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VOLUME III. SOURCES AND MIGRATION OF HIGHWAY RUNOFF POLLUTANTS - RESEARCH REPORT

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16. Abstract

The overall objectives of this research were to identify the sources of highway pollutants, and to determine their deposition and accumulation within the highway system and subsequent removal from the highway system to the surrounding environment. The purpose of this research was to identify opportunities to practice pollution mitigation. Data collected at four sites included atmospheric deposition and removal, saltation, highway surface loads, runoff quantity and quality, groundwater percolation, soil and vegetation, traffic characteristics, highway maintenance, climatological data and source investigative studies. This document is the third volume of a report entitled "Sources and Migration of Highway Runoff Pollutants." The titles of the volumes of this report are:

FHWA/RD-	Subtitle	
84/057	Volume I	Sources and Migration of Highway Runoff Pollutants - Executive Summary
84/058	Volume II	Sources and Migration of Highway Runoff Pollutants - Methods
84/059	Volume III	Sources and Migration of Highway Runoff Pollutants - Research Report
84/060	Volume IV	Sources and Migration of Highway Runoff Pollutants - Appendix

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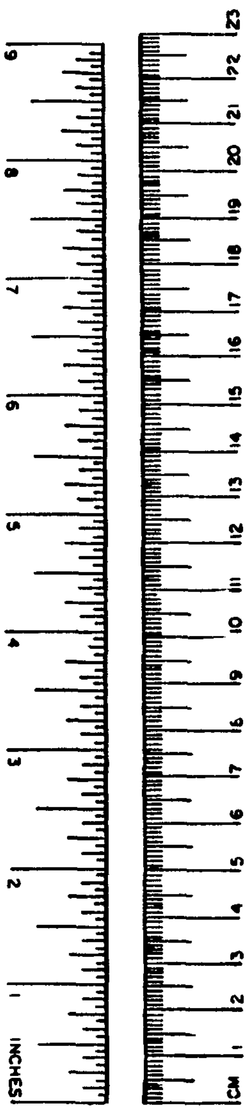
NOTICE

METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS FROM 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	0.6	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



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	8.03	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	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
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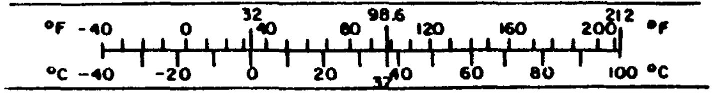

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SECTION I
INTRODUCTION

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

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

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

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

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

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

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

Volume I:	State-of-the-Art Report on Highway Runoff Constituents
Volume II:	A Procedural Manual for Monitoring of Highway Runoff

Volume III:	Predictive Procedure for Determining Pollutant Characteristics in Highway Runoff
Volume IV:	Characteristics of Runoff from Operating Highways. Research Report
Volume V:	Highway Runoff Data Storage Program and Computer User's Manual
Volume VI:	Executive Summary

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

1. Source investigative studies
2. Migration studies

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

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

A four-volume document series describes the results of the Phase 2 research. The titles of the various reports comprising this four volume document series are:

Volume I - Sources and Migration of Highway Runoff Pollutants - Executive Summary

Volume II - Sources and Migration of Highway Runoff Pollutants - Methods

Volume III - Sources and Migration of Highway Runoff Pollutants - Research Report

Volume IV - Sources and Migration of Highway Runoff Pollutants - Appendix

This report constitutes Volume III of the above described document series. This report contains the results of the literature search, analysis of the accumulated data, and the conclusions and recommendations formulated from the data analysis. Volume II, Methods, presents the details of the monitoring site selection and field monitoring procedures. Volume IV, Appendix, contains the detailed data collected as a result of the field monitoring program.

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

SECTION II
SOURCE OF HIGHWAY CONTAMINANTS

Sources of many materials which deposit and accumulate on highway surfaces, median areas and adjoining right-of-ways are documented in the literature. Table 1 lists common highway runoff constituents and their primary sources. Parameters which can affect the magnitude of these constituents in highway runoff can be grouped into the following general categories:

1. Traffic characteristics - speed, volume, vehicular mix (cars/trucks), congestion factors, state regulations controlling exhaust emissions, etc.
2. Highway design - pavement material, percentage pervious and impervious area, drainage design (flush shoulder, curb and gutter, elevated bridgedeck, etc), quantity and type of roadside vegetation, ramps, etc.
3. Maintenance activities - road cleaning, roadside mowing, herbicide spraying, fertilizer application, road sanding/salting, road repair, etc.
4. Surrounding land use - residential, industrial, commercial, agricultural, etc.
5. Climate - form and intensity of precipitation, wind, temperature, etc.
6. Accidental spills - sand, gravel, grains, oils, chemicals, etc.

A discussion of the primary sources of the contaminants generally found on roadways and their appurtenances are presented by constituent group below.

PARTICULATES

Sources of particulates to the highway system include exhaust emissions, roadway abrasion, tire wear, vehicle carry-on, degradation of moving vehicle parts, atmospheric deposition and maintenance. A sample of urban roadway dust and dirt obtained in Urbana, IL was analyzed in order to identify and quantify the sources that contribute to roadway dust (3). The analysis indicated that soil, cement, automobile exhaust emissions, rust, tire wear and deicing agents were the primary sources of particulate material.

Of the vehicle related deposition processes contributing to street loadings, approximately 37 percent can be attributed to tire wear, 37 percent to pavement wear, 18.5 percent to engine and brake component wear and 7.5 percent to settleable exhaust (13). Vehicles vary widely in the amount and

Table 1. Common highway runoff constituents and their primary sources (1 through 12).

Constituent	Primary source
Particulates	Pavement wear, vehicles, atmosphere, highway maintenance
Nitrogen, phosphorus	Atmosphere, roadside fertilizer application
Lead	Leaded gasoline (auto exhaust), tire wear (lead oxide filler material), lubricating oil and grease, bearing wear
Zinc	Tire wear (filler material), motor oil (stabilizing additive), grease
Iron	Autobody rust, steel highway structures (guardrails, etc) moving engine parts
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides applied by maintenance operations
Cadmium	Tire wear (filler material), insecticide application
Chromium	Metal plating, moving engine parts, brake lining wear
Nickel	Diesel fuel gasoline (exhaust) and lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving
Manganese	Moving engine parts
Bromide	Auto exhaust
Cyanide	Anticake compound (ferric ferrocyanide, Prussian Blue or sodium ferrocyanide, Yellow Prussiate of Soda) used to keep deicing salt granular
Sodium, Calcium	Deicing salts, grease
Chloride	Deicing salts
Sulphate	Roadway beds, fuel, deicing salts
Petroleum	Spills, leaks or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate

Table 1. Common highway runoff constituents and their primary sources (1 through 12) (continued).

Constituent	Primary source
Polychlorinated biphenyls, pesticides	Spraying of highway right-of-ways, background atmospheric deposition, PCB catalyst in synthetic tires
Pathogenic bacteria (indicators)	Soil, litter, bird droppings, and trucks hauling livestock and stockyard waste
Rubber	Tire wear
Asbestos	Clutch and brake lining wear

composition of their particulate emissions (14). Emissions vary with age, size and condition of the vehicle, driving speeds, etc. Cold cycle operation produces 2 to 8 times more particulates than hot engine operation. Fuel additives also affect the amount of emitted particulates. From a group of 1970 model cars, it was determined that cars burning unleaded fuels exhausted an average 0.364 lb/1000 vehicle-mi (0.103 kg/1000 vehicle-km) of suspended particulates while the combustion of leaded fuels produced an average 0.335 lb/1000 vehicle-mi (0.094 kg/1000 vehicle-km) of suspended particulates (14). Lead compounds were found to represent less than one-third of the total particulates, the remainder being carbon compounds (average 35 percent) along with ammonium and nitrate ions and unknown materials. Carbon emissions represent nearly 70 percent of the total particulates for cars burning unleaded fuels (14). Another source stated that exhaust emissions averaged 0.225 lb/1000 vehicle-mi (0.066 kg/1000 vehicle-km) and consisted of 45 percent particulate lead and 54 percent other metallic or organic hydrocarbon compounds (10, 15).

Particulates on the highway surface can also be attributed to background atmospheric deposition and the composition and quantity of these particulates vary greatly with the land use of areas adjacent to the highway and geographic location. Typical deposition rates for United States cities may range from 0.1 to 1 g/m^2/day, although values as high as 23 g/m^2/day have been recorded (16). Table 2 provides data (17) showing the geographic variation in dust deposition across the United States. The data indicate that the drier areas of the mid-USA are dustier than the wetter areas to the east. Dustfall loads ranged from 15.2 lb/acre/month (17 kg/ha/month) to 411 lb/acre/month (460 kg/ha/month). The data in Table 3 indicate the variability in atmospheric deposition between land use types within a specified area (18). The data also show a trend for decreasing atmospheric deposition starting in 1967 which is probably due to increased vigilance of air pollution control efforts.

METALS

Sources of metals in highway runoff include background sources, such as atmospheric deposition and naturally occurring metals in soils, and highway related sources. Metals commonly found in highway runoff include lead, zinc, iron, copper, cadmium, chromium and nickel. Lead, zinc and iron represent the major portion of the metal load in highway runoff.

The sources of lead in highway runoff have been documented to be gasoline (2, 5, 9, 13), wear of tires in which lead oxide is added as filler material (5, 8), lubricating oil and grease (2) and bearing wear (4). In certain areas a significant source of lead can be the leaching of lead salts from exposed limestone and galena deposits (2). Christensen and Guinn (9) calculated an average deposition rate of 0.0049 g/vehicle-km for lead, while Terr Haar, et al., (14) reported an emission rate of 0.049 g/vehicle-km for lead. Most of the emitted lead is in the particulate inorganic form (8). Exhausted lead varies with the condition of the exhaust system and ranges between 7 and 30 percent of the lead consumed by the engine (14). Lee et al., (19), reported

Table 2. Dustfall for selected areas in the United States (17).

Geographic region	Site[a]	State	Dustfall, lb/acre/month
North	Sidney	MT	62.5
Central	Tribune	KN	411
	North Platte	NB	67.9
	Hays	KN	50.9
	Manhattan	KN	44.6
	McCredie	MO	42.9
South	Water Valley	TX	19.6
	Riesel	TX	21.4
	Oxford	MS	55.4
East	Coshocton	OH	15.2
	Marcellus	NY	43.8
	Marlboro	NJ	25.0

[a] Sites ordered from west to east within each group.

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

Table 3. Summary of annual atmospheric deposition rates for Milwaukee County, WI (tons/mi^2/month) (18).

Zoning classification	1951[a]	1966	1967	1968	1969	1970	1971
Agricultural	14.0	26.0	29.5	24.0	18.3	21.4	13.4
Residential	22.4	23.4	22.8	22.5	19.4	21.7	13.8
Local business	36.5	26.1	29.2	29.6	23.1	23.4	17.1
Commercial and light manufacturing	45.8	36.8	45.6	40.6	35.1	23.3	27.5
Industrial	82.1	41.7	43.1	42.4	40.8	37.5	33.6
Total	200.8	154.0	170.2	159.1	136.7	127.3	105.4

[a] First year of complete data.

Metric units: To convert tons/mi^2 to metric tons/km^2 multiply by 0.35.

that 95 percent of the measured lead in auto exhaust is associated with particles smaller than 0.5 micrometers.

The primary sources of zinc have been attributed to wear of tires in which zinc is used as a filler material (5, 8, 9, 13), fuel stabilization (13) and lubricating oil and grease (2). Also, exposure of zinc bearing ores in roadway cuts can contribute to zinc in highway runoff (2). Christensen and Guinn (9) calculated the average deposition rate of zinc from tire wear to be 0.0030 g/vehicle-km.

Iron in highway runoff can be attributed to soils and rocks near highways containing soluble iron salts (2), autobody rust (13) steel highway structures (13) and moving engine parts. Sources of copper include fungicides and insecticides applied by maintenance operations (32), wear from bearings and bushings (4, 5, 13) and metal plating (4). Considerable copper is deposited as a result of brake lining wear which has copper added to increase mechanical strength and promote rapid heat dissipation (4). Cadmium originates from tire wear (4, 8, 20), insecticide application (8) and leaching of cadmium from mineral deposits exposed during roadway construction (8). Cadmium concentrations in rubber range from 20 to 90 ppm (21). Nickel is found in diesel fuel (22), lubricating oil (2, 22), gasoline (2), asphalt paving (2), metal plating (5), bushing wear (5) deicing salts (18) and brake lining wear (4). Chromium can be attributed to metal plating (chiefly automotive bumpers) (2, 5), moving engine parts (5), deicing salts (13) and brake lining wear (4). Manganese comes from moving engine parts (4) or from fertilized soils enriched with manganese for landscaping purposes.

Atmospheric deposition is also a source of metals. Ranges for heavy metals in precipitation in Ontario were reported to be not detectable to 700 micrograms/l for copper, not detectable to 830 micrograms/l for nickel, not detectable to 270 micrograms/l for lead, 21 to 1500 micrograms/l for zinc and not detectable to 2300 micrograms/l for iron (23). The maximum values are from the Sudbury smelter area and probably represents a worst case situation. Precipitation samples collected in England showed that lead and cadmium concentrations varied significantly between monitoring sites (24). Low cadmium levels were observed in the absence of industrial emissions. Elevated lead levels were observed in precipitation at the site closest to a heavily traveled roadway. Mean lead concentrations in rainfall at the six monitoring sites ranged from 0.025 to 3.67 micrograms/l, while cadmium ranged from 0.006 to 0.037 micrograms/l. Portele et al., (25) attributed high soluble zinc in highway runoff at one site near Seattle, Washington to precipitation, where zinc levels of up to 600 micrograms/l were observed in the rainfall (26).

DEICING CHEMICALS

Highway salts can cause injury and damage across a wide environmental spectrum and these effects, although not yet evident in certain areas of the country, may appear in the future (27). All living organisms must survive in a precarious balance between too little, just right and too much salt, each in accordance with its genetic limitations and special adaptions (28). It has been indicated that highway salts can seriously disturb a health balance in soils, trees and other vegetation comprising the roadside environment. Chronic effects are the burning or browning of foilage while toxic effects are those which affect the physiological processes. Both may cause death to parts of plants or the entire plant, and dead portions, unless removed, are recycled to the roadside environment (28). Total soluble salts, and sodium and chloride ions reduce soil fertility and structure, depress plant water uptake, and are toxic to plants and vegetation above certain limits (27). Salt concentrations greater than one percent (1g/100 g of water) endanger health, reproduction, and longevity in all species adapted to freshwater environments, including man (28). High salt concentrations in drinking water pose a possible threat to persons with heart disease (27, 29). A new development in salt pollution concerns the potential role of sodium serving as a trace element towards stimulating excessive growth of blue-green algae (29, 30).

In areas where they are applied, deicing agents are the major source of sodium and chloride in highway runoff. Table 4 presents data on salt usage in the United States. In areas where alfalfa is grown, potassium chloride (KCl) is commonly used as a top dressing and can be carried by wind erosion onto the highway system (31), thus contributing to the presence of chloride in the runoff. Deicing salts may also contain significant quantities of nickel (13), chromium (13), cyanide (32, 33) and sulfate (12). Cyanide is a constituent of the anticake compounds used to keep deicing salt granular. These compounds include yellow prussiate of soda (sodium ferrocyanide) and prussian blue (ferric ferrocyanide). Of these two anti-caking additives, sodium ferrocyanide can photodecompose to yield simpler cyanide compounds (34) that are potentially more harmful to aquatic animals than are the original cyanide complex (32). Ferric ferrocyanide does not break down and thus is not a hazard to aquatic life (32). Tests by the state of Wisconsin showed that 15.5 mg/l of sodium salt can produce 3.8 mg/l cyanide after 30 min (33, 34). Chromate and phosphate additives are used in deicers as corrosive inhibitors (33, 34, 35). As with cyanide, chromium is a highly toxic form (35).

Deicing agents were applied during the course of this study at the Milwaukee, Efland and Harrisburg sites. During the first winter period monitored at Milwaukee (1978 to 1979), total deicing agents applied were approximately 137,000 lb/highway mi (38,600 kg/km) of sodium chloride, 2,600 lb/highway mi (730 kg/km) of calcium chloride, 660 gallons/highway mi (1,550 liters/km) of liquid calcium chloride (32 percent $CaCl_2$ solution) and 1,760 lb/highway mi (500 kg/km) of sand. During the second winter period monitored at Milwaukee (1979 to 1980), total deicing agents applied were approximately 115,000 lb/highway mi (32,500 kg/km) of sodium chloride and 120 gallons/highway mi (280 liters/km) of liquid calcium chloride. Solid calcium chloride and sand were not applied during this winter period. During the winter period monitored at Harrisburg (1980 to 1981) total deicing agents applied were approximately 30,200 lb/highway mi (8,500 kg/km) of antiskid (composed largely of limestone screenings), 10,100 lb/highway mi (2,850 kg/km) of sodium chloride and 1,280 lb/highway mi (360 kg/km) calcium chloride. During the winter period monitored at Efland (1981 to 1982) total deicing

Table 4. Salt application to roadways in the United States (42).

Winter year	Salt usage, tons/year
1969 - 70	8,855,000
1970 - 71	9,583,984
1971 - 72	8,721,014
1972 - 73	8,420,092
1973 - 74	8,628,829
1974 - 75	9,492,557
1975 - 76	9,937,180
1976 - 77	10,071,514

Metric units: To convert tons to metric tons multiply by 0.907.

Table 5. Analysis of deicing agents applied at the Milwaukee I-94 monitoring site.

Parameter	$CaCl_2$ solution, mg/l	Salt, mg/kg
Pb	ND	6.29
Zn	0.14	1.57
Fe	1.18	ND
Cr	ND	1.02
Cu	0.10	3.15
Cd	0.01	0.94
Ni	ND	6.29
Hg	ND	ND
As	ND	ND
CN	ND	22
Na	NA	390,000
Cl	NA	588,000

ND = Not detectable.

NA = No analysis performed.

agents applied were approximately 12,000 lb/highway mi (3,400 kg/km) sodium chloride and 6,000 lb/highway mile (1,700 kg/km) sand and calcium chloride mixture (ratio varying from 40:1 to 50:1).

Samples of rock salt (NaCl) and liquid calcium chloride ($CaCl_2$) used as deicing agents at the Milwaukee I-94 site were obtained from the Wisconsin Department of Transportation and analyzed for contaminants (Table 5). Lead, zinc, chromium, copper, cadmium, nickel and cyanide were found to be present in the rock salt sample analyzed.

Based upon the 252,000 lb/highway mi (71,000 kg/km) of sodium chloride applied during the two winter period monitored, an estimated loading of metals applied with the rock salt is as follows:

Pb - 1.59 lb/highway mi (0.45 kg/km)
Zn - 0.40 lb/highway mi (0.11 kg/km)
Cr - 0.26 lb/highway mi (0.07 kg/km)
Cu - 0.79 lb/highway mi (0.22 kg/km)
Cd - 0.24 lb/highway mi (0.07 kg/km)
Ni - 1.59 lb/highway mi (0.45 kg/km)
CN - 5.54 lb/highway mi (1.56 kg/km)

It appears that the loading of cyanide to the highway surface from rock salt application can be significant, approximately 2.8 lb/highway mi/yr (0.79 kg/km/yr).

Comparing the estimated metals deposition to the highway surface from rock salt application to the median metals load removed per runoff event from the highway surface at Milwaukee during the winter periods monitored, it appears that rock salt may be an important source of the cadmium [0.001 lb/highway mi/runoff event (0.0003 kg/km)] and nickel [0.04 lb/highway mi/runoff event (0.011 kg/km)] monitored during the winter periods at Milwaukee.

Only zinc, iron, copper and cadmium were detected in the liquid calcium chloride sample (Table 5). Based upon the 780 gallons/highway mi (1830 liters/highway ~~km~~) applied during the two winter periods monitored, an estimated loading of metals applied with the calcium chloride is as follows:

Zn - 0.0009 lb/highway mi (0.0003 kg/km)
Fe - 0.008 lb/highway mi (0.002 kg/km)
Cu - 0.0007 lb/highway mi (0.0002 kg/km)
Cd - 0.00007 lb/highway mi (0.00002 kg/km)

Deposition of metals to the highway surface from liquid calcium chloride does not appear to be significant at the Milwaukee I-94 site.

Samples of rock salt (NaCl) and $CaCl_2$/sand mixture used as deicing agents at the Efland I-85 site were obtained from the North Carolina Department of Transportation and analyzed for contaminants (Table 6). Lead, iron, chromium, copper and cyanide were found to be present in the rock salt sample analyzed. The salt used at Efland was generally lower in contaminants than the salt used at Milwaukee. Whereas the salt applied at Milwaukee was an important source of cadmium and nickel, it was not detectable in the salt used at Efland. However, the $CaCl_2$/sand mixture was high in zinc, iron, chromium and cadmium.

Based upon the 12,000 lb/highway mi (3,380 kg/km) of sodium chloride and 6,000 lb/highway mi (1,690 kg/km) of calcium chloride-sand mixture applied during the 1981 - 1982 winter period, an estimated loading of metals applied with these deicing agents is as follows:

Pb - 0.025 lb/highway mi (0.007 kg/km)
Zn - 0.120 lb/highway mi (0.034 kg/km)
Fe - 55.7 lb/highway mi (15.7 kg/km)
Cr - 0.040 lb/highway mi (0.011 kg/km)
Cu - 0.033 lb/highway mi (0.009 kg/km)
CN - 0.022 lb/highway mi (0.006 kg/km)

Except for zinc and iron, the loading of metals associated with deicing agents at Efland are at least an order of magnitude lower than at Milwaukee. This can be attributed to the lower quantity of deicing agents applied at Efland and the lower concentration of contaminants in the deicing agents applied.

RUBBER

Rubber originates chiefly from tire wear. Rate of rubber loss from tire wear is influenced by vehicle speed (larger quantities at higher speeds), type of vehicle, tire position, amount of turning and road surface (36). Tire wear is also highest during the summer (5). The average rubber wear from tires has been calculated to be 0.410 g/vehicle-km (9) and 0.360 g/vehicle-km (36) while at a speed of 75 mph (120 km/hr) rubber loss is 0.096 g/vehicle-km and 1.96 g/vehicle-km in cornering at 30 mph (48 km/hr) at a 20° slip angle. The mass mean diameter of rubber particles due to tire wear is 20 micrometers (31, 37).

ASBESTOS

Asbestiform is used to describe a mineral known to occur as asbestos and/or produce fibers when crushed (38). The hazards of prolonged asbestos inhalation have been well established. For example, it has been shown that

Table 6. Analysis of deicing agents applied at the Efland I-85 monitoring site.

Parameter	Salt, mg/kg	$CaCl_2$ plus sand mixture[a], mg/kg
Pb	1.6	1.0
Zn	ND	20
Fe	41	9200
Cr	0.3	6.0
Cu	1.2	3.2
Cd	ND	ND
Ni	ND	ND
CN	1.8	ND
Ca	550	500
Na	370,000	750
Cl	620,000	2300

[a] Ratio of sand to calcium chloride varied from 40:1 to 50:1.

ND = Not detectable.

asbestos inhalation can lead to cancer after a latency period of 20 to 40 years (38). Although the risk is greater for asbestos workers, there is growing concern for the potential hazards of nonoccupational exposures. With this backdrop, studies were initiated to investigate the presence, source and fate of asbestos associated with highway use.

Asbestos is present in brake and clutch linings. Of the total asbestos emissions by all vehicles in the country, on the average, more than 99.7 percent of the asbestos is converted to non-asbestos products. Of the remaining 0.3 percent, 81.7 percent is deposited on the paved highway area, 14.4 percent is retained in the housing and 3.7 percent becomes airborne (6). Average asbestos produced from passenger cars is estimated to be 28.51 micrograms/mi, from light trucks, 87.51 micrograms/mi, from medium trucks, 290.72 micrograms/mi and from heavy trucks, 951.12 micrograms/mi (6). Brake and clutch wear is higher in winter and lower in summer as evidenced by asbestos deposition in dust and dirt on street surfaces (5).

The wear of clutch and brake linings has been reported to be the primary source of asbestos in highway runoff (5). Asbestos studies were initiated at the 35th Street exit ramp near the I-94 monitoring site in Milwaukee. The traffic on this exit ramp is characterized by significant braking and clutching activity. Samples were collected to detect asbestos in background ambient air, roadway surface debris, precipitation, runoff and dustfall.

The analytical results obtained from the air sample taken are presented in Table 7. The results indicate that asbestiform material was not found to be present above the detection limit for the analysis.

In the early fall of 1978, samples were taken at the I-94 monitoring site to detect asbestiform material in paved surface runoff (35th Street exit ramp), sweeping/flushing samples, rain and dustfall. Asbestiform material could not be detected in any of the samples as shown in Table 7. These results are consistent with those of FHWA's Phase I study on highway runoff constituents (39). During this study, no asbestiform material was detected in 19 out of 21 runoff samples. For the two samples which contained asbestiform material, no firm conclusions could be drawn.

POLYCHLORINATED BIPHENYLS/PESTICIDES

PCB's and pesticides can enter the air or atmosphere either as vapors or adsorbed on particles, which may be redeposited on land areas remote from the area of application. Moreover, these contaminants enter receiving water courses through rainfall (atmospheric washout) and or land runoff.

Table 7. Analytical results of 35th Street exit ramp asbestos studies.

Sample Data collected	Lower limits of detection, fibers/filter	Comments
Air September 21, 1978	3141	Most of the material present on the filter was found to be small in size (less than 5 micrometers). Organic material of varying types were quite common. The inorganic portion of the material consisted mainly of the typical chunky and platy particulates. Some "chunky" inorganic fibers were found (aspect ratio 3:1 and 6:1 with appreciable depth) which showed irregular rounded features and did not diffract well--if at all. No asbestiform material was found to be present above the detection limit for the analysis.
Dustfall September 22, 1978	6.3×10^4	This sample was found to contain chunky inorganic matter, spheroidally shaped inorganic particles, spores and bacterial remains. No asbestiform material detected.
Curb inlet August 31, 1978	1.0×10^6	Large chunky inorganic particles predominate. Some platy inorganic material, organic residues (some a fibrous nature) and filmy residues are also present. No asbestiform material detected.
Site A: Sweeping/flushing sample August 31, 1978	6.3×10^5	Large chunky inorganics and filmy residues predominate. Small chunky and platy inorganics, probably fungal remains (which yield tubules) and organic residues were also present. No asbestiform material detected.

(continued)

Table 7. Analytical results of 35th Street exit ramp asbestos studies (cont'd).

Sample Data collected	Lower limits of detection, fibers/filter	Comments
Site B: Sweeping/flushing sample August 31, 1978	6.3×10^5	Very similar to SITE A. No asbestiform material detected.
Site A: Runoff September 11, 1978	7.0×10^5	This sample consisted almost entirely of large chunky, inorganic matter. Some organic material and small inorganic particles were present. No asbestiform material detected.
Site B: Runoff September 11, 1978	6.3×10^5	Very little present aside from chunky inorganics and some organic film. No asbestiform material detected.
Rain water September 11, 1978	6.3×10^4	This specimen showed more organic material than inorganic with spores being quite common. No asbestiform material detected.

Site A is the pavement around an inlet located on the north side of the ramp at the midway point.
Site B is the pavement around an inlet located on the south side of the ramp at the top.

Pesticides originate mostly from the use of weed killer compounds in the highway environment. PCB's deposited on a highway system are likely to originate from the following:

1. Atmospheric deposition - PCB's are emitted into the atmosphere by industrial smoke, in exhaust from aircraft engines, incineration and combustion of PCB containing products (40).
2. Pesticide application on highway right-of-ways - PCB's are added to some pesticide formulations to enhance kill-life (40).
3. Accidental spills or transformer leaks.
4. Breakdown of additives used in vehicle operation.
5. Synthetic tires which are catalyzed in formation by PCB's (11).

Atmospheric deposition is likely to be the main source of PCB's to a highway system. For example, one study showed that atmospheric transport and deposition may dominate PCB input to the Lake Superior ecosystem (41). Another source (42) estimated that the fallout of PCB's over Lake Michigan and its watershed may average 50 micrograms/m^2/yr or 11,800 lb (5352 kg) annually.

Tests were performed at the Milwaukee I-94 site on soil, vegetation, precipitation, sweeping/flushing and runoff samples.

A soil sample was obtained in the Milwaukee I-94 right-of-way near the highway to determine PCB content in the top soil layer. Analyses showed that the concentration of PCB's was 229 micrograms/kg of dry soil. The majority of PCB's present were of the degraded or weathered form, since most water soluble PCB peaks were absent from the gas chromatogram.

