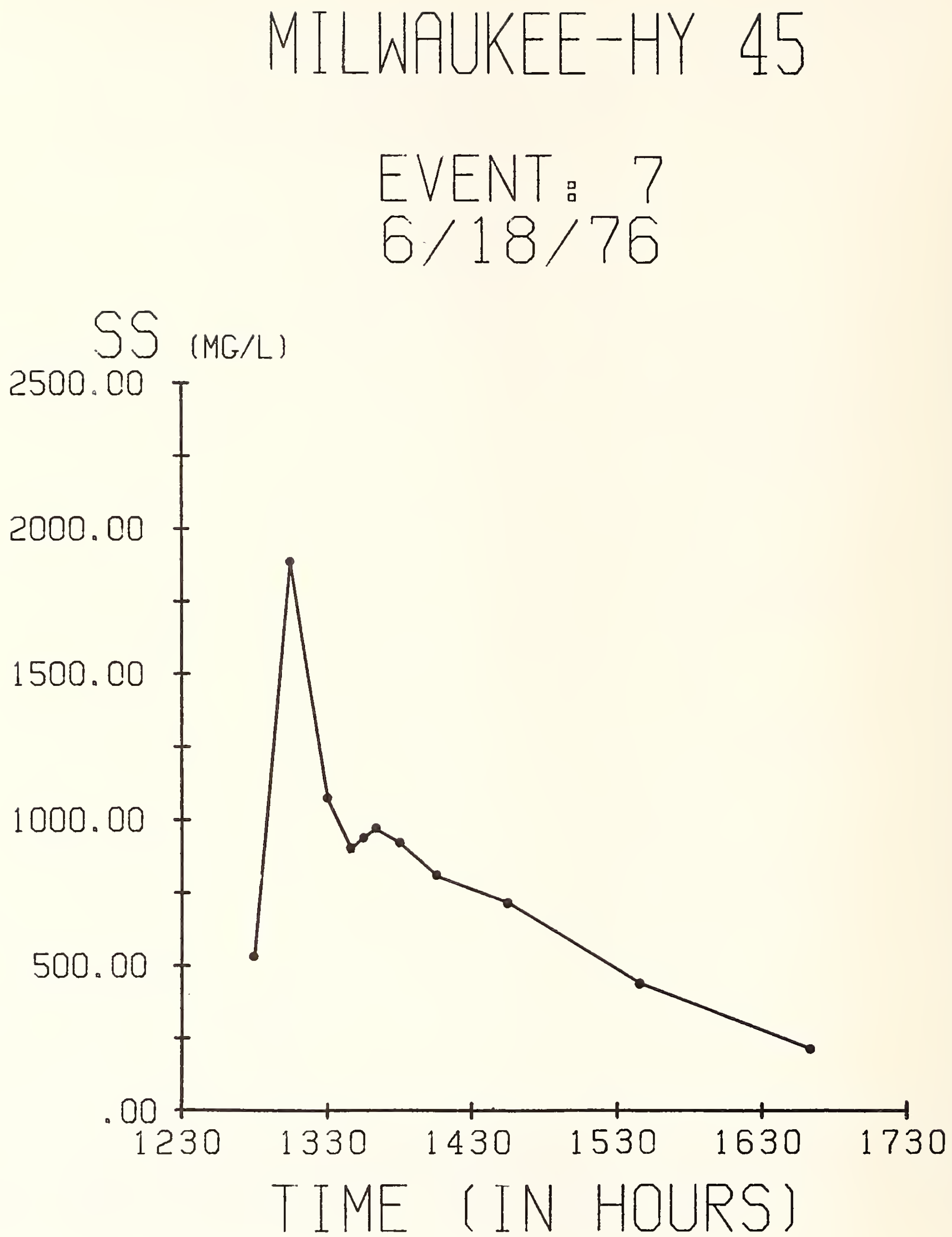


Figure 27. Typical graphical computer output - constituent concentration variations.

To obtain metric units of kg/min, multiply lb/min by 0.454.

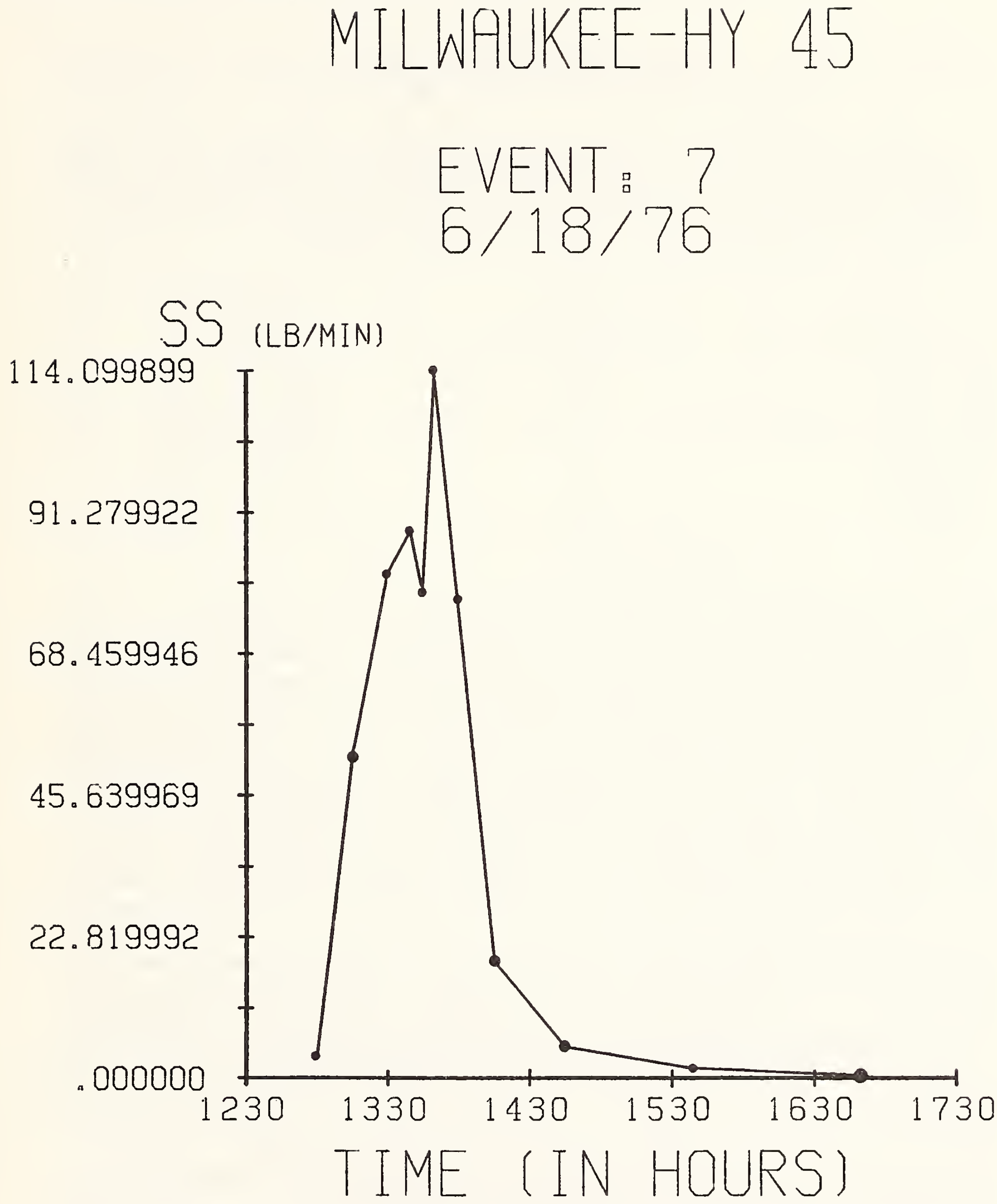


Figure 28. Typical graphical computer output - constituent loading rate variations.

SECTION IV
DATA EVALUATION AND RESULTS

Since the beginning of monitoring in the summer of 1976, a sum total of 159 storm events were monitored through September, 1977 at six sites. The distribution of the monitored events at various sites in a 12 to 16 month monitoring period was as follows:

Site	No. of events	Monitoring period
I - 794	37	6/76 to 9/77
Hwy. 45	32	3/76 to 7/77
Hwy. 45 - Grassy Site	17	6/76 to 9/77
Harrisburg	26	3/76 to 7/77
Nashville	31	10/76 to 9/77
Denver	16	8/76 to 9/77
Total	159	

Only 17 storm events were monitored at the Hwy. 45 grassy site. The lower number of monitored events at the grassy site compared to the other Milwaukee sites was due to the fact that throughout the summer and fall of 1976, not a single storm event with measurable runoff could be recorded at the grassy site. All of the 17 monitored events at this site occurred between late February through the end of September 1977. The summer and fall of 1976 in Milwaukee were drier than normal and any intermittent rainfall activity did not provide the necessary ground cover saturation to enable measurable runoff. Similarly, the low number of monitored events at the Denver site, 16, was undoubtedly a result of dry weather conditions for that area.

It should also be noted that for the four sites where more than 25 events were monitored, all events up to the twenty-fifth event were monitored in a normal manner as described in Section III. However, the monitoring activity after the twenty-fifth event was curtailed significantly for laboratory analysis. For these storm events, laboratory analyses were limited to solids analysis on the flow-composited samples.

The accumulated data from these 159 storm events at six sites are presented and discussed in the ensuing subsections.

RAINFALL RUNOFF RELATIONSHIPS

A complete listing of the rainfall and flow data for all monitored storm events for which runoff quality data was collected is presented in Appendix B. From an analysis of the available rainfall runoff data for the nonwinter (April through October) conditions, the average and range in runoff to rainfall (Q/R) coefficients were calculated for each site. These calculated runoff coefficients are presented in Table 3. As can be expected, the coefficients were lower for the sites with less paved areas and were the highest for the I-794 site with 100% paved area. A few of the coefficient values that were calculated to be above 1.0 for I-794 would seem to be obviously in error but probably relate to the sensitivity of the instrumentation used. The value of 0.40 for the coefficient at this site was obtained for a very small storm of 0.05 in. (0.13 cm) of rainfall of which only 0.02 in. (0.05 cm) was measured as runoff. Rainfall and flow measurements at these small levels are suspect and may have resulted in the low value of runoff coefficient.

The lowest runoff coefficients were obtained for the Hwy. 45 grassy site with a range of zero to 0.53 and an average of 0.20. Generally, the average runoff coefficients were found to be directly related to the perviousness/imperviousness of the drainage area as shown in Table 3. Only the Harrisburg site exhibited some deviation showing a larger than expected average runoff coefficient of 0.43 at 27% paved area. This may have been a result of the rainfall pattern and ground saturation conditions for the monitored events at this site. Many of the monitored storms at this site were high intensity rainfall events and produced more than 1.0 in. (2.54 cm) of total rainfall. These events could have been responsible for the larger runoff coefficient due to increased saturation of the pervious areas of the drainage basin. It is also possible that some runoff was contributed from some upstream drainage area on the north side of the site that was considered to be draining away from the site based on topographic maps and visual field observations of the area. A more detailed examination of the rainfall-runoff data from the monitoring program has previously been made in Volume III of this contract's six-volume document series for developing the hydrologic component of the predictive procedure (7).

HIGHWAY RUNOFF CONSTITUENT CHARACTERIZATION

A very large amount of water quality data was collected by monitoring of highway runoff at the six sites. In order to facilitate discussion of this large volume of data, it has been divided into the following two groups:

Table 3. Summary of runoff to rainfall (Q/R) coefficients for monitored nonwinter[a] runoff events[b].

Site location	Number of monitored events	Runoff coefficients[c] Avg.	Range	% Paved
I-794 Milwaukee	28	0.92	0.40-1.1.0	100
Hwy. 45 Milwaukee	19	0.30	0.10-0.53	31
Grassy site Milwaukee	12	0.20	0.00-0.53[d]	0
Harrisburg	16	0.43	0.04-0.95	27
Nashville	25	0.43	0.10-1.00	37
Denver	16	0.41	0.12-0.66	37

[a] April through October monitoring periods, 1976-1977.

[b] Only those storm events for which runoff quality data were collected.

[c] Represents calculated values of Q/R based on monitored flow volume (Q) and rainfall volume (R) data for the entire duration of the storm events.

[d] The value 0.00 represents a detectable flow that resulted in a runoff coefficient of less than 0.005.

Group I

Consists of all data related to parameters for which flow-composite data were collected such as: solids, heavy metals, chlorides, oxygen demand parameters and nutrients.

Group II

Consists of those parameters for which primarily discrete manual samples were collected such as: coliforms, oil and grease, PCB's, pesticide/herbicide and asbestos.

Data Presentation for Group I Parameters

Data presented here represents only averages and ranges determined from the raw data. A complete listing of the raw data is available separately on a computer tape as described in Volume V - Highway Runoff Data Storage Program and Computer User's Manual (6). Flow composited samples were analyzed for all parameters in Group I to assess the total pollutant loadings from various sites. Also, selective discrete samples were analyzed for parameters such as total solids, suspended solids, lead, zinc, iron, TOC, COD, pH and chlorides. The results of the discrete sample analyses will be used to evaluate the pattern of pollutant discharge with time.

Flow-Composite Sample Analysis Data - In order to suitably characterize highway runoff constituents, both concentrations and loadings in lb/acre (kg/ha) will be examined in terms of nonwinter (April through October) conditions, winter (November through March) conditions and combined (nonwinter-winter) conditions for each site. An overall composite for all sites will then be discussed for the entire project.

A summary of the average and range for all group I constituent concentrations along with pollutant loadings in lb/acre/per event (kg/ha/per event) for all sites is included in Appendix B. The pollutant loadings were arrived at by normalizing the data for area differences between sites and, therefore, provide a better tool for assessing the impact of highway runoff on the environment.

Solids Data - These data refer to the following analyses:

	Nomenclature per 13th Edition of Standard Methods (3)
Total Solids (TS)	Total Residue
Total Volatile Solids (TVS)	Total Volatile Residue
Suspended Solids (SS)	Total Nonfilterable Residue
Volatile Suspended Solids (VSS)	Volatile Nonfilterable Residue

The TS, TVS, SS and VSS concentrations obtained in this study are presented in Table 4. In terms of average composite concentrations listed in Table 4, Hwy. 45 exhibited the largest values for all solids parameters among the six sites, probably because of the largest drainage area and some construction activity near the site. The Harrisburg site exhibited the smallest average solids concentrations probably because of the rural environment and the flush shoulder design of the highway. The all-grassy Hwy. 45 site showed significantly higher concentrations of total and suspended solids compared to the all-paved area I-794 site. These concentration differences can be attributed to the large differences in the runoff volumes at these two sites. The larger runoff volumes at the I-794 site tend to dilute the pollutant concentrations compared to the all grassy site having lower runoff volumes. These differences are dramatically reversed in favor of the I-794 site, when total solids loadings are calculated for these two sites as shown in Table 5.

Some dramatic differences in total solids can be observed for various sites for the nonwinter (April-October) and winter (November-March)

Table 4. Concentration of total, suspended and volatile solids in highway runoff.

	Total solids, mg/l					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	1400	145-21640	378	145-1130	4594	804-21640
Milw.-Hwy. 45	2038	350-11402	992	350-2145	3750	835-11402
Milw.-Grassy site	1110	268-2401	957	268-1850	1447	651-2401
Harrisburg	791	180-3696	360	180-560	1261	301-3696
Nashville	461	223-1001	424	223-698	568	246-1001
Denver	686	295-1334	686	295-1334	--	c

	Total volatile solids, mg/l				
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]
	Avg.	Range	Avg.	Range	Typical value[d]
Milw.-Hwy. 794	138	55-320	127	55-320	233
Milw.-Hwy. 45	319	80-816	323	80-816	299
Milw.-Grassy site	297	70-1522	298	70-1522	284
Harrisburg	204	52-364	177	52-364	363
Nashville	219	26-595	213	26-595	332
Denver	264	88-395	264	88-395	c

	Suspended solids, mg/l					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	268	26-1576	138	26-475	656	201-1576
Milw.-Hwy. 45	445	146-1656	396	146-1260	526	151-1656
Milw.-Grassy site	303	25-938	419	43-938	47	25-75
Harrisburg	53	4-163	47	4-136	60	4-163
Nashville	209	13-478	187	13-475	271	89-478
Denver	259	118-1029	259	118-1029	--	c

	Volatile suspended solids, mg/l					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	84	14-393	53	14-144	150	33-393
Milw.-Hwy. 45	98	27-510	101	34-510	93	27-274
Milw.-Grassy site	95	10-837	134	18-837	16	10-25
Harrisburg	14	1-48	15	3-48	13	1-23
Nashville	78	11-397	89	11-397	45	23-70
Denver	103	10-240	103	10-240	--	c

[a]Represents monitoring periods between April through October, 1976-77. Actual number of months may vary between sites.

[b]Represents monitoring periods between November through March, 1976-77. Actual number of months may vary between sites.

[c]No storm events monitored during winter at Denver site due to lack of sufficient precipitation.

[d]Total volatile solids examined on a cursory basis only.

Metric units: lb/ac x 1.12 = kg/ha.

Table 5. Loadings of total, suspended and volatile solids in highway runoff.

Total solids, pounds per acre per event

	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	60	2-535	34	2-82	143	39.5-535
Milw.-Hwy. 45	72	4-96	29	4-82	142	9.1-384
Milw.-Grassy site	30	0.04-99	23	0.04-99	45	0.8-99
Harrisburg	78	2-191	17	2-73	144	5.8-199
Nashville	28	1-91	33	1-58	43	17.2-91
Denver	21	2-65	21	2-65	--	c

Total volatile solids, pounds per acre per event

	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]
	Avg.	Range	Avg.	Range	Typical value[d]
Milw.-Hwy. 794	15.3	1.8-44.0	16	1.8-44	9.1
Milw.-Hwy. 45	14.3	0.4-35.0	13	0.4-28	20.0
Milw.-Grassy site	7.3	0.01-22.0	6	0.01-21	22.0
Harrisburg	4.3	0.03-14.0	3	0.03-14	12.3
Nashville	9.7	0.76-43.0	10	0.8-43	6.0
Denver	4.2	0.74-10.1	4	0.7-10	c

Suspended solids, pounds per acre per event

	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	19.6	0.95-80	15	0.95-52	32.0	6.7-80.4
Milw.-Hwy. 45	18.6	0.77-96	15	0.77-58	24.0	1.7-96
Milw.-Grassy site	7.8	0.01-46	10	0.01-46	3.0	0.01-5.2
Harrisburg	4.7	0.02-32	4	0.02-28	5.9	0.04-31.5
Nashville	14.0	0.54-57	11	0.54-33	21.9	one sample
Denver	13.7	0.88-47	14	0.88-47		c

Volatile suspended solids, pounds per acre per event

	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	6.2	0.48-20	5.5	0.48-20	7.8	1.0-16.7
Milw.-Hwy. 45	4.3	0.17-24.7	4.2	0.17-25	4.6	0.4-12.9
Milw.-Grassy site	2.0	0.004-12	2.6	0.004-12	1.0	0.004-1.6
Harrisburg	1.1	0.005-5.3	0.9	0.005-5	1.2	0.01-4.1
Nashville	4.5	0.09-28.2	4.9	0.09-28	3.4	1.4-6.9
Denver	2.6	0.20-6.63	2.6	0.20-7		c

[a]Represents monitoring periods between April through October, 1976-77. Actual number of months may vary between sites.

[b]Represents monitoring periods between November through March, 1976-77. Actual number of months may vary between sites.

[c]No storm events monitored during winter at Denver site due to lack of sufficient precipitation.

[d]Total volatile solids examined on a cursory basis only.

Metric units: lb/ac x 1.12 = kg/ha.

conditions as shown in Tables 4 and 5. The average winter concentrations of total solids ranged from 1.3 times the average nonwinter values at Nashville to 12.2 times the nonwinter values at I-794 in Milwaukee. No winter data is available at the Denver site due to lack of precipitation during the winter of 1976-77. The winter concentrations of suspended solids were also larger than the nonwinter values at the I-794 site, the Hwy. 45 site, and the Nashville site. The grassy site in Milwaukee had an average nonwinter concentration of suspended solids 10 times larger than the winter average. For the Harrisburg site, significant differences between the average total solids values were evident between winter and nonwinter data; however, the corresponding suspended solids values were very similar. This is a result of the flush shoulder type drainage design at this site whereby a significant portion of the particulates settle out in the grass covered areas prior to reaching the drainage inlets while dissolved chlorides from salting during winters continue to show up in the total solids analyses. The large differences in the total solids concentrations are undoubtedly due to the salting/sanding maintenance activities during the winter seasons at these sites. The differences at the Nashville site were not as large probably because Nashville does not require as much salting as Milwaukee or Harrisburg.

An examination of the overall solids loadings in lbs/acre/event for each site in Table 5 reveals that on an average basis, these loadings were the highest for I-794 Milwaukee site at 60 lbs/acre/event (67.2 kg/ha/event) total solids and 19.6 lbs/acre/event (22 kg/ha/event) suspended solids. These high loadings at the I-794 site are a result of the high pollutant wash-off efficiency of the accumulated solids due to the high impervious (100% paved) nature of the site drainage area. Also, this site is located in a highly urbanized area (downtown Milwaukee) and the relative higher levels of the air pollutant fallout rates (dustfall rates - Table 6) found near this site would be expected to contribute to some extent. The traffic volume at I-794 compared to other sites would not seem to account for the high solids loadings since the ADT (53,000) at this site is considerably less than other sites except the Harrisburg site. It is suspected that the true solids loadings at this site are even higher than discussed above because of the elevated location of the site, whereby some of the accumulated pollutants are dispersed (blown off) to surrounding areas by high winds and/or vehicle speed.

The Harrisburg site exhibited the lowest overall average suspended solid loading at 4.7 lbs/acre/event (5.3 kg/ha/event) because of factors such as rural environment, flush shoulder type of highway design and low percentage of impervious area. However, the corresponding total solids loadings at this site were not found to be the lowest, particularly in comparison with the total solids loadings at the Nashville and Denver sites. This is due to the salting/sanding maintenance activities wherein relatively little sanding or salting is conducted in Nashville. The average total solids loadings measured for the Denver site are probably lower than actual since

Table 6. Summary of dustfall loading rate data (gm/m^2/day) for monitoring sites.

Monitoring sites	1976 Nonwinter Avg.	1976 Nonwinter Range	1976 Winter[b] Typical value	1977 Nonwinter Avg.	1977 Nonwinter Range	1977 Winter[b] Avg.	1977 Winter[b] Range
Milwaukee-Hwy. 794	0.30	0.12-0.52	0.87	0.56	0.11-2.45	0.15	0.10-0.21
Milwaukee-Hwy. 45	0.21	0.03-0.38	0.11	0.31	0.05-0.58	0.13	0.06-0.20
Harrisburg	0.13	0.07-0.16	0.07	0.06	0.04-0.09	0.07	0.05-0.09
Nashville	0.30	0.23-0.38	NS	0.90	0.37-2.07	1.43	0.53-2.17
Denver	0.37	0.30-0.49	NS	0.32	0.07-0.68	0.34	0.27-0.46

Note: NS = no dustfall samples taken during this period.

[a]Represents monitoring periods between April through October.

[b]Represents monitoring periods between November through March.

no winter storms were monitored at this site. Furthermore, it is suspected that large amounts of solids continue to build up in the site drainage system and are never flushed out because of a lack of large, frequent rainfall events at this site.

A comparison of average suspended solids loading data in Table 5 between Hwy. 45 - Milwaukee, Nashville, and Denver indicates similar loadings for these three sites for the nonwinter period. This similarity in solids loadings can be attributed to similar impervious characteristics at these sites. The Hwy. 45 loading was probably somewhat above normal due to some construction activity near this site during the 1977 monitoring season.

From the above data, it is obvious that several factors such as: percent paved and unpaved areas, ADT, urban vs. rural environment and maintenance activities affect the differences in the monitored levels of solids at various sites. In order to obtain an overview of how these factors affected the observed loadings, the nonwinter monitoring data were correlated with percent imperviousness of the site, ADT, and average nonwinter dustfall loadings. It should be noted here that such correlation analyses are most useful to indicate trends and must be used for qualitative evaluations only.

The correlation coefficients (r value) for the pollutant loadings in pounds per acre per event, for the nonwinter period and the previously mentioned site characteristics are listed in Table 7. The simple r values listed represent the one-on-one correlation of the average nonwinter (April-October) pollutant loading with the site characteristics. The multiple r values represent the correlation of the pollutant with the four combinations of the three site characteristics. Most of the solids parameters do not appear to be highly related to ADT, percent imperviousness, or dustfall on a simple correlation basis (columns 1-3). Percent imperviousness (column 2) generally had the largest r value for these correlations with solids; however, these values ranged from only 0.492 for suspended solids to 0.695 for total solids. Any relationship indicated by these values may be due to the ease at which these materials are washed from paved surfaces during a storm. The multiple correlations indicated stronger relationships to the solids parameter. An interesting result is that ADT and dustfall (column 5) together generally correlated with the solids as well as all three of the site characteristics considered together (column 1). This is interesting in light of the fact that percent imperviousness had the largest simple correlation coefficients. This indicates that although two characteristics by themselves may not be highly correlated to a pollutant on an individual basis, such as the simple r values for ADT and dustfall with total solids (-0.099 and 0.174 respectively), the two characteristics considered together provide a fairly high r value (0.836 in the above sample). The multiple r values for all three site characteristics versus the solids parameters indicates that a fair estimate of loadings can be obtained based on these three site characteristics.

Table 7. Correlation coefficients 'r' for solids vs. site characteristics.

Dependent variable	Simple correlation coefficients			Multiple correlation coefficients			
	ADT	% IMP	DF	ADT and % IMP	ADT and DF	DF and % IMP	ADT % IMP DF
Column #	(1)	(2)	(3)	(4)	(5)	(6)	(7)
TS	-.099	.695	.174	.698	.836	.695	.836
SS	.030	.492	.277	.495	.773	.522	.810
VSS	.415	.643	.649	.784	.896	.828	.896
TVS	.102	.688	.332	.701	.739	.713	.757

ADT = Average daily traffic.
IMP = Imperviousness
DF = Dustfall

Volatile Solids - The volatile fractions of the total and suspended solids for the six sites are shown in Table 8. As can be seen the volatile fractions of both the total solids and suspended solids are significantly influenced by the salting/sanding activities at the respective sites. Salt (NaCl) contributes inorganic chlorides to runoff resulting in an increase in total solids as well as a reduction of the volatile fraction of the total solids. Sand contributes inorganic matter in particulate form to runoff resulting in an increase in both the total and suspended solids values as well as a reduction in the volatile fractions of both the total and suspended solids.

The average volatile fractions for the nonwinter periods, range between 30 and 50% of both the total and suspended solids. However, for the winter conditions, these fractions are significantly reduced because of the increase in the inorganic content of the total solids due to the salting/sanding activities. No significant difference in the volatile fractions for total solids is noted between the nonwinter and winter periods at the Nashville site because of minimized salting activities at this site. Also, no difference in the volatile fractions for suspended solids can be noted between the nonwinter and winter periods at the grassy site. This is due to the fact that most of the sand associated with the particulates (in winter samples) settles out in the grassy areas and therefore, no change in the volatile fractions results between the winter and nonwinter samples of runoff.

Table 8. Calculated volatile fractions of total and suspended solids.