Because PCB's were present in the top soil layer (rooting zone) of the soil sample reported above, vegetation samples were obtained and analyzed for PCB content. It was observed that the above-ground plant tissue contained 107 micrograms/kg PCB and that the below-ground plant tissue had a PCB concentration of 105 micrograms/kg. This investigation indicates that there exists the possibility of uptake of PCB's from contaminated soils by plant matter. A possible source of these PCB's is a major power transformer station which was located just south and downwind of the Milwaukee I-94 site.

Precipitation PCB data were obtained from the four test sites investigated during this study. Precipitation PCB data were obtained from samples taken during three storm events at the Milwaukee site, one event at the Efland and Sacramento sites, and one event (two samples) at the Harrisburg site. PCB data, as well as other pertinent information characterizing the storm events investigated, may be found and examined in Volume IV of this research report, Tables A-1 through A-4. The PCB results obtained are summarized below:

Site	PCB content, micrograms/l
Milwaukee I-94	ND, 0.05, 0.10
Sacramento Hwy. 50	0.31
Harrisburg I-81	0.26 (first half of storm) 0.14 (last half of storm)
Efland	ND

ND = Not detectable.

The data show that detectable concentrations of PCB's were observed in the atmospheric washout at three of the sites. The data indicate that atmospheric transport and deposition of PCB may be significant. The literature supports this contention in that the results of one study suggests that atmospheric transport and deposition may dominate PCB input to the Lake Superior ecosystem (41). Another source (42) estimated that the fallout of PCB's over Lake Michigan and its watershed may average 50 micrograms/m^2 or 11,800 pounds (5352 kg) annually.

PCB analyses were performed on the wet and dry samples collected at the Milwaukee I-94 site on the August 19-20, 1981 sweeping/flushing study from the distress and median lane sections. The PCB loading for the test area was significant and determined to be 0.002 lb/highway mile (0.0006 kg/highway km). Therefore, it is indicated that PCB's are present on highway surfaces and may be washed off those surfaces by storm events and transported from the highway itself as a part of the highway runoff. Again, possible sources include atmospheric fallout and a nearby power transformer station.

Samples of highway runoff were obtained from five separate runoff events at the Milwaukee I-94 site and from one storm event at the Harrisburg site. At the Milwaukee site, five runoff samples were taken from runoff events which occurred over the period, October 1978 to January 1980 and analyzed for PCB's. PCB concentrations in the runoff were significant, namely, 0.93, 1.60, less than 0.13, 0.17 and less than 0.16 micrograms/l. At the Harrisburg site, two runoff samples were taken during one runoff event and analyzed for PCB content. The paved runoff sample contained 0.15 micrograms/l PCB, whereas the unpaved runoff sample was 0.16 micrograms/l PCB.

From the runoff studies performed, it was indicated that PCB's in the highway environment are transported from that environment via runoff during storm events. Furthermore, the PCB studies conducted during this project and reported herein indicate that sources of PCB in highway runoff include:

1. Precipitation (atmospheric washout).
2. Highway surface dust and dirt.

3. Contaminated soil eroded by the runoff from unpaved surfaces adjoining the highway.

A composite pesticide sample was obtained for analysis from the grassy area runoff during the April 11-12, 1979 event at the Milwaukee I-94 site. The pesticide scan performed showed that Dieldrin was present in the sample at a concentration of 0.027 micrograms/l. Interestingly enough, in the previous September 1978, a 3-foot-wide strip of grassy area next to the shoulder was sprayed with Velpar, a weed killer, for the entire length of the study area. The application rate was 6 pounds per acre. However, Velpar was not detectable in the runoff sample obtained during the April 11-12, 1979 event.

The indication from this study is that pesticides can find their way to the highway environment and are transported from that environment via the runoff from storm events.

PATHOGENIC INDICATOR BACTERIA

Geldreich, et al., (43) analyzed 177 samples from street gutters over a two year period and found high counts of total coliform (TC), fecal coliform (FC) and fecal streptococcus (FS). Higher counts were observed in the summer and fall in comparison to the winter and spring. Also, the highest average FC/FS ratio of the four seasons was 0.34 which occurred in the fall, indicating that the fecal contamination in gutter debris is from warm blooded animals other than man (43). Gupta et al., (39) also found significant levels of pathogenic indicator bacteria in highway runoff at sites in Wisconsin, Pennsylvania, Tennessee and Colorado. Again the FC/FS ratio was typically less than 0.7 indicating that the origin was warm blooded animals other than man (39).

Bacteriological Studies

The purpose of the bacteriological studies was to investigate the origin, movement and fate of pathogenic indicator bacteria in highway runoff. These studies were also initiated in an attempt to identify potential aerial sources of pathogenic indicator bacteria, to detect them in roadway sweepings and to determine their survival in highway dust and dirt over extended periods of time. The bacteriological investigations for pathogenic indicator bacteria were conducted along the following lines:

1. Detection of airborne bacteria.
2. Detection in runoff from grassy and paved areas.
3. Detection and fate on roadway surfaces.
4. Survival within a sewer system.

The observations and results of the studies conducted are presented below.

Detection of Airborne Bacteria

The investigations for the detection of airborne bacteria were carried out by taking precipitation samples, bulk precipitation samples and ambient air samples.

A precipitation sample (0.13 inches total rain) and a bacteriological precipitation sample were taken on October 22, 1978 at the Milwaukee I-94 site to help establish the background level of atmospheric pollutants. Although the results obtained from the analysis of the precipitation sample (Volume IV, Appendix Table A-1) showed a low pH, fairly high solids, low metal concentrations except for zinc and measurable quantities of nutrients, it was observed that total coliforms and fecal coliforms were not detectable.

Further investigations to detect airborne bacteria were implemented in the fall of 1978 at the Milwaukee I-94 site by collecting three bulk precipitation samples for periods of three days, seven days and fifteen days and also by collecting an ambient air sample with an impinger designed for bacteriological studies. The results of these studies are presented in Table 8. Total coliforms were detected only in the 3-day and 7-day dustfall samples. All other samples showed negative results for total coliform, fecal coliform and fecal streptococci.

The results indicate that bacteria were not found to be present in the air above the detection limits for the analyses.

Detection in Runoff

A summary of bacteriological analyses conducted on runoff samples obtained from both the paved and grassy areas of the Milwaukee I-94 site are presented in Table 9. As noted from Table 9 all three types of enteric bacteria were consistently present in the storm runoff. The counts were substantially greater in the fall sample than in the early spring samples, a situation which has been found to occur in other similar studies.

Runoff coliform data collected at Harrisburg, Sacramento and Efland are presented in Table 10. An interesting parameter in Tables 9 and 10 which should be elaborated on is the ratio of fecal coliforms to fecal streptococci, FC/FS. Presence of fecal coliforms is considered indicative of pollution by warm blooded animals. Literature reviews (43, 44) indicate that the fecal coliform (FC) group as an indicator has an excellent positive correlation with various warm blooded animals such as:

Table 8. Results of studies to detect airborne bacteria - Milwaukee I-94 site.

Type of sample collection	Total coliform, count/g TPM	Fecal coliform, count/g TPM	Fecal streptococci, count/g TPM
3-day bulk precipitation	380	ND	ND
7-day bulk precipitation	135	ND	ND
15-day bulk precipitation	ND	ND	ND
	count/m^3	count/m^3	count/m^3
Impinger	ND	ND	ND

ND = Not detectable.
TPM = Total particulate matter.

Table 9. Bacteria counts in runoff from grassy and paved areas - Milwaukee I-94 site.

Site	Date	Sample time	Total coliform count/ 100 ml	Fecal coliform count/ 100 ml	Fecal strep, count/100	FC/FS ratio
Paved area	10/2/78	1830[1]				
		1850	100,000	100,000	100,000	
		1900	100,000	96,000	63,000	1.52
		2000	100,000	18,000	24,000	0.75
		2050	100,000	53,000	40,000	1.33
	3/17/79	1215[1]				
		1335	10,000	900	2,000	0.45
		1355	10,500	2,100	2,000	1.05
		1415	3,200	2,050	160	12.8
		1435	1,500	400	330	1.21
	3/18-19/79	2255[1]				
		2315	3,450	90	120	0.75
		2355	95	1	40	
		0035	500	80	500	0.16
	3/29/79	1020[1]				
		1050	14,000	3,200	11,100	0.29
		1200	9,500	4,000	2,300	1.74
	3/29/79	2323[1]				
		0010	275	100	1,500	0.07
		0015	200	100	1,000	0.10
		0200	1,100	95	2,500	0.04
	3/30/79	1108[1]				
		1155	5,200	3,000	3,000	1.00
		1210	4,500	375	5,150	0.07
Grassy area	3/30/79	1310[1]				
		1312	13,000	150	15,000	0.01
		1340	98,000	10	11,000	
		1400	38,000	20	3,750	0.005

---

[1] Storm start time.

Table 10. Bacteria counts in runoff - Harrisburg I-81, Sacramento Hwy 50 and Efland I-85.

Site	Date	Sample time	Fecal coliform, count/100 ml	Fecal strep, count/100 ml	FC/FS ratio
Harrisburg					
Paved area	11/24/80	0330[1]			
		0745	350	5,300	0.07
		0845	660	9,900	0.07
		1045	250	9,000	0.03
		1145	560	12,700	0.04
Unpaved area	11/24/80	0330[1]			
		0745	10	5,600	0.00
		0845	10	10,900	0.00
		1045	10	8,600	0.00
		1145	20	8,400	0.00
Sacramento					
Paved	2/27/80	1815[1]			
		1910	4,600	4,600	1.0
		1930	2,400	2,400	1.0
Paved	3/25/80	0820[1]			
		0840	2,400	11,000	0.22
		0920	1,100	2,400	0.46
		0940	1,100	2,400	0.46
		1040	2,400	4,600	0.52
		1230	750	4,600	0.16
Efland					
Paved	10/27/81	0905[1]			
		1000	570	11,000	0.05
		1435	730	16,000	0.05

[1] Storm start time.

Sources of feces	% Positive correlation
Humans	96.4
Livestock	98.7
Poultry and birds	93.0
Cats, dogs, rodents	95.3

Moreover, efforts were initiated to collect fecal streptococci (FS) data along with fecal coliforms in order to correlate the presence of these organisms with their potential sources. It has been reported (43, 44) that when the ratio of fecal coliforms to fecal streptococci (FC/FS) is in excess of 4.0, it is indicative of pollution from human sources, while ratios less than 0.7 indicate pollution of animal origin.

Relating the above pertinent information to the FC/FS data presented in Tables 9 and 10, it may be seen that almost 70 percent FC/FS ratios are below 0.7 and only one ratio is above 4.0. The conclusion drawn from this examination is that, for the period investigated on the Milwaukee I-94 site, the pollution observed was predominantly of animal origin. This conclusion is strengthened by other independent observations which will be reported in the next subsection of this report.

The data also show that the FC/FS ratio is consistently low wherever the runoff is conveyed through a grassy area, i.e., the FC/FS ratio for two rural sites (Harrisburg and Efland) and Milwaukee grassy area is extremely low compared to the paved runoff of the two urban sites where the drainage design was curb and gutter.

Detection and Fate on Roadway Surfaces

A study was initiated to determine the source and fate of enteric bacteria on roadway surfaces. On May 8, 1979, three different types of roadway surface dust and dirt samples were obtained from the Milwaukee I-94 site, from an 89-sq ft (8-m^2) section in the distress lane. The three types were:

1. Hand swept or coarse material.
2. Vacuumed or fine material.
3. Flushed and vacuumed material.

Representative portions of these roadway samples were suspended in sterile buffered dilution water and analyzed for total coliforms, fecal coliforms and fecal streptococci. None of the samples were found to contain any of these bacteria. For this reason, a bacteria survival test which was initiated on the roof of the laboratory the day before, using these same roadway samples, was terminated.

Table 11. Results of bacteriological analyses on roadway surface sweepings obtained on May 21, 1979 - Milwaukee I-94 site.

	Solids, mg/l		Analyses for water suspended samples			
	TS	SS	TC/100 ml	FC/100 ml	FS/100 ml	FC/FS
Distress lane	44,300	37,900	TNTC	ND	12,000	-
Median lane	22,200	19,400	TNTC	4,400	20,000	0.20

	Analyses for dry samples		
	TC/g TS	FC/g TS	FS/g TS
Distress lane	TNTC	ND	2,710
Median lane	TNTC	2,060	5,280

TNTC = Too numerous to count.
ND = Not detectable.

On May 21, 1979, a 1/3-m by 1-m section of distress and median lanes was swept, flushed and vacuumed to obtain a second dust and dirt sample from the Milwaukee I-94 site and the same bacteriological analyses noted above were conducted on the composite samples obtained from the distress and median lanes. The results are presented in Table 11.

It is of interest to note from Table 11 that aliquots containing high solids concentrations, which was apparent from the debris collected on the membrane filter used in the analysis procedure, showed no colony growth at all, while the more diluted aliquots for the same sample showed abundant growth. This indicates that the high concentration of solids and associated pollutants present on the membrane filter growth surface may have had a toxic effect on bacterial growth during the duration of the test. Data on Table 11 also show that the FC/FS ratio calculated was less than 0.7, indicating pollution from animal sources.

Additionally, during the July 24, 1979, sweeping/flushing study the following was observed:

1. Considerable quantities of rock salt were blown off a passing truck onto the paved highway surface.
2. Large chunks of animal waste were dumped onto the paved highway surface by a passing truck hauling cattle yard waste.

The second observation, which also occurred during the June 17, 1980 sweeping/flushing study is pertinent and related to roadway surface "seeding" of debris containing enteric bacteria which have been observed and monitored in paved surface runoff at the Milwaukee I-94.

On June 8, 1979, a section of median lane on the Milwaukee I-94 site was swept and vacuumed as described in Volume II (Methods) to obtain roadway debris to conduct the fecal coliform die-off study. The collected material was immediately analyzed in duplicate for fecal coliforms with the following results:

Coarse debris (as received) - 122 fecal coliforms per gram.
Coarse debris (as received) - 790 fecal coliforms per gram.

Fine debris (pass 100 mesh sieve) - 6630 fecal coliforms per gram.
Fine debris (pass 100 mesh sieve) - 1870 fecal coliforms per gram.

It would appear from the above results that the enteric bacteria tend to be associated with the fine fraction of roadway sweepings.

The "as received" sweepings noted were stored in glass beakers on the flat roof of the Rexnord R&D single story building as described in Volume II (Methods). The results up to 49 days of storage are presented in Table 12. No firm conclusion can be drawn from these results, other than the obvious and significant fact that fecal coliforms can remain viable within roadway sweepings for periods of at least seven weeks. There is no apparent difference between the shaded and sunny results which suggests that these organisms remain viable within "clumps" or pieces of debris. Though some of the beakers produced results that show a definite die-off rate or kinetics, others did not. One of the reasons for this inconsistent pattern was felt to be the nature of the sample itself. Aliquots that happened to include a few large sand or pebble-like particles probably resulted in disproportionately lower counts when reported in terms of bacteria per gram. It is speculated that the die-off patterns would have been more apparent and consistent had only the fine fraction been stored in the beakers. However, these results would also have been subject to question, since the samples stored would have been different from the nature of the material normally present on roadway surfaces.

The above reported results of the flushing/sweeping, dustfall collection, impinger tests and die-off studies performed, as well as other observations, have indicated that:

1. Enteric bacteria do not appear to be consistently present on roadway surfaces.
2. Enteric bacteria do not appear to be associated with dust and other airborne material.
3. The enteric bacteria present on roadway surfaces appear to be largely of animal origin.
4. The probability exists that debris containing fecal material is deposited on the roadway surface in a random fashion. A possible source could be trucks carrying livestock or hauling stockyard waste.
5. Fecal coliforms appear to remain viable within highway sweepings for relatively long periods of time (at least seven weeks).

Survival Within a Sewer System

Because of the fact that enteric bacteria were consistently present in runoff samples and from other information previously reported, a hypothesis was formulated that a moist storm sewer conduit, periodically "seeded" with roadway surface debris containing enteric bacteria, can provide an environment that would keep these organisms viable for long periods and possibly provide an environment that would promote their reproduction and proliferation.

Table 12. Bacteriological die-off study results - Milwaukee I-94 site.

Storage, days	Fecal coliforms/gram									
	Sunny storage beakers					Shaded storage beakers				
	A	B	C	D	E	F	G	H	I	J
2	400	138	1,000	360	110	14,000[a]	500	220	1,050	3,400
4	ND	105	8	32	ND	32	ND	ND	200	480
7	200	ND	70	1,350	4,710	1,090	70	60	5	47
11	45	25	ND	84	1,390	4	2,810	100	48	11
21	90	ND	64	ND	1,360	48	47	415	415	40,000
35	1,140	400	2,160	500	4,730	396	305	91,200	3,230	5,420
49	161	478	663	687	6,000	2,690	4,760	123,000	1.720	3,500

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[a] High fraction of fines noted in aliquot.

ND = Not detectable.

Zero Day Data

Coarse debris (as received) - 122 fecal coliforms per gram.
Coarse debris (as received) - 790 fecal coliforms per gram.
Fine debris (pass 100 mesh sieve) - 6630 fecal coliforms per gram.
Fine debris (pass 100 mesh sieve) - 1870 fecal coliforms per gram.

Studies were initiated and conducted to test the hypothesis. Table 13 presents the results of two sampling runs conducted on the I-94 site. Storm water entering the gutter-line inlets was sampled at different times during two rainfall events. Samples were also obtained from the outfall of the storm sewer which conveys the storm runoff from the two inlets noted above. This outfall is approximately 40 meters from the inlets, and the conduit is buried for the entire distance. Though the data must be interpreted with caution since the inlet and outfall sample times have not been adjusted to account for conduit flow time, they do demonstrate that enteric bacteria were present at both the inlet and outfall locations, and that the outfall concentrations tended to be higher, especially during the 6/4/79 test run. Admittedly, the results are somewhat obscured by the fact that the inlet counts were also significant during the two test runs in question, which means the roadway dust and debris conveyed by the storm runoff contained the fecal coliform and fecal streptococcus bacteria. Had the roadway dust and debris not contained these bacteria and had enteric bacteria counts still been detected in the outfall samples, the hypothesis noted above would have been more firmly verified.

Another study was performed to determine if bacteria can survive within a sewer system between rainfalls. On September 11, 1979 after 13 dry days, a bacteriological sample was obtained from the stagnant water in the storm sewer at the Milwaukee I-94 site. Bacteria counts on the sample obtained were 28,800 counts/ml fecal coliform and 10,200 counts/ml fecal streptococcus. These data indicate that fecal coliform and fecal streptococcus bacteria remain viable in stagnant storm sewer water for at least 13 days.

NUTRIENTS

Although some ammonia and nitrate ions are exhausted from vehicles (14) and some phosphorus may be associated with deicing salts (2), the major sources of nutrients to the highway are fertilization of right-of-ways (2) and atmospheric deposition. Wastewater discharges from roadside rest stops may also be important localized sources of nutrients. Atmospheric deposition of nutrients for several locations in the United States is presented in Table 14.

BACKGROUND ATMOSPHERIC DEPOSITION

The atmosphere can be conceptualized as a temporary holding area or collective source of pollutants originating from many point sources. Atmospheric deposition or bulk precipitation (rainfall and dust fall) is the mechanism which transports pollutants from the atmosphere to a specified area such as a section of highway. Field studies were conducted at each of the four sites to evaluate the quantitative and qualitative aspects of background pollutant deposition to the highway system. Two types of depositional processes were monitored; precipitation (wet deposition only) and bulk precipitation (wet and dry deposition).

Table 13. Bacteriological analysis of storm inlets and storm sewer outfall - Milwaukee I-94 site.

Storm event - June 4, 1979

Sample time	Fecal coliform/100 ml		Fecal strep/100 ml	
	Inlet no. 1	Sewer outfall	Inlet no. 1	Sewer outfall
1940	4,000		7,000	
1943		110,000		11,500
1950	1,000		6,750	
1952		23,000		450

Storm event - June 7, 1979

Sample time	Fecal coliform/100 ml			Fecal strep/100 ml		
	Inlet no. 1	Inlet no. 2	Sewer outfall	Inlet no. 1	Inlet no. 2	Sewer outfall
0935	700	NS	NS	3,600	NS	NS
1255	ND	100	700	600	4,000	1,200
1315	400	2,600	300	3,300	38,000	7,100
1345	NS	ND	1,400	NS	3,200	13,000
1415	NS	300	3,200	NS	900	24,000
1445	NS	900	400	NS	1,700	8,100

ND = Not detectable.
NS = No sample obtained.

Table 14. Atmospheric deposition of nutrients (kg/ha/yr).

Location	NO_3-N	NH_4-N	NO_2	Total PO_4-P	Soluble P	SO_4
Iowa (45)						
Urban						
Ames	6.0	6.0	-	-	a	16.8
Rural						
Boone	7.2	6.0	-	-	a	15.6
Charles City	6.0	7.2	-	-	a	13.2
Creston	6.0	6.7	-	-	a	16.7
Eldora	4.8	5.0	-	-	a	17.3
Guthrie Center	7.2	7.1	-	-	a	16.1
Michigan (46)						
Rural						
Pellston	4.03	3.09	-	0.25	0.20	18.25
Houghton Lake	3.20	2.09	0.01	0.31	0.29	-
Urban Industry						
Saginaw Bay	4.40	-	0.33	1.21	1.12	-
New York (47)						
Ithaca	4.22	3.17	-	0.05	-	39.49
Aurora	4.28	3.26	-	0.06	-	49.65
Geneva	4.77	3.52	-	0.05	-	34.86

[a] Average for all sites in Iowa was approximately 0.09 lb/acre/yr (0.1 kg/ha/yr).

Precipitation

Precipitation quantity data were collected at all sites to develop rainfall to runoff relationships and to provide the basis for establishing background contaminant loadings to the highway system due to precipitation wash-out. During the monitoring periods, Milwaukee and Sacramento received total precipitation quantities which were near normal (Table 15), indicating typical precipitation periods were monitored. Harrisburg received precipitation which was 22.5 percent below normal while Efland received 15.6 percent more precipitation than normal (Table 15). Precipitation at Milwaukee, Efland and Harrisburg consisted of both rainfall and snowfall events. Sacramento received no snowfall during the monitoring period. Characteristics of precipitation events during the monitoring period at each site are presented in Table 16.

Background precipitation quality samples (snowfall and rainfall) were obtained at each site to establish the background level of atmospheric pollutants reaching the highway system through precipitation wash-out. Quality data for individual events at the four monitoring sites can be found in Volume IV, Appendix, Tables A-1 to A-4. A summary of the precipitation quality data for precipitation events at the four monitoring sites is presented in Table 17. Data for each site are summarized using the range, median and number of observations (n) for each of the 25 parameters. The median is the middle number in a data set such that the median value is neither greater than half the observed values nor less than half of them. The median was used to characterize each parameter data set, in-lieu-of a mean value, because of the large number of observations reported as ND, not detectable.

Total precipitation for quality monitored events at the four sites ranged from 0.10 to 3.70 in (0.25 to 9.40 cm)(Table 17). Excluding the smallest events [less than 0.10 in (0.25 cm) water equivalent] for which representative quality samples are difficult to obtain, this range provides a cross section of precipitation events characteristic for each site. Based upon the detection limits for analyses on the precipitation samples collected for these events, quality analysis results can be generalized by grouping parameters as follows (detection limit, mg/l, given in parenthesis):

1. Never detectable - As (0.01) and Hg (0.0002)
2. Near detection limits - Pb (0.1), Cr (0.02), Cd (0.02), Ni (0.05), TKN (1), PO_4-P (0.01), Sulphate (1), Rubber (0.1%), Oil & grease(1)
3. Generally detectable - Solids (1), TOC (0.01), COD (6), Zn (0.01), Fe (0.1), Cu (0.02), NO_2+NO_3 (0.01, Na (0.1), Cl (1), PCB (0.00005)

Table 15. Total precipitation during the monitoring period at each site.

Site	Monitoring period	Precipitation during monitoring period[a], in	Normal for the period[a], in
Milwaukee, I-94	August 1978 to May 1980	56.58	52.95
Sacramento Hwy. 50	December 1979 to December 1980	22.75	20.34
Harrisburg I-81	June 1980 to June 1981	30.69	39.58
Efland I-85	July 1981 to July 1982	47.53	41.13

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[a] Data from the National Climatic Center.

Metric units: To convert inches to cm multiply by 2.54.

Table 16. Characteristics of precipitation events during the monitoring period at each site.

Site	Monitoring period	No. of events	Precipitation, in/event Range	Precipitation, in/event Mean	Duration, hours Range	Duration, hours Mean	Intensity, in/hr Range	Intensity, in/hr Mean	Dry days Range	Dry days Mean
Milwaukee I-94[a]	8/16/78- 5/15/80	241	0.01-1.42	0.20	0.05-26.25	3.95	0.002-3.00	0.11	0.18	2
Sacramento Hwy. 50	12/19/79- 1/2/81	66	0.02-1.62	0.34	0.25-19.00	4.91	0.004-0.40	0.08	0-190	6
Harrisburg I-81[a]	6/15/80- 6/10/81	113	0.01-2.02	0.27	0.08-23.00	4.37	0.003-2.63	0.16	0-16	3
Efland I-85[a]	7/1/81- 7/15/82	135	0.02-4.27	0.44	0.25-41.5	4.40	0.013-0.67	0.11	0-14	3

[a] Includes both rainfall and snowfall events.

Metric units: To convert inches to cm multiply by 2.54.

Table 17. Summary of precipitation quality (mg/l) at monitoring sites.

Parameter	Milwaukee I-94			Sacramento Hwy. 50			Harrisburg, I-81			Efland, I-85		
	Range	Median	n	Range	Median	n	Range	Median	n	Range	Median	n
pH	2.7-6.8	3.8	16	4.9-6.3	5.0	5	3.2-5.6	4.3	10	3.4-5.4	4.2	14
TS	16-210	44	16	20-84	64	5	4-68	30	10	2-33	12	13
TVS	7-70	19	16	6-20	13	4	5-48	12	8	ND-24	7	6
SS	3-55	12	16	2-18	4	5	2-30	5	10	ND-9	1	13
VSS	2-12	5	15	ND-12	1	5	1-3	2	8	ND-5	ND	6
TOC	ND-26	8	7	ND-11	11	4	ND-19	5	5	5-16	11	2
COD	11-45	23	7	8-32	11	4	ND-12	ND	5	8-17	13	2
Pb	ND-0.3	ND	16	ND-0.1	ND	5	ND-0.2	0.02	10	ND-0.02	ND	13
Zn	ND-3.9	0.17	16	0.03-0.20	0.11	5	0.048-0.29	0.08	10	ND-0.05	0.03	13
Fe	ND-1.0	0.20	16	ND-0.3	0.18	5	0.15-0.82	0.30	10	0.05-1.50	0.08	13
Cr	ND-0.04	ND	16	ND-0.02	ND	5	ND-0.11	ND	8	ND-0.01	0.002	13
Cu	ND-0.71	0.04	16	ND-0.06	0.035	5	0.020-0.16	0.04	8	0.01-0.09	0.03	13
Cd	ND-0.02	ND	16	ND-0.04	0.008	5	ND-0.04	ND	8	ND-0.004	ND	13
Ni	ND-0.2	ND	16	ND-0.1	0.05	5	ND-0.2	ND	8	ND-0.02	ND	13
As	ND	ND	2	ND	ND	2		ND	1		ND	1
Hg x 10^{-3}	ND	ND	2	ND	ND	3	ND	ND	2		ND	1
NO_2+NO_3	0.25-1.96	0.79	16	0.07-0.52	0.16	4	0.03-1.03	0.20	8	0.03-0.81	0.19	7
TKN	1.0-3.2	2.0	16	ND-1.3	1.1	4	ND-1.1	0.64	8	ND-2.00	0.84	7
PO_4-P	ND-0.14	0.05	16	ND-0.06	ND	4	ND-0.04	ND	8	ND-0.03	ND	7
Sulfate	ND-12	3	15	ND-1	ND	5	ND-13	ND	8	ND-5.00	ND	5
Na		1.25	1	0.3-14	2.0	3	ND-1.4	0.2	5	ND-2.00	0.23	8
Cl	ND-27	9	15	ND-25	3	5	ND-5	1	9	ND-6.00	3.00	8
PCB x 10^{-3}	ND-0.10	0.05	3		0.31	1	0.14-0.26	0.20	2		ND	1
Rubber		0.275	1		ND	1			0			0
Oil & grease		ND	1			0	ND-2	ND	4	ND	ND	2
Precipitation, inches	0.10-1.18	0.25	16	0.50-1.47	1.14	5	0.10-1.18	0.54	10	0.22-3.70	1.15	14

n = Number of observations.
ND = Not detectable.

Metric units: To convert inches to cm multiply by 2.54.

Emissions into the atmosphere from man-related sources are changing precipitation quality and chemical climate over many parts of the United States, especially those areas downwind from highly urbanized and industrialized sections. Of recent concern is the problem of acid rain. The components of acid rain have been found to be sulphuric acid, nitric acid, hydrochloric acid and organic acids which are formed by the oxidation of various contaminants found in rain, largely SO_2 and NO (48). In 1977, total man-made emissions of SO_2 in the United States were estimated to be approximately 29.9 million tons (27.1 metric tons) (81 percent from fuel combustion in stationary sources and 19 percent from industrial processes) (49). During the same year NO emissions were approximately 25.1 million tons (22.8 metric tons) (39 percent from fuel combustion in cars, trucks, planes, trains, etc. and 61 percent from fuel combustion in stationary sources) (49).

Precipitation at the four monitoring sites can be characterized as excessively acid because all median pH values are below 5.7 (Table 17) which is the theoretical pH of unpolluted precipitation [pH of pure water in equilibrium with atmospheric concentrations of CO_2 (49)]. Milwaukee, the most urbanized and industrialized of the sites, had the lowest pH, 2.7, for a precipitation event and the lowest median pH, 3.8, with 69 percent of the monitored events having a pH less than 4.0. Milwaukee also had the highest maximum and median value for most contaminant concentrations (Table 17). A notable exception was PCB concentrations which were higher at Sacramento and Harrisburg.

Precipitation quality data (Table 17) were converted to loading values, mg/m^2/event. Table 18 summarizes the loading data for each site using the range, median and number of observations (n) for each of the 25 parameters. Although Milwaukee had the highest precipitation contaminant concentrations, the contaminant loadings per event were generally the lowest of the four sites based upon maximum and median loading values. Higher loadings per event at Sacramento, Efland and Harrisburg are probably a function of the larger storm events which were monitored (Table 17). Compared to Milwaukee, larger storm events (total precipitation) appear to be characteristic of the Sacramento, Efland and Harrisburg sites (Table 16). Regression analyses were performed on data for constituent loading values (mg/m^2), total precipitation (cm), wind direction (degrees), wind speed (km/hr) and dry days. A correlation between loading values and these meteorological parameters was not found.

Monitored precipitation events at Milwaukee and Harrisburg had higher chloride loadings in winter than in summer. Winter chloride loadings for Milwaukee ranged from 30.5 to 300 mg/m^2 with a median value of 69.6 mg/m^2, while summer values ranged from not detectable to 57.9 mg/m^2 with a median value of 15.4 mg/m^2. Harrisburg had a winter chloride range of 25.9 to 89.9 mg/m^2 with a median value of 40.6 mg/m^2 and a summer chloride range of not detectable to 33.3 mg/m^2 with a median value of 13.9 mg/m^2. Higher winter precipitation chloride loadings are probably attributable to chloride aerosols from street and highway salting activities.

Table 18. Summary of precipitation loadings (mg/m^2/event) at monitoring sites.

Parameter	Milwaukee I-94			Sacramento Hwy. 50			Harrisburg I-81			Efland I-85		
	Range	Median	n	Range	Median	n	Range	Median	n	Range	Median	n
TS	93.5-2550	361	16	589=1930	1120	5	52.8-1740	413	10	792-1350	225	13
TVS	40.9-809	129	16	168-513	422	4	64.3-898	211	8	ND-725	272	6
SS	17.5-689	63.5	16	74.7-530	102	5	26.4-180	47.3	10	ND-187	36.3	13
VSS	8.13-270	23.6	15	ND-354	27.9	5	17.5-51.3	23.6	8	ND-104	ND	6
TOC	ND-139	36.6	7	ND-324	210	4	ND-257	102	5	259-260	260	2
COD	6.10-240	140	7	102-943	294	4	ND-244	ND	5	130-881	505	2
Pb	ND-3.00	ND	16	ND-25.7	ND	5	ND-5.13	0.26	10	ND-1.88	ND	13
Zn	ND-54.5	1.33	16	0.38-7.47	3.24	5	0.18-2.05	1.45	10	ND-2.30	0.76	13
Fe	ND-11.1	1.16	16	ND-25.7	5.89	5	1.60-7.70	4.86	10	1.03-70.5	3.11	13
Cr	ND-0.25	ND	16	ND-0.75	ND	5	ND-0.70	ND	8	ND-0.47	0.04	11
Cu	ND-3.79	0.28	16	ND-2.24	0.98	5	0.41-1.03	0.56	8	0.18-2.77	0.73	13
Cd	ND-0.13	ND	16	ND-1.49	0.22	5	ND-0.52	ND	8	ND-0.38	ND	13
Ni	ND-0.25	ND	16	ND-37.3	1.40	5	ND-1.27	ND	8	ND-1.32	ND	13
As	ND	ND	2	ND	ND	2		ND	1		ND	1
Hg x 10^{-3}	ND	ND	2	ND	ND	3	ND	ND	2		ND	1
NO_2+NO_3	2.29-13.2	4.57	16	1.78-13.3	3.48	4	0.43-10.5	3.23	8	1.41-42.0	6.58	7
TKN	5.59-57.0	11.1	16	ND-32.4	22.4	4	ND-33.0	8.62	8	ND-98.4	42.3	7
PO_4-P	ND-4.20	0.22	16	ND-1.54	ND	4	ND-0.25	ND	8	ND-0.55	ND	7
Sulfate	ND-61.0	12.2	15	ND-25.7	ND	5	ND-75.9	ND	8	ND-259	ND	5
Na		17.5	1	8.38-178	58.9	3	ND-35.9	5.18	5	ND-89.9	7.13	8
Cl	ND-300	32.5	15	ND-317	88.4	5	ND-89.9	25.9	9	ND-282	108	8
PCB x 10^{-3}	ND-0.30	0.27	3		9.13	1	4.20-5.28	4.74	2		ND	1
Rubber		1.68	1		ND	1			0			0
Oil & grease		ND	1			0	ND-59.9	ND	4	ND	ND	2

n = Number of observations

ND = Not detectable.

Bulk Precipitation

Precipitation quality data collected at the monitoring sites showed that measurable quantities of solids and several other constituents reach the highway system through the atmosphere. However, deposition of pollutants by precipitation is only a part of the total atmospheric deposition process. Total atmospheric deposition, called bulk precipitation, includes both wet (rainfall and snowfall) and dry (dustfall) deposition. Background bulk precipitation data were collected at each site to quantify total atmospheric deposition as a source of pollutants to the highway system. Background sample collection interval at each site was four weeks.

A summary of background bulk precipitation loadings at the monitoring sites is presented in Table 19. Milwaukee had one background monitoring station (Figures 1 and 2), while Efland, Sacramento and Harrisburg had two background monitoring stations (Figures 3 through 5). Due to the severe winter characteristic of Milwaukee, atmospheric monitoring was not possible during most of the winter period, whereas atmospheric data were collected throughout the monitoring year at Sacramento, Efland and Harrisburg. The single background monitoring location and abbreviated monitoring period at Milwaukee accounts for the smaller number of observations (n) for TPM (total particulate matter) at this site compared to the other sites (Table 19). Metals analyses were performed on selected TPM samples collected at each site. Copper analyses were not possible because copper sulfate was added to the distilled water in bulk precipitation collectors to eliminate algal growth which would have caused elevated TPM loading values.

TPM loading values were highest at Sacramento and Milwaukee (urban sites) and lowest at Harrisburg and Efland (rural sites). Metals loadings generally showed the same pattern as TPM loadings. The low background TPM and metal loadings at Harrisburg and Efland would be expected because these sites are located in rural settings. The lower TPM and metal loadings at Milwaukee compared to those values observed at Sacramento are difficult to explain based upon surrounding landuse activities at these two sites. The Milwaukee I-94 monitoring site is located within a highly industrial area while the Sacramento site was located in a residential area. The Menomonee Industrial Valley is located just south of the Milwaukee site and the predominant wind direction is out of the southwest.

The data in Table 19 indicate that background metals deposition is lower in rural areas (Harrisburg and Efland) than in urban-industrialized areas (Sacramento and Milwaukee). The data also show that Pb, Zn, Fe and Cr were generally present in detectable quantities for TPM samples which were analyzed. This is in contrast to these metals loadings associated with precipitation which were often nondetectable quantities (Table 18). The data indicate that metals are probably associated more with the dry deposition component (dustfall) of bulk precipitation than the wet deposition component (precipitation). Dustfall, a continuous process, is probably a more important source of background metals loading to the highway surface than is precipitation.

Table 19. Summary of bulk precipitation loadings (mg/m^2/day) at monitoring sites.

Para-meter	Milwaukee I-94			Sacramento Hwy. 50			Harrisburg I-81			Efland I-85		
	Range	Mean Median*	n	Range	Mean Median*	n	Range	Mean Median*	n	Range	Mean Median*	n
TPM[a]	60-230	130	10	20-890	160	24	11-65	30	22	8.66-103	40.3	27
Pb	0.008-0.124	0.057	3	0.033-1.00	0.245	5	ND-0.063	ND*	4	0.001-0.015	0.006	7
Zn		0.258	1	0.009-0.042	0.023	5	0.008-0.026	0.015	4	0.00004-0.018	0.007	7
Fe	0.327-4.17	1.86	3	1.00-4.70	2.59	5	0.236-0.617	0.382	4	0.024-0.672	0.424	7
Cr	0.001-0.012	0.005	3	0.009-0.120	0.033	5	0.001-0.002	0.002	4	0.00002-0.005	0.002	7
Cd		ND	1	ND-0.11	ND*	5	ND-0.001	ND*	4	ND-0.0007	ND*	7
Ni	0.001-0.012	0.008	3	ND-0.663	0.004*	5		ND	4	ND-0.002	ND*	7

[a] TPM = Total particulate matter.
n = Number of observations.

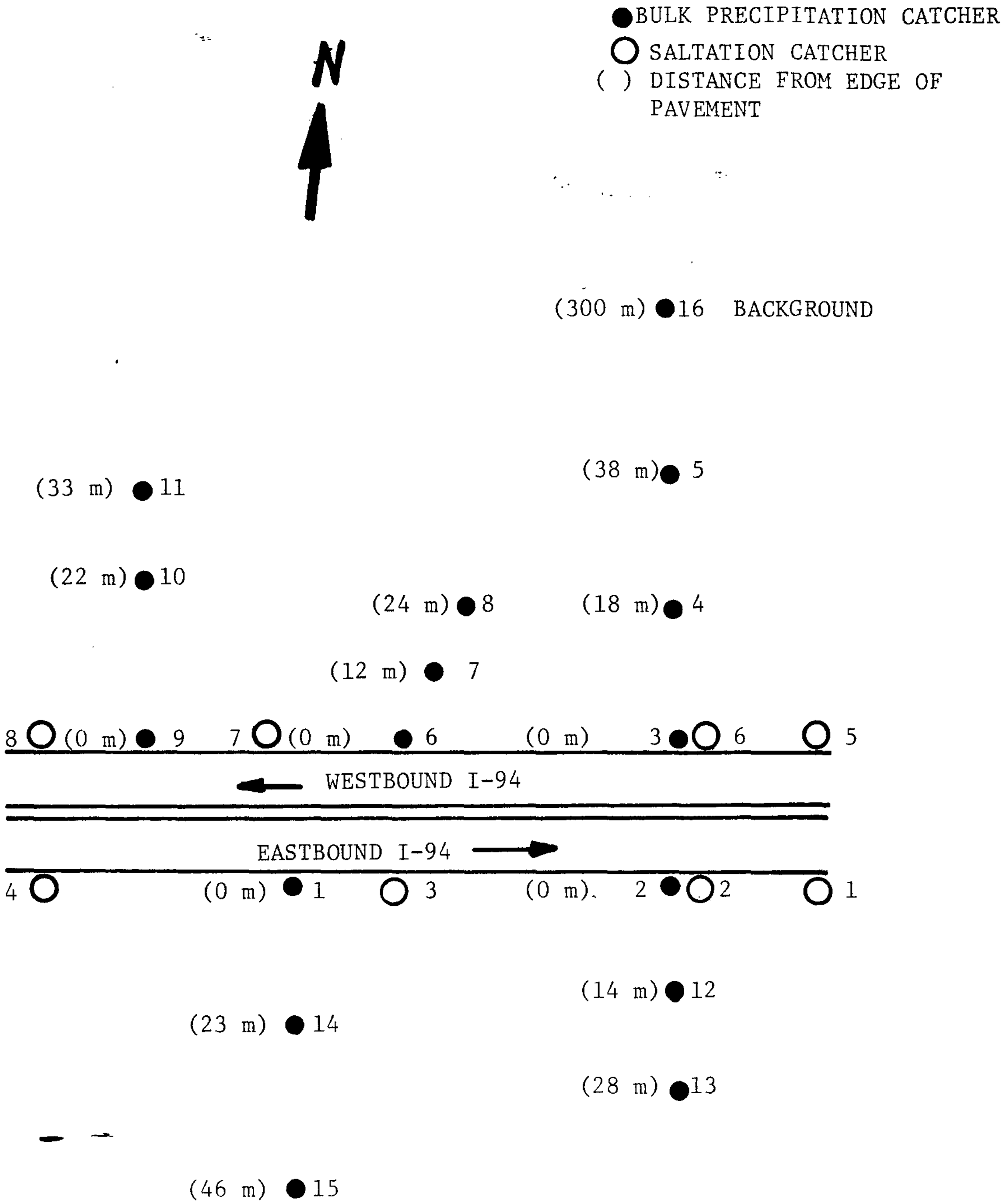

Figure 1. Bulk precipitation and saltation catcher installations - Milwaukee I-94 site, 1978.

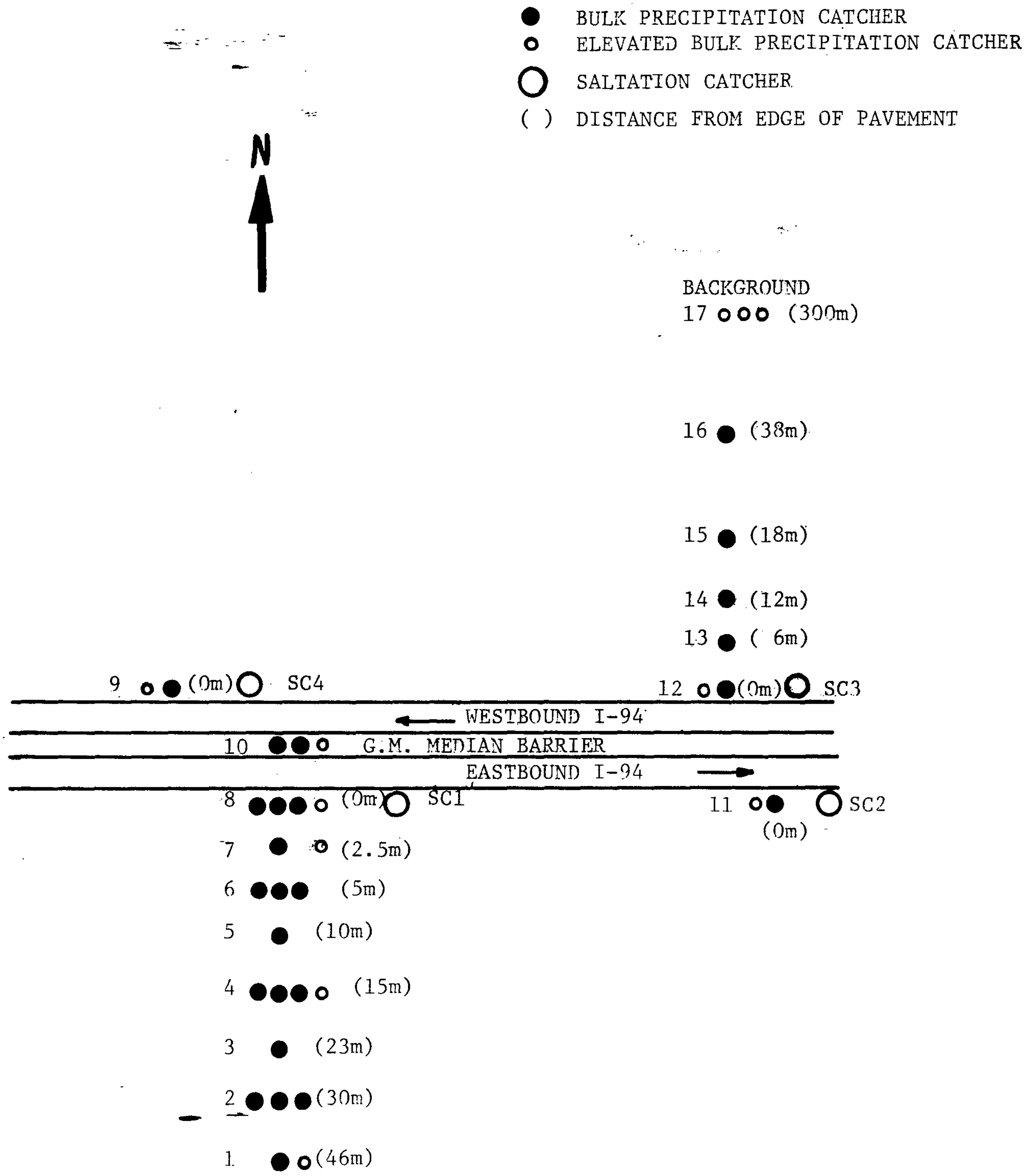

Figure 2. Bulk precipitation and saltation catcher installations - Milwaukee I-94 site, 1979.

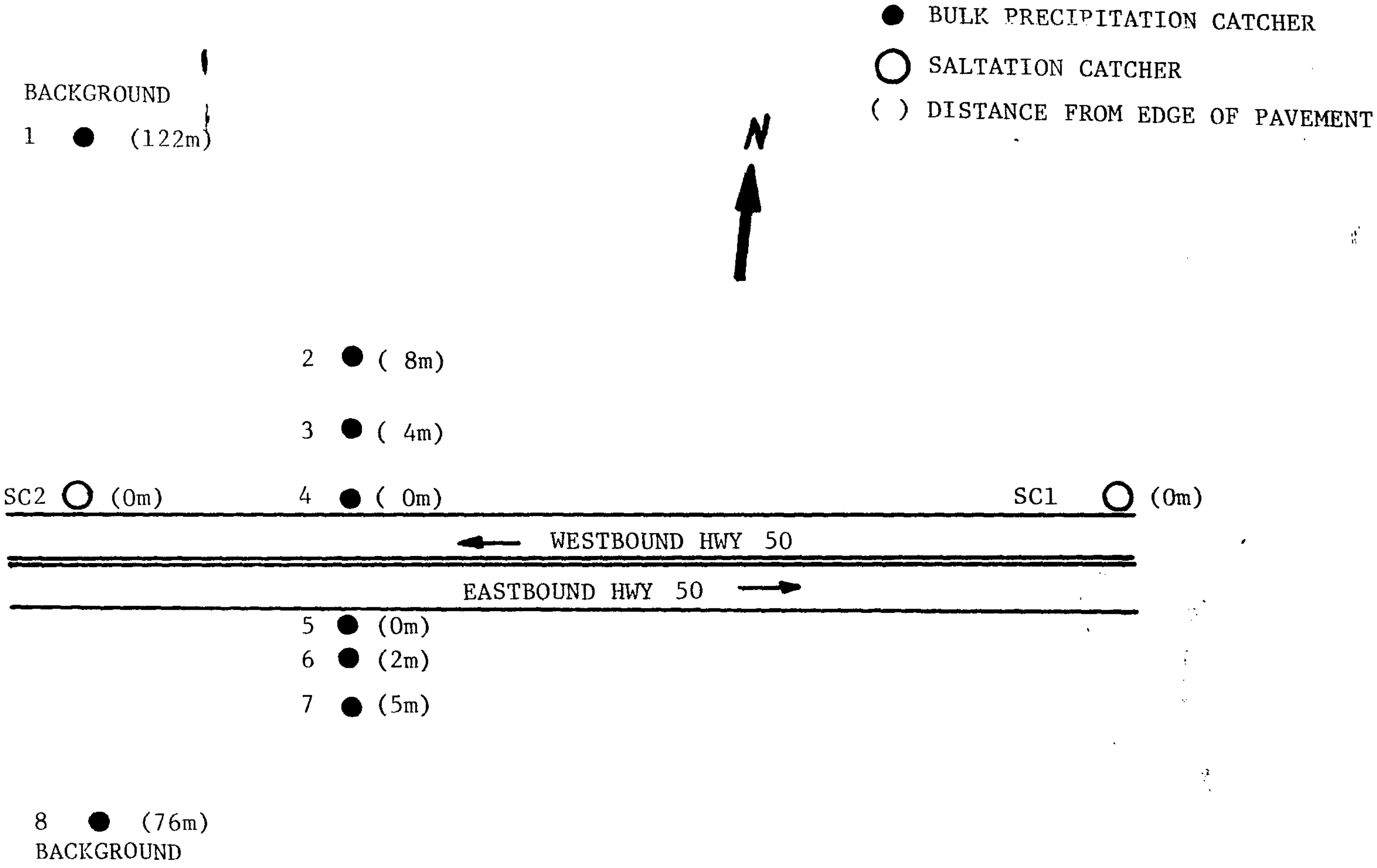

Figure 3. **Bulk precipitation and saltation catcher installations - Sacramento Hwy 50 site.**

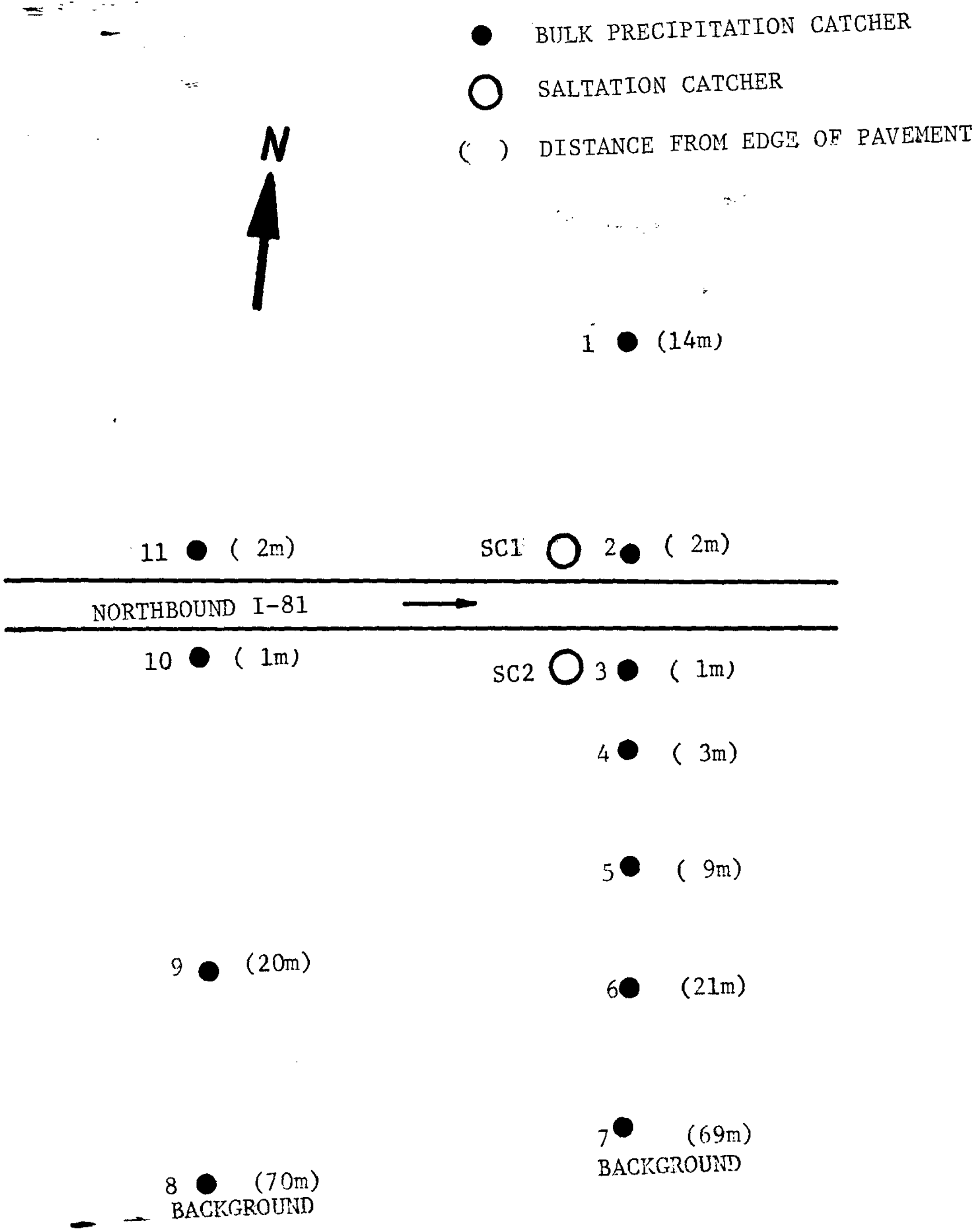

Figure 4. Bulk precipitation and saltation catcher installations - Harrisburg I-81.

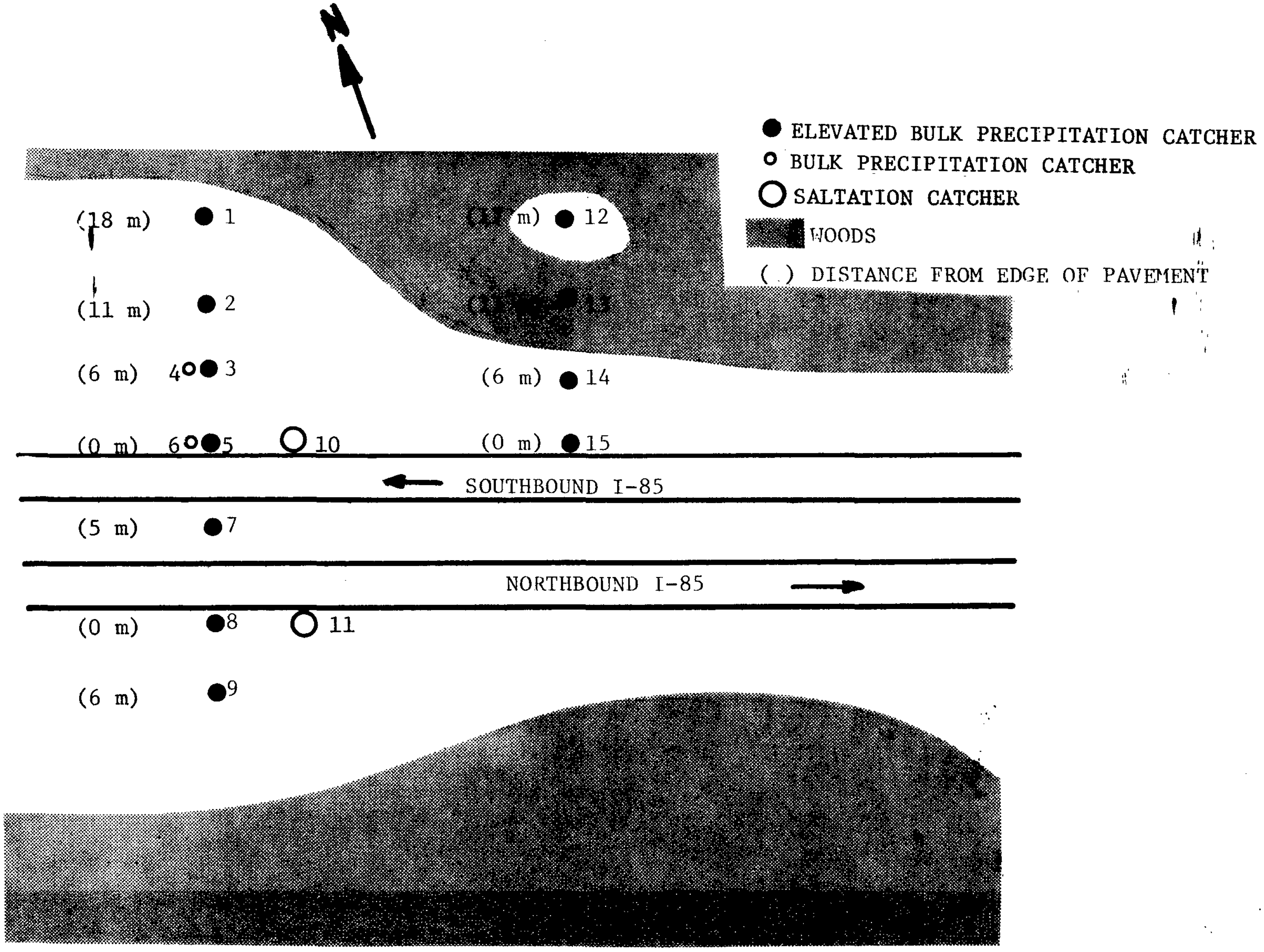

Figure 5. Bulk precipitation and saltation catcher installations - Efland I-85.