	Avg. TVS/Avg. TS, %			Avg. VSS/Avg. SS, %		
Site	Yearly	Nonwinter[a]	Winter[b]	Yearly	Nonwinter[a]	Winter[b]
I-794 Milwaukee	9.9	33.6	5.1	31.3	38.4	22.9
Hwy. 45 Milwaukee	15.6	32.6	8.0	22.0	25.5	17.7
Grassy Site Milwaukee	26.8	31.1	19.6	31.3	32.0	34.0
Harrisburg	25.8	49.2	28.8	26.4	31.9	21.7
Nashville	47.5	50.2	58.5	37.3	47.6	16.6
Denver	38.5	38.5	c	39.8	39.8	c

[a]Represents monitoring periods between April through October, 1976-77. Actual number of months may vary between sites.

[b]Represents monitoring periods between November through March, 1976-77. Actual number of months may vary between sites.

[c]No storm events were monitored during winter in Denver due to lack of sufficient precipitation.

Heavy Metals Data - These data refer to the following metal analysis: Pb, Zn, Fe, Cu, Cr, Cd, Ni and Hg. In terms of the average composite concentrations listed in Tables 9 and 10, the I-794 site in Milwaukee exhibited the highest values for lead and zinc (2.9 and 0.69 mg/l) while the Harrisburg site had the lowest average composite concentrations (0.10 and 0.08 mg/l). The average composite concentrations for iron ranged between 2.0 and 16.5 mg/l for the various sites with Harrisburg having the lowest value at 2.0 mg/l and Denver the highest value at 16.5 mg/l. Generally, concentrations of all other metals, i.e., copper, chromium, cadmium, nickel and mercury were significantly lower for all sites compared to the metals lead, zinc and iron. Also, nickle was examined only on a cursory basis since initial investigations indicated that it was present in low concentrations at most sites (<0.2 mg/l).

A noticeable increase in the average concentrations of lead, zinc, iron and copper was observed for the two Milwaukee sites (I-794 and Hwy. 45)

Table 9. Concentration of lead, zinc, iron and copper in highway runoff.

	Lead, mg/l					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	2.90	0.80-13.1	1.50	0.80-3.10	5.53	1.8-13.1
Milw.-Hwy. 45	1.20	0.40-6.6	0.78	0.40-1.50	1.88	0.5-6.6
Milw.-Grassy site	0.21	0.05-0.70	0.26	0.10-0.70	0.11	0.05-0.20
Harrisburg	0.10	0.05-0.20	0.09	0.05-0.10	0.11	0.05-0.20
Nashville	0.50	0.02-1.70	0.50	0.02-1.70	0.50	0.30-0.70
Denver	0.45	0.30-1.80	0.45	0.03-1.80	c	

	Zinc, mg/l					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.69	0.14-3.40	0.35	0.14-0.86	1.32	0.47-3.40
Milw.-Hwy. 45	0.55	0.20-1.90	0.39	0.20-0.70	0.80	0.24-1.90
Milw.-Grassy site	0.18	0.07-0.34	0.21	0.10-0.34	0.12	0.07-0.15
Harrisburg	0.08	0.01-0.23	0.06	0.01-0.12	0.11	0.02-0.23
Nashville	0.28	0.10-0.61	0.28	0.10-0.61	0.29	0.11-0.41
Denver	0.72	0.33-1.50	0.72	0.33-1.50	c	

	Iron, mg/l					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	11.5	2.5-43.0	7.5	2.5-39.0	18.9	7.0-43.0
Milw.-Hwy. 45	14.6	5.6-45.0	13.3	5.6-38.6	16.8	6.5-45.0
Milw.-Grassy site	14.9	1.1-43.6	19.9	2.7-43.6	3.9	1.1-10.0
Harrisburg	2.0	0.1-6.6	1.8	0.1-6.4	2.3	0.1-6.6
Nashville	5.5	1.5-12.0	5.2	1.5-12.0	6.4	3.1-9.2
Denver	16.5	6.5-37.0	16.5	6.5-37.0	c	

	Copper, mg/l					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.159	0.01-0.66	0.10	0.01-0.22	0.27	0.11-0.66
Milw.-Hwy. 45	0.135	0.01-0.88	0.08	0.01-0.14	0.22	0.07-0.88
Milw.-Grassy site	0.083	0.01-0.23	0.07	0.01-0.14	0.11	0.05-0.23
Harrisburg	0.045	0.01-0.10	0.04	0.01-0.10	0.05	0.02-0.09
Nashville	0.070	0.01-0.20	0.07	0.01-0.20	0.07	0.05-0.09
Denver	0.110	0.03-0.26	0.11	0.03-0.26		

[a]Represents monitoring periods between April through October, 1976-77. Actual number of months may vary between sites.

[b]Represents monitoring periods between November through March, 1976-77. Actual number of months may vary between sites.

[c]No storm events monitored during winter at Denver site due to lack of sufficient precipitation.

Table 10. Concentrations of cadmium, chromium and mercury in highway runoff.

	Cadmium, mg/l					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.068	0.01-0.40	0.04	0.01-0.08	0.12	0.03-0.40
Milw.-Hwy. 45	0.044	0.01-0.09	0.04	0.01-0.09	0.05	0.01-0.09
Milw.-Grassy site	0.047	0.02-0.10	0.05	0.02-0.10	0.04	0.02-0.07
Harrisburg	0.025	0.01-0.07	0.03	0.01-0.07	0.02	0.01-0.05
Nashville	0.027	0.01-0.06	0.03	0.01-0.06	0.02	0.01-0.03
Denver	0.020	0.01-0.08	0.02	0.01-0.08	c	

	Chromium, mg/l					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.057	0.01-0.14	0.05	0.01-0.12	0.07	0.03-0.14
Milw.-Hwy. 45	0.054	0.01-0.14	0.05	0.01-0.14	0.06	0.01-0.14
Milw.-Grassy site	0.040	0.01-0.10	0.05	0.01-0.10	0.02	0.01-0.02
Harrisburg	0.025	0.01-0.11	0.03	0.01-0.11	0.02	0.01-0.02
Nashville	0.023	0.01-0.05	0.02	0.01-0.05	0.03	0.02-0.05
Denver	0.030	0.01-0.09	0.03	0.01-0.09		c

	Mercury, μg/l					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	2.87	0.13-24.0	3.85	0.13-24.0	0.76	0.25-2.00
Milw.-Hwy. 45	5.18	0.20-67.0	6.30	0.20-67.0	3.15	0.25-11.0
Milw.-Grassy site	1.52	0.25-11.5	2.0	0.25-11.5	0.44	0.25-0.50
Harrisburg	4.86	0.25-49.0	23.68	0.25-2.50	7.14	0.25-49.0
Nashville	1.75	0.50-6.70	1.18	0.05-2.5	2.88	0.80-6.7
Denver	1.09	0.25-4.00	1.09	0.25-4.0		c

[a]Represents monitoring periods between April through October, 1976-77. Actual number of months may vary between sites.

[b]Represents monitoring periods between November through March, 1976-77. Actual number of months may vary between sites.

[c]No storm events monitored during winter at Denver site due to lack of sufficient precipitation.

during the winter compared to nonwinter data (Table 9). It is likely that the smaller winter runoff quantities, the length of time between winter runoff events, and the retention of these metals in snow are the reasons for the increased winter concentrations. Only minor differences were noticed between the nonwinter and winter metal data at the Harrisburg and Nashville sites and the grassy site in Milwaukee.

A comparison of the metals loadings indicates that the I-794 site in Milwaukee generally exhibited the largest average summer loadings for all the metals except mercury (Tables 11 and 12). The average loading of lead at I-794 of 0.18 lb/acre/event (0.2 kg/ha/event) is 6.5 times higher than the next highest value (0.028 lb/acre at Hwy. 45) (0.031 kg/ha). The reason for these high metals loadings is that the I-794 site is entirely paved and that the pollutant wash-off efficiency for accumulated pollutants from the elevated bridge-deck drainage system is high.

The Denver, Nashville, and Milwaukee Hwy. 45 sites all had similar average nonwinter loadings for the various metals (Tables 11 and 12). This is likely due to the similarities in site characteristics such as percent paved and urban environment. Since many of the metals originate from automobiles, ADT would seem to be a critical factor in metals loadings. The Denver site has nearly twice the ADT of the Nashville and Milwaukee Hwy. 45 sites, however, the metals loadings are quite similar. It is suspected that the measured metals loadings for the Denver site are probably lower than actual, similar to the solids loadings discussed earlier, particularly because metals are believed to be associated with the particulate solids. Also, pollutant correlations, which are discussed later in this section, indicate that the metals loadings are more highly related to the percentage of the drainage area that is paved rather than the ADT.

Both the Hwy. 45 grassy site in Milwaukee and the Harrisburg site had small average nonwinter loadings of metals. The small loadings at the Harrisburg site may relate to the large number of rainfall events and the short periods of time for pollutants to accumulate between events. The small metals loadings at the grassy site are probably due to the accumulation/retention of these constituents in grassy areas.

The correlation coefficients for heavy metals shown in Table 13 indicate that average nonwinter metals loadings correlated extremely well with a combination of the three site characteristics, i.e., ADT, percent imperviousness and dustfall (Column 7, Table 13). These values ranged from 0.907 (chromium) to 0.996 (zinc). Combination of two site characteristics (columns 4-6) also had high multiple r values for many of the metals. Lead seems to be highly related to any combination of two of the three characteristics. This is interesting since only percent imperviousness has a high simple r value for lead. This same observation holds true for zinc. Total iron loadings had the highest simple r value with percent imperviousness (0.605)

Table II. Loading of lead, zinc, iron and copper in highway runoff.

Lead, pounds per acre

	Overall 1976-77 monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Avg.	Range	Avg. x 10^{-3}	Range x 10^{-3}	Avg.	Range
Milw.-Hwy. 794	0.210	0.009-0.45	180	9-480	0.260	0.080-0.48
Milw.-Hwy. 45	0.046	0.002-0.205	23	2-80	0.076	0.008-0.205
Milw.-Grassy Site	0.007	0.00001-0.28	7	0.01-230	0.006	0.00002-0.02
Harrisburg	0.007	0.001-0.33	6	1-30	0.009	0.001-0.023
Nashville	0.036	0.0016-0.10	25	2-90	0.040	0.010-0.10
Denver	0.023	0.001-0.1	23	1-100		c

Zinc, pounds per acre

	Overall 1976-77 monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.05	0.005-0.12	40	5-110	0.060	0.02-0.12
Milw.-Hwy. 45	0.027	0.001-0.090	12	1-30	0.036	0.004-0.09
Milw.-Grassy Site	0.006	0.000001-0.02	5	0.001-20	0.007	0.00002-0.02
Harrisburg	0.006	0.00005-0.03	4	0.05-10	0.009	0.005-0.03
Nashville	0.016	0.0009-0.05	14	0.09-40	0.020	0.006-0.05
Denver	0.019	0.002-0.06	19	2-60		c

Iron, pounds per acre

	Overall 1976-77 monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Avg.	Range	Avg. x 10^{-3}	Range x 10^{-3}	Avg.	Range
Milw.-Hwy. 794	0.83	0.024-2.44	780	24-2440	0.93	0.25-2.12
Milw.-Hwy. 45	0.653	0.037-3.50	490	37-1770	0.92	0.06-3.50
Milw.-Grassy Site	0.444	0.0000004-2.42	510	0.0004-2420	0.30	0.0002-0.77
Harrisburg	0.193	0.001-1.28	150	1-1130	0.24	0.002-1.28
Nashville	0.380	0.0097-2.05	300	10-840	0.61	0.12-2.05
Denver	0.48	0.04-1.76	480	40-1760		c

Copper, pounds per acre

	Overall 1976-77 monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Avg.	Range	Avg. x 10^{-3}	Range x 10^{-3}	Avg.	Range
Milw.-Hwy. 794	0.011	0.001-0.29	10	1-29	0.012	0.005-0.024
Milw.-Hwy. 45	0.006	0.000018-0.029	3	0.02-9	0.010	0.001-0.029
Milw.-Grassy Site	0.003	0.000003-0.008	2	0.003-8	0.004	0.00001-0.008
Harrisburg	0.003	0.0004-0.016	2	0.04-6	0.005	0.0002-0.016
Nashville	0.005	0.0004-0.02	5	0.04-20	0.006	0.001-0.02
Denver	0.004	0.0006-0.017	4	0.06-17		c

[a] Represents monitoring periods between April through October, 1976-77. Actual numbers may vary between sites.

[b] Represents monitoring periods between November through March, 1976-77. Actual numbers may vary between sites.

[c] No storm events monitored during winter at Denver due to lack of sufficient precipitation.

Metric units: pounds per acre x 1.12 = kg/ha.

Table 12. Loadings of cadmium, chromium and mercury in highway runoff.

	Cadmium, pounds per acre					
	Overall 1976-77 monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Avg.	Range	Avg. $\times 10^{-3}$	Range $\times 10^{-3}$	Avg.	Range
Milw.-Hwy. 794	0.004	0.001-0.014	4	1-14	0.006	0.0009-0.014
Milw.-Hwy. 45	0.001	0.000018-0.004	1	0.02-4	0.002	0.0002-0.005
Milw.-Grassy Site	0.001	0.000001-0.004	1	0.001-4	0.002	0.00001-0.004
Harrisburg	0.001	0.0002-0.006	1	0.2-3	0.002	0.0002-0.006
Nashville	0.002	0.00007-0.003	2	0,07-5	0.002	0.0004-0.003
Denver	0.001	0.00008-0.0017	1	0.08-2		c

	Chromium, pounds per acre					
	Overall 1976-77 monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Avg.	Range	Avg. $\times 10^{-3}$	Range $\times 10^{-3}$	Avg.	Range
Milw.-Hwy. 794	0.005	0.001-0.29	6	0.1-29	0.004	0.0009-0.01
Milw.-Hwy. 45	0.004	0.000018-0.029	4	0.02-4	0.004	0.0002-0.029
Milw.-Grassy Site	0.001	0.0000004-0.004	1	0.0004-4	0.001	0.000004-0.002
Harrisburg	0.003	0.0002-0.020	3	0.4-20	0.002	0.0002-0.005
Nashville	0.001	0.00004-0.008	1	0.04-3	0.003	0.0007-0.008
Denver	0.001	0.00006-0.007	1	0.06-7		c

	Mercury, pounds per acre					
	Overall 1976-77 monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Avg. $\times 10^{-6}$	Range $\times 10^{-6}$	Avg. $\times 10^{-6}$	Range $\times 10^{-6}$	Avg. $\times 10^{-6}$	Range $\times 10^{-6}$
Milw.-Hwy. 794	0.15	0.048-2.1	0.39	0.048-2.1	0.054	0.048-0.095
Milw.-Hwy. 45	0.16	0.0028-0.75	0.10	0.0028-0.75	0.2	0.004-0.4
Milw.-Grassy Site	0.028	0.00001-0.08	0.03	0.00001-0.04	0.035	0.0008-0.08
Harrisburg	0.50	0.001-7.0	0.72	0.001-1.1	0.3	0.01-1.0
Nashville	2.73	0.005-0.03	0.07	0.005-0.17	0.2	0.02-0.3
Denver	0.07	0.001-0.6	0.07	0.001-0.6		c

[a]Represents monitoring periods between April through October, 1976-77. Actual numbers may vary between sites.

[b]Represents monitoring periods between November through March, 1976-77. Actual numbers may vary between sites.

[c]No storm events monitored during winter at Denver due to lack of sufficient precipitation.

Metric units: pounds per acre x 1.12 = kg/ha

Table 13. Correlation coefficients 'r' for metals vs. site characteristics.

Dependent variable	Simple correlation coefficients			Multiple correlation coefficients			
	ADT	%IMP	DF	ADT and %IMP	ADT and DF	DF and %IMP	ADT % IMP DF
Column no.	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Pb	-0.174	0.942	0.125	0.950	0.913	0.945	0.978
Zn	-0.54	0.949	0.255	0.949	0.950	0.950	0.996
Fe	-0.315	0.605	-0.008	0.669	0.955	0.621	0.988
Cu	0.095	0.954	0.387	0.965	0.928	0.972	0.994
Cd	0.036	0.894	0.302	0.898	0.831	0.901	0.913
Cr	-0.474	0.779	-0.279	0.892	0.707	0.904	0.907
Hg	0.960	0.027	0.889	0.963	0.962	0.905	0.987

ADT = Average daily traffic.
IMP = Imperviousness.
DF = Dustfall

compared to -0.315 for ADT and -0.008 for dustfall), however, ADT and dustfall had a much larger multiple r (column 5) than either of these factors considered with percent imperviousness (columns 4 and 6). All of the metals except mercury are most highly related on a simple correlation basis to percent imperviousness (column 2). As mentioned previously, this is an indication that the material which accumulates on the paved surface is readily washed off during a storm event.

It should be noted that all of the above discussed metals data were obtained as total metal concentrations by analyzing after acidification and digestion of the samples. However, some Pb, Zn and Fe samples were analyzed after filtration to obtain an idea about the dissolved fraction of the total metal concentrations. The results of these tests are shown in Table 14. As can be seen the dissolved metal fractions for most samples were extremely small and generally were near or below the detection limits. Based on these results, it was concluded that a major fraction of the heavy metals in highway runoff are associated with the particulate solids.

Chloride Data - As expected, there is a dramatic difference in the average chloride concentrations in the nonwinter (April through October period) versus the winter (November through March periods) values at the sites where deicing chemicals are used (Table 15). Since much less salt is used in Nashville than at the other sites, the winter and nonwinter average chloride values (28 vs. 17 mg/l respectively) are quite close. However, at I-794 in Milwaukee, the winter average at 2343 mg/l is nearly 40 times the nonwinter average (63 mg/l). This site is frequently salted in winter because it is an elevated freeway and has a tendency to become icy very quickly. However, some of this chloride concentration difference is due to the low snow-melt runoff volume during winters compared to significantly higher runoff volumes during nonwinter periods. The increases in concentrations during the winter periods were not as dramatic at the other sites ranging from 4 to 6 times the nonwinter values. The differences in chloride values continued to be significant when loadings were calculated in pounds per acre per event (elimination of differences in concentrations due to flow volumes) as shown in Table 15. These differences in chloride loadings demonstrate the significant impact of salting practices for deicing at the respective sites. Salting maintenance practices are discussed in more detail in a later section of this report.

Oxygen Demand Parameters - The oxygen demand parameters included in the study were the 5-day biochemical oxygen demand (BOD_5), the total organic carbon (TOC), and the chemical oxygen demand (COD). In a few instances the 20-day biochemical oxygen demand (BOD_{20}) analysis

Table 14. Total and dissolved analysis for lead, zinc and iron at various sites.

Site	Storm no.	Storm date	Type of sample	Lead, mg/l		Zinc, mg/l		Iron, mg/l	
				Total	Dissolved	Total	Dissolved	Total	Dissolved
I-794 Milwaukee	11	3/8/77	Composite	13.1	<0.05	3.4	0.21	43.0	0.03
			Discrete	160.0	<0.05	25.0	0.58	39.0	0.48
			Discrete	17.0	<0.05	3.3	0.20	52.0	0.09
			Discrete	2.5	<0.05	0.8	0.31	10.0	0.08
			Discrete	0.2	<0.05	0.1	0.09	0.4	0.07
Hwy. 45 Milwaukee	17	3/8/77	Composite	6.6	<0.05	1.9	0.36	35.0	0.11
			Discrete	8.6	<0.05	2.8	0.25	43.0	0.12
			Discrete	9.3	<0.05	3.0	0.29	51.0	0.14
			Discrete	2.3	<0.05	1.2	0.48	14.0	0.20
	18	3/11/77	Composite	2.2	<0.05	0.94	0.39	15.0	0.23
			Discrete	6.5	<0.05	2.35	0.33	39.0	0.13
			Discrete	6.4	<0.05	2.00	0.37	34.0	0.24
			Discrete	0.1	<0.05	0.35	0.34	1.1	0.16
Grassy Site Milwaukee	01	2/23/77	Composite	<0.05	<0.05	0.14	0.08	2.9	0.25
			Discrete	0.20	<0.10	0.16	0.08	3.6	0.19
			Discrete	0.40	<0.10	-	-	2.1	0.20
			Discrete	<0.10	<0.10	-	-	1.5	0.15
I-81 Harrisburg	15	2/24/77	Composite	<0.05	<0.05	0.15	0.02	6.6	0.13
			Discrete	<0.05	<0.05	0.09	0.08	1.9	0.05
I-40 Nashville	03	2/23/77	Discrete	2.0	<0.05	1.10	0.20	27.0	0.05
	04	2/26/77	Composite	0.5	<0.05	0.36	0.03	6.3	0.34
			Discrete	2.2	<0.10	1.30	0.16	32.0	0.43
			Discrete	0.8	<0.10	0.40	0.14	7.9	0.04
			Discrete	0.3	<0.10	0.19	0.01	3.7	0.05

Table 15. Concentration and loadings of chloride in highway runoff.

	Chloride, mg/l					
	Overall 1976-77 monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	856	10-13300	63	10-118	2343	62-13300
Milw.-Hwy. 45	645	40-3413	229	40-828	1327	150-3413
Milw.-Grassy site	315	40-1165	168	40-366	610	219-1165
Harrisburg	195	20-800	56	20-110	347	20-800
Nashville	21	5-55	17	5-45	28	7-55
Denver	36	8-90	36	8-90		c

	Chloride, pounds per acre per event					
	Overall 1976-77 monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	23.0	0.95-329	2.7	0.95-76	61	10-329
Milw.-Hwy. 45	24.8	0.91-188	4.6	0.91-15.2	58	3-188
Milw.-Grassy site	6.3	0.008-34.4	2.4	0.008-7.6	14	0.3-34
Harrisburg	11.2	0.32-82.8	2.6	0.32-8.6	21	1-83
Nashville	1.2	0.054-4.55	0.8	0.05-1.6	2	0.6-5
Denver	0.8	0.11-2.38	0.8	0.11-2.4		c

[a]Represents monitoring periods between April through October, 1976-77. Actual number of months may vary between sites.

[b]Represents monitoring periods between November through March, 1976-77. Actual number of months may vary between sites.

[c]No storm events monitored during winter at Denver site due to lack of sufficient precipitation.

Metric units: pounds per acre x 1.12 = kg/ha was also conducted. The BOD_5 and COD analyses have traditionally been employed in the water pollution control and water resources fields as a means of assessing the oxygen demand values of water discharges of all types and also of receiving waters. In recent years the TOC determination has also gained acceptance as still another means of characterizing oxygen demand levels. Though subject to some shortcomings, the biochemical oxygen demand test provides a means of assessing oxygen demand impacts on receiving waters under natural conditons, since microorganisms of the same type found in nature are principally responsible for the deoxygenation activity.

The COD and TOC analyses are measures of ultimate oxygen demand but unfortunately, can include an array of organic compounds that would exert little or no oxygen demand in a receiving water. Very finely ground pieces of rubber in a water sample, for example, could add to the magnitude of the COD and TOC values, but would have virtually no effect on the BOD_5 and BOD_{20} values.

The BOD_5, TOC and COD concentrations obtained in this study are summarized in Table 16. As noted, for those sites in which at least several events are included, the average BOD_5 values are in the range of what one would expect for an effluent from a well operated municipal secondary wastewater treatment plant. The exception would be the Harrisburg site, where substantially lower BOD concentrations were obtained. This is reasonable since higher concentrations would be expected from those sites with higher particulate solids, and sites that are urban rather than rural, due to the higher dustfalls in the case of the former. Maximum BOD_5 values approaching and even over 100 mg/l in the runoff from various sites were obtained in a few instances indicating that "slug" loadings of oxygen demanding pollutants are possible at times. Such loadings would be of particular concern if the highway runoff is tributary to a low flow/volume receiving water body. In terms of normalized BOD_5 loadings in lbs/acre/event (Table 17), again, the highest loadings were exhibited from the I-794 site in Milwaukee and the lowest loadings were exhibited for the Harrisburg site.

As noted from the data in Table 16, the ratio of BOD to COD analysis is fairly low. The magnitude of the TOC and COD analyses, relative to the BOD analysis, indicates that the greatest percentage of the organics in highway runoff is of the nonbiodegradable type, and that possible toxic materials in the runoff samples have an inhibitory effect on the BOD results. The same is true when comparing the BOD_5 and TOC results, which means that even though some fairly high COD and TOC values were obtained at all of the sites except Harrisburg, the impact on the oxygen level in nearby receiving waters will for the most part be minimal, except possibly for some slug events. In the case of the Milwaukee Hwy. I-794 site for example, a

Table 16. Concentrations of oxygen demand parameters in highway runoff.

BOD$_5$, mg/l

	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	32	5-133	21	5-63	68	31-133
Milw.-Hwy. 45	20	8-73	16	8-46	29	8-73
Milw.-Grassy site	15	7-22	14	7-22	17	14-19
Harrisburg	4	2-6	3	2-4	4	2-6
Nashville	26	5-52	27	15-52	22	5-39
Denver	46	20-73	46	20-73	c	

COD, mg/l

	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	232	5-1058	105	5-226	471	158-1058
Milw.-Hwy. 45	165	64-774	120	64-185	245	73-774
Milw.-Grassy site	107	42-167	92	42-144	138	80-167
Harrisburg	36	21-89	30	21-54	43	26-89
Nashville	125	13-264	139	31-264	97	13-181
Denver	191	119-718	191	119-718	c	

TOC, mg/l

	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	50	5-230	31	5-67	86	34-230
Milw.-Hwy. 45	54	16-290	34	16-63	88	27-290
Milw.-Grassy site	38	23-57	38	23-57	37	25-44
Harrisburg	13	6-24	12	6-17	14	6-24
Nashville	38	12-85	37	12-74	39	14-85
Denver	54	14-212	54	14-212	c	

[a]Represents monitoring periods between April through October, 1976-77. Actual number of months may vary between sites.

[b]Represents monitoring periods between November through March, 1976-77. Actual number of months may vary between sites.

[c]No storm events monitored during winter at Denver site due to lack of sufficient precipitation.

Table 17. Loadings of oxygen demand parameters in highway runoff.

	BOD5, pounds per acre per event					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	1.59	0.29-3.24	1.52	0.29-3.19	1.82	1.05-3.24
Milw.-Hwy. 45	0.52	0.007-1.64	0.42	0.10-0.75	0.73	0.15-1.64
Milw.-Grassy site	0.45	0.0004-1.2	0.35	0.0004-1.00	0.60	0.004-1.20
Harrisburg	0.35	0.022-1.34	0.09	0.05-0.14	0.43	0.022-1.34
Nashville	1.17	0.18-4.1	1.02	0.13-3.80	1.52	0.43-4.10
Denver	0.79	0.35-1.67	0.79	0.35-1.67	c	

	COD, pounds per acre per event					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	12.30	0.19-34.3	9.3	1.4-19.5	17.8	0.19-34.3
Milw.-Hwy. 45	5.96	0.35-26.9	3.6	0.4-8.1	10.2	1.04-26.9
Milw.-Grassy site	3.76	0.004-19.2	2.2	0.004-8.0	6.9	0.04-19.2
Harrisburg	3.04	0.11-20.5	1.0	0.1-4.1	6.0	0.27-20.5
Nashville	6.84	0.61-21.8	6.1	0.6-12.9	8.2	3.26-21.8
Denver	8.19	1.13-20.9	8.2	1.1-20.9	c	

	TOC, pounds per acre per event					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	3.83	0.48-11.4	3.3	0.48-10.0	4.8	1.4-11.4
Milw.-Hwy. 45	1.99	0.09-11.5	1.1	0.09-2.3	3.5	0.4-11.5
Milw.-Grassy site	1.25	0.002-5.6	0.9	0.002-2.8	2.1	0.01-5.6
Harrisburg	0.96	0.03-5.3	0.9	0.03-5.3	1.0	0.1-2.3
Nashville	1.78	0.22-3.33	1.7	0.22-3.1	1.9	0.9-2.3
Denver	2.53	0.17-6.15	2.5	0.17-6.2	c	

[a]Represents monitoring periods between April through October, 1976-77. Actual number of months may vary between sites.

[b]Represents monitoring periods between November through March, 1976-77. Actual number of months may vary between sites.

[c]No storm events monitored during winter at Denver site due to lack of sufficient precipitation.

Metric units: To convert lbs/ac to kg/ac multiply by 1.12.

composite maximum COD concentration of 1058 mg/l (Table 16) would be considered a rather high strength waste, but from the standpoint of impact on a receiving water body, the associated BOD_5 value of 133 mg/l is of greater concern. However, as stated previously, a COD value of this concentration can still be very significant depending upon the receiving water situation.

There have been a number of investigations in recent years on the quality of stormwater runoff from urban drainage areas where it has been reported that the BOD_5 values were found to be supressed relative to COD and TOC values. Defillippi and Shih (8) suspected that toxic constituents in storm runoff in the Washington, D.C. area inhibited the BOD_5 analysis and thus caused the low BOD_5 to COD ratios reported in their study. Sartor and Boyd (9) concluded that the COD test provides a better basis for estimating the oxygen demand potential than the BOD_5 value, because the presence of toxic materials in street surface contaminants (particularly heavy metals) seriously interfered with the latter test. Interestingly, Pitt and Amy (10) found that BOD_5/COD ratios were much less for rural road and highway samples than for city street samples, speculating that toxicity caused a depression in some of the BOD_5 values. Colston (11), as a result of his studies on urban land runoff, became convinced that the BOD_5 analysis was, "an inappropriate analytical test for organic characterization of urban land runoff". He found that the BOD_5 value of urban runoff samples varies with the dilution of sample used in performing the test, the more dilute samples resulting in higher BOD_5 results. He speculated that this phenomenon could be due to:

1. The inhibitory effect of heavy metals.
2. The presence of other unidentified inhibitory compounds.
3. Inherent problems of the standard BOD test.

The magnitudes of the BOD_5, COD and TOC values obtained in this study are in the range of what would be expected in urban stormwater runoff. This is demonstrated in Table 18 which presents a summary of BOD_5, COD and TOC values reported in a number of selected studies on urban stormwater runoff. As expected, the variability in results can be quite excessive as indicated by the disparity in the reported range of values. It is also apparent that the BOD_5 to COD ratio for urban runoff is quite low as is the case for the highway runoff results reported in this study.

Table 19 presents the results of several long term BOD tests conducted on selected highway runoff samples. The results indicate that the organics present in these samples are biodegradable, but the reaction kinetics can be characterized as slow or somewhat retarded. This situation usually occurs in samples such as river waters,

Table 18. Summary of BOD_5, COD and TOC values in urban stormwater runoff from selected cities in the U.S.

Area	Ref.	BOD_5,mg/l Mean	Range	COD,mg/l Mean	Range	TOC, mg/l Mean	Range
Washington, D.C.	(8)	19	3-90	335	29-1514	--	--
Durham, NC	(12)	15	2-232	179	40-600	--	--
Cincinnati, OH	(13)	17	1-173	111	20-610	--	--
Durham, NC	(11)	--	2-220[a]	170	20-1042	42	5.5-384
Ann Arbor, MI	(14)	28	1-62[b]	--	--	--	--
Tulsa, OK	(15)	7.3	--	48	--	--	--
Highway Runoff[c]							
Milwaukee I-794		32	5-133	232	5-1058	50	5-230
Milwaukee Hwy. 45		20	8-73	165	64-774	54	16-290
Milwaukee Grassy Site		15	7-22	107	42-167	38	23-57
Harrisburg		4	2-6	36	21-89	13	6-24
Nashville		26	5-52	125	13-264	38	12-85
Denver		46	20-73	191	119-718	54	14-212

[a] BOD_5 test not found to be an appropriate test for urban land runoff.

[b] Reported as maximum value.

[c] Measured values for 1976-77 monitoring period.

Table 19. BOD_5 and BOD_{20} values of selected composite samples of highway runoff.

Site	Date 1977	BOD_5, mg/l	BOD_{20}, mg/l
Milwaukee-Hwy. 794	6/08	18	30
	6/30	5	20
Denver	6/23	--	320
Nashville	6/23	--	36
	9/06	40	110
Milwaukee-Hwy. 45	6/08	12	33
	6/30	7	33
Milwaukee-Grassy site	7/20	13.5	27[a]
	9/18	--	24
	9/24	--	16

[a]BOD_{25}

stormwater runoff and treated effluents, either because the organics tend to be resistant to biochemical oxidation or the presence of toxic materials tends to inhibit the reaction, as discussed previously. The impact of highway runoff with the range of BOD_{20} values shown in Table 19 depends on the type of receiving water body involved; the potential for adverse effects being greater for sluggish streams, stagnant waters and certain lakes.

The relationships between the BOD_5 and COD and BOD_5 and TOC discussed previously apply for loading rates as they do for concentrations. As expected, oxygen demand loadings in urban areas were greater than loadings in the rural area by a factor of 2 to 5 and in a few cases even more (Table 17). This is no doubt, the result of lower ADT and dustfall values in the rural area. The higher loadings in the Denver area in comparison to the other urban areas may be related to the higher ADT value even though the same wasn't apparent in solids or metal data discussed earlier. The two Milwaukee sites, Hwy. 794 and Hwy. 45, showed an increase in winter oxygen demand loadings, which are not readily explained. For the remaining sites, the nonwinter oxygen demand loadings did not differ greatly from the winter loadings.

Of particular interest is: can BOD_5 values be predicted with a reasonable degree of precision using either the COD or TOC determination in conjunction with a previously established correlation? Presented in Table 20 are the results of BOD_5/TOC, BOD_5/TOC/COD simple correlations (correlation coefficients presented represent all the oxygen demand data compiled at the six test sites). Underlined r values are significant at the 95 percent confidence level. The null hypothesis R=0, i.e., that the sample values were taken from a population for which no correlation existed, can be rejected for r values exceeding the critical r. In most cases a correlation existed for regression analysis of oxygen demanding parameters and these showed a high percentage of explained variance (r^2). This was especially true for the TOC/COD regressions where analysis for all six sites showed the existance of a correlation and a high r^2 value in most cases. This is not surprising since the TOC and COD measure the same type of organic matter. A correlation was not found in all cases for BOD/TOC and BOD/COD regression analysis. The BOD_5 is a measure of organic matter which is subject to microbial stabilization, and thus the results are more inherently variable.

The correlation coefficients for oxygen demand parameters with the three sites characteristics, ADT, percent imperviousness and dustfall are shown in Table 21.

Table 21. Correlation coefficients 'r' for oxygen demand parameters vs. site characteristics.

	Simple correlation coefficients			Multiple correlation coefficients			
Dependent variable	ADT	% IMP	DF	ADT and % IMP	ADT and DF	DF and % IMP	ADT % IMP DF
Column #	(1)	(2)	(3)	(4)	(5)	(6)	(7)
BOD_5	0.317	0.842	0.600	0.915	0.980	0.944	0.996
COD	0.209	0.768	0.478	0.807	0.892	0.832	0.900
TOC	0.040	0.868	0.322	0.872	0.879	0.879	0.919

ADT = Average daily traffic
IMP = Imperviousness
DF = Dustfall

The multiple correlation coefficients for the three site characteristics ranged between 0.900 (COD) to 0.996 (BOD_5). These multiple r values are much larger than the simple r values or the multiple r values determined for only two site characteristics. The percent imperviousness again provided the highest simple r values for these

Table 20. Correlation coefficients from regression analyses for pounds of BOD, COD, and TOC.

Site	BOD/TOC			BOD/COD			TOC/COD		
	n	r	r^2	n	r	r^2	n	r	r^2
Milwaukee-Hwy. 794	16	0.657	0.432	16	0.800	0.640	23	0.636	0.404
Milwaukee-Hwy. 45	22	0.909	0.826	22	0.925	0.856	28	0.830	0.689
Milwaukee-Grassy Site	4	0.994	0.988	4	0.990	0.980	13	0.996	0.992
Harrisburg	8	0.932	0.869	4	0.931	0.867	19	0.741	0.549
Nashville	9	0.640	0.410	10	0.754	0.569	20	0.867	0.752
Denver	7	0.792	0.627	7	0.865	0.748	14	0.973	0.947

NOTE: Underlined r values exceed the critical r value at the 95% confidence level.

parameters. The high multiple r values indicate that a reasonably accurate prediction of the loadings of oxygen demand parameters at a site can be made with information on ADT, percent imperviousness and dustfall. However, any predictions based upon these three site characteristics must be considered only as rough estimates.

Nutrients - The highway runoff samples were analyzed for total kjeldahl nitrogen (TKN), nitrate plus nitrite nitrogen, and total phosphate. The nutrient constituents which were obtained at the six sites are summarized in Table 22, whereas the normalized loadings in lbs/ac/event are presented in Table 23. As in the case of the oxygen demand parameters, the concentration of nutrients in rural highway runoff was lower than in urban runoff. This was not always true in the case of the loadings. The nutrient concentrations and loadings were higher in most instances at the Denver site in comparison to the other urban sites, again a possible reflection of higher ADT values at the former site. As in the case of oxygen demand parameters, the runoff from the grassy site has a concentration amd loading of nutrients somewhat lower than for the other types of urban sites. Finally, for the most part, the concentrations of nutrients in runoff from highway sites are lower than the concentrations normally present in the effluent of a secondary treatment plant, but in the range of values for urban runoff as demonstrated in Table 24. If there is any difference, the nitrogen concentrations tend to be lower in urban runoff compared to highway runoff. However, the reverse is true for phosphate concentrations wherein the phosphate concentrations are generally higher in urban runoff than in highway runoff, with the possible exception of the rural Harrisburg site where comparatively low phosphate concentrations were found.

The correlation coefficients for nutrients with the three site characteristics, ADT, percent imperviousness and dustfall are shown in Table 25. Again, the multiple r values are larger than the simple r values. The percent imperviousness again provided the highest simple r values for these parameters with the one exception being total phosphates. ADT and dustfall had simple r values for TP of 0.964 and 0.961 respectively. The high simple r values for dustfall is understandable since dustfall is considered a major nonpoint source of phosphorus to receiving waters. There seems to be no readily apparent reason for the high sample correlation between TP and ADT and the lack of correlation between TP and percent imperviousness.

The multiple r values for all three site characteristics for the nutrients are very high. This indicates a reasonably accurate prediction of the loadings of these parameters at a site can be made with information on ADT, percent imperviousness, and dustfall. These

Table 22. Concentrations of nutrients in highway runoff.

	Total phosphate, mg/l					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.50	0.12-1.81	0.31	0.12-0.63	0.90	0.28-1.81
Milw.-Hwy. 45	0.52	0.10-1.27	0.48	0.10-1.27	0.59	0.28-1.23
Milw.-Grassy site	0.81	0.31-1.51	0.90	0.33-1.51	0.64	0.31-1.11
Harrisburg	0.34	0.05-0.86	0.29	0.05-0.56	0.39	0.12-0.86
Nashville	1.92	0.77-3.55	1.89	0.77-3.55	1.97	0.78-3.50
Denver	0.92	0.48-2.36	0.92	0.48-2.36	c	

	Total Kjeldahl nitrogen, mg/l					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	3.43	0.60-10.7	2.04	0.60-4.01	6.2	2.2-10.7
Milw.-Hwy. 45	3.28	0.8-11.4	3.40	0.80-11.4	3.1	1.4-7.1
Milw.-Grassy site	2.87	0.7-3.3	2.90	0.7-5.0	2.8	2.3-3.3
Harrisburg	1.58	0.1-8.1	2.12	0.6-8.1	1.0	0.1-1.6
Nashville	2.67	0.4-10.0	3.02	0.5-10.0	1.9	0.4-6.2
Denver	4.47	1.6-14.0	4.47	1.6-14.0	c	

	Nitrate & nitrite, mg/l					
	Overall 1976-77 monitoring period		Non-winter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	1.70	0.34-8.40	1.57	0.34-5.60	1.95	0.35-8.4
Milw.-Hwy. 45	1.46	0.35-3.55	1.55	0.49-2.90	1.34	0.35-3.55
Milw.-Grassy site	0.48	0.01-1.80	0.38	0.01-0.85	0.67	0.03-1.80
Harrisburg	0.83	0.26-1.76	0.76	0.38-1.76	0.90	0.26-1.34
Nashville	0.98	0.25-3.00	0.82	0.25-1.90	1.31	0.59-3.00
Denver	1.07	0.36-2.70	1.07	0.36-2.70	c	

[a]Represents monitoring periods between April through October, 1976-77. Actual number of months may vary between sites.

[b]Represents monitoring periods between November through March, 1976-77. Actual number of months may vary between sites.

[c]No storm events monitored during winter at Denver site due to lack of sufficient precipitation.

Table 23. Loadings of nutrients in highway runoff.

	Overall 1976-77 monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Avg.	Range	Avg.	Range	Avg.	Range
Total phosphate, lbs/acre/event						
Milw.-Hwy. 794	0.041	0.003-0.11	0.04	0.003-0.10	0.042	0.005-0.11
Milw.-Hwy. 45	0.024	0.001-0.125	0.02	0.001-0.06	0.026	0.001-0.13
Milw.-Grassy Site	0.032	0.00008-0.13	0.02	0.0004-0.08	0.050	0.00008-0.13
Harrisburg	0.036	0.0002-0.169	0.02	0.0002-0.17	0.050	0.002-0.15
Nashville	0.124	0.0045-0.36	0.11	0.005-0.29	0.150	0.06-0.36
Denver	0.026	0.004-0.089	0.03	0.004-0.09		c
Total Kjeldahl nitrogen, lbs/acre/event						
Milw.-Hwy. 794	0.23	0.01-0.63	0.20	0.01-0.53	0.30	0.06-0.63
Milw.-Hwy. 45	0.16	0.007-0.76	0.13	0.01-0.57	0.20	0.01-0.76
Milw.-Grassy Site	0.10	0.0001-0.35	0.07	0.0001-0.26	0.15	0.0004-0.35
Harrisburg	0.10	0.003-3.2	0.09	0.004-0.30	0.12	0.003-0.32
Nashville	0.16	0.0045-1.04	0.19	0.005-1.04	0.11	0.04-0.31
Denver	0.11	0.085-0.38	0.11	0.09-0.38		c
Nitrate & nitrate, lbs/acre/event						
Milw.-Hwy. 794	0.11	0.009-0.40	0.11	0.01-0.21	0.12	0.009-0.4
Milw.-Hwy. 45	0.06	0.005-0.31	0.04	0.01-0.06	0.08	0.006-0.31
Milw.-Grassy Site	0.026	0.00004-0.24	0.01	0.0004-0.05	0.06	0.00004-0.24
Harrisburg	0.058	0.002-0.28	0.02	0.002-0.14	0.09	0.003-0.28
Nashville	0.100	0.0025-0.42	0.04	0.003-0.07	0.13	0.02-0.42
Denver	0.039	0.002-0.18	0.04	0.002-0.18		c

[a]Represents monitoring periods between April through October, 1976-77. Actual numbers may vary between sites.

[b]Represents monitoring periods between November through March, 1976-77. Actual numbers may vary between sites.

[c]No storm events monitored during winter at Denver due to lack of sufficient precipitation.

Metric units: to convert lbs/ac/event to kg/ha/event, multiply by 1.12

Table 24. Summary of nutrient values in urban stormwater runoff from selected cities in the U.S.

Area	Ref.	Nitrogen, mg/l Form	Mean	Range	Total phosphate, mg/l Mean	Range
Washington, DC	(8)	Total N	2.1	0.5-6.5	1.3	0.2-4.5
Durham, NC	(12)	--	--	--	0.58	0.15-2.50
Cincinnati, OH	(13)	Total N	3.1	0.3-7.5	1.1[a]	0.02-7.3
		Inorg. N	1.0	0.1-3.4	--	--
Durham, NC	(11)	Kjel-N	0.96	0.1-11.6	2.5	0.6-48
Ann Arbor, MI	(15)	Kjel-N	2.0	0.1-6.0[b]	5.0	0.1-16.4[b]
		NO_3-N	1.5	0.1-3.6	--	--
Tulsa, OK	(15)	Kjel-N	1.6	--	2.0	--
Highway Runoff[c]						
Milw. I-794		Kjel-N	3.43	0.60-10.7	0.50	0.12-1.81
Milw. -Hwy. 45		Kjel-N	3.28	0.8-11.4	0.52	0.10-1.27
Milw.-Grassy site		Kjel-N	2.87	0.7-3.3	0.81	0.31-1.51
Harrisburg		Kjel-N	1.58	0.1-8.1	0.34	0.05-0.86
Nashville		Kjel-N	2.67	0.4-10.0	1.92	0.77-3.55
Denver		Kjel-N	4.47	1.6-14.0	0.92	0.48-2.36

a Hydrolyzable PO_4

b Reported as maximum value

c Measured values for 1976-77 monitoring period.

Table 25. Correlation coefficients 'r' for nutrients vs. site characteristics.

	Simple correlation coefficients			Multiple correlation coefficients			
Dependent variable	ADT	% IMP	DF	ADT and % IMP	ADT and DF	DF and % IMP	ADT % IMP DF
Column#	(1)	(2)	(3)	(4)	(5)	(6)	(7)
TP	0.964	0.159	0.961	0.986	0.976	0.962	0.987
TKN	0.522	0.794	0.725	0.973	0.884	0.975	0.975

ADT = Average daily traffic
IMP = Imperviousness
DF = Dustfall

correlations were developed with average nonwinter (April through October monitoring period) loading values, however, with no recognition of factors such as the range in pollutant loadings, number of dry days between events, rainfall volume and intensity, and other pertinent site and storm event characteristics. Therefore, any predictions based upon these site specific characteristics must be considered rough estimates despite the high correlation coefficients.

Discrete Sample Analysis Results (Group I Parameters) - The pattern of pollutant discharge during a runoff event was defined by discrete samples collected at constant time intervals throughout the event. The pollutant concentrations and flow measurements were utilized to determine loadings of various constituents during each time interval. In this study, total solids, suspended solids, lead, zinc, and iron were analyzed as discrete samples. Graphs of rainfall intensity, runoff flow, constituent concentrations (mg/l) and loadings (lb/min) with time for each of the monitoring sites are discussed in order to illustrate how these patterns vary.

A storm event on June 17, 1977 was monitored at each of the three monitoring sites in Milwaukee and is, therefore, excellent for the comparison of rainfall/runoff patterns and patterns of pollutant discharge. Figures 29 to 43 illustrate typical monitoring results for these three sites. The rainfall intensities in inches per hour during 5 minute time intervals and the runoff in cfs are illustrated in Figure 29 for the Hwy. 45 site. The first five minute rainfall intensity was quite high being nearly four inches per hour (10 cm/hr).

To obtain cm, multiply in. by 2.54
To obtain kg, multiply lbs by 0.454
To obtain m^3/sec, multiply cfs by 0.028

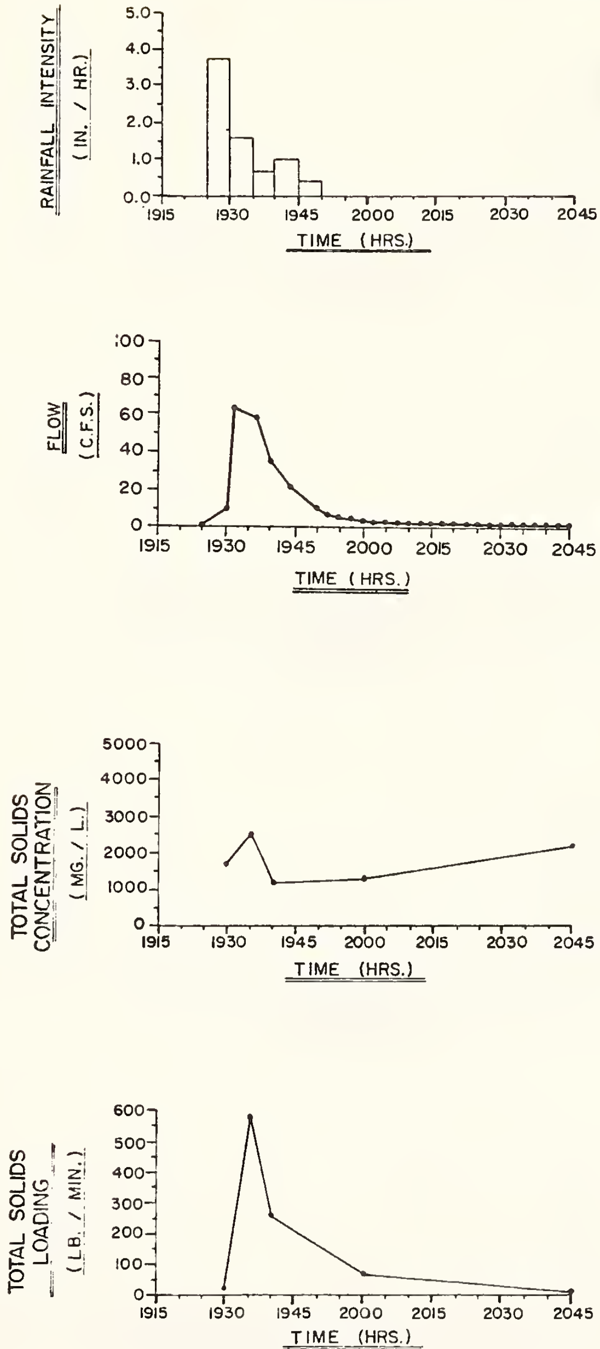


Figure 29. Pattern of discharge of total solids, Hwy. 45 site, Milwaukee, Wisconsin, event 30 (6/17/77).

To obtain cm, multiply in. by 2.54
To obtain kg, multiply lbs by 0.454
To obtain m^3/sec, multiply cfs by 0.028

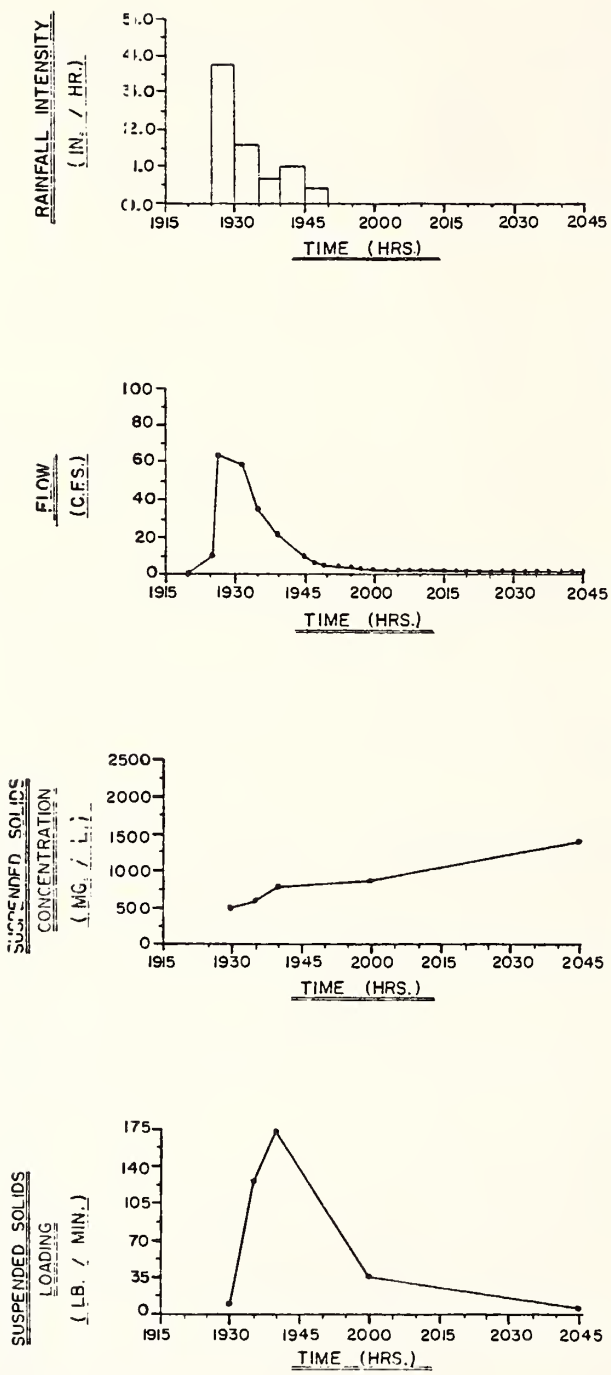


Figure 30. Pattern of discharge of suspended solids Hwy. 45 site, Milwaukee, Wisconsin, event 30 (6/17/77).

To obtain cm, multiply in. by 2.54.
To obtain kg, multiply lb by 0.454.
To obtain m^3/sec, multiply cfs by 0.028.

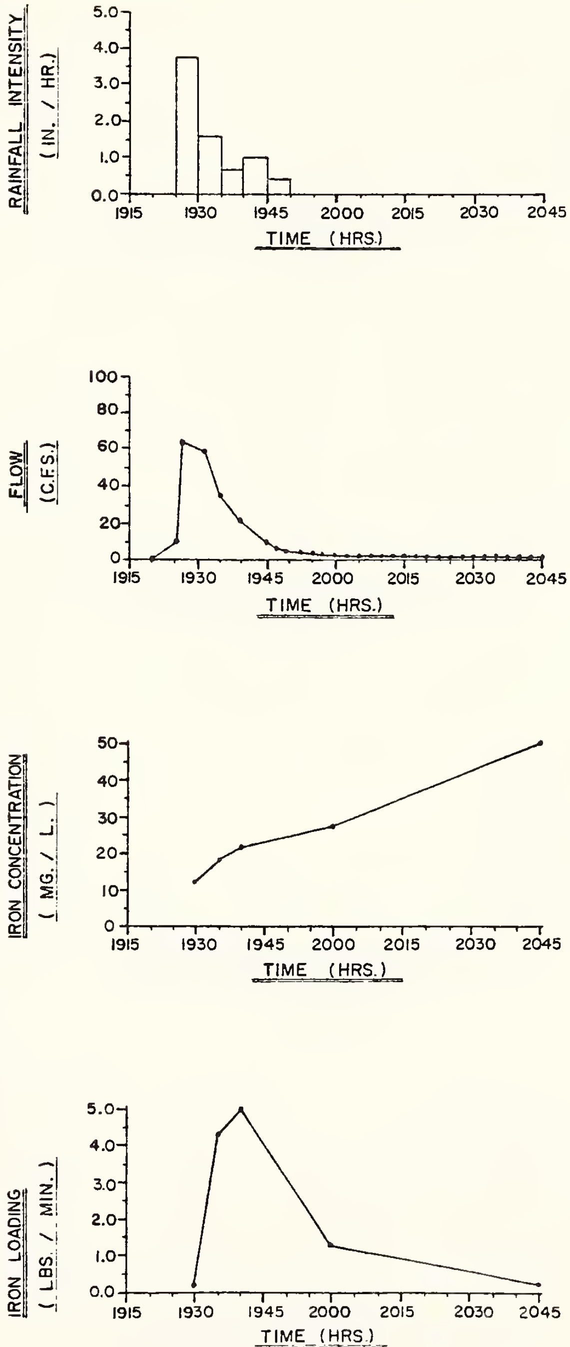


Figure 31. Pattern of discharge of lead, Hwy. 45 site, Milwaukee, Wisconsin, event 30 (6/17/77)

To obtain cm, multiply in. by 2.54
To obtain kg, multiply lbs by 0.454
To obtain m^3/sec, multiply cfs by 0.028

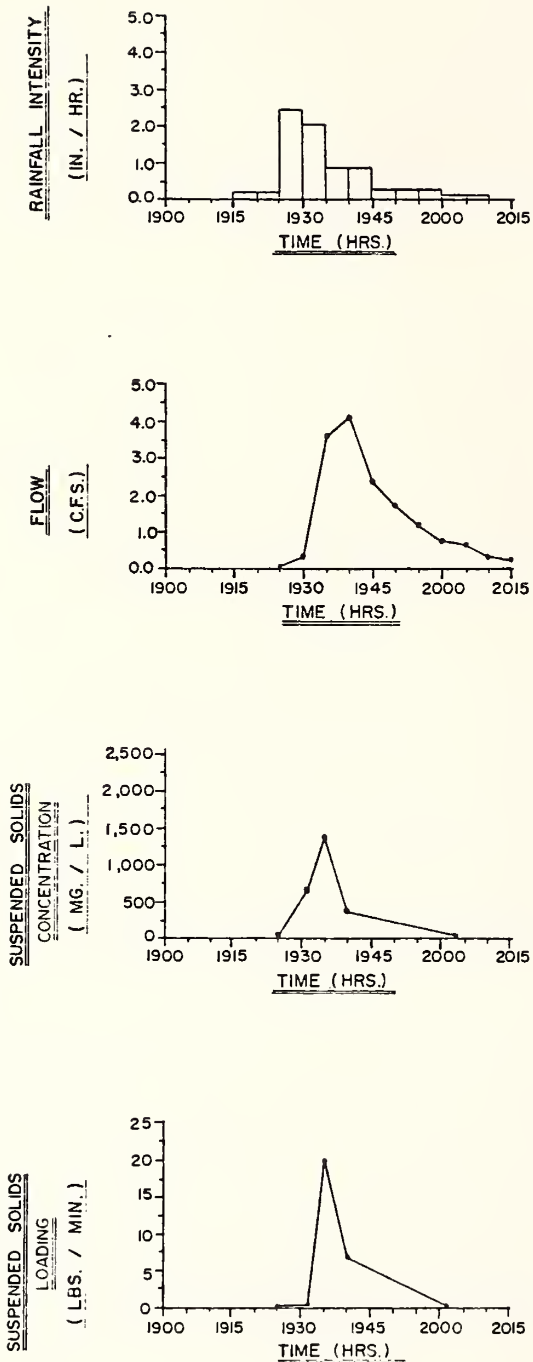


Figure 32. Pattern of discharge of zinc, Hwy. 45 site, Milwaukee, Wisconsin, event 30 (6/17/77).