This premise is supported by the wet/dry collector data obtained at the Efland site. The data show (Table 20) that except for Cd and Ni which were generally nondetectable in both fractions, loadings of solids and metals were higher in the dry fraction (dustfall) than in the wet fraction (precipitation).

SUMMARY AND CONCLUSIONS

Sources of many materials which deposit and accumulate on highway surfaces, median areas and adjoining right-of-ways are documented in the literature. Order of magnitude deposition rates are also available for many of these constituents. However, deposition and subsequent magnitude of these constituents in highway runoff are site specific and affected by such parameters as traffic characteristics, highway design, maintenance activities, surrounding land use, climate and accidental spills.

Precipitation monitored at Milwaukee, the most urbanized and industrialized of the sites monitored, had the highest maximum and median values for most quality parameters (mg/l). However, for many constituents, Sacramento, Efland and Harrisburg had the larger loadings per precipitation event (mg/m^2) than Milwaukee which is probably due to the larger total volume per rainfall event observed at Sacramento, Efland and Harrisburg. Deposition of chlorides via precipitation was higher during the winter than summer at Milwaukee and Harrisburg which may be attributable to chloride aerosols from street and highway salting activities.

Background bulk precipitation data (wet and dry deposition) indicate that TPM (total particulate matter) loadings were approximately four times higher at the urban sites than at the rural sites. Similarly, background metals deposition was higher at the urban sites. The data also indicate that dry deposition is a more important source of metals than wet deposition.

Although enteric bacteria (total coliform, fecal coliform and fecal streptococci) were present in paved and unpaved runoff at the Milwaukee site, they were not detectable in precipitation, dustfall or ambient air samples. It appears that the roadway surface is periodically "seeded" with debris containing enteric bacteria. A possible source could be trucks carrying livestock and stockyard waste. This is consistent with the FC/FS ratios monitored in runoff which indicate that the enteric bacteria present on roadway surfaces appear to be largely of animal origin. Bacteriological data also indicated that fecal coliforms remained viable within roadway dust and dirt for relatively long periods of time (at least seven weeks). Data also indicated that fecal coliform and fecal streptococcus bacteria remain viable in stagnant storm sewer water for at least 13 days.

Asbestiform material was not detected in precipitation, runoff, dustfall and air samples collected at the Milwaukee I-94 site. These results are

Table 20. Summary of wet/dry collector data (mg/m^2/day) - Efland I-85.

Parameter	Collector	Range	Mean Median (*)	n
TPM[a]	Wet	0.047-39.9	11.0	23
	Dry	4.05-68.9	26.5	23
Pb	Wet	ND-0.002	ND*	6
	Dry	0.0001-0.007	0.004	6
Zn	Wet	ND-0.015	ND*	6
	Dry	0.0004-0.011	0.003	6
Fe	Wet	ND-0.159	0.041*	6
	Dry	0.024-0.626	0.320	6
Cr	Wet	ND-0.001	ND*	6
	Dry	0.00002-0.002	0.001	6
Cd	Wet	ND	ND*	6
	Dry	ND-0.001	ND*	6
Ni	Wet	ND-0.001	ND*	6
	Dry	ND-0.001	ND*	6

[a] TPM = Total particulate matter.
n = Number of observations.

consistent with those of FHWA's Phase I Study on highway runoff constituents (39). No asbestiform material was detected in 19 out of 21 runoff samples. These data indicate that the quantity of asbestiform material present in the highway systems is below detection limits or that it is difficult to detect.

Polychlorinated biphenyls were detected in soil, vegetation, precipitation, highway surface dust and dirt and runoff samples. Runoff studies indicated that PCB's in the highway environment are transported from that environment via runoff during storm events. The data also indicated sources of PCB in highway runoff include precipitation, highway surface dust and dirt, and contaminated soil eroded by the runoff from unpaved surfaces adjoining the highway.

SECTION III
MIGRATION OF HIGHWAY CONTAMINANTS

Field studies were conducted at each of the four sites to evaluate the quantitative and qualitative aspects of background pollutant deposition to the highway system (discussed in Section II), pollutant accumulation within the highway system due to background and highway related sources, and the mechanism of pollutant dispersion within and out of the highway system. Details of the field study results associated with the processes of pollutant accumulation and removal will be discussed first in this section. Next, a mass balance for selected pollutants associated with the highway system (paved highway surface and associated drainage scheme) will be formulated using field data and data from the literature. Finally, the mechanisms of pollutant accumulation and migration in the environment adjacent to highways will be discussed.

ACCUMULATION AND REMOVAL OF HIGHWAY CONTAMINANTS

Bulk Precipitation and Saltation

Bulk precipitation data (wet and dry deposition) were collected at each site to establish the level of pollutants migrating from the highway to the surrounding environment through atmospheric processes. Another mechanism for the removal of pollutants from the highway through the atmosphere is saltation. The phenomenon of saltation, sand-sized particles injected into the atmosphere by vehicular turbulence, was monitored at all sites. Data were collected to determine the magnitude of saltation transport from the paved highway surface to the surrounding environment. As described in Volume II - Methods, saltation measurements are not precise but provide data which are qualitative. Therefore, saltation data was collected as part of this study to provide order of magnitude comparisons between sites and to provide information on the magnitude of saltation transport relative to bulk precipitation.

Intensive studies were conducted at the Milwaukee I-94 site to determine the optimum bulk precipitation and saltation sampling strategy to be implemented at all sites. Variables included number of collectors, collector spacing and sample collection interval. The initial sampling scheme used to define these variables is depicted in Figure 1 (Section II). Installation occurred in late summer, 1978 and included eight saltation catchers, four catchers each on the north and south side of the highway, 15 bulk precipitation collectors spaced at various distances perpendicular and parallel to the paved highway surface, and a background bulk precipitation collector. The south side of the highway at this site consists of relatively flat terrain, while the north side of the highway consisted of both a cut and fill section of highway. Bulk precipitation collectors no. 4, 5, and 8 were located on elevated terrain, and no. 7, 10, and 11 on depressed terrain.

Optimum sample collection interval at the Milwaukee I-94 site was determined to be four weeks for background samples, one week for saltation catchers and bulk precipitation collectors located adjacent to the highway pavement, and two weeks for all other bulk precipitation collectors. Particulate matter concentration required for analysis was the determining factor in selecting these intervals. Particulate matter analysis consisted of pouring sample bucket contents through a filter under vacuum and obtaining the dry weight of the matter collected on the filter. Four weeks were required to collect enough particulate matter in background bulk precipitation collectors for valid analysis. Samples from bulk precipitation collectors adjacent to the highway and saltation catchers for intervals greater than one week, and greater than two weeks for all other bulk precipitation collectors, generally contained excessive particulate matter which required numerous filters to completely analyze each bucket. Subsequent metals analyses on filter contents became difficult because multiple filters per sample had to be digested prior to metals analysis. Saltation catchers and bulk precipitation collectors adjacent to the highway were typically collecting 20 to 40 times more particulates than background. Particulate quantities monitored by remaining bulk precipitation collectors were similar to background levels or as much as four times greater than background, depending on collector location relative to the highway.

A revised atmospheric deposition monitoring scheme (Figure 2) was implemented in the spring of 1979 with the following objectives:

1. Data from the preliminary monitoring scheme (Figure 1) indicated that additional bulk precipitation collectors were required to better define the extent of the area adjacent to the highway that is affected by atmospheric deposition of highway generated pollutants. Collectors were added to the southern sampling transect, collector locations no. 1 through 8, and to the northern sampling transect, collector locations no. 12 through 16 (Figure 2).

2. Multiple collectors were also added at several locations (collector locations no. 2, 4, 6, 10, and 17) to evaluate the precision of bulk precipitation measurements. Precision experiments were conducted on the flat terrain located on the south side of the highway to eliminate any localized effects of the wind interacting with the variable terrain on the north side of the highway.

3. Included in the revised sampling scheme were eight collectors elevated 30 in (76 cm) from the ground or pavement to the top lip of the collector (refer to Volume II - Methods). These collectors were installed to determine the quantity of saltating particles [particles bouncing off the highway surface within the height interval of 30 in (76 cm)] which enter ground level dustfall buckets.

4. Bulk precipitation collectors were also installed in the median area between the GM barriers (collector location no. 10) to determine loadings to this area through atmospheric deposition. The median area, approximately 1-m-wide, is filled with dirt and is drain tiled with outlets to the paved highway surface.

Saltation data from the preliminary monitoring scheme (Figure 1) for the period 9/20 to 11/22/78 (period prior to snow accumulation) showed mean daily rates as follows:

Total particulates, mg/bucket/day							
South of highway				North of highway			
SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8
44	47	56	50	73	74	124	124

The data show that saltation catchers south of the highway collected quantities of total particulates which were of the same order of magnitude with catchers no. 3 and 4 collecting slightly more particulates than catchers no. 1 and 2. Saltation catchers north of the highway collected more particulates than catchers south of the highway, indicating that the predominant wind direction which is out of the southwest may be a variable in the transport of saltating particles. Saltation rates for catchers no. 7 and 8 were comparable and higher than catchers no. 5 and 6 which also showed similar values. At the west end of the I-94 monitoring site the distress lane (outside non travel lanes) narrow as they approach a bridgedeck which begins near saltation catchers no. 4 and 8. Therefore saltation catchers no. 3, 4, 7, and 8 are closer to the travel lanes than saltation catchers no. 1, 2, 5, and 6 which probably accounts for the higher mean saltation rates for catchers on the western end of the monitoring site. Saltation catchers no. 1, 4, 5, and 8, the four saltation catchers located at the outermost boundaries of the site, were removed for the revised monitoring strategy because the data show that saltation catchers no. 2, 3, 6 and 7 provide essentially the same information.

The monitoring scheme used at the Sacramento Hwy 50 site is depicted in Figure 3 (Section II). Installation included two saltation catchers on the north side of the highway, six bulk precipitation collectors spaced at various distances perpendicular to the paved highway surface, and two background bulk precipitation collectors, one on each side of the highway. All terrain surrounding the site, excluding the highway runoff channels, was relatively flat. Background bulk precipitation collectors no. 1 and 8 were located in a powerline right-of-way which transversed the western portion of the highway section monitored. This right-of-way was also utilized for recreational activities, in fact, the entire area north of the highway section monitored was a park. The area south of the highway section monitored, bordered by the powerline and highway right-of-way, was residential. Bulk precipitation collectors no. 2 and 7 were located at the edge of the right-of-way areas which were enclosed with chainlinke fences. Bulk precipitation collectors could not be installed beyond the edge of the right-of-way due to the high risk of vandalism.

The monitoring scheme used at the Harrisburg I-81 site is presented in Figure 4 (Section II). Installation included two saltation catchers north and south of the northbound lane, nine bulk precipitation collectors spaced on two transects perpendicular to the highway surface, and two background bulk precipitation collectors located south of the highway. The median area, approximately 30 m wide, was monitored for atmospheric deposition by two bulk precipitation collectors near the edge-of-pavement and one collector near the median area midpoint. The sampling transect with bulk precipitation collectors no. 1 through 7 (Figure 4) covered relatively flat terrain which provided ideal conditions to monitor the effects of predominant wind direction (out of the northwest) on atmospheric deposition processes. The sampling transect with bulk precipitation collectors no. 8 through 11 was on elevated ground in a cut section of the highway. A comparison could then be made of atmospheric deposition on flat and elevated terrain.

The monitoring scheme used at the Efland I-85 site is presented in Figure 5 (Section II). Installation included two saltation catchers on the north and south side of the highway, thirteen bulk precipitation collectors spaced on two transects perpendicular to the highway surface and two wet/dry collectors monitoring background bulk precipitation. Two ground level bulk precipitation collectors were installed to monitor the influence of saltating particles on bulk precipitation measurements. The remaining eleven collectors were elevated 30 in (76 cm) from the ground or pavement to the top lip of the collector. The median area, approximately 10-m-wide, was monitored for atmospheric deposition by a collector located near the median area mid-point. The sampling transect with collectors no. 1 through 9 was located in a slightly depressed area while the transect with collectors no. 12 through 15 was located on slightly elevated ground. To determine the effect of roadside vegetation on atmospheric deposition, collector no. 13 was installed under the canopy of the wooded area while collector no. 12 was located in a clearing.

Saltation--

Average monthly saltation rates, and monthly wind and traffic data for the Milwaukee I-94 site are presented in Table 21. Wind data include resultant wind direction (sum of hourly wind vectors), resultant wind speed (length of resultant wind vector) and average wind speed (calculated without regard to wind direction). Resultant wind speed and direction provide information relative to particle trajectory for comparison of directional effects on loadings. Average wind speed data provide information on overall wind mix for comparison of monthly total loading values. Saltation could not be monitored at the Milwaukee site during most of the winter period because plowing operations either destroyed the catchers or buried them in snow. Mean total highway saltation rate (time weighted) for the period monitored was 37.9 lb/mi/day (10.7 kg/km/day); 23.2 lb/mi/day (6.5 kg/km/day) for the westbound lanes and 14.7 lb/mi/day (4.1 kg/km/day) for the eastbound lanes. Average daily traffic for the period was slightly higher for westbound lanes than eastbound lanes and probably contributed to the differences in saltation rates. However, the difference in traffic counts alone would not explain the large difference in saltation rates between the two highway sections. Highway configuration can be eliminated as a variable because westbound and eastbound highway sections have identical configuration consisting of four travel lanes,

Table 21. Average monthly saltation rate at Milwaukee I-94.

Period monitored	Total particulates, lb/mi/day			Resultant wind		Avg wind speed mi/hr	Average daily traffic, vehicles/day		
	Westbound	Eastbound	Total highway[a]	Direction	Speed, mi/hr		Westbound	Eastbound	Total
1978									
October	27.3	12.0	39.3	SW	5.2	11.1	60,000	57,000	117,000
November	24.9	14.2	39.1	W	3.9	12.3	59,000	59,000	118,000
1979									
April	28.7	19.1	47.8	N	1.6	10.9	61,000	61,000	122,000
May	25.3	26.7	52.0	SE	0.3	11.3	60,000	61,000	121,000
June	19.6	14.7	34.3	SW	1.1	11.2	62,000	62,000	124,000
July	20.7	12.7	33.4	S	0.4	8.1	60,000	56,000	116,000
August	17.3	14.1	31.4	SW	1.4	9.5	61,000	56,000	117,000
September	16.8	7.4	24.2	SW	2.9	9.7	57,000	46,000	103,000
October	23.4	12.9	36.3	SW	4.3	12.0	61,000	54,000	115,000
November	28.1	13.0	41.1	SW	6.7	12.2	58,000	56,000	114,000
Mean[b]	23.2	14.7	37.9	--	--	--	60,000	57,000	117,000

[a] Westbound plus eastbound.

[b] Time weighted.

Metric units: To convert lb/mi to kg/km multiply by 0.2819.
To convert mi to km multiply by 1.609.

one median lane, and one distress lane with a curb and gutter drainage design. One variable which may contribute to the difference in saltation rates is wind direction. For most of the months monitored, wind direction was predominantly out of the southwest which may account for the higher saltation rates monitored by catchers on the north side of the highway (westbound lanes). The April 1979 saltation and wind pattern would be an exception to this theory. During this month, westbound and eastbound average daily traffic was equal and the resultant wind direction was north. However, saltation was still higher on the north side of the highway (westbound lanes). November, 1978 was characterized by a neutral wind direction (westerly) and identical traffic counts for the westbound and eastbound lanes. Under these conditions, westbound and eastbound saltation rates should have been similar. However, westbound saltation was significantly higher. The May saltation rate was slightly higher in the eastbound lane, 26.7 lb/mi/day (7.1 kg/km/day) than the westbound lane 25.3 lb/mi/day (7.1 kg/km/day); the only month during the monitoring period to display this trend. May was also the only month in which average daily traffic was slightly higher for the eastbound lanes. Resultant wind was out of the southeast with a resultant wind speed of 0.3 mph (0.5 km/hr). Although the resultant wind direction was southeast, the small resultant wind speed indicated that a directional wind effect was essentially nonexistent. The May data provide a good case for the effect of traffic on saltation.

The data (Table 21) also show that the highest total highway saltation rates occur in spring (April and May) which is probably a function of the larger quantity of particles available for saltation due to dust and dirt build-up on the paved highway surface from the winter period (discussed later in this section). Elevated values also occurred in the fall (October - November), months which also had high average wind speeds. September, 1979 had the lowest total highway saltation rates, 24.2 lb/mi/day (6.8 kg/km/day) which is probably a function of the relatively low average wind speed for the month and the lowest average daily traffic for the monitoring period. These data indicate that saltation at the Milwaukee I-94 site is probably related to available surface load, wind direction and speed, and average daily traffic.

Average monthly saltation rates, and monthly wind and traffic data for the Sacramento Hwy 50 site are presented in Table 22. Both saltation catchers, SC1 and SC2, were located on the north side of the highway (westbound lanes)(Figure 3). Except for January and February, monthly saltation rates for SC1 and SC2 were generally comparable indicating little lateral variation in saltation along the westbound lanes. January and February had the highest mean saltation rates for the period monitored and saltation catcher SC1 was significantly higher than saltation catcher SC2 (195 to 256 percent higher). However, saltation rates for catcher SC2 during January and February were comparable to the other months monitored, while saltation rates for catcher SC1 were extremely high compared to other months. January and February are the only months for which the resultant wind direction was directly out of the south. Saltation catcher SC1 is located on the section of highway where the powerline right-of-way transects the highway. The south side of the highway across from saltation catcher SC2 is residential. Apparently the high saltation rates monitored by catcher SC1

Table 22. Average monthly saltation rate at Sacramento Hwy 50.

Period monitored	Total particulates, lb/mi/day Westbound no. SC1	 Westbound no. SC2	 Westbound mean	Resultant wind Direction	 Speed, mi/hr	Average wind speed, mi/hr	Westbound average daily traffic, vehicles/day
1980							
January	45.1	17.6	31.4	S	1.6	6.9	41,000
February	30.6	15.7	23.2	S	2.2	8.3	43,000
March	21.2	19.3	20.3	NW	2.7	9.1	45,000
April	13.2	11.8	12.5	SW	4.0	8.4	44,000
May	21.7	18.3	20.0	SW	6.7	9.3	45,000
June	17.9	21.1	19.5	SW	6.9	9.7	44,000
July	17.1	23.1	20.1	SW	6.8	8.5	44,000
August	14.9	22.2	18.6	SW	8.1	9.4	48,000
September	18.4	24.8	21.6	SW	5.2	7.8	47,000
October	12.6	12.0	12.3	SW	1.5	5.2	47,000
November	15.4	14.7	15.1	NW	1.3	5.8	46,000
December	19.1	22.5	20.8	SE	0.6	5.4	45,000
Mean[a]	20.6	18.6	19.6	--	--	--	45,000

[a] Time weighted

Metric units: To convert mi to km multiply by 1.609.
To convert lb/mi to kg/km multiply by 0.2819.

are due to southerly-winds tunneling down the powerline right-of-way which increases the carrying capacity of particulates injected into the atmosphere by vehicular turbulence. The southerly wind effect on saltation catcher SC2 is negated by the buildings, fences and trees in the residential area on the side of the highway.

Saltation data for the Sacramento Hwy 50 site (Table 22) do not indicate the seasonal variations which were evident at the Milwaukee I-94 site. Sacramento does not have a winter season in the same sense as the other three sites. During the monitoring period snowfall was non-existent and the mean temperature range for the months of December, January, and February was 45.4 to 53.5°F (7.4 to 11.9°C). Deicing agent application (salt and sand), rusting cars, etc., processes associated with winter which increase the paved surface dust and dirt load in Milwaukee and Harrisburg, do not occur in Sacramento.

Average monthly saltation rates, and monthly wind and traffic data for the Harrisburg I-81 site are presented in Table 23. One saltation catcher (SC1) was installed north of the northbound lane in the median area and one saltation catcher (SC2) was located south of the northbound lane in the right-of-way area. The data show that except for June, 1980 saltation catcher SC1 was consistently higher than saltation catcher SC2. This saltation pattern is probably a function of saltation catcher proximity to the travel lanes. A two meter median strip separated saltation catcher SC1 from the travel lanes, while saltation catcher SC2 was one meter from the distress lane which is three meters wide, placing saltation catcher SC2 a total of four meters from the travel lanes. Wind direction at Harrisburg was predominantly out of the west or northwest. Except for June, the effect of a northwesterly wind on saltation was not evident from the data. Apparently, proximity of saltation catcher to travel lane has a greater effect on the quantity of saltating particles collected than the predominant wind direction.

Saltation data was not collected at the Harrisburg site for catcher SC1 during the months of November and December. The November sample was lost in shipment and the installation was destroyed during a truck accident in December. However, the trend of elevated saltation during winter and spring noted at the Milwaukee I-94 site is also evident at the Harrisburg I-81 site. Saltation values were approximately 2 to 6 times higher during winter and spring than during the summer months monitored (June through October). The rate of saltation appears to reach a peak during January with elevated saltation rates observed through April. Elevated saltation rates observed during winter and spring months may be due to the application of antiskid, an abrasive traction aid composed largely of limestone screenings. Summer rates did appear to be somewhat related to average daily traffic. July had the highest summer monthly saltation rate and the highest average daily traffic, while September had the lowest summer monthly saltation rate and the lowest average daily traffic.

Average monthly saltation rates, and monthly wind and traffic data for the Efland I-85 site are presented in Table 24. Efland had the lowest traffic

Table 23. Average monthly saltation rate at Harrisburg I-81.

Period monitored	Total particulates, lb/mi/day			Resultant wind		Average wind speed, mi/hr	Northbound average daily traffic, vehicles/day
	Northbound median no. SC1	Northbound right-of-way no. SC2	Northbound mean	Direction	Speed, mi/hr		
1980							
June	1.63	2.48	4.11	NW	3.1	6.7	16,000
July	3.02	1.54	4.56	W	2.7	5.9	17,000
August	2.10	1.90	4.00	W	2.5	6.1	17,000
September	1.99	1.78	3.77	W	1.5	6.3	14,000
October	2.20	1.95	4.15	W	4.1	7.5	15,000
November	NA	6.31	-	NW	5.0	8.3	13,000
December	NA	4.55	-	NW	4.7	7.7	12,000
1981							
January	18.8	8.07	26.9	NW	5.9	8.3	11,000
February	15.0	6.04	21.0	W	2.7	8.5	12,000
March	6.64	5.26	11.9	NW	7.3	10.2	13,000
April	5.52	5.00	10.5	W	3.3	8.9	14,000
Mean[a]	6.32	3.78	10.1	-	-	-	14,000

[a] Time weighted.

NA = Data unavailable.

Metric units: To convert lb/mi to kg/km multiply by 0.2819.
To convert mi to km multiply by 1.609.

Table 24. Average monthly saltation rate at Efland I-85.

	Total particulates, lb/mi/day			Resultant wind		Average wind speed, mi/hr	Average daily traffic, vehicles per day		
Period monitored	Northbound	Southbound	Total highway[a]	Direction	Speed, mi/hr		Northbound	Southbound	Total
1981									
July	0.66	1.26	1.92	S	0.6	5.2	NA	NA	NA
August	0.91	1.22	2.13	NE	1.1	4.5	14,000	14,000	28,000
September	1.41	1.74	3.15	W	0.5	5.9	13,000	13,000	26,000
October	1.08	1.56	2.64	N	2.3	8.1	13,000	14,000	27,000
November	0.97	1.07	2.04	NW	3.0	8.2	14,000	14,000	28,000
December	1.90	1.68	3.58	NW	3.6	8.8	12,000	12,000	24,000
1982									
January	3.06	3.79	6.85	W	2.5	8.9	11,000	11,000	22,000
February	3.19	2.75	5.94	N	2.5	8.8	11,000	11,000	22,000
March	2.22	2.71	4.93	NW	0.4	7.9	13,000	12,000	25,000
April	1.51	3.11	4.62	SW	1.5	8.4	13,000	13,000	26,000
May	1.08	2.12	3.20	S	1.7	5.9	12,000	13,000	25,000
June	0.98	1.29	2.27	S	1.1	5.9	14,000	14,000	28,000
Mean[b]	1.57	2.02	3.59	--	--	--	13,000	13,000	26,000

[a] Northbound plus southbound.

[b] Time weighted.

NA = No traffic data for July, traffic recorders were installed in August, 1981.

Metric units: To convert lb/mi to kg/km multiply by 0.2819.
To convert mi to km multiply by 1.609.

of the four sites. Therefore, it is not surprising that Efland also had the lowest overall saltation rates, again indicating that saltation is related to traffic volume. ADT for opposing traffic directions during the monitoring period was identical for most months. However, average monthly saltation rates for northbound and southbound travel lanes were significantly different for many months indicating that traffic volume alone does not completely explain the variation in saltation rates.

Resultant wind direction appears to account for some of the variation in average monthly saltation rate. Whenever the resultant wind direction is south or southwest the average monthly saltation rate is highest on the north side of the highway (southbound travel lanes). For those months with a neutral wind direction, northwest or west, saltation rates were similar for northbound and southbound travel lanes. During February, 1982 wind direction was out of the north and saltation was highest on the south side of the highway (northbound travel lanes). During October, 1981 resultant wind direction was also north but saltation was lowest on the south side of the highway. However, unlike February, southbound (northside) ADT was higher than northbound.

Similar to Milwaukee and Harrisburg, average monthly saltation rates are higher during winter and spring months at Efland (December through April). These months were characterized by high average wind speeds compared to summer and fall months.

An order of magnitude comparison of total highway saltation (both directions) between the four monitoring sites is possible if the westbound mean saltation rate for Sacramento and the northbound right-of-way mean saltation rate for Harrisburg are doubled, and if nonwinter influenced months (June through October) are used for Milwaukee, Efland and Harrisburg. The resulting saltation rates and site characteristics are presented in Table 25. The data show that Milwaukee and Sacramento have comparable saltation rates. Based upon average daily traffic, Milwaukee should have a higher saltation rate than Sacramento. However, the curb and gutter drainage design at Milwaukee may prevent a portion of the saltation load from reaching the right-of-way area. Harrisburg and Efland, with low average daily traffic and flush shoulder drainage designs, did have lower saltation rates than Milwaukee and Sacramento. Order of magnitude estimates for annual saltation loads to the right-of-way areas, based upon the overall mean saltation rates observed during the monitoring period at each site, were calculated to be; 14,000 lb/mi/yr (3,900 kg/km/yr) at Milwaukee, 14,000 lb/mi/yr (3,900 kg/km/yr) at Sacramento and 3,700 lb/mi/yr (1,000 kg/km/yr) at Harrisburg and 1,300 lb/mi/yr (370 kg/km/yr) at Efland.

The results of regression analyses to determine if a correlation (95 percent confidence level) exists between selected metals and saltating particles at the monitoring sites are listed in Table 26. The data indicate that when metals are present in detectable quantities they are generally significantly correlated with saltating particulates (r value greater than the

Table 25. Mean monthly saltation rates [a] and site characteristics for all monitoring sites.

Site	Total particulates, lb/mi/day	Average daily traffic, vehicles per day [b]	Highway drainage design
Milwaukee I-94	33.1	115,000	Curb and gutter
Sacramento Hwy 50	39.2	90,000	Flush shoulder
Harrisburg I-81	4.12	32,000	Flush shoulder
Efland I-85	2.42	27,000	Flush shoulder

[a] Nonwinter influenced months: Milwaukee, Efland, and Harrisburg - June through October.
Sacramento - January through December

[b] Both directions for the nonwinter influenced months.

Metric units: To convert lb/mi/day to kg/km/day multiply by 0.2819.

Table 26. Correlation between selected metals and total particulates (saltating particles).

Site	Parameter	$r > r_{crit}$ [a]	Number of observations
Milwaukee I-94	Pb	yes	19
	Zn	yes	11
	Fe	yes	19
	Cr	no	12
	Ni	yes	14
Sacramento Hwy. 50	Pb	yes	6
	Zn	yes	6
	Fe	yes	6
	Cr	no	6
	Cd[b]	no[b]	6
	Ni	no	6
Harrisburg I-81	Pb	yes	4
	Zn	yes	4
	Fe	yes	4
	Cr	yes	4
	Cd	yes	4
	Ni	ND	4
Efland I-85	Pb	no	4
	Zn	yes	4
	Fe	no	4
	Cr	no	4
	Cd	ND	4
	Ni	ND	4

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[a] Ninety-five percent confidence interval.
[b] Two of the six values were nondetectable.
ND = At least half the values were nondetectable.

critical value). On a strict statistical basis, significantly correlated means that the null hypothesis, r = 0 (i.e. that the data is from a population for which no correlation exists) can be rejected at the 95 percent confidence level. It is interesting that the lowest ADT site, Efland, was the only site for which lead did not correlate to saltating particles.

Concentrations for selected metals associated with saltating particles are presented in Table 27. Lead, a vehicle related pollutant, was highest at Milwaukee, intermediate at Sacramento and lowest at Efland and Harrisburg. These data indicate that the quantity of lead associated with saltating particles is related to site average daily traffic. Iron concentrations associated with saltating particles followed the same general trend. However, zinc, chromium and cadmium concentrations were highest at Harrisburg and the nickel concentration was highest at Sacramento.

In summary, the data collected at the four monitoring sites indicate that the quantity of saltating particles reaching the right-of-way area is related to:

1. Average daily traffic.
2. Wind speed and direction.
3. Available surface load (seasonal variations).
4. Highway drainage design.
5. Proximity of travel lanes to right-of-way area.
6. Landscape features near the highway affecting wind patterns.

The data also indicate that a correlation exists between metals and saltating particles, and that the quantity of lead and iron associated with saltating particles is related to average daily traffic.

Bulk Precipitation--

Bulk precipitation monitoring schemes used at Milwaukee (Figures 1 and 2), Sacramento (Figure 3), Harrisburg (Figure 4), and Efland (Figure 5) were described earlier in Section II. These monitoring schemes were devised to determine the quantity of TPM (total particulate matter) transport from the paved highway surface to areas adjacent to the highway through the atmosphere by blow-off due to wind and vehicular turbulence. The area adjacent to the highway receiving TPM originating from the highway surface is defined as that area (impacted area) for which monitored bulk precipitation exceeds background levels. Before TPM loading to the impacted area could be calculated, the boundary (distance from edge of pavement) of the impacted area had to be defined.

Bulk precipitation loading data (g/m^2/day) monitored by ground level collectors were graphed as a function of linear distance (meters) from the

Table 27. Concentration of selected metals associated with saltating particles.

Site	Lead, mg/kg		Zinc, mg/kg		Iron, mg/kg	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	3320-8600	4960	444-1710	792	34300-55000	44700
Sacramento Hwy 50	1190-2300	1550	172-228	191	25000-29700	27500
Harrisburg I-81	849-1600	1260	1200-2500	1880	19900-30000	26300
Efland I-85	731-1500	1030	246-350	285	11900-29900	20900
	Chromium mg/kg		Cadmium, mg/kg		Nickel, mg/kg	
Milwaukee I-94	30.8-245	86.5		NA	34.2-107	55.3
Sacramento Hwy 50	29.3-59.5	47.8	ND-6.29	ND	46.5-739	207
Harrisburg I-81	55.2-204	111	8.51-14.0	10.6	ND-64.0	ND
Efland I-85	19.0-49.0	31.8	ND	ND	ND-20	ND

NA = No analysis performed.
ND = Not detectable.

edge of highway pavement for Milwaukee (Figure 6), Sacramento (Figure 7), Harrisburg (Figure 8) and Efland (Figure 9). The squares (☐) represent average monthly TPM loading values for each collector location in the monitoring scheme. The curve on each graph is the best-fit curve generated by regression analysis of individual collector loading values (log transformed data). Split graphs were used to show TPM removal from both sides of the paved highway (center area on graph) for Milwaukee, Sacramento and Efland, and both sides of the northbound travel lanes (center area on graph) for Harrisburg. These graphs were developed to visually define the impacted areas at each site.

The Milwaukee I-94 data (Figure 6) show that atmospheric deposition of highway generated TPM to areas adjacent to the highway drops sharply within the first 10 m from edge of pavement, and approaches background levels (0.13 $g/m^2/day$) at approximately 30 to 40 m from edge of pavement. Background dustbuckets at Milwaukee were located approximately 300 m from the edge of highway pavement. Background data points were not included on the graph because the scale required on the horizontal axis to include background points would obscure the information provided by the first 50 m from edge of highway pavement which are most critical to the analysis. However, the best fit curve does represent the background data points. The regression coefficient (R^2 value) for the resultant curve is 0.87, which means that 87 percent of the variation in TPM deposition is explained by distance from the edge of highway surface. The scatter of data points is greatest near the highway indicating that TPM deposition nearest the paved surface is the most sensitive to the variables affecting TPM removal from the highway surface. These variables which include average daily traffic, wind speed and direction, and seasonal variations probably account for a large portion of the unexplained variance and will be discussed later in this section.

The Sacramento Hwy 50 data (Figure 7) also show that atmospheric deposition of highway generated TPM to areas adjacent to the highway drop sharply within the first 10 m from the edge of pavement, and approach background levels (0.16 $g/m^2/day$) at 35 to 45 m from the edge of pavement. The regression coefficient (R^2 value) for the resultant curve is 0.82 and again, the widest scatter of data points is nearest the highway.

The Harrisburg I-81 and Efland I-85 data (Figure 8 and 9) show that atmospheric deposition of highway generated TPM to areas adjacent to the highway drop to background levels (0.03 $g/m^2/day$) within the first 10 to 20 m from the edge of pavement. The regression coefficient (R^2 value) for the resultant curve is 0.80 at Harrisburg and 0.74 at Efland. Similar to Milwaukee and Sacramento the widest scatter of data points at these two sites is nearest the highway.

Metals associated with bulk precipitation follow the same general pattern observed for TPM deposition in areas adjacent to the highway at the four sites monitored. As an example, graphs for lead deposition at the four sites for selected months are presented in Figures 10 through 13. Figure 10 shows that

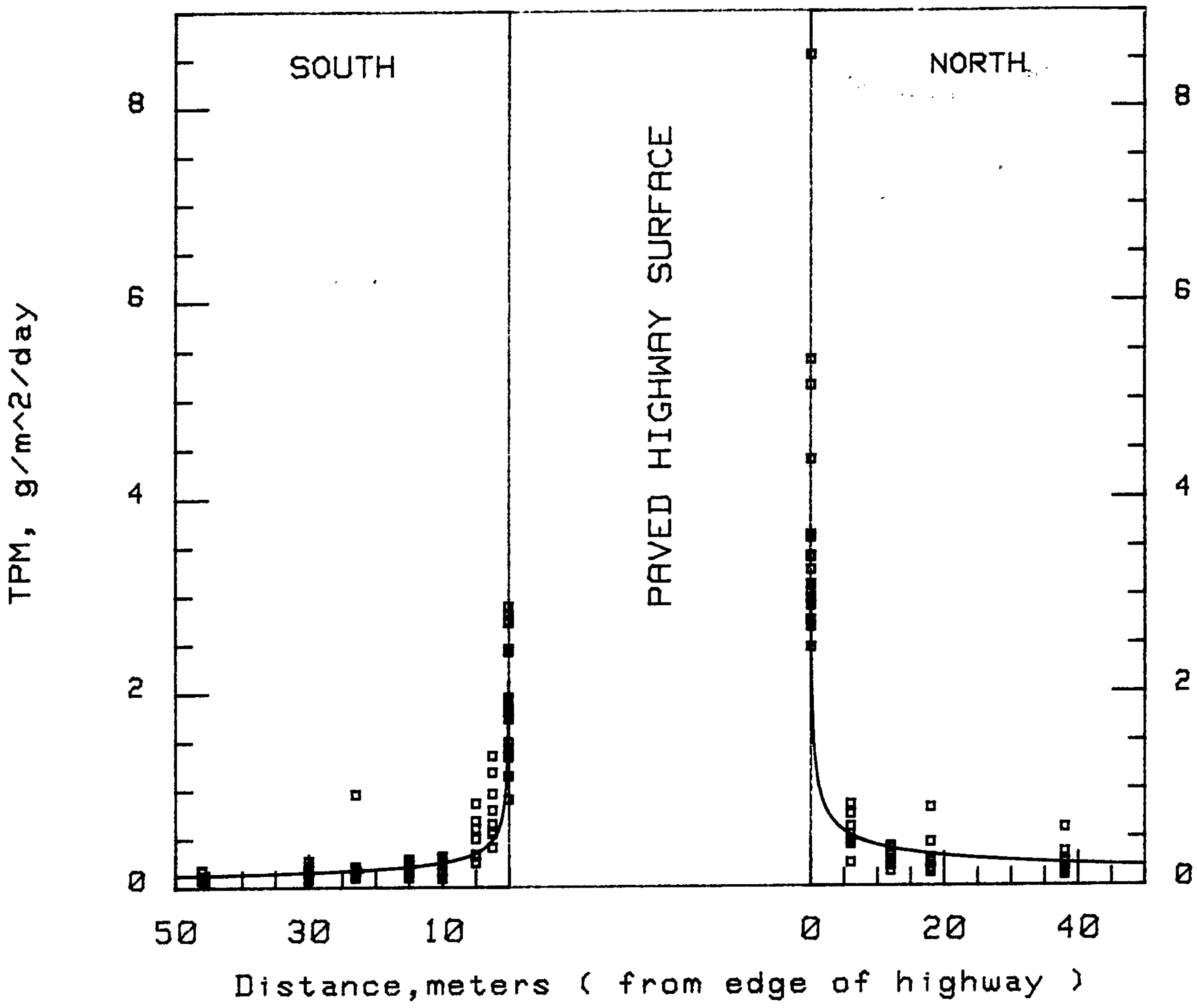


Figure 6. TPM deposition on areas adjacent to the paved highway surface - Milwaukee I-94.

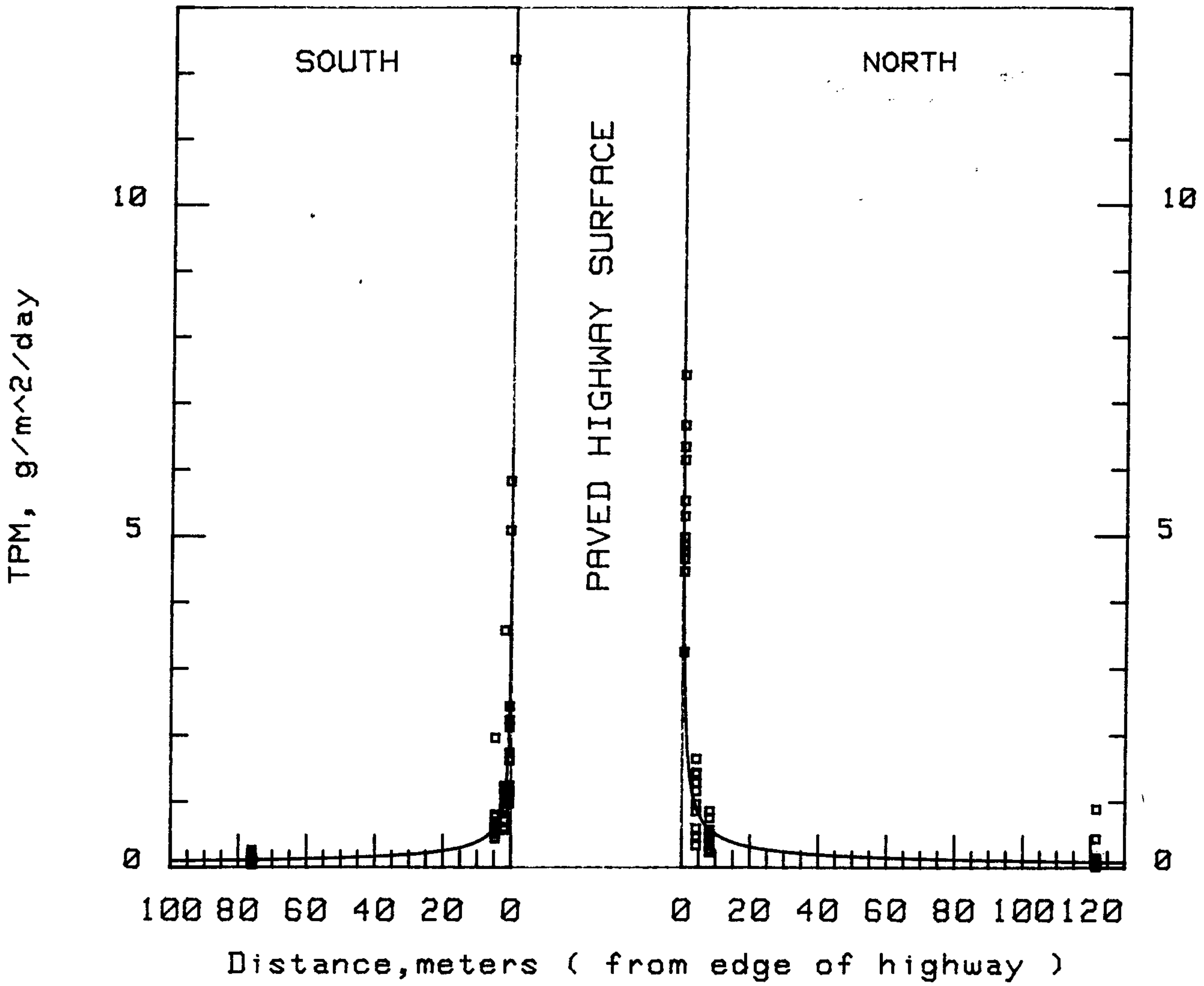


Figure 7. TPM deposition on areas adjacent to the paved highway surface - Sacramento Hwy 50.

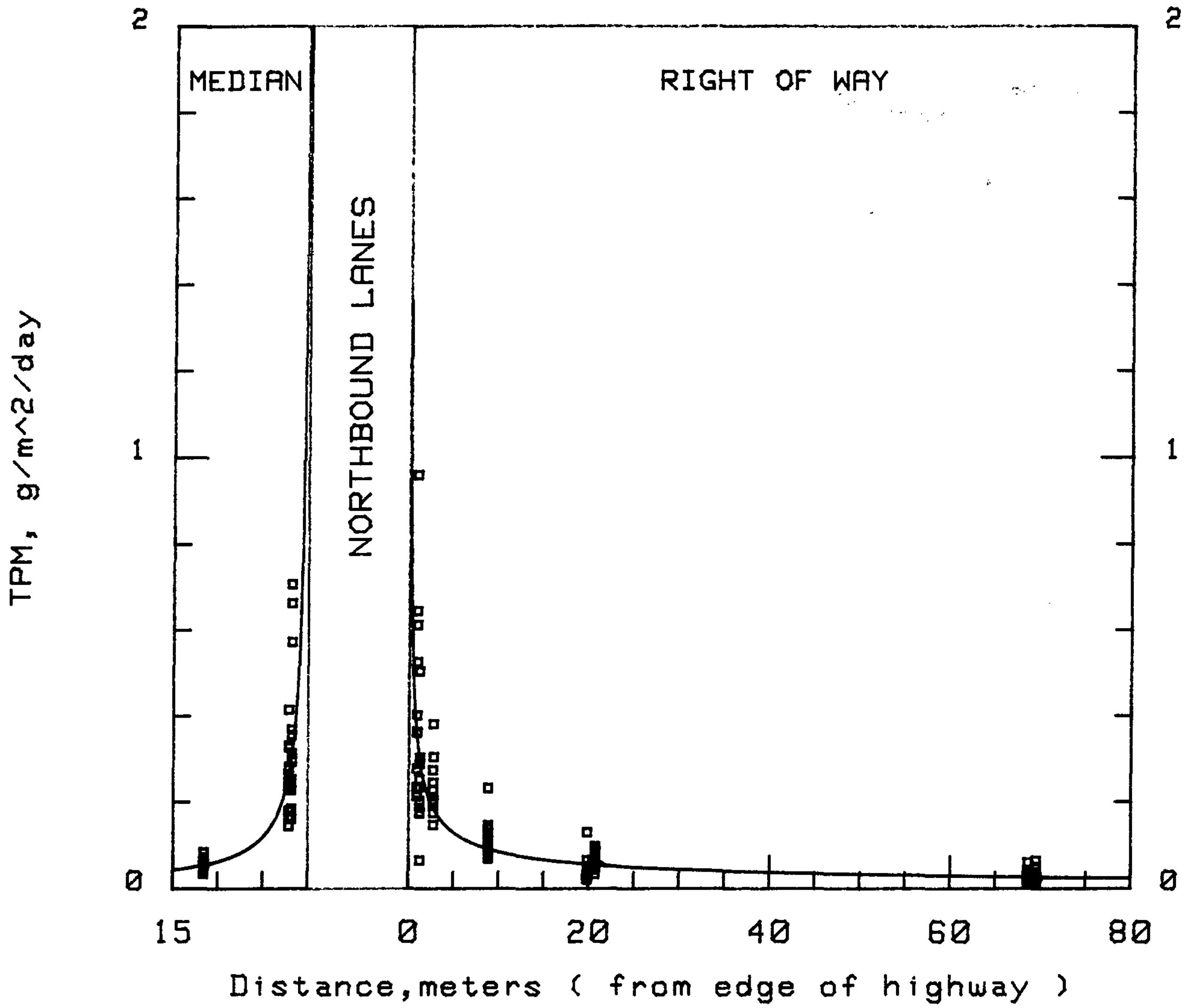


Figure 8. TPM deposition on areas adjacent to the paved highway surface - Harrisburg I-81.

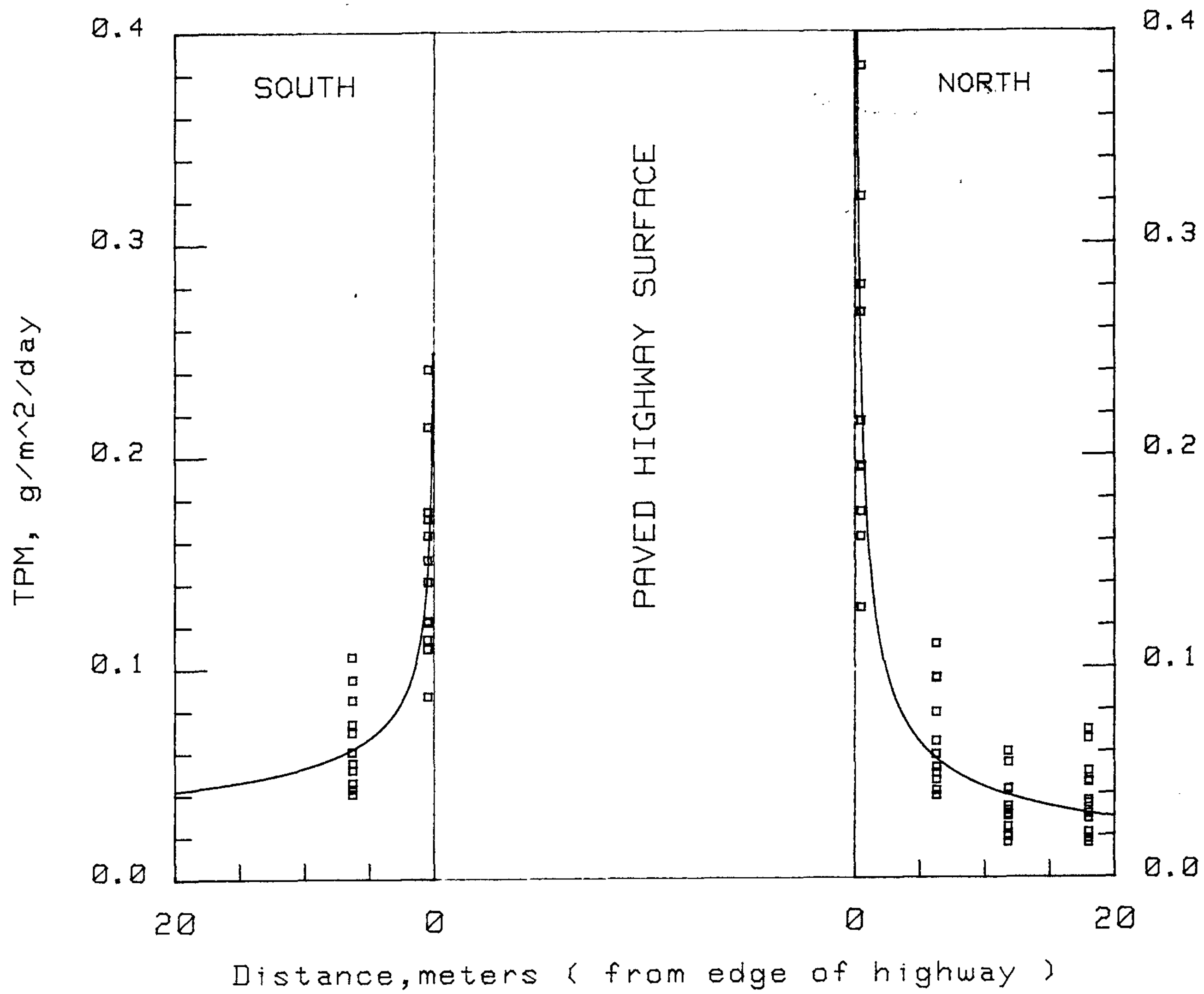


Figure 9. TPM deposition on areas adjacent to the paved highway surface - Efland I-85.

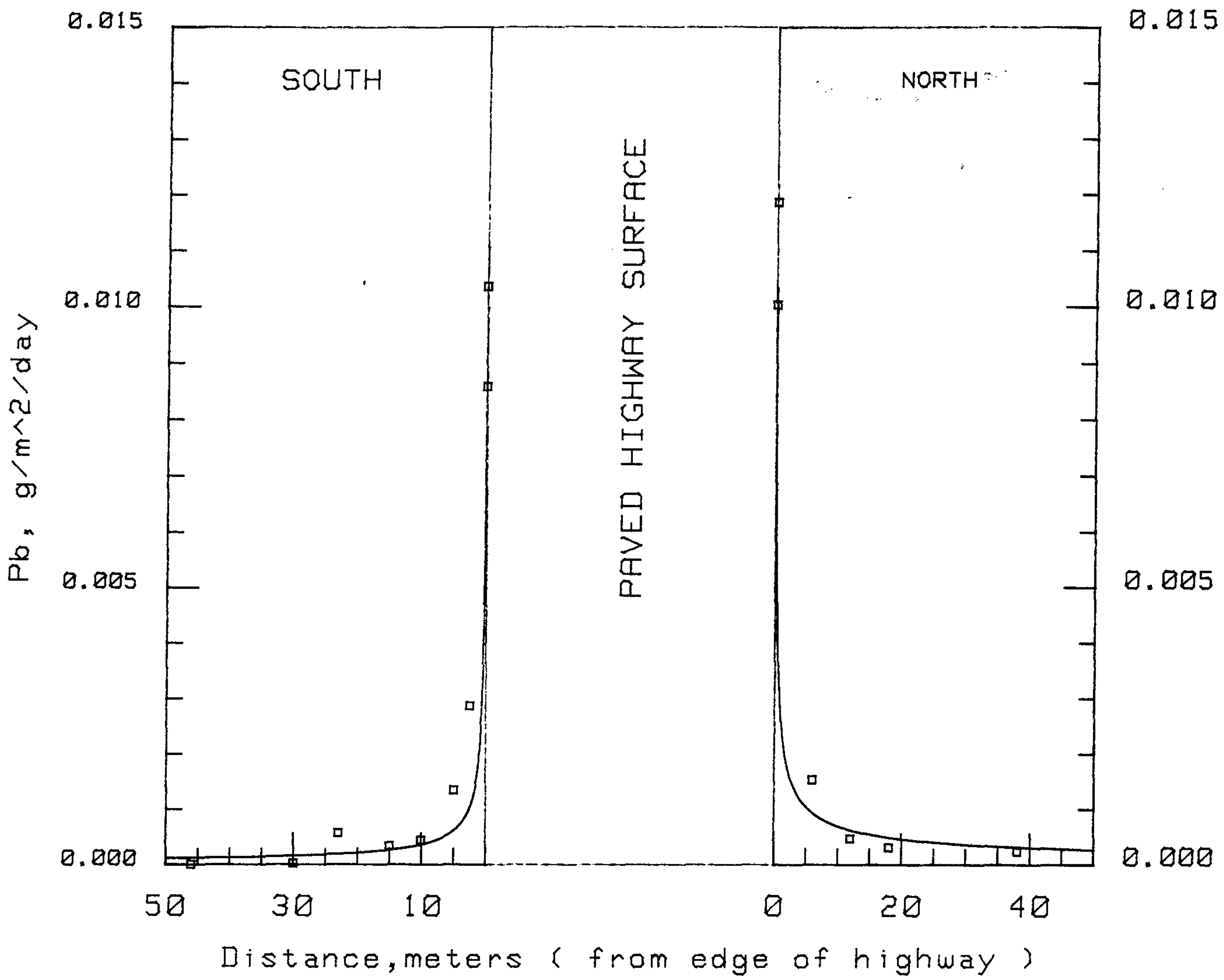


Figure 10. Lead deposition on areas adjacent to the paved highway surface, July 1979 - Milwaukee I-94.

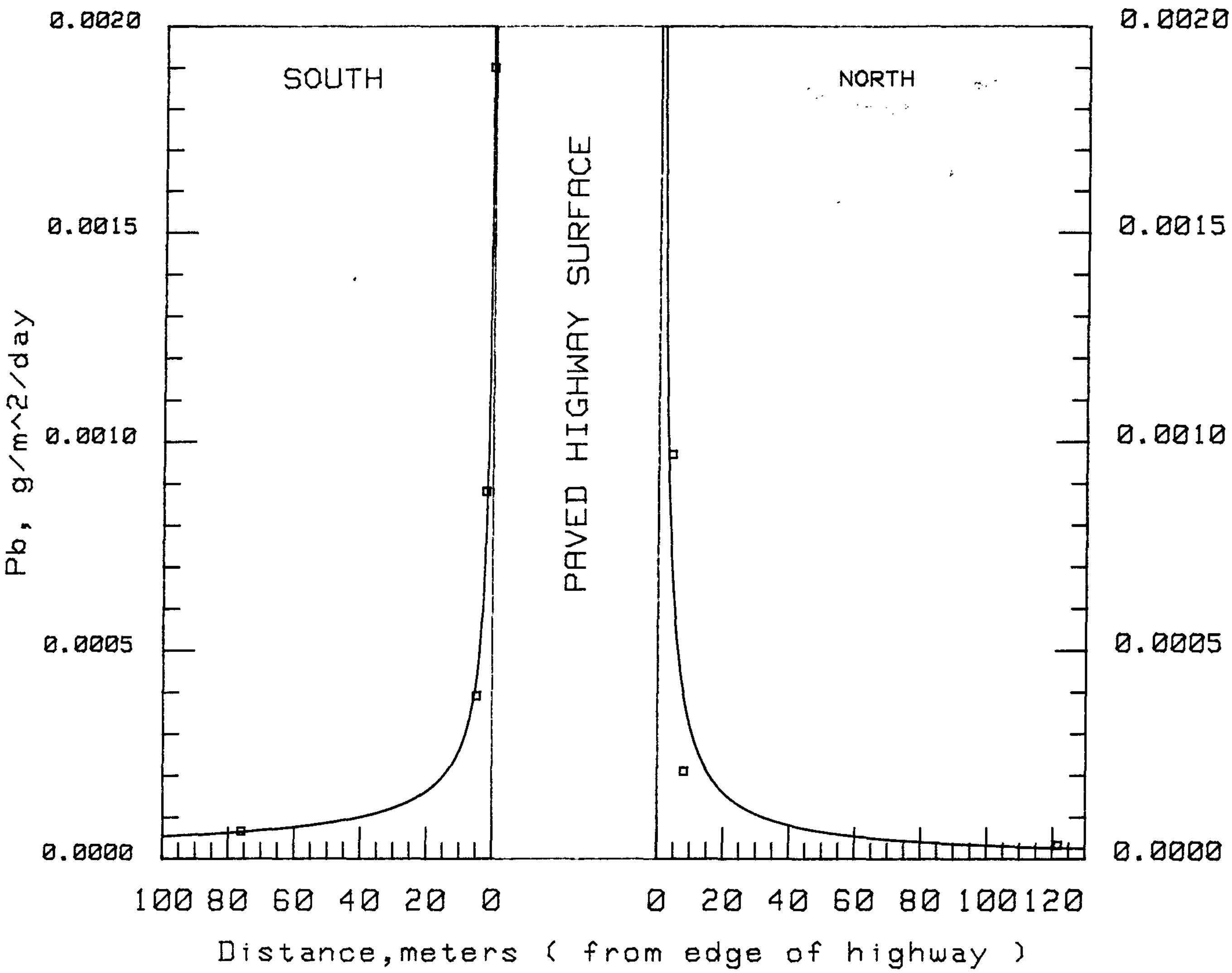


Figure 11. Lead deposition on areas adjacent to the paved highway surface, June 1980 - Sacramento Hwy 50.