To obtain cm, multiply in. by 2.54.
To obtain kg, multiply lbs by 0.454.
To obtain m^3/sec, multiply cfs by 0.028

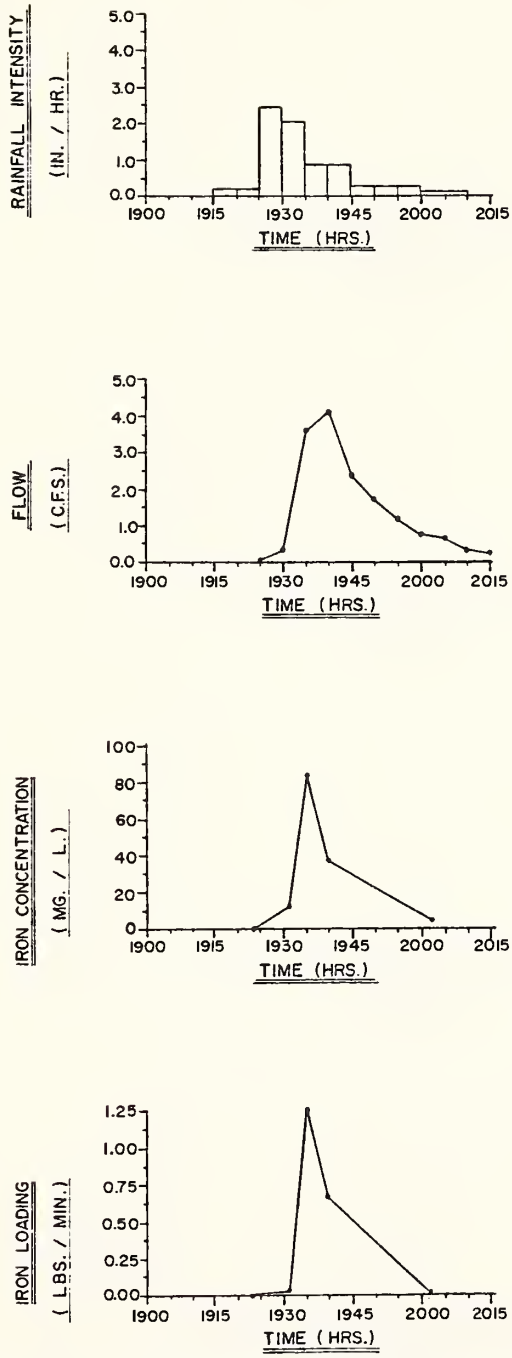


Figure 33. Pattern of discharge of iron, Hwy. 45 site, Milwaukee, Wisconsin, event 30 (6/17/77).

To obtain cm, multiply in. by 2.54.
To obtain kg, multiply lbs by 0.454.
To obtain m^3/sec, multiply cfs by 0.028.

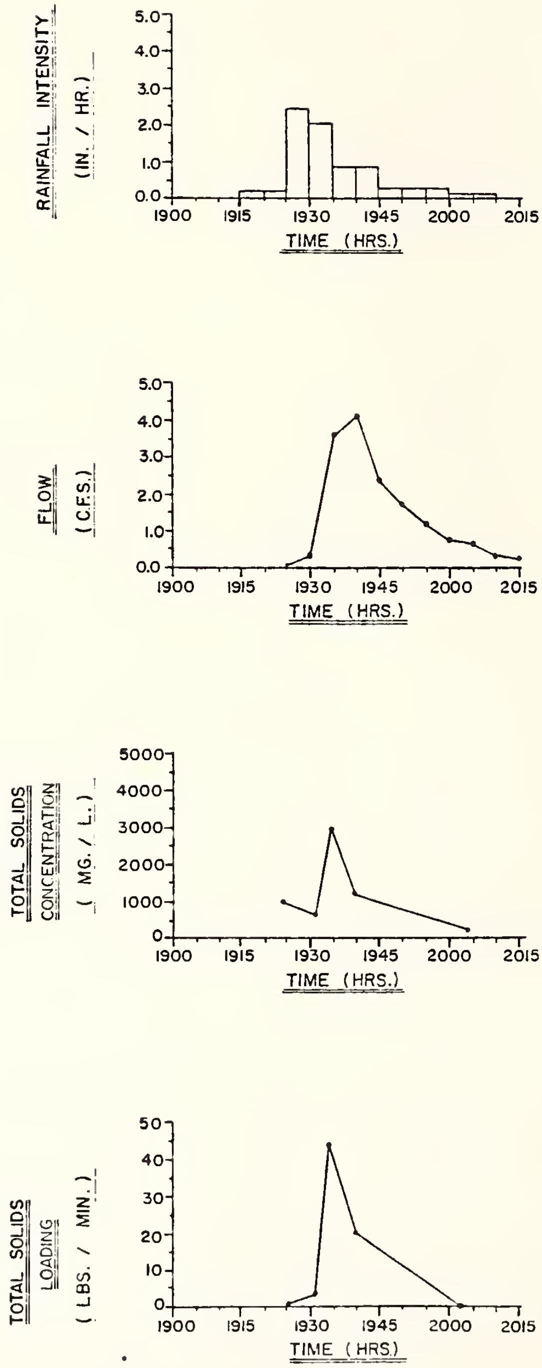


Figure 34. Pattern of discharge of total solids, Hwy. 45 grassy site, Milwaukee, Wisconsin, event 6 (6/17/77).

To obtain cm, multiply in. by 2.54.
To obtain kg, multiply lbs by 0.454.
To obtain m^3/sec, multiply cfs by 0.028.

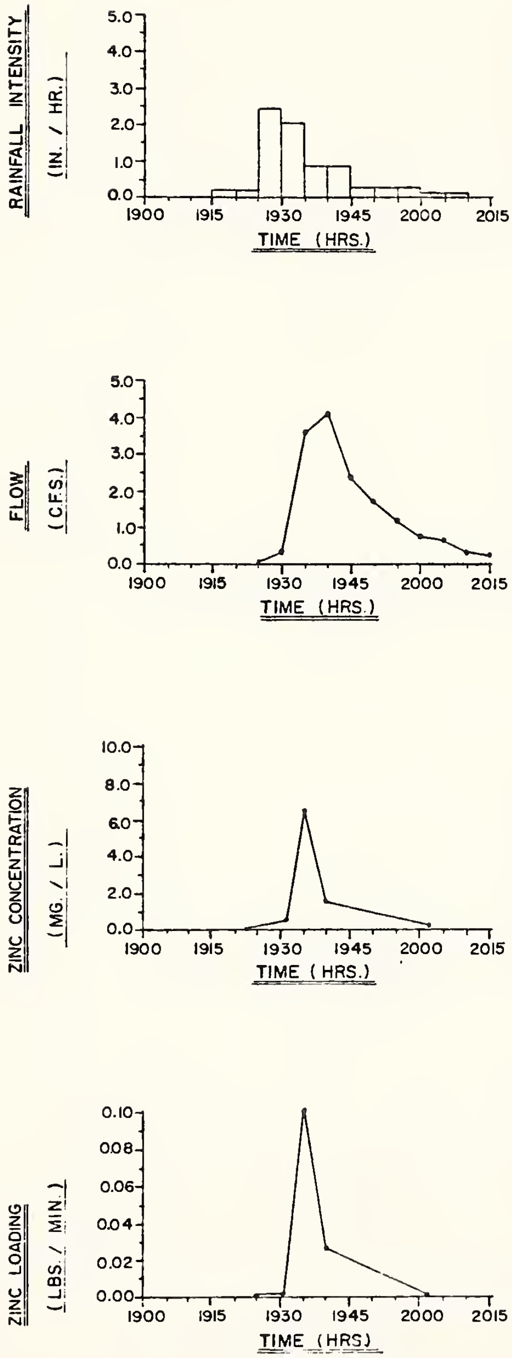


Figure 35. Pattern of discharge of suspended solids, Hwy. 45 grassy site, Milwaukee, Wisconsin, event 6 (6/17/77).

To obtain cm, multiply in. by 2.54
To obtain kg, multiply lbs by 0.454
To obtain m^3/sec, multiply cfs by 0.028

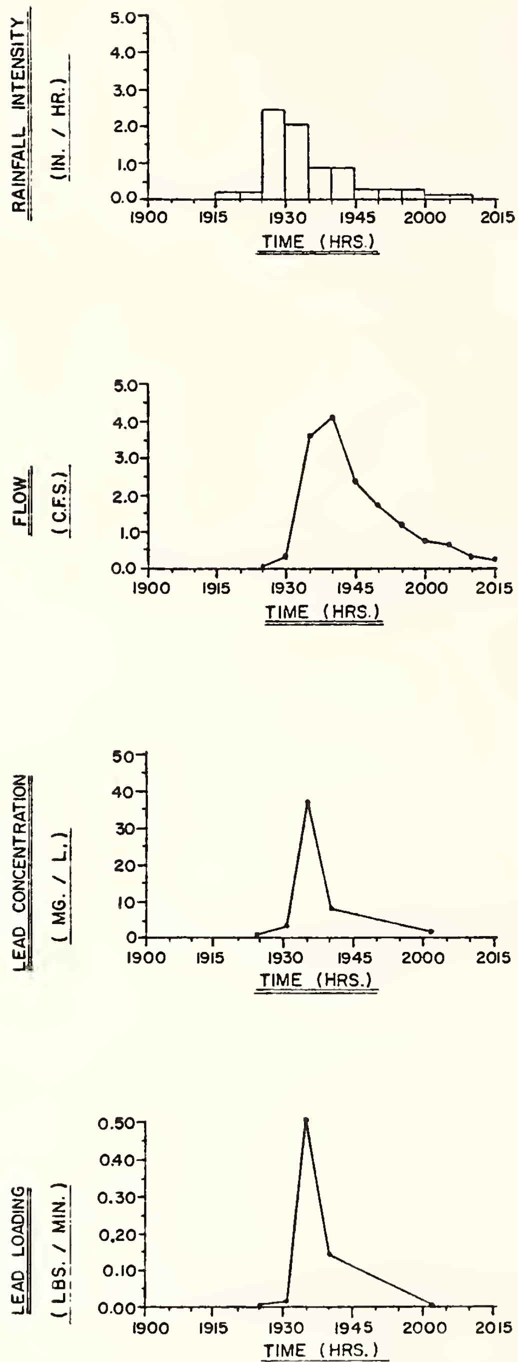


Figure 36. Pattern of discharge of lead, Hwy. 45 grassy site, Milwaukee, Wisconsin, event 6 (6/17/77).

To obtain cm, multiply in. by 2.54
To obtain kg, multiply lbs by 0.454
To obtain m^3/sec, multiply cfs by 0.028

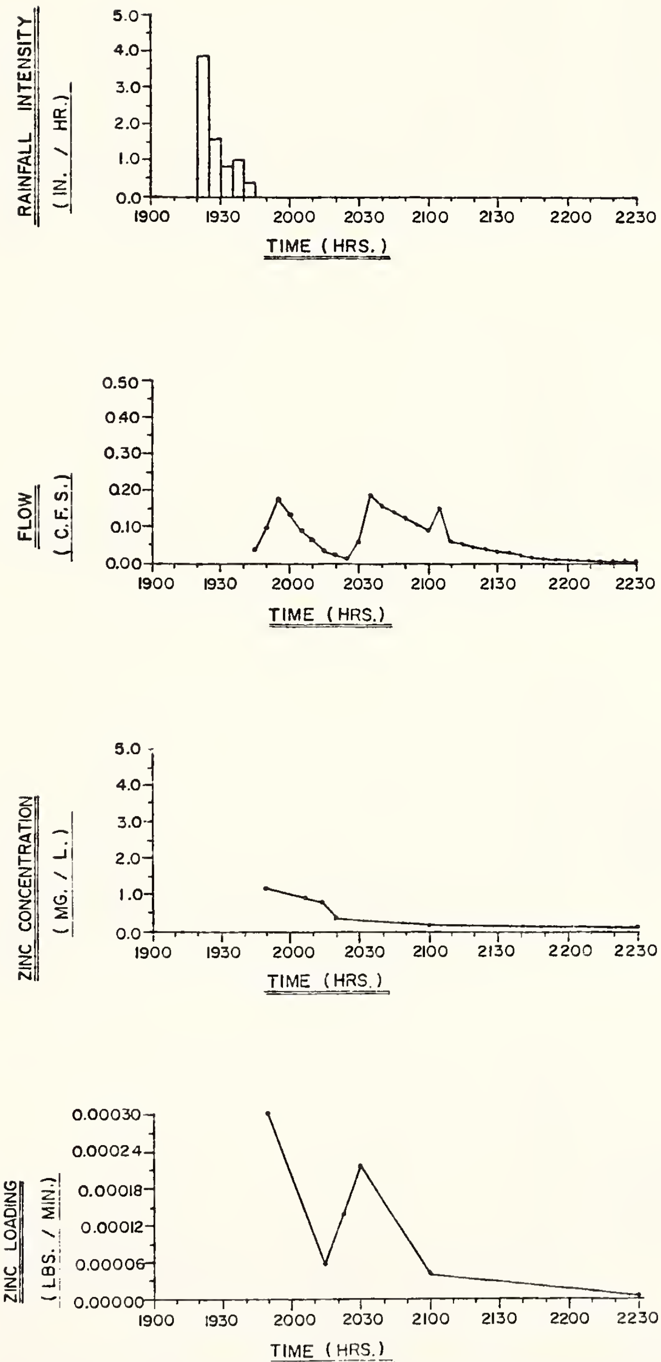


Figure 37. Pattern of discharge of zinc, Hwy. 45 grassy site, Milwaukee, Wisconsin, event 6 (6/17/77).

To obtain cm, multiply in. by 2.54
To obtain kg, multiply lbs by 0.454
To obtain m^3/sec, multiply cfs by 0.028

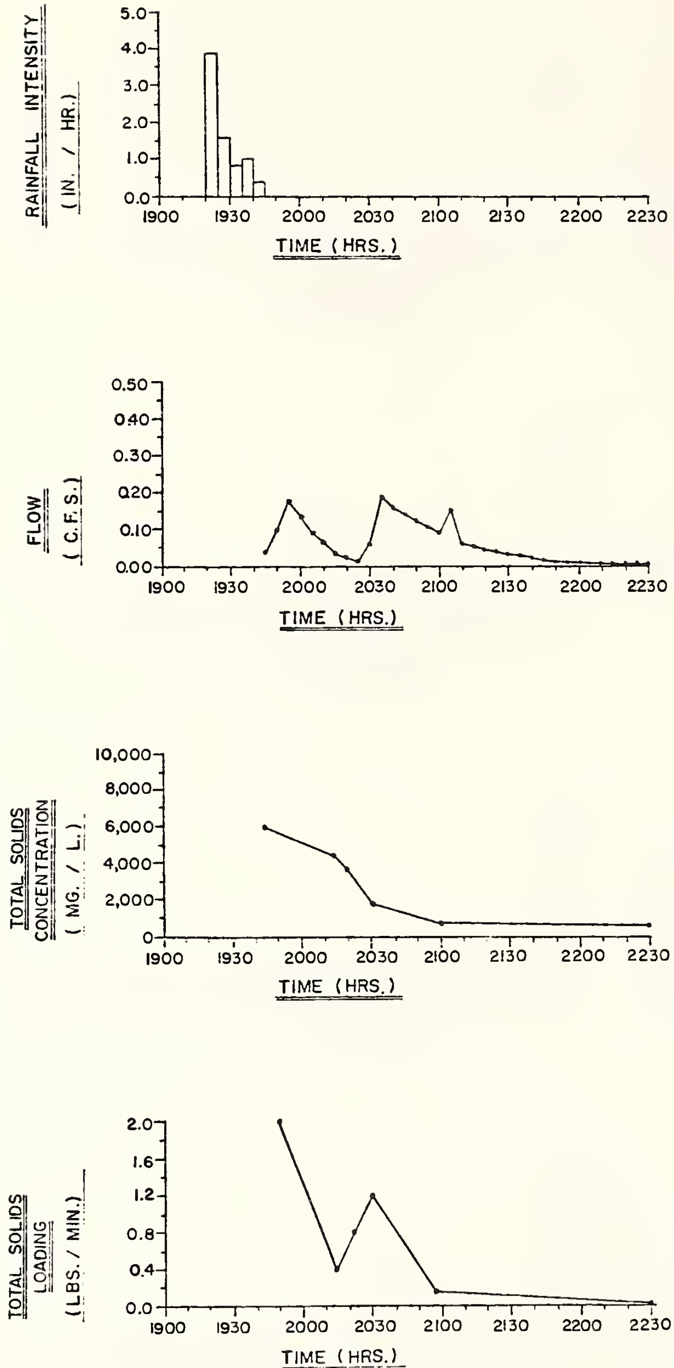


Figure 38. Pattern of discharge of iron, Hwy. 45 grassy site, Milwaukee, Wisconsin, event 6 (6/17/77).

To obtain cm, multiply in. by 2.54
To obtain kg, multiply lbs by 0.454
To obtain m^3/sec, multiply cfs by 0.028

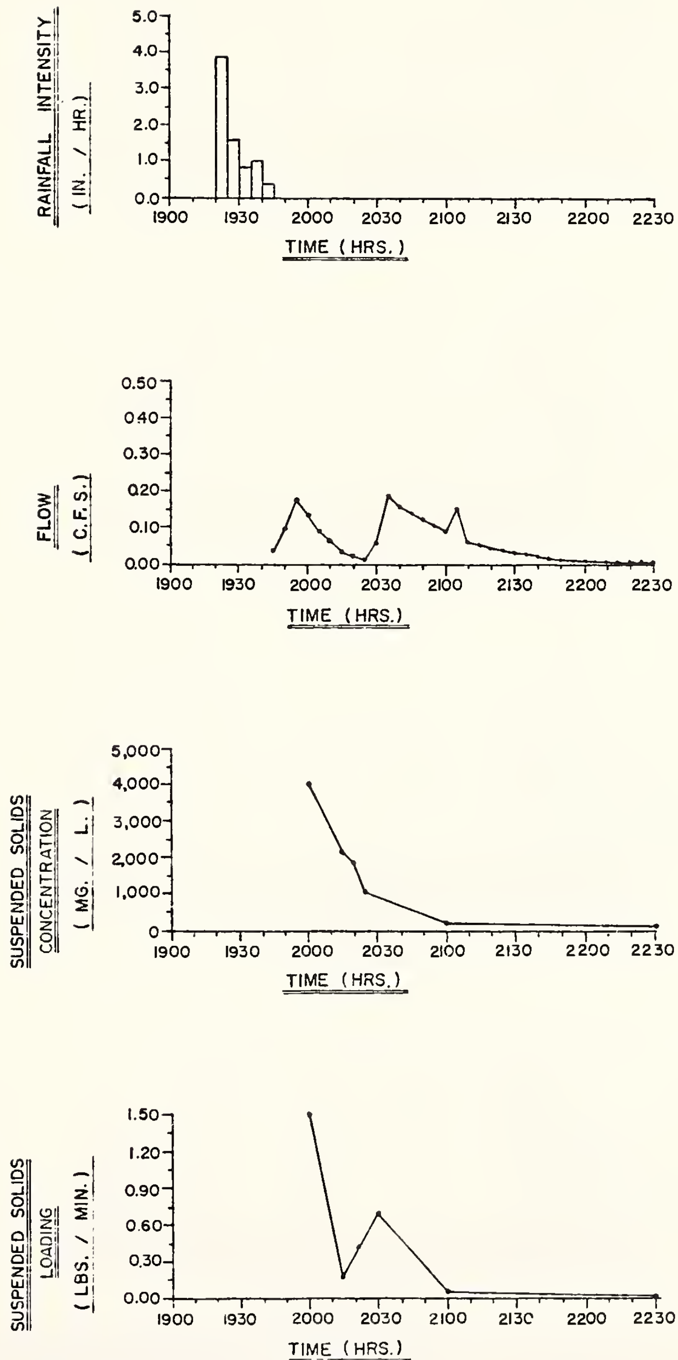


Figure 39. Pattern of discharge of total solids, I-794 site, Milwaukee, Wisconsin, event 24 (6/17/77).

To obtain cm, multiply in. by 2.54
To obtain kg, multiply lbs by 0.454
To obtain m^3/sec, multiply cfs by 0.028

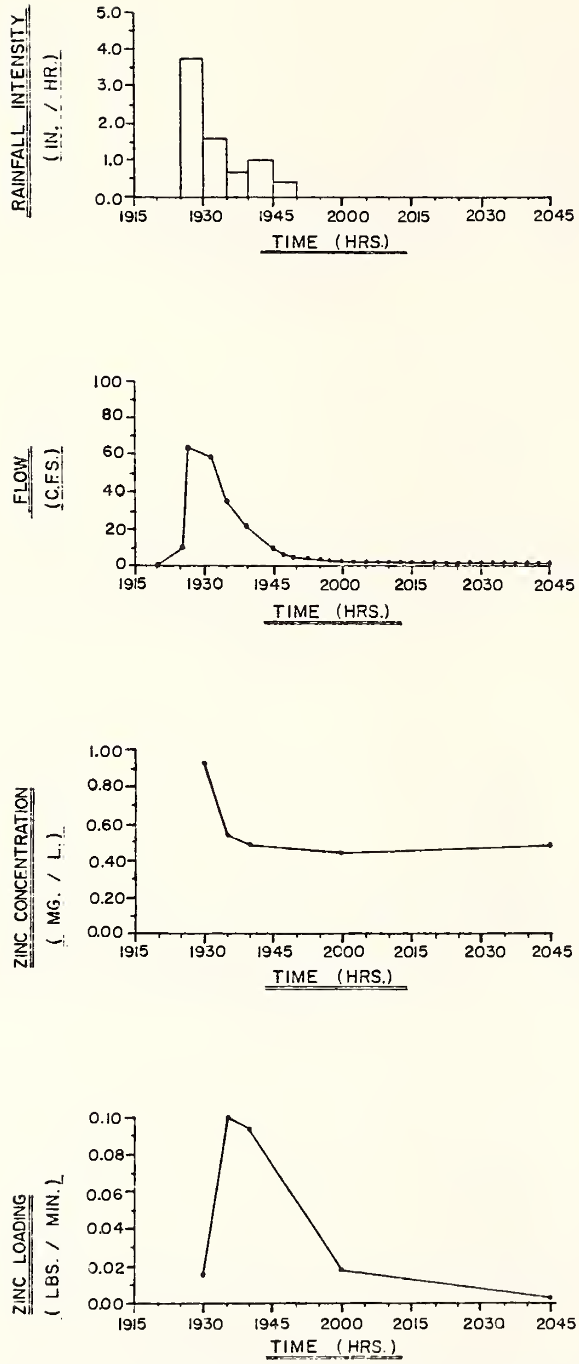


Figure 40. Pattern of discharge of suspended solids, I-794 site Milwaukee, Wisconsin, event 24 (6/17/77).

To obtain cm, multiply in. by 2.54
To obtain kg, multiply lbs by 0.454
To obtain m^3/sec, multiply cfs by 0.028

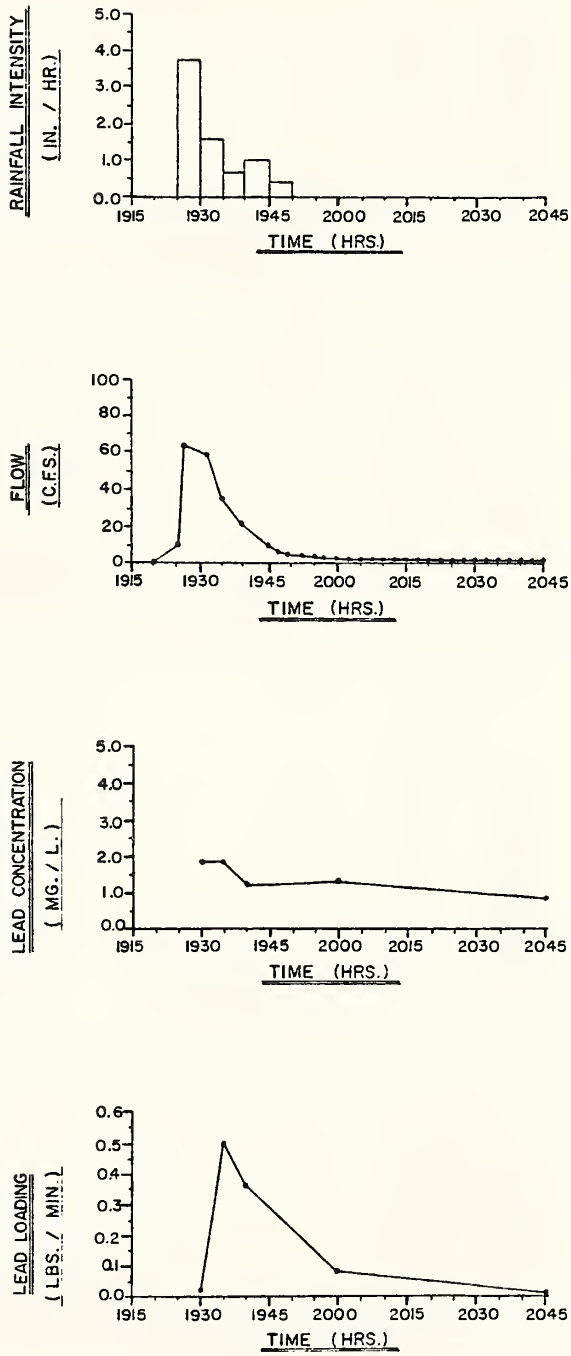


Figure 41. Pattern of discharge of lead, I-794 site, Milwaukee, Wisconsin, event 24 (6/17/77).

To obtain cm, multiply in. by 2.54
To obtain kg, multiply lb by 0.454
To obtain m^3/sec, multiply cfs by 0.028

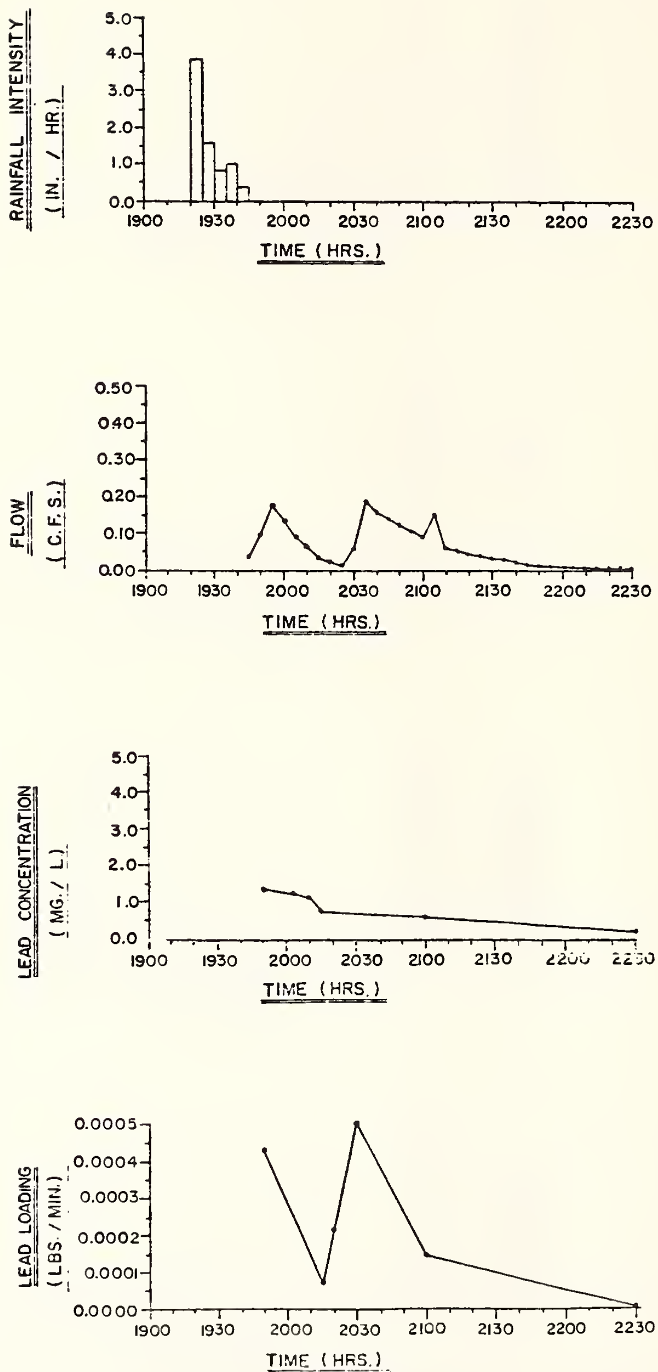


Figure 42. Pattern of discharge of zinc, I-794, Milwaukee, Wisconsin, event 24 (6/17/77).

To obtain cm, multiply in. by 2.54
To obtain kg, multiply lbs by 0.454
To obtain m^3/sec, multiply cfs by 0.028

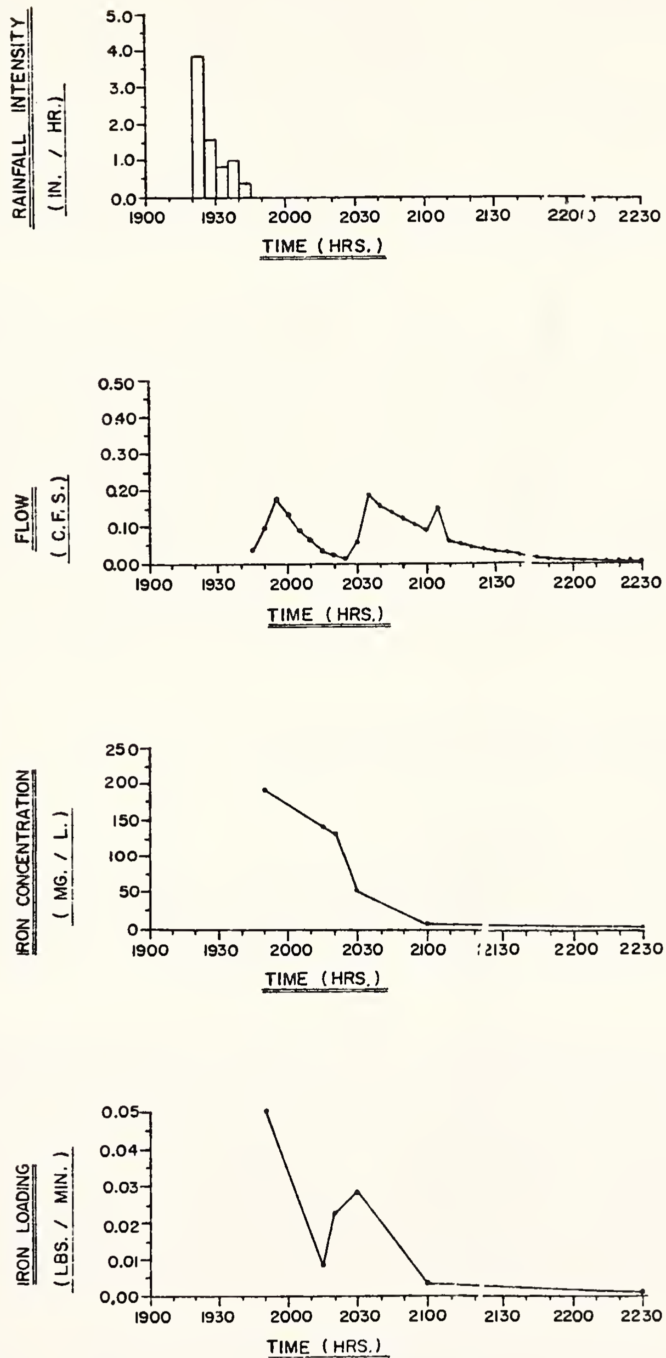


Figure 43. Pattern of discharge of iron, I-794 site, Milwaukee, Wisconsin, event 24 (6/17/77).

Intensities after this first interval dropped off quite rapidly. Measurable runoff was recorded approximately 10 minutes after the rainfall began, and the peak runoff of approximately 60 cfs ($1.7 m^3/s$) occurred 15 minutes after the beginning of rainfall. Runoff for this 25 minute storm lasted for approximately one hour and 35 minutes. The peak flow occurred quite rapidly after the beginning of the storm due to the high rainfall intensity. Runoff from the grassy site at Hwy. 45 (Figure 34) did not begin until 15 minutes after the rainfall began. The peak overflow of about 0.16 cfs ($.005 m^3/s$) occurred twice in the runoff hydrograph. The first peak occurred approximately 35 minutes after the beginning of rainfall whereas the second peak occurred 75 minutes after the beginning of the storm. Runoff from this 2.6 acre (1.05 ha) drainage area persisted for approximately three hours.

An examination of the rainfall and runoff for this same storm at the I-794 site (Figure 39) indicates that runoff from this 2.1 acre (0.85 ha) completely paved site began shortly after the beginning of the rainfall. The rainfall pattern for this storm was longer and less intense at the I-794 site than at Hwy. 45. There were two five-minute intervals with intensities greater than 2.0 in./hr (5.0 cm/hr) before the rainfall began to subside. The rainfall lasted for 55 minutes at this site compared with 25 minutes at the Hwy. 45 site. Runoff from the I-794 site occurred for only one hour with the peak flow being approximately 4.0 cfs ($0.11 m^3/s$). The peak runoff occurred approximately 10 minutes after the peak rainfall intensity.

In comparing the rainfall/runoff differences between the sites a number of factors must be considered:

1. Climate
2. Rainfall intensities
3. Area of the drainage basin
4. The effects of the paved and unpaved fractions of the drainage area
5. Configuration of drainage systems

The I-794 site had the most rapid runoff despite the length of the storm at this site, however, this site has a drainage area of only 2.1 acres (.85 ha). The Hwy. 45 site had a fairly rapid peak and decline in runoff, however, runoff from the pervious areas of the site continued for many hours. The runoff from the grassy site at Hwy. 45 had a long lag time. Runoff did not begin until after the rainfall had ceased. Runoff persisted at a low level for a number of hours, however, because of the smaller and the unpaved nature of the drainage area at this site.

In addition to affecting the rate at which runoff occurs, the amount of paved area also affects the quantity of runoff. Some proportion of the rainfall does not become runoff due to the infiltration/

percolation of runoff into the drainage basin. This phenomenon is well illustrated by the ratio of runoff to rainfall (runoff coefficient) for the June 17, 1977 storm at the three Milwaukee monitoring sites. Most of the rainfall at the I-794 sites was recorded as runoff (i.e., runoff coefficient approaching 1.0). The high runoff coefficient may be due to a number of factors:

1. The sensitivity of the rainfall and flow measurement equipment.
2. The rainfall intensity was high.
3. The surface saturation capacity of this completely paved site may have been satisfied by a preceding rainfall event.
4. Any human error in measurements.

Since there were approximately 6 days of dry weather prior to the June 17, 1977 monitoring event at the I-794 site, the first two factors are the most reasonable explanation of the high runoff coefficient. At the Hwy. 45 site which is 31 percent paved, the runoff coefficient for this event was 0.35 or 35 percent. A runoff coefficient greater than the fraction paved is an indication that runoff from the nonpaved areas occurred. Only 10 percent of the rainfall was monitored as runoff at the grassy site. This low coefficient value is due to the infiltration/percolation of most of the rainfall into the ground at this unpaved (grassy) site.

In discussions of the time dependent nature of pollutant discharges during a runoff event, the term "first flush" is commonly used. The first flush is generally the initial portion of the runoff and contains the highest loading of pollutants. It is important to remember that the first flush does not always correspond with the highest pollutant concentration. <u>The rate of flow and pollutant concentrations must both be considered because the major item of concern is the pounds of pollutant being discharged to a receiving water</u>.

The concentrations in milligrams per liter and loadings in pounds per minute for the June 17, 1977 storm at the three monitoring sites in Milwaukee are shown in Figures 29 through 43. Rainfall intensities and runoff rates are illustrated alongside so they can be examined in relation to the constituent values. For example, at the I-794 site, the peak total solids concentration was approximately 3000 mg/l while the peak suspended solids are 1300 mg/l (Figure 39). The peaks in the metals concentrations were extremely high, being 36.0 mg/l for lead, 6.5 mg/l for zinc, and 82.0 mg/l for iron. Concentration of the solids and metal were much smaller in the other discrete samples. The observed peak loadings of 0.55 pounds per minute (.25 kg/min) of lead and 1.25 pounds per minute (.57 kg/min) of iron are an indication of the large quantity of pollutants which may be discharged from an all-paved area highway drainage system at a point in time.

Similar pollutant variations with time were seen at the Hwy. 45 site as shown in Figures 29 through 33. There were distinct first flushes at both the Hwy. 45 and I-794 sites whereby a majority of the pollutant (60 to 90%) loads were being discharged within the first 30 to 50 minutes of the runoff events. At the Hwy. 45 grassy site, the initial concentrations of solids and metals were all high when runoff began, however, these concentrations declined rapidly during the event. The peak concentration of total solids was 6,000 mg/l and the peak concentration of suspended solids was 4,500 mg/l. Lead, zinc, and iron had peak concentrations of 1.30 mg/l, 1.03 mg/l, and 185.0 mg/l, respectively. Two to three distinct peaks in the runoff hydrograph caused a bimodal shape for the pollutographs for this site (Figures 34 through 38). The first loadings peak was generally the higher one for most pollutants. These pollutant peaks may be influenced significantly by the intensity and pattern of rainfall and how it scours any of the accumulated pollutants in the grassy (unpaved) areas.

The Hwy. 45 site in Milwaukee and the Harrisburg and Nashville sites had some base flow in the sewers during dry weather periods. This was largely due to infiltration of groundwater into the runoff collection system. For some events prestorm and poststorm samples were collected in order to determine base level pollutant concentrations. These pre and poststorm samples generally showed the distinct presence of the first flush phenomenon. For the high intensity storm events, the paved highway surface was generally well flushed out of accumulated pollutants.

Pollutant discharge patterns from all other sites exhibited similar behaviors as the Milwaukee sites and these discharges could generally be correlated well to the rainfall patterns.

Data Presentation for Group II Parameters

The parameters examined in this group were: pathogenic indicator bacteria, oil and grease, polychlorinated biphenyls (PCBs), pesticide/herbicides and asbestos. Manual grab (discrete) samples were collected for all of these parameters for a limited number of events. A discussion of any special methodology used and an analysis of the data obtained follows:

Pathogenic Indicator Bacteria - The pathogenic indicator bacteria most commonly employed in the water resources and water pollution control fields are the total coliform (TC), the fecal coliform (FC) and the fecal streptococcus (FS). The principal reason for conducting these analyses is to provide a means of assessing the sanitary quality of a water sample, since the presence of any one of these broad groupings of bacteria is an indication that the particular water source involved has been contaminated with fecal discharges from animals and/or human beings. These parameters are of public health interest, but unfortunately the interpretation of the results of such analyses is often obscured by the myriad of possible sources of such organisms, and the fate of these organisms once introduced into the aquatic environment. The TC group, which has been used for many years in the water field, includes the widest spectrum of bacteria ranging from E. coli found in copious quanties in human excrement, to A. aerogenes commonly associated in nature with various soils and grains. Thus, high concentrations of TC may be of little or no public health significance particularly when found in stormwater runoff and natural water bodies.

The FC group, which has been introduced into the water field in more recent years, includes mainly bacteria which are definitely associated with the fecal discharges of all warm blooded animals, including man. The literature includes well documented evidence of a high degree of correlation of FC with the feces of humans, household pets, rodents, poultry, birds and livestock. Raw municipal wastewaters can contain approximately 10,000 to 1,000,000 FC per 100 ml, in comparison to one million to 100 million TC per 100 ml.

Interest in the FS group has flourished in recent years because of its significance in the assessment of pollutional loadings from non-point sources such as urban and agricultural runoff. Significant concentrations of this group of bacteria have been found to be associated with insects, plants and the feces of warm blooded animals including man. In spite of the wide distribution of these indicator bacteria, studies have shown that the ratio of the fecal coliforms to fecal streptococci (FC/FS) in a water sample can be used as a guide in estimating the source of fecal contamination. It has been suggested that such ratios in excess of 4.0 are indicative of pollution from human sources, whereas ratios less than 0.7 are indicative of pollution from animal sources.

A summary of the pathogenic bacteria indicator counts monitored in this study is presented in Table 26. As noted, sizable concentrations of all three indicators groups were found in the highway runoff from all the sample sites. Though it is not apparent from these tabulated results, the counts were found to persist for the entire duration of the storm, as demonstrated from the selected coliform data presented in Table 27 for the completely impervious urban Hwy. I-794 site in Milwaukee, and in Table 28 for the rural Harrisburg site. The results presented in these two tables are typical of the bacteriological results obtained at all the sites. In fact, for some of the events, the counts at the end of the storm were higher than the ones at the

Table 26. Monitored bacterial counts for highway runoff, (counts per 100 ml) 1976-1977

Monitoring sites	Total coliform (TC)		Fecal coliform (FC)		Fecal streptococi coliform (FS)		Average ratio FC/FS
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	
Milw.-Hwy. 794	600,000	3,000	>100,000	10	4,300	40	0.63
Milw.-Hwy. 45	7,900,000	4,500	300,000	490	300,000	1,320	0.76
Milw.-Grassy Site			200	<2	360	40	0.04
Harrisburg	175,000	100	>100,000	0	200,000	640	0.33
Nashville	2,900,000	1,700	260,000	150	3,520,000	3,900	0.14
Denver	>100,000	0	2,700	0	>100,000	0	0.33

Table 27. Bacteria counts with flow duration, Milwaukee-Hwy. 794.

Date 1976	No. of preceding dry days[a]	Total rain, in. (cm)	Time of sample	Total coliform no./100 ml	Fecal coliform no./100 ml
7/28	40	0.33 (0.84)	0706[b]	>100,000	>100,000
			0715	>100,000	>100,000
			0730	>100,000	20,000
			0830	>100,000	4,800
			0930	>100,000	14,000
7/30	3	1.59 (4.04)	2020	250,000	24,000
			2040	136,000	77,000
			2100	600,000	36,000
			2110	10,300	53,000
			2120	17,000	60,000
			2140	>100,000	52,000
			2240	>100,000	40,000
			2330	75,000	28,000
			2400	23,000	18,000
			0030	>100,000	44,000
8/5	5	0.05 (0.13)	0250[b]	3,000	30
			0255	21,000	610
			0305	3,000	50
			0315	23,000	50
8/25-26	13	0.14 (0.36)	2225		
			downspout[c]	170,000	68,000
			sewer	190,000	18,000
9/9	12	0.85 (2.16)	0205	59,000	8,700
			0215	81,000	5,400
			0235	16,000	630
			0250	37,000	1,300
			0305	59,000	1,200
			0320	43,000	310
9/19	10	0.30 (0.76)	1535	340,000	42,000
			1545	140,000	24,000
			1645	40,000	9,000
			0936	3,400	1,900

[a]Less than 0.1 in. (0.25 cm) rainfall.

[b]Background sample

[c]Two samples taken simultaneously from downspout and sewer during storm event.

Table 28. Bacteria counts with flow duration, Harrisburg.

Date	No. of preceding dry days[a]	Total rain, in. (cm)	Time of sample	Total coliform no./100 ml	Fecal coliform no./100 ml
9/10/76	16	1.00 (2.54)	0525	108,000	17,600
			0535	75,000	21,000
			0545	23,000	17,000
			0600	10,000	>100,000
			0650	83,000	20,600
			0720	140,000	26,000
			0800	175,000	13,000
			1105	56,000	27,000
2/24/77	4	0.95 (2.41)	1305[b]	400	133
			1500	2,700	770
			1515	1,350	430
			1530	1,350	330
			1545	1,500	470
			1600	950	330
			1645	500	300
4/2/77	5	1.42 (3.61)	0915	21,000	19,000
			0930	27,000	20,000
			1045	13,000	7,500
			1102	20,000	9,500
			1115	17,000	7,300
			1245	18,000	12,000
			1910	4,000	2,300
4/24/77	16	0.20 (0:51)	1332	30,000	17,000
			1335	42,000	19,000
			1350	27,000	18,000
			1405	28,000	13,000
			1435	26,000	12,000
			1630	51,000	7,700
			0520	1,000	300

[a] Less than 0.1 in. (0.25 cm) rainfall
[b] Background sample

beginning of the storm. Thus, these organisms were being continually scoured from the highway and right-of-way surface throughout the runoff event. It is of interest to note that significant levels of indicator bacteria persisted to the end of every one of the storm events surveyed in this study, even events that lasted twelve hours and over.

The fact that significant levels of fecal coliforms were present at all of the sites is particularly noteworthy since these organisms could only have originated from the feces of warm blooded animals. Since the FC/FS ratios were significantly below 4.0 (actually less than 0.7 in most cases), it is apparent that the bacteria are probably from animal or bird origin. The FC and FS counts from the grassy area site in Milwaukee were considerably lower than those from the other sites, which would indicate that this type of surface tends to retain or ameliorate the bacteria laden debris during runoff producing events.

The fact that comparatively high concentrations of total coliforms and fecal streptococci were found in highway runoff was not surprising, since a spate of literature has appeared in recent years with evidence that copious quantities of these organisms have also been found in urban and rural stormwater runoff. A sampling of the results of such studies are presented in Table 29. Though the high counts and inherent variability generally associated with these bacteriological analyses tends to make meaningful comparisons difficult, it would appear reasonable to conclude that these counts are in the range which have been found in the study for highway runoff, as previously presented in Table 26. It is of interest to note further, that the work done by Geldreich and co-workers (16) on indicator bacteria in stormwater runoff collected during the four seasons of the year, resulted in FC/FS ratios ranging from 0.02 to 0.34 in street gutter runoff, ratios ranging from 0.15 to 0.26 in business district runoff, and ratios ranging from 0.01 to 0.10 in rural runoff. In a more recent study by Olivieri and co-workers (18), the authors cautioned that "the FC/FS ratio was not intended nor should it be employed as a magic number to evaluate the source of contamination in a complex system". In their investigation on microorganisms in stormwater runoff, (though some leakage of sanitary wastewater may be involved) 86 percent of the 400 calculated FC/FS ratios had values less than 1.0, 8 percent had values between 1.0 and 4.0 and 6 percent had values greater than 4.0.

The high concentrations of fecal coliforms present at the Milwaukee I-794 site is somewhat perplexing, since this is an entirely impervious roadway surface located on an elevated bridge deck. The only likely sources of fecal coliforms in this area are bird droppings and possibly the debris that fall from livestock trucks and other soiled vehicles which pass along this route.

Table 29. Summary of pathogenic indicator bacteria counts in urban stormwater runoff for selected cities in the U.S., counts/100 ml.

Area	Ref.	Total coliform		Fecal coliform		Fecal streptococus	
		Mean	Range	Mean	Range	Mean	Range
Washington, DC	(8)	600,000	120,000-3,200,000	310,000	40,000-1,300,000	21,000	3,000-60,000
Durham, NC	(12)	-	-	30,000	7,000-86,000	-	-
Durham, NC	(11)	-	-	23,000	100-200,000	-	-
Tulsa, OK	(15)	3,850,000	-	64,000	-	-	-
Cincinnati, OH[a]	(16)						
Street gutter		90,000	-	6,400	-	150,000	-
Business dist.		172,000	-	13,000	-	51,000	-
Rural		29,000	-	2,700	-	58,000	-
Baltimore, MD[b]	(17)	-	1,300-2,400,000	-	80-2,400,000	-	1,700-1,900,000

- Not reported.

[a]Summer data.

[b]Stations known to include combined sewer overflow excluded.

Though it would depend somewhat on the rainfall intensity and other rainfall conditons, it would appear likely that the highest bacteria counts would probably occur at the initial part of the storm. Table 30 presents the bacteria counts in the first samples taken during each of the runoff events. As noted in some cases these counts reached fairly high levels at the outset of the runoff event, but as noted previously, even higher counts occurred in some cases in samples taken well after the start of the storm. The "first flush" concept which has been commonly reported for urban runoff, does not necessarily always apply in the case of bacterial contamination in highway runoff.

Significant indicator bacteria counts still occurred from storms following extended periods of dry weather, as shown in Table 31. Both the maximum and minimum counts are included in the table. These results indicate that either these bacteria remain viable in the animal and bird dropping for long periods following deposition, or that they are being added to the particular watershed on a regular or constant basis. It is likely that both situations are involved to some extent. The data presented in Table 32, however, suggest that the sources of bacterial contamination are continuous rather than sporadic or random in nature. As noted, sizable counts were obtained in all cases following minimal durations between rainfall events of one or two days. Apparently a runoff producing rainfall event will not "cleanse" a highway right-of-way surface free of indicator bacteria for even a very short period of time.

As already noted, the presence of any of the indicator bacteria groups discussed above is not conclusive evidence that pathogenic bacteria are present, and in fact, that a public health problem actually exists. This can only be done by analyzing water samples for the particular pathogen of concern. Table 33 presents the results of Salmonella determinations conducted at the two Milwaukee sites for one storm event. The Salmonella group contain a wide spectrum of bacteria of varying degree of pathogenicity to man. Though the testing procedure is basically a qualitative one, as noted, some positive evidence of these bacteria were found in the runoff samples taken at the two sites, and particularly in the case of the Hwy. 45 site. Firm conclusions cannot be drawn from such limited data, however, these results do suggest that the presence of Salmonella in natural water bodies does not necessarily mean that these organisms have originated from wastewater plant effluents or sanitary sewer discharges.

Shown also in Table 33 are the results of the two common bacteria indicators used to assess the quality of swimming areas, namely Staphylococcus aureus and Pseudomonos aeruginosa , at the same two Milwaukee sites noted above. These limited results suggest that this is not an area of concern in the case of the two sites considered in this study.

Table 30. Bacteria counts at the start of flow.

Site	Date	Total coliform, counts/100 ml	Fecal coliform, counts/100 ml	Fecal streptococci, counts/100 ml
Milw.-Hwy. 794	7/28/76	>100,000	>100,000	
	7/30/76	250,000	24,000	
	8/5/76	21,000	610	
	8/25/76	170,000	68,000	
	9/9/76	59,000	8,700	
	9/19/76	340,000	42,000	
	3/13/77		10	40
	3/17/77		17	1,400
	6/5/77		1,300	2,400
Milw.-Hwy. 45	3/26/76	4,500	2,000	
	7/28/76	>100,000	15,000	
	7/30/76	7,900,000	42,000	
	8/5/76	36,000	2,000	
	9/19/76	46,000	5,300	
	2/23/77		600	
	3/17/77	3,500	7,200	
	6/5/77	2,200	23,000	
Milw.-Grassy Site	2/23/77		<100	
Harrisburg	9/10/76	108,000	17,600	70,000
	9/20/76	81,000	55,000	70,000
	2/12/77	450	330	49,000

Table 31. Bacteria counts in highway runoff after an extended dry period between rainfall events, counts/100 ml.

Site	No. of dry days	Date	Total coliform (TC) Maximum	Total coliform (TC) Minimum	Fecal coliform (FC) Maximum	Fecal coliform (FC) Minimum	Fecal streptococcus (FS) Maximum	Fecal streptococcus (FS) Minimum	FC/FS
Milw.-Hwy. 794	31	7/28/76	>100,000	>100,000	>100,000	4,800			
Milw.-Hwy. 45	31	7/28/76	>100,000	>100,000	24,000	15,000			
Milw.-Grassy site	8	3/3/77			18	<2	360	40	0.044
Harrisburg	26	9/10/76	175,000	10,000	>100,000	17,000	70,000	18,000	0.921
Nashville	5	10/30/76	8,100	6,000	2,100	900	9,800	6,800	0.182
Denver	42	9/13/76	110,000	64,000					

Table 32. Bacteria counts in highway runoff after a minimum dry day period between rainfall events, counts/100 ml.

Site	No. of dry days	Date	Total coliform (TC)		Fecal coliform (FC)		Fecal streptococcus (FS)		Avg. FC/FS
			Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	
Milw.-Hwy. 794	2	7/30/76	600,000	10,300	77,000	18,000			
Milw.-Hwy. 45	2	7/30/76	7,900,000	54,000	87,000	1,500			
Harrisburg	1	6/13/77	51,000	1,000	19,000	300	200,000	2,100	0.141
Nashville	1	4/23/77	2,900,000	1,900,000	260,000	124,000	3,520,000	3,520,000	0.038
Denver	1	4/12/77	3,600	900	900	500	0	0	

Table 33. Analyses for the presence of Staphylococcus aureus, Pseudomonas aeruginosa and Salmonella in highway runoff at Milwaukee for the storm event of June 6, 1977.