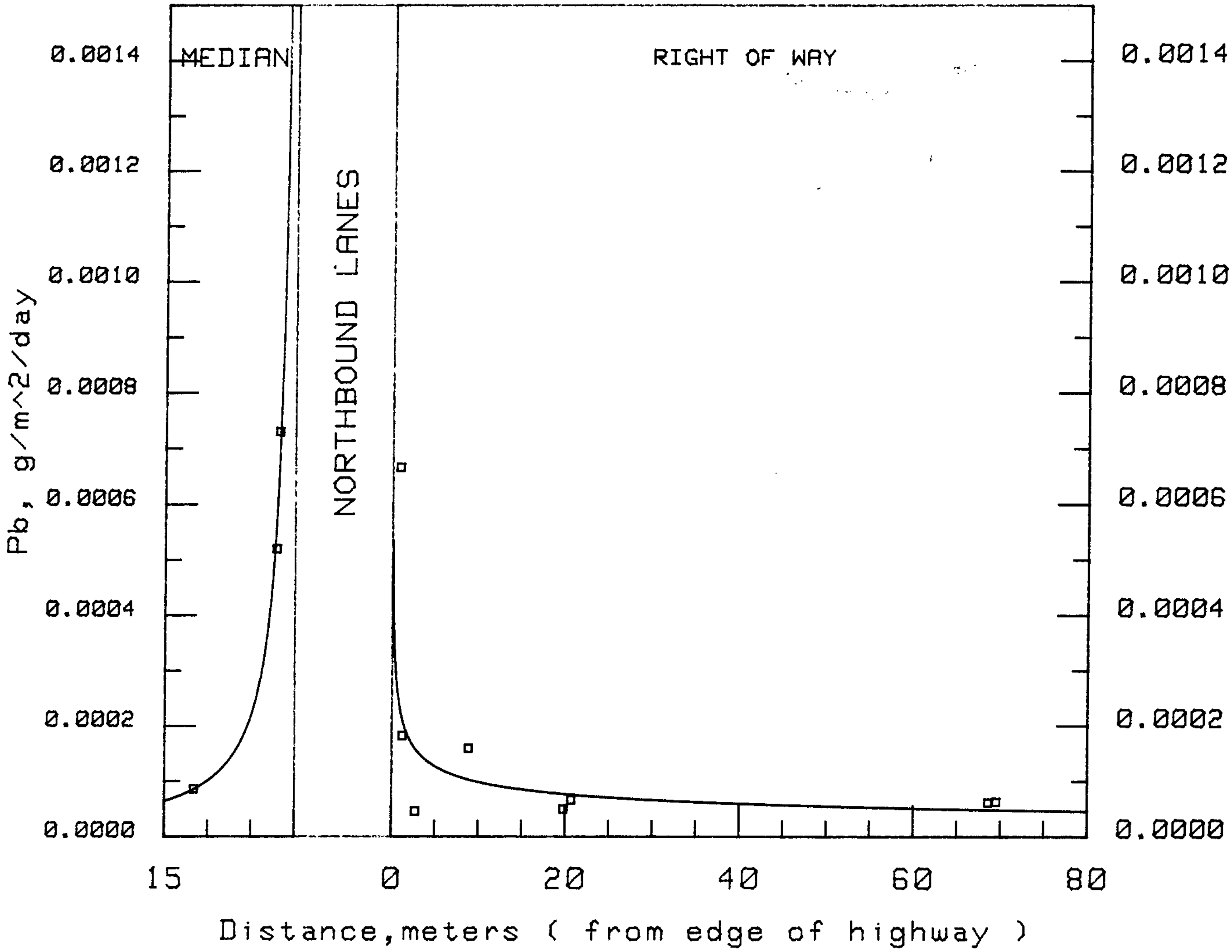


Figure 12. Lead deposition on areas adjacent to the paved highway surface, February 1980 - Harrisburg I-81.

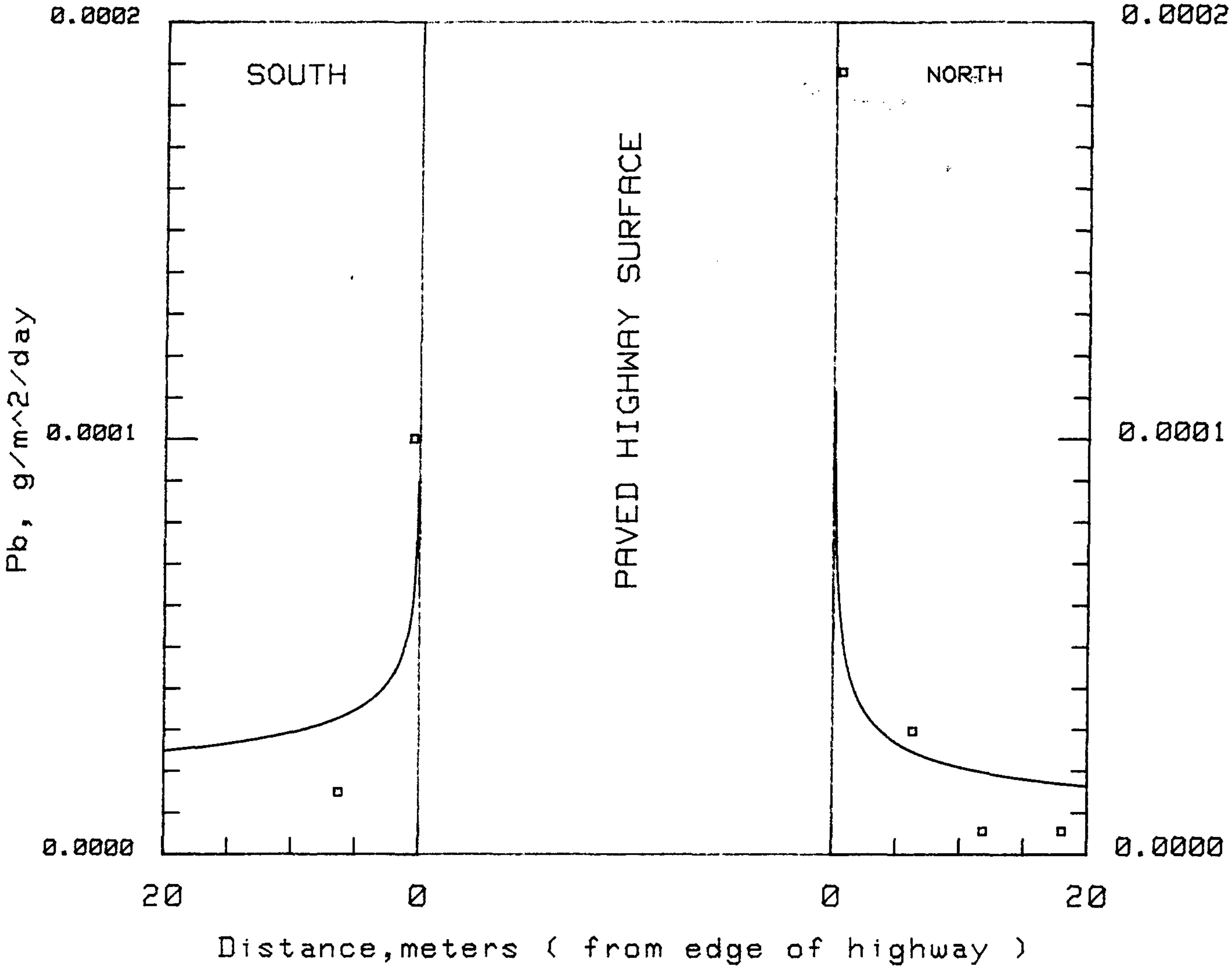


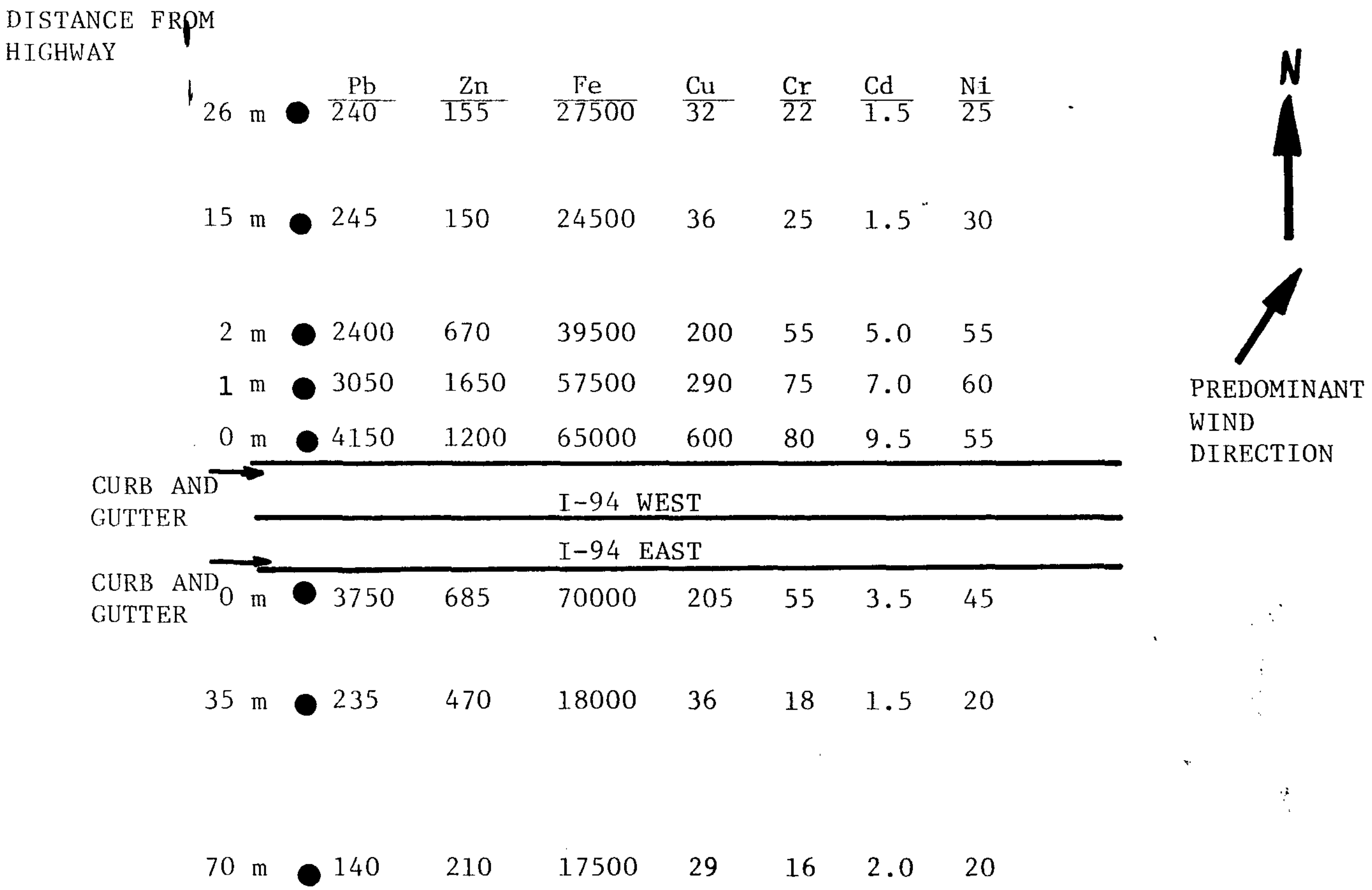
Figure 13. Lead deposition on areas adjacent to the paved highway surface, April 1982 - Efland I-85.

at Milwaukee lead drops sharply within the first 10 m from edge of pavement, and approaches background levels at approximately 30 to 40 m from edge of pavement. At Sacramento, lead drops sharply within the first 10 m from edge of pavement, and approaches background levels at 50 to 60 m from edge of pavement (Figure 11). At Harrisburg (Figure 12), lead approaches background at 15 to 25 m from the edge of pavement, and at 10 to 20 m at Efland (Figure 13).

Accumulation of highway related metals from atmospheric deposition should be reflected in the topsoil layer of areas adjacent to the highway. To support the bulk precipitation data collected at the four monitoring sites and to better define the impacted areas, the top centimeter of soil was sampled along a transect crossing the right-of-ways at each site monitored including the median area (if present) and the unpaved areas on either side of the highway. These soil samples were then analyzed for selected metals. This study is especially important to define the impact area boundary at Sacramento where ground level dustbucket installations were not possible in the area 8 m from edge of pavement to background.

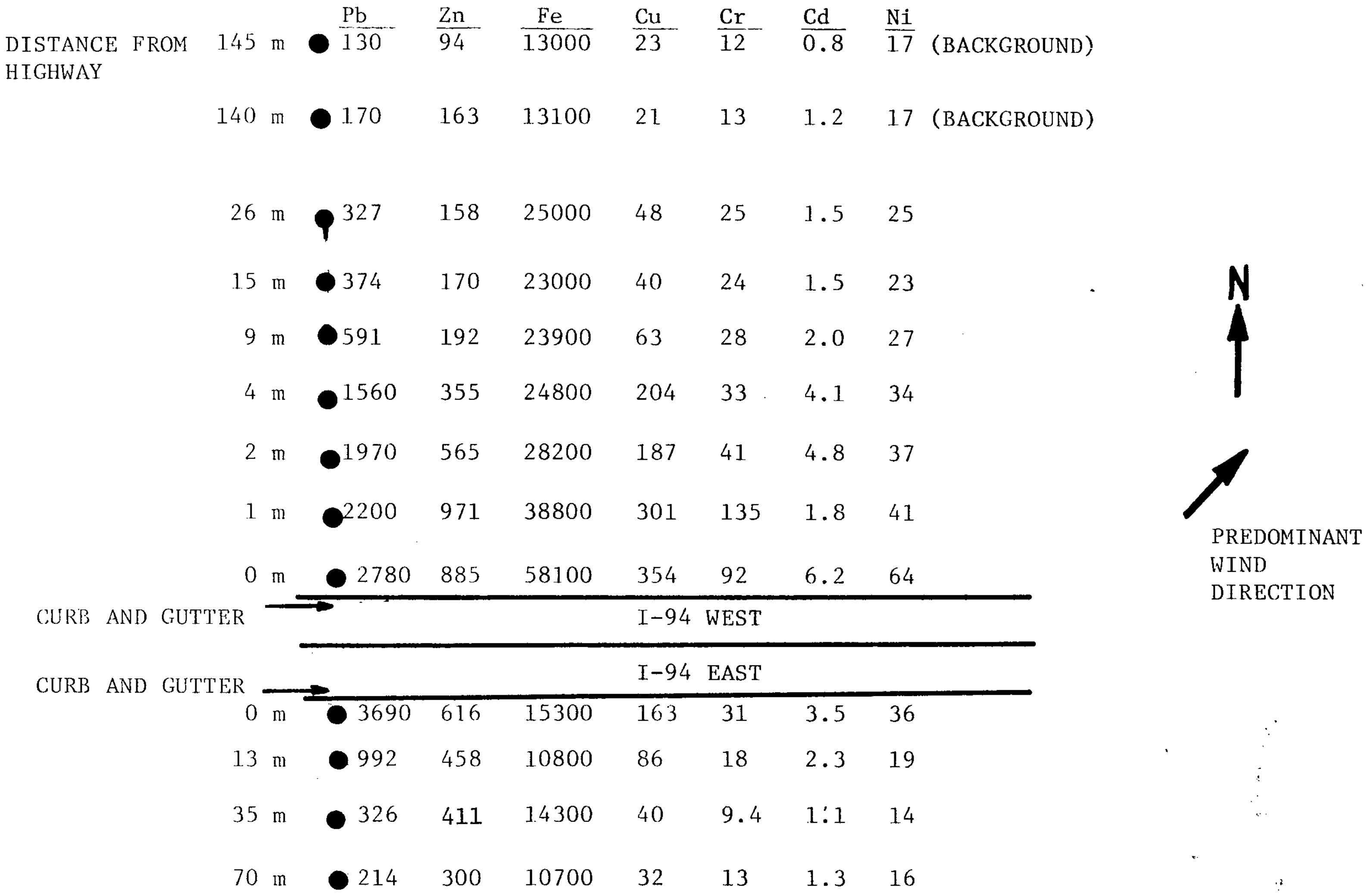
On July 17, 1979, September 12, 1979 and May 8, 1980 the top centimeter of soil was sampled along a transect crossing the Milwaukee I-94 right-of-way. The July study was the initial attempt to define metal concentrations in the top centimeter of soil (Figure 14). Based upon the results of the July study, five sampling points were added to the September study (Figure 15) to better define the area of metals contamination. Additional sampling points included three on the transect (13 m south of I-94, 4 m north of I-94 and 9 m north of I-94) and two background samples. The May study (Figure 16) was performed to verify the results of the September study. The shaded circles on each figure represent the sampling point. To the left of each point is the distance from edge of pavement and to the right of each point are the metals analysis results.

In general, the Milwaukee data show that metal concentrations in the top centimeter of soil are highest near the highway and that these concentrations decrease rapidly within the first 9 m and reach background levels at approximately 35 m from the paved surface. This pattern is similar to that observed for TPM deposition (Figure 6). The Milwaukee data (Figures 14, 15 and 16) also show that the concentrations of zinc, copper, chromium, cadmium and nickel are generally much higher for the northern near-highway soil samples than for the southern near-highway soil samples which indicates that the predominant wind direction may be an important factor in the distribution of these metals within the Milwaukee I-94 ROW. The Milwaukee I-94 data (Figures 15, 16 and 17) also suggest that the Menomonee Industrial Valley which lies just south of the study area may be a source of zinc contamination. Zinc concentrations at 35 and 70 m south of I-94 consistently exceed background levels and are higher than at the 26 m sampling point north of I-94. Again, this may be a function of the prevailing winds which carry the zinc out of the Menomonee Industrial Valley and deposit it in the southern right-of-way.



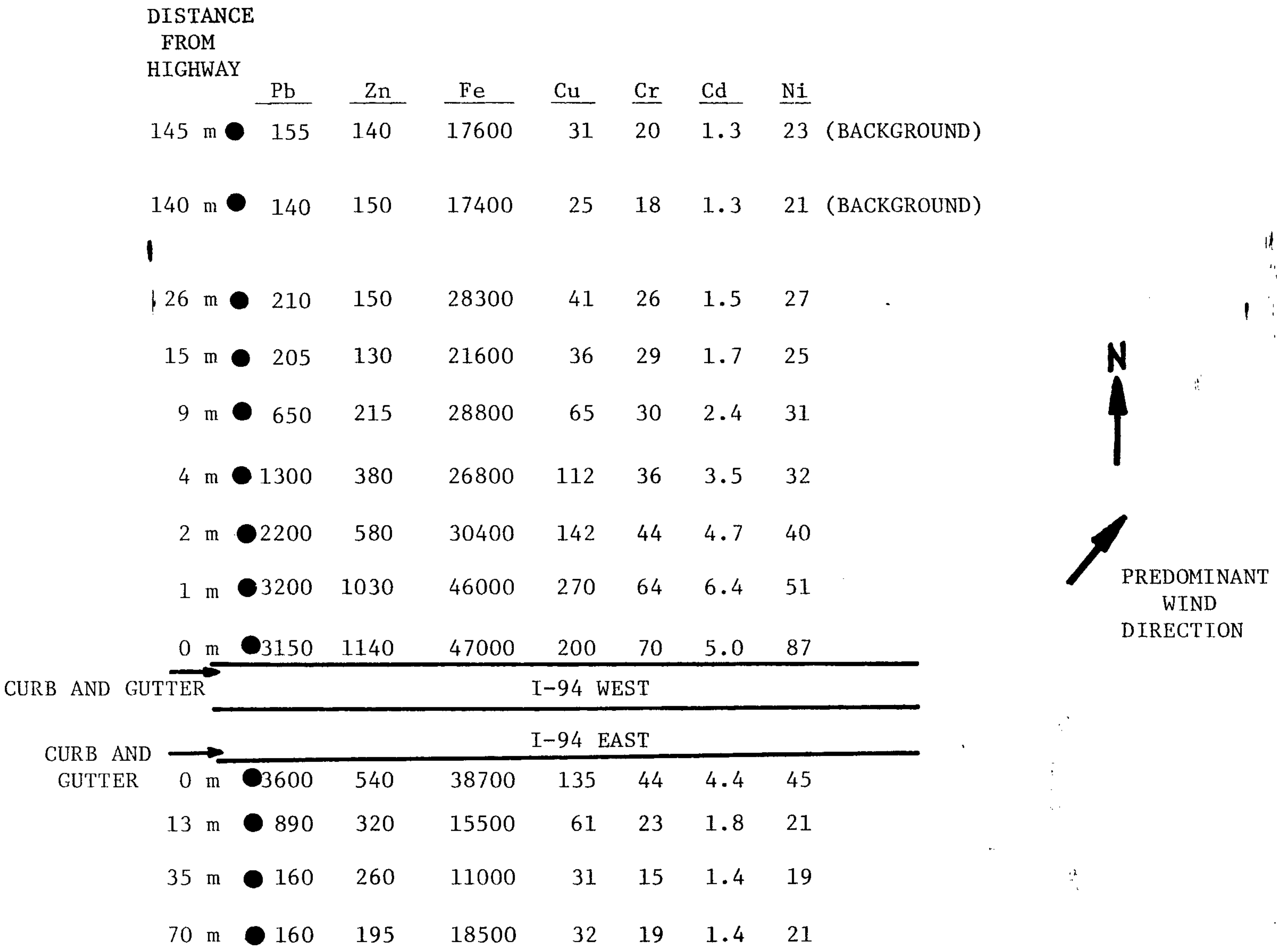
DISTANCE FROM HIGHWAY	Pb	Zn	Fe	Cu	Cr	Cd	Ni
26 m ●	240	155	27500	32	22	1.5	25
15 m ●	245	150	24500	36	25	1.5	30
2 m ●	2400	670	39500	200	55	5.0	55
1 m ●	3050	1650	57500	290	75	7.0	60
0 m ●	4150	1200	65000	600	80	9.5	55
0 m ●	3750	685	70000	205	55	3.5	45
35 m ●	235	470	18000	36	18	1.5	20
70 m ●	140	210	17500	29	16	2.0	20

Figure 14. **Distribution of selected metals (mg/kg) within the top 1 cm of soil at the Milwaukee I-94 monitoring site - July 17, 1979.**



DISTANCE FROM HIGHWAY	Pb	Zn	Fe	Cu	Cr	Cd	Ni	
145 m	130	94	13000	23	12	0.8	17	(BACKGROUND)
140 m	170	163	13100	21	13	1.2	17	(BACKGROUND)
26 m	327	158	25000	48	25	1.5	25	
15 m	374	170	23000	40	24	1.5	23	
9 m	591	192	23900	63	28	2.0	27	
4 m	1560	355	24800	204	33	4.1	34	
2 m	1970	565	28200	187	41	4.8	37	
1 m	2200	971	38800	301	135	1.8	41	
0 m	2780	885	58100	354	92	6.2	64	
CURB AND GUTTER								
I-94 WEST								
I-94 EAST								
CURB AND GUTTER								
0 m	3690	616	15300	163	31	3.5	36	
13 m	992	458	10800	86	18	2.3	19	
35 m	326	411	14300	40	9.4	1.1	14	
70 m	214	300	10700	32	13	1.3	16	

Figure 15. **Distribution of selected metals (mg/kg) within the top 1 cm of soil at the Milwaukee I-94 monitoring site - September 12, 1979.**



DISTANCE FROM HIGHWAY	Pb	Zn	Fe	Cu	Cr	Cd	Ni	
145 m ●	155	140	17600	31	20	1.3	23	(BACKGROUND)
140 m ●	140	150	17400	25	18	1.3	21	(BACKGROUND)
26 m ●	210	150	28300	41	26	1.5	27	
15 m ●	205	130	21600	36	29	1.7	25	
9 m ●	650	215	28800	65	30	2.4	31	
4 m ●	1300	380	26800	112	36	3.5	32	
2 m ●	2200	580	30400	142	44	4.7	40	
1 m ●	3200	1030	46000	270	64	6.4	51	
0 m ●	3150	1140	47000	200	70	5.0	87	

CURB AND GUTTER

I-94 WEST

I-94 EAST

CURB AND GUTTER

DISTANCE FROM HIGHWAY	Pb	Zn	Fe	Cu	Cr	Cd	Ni
0 m ●	3600	540	38700	135	44	4.4	45
13 m ●	890	320	15500	61	23	1.8	21
35 m ●	160	260	11000	31	15	1.4	19
70 m ●	160	195	18500	32	19	1.4	21

Figure 16. Distribution of selected metals (mg/kg) within the top 1 cm of soil at the Milwaukee I-94 monitoring site - May 8, 1980.

	DISTANCE FROM HIGHWAY	Pb	Zn	Fe	Cu	Cr	Cd	Ni	
	122 m ●	41	97	30300	41	84	1.3	51	(BACKGROUND)
	35 m ●	38	75	30100	43	51	1.0	74	
	15 m ●	129	103	39100	41	60	1.2	83	
	9 m ●	416	327	24000	59	37	1.2	59	
RIGHT-OF-WAY FENCE (8.7 m)									
DRAINAGE DITCH BOTTOM	3.5 m ●	765	128	30900	64	51	1.3	71	
DRAINAGE DITCH SLOPE	2 m ●	230	126	34500	64	62	1.0	85	
DRAINAGE DITCH SLOPE	1 m ●	316	91.2	39800	55	55	0.9	77	
	0 m ●	932	168	39100	69	54	2.0	75	FLUSH SHOULDER
HWY 50 - WESTBOUND									
HWY 50 - EASTBOUND									FLUSH SHOULDER
	0 m ●	1580	511	26300	74	47	5.1	74	
	15 m ●	72	185	25200	57	57	0.9	72	
	35 m ●	40	134	28600	70	55	1.2	75	
	122 m ●	41	127	31300	52	57	1.3	75	(BACKGROUND)

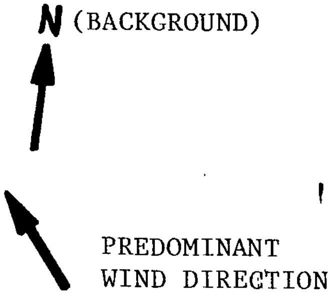


Figure 17. Distribution of selected metals (mg/kg) within the top 1 cm of soil at the Sacramento, Hwy 50 monitoring site - March 26, 1980.

On March 26, 1980, the top centimeter of soil was sampled along a transect crossing the Sacramento Hwy 50 right-of-way including the unpaved areas north and south of the highway (Figure 17). Similar to the Milwaukee data, the Sacramento data show that the metal concentrations in the top centimeter of soil are generally highest near the highway and that these concentrations decrease rapidly within the first 9 to 15 m, reaching background at approximately 35 m from the paved surface. This pattern is similar to that observed for TPM deposition (Figure 7). The data also indicate a buildup of lead in the bottom of the drainage ditch (3.5 m) and a corresponding decrease in the lead concentrations on the side slope of the drainage ditch (1 and 2 m). Apparently, lead concentrations in the bottom and side slopes of the drainage ditch are a function of both dustfall and runoff.

On September 9, 1980 the top centimeter of soil was sampled along a transect crossing the Harrisburg, I-81 right-of-way including the unpaved area north and south of the highway, and the grassy area in the median (Figure 18). Harrisburg data show that the metal concentrations in the top centimeter of soil are highest near the highway and that these concentrations decrease rapidly within the first 4 m and reach background levels at approximately 15 m. Even at the midpoint of the median grassy area (11 m) which is bordered by the north and southbound travel lanes, the metal concentrations are at or near background levels (Figure 18). This pattern is similar to that observed for TPM deposition (Figure 8).

On December 6, 1981 the top centimeter of soil was sampled along a transect crossing the Efland I-85 right-of-way including the unpaved area north and south of the highway, and the grassy area in the median (Figure 19). The Efland soils data do not display the distinct patterns observed at the other three sites. This is probably a function of the overall low metals concentrations observed at this site. However, metals concentrations, especially lead and zinc, are highest near the paved highway surface and metals concentrations approach background levels at approximately 6 to 12 m. Except for chromium and nickel, it appears that predominant wind direction may play a role in metals accumulation in areas adjacent to the highway.