Site	Time	Staphylococcus aureus per ml	Pseudomonas aeruginosa per ml	Salmonella per 200 ml
Hwy. 794	0245[a]	<10[b]	<10	Negative[b]
	0255	<10	<10	Negative
	0330	<10	<10[b]	Negative
	0400	<10	<10[b]	Negative
	0530	<10	<10[b]	Negative
	0640	<10	<10[b]	Positive
Hwy. 45	0255	<10[b]	<10	Positive
	0335	<10	<10	Positive
	0435	<10	<10[b]	Negative
	0625	<10	<10[b]	Positive
	0910	<10	<10[b]	Positive

[a]Prestorm value.

[b]Samples were confirmed to be negative by additional tests.

The isolation of these same pathogens in stormwater has been reported in other studies (16) (17) (18). The most recent study (18) suggested the following ratios of pathogens to indicator bacteria: P. aeruginosa to FC of 1:14, Staph. aureus to FC of 1:1410, and Salmonella to FC of 1:105,000. According to the authors these results may have been contaminated with combined sewer overflows, as well as urban storm runoff samples, in the calculation of the ratios above.

Polychlorinated Biphenyl (PCBs), Pesticides/Herbicides and Oil & Grease - A total of twenty-seven storm events were monitored at the six sites during which special manual grab samples were collected for the PCB and selected pesticide/herbicide analyses. A complete listing of the PCB analyses is given in Table 34. The composite values in this table are for flow proportionated composite sample analyses. The initial monitoring at each of these sites included a pesticide scan analysis. A typical pesticide scan, as conducted during this study consisted of extracting and isolating those chlorinated hydrocarbons which have the greatest environmental persistance and are able to do the most damage due to long term accumulation. The list of pesticides presented in the EPA's "Proposed Environmental Regulations on Toxic Pollutant Standards" provides an extensive, if not exhaustive basis for the scan. By functional group these include the Aldrin group (aldrin, dieldrin and endrin), the DDT group (o,p' and p,p' isomers of DDT, DDE, DDD), lindane and PCBs. In addition the scan included those herbicides most widely used for weed control along highways such as the esters of 2,4-D and 2, 4, 5-T. Strictly speaking, PCBs are not pesticides, however, mounting evidence of their environmental distribution and toxic effects previously cited, merit their inclusion in scans done on highway runoff. Organophosphorous and carbamate pesticides (C-N organics containing an amide bond) were not scanned due to their rapid degradation in environmental systems. A list of the chemical names of the chlorinated hydrocarbons scanned in this study is presented in Table 35. If a constituent was found in the initial scan, future samples from that site were monitored for that chlorinated hydrocarbon. Only heptachlor epoxide, lindane, dieldrin and the methyl ester of 2, 4, 5-T were detected at measurable concentrations as shown in Table 36. Among the measured pesticides/herbicides reported in this table only 2, 4, 5-T was reported in the maintenance data from the Denver site. No quantitative relationships could be established between the monitored and the reported maintenance data.

The PCB results in Table 34 include all prestorm, discrete and composite data gathered over a one year monitoring period. Statistical analysis conducted on the PCB data along with corresponding suspended and volatile suspended solids data indicated that these data fit a log normal distribution. The implications of these evaluations are that the geometric mean is a better measure of control tendency for

Table 34. Monitored PCB concentrations for highway runoff.

Site	Storm event	Date	Sample type	PCB, µg/l
I-794 Milwaukee	02	7/28/76	Prestorm	0.73
			Composite	0.40
	03	7/30/76	#1 grab	1.16
			#4 grab	0.32
			#5 grab	0.32
			#12 grab	0.32
			Composite	0.52
	09	9/19/76	Composite	0.61
	11	2/23/77	#1 #2 grab	8.89
			#3 #11 grab	0.48
			Composite	2.00
	18	5/31/77	Composite	1.69
	19	6/5/77	Composite	4.33
Hwy. 45 Milwaukee	05	3/26/76	Composite	0.09
	08	7/28/76	#1 grab	0.10
			#2 grab	0.33
			#4 grab	0.37
			#7 grab	0.35
			#8 grab	0.13
	09	7/30/76	Prestorm	0.13
			Composite	0.12
	18	2/23/77	Composite	0.71
	25	6/5/77	Composite	1.44
	32	6/30/77	Composite	0.33
Grassy Site Milwaukee	01	2/23/77	#1 #2 grab	0.45
			#3 #13	0.04
			Composite	0.10
	11	8/13/77	Composite	0.02
	13	9/17/77	Composite	0.04

(continued)

Table 34.(continued).

Site	Storm event	Date	Sample type	PCB, µg/l
I-81 Harrisburg	07	7/7/76	Prestorm	0.12
			Composite	0.08
	10	9/10/76	#I grab	0.15
			#II grab	0.32
			Composite	0.24
	24	6/27/77	Prestorm	0.02
			Composite	0.07
I-40 Nashville	03	2/23/77	#I #2 grab	4.0
			Composite	0.86
	09	4/2/77	Composite	0.30
	10	4/3/77	Composite	0.15
	25	9/6/77	Composite	0.26
I-25 Denver	01	8/3/76	Composite	0.13
	03	9/25/77	Composite	0.10
	05	4/11/77	Composite	1.14
	08	4/19/77	Composite	0.15
	13	7/5/77	Composite	0.50

Table 35. Common and chemical names of the chlorinated hydrocarbons scanned in this study.

Common name	Chemical name
Aldrin	1,2,3,4,10,10-hexachloro-1,r,4a,5,8,8a-hexahydro-14-_endo_, _exo_-5,8-dimethanonaphthalene
Dieldrin	1,2,3,4,10,10-hexachloro-6,7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4-_endo_, _exo_-5,8, dimethanonaphthalene
p,p'-DDD	2,2-bis(p-chlorophenyl)-1,1-dichloroethane
o'p'-DDD	2,2-bis(O-chlorphenyl)-1,1-dichloroethane
p,p'-DDE	2,2-bis(p-chlorophenyl)-1,1-dichloroethylene
o,p'-DDE	2,2-bis(o-chlorophenyl)-1,1-dichloroethylene
p,p'-DDT	2,2-bis(p-chlorophenyl)-1,1,1-trichlorocthane
	2,2-bis(p -chlorophenyl)-1,1,1-trichloroethane
t-DDT	Summed concentration of the six DDT analogs
Endrin	1,2,3,4,10,10-hexachloro-g, 7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1,4 endo, endo-5, 8-dimethanonaphthalene
Lindane	gamma 1,2,3,4,5,6-hexachlorocyclohexane
PCB	Polychlorinated biphenyl
Aroclor #1242	PCB manufactured by Monsanto Chemical Co. - contains 42% chlorine
Aroclor #1254	PCB manufactured by Monsanto Chemical Co. - contains 54% chlorine
2,4,-D, BE I	2,4 dichloro henoxyacetic acid, butyl esters
2,4-D, BE II	2,4 dichlorophenozyacetic acid, butoxy ethanol ether esters
2,4,5-T (esters)	Esters of 2,4,5 trichlorophenoxyacetic acid
Simazine	2-chloro-4,5,6-bis (ethylamino)-S-Triazine
Hetachlor epoxide	1,4,6,7,8,-8 heptachloro -2-3 epoxy -2,3,3a,4,7,7a-hexahydro-4-7-methamoindene

Table 36. Monitored pesticide/herbicide concentrations in highway runoff.

Site	Storm event	Date	Sample type	Chlorinated hydrocarbon	Concentration, μg/l
I-40	03	2/23/77	#1#2 grab	Heptachlor epoxide	0.28
				lindane(y-BHC)	0.05
			composite	lindane(y-BHC)	0.03
I-25	01	8/3/76	composite	dieldrin	0.007
	03		composite	dieldrin	0.002
				2,4,5-T,ME	0.05

these parameters and that the logs of these parameters follow a normal arithmetic distribution. The calculated geometric mean PCB concentrations and average loadings per event at the various sites were as follows:

	Mean PCB concentrations, μg/l	Average PCB loadings, lb/event (kg/event)
I-794 Milw.:	1.11	4×10^{-4} (1.8×10^{-4})
Hwy. 45 Milw.:	0.16	34×10^{-4}(15×10^{-4})
Grassy site, Milw.:	0.06	0
I-81 Harrisburg:	0.10	4×10^{-4}(1.8×10^{-4})
I-40 Nashville:	0.32	16×10^{-4}(7.2×10^{-4})
I-25 Denver:	0.26	6×10^{-4}(2.7×10^{-4})

The most significant result of the study in terms of PCBs was that very low concentrations of this constituent were found to be prevalent in highway runoff. The EPA has proposed a restriction of 1 μg/l for industrial effluents subject to NPDES monitoring permits (Federal Register 40 FR part 129). The mean concentration for all sites (composite values) was only 0.33 μg/l and only the I-794 site with an all-paved area averaged above 1 μg/l (1.11 μg/l).

Samples of oil and grease (O&G) were analyzed from a significantly larger number of storm events (66 events). A summary of the O&G concentrations monitored during this study is presented in Table 37.

Table 37. Summary of composite O&G data for monitored sites.

Site	Nonwinter[a] O&G concentrations, mg/l				Winter[b] O&G concentrations, mg/l				Overall 1976-77 O&G concentration, mg/l			
	Avg.	Max.	Min.	Number of events sampled	Avg.	Max.	Min.	Number of events sampled	Avg.	Max.	Min.	Number of events sampled
I-794; Milw.	8	12	3	6	43	104	9	3	20	104	4	9
Hwy. 45; Milw.	6	17	2	5	6	15	2	5	6	17	1	10
Grassy site; Milw.	1	2	1	4	<1			1	1	2	<1	5
Harrisburg	3	6	1	9	3	10	1	10	3	10	1	19
Nashville	4	9	2	4	27	57	11	4	16	57	1	8
Denver[c]	14	55	3	15				0	14	55	3	15
All 6 sites	6	55	1	43	16	104	<1	23	10	104	<1	66

[a]Nonwinter: April through October periods (1976-77).

[b]Winter: November through March periods (1976-77).

[c]No storm events monitored during winter at Denver due to lack of sufficient precipitation.

The composite O&G values (Table 37) represent weighted values as calculated from discrete sample analyses in proportion to corresponding flow rates. As can be seen, significant concentrations of O&G were found to be discharging from various highway sites. In terms of arithmetic average concentrations (1976-77), I-794 showed the highest O&G value at 20 mg/l and the grassy site the lowest value at 1 mg/l. The Harrisburg site also showed lower O&G concentrations closely in line with the grassy site probably because of the higher proportion of unpaved areas in the total drainage area. However, the Nashville site showed surprisingly high O&G concentrations. These may have been influenced by possible contributions from a truck maintenance company's small parking lot drainage that discharged into the site drainage system. Significantly higher concentrations of O&G in winters were noticed compared to the nonwinter data as shown in Table 37. However, this comparison was not possible for Denver because no winter storm events were monitored.

As expected, the O&G nonwinter loadings (lb/acre/in. runoff) from the Denver site having an asphalt paved surface (the only site with this type of surface compared to concrete at all other sites) were found to be the highest, while the Milwaukee grassy site had the lowest (Table 38). In terms of O&G loadings in lb/ac/event (1976-77) shown in Table 38, the all-paved area I-794 site showed the highest average loadings while the grassy site showed the lowest loadings. Loadings (lb/ac/event) appear low for Denver because no winter data was available and 60 percent of the events monitored had less than 0.09 in. (0.23 cm) of runoff.

Statistical correlation analysis conducted on the PCB and O&G data with suspended solids, volatile suspended solids and ADT volume showed no significant correlation for these factors. The lack of a significant relationship between suspended solids and the non-polar parameters of O&G and PCB's in this study may be related to the inability of the SS test to differentiate among particulates. Most workers have shown the silt and clay fractions (i.e., >60 μm) to be efficient sorbers of PCB's (19)(20)(21)(22)(23)(24)(25). The 75 μm and smaller fraction of road sweepings were reported to be the fraction of the particulates containing the largest concentrations of grease (24). The same study reported elevated PCB concentrations in the sediment of a highway runoff receiving stream at a point further from the discharge than other pollutants associated with solids. This was attributed to the PCB's being associated with the fines in the runoff and, therefore, being carried further before settling (24). It would be most improbable that either PCB's or O&G would be dissolved in the liquid phase rather than sorbed to the solid phase of the storm generated runoff. It is more likely that total suspended solids or even volatile solids are a poor measure of the silt and clay fines in highway runoff, therefore, the lack of correlation to PCB and O&G.

The lack of correlation of ADT and PCB concentrations is consistent with the work of Shaheen (24) where no dependency between traffic

Table 38. Monitored oil & grease loadings in highway runoff.

Monitoring sites	Overall 1976 - 1977 loadings, lb/acre/event				Nonwinter[a] loadings, lb/acre/in. runoff			
	Events monitored	Avg.	Min.	Max.	Events monitored	Avg.	Min.	Max.
I-794, Milw.	9	1.04	0.08	2.62	6	1.96	0.82	3.00
Hwy. 45, Milw.	10	0.24	0.01	0.84	5	1.53	0.42	3.87
Grassy site, Milw.	5	0.03	0.00007	0.06	4	0.34	0.22	0.46
Harrisburg	19	0.16	0.002	0.55	9	0.46	0.02	1.15
Nashville	8	0.52	0.13	1.82	4	1.02	0.45	2.16
Denver	15	0.35[b]	0.02	1.55	15	3.12	0.72	12.40

Metric units: To convert lb/acre/event to kg/ha/event multiply by 1.12.

[a]Nonwinter: April through October periods (1976-77).

[b]No storm events monitored during winter at Denver due to lack of sufficient precipitation.

volume and PCB concentrations was demonstrated. However, the apparent increase in O&G concentrations noticed during the winter season in this study is contrary to Shaheen's data which showed highest concentrations during the fall for the Washington I-495 site. More data is necessary to resolve this inconsistancy.

Another time related variable is the concentration of O&G and PCB during the storm event. The prestorm samples had an average PCB concentration about 1/3 of the average composites (0.11 μg/l). During the storm event the concentrations of the PCBs generally followed the well established "first flush" profile with the highest concentrations occurring during the initial flow and tapering off into the event (see Table 34, I-794 storms 03 & 11; grassy site, storm 01; I-40, storm 03). Similar time related variations were noted in the oil and grease data.

Asbestos - The wear of clutch and brake linings has been reported to be the primary source of asbestos in highway runoff (24). However, insufficient data was available in the literature to evaluate the status of the presence of asbestos in highway runoff. Therefore, several flow-composited and grab samples collected from the selected sites in the present study were analyzed for the presence of asbestiform material.

A total of 21 samples were analyzed for asbestos in samples from the six sites. Table 39 presents a complete listing of the samples analyzed during this study along with results and comments provided by Walter C. McCrone Associates Inc., of Chicago who performed these analyses. As can be seen, out of the 21 samples analyzed, only two samples from the Nashville site showed measurable quantities of chrysotile asbestiform material, while 19 samples from the five other sites did not show the presence of any asbestiform fibers. In order to get some insight into the presence of chrysotile asbestiform noted in the Nashville samples, several grab samples were collected and analyzed from the roadway, as well as ramp surfaces and ramp drop inlets in Harrisburg and Nashville. None of these samples showed the presence of any asbestiform material. Although the exact cause of the presence of chrysotile asbestiform material in two Nashville samples could not be determined for sure, there is a reason to believe that in the past, the city of Nashville may have utilized some sewer pipes made of asbestos and this may have been the source of such identification. Further investigations regarding the presence of asbestiform materials in highway runoff is continued under another FHWA contract (DOT-FH-11-9357) titled, "Sources and Migration of Highway Runoff Pollutants".

In order to better interpret the asbestos results, a literature review of the reported asbestos values in several drinking water supplies was made. The findings of tbis review are listed below:

Table 39. Results of asbestos samples analyzed during the study.

Sample description	Lower limit of detection, fibers/liter	Asbestiform material, fibers/liter	Description
ESD 11170 I-794-Milw. Event No. 2 Composite	1.26×10^6	BDL[a]	Organic material is very common. Organic films, fibrous organic matter, what may possibly be sporangia, and bacterial remains are present. Inorganic particulate matter ranges from smaller platy material to larger chunky types and usually occurs agglomerated with other sample material. No asbestiform material was detected.
ESD 11171 Hwy. 45-Milw. Event No. 8 Composite	3.12×10^6	BDL	Much material is present. Inorganic particles ranging from small platy to large (>5 μm) chunky types are present - a large portion of the inorganic material is agglomerated. Organic residues ranging from globules to fibrous aspects, organic films, and various remains are also present in this specimen. No asbestiform material was detected.
ESD 6883 I-81 Harrisburg Event No. 7 Composite	1.26×10^6	BDL	Organic residues of varying type and shape remains, platy to chunky inorganic particulates, and a significant amount of material agglomeration are to be noted in this sample. No asbestiform material detected.
Control Deionized water	0.5×10^6	BDL	Mainly bacterial remains and some large chunky inorganic particles.
18033 Grassy Site Event No. 1 Composite	2.1×10^6	BDL	Organic residues and small to moderate sized inorganic particles are the principal components of this specimen. Some large chunky material and agglomerated inorganics were also noted. No asbestiform material detected.
18034 I-40 Nashville Event No. 3 Composite	5.0×10^6	9.0×10^7 Chrysotile	Although some organic residues are present the vast majority of sample material consists of small to moderately large and agglomerated inorganic particles of generally chunky morphology. Occasional fungal remains noted. Chrysotile asbestos detected, but no other asbestiform minerals present.
18035 Hwy. 45-Milw. Event No. 18 Composite	8.4×10^6	BDL	Small to moderately sized chunky inorganics and various organic residues make up this sample. No asbestiform material detected.
18036 I-794-Milw. Event No. 11 Composite	8.4×10^6	BDL	Sample consists primarily of chunky inorganic particles ranging to large sizes and often in an agglomerated state. Some organic residues and possibl fungal remains noted. No asbestiform material.
18037 I-25 Denver Event No. 1 Composite	8.4×10^6	BDL	Small to moderately sized chunky inorganic particles, some organic residues and occasional remains which might be fungal are present. No asbestiform material detected.

(continued)

[a]BDL : Below detection limit

Table 39 (continued).

Sample description	Lower limit of detection fibers/liter	Asbestiform material, fibers/liter	Description
18038 I-81 Harrisburg Event No. 11 Composite	0.84×10^6	BDL	Generally, small to moderately sized chunky inorganic material and some organic residues make up this sample. Some large inorganic particles showing well-defined faces and angles are also present. No asbestiform material.
24400 Hwy. 45-Milw. Event. No. 31 Composite	4.2×10^5	BDL	Small to quite large (>15 μm) chunky inorganic matter, a binding inorganic which holds the other material present, some platy inorganic material, organic residues, some pollen grains and probable fungal remains (a source of organic tubules) are found in this specimen. Agglomeration is quite common. No asbestiform material detected.
24404 I-81 Harrisburg Event No. 24 Composite	20.9×10^5	BDL	A light filmy layer is quite common, chunky inorganic particles ranging to large sizes, organic residues, agglomeration of sample material, some "spheroidal" particles and platy inorganics noted in this sample. An organic tubule source of probable fungal origin is present. No asbestiform material detected.
24405 I-40 Nashville Event No. 22 Composite	4.2×10^5	BDL	This sample's primary constituent is chunky inorganic matter ranging to quite large sizes. A material binding the particles is quite common. Filmy and organic residues are noted, as well as probable hyphae which are a source of organic tubules. No asbestiform material detected.
24411 I-40 Nashville Event No. 16 Composite	3.4×10^5	BDL	One finds chunky inorganic particles, organic residues, probable pollen grains, a source of organic tubules (probably fungal in nature) and some agglomeration of sample material. No asbestiform material detected.
24115 I-81 Harrisburg Event No. 24 Ramp grab	4.2×10^5	BDL	Chunky inorganics range to large sizes and much organic and filmy residue present. Some platy inorganics material noted. Agglomerate type material and agglomeration of sample material both noted. No asbestiform material detected.
24116 I-81 Harrisburg Event No. 24 Ramp grab	4.2×10^5	BDL	This sample consists primarily of large chunky inorganic particles and various types of organic residue. Platy inorganic particles, agglomeration of sample.material and a fine agglomerate material also occur. No asbestiform material.

(continued)

[a]BDL : Below detection limit

Table 39 (continued).

Sample description	Lower limit of detection fibers/liter	Asbestiform material, fibers/liter	Description
24117 1-81 Harrisburg Event No. 24 Ramp drop inlet grab	4.2×10^5	BDL	Chunky inorganics range from submicrometer sizes to sizes in excess of 10 μm. platy inorganics, organic films and residues, some agglomeration of sample material, some agglomerate material and organic tubules are present. No asbestiform material detected.
24418 1-25 Denver Event No. 10 Composite	4.2×10^5	BDL	Organic residues, films, heavy agglomeration of sample material, chunky inorganic particles ranging to sizes in excess of 15 μm, occasional spheroidal particles and a fine agglomerate material comprise this sample. No asbestiform material detected.
27670 1-40 Nashville Event No. 25 Road surface grab	3.1×10^5	BDL	Agglomerated chunky inorganic material is the main component of this specimen. Some filmy residues and platy material are present. Remains which may come from a fungal source are noted. Little was noted in the way of inorganic fibers. No asbestiform material detected.
27671 1-40 Nashville Event No. 25 Sewer grab	8.4×10^5	8.4×10^6 Chrysotile	In this sample we find agglomeration of sample material to be quite common though chunky inorganic matter predominated a significant amount of platy inorganic material is noted. Some films and organic residues present. Chrysotile fibrils noted. Probable fungal remains found in addition to probable spores and pollen grains.
27672 1-40 Nashville Event No. 25 Composite	3.1×10^5	BDL	Films, chunky inorganics, probable fungal remains, spores and pollen make up this specimen. The tubules present come from a suspected fungal source. No asbestiform material detected.

[a]BDL : Below detection limit

Source	Reference number	Asbestos, fibers/liter (x 10^6)
Canadian beer and tap water	26	2 to 10
22 Canadian cities and towns	26	0.14 to 3.87
Thunder Bay, Lake Superior	26	0.83 to 1.40
Western Lake Superior	26	9.50 to 87.3
Duluth drinking water	27	≈42
Chicago drinking water (raw)	28	0.42 to 4.20
Chicago drinking water (treated)	28	0.08 to 0.55

It was noted that there is much controversy as to the effects of asbestos in potable water. From the above, it is obvious that 0.1 to 10 (x10^6) fibers/liter were fairly common in most potable waters (26)(27)(28)(29)(30). However, 42x10^6 fibers/liter found in Duluth, MN drinking water was high enough to cause concern (29). It was also noted that chrysotile was the most commonly reported asbestiform fiber. In light of these data it does not appear that presence of asbestiform material in highway runoff should be of significant concern.

HIGHWAY MAINTENANCE ACTIVITIES AND EFFECT ON RUNOFF QUALITY

Highway maintenance activities can have significant effects on the pollutant loadings observed at a monitoring site. These activities can be minor such as grass mowing or major such as deicing. Any of these activities can affect both the overall pollutant loadings and the pattern of pollutant discharge during a storm event. Table 40 is a list of nonwinter and winter maintenance activities reported in the vicinity of the six monitoring locations. In addition to the maintenance activities listed in Table 40, highway construction took place adjacent to the Nashville site, and a parking lot was constructed adjacent to the Hwy. 45 site in Milwaukee. It should be noted that the Harrisburg site is on a new highway at which construction was completed in 1975. These activities may also have affected the observed pollutant loadings.

From the reported maintenance data, no significant correlations could be established with the monitored water quality data except for obvious effects such as those due to salting and sweeping. The effects of salting can probably be best evaluated for the Milwaukee sites because of the close proximity of the contractor personnel to these sites and their frequent contacts with the state maintenance personnel. At the I-794 site in Milwaukee approximately 30,550 pounds (13855 kg) of chlorides were applied from November 1976 to March 1977. Only a small fraction (of the order of 15 to 30%) of the total applied salt could be accounted for in the form of chlorides in the monitored storm events through March 1977. The unaccounted portion of the applied salt probably was due to losses in groundwater, unmonitored snowmelt events as

Table 40. Monitored highway maintenance activities at the study sites.

	I-794		U.S. 45		Grassy Site		Harrisburg		Nashville		Denver	
	Nonwinter[a]	Winter[b]	Nonwinter[a]	Winter[b]	Nonwinter[a]	Winter[b]	Nonwinter[a]	Winter[b]	Nonwinter[a]	Winter[b]	Nonwinter[a]	Winter[b]
Roadway sweeping	✓	✓	✓		✓					✓	✓	✓
Roadway washing										✓		
Lane line painting	✓	✓	✓	✓								
Lane line sandblasting	✓											
Sewer flushing/cleaning	✓		✓									
Inlet flushing/cleaning	✓											
Bridge drain cleaning		✓										
Lawn mowing			✓		✓		✓			✓	✓	
Lawn watering											✓	
Herbicide application			✓				✓				✓	
Insecticide application											✓	
Fertilizers											✓	
Salt application	✓	✓		✓		✓		✓		✓		✓
Snowplowing	✓	✓		✓								
Crushed stone application								✓				
Construction activities												
Topsoil addition			✓									
Seeding mulching			✓									
Light pole installation			✓									
Sign installation			✓									
Concrete barrier Removal/installation			✓									
Concrete gutter and shoulder installation			✓									
Asphalt and concrete repair			✓									
Guard rail installation			✓									
Reported accidents on site during study			✓				✓					

[a]April through October period (1976-77)
[b]November through March period (1976-77)

ambient temperatures increased, and some losses due to the removal of snow from site area and salt attachment on vehicles themselves. Similar low correlations between the applied salt and monitored chlorides were found to be existing at all sites. All available salt application data was estimated from targeted application rates between 300 to 400 lb per lane mile (85 to 116 kg/lane km) at Milwaukee and Denver area sites and up to 600 lb/lane mile (170 kg/lane km) at the Harrisburg site. These application rates were generally calculated from truck volumes and time and frequency of salt applications reported by salting crews. No exact salt application rate records were maintained.

Generally, the effects of salting were obvious in terms of increased chloride and total solids concentrations in highway runoff during winter periods compared to nonwinter concentrations. Moreover, profound increases in suspended and total solids loading in winters compared to nonwinters were exhibited probably because of the use of sand in salting operations for the Milwaukee sites. At Harrisburg, PA, salt and a fine crushed stone material called "anti-skid" was used for snow and ice control, which contributed to the increase in the monitored suspended solids levels during winter periods.

The available sweeping data from various sites did not show any appreciable effects on the quality of highway runoff. However, this was probably a result of the lack of availability of accurate sweeping data from various sites. Similarly, none of the other reported maintenance data could be used to develop any significant trends or correlations with the monitored runoff quality data. However, vigilance of the operating personnel and close rapport with the respective highway departments did uncover two unexpected construction activities near the I-40 Nashville and Hwy. 45, Milwaukee sites. The effect of construction activity in particular is noticeable in the dustfall activity recorded at the Nashville site (Table 6). Such vigilance was particularly helpful in enabling better use of the available data for predictive procedure development (7).

DEVELOPMENT OF A CARRIER PARAMETER FOR THE PREDICTION OF OTHER CONSTITUENTS OF HIGHWAY RUNOFF

In order to develop some interrelations of the pollutants monitored in highway runoff, the observed nonwinter loadings of total solids and suspended solids were correlated with other parameters at each of the sites for all of the monitored events. These correlations indicate the degree of association of oxygen demand parameters, nutrients, and metals with the solids parameters. This type of analysis is particularly useful in the development of a method for predicting pollutant concentrations based upon the solids parameters such as total solids or suspended solids.

The correlation coefficients and critical values for a 0.01 level of significance (99 percent confidence) for the correlations of total solids with the other pollutants at each site are listed in Table 41. The loadings of suspended solids, TOC, COD, total phosphorus and lead are significantly correlated (r value greater than the critical value) with total solids at all six of the monitoring sites. On a strict statistical basis, significantly correlated means that the null hypothesis (i.e., the hypothesis that the r value = 0) can be rejected at the 99 percent confidence level. Total nitrogen, zinc, iron, and cadmium are significantly correlated at five monitoring sites. Total kjeldahl nitrogen and BOD_5 were only significantly correlated at two sites while total volatile solids were significantly correlated at the three sites outside of the Milwaukee area. Generally, these results indicate that the loadings of most of the monitored pollutants are highly related to total solids, therefore, pollutant loadings could be estimated based upon the loading of total solids.

In examining the pollutant correlation with total solids on a site by site basis, there are some interesting trends. The Hwy. 45 site in Milwaukee had the fewest number of significant correlations and generally had the lowest correlation coefficients. This may have been due to the construction activity in the vicinity of the monitoring site. However, total nitrogen, total phosphorus, TOC, COD, and lead correlated well with the total solids at this site despite the construction activity.

The Harrisburg site, Denver site and Grassy site at Hwy. 45 Milwaukee had the largest number of significant correlations with each site having a large number of correlation coefficients values greater than 0.90 and some values as large as 0.98. The Nashville site also had a large number of significant correlations, however, only 3 of the coefficient values were greater than 0.90.

The total number of significant correlations at each site for suspended solids versus the other pollutants were quite similar to those observed with total solids correlations. The individual correlation coefficients for the two different correlations were often quite close, however, when there was a difference in the coefficient values, the total solids correlation coefficient was generally higher.

OVERALL CONCENTRATIONS AND LOADINGS OF VARIOUS CONSTITUENTS IN HIGHWAY RUNOFF

The data presented so far in the report have been site specific. In order to get an overall picture of the highway runoff constituent loads, the average and range were calculated for all flow composite data collected from the six sites. These overall averages and ranges

Table 41. Summary of correlation coefficient and critical values for correlation of total solids with other parameters at all six sites.

	I-794		Hwy. 45		Grassy Site		Harrisburg		Nashville		Denver		A
	CC	CV	CC	CV	CC	CV	CC	CV	CC	CV	CC	CV	
SS	*.889	.517	*.938	.590	*.981	.735	*.877	.708	*.931	.561	*.986	.641	6
VSS	*.780	.606	.578	.590	.562	.765	*.879	.708	*.576	.561	*.944	.641	4
TVS	.444	.798	.367	.798	.587	.735	*.956	.917	*.721	.561	*.891	.708	3
TKN	.574	.623	.430	.590	*.955	.765	.674	.708	.547	.661	*.919	.641	2
BOD_5	*.773	.684	.576	.641	.998	-	-	-	*.876	.875	.849	.875	2
TOC	*.842	.641	*.786	.590	*.970	.765	*.968	.708	*.857	.684	*.930	.661	6
COD	*.843	.641	*.793	.590	*.970	.765	*.945	.765	*.830	.661	*.964	.641	6
TN	.620	.641	*.736	.623	*.954	.765	*.952	.708	*.823	.661	*.851	.641	5
TPO_4	*.834	.623	*.931	.590	*.978	.765	*.944	.708	*.935	.684	*.973	.641	6
Cl	*.730	.661	.514	.590	*.901	.765	*.938	.708	.614	.661	*.794	.641	4
Pb	*.863	.641	*.888	.590	*.929	.735	*.951	.708	*.666	.561	*.916	.641	6
Zn	.639	.641	*.895	.590	*.955	.735	*.981	.708	*.939	.561	*.984	.641	5
Fe	.507	.641	*.933	.590	*.991	.735	*.899	.708	*.949	.561	*.985	.641	5
Cu	*.762	.641	.500	.606	*.955	.765	*.869	.708	.358	.661	*.966	.641	4
Cd	*.879	.641	.501	.590	*.877	.765	*.876	.708	*.751	.661	*.823	.641	5
Cr	.497	.641	.294	.590	*.906	.765	*.867	.708	*.712	.661	*.648	.641	4
Hg	-.028	.641	.427	.590	*.869	.798	-.060	.708	.597	.708	.110	.641	1

CC: Correlation coefficient.

CV: Critical value at 99% confidence limit based upon the number of data points.

* Signifies that a correlation exists between total solids and the correlated parameter.

A Represents number of sites for which correlation existed at 99% confidence limit.

for various constituents are presented in Table 42. Also presented in this table are the corresponding average and range of pollutant loadings in lb /acre/event to normalize for site area differences. Furthermore, corresponding average and range values in terms of lb /acre/inch of runoff flow are also included to provide an overall idea of the impact of highway runoff as it leaves the highway drainage system and discharges to the surrounding environment.

Highway surface pollutant accumulation rates expressed as pounds per mile per day (kg/km/day) were found to have a strong relationship with average daily traffic. Based on the results of regression analysis on the data monitored during this study, the build-up of total solids on the drainage area was simulated in a predictive model as follows:

$$K_1 = (ADT^{0.89}) * 0.007$$

Where K_1 = Total solids accumulation, lb/mile/day
ADT= Average daily traffic.

Additional details about the development of the pollutant build-up rates have been presented in Volume III (Predictive Procedure) of this contract's six volume document series (7).

Table 42. Summary of highway runoff quality data for all six monitoring sites - 1976-77.

	Pollutant concentration, mg/l		Pollutant loadings lb/ac/event		Pollutant loading, lb/ac/in-runoff	
	Avg.	Range	Avg.	Range	Avg.	Range
pH		6.5-8.1				
TS	1147	145-21640	51.8	0.04-535.0	260	33-4910
SS	261	4-1656	14.0	0.008-96.0	59	0.9-375
VSS	77	1-837	3.7	0.004-28.2	17	0.2-190
BOD_5	24	2-133	0.88	0.000-4.1	5.4	0.5-30
TOC	41	5-290	2.1	0.002-11.5	9.3	1.1-66
COD	14.7	5-1058	6.9	0.004-34.3	33	1.1-240
TKN	2.99	0.1-14	0.15	0.000-1.04	0.68	0.02-3.17
NO_2+NO_3	1.14	0.01-8.4	0.069	0.000-0.42	0.26	0.002-1.90
TPO_4	0.79	0.05-3.55	0.047	0.000-0.36	0.18	0.011-0.81
Cl	386	5-13300	13.0	0.008-329.0	88	1.1-3015
Pb	0.96	0.02-13.1	0.058	0.000-4.8	0.22	0.005-2.97
Zn	0.41	0.01-3.4	0.022	0.000-0.48	0.093	0.002-0.771
Fe	10.3	0.1-45.0	0.50	0.000-3.5	2.34	0.023-10.2
Cu	0.103	0.01-0.88	0.0056	0.000-0.029	0.023	0.002-0.199
Cd	0.040	0.01-0.40	0.0017	0.000-0.014	0.009	0.002-0.091
Cr	0.040	0.01-0.14	0.0028	0.000-0.029	0.009	0.002-0.032
Hg, X10-3	3.22	0.13-67.0	0.00059	0.000-0.002	0.730	0.029-15.2
Ni	9.92	0.1-49	0.27	0.007-1.33	2.25	0.023-11.1
TVS	242	26-1522	9.34	0.01-44.	55	5.89-345

Metric units: To convert lbs/ac to kg/ha multiply by 1.12.

SECTION V
CONCLUSIONS AND RECOMMENDATIONS

1. The average runoff volume to rainfall volume coefficients (Q/R) for nonwinter (April-October) storm events were found to vary between 0.20 to 0.92 for the sites monitored in this study. The lower coefficient value is representative of all unpaved (grassy) drainage areas and the higher coefficient value is representative of all paved (impervious) drainage areas. Typical highway drainage systems having a combination of paved and unpaved areas can be expected to have average Q/R coefficients within this range.

2. The overall solids loadings in highway runoff for the 159 monitored storm events at six sites were found to be as follows:

	Pollutant Concentration, mg/l		Pollutant Loadings, lb /Ac/event		Pollutant loadings lb /Ac/in. of runoff	
	Avg.	Range	Avg.	Range	Avg.	Range
Total Solids (TS)	1147	145-21640	52	0.04-535	260	33-4910
Total Volatile Solids (TVS)	242	26-1522	9	0.01-44.	55	6-345
Suspended Solids (SS)	261	4-1656	14	0.008-96	59	.9-375
Volatile Suspended Solids (VSS)	77	1-837	4	0.004-28	17	.2-190

Metric conversion units: To convert lb/ac to kg/ha multiply by 1.12.

3. Among sites, the all-paved site, I-794, exhibited the largest solids loadings in lbs/acre at 60 lbs/acre (67 kg/ha) TS and 19.6 lbs/acre (22 kg/ha) SS on an average basis. These high solids loadings at the I-794 site were due to the high pollutant wash-off efficiency of accumulated solids from the highly impervious (100% paved) drainage area of the site. The Harrisburg site exhibited the lowest overall average suspended solids loading at 4.7 lbs/acre (5.3 kgm/ha) because of factors such as rural environment, flush-shoulder type of highway design and low percentage of impervious area.

4. The average volatile fractions of total and suspended solids for nonwinter conditions ranged between 30 and 50%. For winter (November-March) conditions, these fractions were significantly reduced because of the inorganic content of solids due to salting/sanding for deicing at the Milwaukee and Harrisburg sites. However, minimal differences in volatile fractions for winter and nonwinter periods were observed at the Nashville site where relatively little salt/sand is used.

5. Most heavy metals were associated with the particulate matter in highway runoff. Dissolved metal fractions were extremely small and generally were near or below detection limits. The following

levels of heavy metals were present in highway runoff for all the 159 storm events at the six sites:

	Pollutant concentration, mg/l		Pollutant loadings, lb/ac/event		Pollutant loading, lb/ac/in-runoff	
	Avg.	Range	Avg.	Range	Avg.	Range
Lead	0.96	0.02-13.1	0.058	0.000-0.48	0.22	0.005-2.97
Zinc	0.41	0.01-3.4	0.022	0.000-0.12	0.093	0.002-0.771
Iron	10.30	0.1-45.0	0.50	0.000-3.5	2.34	0.023-10.2
Copper	0.103	0.01-0.88	0.0056	0.000-0.029	0.023	0.002-0.199
Cadmium	0.040	0.01-0.40	0.0017	0.000-0.014	0.009	0.002-0.091
Chromium	0.040	0.01-0.14	0.0028	0.000-0.029	0.009	0.002-0.032
Mercury	3.22[a]	0.13[a]-67.0[a]	0.00059	0.000 - 0.00214	0.730	0.029-15.2
Nickel	9.92	0.1-49.0	0.27	0.007-1.33	2.25	0.023-11.1

Note: The unit acre (ha) represents the entire contributing drainage area including any unpaved area(right-of-way) present.

[a]Expressed as μg/l

Metric conversion units: To convert lb/ac to kg/ha multiply by 1.12.

6. Most of the solids and heavy metal parameters did not appear to be highly related to average daily traffic (ADT), percent imperviousness or dustfall on a simple correlation basis. However, multiple correlation of these characteristics with solids and metal loadings data showed stronger relationships.

7. The solids, heavy metals and chlorides data exhibited significant increases in loadings during winter periods as compared to non-winter data for those sites where salting/sanding deicing practices were observed.

8. The average BOD_5 (5 day biochemical oxygen demand) values in highway runoff were found to be comparable with effluent from a well operated secondary municipal treatment plant. Maximum BOD_5 values approaching 100 mg/l were exhibited in a few instances indicating that "slug" loadings of oxygen demanding pollutants are possible.

9. The biochemical oxygen demand to chemical oxygen demand (BOD/COD) ratios in highway runoff were considerably below values normally found in treated or untreated municipal wastewaters and were slightly lower than urban stormwater runoff values reported in the literature. This indicates that a higher percentage of the oxygen demanding material in highway runoff is of the nonbiodegradable types.

10. The nutrient loadings in highway runoff were generally comparable to urban stormwater runoff.

11. Sizable concentrations of the three widely used pathogenic indicator bacteria i.e., total coliforms (TC), fecal coliforms (FC), and fecal streptococci (FS) were found at all sites. The FC/FS ratios indicated origin of these bacteria from non-human sources. The bacteria counts were found to persist through the duration of the storm events and in successive or frequent rainfall events indicating that either these bacteria remain viable in the animal and bird droppings for long periods or they are being added on a regular or constant basis.

12. The geometric mean concentration of polychlorinated biphenyls (PCBs) was found to be 0.33 μg/l and generally the monitored PCB concentrations were well below the proposed 1 μg/l effluent standard for point discharge sources.

13. No significant concentrations of pesticides/herbicides were found to be present in highway runoff.

14. The average oil and grease concentrations in monitored storm events ranged between 1 mg/l at the all-grassy site to 20 mg/l at the all-paved area site (I-794). The anticipated higher oil and grease loading (lb/ac/in. runoff) at the asphalt-paved Denver site were observed. Significantly increased concentrations of oil and grease during winter conditions compared to nonwinter conditions were observed at only 2 sites (I-794, Milwaukee and I-40 Nashville).

15. No asbestiform material was detected in 19 out of 21 samples analyzed for this constituent during this study. No firm conclusions could be drawn for the presence of asbestiform material in two of the five Nashville site samples.

16. Generally, the all-paved area I-794 site showed the highest loadings for various constituents. The grassy area site in Milwaukee and the flush shoulder design Harrisburg sites showed the lowest constituent loadings among the various sites monitored in this study.

17. Total solids and suspended solids showed significant correlations with SS, VSS, TOC, COD, NO_2 & NO_3, TPO_4, Cl, Pb, Zn, Fe, Cn, Cd, and Cr. Total solids coefficients generally showed slightly better correlations compared to suspended solids.

RECOMMENDATIONS

1. Further investigations on highway generated runoff should be continued to expand the data base generated during the study. The Following site features may be incorporated in similar research in the future to complement the results of this study:

    a. ADT volumes greater than 85,000.
    b. Drainage areas with impervious areas between 40 and 80%.
    c. Asphalt paved highway surfaces.
    d. Flush shoulder type drainage design systems.
    e. Roadway slopes between 2 and 3%.
    f. Varying right-of-way characteristics such as different vegetative types, soil types and slopes.
    g. Location of a site in a low rainfall area with no snowfall, where runoff monitoring may be conducted over an extended period (say 3 years). Such a site will enable development of more data on extended pollutant buildup rates, pollutant accumulations within the collection system and wash-off of pollutants in arid climate areas.

2. Identify the relative magnitude of pollutant dispersion of highway environment by separating the background pollution, pollutants brought on to the highway system through external sources, pollutants generated within the highway system and the mechanisms of dispersion of these pollutants within and out of the highway drainage system. (These investigations are presently underway under a Phase II contract titled, "Sources and Migration of Highway Runoff Pollutants".)

3. Continue further investigations on the origin and fate of certain constituents in highway runoff such as bacteria, asbestos, polychlorinated biphenyls and oil and grease.

4. Establish the fate of pollutants in grassy areas. Develop long term data on the characteristics of pollutant build-up and washoff in unpaved areas of highway right-of-ways.

5. Analyze the impacts of highway runoff pollutants on receiving waters through instream monitoring. (These investigations are planned to be undertaken under Phase III research by FHWA).

6. Incorporate procedures that will enable highway departments to record more precise highway maintenance data relative to potential pollutants for future studies.

7. Develop procedures to include consideration of highway runoff quality data in drainage design and planning.

8. Identify potential points of partial or complete abatement/ treatment methods for objectionable constituents. (These investigations are planned to be undertaken under Phase IV research by FHWA).

SECTION VI

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APPENDIX A

ANALYTICAL PROCEDURES

All laboratory analysis for the various parameters were performed by NPDES approved methods as recommended in Federal Register, 38, 199, 28758-60 (October 16, 1973) and according to accepted Standard Methods (3) of water and wastewater analyses or EPA approved procedures (4,5). Some of the modifications and/or special techniques utilized for determinations such as oil and grease, PCB, chlorinated hydrocarbons, and asbestos are described below:

OIL AND GREASE ANALYSIS

Oil and grease (O&G) samples were acidified to a pH <2.0 with concentrated sulfuric acid and refrigerated. O&G analyses were performed according to the liquid-liquid partition method of Standard Methods (3). This technique measures those constituents which can be dissolved in freon at room temperature but which do not volatilize between 70°C and 103°C. Detection limits are approximately 1 mg/l. The method has a reported coefficient of variation of 6% at 14 mg/l with recoveries averaging 97%.

POLYCHLORINATED BIPHENYLS AND PESTICIDE ANALYSIS

Samples for PCB and pesticide analyses were preserved with 5 mg/l of a 38% formaldehyde solution and refrigerated. PCB and chlorinated hydrocarbon analyses were performed according to the general procedure prescribed for NPDES analytical work. Some modifications and additions to the procedure were made to accommodate the interferences and special conditions peculiar to the samples tested. Water samples were extracted with 15 percent methylene chloride in hexane using a separatory funnel. Samples high in solids were centrifuged to separate the solids from the liquid fraction. The solids were dried with anhydrous sodium sulfate and extracted with a 9:1 hexane-acetone mixture for 24 hours using a Soxhlet apparatus. After concentration of the extracts using a Kuderna-Danish concentrator the extracts were subjected to Florisil and silicic acid column clean up as necessary (26). Sulfur was removed by reaction with elemental copper. Micro-alkali dehydrochlorination was used as a chemical derivation - confirming and clean-up technique (27). Separation and measurement was performed using a Barber-Coleman or Perkin-Elmer Model 3920B gas chromatograph equipped with a Ni^{63} electron capture detector. Solvents used throughout were of pesticide grade (Burdik and Jackson). Confirmation of PCBs were made by comparing the relative retention time (relative to pp'DDE) of the sample injections with those of Arochlor standards obtained from EPA Pesticide and Toxic Substances Laboratory, Research Triang Park, NC. Two glass columns 183 cm long and 0.4 cm diameter, one packed with 3% OV210 on chromosorb W-HP, the other 1.5% OV-17/1.95% OF-1, were operated at optimum temperature for resolving the multicomponent PCB mix.

The detection limit of chlorinated hydrocarbons is a function of their individual response to the EC detector and the amount of sample available for extraction. In general Envirex laboratory can quantitate 200 pg of the PCB arochlor No. 1254 which, for two liters sample would correspond to a detection limit of 0.02 µg/l for arochlor No. 1254. Recoveries ranged from 70% to 96% in deionized water.

ASBESTOS

The analytical procedure utilized by Walter C. McCrone Associates, Inc., for asbestos analysis was substantially similar to that given in the U.S. EPA "Preliminary Interim Procedure for Determining Fibrous Asbestos", a copy of which is available from the U.S. EPA Environmental Research Laboratory, Athens, GA, 30601. Details of the procedure follow.

After an aliquot of the sample has been filtered, under clean room conditions, through a 47 mm, 45 µm pore size membrane filter discs, approximately 3 mm in diameter are punched out of the filter while in a laminar flow clean bench. These discs are then placed face-down on previously carbon-coated electron microscope support grids either of copper, if only chrysotile is expected, or nylon. Nylon is used for samples in which there is a reasonable likelihood of amphibole fibers in order that chemical analyses may be performed on the fibers, by either the X-ray energy or wavelength dispersive system fitted to the microscope. The use of nylon minimizes extraneous X-ray signals from the support grid which would otherwise saturate the detector system. Such an analysis is essential in order to classify the amphibole type present. The grids are then transferred to a cold finger in a Soxhlet extraction apparatus in which the membrane filter is dissolved using acetone for Millipore Type MF R and for Gelman GN-6 Metricel R filters or chloroform for Nuclepore filters. A "wicking" method may also be used for Nuclepore filters but is unsuitable for the Millipore or Gelman types. Previous work has shown that there is very little risk of contamination in transferring the filter on the electron microscope grid to the Soxhlet extractor. Furthermore, by dissolving the filter <u>in situ</u> on the grid ("direct transfer"), the risk of losing portions of the sample is minimal.

The sample grids for this project were analyzed on the EMMA-4 electron microscope (combined 100 Kv transmission electron microscope-microprobe analyzer, manufactured by Associated Electrical Industries (AEI) using a magnification such that the intermediate lens aperture is in focus in the specimen plane. It is thus possible, by inserting the aperture and switching to the diffraction position, to obtain a selected area electron diffraction (SAED) pattern of the fiber with no other adjustments to the microscope. In this way it is possible to spot check the diffraction pattern of individual fibers very rapidly.

Prior to commencing measurement the electron microscope grid is scanned at low magnification, approximately 2000X - 4000X, to insure uniformity of dispersion on the filter. In the case of non-uniform deposition, which may occur with cemented or aggregated fibers, several grids may be examined from the same filter. This prior examination indicated which areas should be examined to obtain a truly representative analysis of the sample. Magnifications in excess of 10,000X are required for the observation of the smallest chrysotile fibrils present.

The magnification of examination used in EMMA-4 is 24,800X which is based on user convenience in switching from viewing to diffraction.

The length and width of each asbestos fiber is recorded. Only fibers which are positively identified as asbestos are measured. Interpolation from intervals scribed on the viewing screen allows an accuracy of measurement on the screen of approximately 0.05 cm. This corresponds to an accuracy in size measurement of about 0.02-0.04 µm. Measurements of the individual fibers are computer processed to give listings of the length and width of the fibers, together with a computed mass of each fiber computed on the basis of density, D, and dimensions, L and W ($D \times L \times W^2$). A value of 3.3 is taken as the mean density of amphibole fibers: a density of 2.3 is used for chrysotile. Because many of the amphiboles are lath-shaped rather than square in cross section, this figure may well be slightly high, since the laths will, in general, tend to lie flat rather than on edge. There is, however, a finite possibility that some laths will be on edge and, due to the very small size of many of the fibers of interest, the approximation to a square fiber will not give more than a slightly high bias to the mass readings. The program automatically assigns the longest dimension to the fiber length and excludes all particles with an aspect ratio below three.

Also presented in the computer printout are the calculated number of fibers per unit volume, the calculated mass of fiber per unit volume, the size distribution of the fibers based on length and width, and the distribution of fibers by aspect ratio together with the relevant statistical information on these parameters. A physical description of the sample accompanies the measurements and is considered an integral and essential part of the analysis.

APPENDIX B
SUMMARY TABLES OF RAINFALL, RUNOFF AND RUNOFF QUALITY DATA FOR ALL MONITORED STORM EVENTS

Table B-1. Milwaukee - Hwy. 794 rain and flow data[a], 1976 - 1977.

Event no.	Date 1976	Rainfall, R, in.	Total measured flow, Q, in.	Q/R
1	6/18	.90	.73	.81
2	7/28	.33	.27	.82
3	7/30	1.59	1.39	.87
4	8/5	.05	.04	.80
5	8/13-14	.64	.58	.91
6	8/25	.14	.12	.86
7	8/28	1.05	1.17	1.11
8	9/9	.85	.86	1.01
9	9/19	.30	.28	.93
10	10/30	.15	.15	1.00
	1977			
11	2/23[b]	.14	.11	.79
12	3/3	.15	.11	.73
13	3/3-4	.62	.43	.69
14	3/12	.30	.21	.70
15	3/17	.21	.17	.81
16	3/27	.29	.20	.69
17	3/28-29	1.12	.85	.76
18	5/31	.20	.17	.85
19	6/5	.69	.65	.94
20	6/5	.54	.49	.91
21	6/8	.25	.24	.96
22	6/10	.05	.04	.80
23	6/11	1.22	1.15	.94
24	6/17	.61	.61	1.00
24A	6/28	.10	.10	1.00
24B	6/28	.57	.57	1.00
25	6/30	.79	.76	.96
26	7/3	.35	.33	.94
27	7/17-18	2.10	2.01	.96
28	8/4	.17	.17	1.00
29	8/5	.15	.14	.93
30	8/5	.24	.15	.63
31	8/13	1.28	1.04	.81
32	8/28	1.10	.79	.72
33	9/23	.05	.02	.40
34	9/23	.13	.12	.92
35	9/24	.81	.80	.99

Note: To obtain metric units of cm, multiply in. by 2.54.

[a]Data presented are for only those storm events for which runoff quality data were collected

[b]Snowmelt event.

Table B-2. Milwaukee - Hwy. 45 rain and flow data[a], 1976-1977.

Event no.	Date 1976	Rainfall, R, in.	Total measured flow, Q, in.	Q/R
1	2/9[b]	--	.02	--
2	2/10[b]	--	.18	--
3	2/12[b]	--	.16	--
4	2/16	.55	.39	.71
5	3/26-27	1.56	.90	.58
6	3/29-30	.22	.19	.86
7	6/18	.66	.27	.41
8	7/28	.33	.06	.18
9	7/30-31	1.14	.23	.20
10	8/5	.04	.01	.25
11	8/14	.31	.08	.26
12	8/25	.37	.09	.24
13	8/27-28	.92	.29	.31
14	9/9	.80	.32	.40
15	9/19	.37	.08	.22
16	10/30	.20	.05	.25
	1977			
17	2/23[b]	.13	.03	.23
18	2/23[b]	.12	.17	1.42
19	3/3-4	.62	.59	.95
20	3/12	.40	.15	.38
21	3/17-18	.26	.07	.27
22	3/27	.09	.08	.89
23	3/28-29	1.06	.57	.54
24	5/4-5	.18	.03	.17
25	6/5	.83	.23	.28
26	6/5	.56	.20	.36
27	6/6	.10	.01	.10
28	6/8	.27	.04	.15
29	6/11	.61	.15	.25
30	6/17	.60	.21	.35
31	6/27-28	.40	.21	.53
32	6/30	.71	.22	.31

Note: To obtain metric units of cm, multiply in. by 2.54

[a]Data presented are for only those storm events for which runoff quality data were collected.

[b]Snowmelt event.

Table B-3. Milwaukee grassy site rain and flow data[a], 1977.

Event no.	Date 1977	Rainfall, R, in.	Total measured flow, Q, in.	Q/R
1	2/23[b]	.10	.27	2.70
2	3/3-4[b]	.62	.60	.97
3	3/12	.40	.01	.025
4	3/27	.10	.001	.01
5	3/28-29	1.06	.34	.32
6	6/17	.96	.06	.06
7	7/17	2.32	.32	.14
8	7/17-18	1.84	.97	.53
9	7/20	.47	.01	.02
10	7/24	.62	.11	.18
11	8/13	1.15	.20	.17
12	8/28	1.11	.09	.08
13	9/17	.28	.0003	.001
14	9/18	.29	.02	.069
15	9/23	.20	.0002	.001
16	9/24	.72	.27	.38
17	9/30-10/1	1.00	.19	.19

Note: To obtain metric units of cm, multiply in. by 2.54.

[a]Data presented are for only those storm events for which runoff quality data were collected. No runoff events occurred in the 1976 monitoring period at this site.

[b]Snowmelt event.

Table B-4. Harrisburg rain and flow data[a], 1976 - 1977.

Event no.	Date 1976	Rainfall, R, in.	Total measured flow, Q, in.	Q/R
1	2/16	0.19	0.09	0.47
2	2/17	0.30	0.22	0.73
3	3/4	0.30	0.04	0.13
4	3/10-11[b]	--	0.08	--
5	5/16-17	0.65	0.12	0.18
6	7/3	1.21	0.74	0.61
7	7/7	0.49	0.15	0.31
8	7/7	1.53	1.46	0.95
9	7/15	0.57	0.29	0.51
10	9/10	1.00	0.15	0.15
11	10/20-21	1.38	0.84	0.61
12	11/28-29	0.20	0.05	0.25
13	12/6	1.29	1.02	0.79
	1977			
14	2/10-14[b]	--	0.64	--
15	2/24	0.96	0.85	0.89
16	3/12-13	1.42	0.99	0.70
17	3/18	0.45	0.15	0.33
18	4/2	1.40	0.85	0.61
19	4/24	0.78	0.22	0.28
20	6/6	0.45	0.02	0.04
21	6/9	0.31	0.02	0.06
22	6/14	0.82	0.13	0.16
23	6/17	0.33	0.06	0.18
23A	6/20	0.32	0.05	0.16
24	6/25	0.64	0.08	0.13
25	6/25	0.36	0.13	0.36

Note: To obtain metric units of cm, multiply in. by 2.54.