Based upon TPM and associated metals deposition, and upon data from the one centimeter soil study, impact area is defined to be approximately 35 m from the edge of pavement at Milwaukee, 35 m at Sacramento, and 15 m at Harrisburg and 12 m at Efland. The smaller impact areas at Harrisburg and Efland compared to Milwaukee and Sacramento are probably a function of average daily traffic (27,800 and 25,500 vehicles per day at Harrisburg and Efland to 116,000 and 85,900 vehicles per day at Milwaukee and Sacramento).

Once the width of the area adjacent to the highway receiving TPM and associated metals originating from the highway surface was defined, total loadings (lb/mi/day) to these areas could be calculated. For Milwaukee, trapazoidal grid system was used to approximate the impacted area within the monitoring site boundaries. Trapazoids provide a realistic grid pattern because the sides of the trapazoids are perpendicular to the edge of the

DISTANCE FROM HIGHWAY	Pb	Zn	Fe	Cu	Cr	Cd	Ni
0 m ●	1750	860	20000	70	35	4.0	47
FLUSH SHOULDER			I-81 SOUTHBOUND				
0 m ●	3250	568	23000	81	129	4.0	58
11 m ●	90	83	21000	20	32	0.7	30
0 m ●	1500	386	19000	72	72	3.6	37
FLUSH SHOULDER			I-81				
0 m ●	1600	379	18000	118	29	4.2	47
1 m ●		779	16000	62	25	3.8	27
2 m ●	253	227	27000	39	21	1.6	29
4 m ●	41	76	24000	24	25	0.5	32
9 m ●	97	80	22000	28	22	0.7	36
15 m ●	76	92	23000	23	26	0.8	35
35 m ●	68	89	21000	20	21	0.8	37
61 m ●	80	82	22000	15	20	0.8	40
BACKGROUND							

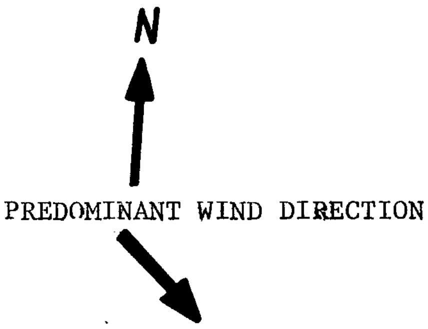
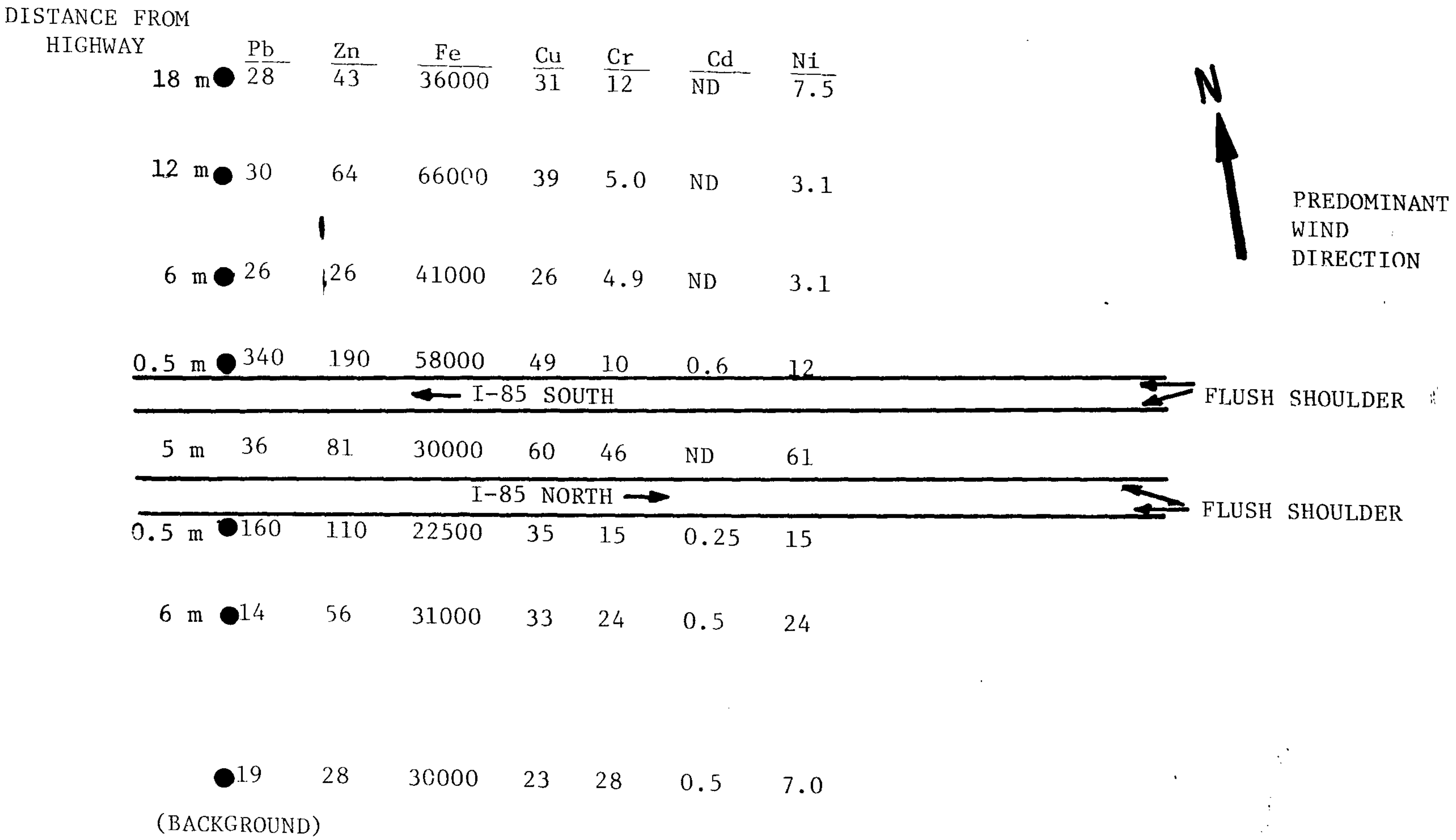


Figure 18. Distribution of selected metals (mg/kg) within the top 1 cm of soil at the Harrisburg I-81 monitoring site - September 9, 1980.



DISTANCE FROM HIGHWAY	Pb	Zn	Fe	Cu	Cr	Cd	Ni
18 m	28	43	36000	31	12	ND	7.5
12 m	30	64	66000	39	5.0	ND	3.1
6 m	26	26	41000	26	4.9	ND	3.1
0.5 m	340	190	58000	49	10	0.6	12
5 m	36	81	30000	60	46	ND	61
0.5 m	160	110	22500	35	15	0.25	15
6 m	14	56	31000	33	24	0.5	24
(BACKGROUND)	19	28	30000	23	28	0.5	7.0

ND = Not detectable.

Figure 19. Distribution of selected metals (mg/kg) within the top 1 cm of soil at the Efland I-85 monitoring site - December 6, 1981.

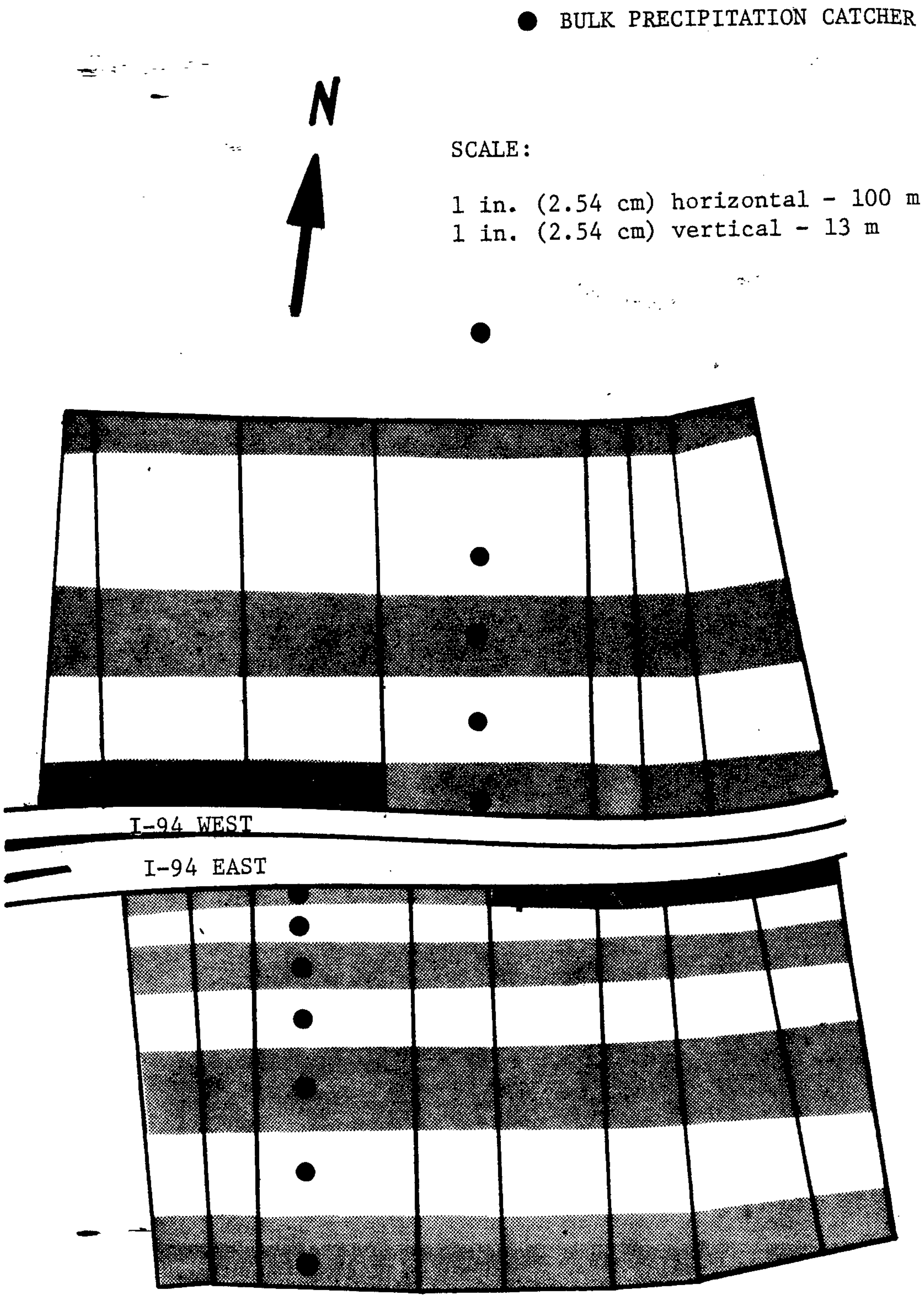


Figure 20. Bulk precipitation monitoring scheme for the period 4/16 to 11/21/79 and associated impact areas, Milwaukee I-94.

Table 28. Average monthly transport of total particulates from the paved highway surface at Milwaukee I-94 to adjacent areas.

Period monitored	Total particulate matter, lb/mi/day			Resultant wind		Average wind speed, mi/hr	Average daily traffic, vehicles per day		
	Westbound	Eastbound	Total highway[a]	Direction	Speed, mi/hr		Westbound	Eastbound	Total
1978									
October	132	75.0	207	SW	5.2	11.1	60,000	57,000	117,000
November	71.9	68.4	140	W	3.9	12.3	59,000	59,000	118,000
1979									
April	52.6	27.3	79.9	N	1.6	10.9	61,000	61,000	122,000
May	58.1	37.7	95.8	SE	0.3	11.3	60,000	61,000	121,000
June	39.2	33.4	72.6	SW	1.1	11.2	62,000	62,000	124,000
July	53.5	23.5	77.0	S	0.4	8.1	60,000	56,000	116,000
August	55.4	19.7	75.1	SW	1.4	9.5	61,000	56,000	117,000
September	51.9	19.4	71.3	SW	2.9	9.7	57,000	46,000	103,000
October	92.6	36.7	129	SW	4.3	12.0	61,000	54,000	115,000
November	101	8.42	109	SW	6.7	12.2	58,000	56,000	114,000
Mean[b]	68.3	37.0	105	--	--	--	60,000	57,000	117,000

[a] Westbound plus eastbound.

[b] Time weighted.

Metric units: To convert lb/mi to kg/km multiply by 0.2819.
To convert mi to km multiply by 1.609.

highway surface thus reflecting the curvature of the paved highway surface. The grid system used for the 1979 monitoring scheme is depicted in Figure 20. Grid system divisions were dictated by dustbucket locations (Figure 2). The net atmospheric deposition monitored by the dustbuckets located within the impacted area (monitored value minus background value) was assigned to the appropriate grid(s). Loading values for individual grids were then summed to obtain the total loading value for the impacted area. A similar grid system, differing only in dustbucket location, was used to calculate loading for the 1978 monitoring scheme at Milwaukee (Figure 1). At Sacramento and Harrisburg, the highway sections monitored were straight and rectangular grid systems were used to approximate the impacted areas.

Data for the average monthly transport of TPM from the paved highway surface to adjacent areas, and wind and traffic data for the Milwaukee I-94 site are presented in Table 28. Wind data include resultant wind direction (sum of hourly wind vectors), resultant wind speed (length of resultant wind vector) and average wind speed (calculated without regard to wind direction). Resultant wind speed and direction provide information relative to particle trajectory for comparison of directional effects on loadings. Average wind speed data provide information on overall wind mix for comparison of monthly total loading values.

The bulk precipitation monitoring schemes used at Milwaukee are presented in Figures 1 and 2. Collectors were located north of the westbound lanes and south of the eastbound lanes. Bulk precipitation could not be monitored at the Milwaukee site during most of the winter period because plowing operations either destroyed the dustfall buckets close to the paved highway surface or buried them under snow. Mean (time weighted) total particulate matter (TPM) transported from the paved highway surface for the period monitored was 105 lb/mi/day (29.6 kg/km/day); 68.3 lb/mi/day (19.3 kg/km/day) from the westbound lanes and 37.0 lb/mi/day (10.7 kg/km/day) from the eastbound lanes. Average daily traffic for the period monitored was slightly higher for westbound lanes than eastbound lanes and probably contributed to the differences in TPM removal rates. However, the difference in traffic counts alone would not explain the large differences in TPM removal rates between the two highway sections. The June and September data appear to support the fact that TPM removal is not strictly a function of average daily traffic. While September did have the lowest average daily traffic and the lowest monthly TPM removal rate, June with the highest average daily traffic had the second lowest monthly TPM removal rate. The variables of resultant wind direction and speeds probably contribute to the difference in TPM removal rates. For most of the months monitored, wind direction was predominantly out of the southwest which may account for the higher TPM removal rates monitored by dustbuckets on the north side of the highway (westbound lanes). However, the April 1979 data is difficult to explain because westbound and eastbound average daily traffic was equal and the resultant wind direction was out of the north but TPM removal was still higher on the north side of the highway (westbound lanes). November, 1978 was characterized by a neutral wind direction (westerly) and identical traffic counts for the westbound and eastbound lanes. As would be expected based upon these data, TPM transport rates for westbound and eastbound lanes were comparable. November 1979 had the highest resultant wind speed with a southwest resultant wind direction. TPM transport from westbound lanes was an order of magnitude higher than from eastbound lanes for this month. The highest resultant wind speed produced the most dramatic difference in TPM removal from westbound vs. eastbound lanes.

The data (Table 28) also indicate that total TPM transport from the highway system at Milwaukee is seasonal. The fall months, October and November, are consistently higher than the other months monitored, April through August. Traffic during the fall months is not exceptionally high for the period monitored. Therefore, the seasonal pattern of TPM transport is not a function of average daily traffic. Fall months are characterized by high monthly average wind speeds which may contribute to the higher fall TPM transport rates.

A study was conducted at the Milwaukee I-94 site to determine TPM deposition to the median area. TPM deposition was monitored by bulk precipitation collectors (collector location no. 10) located in this area between the GM barriers (Figure 2). The median area, approximately 1 m wide, is filled with dirt and is drain tiled with outlets to the paved highway surface. The average monthly loading of TPM originating from the highway surface (background subtracted out) during 1979 is summarized in Table 29. Except for July, TPM loading to the median area was significantly higher than the total TPM loading to areas adjacent to the highway (Table 28). Surface load and traffic may exert a greater effect on TPM loading to the median area than on TPM loadings to areas adjacent to the highway. The median area would be expected to receive large quantities of TPM originating from the highway surface, by the very nature of its location in proximity to the traffic. The highway surface load at Milwaukee I-94 in April is significantly higher than other months, May through November, due to the winter accumulated surface load. The median lane also typically contains a higher surface load than the distress lane (see section on Highway Surface Constituents for a detailed discussion). The high surface load present during April and the beginning of May probably accounts for the high TPM loadings during these months. July had the lowest TPM loading to the median area and the lowest average daily traffic for the months the median area was monitored. The median area between the GM barriers appears to effectively trap highway generated particulates (Table 29) and associated contaminants. Perhaps a mitigation measure is to periodically "clean out" these areas.

Table 29. Average monthly TPM loading to the median area - Milwaukee I-94.

Month	Total particulate matter lb/mi/day
April	175
May	138
June	106
July	56.2
Mean[a]	120

[a] Time weighted.

Metric units: To convert lb/mi to kg/km multiply to 0.2819.

Data for the average monthly transport of TPM from the paved highway surface to adjacent areas and wind and traffic data for the Sacramento Hwy 50 site are presented in Table 30. Continuous bulk precipitation data was collected during 1980 at this site. The bulk precipitation, monitoring scheme used at Sacramento is presented in Figure 3. Collectors were located north of the westbound lanes and south of the eastbound lanes. Mean TPM transport from the paved highway surface for the period monitored was 102 lb/mi/day (28.8 kg/km/day); 58.5 lb/mi/day (16.5 kg/km/day) from the westbound lanes and 43.2 lb/mi/day (12.2 kg/km/day) from the eastbound lanes. Similar to Milwaukee, average daily traffic for the period monitored was slightly higher for westbound lanes than eastbound lanes and probably contributed to the differences in TPM transport rates. However, the difference in traffic counts alone would not explain the large differences in TPM transport rates between the two highway sections. For most of the months the predominant wind direction was out of the southwest which may account for the higher TPM transport rates on the north side of the highway (westbound lanes).

Analysis of the Sacramento data on a monthly basis shows few distinct trends or relationships between TPM transport, and wind and traffic variables. Distinct relationships between TPM transport and wind data may be obscured by the interference to wind patterns from the residential area south of the eastbound lane. Observed monthly total highway TPM transport rates for the period May through July were comparable as was the difference in transport rates between westbound and eastbound lanes (Table 30). Resultant wind direction and speed, and average wind speed for each of these months were also similar for the period. The data also indicate that total TPM transport from the highway system at Sacramento is seasonal. Except for August, the period February through September is characterized by high TPM transport and high average wind speed. This period also incorporates the dry season at Sacramento, April through September. Except for a rainfall event on April 4, 1980, no precipitation occurred during this period.

Data for the average monthly transport of TPM from the paved highway surface to adjacent areas, and wind and traffic data for the Harrisburg I-81 site are presented in Table 31. Collectors were installed north of the northbound lane in the median area and south of the northbound lane in the right-of-way area (Figure 4). Mean TPM (time weighted) transport from the northbound lane for the period monitored was 30.2 lb/mi/day (8.5 kg/km/day); 21.8 lb/mi/day (6.1 kg/km/day) to the northbound right-of-way area and 8.35 lb/mi/day (2.4 kg/km/day) to the northbound median area. The bulk precipitation sampling scheme provides the ideal situation to study the effects of wind on TPM transport. Because TPM monitored by this scheme originates from the northbound lanes (data defining impact area suggest that TPM reaching the median area from southbound lanes would be minimal), average daily traffic is eliminated as a variable when discussing wind effects in relationship to TPM transport north or south of the northbound lane. When the resultant wind direction was west, a neutral direction, the right-of-way area received 1.87 times more TPM than the median area. When the resultant wind direction was north, the right-of-way (south of the northbound lanes) received 3.85 times more TPM than the median area.

Table 30. Average monthly transport of total particulates from the paved highway surface at Sacramento Hwy 50 to adjacent areas.

Period monitored	Total particulate matter lb/mi/day			Resultant wind		Avg. wind speed, mi/hr	Average daily traffic, vehicles per day[b]		
	Westbound	Eastbound	Total highway[a]	Direction	Speed, mi/hr		Westbound	Eastbound	Total
1980									
January	39.2	25.0	64.2	S	1.6	6.9	41,000	37,000	78,000
February	61.4	55.3	117	S	2.2	8.3	43,000	39,000	82,000
March	102	44.5	147	NW	2.7	9.1	45,000	41,000	86,000
April	94.3	129	223	SW	4.0	8.4	44,000	41,000	85,000
May	80.4	38.8	119	SW	6.7	9.3	45,000	41,000	86,000
June	76.3	33.9	110	SW	6.9	9.7	44,000	44,000	88,000
July	90.5	35.4	126	SW	6.8	8.5	44,000	45,000	89.000
August	24.3	35.3	59.6	SW	8.1	9.4	48,000	46,000	94,000
September	52.8	31.3	84.1	SW	5.2	7.8	47,000	44,000	91,000
October	44.0	25.8	69.8	SW	1.5	5.2	47,000	44,000	91,000
November	38.2	34.1	72.3	NW	1.3	5.8	46,000	42,000	88,000
December	14.8	36.4	51.2	SE	0.6	5.4	45,000	38,000	83,000
Mean	58.5	43.2	102	--	--	--	45,000	42,000	87,000

[a] Westbound plus eastbound.

[b] Time weighted.

Metric units: To convert lb/mi to kg/km multiply by 0.2819.
To convert mi to km multiply by 1.609.

Table 31. Average monthly transport of total particulates from the paved highway surface at Harrisburg I-81 to adjacent areas.

Period monitored	Total particulates, lb/mi/day Northbound Right-of way	 Northbound median	 Northbound total	Resultant wind Direction	 Speed, mi/hr	Avg. wind speed, mi/hr	Average daily traffic vehicles/day Northbound
1980							
June	13.8	7.15	21.0	NW	3.1	6.7	16,000
July	12.6	8.72	21.3	W	2.7	5.9	17,000
August	16.9	4.93	21.8	W	2.5	6.1	17,000
September	9.86	6.07	15.9	W	1.5	6.3	14,000
October	16.8	6.08	22.9	W	4.1	7.5	15,000
November	17.1	6.09	23.2	NW	5.0	8.3	13,000
December	47.0	3.94	50.9	NW	4.7	7.7	12,000
1981							
January	37.2	9.62	46.8	NW	5.9	8.3	11,000
February	31.5	18.2	49.7	W	2.7	8.5	12,000
March	25.9	9.78	35.7	NW	7.3	10.2	13,000
April	13.6	10.2	23.8	W	3.3	8.9	14,000
Mean[a]	21.8	8.35	30.2	--	--	--	14,000

[a] Time weighted.

Metric units: To convert lb/mi to kg/km multiply by 0.2819.
To convert mi to km multiply by 1.609.

A seasonal effect is also apparent at Harrisburg (Table 31). Winter months (November through March) had the highest TPM transport rates for the period monitored. These months had the lowest monthly average daily traffic but the highest monthly average wind speeds. These data indicate the importance of wind and possibly winter surface load characteristics on bulk precipitation patterns.

Data for the average monthly removal of TPM from the paved highway surface, and wind and traffic data for the Efland I-85 site are presented in Table 32. Bulk precipitation collectors were installed north and south of the travel lanes and in the median area. For most of the months monitored, northbound and southbound particulate transport was comparable. Mean northbound transport (time weighted) was 2.07 lb/mi/day (0.58 kg/km/day), while mean southbound transport was 1.99 lb/mi/day (0.56 kg/km/day). This may be related to the similarity of northbound and southbound ADT; mean northbound and southbound ADT for the period was 13,000 vehicles per day in each lane (Table 32). The seasonal pattern observed at Milwaukee and Harrisburg was not as distinct at Efland. However, the highest transport rates were observed for September, October and January while the lowest rate was during June.

TPM deposition total median area at the Efland I-85 site was monitored. The grassy median area was approximately 10 m wide. The data in Table 33 indicate that the TPM loading to the median area [4.31 lb/mi/day (1.21 kg/km/day)] was generally comparable to that deposited on the area adjacent to the paved highway surface [4.06 lb/mi/day (1.14 kg/km/day)].

An order of magnitude comparison of TPM transported from the highway system (both directions) between the four monitoring sites is possible if the northbound right-of-way TPM transport rate for Harrisburg is doubled. The resulting TPM transport rates and site characteristics are presented in Table 34. The data show at best a weak relationship between TPM transport and average daily traffic. However, several factors must be considered. Based upon the elevated TPM transport rates observed at the Harrisburg site during winter, the Milwaukee mean TPM transport rate, 105 lb/mi/day (29.6 kg/km/day), may be low because most of the winter period was not monitored. Mean TPM transport rate at Sacramento, 102 lb/mi/day (28.8 kg/km/day), may be high from the addition of TPM due to wind erosion of the sandy soil in areas monitored by bulk precipitation collectors during the drought period, April through October, which was also characterized by high average wind speed.

Studies were conducted at the Milwaukee I-94 and Efland I-85 sites to determine the amount of saltating particles entering ground level dustfall buckets close to the highway. The 1978-79 Milwaukee and 1981-82 Efland monitoring schemes (Figures 2 and 5) included buckets elevated 30 in (76 cm) from the ground or pavement to the top lip of the bucket. The difference between the loading values for ground level buckets and elevated buckets would be due to saltation [particles bouncing off the highway surface within the height interval of 30 in (76 cm)]. Table 35 compares the TPM loading values to areas adjacent to the highway at Milwaukee based upon ground level and elevated dustfall bucket data. The same data for Efland is presented in Table

Table 32. Average monthly transport of total particulates from the paved highway surface at Efland I-85.

	Total particulate matter, lb/mi/day			Resultant wind			Average daily traffic, vehicles per day		
Period monitored	Northbound	Southbound	Total highway[a]	Direction	Speed mi/hr	Average wind speed, mi/hr	Northbound	Soundbound	Total
1981									
July	1.63	1.54	3.17	S	0.6	5.2	NA	NA	NA
August	1.97	1.51	3.48	NE	1.1	4.5	14,000	14,000	28,000
September	3.21	3.59	6.80	W	0.5	5.9	13,000	13,000	26,000
October	3.27	2.65	5.92	N	2.3	8.1	13,000	14,000	27,000
November	1.57	1.39	2.96	NW	3.0	8.2	14,000	14,000	28,000
December	1.91	1.57	3.48	NW	3.6	8.8	12,000	12,000	24,000
1982									
January	3.69	3.99	7.68	W	2.5	8.9	11,000	11,000	22,000
February	2.05	1.73	3.78	N	2.5	8.8	11,000	11,000	22,000
March	1.50	1.55	3.05	NW	0.4	7.9	13,000	12,000	25,000
April	2.47	2.28	4.75	SW	1.5	8.4	13,000	13,000	26,000
May	2.13	1.69	3.82	S	1.7	5.9	12,000	13,000	25,000
June	0.45	0.29	0.74	S	1.1	5.9	14,000	14,000	28,000
Mean[b]	2.07	1.99	4.06	--	--	--	13,000	13,000	26,000

[a] Northbound plus southbound.

[b] Time weighted.

Metric units: To convert lb/mi to kg/km multiply by 0.2819.
To convert mi to km multiply by 1.609.

Table 33. Comparison of the average monthly TPM loading to the median area and area adjacent to the highway[a] - Efland I-85.

Period monitored	Median area, lb/mi/day	Area adjacent to highway[a], lb/mi/day
1981		
July	3.77	3.17
August	3.49	3.48
September	7.48	6.80
October	4.74	4.92
November	2.36	2.96
December	3.17	3.48
1982		
January	8.94	7.68
February	5.05	3.78
March	3.57	3.05
April	4.35	4.75
May	3.00	3.82
June	1.79	0.74
Mean[b]	4.31	4.06

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[a] Impacted area north and south of the paved highway surface.

[b] Time weighted.

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

Table 34. Mean monthly TPM transport rates[a] and site characteristics for all monitoring sites.

Site	Total particulates, lb/mi/day[b]	Average daily traffic, vehicles/day[b]	Highway drainage design
Milwaukee I-94	105	117,000	curb and gutter
Sacramento Hwy. 50	102	87,000	flush shoulder
Harrisburg I-81	43.6	28,000	flush shoulder
Efland I-85	4.06	26,000	flush shoulder

[a] Entire period monitored.
[b] Both directions for the period monitored.

Metric units: To convert lb/mi/day to kg/km/day multiply by 0.2819.

Table 35. Comparison of monthly TPM loading rates (lb/mi/day)[a] based upon elevated and ground level bulk precipitation collectors - Milwaukee I-94 site.