[a]Data presented are for only those storm events for which runoff quality data were collected

[b]Snowmelt event.

Table B-5. Nashville rain and flow data[a], 1976 - 1977.

Event no.	Date 1976	Rainfall, R, in.	Total measured flow, Q, in.	Q/R
1	10/23-24	.58	.11	.19
2	10/30	1.09	.39	.36
	1977			
3	2/23-24	2.05	.36	.18
4	2/26-27	.62	.15	.18
5	3/3-4	2.90	.62	.21
6	3/11	.55	.15	.27
7	3/12	2.02	1.13	.56
8	3/28	.21	.08	.38
9	4/2	1.21	.27	.22
10	4/3-4	1.91	1.15	.60
11	4/21-22	.99	.35	.35
12	4/22	.41	.25	.61
13	4/28	.20	.03	.15
14	5/7	.47	.15	.32
15	6/12	.05	.01	.20
16	6/13-14	.09	.02	.22
17	6/14	.12	.08	.67
18	6/19	.69	.22	.32
19	6/22-23	1.21	.42	.35
20	6/23	.76	.47	.62
21	6/24	.30	.24	.80
22	6/25	.86	.46	.53
23	7/23	.04	.04	1.00
24	9/5	.42	.12	.29
25	9/6	.10	.01	.10
26	9/13	.15	.03	.20
27	9/13	.53	.21	.40
28	9/14	.23	.11	.48
29	9/14	.92	.75	.81
30	9/16	.19	.09	.47
31	9/19	.60	.16	.27

Note: To obtain metric units of cm, multiply in. by 2.54

[a]Data presented are for only those storm events for which runoff quality data were collected.

Table B-6. Denver rain and flow data[a], 1976 - 1977.

Event no.	Date 1976	Rainfall, R, in.	Total measured flow, Q, in.	Q/R
1	8/2	.42	.26	.62
2	9/13	.15	.05	.33
3	9/25	.40	.22	.55
4	9/26-77	1.11	.73	.66
	1977			
5	4/11	.29	.06	.21
6	4/12	.10	.04	.40
7	4/15	.46	.17	.37
8	4/19-20	.65	.35	.54
9	5/7	.20	.04	.20
10	6/6	.08	.02	.25
11	6/9	.09	.02	.22
12	6/23	.05	.01	.20
13	7/5	1.15	.37	.32
14	7/20-21	.70	.21	.30
15	7/24	.34	.04	.12
16	7/25	.30	.09	.30

Note: To obtain metric units of cm, multiply in. by 2.54.

[a]Data presented are only for those storm events for which runoff quality data were collected.

Table B-7. Summary of highway runoff constituent concentrations (flow composite values), mg/l - nonwinter[a] 1976-77

	pH		TS		SS	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	-	6.8-7.6	378	145-1130	138	26-475
Milw.-Hwy. 45	-	7.3-8.0	992	350-2145	396	146-1260
Milw.-Grassy Site	-	7.2-7.9	957	268-1850	419	43-938
Harrisburg	-	6.8-7.9	360	180-560	47	4-136
Nashville	-	7.2-8.3	424	223-698	187	13-475
Denver	-	6.5-7.5	686	295-1334	259	118-1029

	VSS		TVS		TOC	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	53	14-144	127	55-320	31	5-67
Milw.-Hwy. 45	101	34-510	323	80-816	34	16-63
Milw.-Grassy Site	134	18-837	298	70-1522	38	23-57
Harrisburg	15	3-48	177	52-364	12	6-17
Nashville	89	11-397	213	26-595	37	12-74
Denver	103	10-240	264	88-395	54	14-212

	COD		TKN		NO2+NO3	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	105	5-226	2.04	0.60-4.01	1.57	0.34-5.60
Milw.-Hwy. 45	120	64-185	3.40	0.8-11.4	1.55	0.49-2.90
Milw.-Grassy Site	92	42-144	2.90	0.7-5.0	0.38	0.01-0.85
Harrisburg	30	21-59	2.12	0.6-8.1	0.76	0.38-1.76
Nashville	139	31-264	3.02	0.5-10.0	0.82	0.25-1.90
Denver	191	119-718	4.47	1.6-14.0	1.07	0.36-2.70

	TPO4		Cl		Pb	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.31	0.12-0.63	63	10-118	1.50	0.80-3.10
Milw.-Hwy. 45	0.48	0.10-1.27	229	40-828	0.78	0.40-1.50
Milw.-Grassy Site	0.90	0.33-1.51	168	40-366	0.26	0.10-0.70
Harrisburg	0.29	0.05-0.56	56	20-110	0.09	0.05-0.10
Nashville	1.89	0.77-3.55	17	5-45	0.50	0.02-1.70
Denver	0.92	0.48-2.36	36	8-90	0.45	0.30-1.80

	Zn		Fe		Cu	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.35	0.14-0.86	7.5	2.5-39.0	0.10	0.01-0.22
Milw.-Hwy. 45	0.39	0.20-0.70	13.3	5.6-38.6	0.08	0.01-0.14
Milw.-Grassy Site	0.21	0.10-0.34	19.9	2.7-43.6	0.07	0.01-0.14
Harrisburg	0.06	0.01-0.12	1.8	0.1-6.4	0.04	0.01-0.10
Nashville	0.28	0.10-0.61	5.2	1.5-12.0	0.07	0.01-0.20
Denver	0.72	0.33-1.5	16.5	6.5-37.0	0.11	0.03-0.26

[a]April through October.

Table B-7 (continued)

	Cd		Cr		Hg, μg/l	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.04	0.01-0.08	0.05	0.01-0.12	3.85	0.13-24.0
Milw.-Hwy. 45	0.04	0.01-0.09	0.05	0.01-0.14	6.30	0.20-67.0
Milw.-Grassy Site	0.05	0.02-0.10	0.05	0.01-0.10	2.00	0.25-11.5
Harrisburg	0.03	0.01-0.07	0.03	0.01-0.11	23.68	0.25-250
Nashville	0.03	0.01-0.06	0.02	0.01-0.05	1.18	0.05-2.5
Denver	0.02	0.01-0.08	0.03	0.01-0.09	1.09	0.25-4.0

	BOD_5	
	Avg.	Range
Milw.-Hwy. 794	21	5-63
Milw.-Hwy. 45	16	8-46
Milw.-Grassy Site	14	7-22
Harrisburg	3	2-4
Nashville	27	15-52
Denver	46	20-73

Table B-8. Summary of highway runoff constituent concentrations (flow composite values), mg/l - winter[a] 1976-1977.

	pH		TS		SS	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	-	7.2-7.8	4594	804-21640	656	201-1576
Milw.-Hwy. 45	-	6.9-7.8	3750	835-11402	526	151-1656
Milw.-Grassy Site	-	7.2-8.1	1447	651-2401	47	25-75
Harrisburg	-	7.0-8.1	1261	301-3696	60	4-163
Nashville	-	6.9-7.8	568	246-1001	271	89-478
Denver	-	-	-	-	-	-

	VSS		TVS	TOC	
	Avg.	Range	Typical Value[b]	Avg.	Range
Milw.-Hwy. 794	150	33-393	233	86	34-230
Milw.- Hwy. 45	93	27-274	299	88	27-290
Milw.-Grassy Site	16	10-25	284	37	25-44
Harrisburg	13	1-23	363	14	6-24
Nashville	45	23-70	332	39	14-85
Denver	-	-	-	-	-

	COD		TKN		NO_2+NO_3	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	471	158-1058	6.2	2.2-10.7	1.95	0.35-8.4
Milw.-Hwy. 45	245	73-774	3.1	1.4-7.1	1.34	0.35-3.55
Milw.-Grassy Site	138	80-167	2.8	2.3-3.3	0.67	0.03-1.80
Harrisburg	43	26-89	1.0	0.1-1.6	0.90	0.26-1.34
Nashville	97	13-181	1.9	0.4-6.2	1.31	0.59-3.00
Denver	-	-	-	-	-	-

	TPO4		Cl		Pb	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.90	0.28-1.81	2343	62-13300	5.53	1.8-13.1
Milw.-Hwy. 45	0.59	0.28-1.23	1327	150-3413	1.88	0.5-6.6
Milw.-Grassy Site	0.64	0.31-1.11	610	219-1165	0.11	0.05-0.20
Harrisburg	0.39	0.12-0.86	347	20-800	0.11	0.05-0.20
Nashville	1.97	0.78-3.50	28	7-55	0.50	0.30-0.70
Denver	-	-	-	-	-	-

	Zn		Fe		Cu	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	1.32	0.47-3.40	18.9	7.0-43.0	0.27	0.11-0.66
Milw.-Hwy. 45	0.80	0.24-1.90	16.8	6.5-45.0	0.22	0.07-0.88
Milw.-Grassy Site	0.12	0.07-0.15	3.9	1.1-10.0	0.11	0.05-0.23
Harrisburg	0.11	0.02-0.23	2.3	0.1-6.6	0.05	0.02-0.09
Nashville	0.29	0.11-0.41	6.4	3.1-9.2	0.07	0.05-0.09
Denver	-	-	-	-	-	-

[a] November through March.

[b] Total volatile solids examined on a cursory basis only.

Table B-8 (continued).

	Cd		Cr		Hg, µg/l	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.12	0.03-0.40	0.07	0.03-0.14	0.76	0.25-2.00
Milw.-Hwy. 45	0.05	0.01-0.09	0.06	0.01-0.14	3.15	0.25-11.0
Milw.-Grassy Site	0.04	0.02-0.07	0.02	0.01-0.02	0.44	0.25-0.50
Harrisburg	0.02	0.01-0.05	0.02	0.02-0.02	7.14	0.25-49.0
Nashville	0.02	0.01-0.03	0.03	0.02-0.05	2.88	0.80-6.7
Denver	-	-	-	-	-	-

	BOD_5	
	Avg.	Range
Milw.-Hwy. 794	68	31-133
Milw.-Hwy. 45	29	8-73
Milw.-Grassy Site	17	14-19
Harrisburg	4	2-6
Nashville	22	5-39
Denver	-	-

Table B-9. Summary of highway runoff constituent concentrations (flow composite values), mg/l - 1976-77.

	pH Avg.	pH Range	TS Avg.	TS Range	SS Avg.	SS Range
Milw.-Hwy. 794	-	7.2-7.8	1400	145-21640	268	26-1576
Milw.-Hwy. 45	-	6.9-7.8	2038	350-11402	445	146-1656
Milw.-Grassy Site	-	7.2-8.1	1110	268-2401	303	25-938
Harrisburg	-	7.0-8.1	791	180-3696	53	4-163
Nashville	-	6.9-7.8	461	223-1001	209	13-478
Denver	-	6.5-7.5	686	295-1334	259	118-1029

	VSS Avg.	VSS Range	TVS Avg.	TVS Range	TOC Avg.	TOC Range
Milw.-Hwy. 794	84	14-393	138	55-320	50	5-230
Milw.-Hwy. 45	98	27-510	319	80-816	54	16-290
Milw.-Grassy Site	95	10-837	297	70-1522	38	23-57
Harrisburg	14	1-48	204	52-364	13	6-24
Nashville	78	11-397	219	26-595	38	12-85
Denver	103	10-240	264	88-395	54	14-212

	COD Avg.	COD Range	TKN Avg.	TKN Range	NO2+NO3 Avg.	NO2+NO3 Range
Milw.-Hwy. 794	232	5-1058	3.43	0.60-10.7	1.70	0.34-8.40
Milw.-Hwy. 45	165	64-774	3.28	0.8-11.4	1.46	0.35-3.55
Milw.-Grassy Site	107	42-167	2.87	0.7-3.3	0.48	0.01-1.80
Harrisburg	36	21-89	1.58	0.1-8.1	0.83	0.26-1.76
Nashville	125	13-264	2.67	0.4-10.0	0.98	0.25-3.00
Denver	191	119-718	4.47	1.6-14	1.07	0.36-2.70

	TPO4 Avg.	TPO4 Range	Cl Avg.	Cl Range	Pb Avg.	Pb Range
Milw.-Hwy. 794	0.50	0.12-1.81	856	10-13300	2.90	0.80-13.1
Milw.-Hwy. 45	0.52	0.10-1.27	645	40-3413	1.20	0.40-6.6
Milw.-Grassy Site	0.81	0.31-1.51	315	40-1165	0.21	0.05-0.70
Harrisburg	0.34	0.05-0.86	195	20-800	0.10	0.05-0.20
Nashville	1.92	0.77-3.55	21	5-55	0.50	0.02-1.70
Denver	0.92	0.48-2.36	36	8-90	0.45	0.3-1.8

	Zn Avg.	Zn Range	Fe Avg.	Fe Range	Cu Avg.	Cu Range
Milw.-Hwy. 794	0.69	0.14-3.40	11.5	2.5-43.0	0.159	0.01-0.66
Milw.-Hwy. 45	0.55	0.20-1.90	14.6	5.6-45.0	0.135	0.01-0.88
Milw.-Grassy Site	0.18	0.07-0.34	14.9	1.1-43.6	0.083	0.01-0.23
Harrisburg	0.08	0.01-0.23	2.0	0.1-6.6	0.045	0.01-0.10
Nashville	0.28	0.10-0.61	5.5	1.5-12.0	0.070	0.01-0.20
Denver	0.72	0.33-1.50	16.5	6.5-37.0	0.110	0.03-0.26

Table B-9 (continued)

	Cd		Cr		Hg, µg/l	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.068	0.01-0.40	0.057	0.01-0.14	2.87	0.13-24.0
Milw.-Hwy. 45	0.044	0.01-0.09	0.054	0.01-0.14	5.18	0.20-67.0
Milw.-Grassy Site	0.047	0.02-0.10	0.040	0.01-0.10	1.52	0.25-11.5
Harrisburg	0.025	0.01-0.07	0.025	0.01-0.11	4.86	0.25-49.0
Nashville	0.027	0.01-0.06	0.023	0.01-0.05	1.75	0.50-6.7
Denver	0.020	0.01-0.08	0.030	0.01-0.09	1.09	0.25-4.0

	BOD_5	
	Avg.	Range
Milw.-Hwy. 794	32	5-133
Milw.-Hwy.45	20	8-73
Milw.-Grassy Site	15	7-22
Harrisburg	4	2-6
Nashville	26	5-52
Denver	46	20-73

Table B-10. Summary of pollutant loadings from highway runoff at monitoring sites in pounds per acre - nonwinter[a] 1976-77.

	pH		TS		SS	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	-	6.8-7.6	34	2-82	15	0.95-52
Milw.-Hwy. 45	-	7.3-8.0	29	4-82	15	0.77-58
Milw.-Grassy Site	-	7.2-7.9	23	0.04-99	10	0.01-46
Harrisburg	-	6.8-7.9	17	2-73	4	0.02-28
Nashville	-	7.2-8.3	33	1-58	11	0.54-33
Denver	-	6.5-7.5	21	2-65	14	0.88-47

	VSS		TVS		TOC	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	5.5	0.48-20	16	1.8-44	3.3	0.48-10.0
Milw.-Hwy. 45	4.2	0.17-25	13	0.4-28	1.1	0.09-2.3
Milw.-Grassy Site	2.6	0.004-12	6	0.01-21	0.9	0.002-2.8
Harrisburg	0.9	0.005-5	3	0.03-14	0.9	0.03-5.3
Nashville	4.9	0.09-28	10	0.8-43	1.7	0.22-3.1
Denver	2.6	0.20-7	4	0.7-10	2.5	0.17-6.2

	COD		TKN	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	9.3	1.4-19.5	0.20	0.01-0.53
Milw.-Hwy. 45	3.6	0.4-8.1	0.13	0.01-0.57
Milw.-Grassy Site	2.2	0.004-8.0	0.07	0.000-0.26
Harrisburg	1.0	0.1-4.1	0.09	0.004-0.30
Nashville	6.1	0.6-12.9	0.19	0.005-1.04
Denver	8.2	1.1-20.9	0.11	0.09-0.38

	NO_2+NO_3		TPO_4	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.11	0.01-0.21	0.04	0.003-0.10
Milw.-Hwy. 45	0.04	0.01-0.06	0.02	0.001-0.06
Milw.-Grassy Site	0.01	0.000-0.05	0.02	0.000-0.08
Harrisburg	0.02	0.002-0.14	0.02	0.0002-0.17
Nashville	0.04	0.003-0.07	0.11	0.005-0.29
Denver	0.04	0.002-0.18	0.03	0.004-0.09

	Cl		Pb, 10^{-3}		Zn, $X10^{-3}$	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	2.7	0.95-76	180	9-480	40	5-110
Milw.-Hwy. 45	4.6	0.91-15.2	28	2-80	12	1-30
Milw.-Grassy Site	2.4	0.008-7.6	7	0.01-280	5	0.001-20
Harrisburg	2.6	0.32-8.6	6	1-30	4	0.05-10
Nashville	0.8	0.05-1.6	25	2-90	14	0.09-40
Denver	0.8	0.11-2.4	23	1-100	19	2-60

[a]April through October. NOTE: lb/ac x 1.12 = kg/ha

Table B-10 (continued)

	Fe, X10^{-3}		Cu, X10^{-3}		Cd, X10^{-3}	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	780	24-2440	10	1-29	4	1-14
Milw.-Hwy. 45	490	37-1770	3	0.02-9	1	0.02-4
Milw.-Grassy Site	510	0.000-2420	2	0.003-8	1	0.001-4
Harrisburg	150	1-1130	2	0.04-6	1	0.2-3
Nashville	300	10-840	5	0.04-20	2	0.07-5
Denver	480	40-1760	4	0.06-17	1	0.08-2

	Cr, X10^{-3}		Hg, X10^{-6}	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	6	0.1-29	0.39	0.00-2.1
Milw.-Hwy. 45	4	0.02-4	0.10	0.00-0.75
Milw.-Grassy Site	1	0.0004-4	0.03	0.00-0.04
Harrisburg	3	0.4-20	0.72	0.00-1.1
Nashville	1	0.04-3	0.07	0.00-0.17
Denver	1	0.06-7	0.07	0.00-0.6

	BOD5	
	Avg.	Range
Milw.-Hwy. 794	1.52	0.29-3.19
Milw.-Hwy. 45	0.42	0.10-0.75
Milw.-Grassy Site	0.35	0.000-1.00
Harrisburg	0.09	0.05-0.14
Nashville	1.02	0.13-3.80
Denver	0.79	0.35-1.67

Table B-11. Summary of pollutant loadings from highway runoff at monitoring sites in pounds per acre - winter[a] 1976-77.

	pH		TS		SS	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	-	7.2-7.8	143	39.5-535	32.0	6.7-80.4
Milw.-Hwy. 45	-	6.9-7.8	142	9.1-384	24.0	1.7-96
Milw.-Grassy Site	-	7.2-8.1	45	0.8-99	3.0	0.01-5.2
Harrisburg	-	7.0-8.1	144	5.8-199	5.9	0.04-31.5
Nashville	-	6.9-7.8	43	17.2-91	21.9	6.5 - 57.4
Denver	-	-	-	-	-	-

	VSS		TVS	TOC	
	Avg.	Range	Typical Value[b]	Avg.	Range
Milw.-Hwy. 794	7.8	1.0-16.7	9.1	4.8	1.4-11.4
Milw.-Hwy. 45	4.6	0.4-12.9	20.0	3.5	0.4-11.5
Milw.-Grassy Site	1.0	0.004-1.6	22.0	2.1	0.01-5.6
Harrisburg	1.2	0.01-4.1	12.3	1.0	0.1-2.3
Nashville	3.4	1.4-6.9	6.0	1.9	0.9-2.3
Denver	-	-		-	-

	COD		TKN	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	17.8	0.19-34.3	0.30	0.06-0.63
Milw.-Hwy. 45	10.2	1.04-26.9	0.20	0.01-0.76
Milw.-Grassy Site	6.9	0.04-19.2	0.15	0.000-0.35
Harrisburg	6.0	0.27-20.5	0.12	0.003-0.32
Nashville	8.2	3.26-21.8	0.11	0.04-0.31
Denver	-	-	-	-

	NO2+NO3		TPO4	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.12	0.009-0.40	0.042	0.005-0.11
Milw.-Hwy. 45	0.08	0.006-0.31	0.026	0.001-0.13
Milw.-Grassy Site	0.06	0.000-0.24	0.050	0.000-0.13
Harrisburg	0.09	0.003-0.28	0.050	0.002-0.15
Nashville	0.13	0.02-0.42	0.150	0.06-0.36
Denver	-	-	-	-

	Cl		Pb		Zn	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	61	10-329	0.260	0.080-0.48	0.060	0.02-0.12
Milw.-Hwy. 45	58	3-188	0.076	0.008-0.205	0.036	0.004-0.09
Milw.-Grassy Site	14	0.3-34	0.006	0.000-0.02	0.007	0.000-0.02
Harrisburg	21	1-83	0.009	0.001-0.023	0.009	0.005-0.03
Nashville	2	0.6-5	0.040	0.010-0.10	0.020	0.006-0.05
Denver	-	-	-	-	-	-

[a]November through March.

NOTE: lb/ac x 1.12 = kg/ha

[b]Total volatile solids examined on a cursory basis only.

Table B-11 (continued).

	Fe		Cu	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.93	0.25-2.12	0.012	0.005-0.024
Milw.-Hwy. 45	0.92	0.06-3.50	0.010	0.001-0.029
Milw.-Grassy Site	0.30	0.000-0.77	0.004	0.000-0.008
Harrisburg	0.24	0.002-1.28	0.005	0.000-0.016
Nashville	0.61	0.12-2.05	0.006	0.001-0.02
Denver	-	-	-	-

	Cd		Cr	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.006	0.00-0.014	0.004	0.00-0.01
Milw.-Hwy. 45	0.002	0.00-0.005	0.004	0.000-0.029
Milw.-Grassy Site	0.002	0.000-0.004	0.001	0.000-0.002
Harrisburg	0.002	0.00-0.006	0.002	0.000-0.005
Nashville	0.002	0.000-0.003	0.003	0.000-0.008
Denver	-	-	-	-

	Hg, $X10^{-6}$		BOD_5	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.054	0.0-0.095	1.82	1.05-3.24
Milw.-Hwy. 45	0.2	0.00-0.4	0.73	0.15-1.64
Milw.-Grassy Site	0.035	0.000-0.08	0.60	0.004-1.20
Harrisburg	0.3	0.0-1.0	0.43	0.022-1.34
Nashville	0.2	0.0-0.3	1.52	0.43-4.10
Denver	-	-	-	-

Table B-12. Summary of pollutant loadings from highway runoff at monitoring sites in pounds per acre - 1976-77.

	pH		TS		TVS	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	-	7.2-7.8	60	2-535	15.3	1.8-44.0
Milw.-Hwy. 45	-	6.9-7.8	72	4-96	14.3	0.4-35.0
Milw.-Grassy Site	-	7.2-8.1	30	0.04-99	7.3	0.01-22.0
Harrisburg	-	7.0-8.1	78	2-191	4.3	0.03-14.0
Nashville	-	6.9-7.8	28	1-91	9.7	0.76-43.0
Denver	-	6.5-7.5	21	2-65	4.2	0.74-10.1

	SS		VSS		TOC	
	Avg.	Range	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	19.6	0.95-80	6.2	0.48-20	3.83	0.48-11.4
Milw.-Hwy. 45	18.6	0.77-96	4.3	0.17-24.7	1.99	0.09-11.5
Milw.-Grassy Site	7.8	0.01-46	2.0	0.004-12	1.25	0.002-5.6
Harrisburg	4.7	0.02-32	1.1	0.005-5.3	0.96	0.03-5.3
Nashville	14.0	0.54-57	4.5	0.09-28.2	1.78	0.22-3.33
Denver	13.7	0.88-47	2.6	0.20-6.63	2.53	0.17-6.15

	COD		TKN	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	12.30	0.19-34.3	0.23	0.01-0.63
Milw.-Hwy. 45	5.96	0.35-26.9	0.16	0.007-0.76
Milw.-Grassy Site	3.76	0.004-19.2	0.10	0.000-0.35
Harrisburg	3.04	0.11-20.5	0.10	0.003-3.2
Nashville	6.84	0.61-21.8	0.16	0.005-1.04
Denver	8.19	1.13-20.9	0.11	0.085-0.38

	NO2+NO3		TPO4	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.11	0.009-0.40	0.041	0.003-0.11
Milw.-Hwy. 45	0.06	0.005-0.31	0.024	0.001-0.125
Milw.-Grassy Site	0.026	0.000-0.24	0.032	0.000-0.13
Harrisburg	0.058	0.002-0.28	0.036	0.000-0.169
Nashville	0.100	0.002-0.42	0.124	0.005-0.36
Denver	0.039	0.002-0.18	0.026	0.004-0.089

	Cl		Pb	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	23.0	0.95-329	0.210	0.009-0.45
Milw.-Hwy. 45	24.8	0.91-188	0.046	0.002-0.205
Milw.-Grassy Site	6.3	0.008-34.4	0.007	0.000-0.28
Harrisburg	11.2	0.32-82.8	0.007	0.001-0.33
Nashville	1.2	0.054-4.55	0.036	0.002-0.10
Denver	0.8	0.11-2.38	0.023	0.001-0.1

NOTE: lb/ac x 1.12 = kg/ha.

Table B-12 (continued).

	Zn		Fe	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.05	0.005-0.12	0.83	0.024-2.44
Milw.-Hwy. 45	0.027	0.001-0.090	0.653	0.037-3.50
Milw.-Grassy Site	0.006	0.00000-0.02	0.444	0.000-2.42
Harrisburg	0.006	0.00000-0.03	0.193	0.001-1.28
Nashville	0.016	0.0000-0.05	0.380	0.01-2.05
Denver	0.019	0.002-0.06	0.48	0.04-1.76

	Cu		Cd	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.011	0.001-0.29	0.004	0.001-0.014
Milw.-Hwy. 45	0.006	0.000-0.029	0.001	0.000-0.004
Milw.-Grassy Site	0.003	0.000-0.008	0.001	0.000-0.004
Harrisburg	0.003	0.000-0.016	0.001	0.000-0.006
Nashville	0.005	0.000-0.02	0.002	0.000-0.003
Denver	0.004	0.000-0.017	0.001	0.000-0.0017

	Cr		Hg, 10^{-6}	
	Avg.	Range	Avg.	Range
Milw.-Hwy. 794	0.005	0.001-0.29	0.15	0.000-2.1
Milw.-Hwy. 45	0.004	0.000-0.0029	0.16	0.00-0.75
Milw.-Grassy Site	0.001	0.000-0.004	0.028	0.000-0.08
Harrisburg	0.003	0.000-0.020	0.50	0.000-7.0
Nashville	0.001	0.000-0.008	2.73	0.000-0.03
Denver	0.001	0.000-0.007	0.07	0.000-0.6

	BOD_5	
	Avg.	Range
Milw.-Hwy. 794	1.59	0.29-3.24
Milw.-Hwy. 45	0.52	0.007-1.64
Milw.-Grassy Site	0.45	0.000-1.2
Harrisburg	0.35	0.022-1.34
Nashville	1.17	0.18-4.1
Denver	0.79	0.35-1.67

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

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1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

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* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.