Period monitored	Ground level dustfall buckets	Elevated dustfall buckets
1978		
October	207	90.6
November	140	66.3
1979		
April	79.9	35.0
May	95.8	45.3
June	72.6	38.3
July	77.0	34.7
August	75.1	36.3
September	71.3	36.1
October	129	74.6
November	109	50.5
Mean[b]	105	50.3

[a] Both directions.

[b] Time weighted

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

Table 36. Comparison of monthly TPM loading rates (lb/mi/day)[a] based upon elevated and ground level bulk precipitation collectors - Efland I-85 site.

Period monitored	Ground level dustfall buckets	Elevated dustfall buckets
1981		
July	3.17	1.19
August	3.48	1.97
September	6.80	3.97
October	4.92	2.98
November	2.96	1.79
December	3.48	2.12
1980		
January	7.68	4.80
February	3.78	1.72
March	3.05	1.04
April	4.75	1.69
May	3.82	0.00
June	0.74	0.00
Mean[b]	4.06	1.92

[a] Both directions.

[b] Time weighted.

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

36. In general, the data show that saltating particles are slightly more than half the total TPM load monitored.

The data were also analyzed to determine if a relationship existed between saltation load reaching roadside ground level buckets and saltation load monitored by saltation catchers. Four roadside monitoring locations at Milwaukee (Figure 2) included a saltation catcher, ground level dustfall bucket and elevated dustfall bucket. Regression analyses were performed on the absolute difference in TPM loadings values between elevated and ground level dustfall buckets and the saltation load monitored at each location. The following equation was developed:

$$\text{Saltation entering ground level bucket (mg)} = [\text{saltation load monitored (mg)} \times 0.5135)] + 362.1$$

The correlation coefficient (r value) for this analysis, 0.658, exceeded the critical value at the 95 percent confidence interval, indicating that a relationship does exist.

The same analysis to determine the relationship between saltation load reaching roadside ground level buckets and saltation load monitored by saltation catchers was performed at Efland. The following equation was developed:

$$\text{Saltation entering ground level bucket (mg)} = [\text{saltation load monitored (mg)} \times 0.2684] + 28.8$$

The correlation coefficient was 0.749 and exceeded the critical value at the 95 percent confidence interval, indicating that a relationship does exist.

The developed equation was applied to the Harrisburg and Sacramento data to estimate bulk precipitation loading values that did not include saltating particles. Mean TPM loading without saltating particles was calculated to be 55.8 lb/mi/day (15.7 kg/km/day) at Sacramento and 19.5 lb/mi/day (5.5 kg/km/day) at Harrisburg, compared to the mean TPM loading based on ground level dustfall bucket data of 102 lb/mi/day (28.8 kg/km/day) at Sacramento (Table 30) and 30.2 lb/mi/day (8.5 kg/km/day) at Harrisburg (Table 31).

Order of magnitude estimates for annual TPM deposition to areas adjacent to the highways at the four sites monitored were calculated based upon overall mean TPM deposition rates (bulk precipitation rates) which excluded saltation. Annual TPM deposition due to bulk precipitation for areas adjacent to the highway was calculated to be 18,000 lb/mi/yr (5,100 kg/km/yr) at Milwaukee, 20,000 lb/mi/yr (5,600 kg/km/yr) at Sacramento, 7,000 lb/mi/yr (2,000 kg/km/yr) at Harrisburg and 700 lb/mi/yr (198 kg/km/yr) at Efland. In comparison, estimates of annual saltation loads for areas adjacent to the highway were calculated to be 12,000 lb/mi/yr (3,400 kg/km/yr) at Milwaukee, 14,000 lb/mi/yr (3,900 kg/km/yr) at Sacramento, and 2,800 lb/mi/yr (780 kg/km/yr) at Harrisburg and 1,300 lb/mi/yr (370 kg/km/yr) at Efland.

Mean metals deposition on areas adjacent to the paved highway surface at the sites monitored is presented in Table 37. A zinc value does not appear for Milwaukee because filter pads used early in the study were found to be contaminated with zinc. Except for zinc, metals deposition was highest at Milwaukee, lowest at Efland and intermediate at Sacramento and Harrisburg. These results would be expected based upon site average daily traffic; 116,000 vehicles per day at Milwaukee, 85,900 vehicles per day at Sacramento, 27,800 vehicles per day at Harrisburg and 25,500 vehicles per day at Efland.

Studies were performed for the period April 16 to November 26, 1979 at the Milwaukee I-94 site to determine the precision of bulk precipitation measurements at various distances from the highway. Statistically defined, precision is the closeness of repeated measurements of the same quantity (82). Figure 2 (Section II) shows multiple bucket (three buckets) installations at location 8, 6, 4, 2 and 17 (background). Location 8 buckets, because of their close proximity to the highway, and subsequent high TPM loadings were analyzed weekly while location 2, 4 and 6 (5, 15 and 30 m, respectively from edge of highway pavement) were analyzed every two weeks; Location 17, the background station (366 m from the highway), was analyzed monthly. Precision results are presented in Table 38. Precision is the reproducibility of a method when it is repeated on a homogeneous sample and is expressed as percent precision, the standard deviation divided by the mean for the three measurements.

The data show (Table 38) that the smallest variability for bulk precipitation measurements occurred at collectors located 5, 15 and 30 m from the edge of highway pavement. The higher variability monitored by roadside collectors may be related to localized effects due to vehicular turbulence and the inclusion of saltating particles in these buckets. Higher variability for background bulk precipitation measurements is probably due to the smaller quantities of TPM being measured. A small difference in any one of the background collectors from the other two resulted in a high percent precision.

Bulk precipitation measurements for the collection period ending October 22, 1979 resulted in high percent precision values for most sampling locations; 63 percent at 0 m, 53 percent at 5 m, 93 percent at 15 m, 12 percent at 30 m and 37 percent at background. Except for the 30 m value, the percent precision was the highest or second highest recorded at each location (Table 38). The week of October 16 through 22, 1979 had meteorological conditions which were atypical compared to the overall monitoring period including three thunderstorms with high rainfall intensities, winds that gusted to 34 miles per hour (55 km/hr) and seven consecutive days of poor air quality (smoke and haze). Apparently these meteorological parameters greatly influenced bulk precipitation measurements for that week. In fact, if the TPM loading data for this period is removed

Table 37. Mean metals deposition (lb/mi/day[a]) on areas adjacent to the paved highway surface at the sites monitored.

Parameter	Milwaukee I-94	Sacramento Hwy 50	Harrisburg I-81	Efland I-85
Pb	0.745	0.420	0.028	0.001
Fe	8.00	3.56	0.574	0.053
Zn	--	0.030	0.052	0.0007
Cr	0.016	0.005	0.002	0.00001
Cd	0.0004	0.00006	0.00001	ND
Ni	0.012	0.008	0.0001	ND

[a] Both directions.

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

Table 38. Dustfall measurement precision results - Milwaukee I-94.

Distance edge of pavement, m	Percent precision[a] Range	Percent precision[a] Mean	Number of observations
0	9-64	23	92
5	5-53	14	38
15	2-93	17	39
30	4-52	13	39
366[b]	9-37	19	39

[a] Standard deviation divided by the mean.

[b] Background.

from the precision analysis, the mean percent precision at each location, except the 30 m location, decreases from 23 to 21 at 0 m, 14 to 11 at 5 m, 17 to 10 at 15 m and 19 to 16 at background.

The precision data indicate that generally bulk precipitation monitoring conducted as a part of this study provided precise measurements of TPM deposition. However, the data also show that these measurements can be affected by the following:

1. Localized effects due to vehicular turbulence.
2. Severe meteorological conditions.

Topography at the Harrisburg I-81 site provided conditions appropriate to study the effects of terrain on atmospheric deposition. To meet this objective, bulk precipitation collectors were installed along two transects at this site (Figure 4) with several collectors on each transect located at comparable distances from the edge of highway pavement. One transect was located on relatively flat terrain (collector locations no. 2, 3 6 and 7) and one transect on elevated terrain (cut section) (collector locations no. 8, 9, 10 and 11). Mean monthly TPM loadings (mg/collector) measured at these locations (distance from edge of the pavement provided in parentheses) for the overall monitoring period were as follows:

North edge of pavement (2 m)		South edge of pavement (1 m)		Right-of-way (20-21 m)		Background (69-70 m)	
No. 11	No. 2	No. 10	No. 3	No. 9	No. 6	No. 8	No. 7
232	351	228	420	41	61	27	31

The data show a significant lateral variation for edge of pavement collectors. TPM measured at collector location no. 2 was 1.5 times higher than no. 11 and no. 3 was 1.8 times higher than no. 10. TPM monitored at collector locations nos. 10 and 11 were comparable. Both collectors are located in the cut section. The elevated terrain in the median and right-of-way area appear to negate any wind effect on these collectors. Collector location no. 3 (south of the travel lane) was higher than no. 2 (north of the travel lane). Both collectors are located on the relatively flat terrain. Predominant wind direction is out of the north and probably accounts for the difference. TPM monitored at collector location no. 6 (flat terrain) was 1.5 times higher than no. 9 (elevated terrain). Values for background collectors no. 7 and 8, were comparable showing little lateral variation.

Runoff

The quantity and quality of the runoff from paved, as well as unpaved area at each site were monitored at separate points in order to establish the overall fate of pollutants leaving the highway drainage system. Monitoring of the paved and unpaved areas was segregated to determine pollutant loadings leaving the highway drainage system and to develop insights into the hydraulics of pollutant movement and strengths at various points in the drainage scheme. Paved and unpaved runoff characteristics are discussed in detail in Volume II - Methods.

Paved Runoff--

Since the beginning of the monitoring program, a total of 374 runoff events occurred at the four monitoring sites. Of these runoff events, a total of 233 events were monitored for quality data. The distribution of monitored events at the four sites is presented in Table 39.

Table 39. Distribution of paved runoff events at the sites monitored.

Site	Number of runoff events	Quality monitored events	Monitoring period
Milwaukee I-94	228	139	8/16/78 - 5/15/80
Sacramento Hwy 50	57	35	12/19/79 - 1/22/81
Harrisburg I-81	30	21	6/15/80 - 6/10/81
Efland I-85	59	38	7/10/81 - 7/15/82
Total	374	233	

The majority of runoff events which were not monitored for quality had small total flow volumes, less than 0.10 in (0.25 cm). For low flow volume events, sufficient composite sample volume for parameter analysis could not be obtained when sampling equipment was in the automatic mode. Equipment in the automatic mode was programmed to sample the "typical storm event" characteristics for each site. Manual sampling or reprogramming of automatic sampling equipment was required for these small total flow events. Because of the unpredictability of rainfall start times and total rainfall volume, personnel did not always reach the site in time to manually catch the first part of the storm or to reprogram sampling equipment for small events. Also, quality data were not collected for a few runoff events because of equipment malfunction.

Accumulated data from those 233 quality monitored storm events at four sites are presented and discussed in the ensuing subsections.

Rainfall runoff relationships--A complete listing of the rainfall and flow data for all monitored events for which runoff quality data was collected is presented in Volume IV - Appendix. From analysis of the available rainfall runoff data for nonwinter conditions, the mean and range of runoff to rainfall (Q/R) coefficients were calculated for each site. Nonwinter conditions for Milwaukee, Efland and Harrisburg are defined as the period April through October. Sacramento does not typically have winter conditions (snowfall or ground frost) which might affect rainfall-runoff relationships. Therefore, Sacramento was considered to have year round nonwinter conditions.

Calculated runoff coefficients for all runoff events and quality monitored runoff events are presented in Table 40. Milwaukee and Sacramento had runoff coefficients with similar ranges and identical means for all nonwinter runoff events. The drainage scheme at the Milwaukee I-94 site is a curb and gutter design, whereas the Sacramento Hwy 50 site is a flush shoulder design. However, for purposes of this study, an asphalt berm was installed along the length of highway section monitored at Sacramento to divert runoff from the paved area to the monitoring point via an asphalt channel (refer to Volume II - Methods). Essentially, these site modifications transformed the drainage scheme at Sacramento from a flush shoulder to a curb and gutter design. Similarity in runoff coefficients for these two sites can therefore be attributed to the fact that both sites are 100 percent paved and have curb and gutter drainage designs. The 1.02 runoff coefficient calculated for a runoff event at the Sacramento Hwy 50 site is theoretically an impossible value. Several runoff coefficients were also calculated to be 1.00 at both sites which implies that all rainfall reaching the paved highway surface was monitored as runoff. Runoff coefficients monitored at these sites which were greater than or equal to 1.00 are probably a function of instrumentation sensitivity. Most of the low runoff coefficients (less than 0.50) calculated at these two sites were for small total runoff volume events [less than 0.10 in (0.25 cm)]. As previously discussed quality data was not normally collected for small total runoff volume events. Comparison of mean runoff volumes and range of runoff coefficients between quality monitored runoff events and all runoff events (Table 40) demonstrates the absence of small quality monitored runoff events. The data show the mean runoff coefficient and minimum runoff coefficient both increase when only quality monitored runoff events are considered. However, the mean runoff coefficient remains essentially the same because the mean runoff coefficient is a weighted mean using total rainfall volume and total runoff volume for the period. Although the number of events which were less than or equal to 0.10 in (0.25 cm) of runoff and were not monitored for quality is large, 23 percent at Sacramento and 27 percent of Milwaukee, the portion of total flow volume is relatively small, 3.7 percent at Sacramento and 7.6 percent at Milwaukee.

The Harrisburg I-81 site had a flush shoulder drainage design and paved runoff was channelized through a pervious right-of-way ditch to the monitoring point. The paved highway surface in the section monitored was 77 percent of the drainage area (Table 40) and the drainage ditch accounted for the remaining 23 percent. Mean runoff, 0.02 in (0.05 cm) and mean runoff coefficient, 0.04 at the Harrisburg site were extremely low values (Table 40). During FHWA's study on highway runoff constituents (39), a site was also operated at Harrisburg which was only 27 percent paved but had a mean runoff coefficient of 0.43. A runoff coefficient of 0.04 indicates that 96 percent of the rainfall is lost from the drainage system prior to reading the monitoring point. It was discovered that the runoff was lost to groundwater seepage through a gravel sub-base and drain tile network which existed beneath the soil cover next to the highway shoulder (refer to Volume II - Methods). An extensive lysimeter network was installed at the Harrisburg site to estimate the quantity and quality of runoff lost to groundwater seepage. Details of this monitoring effort are discussed later in this section.

The Efland I-85 site which is 51 percent paved had a mean runoff coefficient of 0.70 for all runoff events. Based upon the percent paved area for this site the runoff coefficient appears high. However, rainfall per storm event producing runoff was high, 0.95 in per event (2.42 cm per event). Also, many of these storms occurred during periods which had several days of wet weather where depression storage was filled for most of the period.

Data on runoff coefficients (nonwinter) presented in Table 40 are only for rainfall events which produced runoff. Milwaukee had one 0.02-in (0.05-cm) rainfall which produced no runoff, while Sacramento had three rainfall events, 0.02 to 0.05 in (0.05 to 0.13 cm), which produced no runoff. At Sacramento two of the rainfall events which produced no runoff occurred after 190 dry days, while the third event occurred after 25 dry days. Harrisburg had 58 rainfall events, 0.02 to 0.52 in (0.05 to 1.32 cm), while Efland had 55 rainfall events, 0.03 to 0.54 in (0.08 to 1.37 cm), which produced no runoff. Runoff coefficients based upon total rainfall and total runoff for the nonwinter period are 0.81 for Milwaukee, 0.83 for Sacramento, 0.03 for Harrisburg and 0.56 for Efland.

Highway runoff quality data--A large volume of highway runoff quality data was collected at the four sites monitored. Samples were analyzed individually or as a single flow proportional composite sample. A listing of parameter analyses typically performed on composite and discrete samples are listed in Table 41. Quality data from composite samples characterize the entire runoff event. Quality data from selected discrete samples were used to determine changes in pollutant strength with flow time.

Composite quality data--Composite data collected at each site provided information on the total pollutant load leaving the highway system during a runoff event. In order to suitably characterize flow composite sample analysis data, concentrations (mg/l), loadings [lb/mi/event (kg/km/event)], and loadings normalized for runoff volume [lb/mi/in of runoff (kg/km/cm of runoff)] were examined in terms of nonwinter conditions, winter conditions and combined (nonwinter-winter) conditions for each site. Loading data,

Table 40. Summary of runoff (Q) to rainfall (R) coefficient (Q/R) - nonwinter periods[a].

	All runoff events				Quality monitored runoff events				
	Mean runoff,	Runoff conﬀicient			Mean runoff,	Runoff coefficient			Percent
Site	in	Range	Mean	n	in	Range	Mean	n	paved
Milwaukee I-94	0.18	0.25-1.00	0.81	139	0.22	0.50-1.00	0.83	90	100
Sacramento Hwy 50	0.29	0.22-1.02	0.83	57	0.39	0.57-1.02	0.84	35	100
Harrisburg I-81	0.02	0.0006-0.13	0.04	23	0.03	0.004-0.13	0.05	16	77
Efland I-85	0.67	0.01-1.03	0.70	35	0.63	0.26-1.03	0.71	38	51

n = Number of observations.

[a] Nonwinter: Milwaukee, Efland and Harrisburg - April through October.
Sacramento - January through December.

Metric units: To convert inches to cm multiply by 2.54.

Table 41. Analyses performed on composite and discrete samples.

Sample type	Constituent group	Parameter	Parameter abbreviation
Composite		pH	
	Solids	Total solids	TS
		Volatile total solids	VTS
		Suspended solids	SS
		Volatile suspended solids	VSS
	Metals	Lead	Pb
		Zinc	Zn
		Iron	Fe
		Copper	Cu
		Chromium	Cr
		Cadmium	Cd
		Nickel	Ni
		Mercury	Hg
		Arsenic	As
	Nutrients	Phosphate	PO_4-P
		Total Kjeldahl nitrogen	TKN
		Nitrite plus nitrate nitrogen	NO_2+NO_3
	Salts	Calcium	Ca
		Sodium	Na
		Chloride	Cl
		Sulfate	SO_4
		Oil and grease	O&G
Discrete		pH	
		Total solids	TS
		Suspended solids	SS
		Lead	Pb
		Iron	Fe
		Zinc	Zn
		Chloride	Cl

lb/mi/event (kg/km/event) provide information on pollutants actually leaving a highway section [the term mile (km) includes both directions] for each event monitored. Loading values normalized for runoff volume, lb/mi/in of runoff, eliminate the situation where the majority of runoff events had either small or large total volumes and therefore, provides a loading unit which can be used to compare sites in relationship to site characteristics by eliminating flow volume bias. At Milwaukee both lane directions were monitored directly, while at Sacramento and Harrisburg only one lane direction was actually monitored. At Efland 1-1/2 lane directions were monitored. Therefore, composite loading values calculated for Sacramento and Harrisburg were multiplied by two to reflect values which indicate loadings on a pounds per highway mile (both directions) basis, while an appropriate factor was applied to the Efland data. Loading values at all sites could then be directly compared. Combined composite data for all sites will also be discussed to provide an overall idea of the impact of highway runoff as it leaves the highway drainage system and discharges to the surrounding environment.

All composite data presented in this section has been summarized using the range, and mean or median for each parameter. Median value was calculated in-lieu-of a mean value for those parameters characterized with a large number of concentration values which were ND, not detectable. The median is the middle number in a data set such that the median value is neither greater than nor less than half of the observed values. Composite runoff data for all events at the four sites is provided in Volume IV - Appendix.

pH--Highway runoff pH values monitored at the four sites are summarized in Table 42. The overall pH range and median for the monitoring period at each site were comparable. Nonwinter pH values ranged from 4.90 to 7.95 with the median for each site near neutral. Milwaukee, Harrisburg and Efland winter pH values were generally higher than summer values.

As previously discussed, precipitation at the four monitoring sites was characterized as acid; median pH at Milwaukee was 3.8, 4.3 at Harrisburg, 4.2 at Efland and 5.0 at Sacramento. Table 43 compares runoff pH with precipitation pH for events where both were monitored. The data indicate that the highway systems at all sites had a large buffer capacity capable of neutralizing acid precipitation before it reached the surrounding environment. This buffering capacity can probably be attributed to concrete paving which typically contains calcium carbonate and calcium sulfate, and to the buffers associated with the highway surface dust and dirt load. Travel lanes at the Harrisburg and Sacramento sites were concrete paved, and the distress and median lanes at the Milwaukee site were concrete paved. AT Efland and Harrisburg, where the drainage design was flush shoulder, the soil in the drainage ditch probably contributed to the buffering capacity. During winter periods, the deicing agent antiskid is used at Harrisburg and consists largely of limestone (calcium carbonate) screenings which would also add to the buffering capacity.

Table 42. Highway runoff pH.

Site	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	5.10-7.95	6.90	5.10-7.70	6.85	6.40-7.95	7.20
Sacramento Hwy 50	5.75-7.70	6.90	5.75-7.70	6.90		--
Harrisburg I-81	5.50-7.80	6.60	5.50-7.80	6.45	6.70-7.50	7.45
Efland I-85	4.90-6.85	6.43	4.90-6.72	6.30	6.10-6.85	6.50

[a] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[b] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

Table 43. Monitored pH for rainfall events and associated paved area runoff.

Date	Rainfall	Runoff
Milwaukee I-94		
4/24-25/79	3.5	6.8
6/7	3.8	6.7
7/24	4.0	6.8
8/22	4.1	6.9
10/1	4.8	6.8
11/6	3.5	6.9
1/11/80	3.4	7.8
1/15-16	3.5	7.7
1/16	3.7	7.0
3/4	4.8	7.3
4/3	3.2	7.1
5/13	2.7	6.6
Harrisburg I-81		
10/25/80	4.1	6.5
10/24	5.6	6.5
11/24	3.4	6.7
2/20/81	4.8	7.4
4/23	4.2	7.4
4/24	4.3	7.5
Sacramento Hwy. 50		
12/19/79	4.9	6.7
1/9/80	4.9	7.0
2/14-15	5.0	6.8
12/3-4	6.3	6.6
1/22-23/81	5.1	5.8
Efland I-85		
8/11-12	3.4	6.4
8/19	4.6	6.3
9/7	4.7	6.0
10/24-24	4.6	6.5
10/27	5.4	6.4
12/14-15	4.2	6.3
3/20-21	3.8	6.9
4/8-9	3.8	6.1

Solids--During the initial research performed to define highway runoff constituents (56) the carrier pollutant in highway runoff was determined to be total solids. Carrier pollutant is that pollutant exhibiting the highest degree of association with the other pollutants. Highway surface pollutants also showed a high correlation to suspended solids (39). Total solids accumulation on the highway surface was also shown to be correlated to average daily traffic (56).

Concentrations of total solids (TS), volatile total solids (VTS), suspended solids (SS) and volatile suspended solids (VSS) in highway runoff monitored at the four sites are presented in Tables 44 and 45. For nonwinter periods, Harrisburg I-81 site had the highest runoff concentration for TS, VTS and SS, the Efland I-85 site had the lowest and the Sacramento Hwy 50 and Milwaukee I-94 sites were intermediate. This trend appears to be inversely related to mean nonwinter runoff volume (Table 40). The larger mean runoff volumes at Efland appear to dilute these solids parameters, TS, VTS and SS. Elevated Harrisburg SS concentrations may also indicate some erosion in the drainage ditch which did contain several unvegetated areas. Runoff samples for several events were red colored, indicating eroded clay particles were reaching the monitoring point. Mean nonwinter VSS concentrations did not follow the same trend as the other solids parameters. VSS was highest at Milwaukee, comparable for Sacramento and Harrisburg, and lowest at Efland.

At the Milwaukee I-94 site, mean winter total solids concentration was approximately ten times higher than the mean nonwinter concentration while suspended solids were approximately three times higher (Tables 44 and 45). Presumably, the large winter total solids concentration was due to dissolved chlorides from winter application of deicing agents. At the Harrisburg I-81 and Efland I-85 sites, mean suspended solids concentrations were comparable between nonwinter and winter periods, while mean total solids concentration increased during the winter period. Presumably, the difference is again due to winter application of deicing agents.

Solids loadings in pounds per mile per event for each site are presented in Tables 46 and 47. Milwaukee had the highest nonwinter total solids loadings, Harrisburg the lowest while Sacramento and Efland had values which were comparable and approaching that of Milwaukee. Per event loading values were probably high at Milwaukee and Sacramento due to high paved surface load, while Efland had high total solids loadings per event due to the large runoff volume per event. Solids loadings at Milwaukee and Harrisburg always increased during winter periods.

To facilitate interpretation of the loading data (lb/mi/event), the loading data were normalized for runoff volume (lb/mi/in of runoff). The normalized data are presented in Tables 48 and 49. Although Milwaukee had a smaller mean runoff volume for quality monitored nonwinter events than did Sacramento (Table 40), the mean total solids loading per event was higher (Table 46). This fact is reflected in the normalized total solids data (Table 48) which shows that for every inch of runoff Milwaukee is removing 2.3 times

Table 44. Concentration of total solids and total volatile solids in highway runoff.

	Total solids, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
Site	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	90-57,400	1230	90-4880	381	110-57,400	3260
Sacramento Hwy 50	68-411	204	68-411	204		
Harrisburg I-81	238-2590	790	238-2590	550	365-1040	837
Efland I-85	70-3860	218	70-710	125	109-3860	441

	Total volatile solids, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	10-510	120	10-202	84	41-510	219
Sacramento Hwy 50	20-93	58	20-93	58		
Harrisburg I-81	39-378	103	39-378	112	90-143	98
Efland I-85	30-472	53	30-75	42	40-472	69

[a] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[b] Milwaukee, Efland and Harrisburg - period with snowfall and ground frost, November through March.

Table 45. Concentration of suspended solids and volatile suspended solids in highway runoff.

Site	Suspended solids, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	17-1860	257	17-938	157	26-1860	461
Sacramento Hwy 50	12-279	106	12-279	106		--
Harrisburg I-81	48-2160	329	48-2160	345	104-503	327
Efland I-85	6-57	22	7-57	23	6-35	20

Site	Volatile suspended solids, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	15-317	68	15-109	38	26-317	148
Sacramento Hwy 50	7-46	21	7-46	21		--
Harrisburg I-81	6-62	17	6-62	22	12-34	15
Efland I-85	4-7	5	4-5	5	5-7	6

[a] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[b] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

Table 46. Loading of total solids and total volatile solids in highway runoff.

Site	Total solids, pounds per mile[a] per event: Overall monitoring period Range	Mean	Nonwinter periods[b] Range	Mean	Winter periods[c] Range	Mean
Milwaukee I-94	15.3-17,400	1090	15.3-2910	358	64.1-17,400	2500
Sacramento Hwy 50	12.2-1530	277	12.2-1530	277		--
Harrisburg I-81	0.847-2560	225	0.847-165	33.8	9.85-2560	837
Efland I-85	10.1-1350	372	10.1-975	230	53.5-1350	644

Site	Total volatile solids, pounds per mile[a] per event: Overall monitoring period Range	Mean	Nonwinter periods[b] Range	Mean	Winter periods[c] Range	Mean
Milwaukee I-94	11.6-1200	176	11.6-478	131	57.8-1200	276
Sacramento Hwy 50	13.5-400	101	13.5-400	101		--
Harrisburg I-81	0.254-130	20.7	0.254-42.1	9.16	38.2-130	84.1
Efland I-85	121-308	184	266-308	287	121-178	143

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

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

Table 47. Loadings of suspended solids and volatile suspended solids in highway runoff.

Site	Suspended solids, pounds per mile[a] per event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	2.18-6080	217	2.18-1240	139	2.18-6080	353
Sacramento Hwy 50	2.06-799	144	2.06-799	144		--
Harrisburg I-81	0.215-1240	93.9	0.215-137	21.2	2.35-1240	327
Efland I-85	2.44-252	39.9	2.44-252	44.2	2.65-106	31.5

Site	Volatile suspended solids, pounds per mile[a] per event					
	Overall monitoring period		Winter period[b]		Winter periods[c]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	5.36-915	100	5.36-211	59.5	16.8-915	187
Sacramento Hwy 50	5.78-111	36.7	5.78-111	36.7		
Harrisburg I-81	0.042-17.3	3.43	0.042-8.29	1.65	9.07-17.3	13.2
Efland I-85	1.74-51.3	18.9	14.2-51.3	32.7	1.74-21.2	13.4

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

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

Table 48. Total solids and total volatile solids loading normalized for runoff volume.

Site	Total solids, pounds per mile[a] per inch of runoff					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	377-241,000	5,170	377-20,500	1,590	461-241,000	13,700
Sacramento Hwy 50	234-1,410	702	234-1,410	702	934-2,660	--
Harrisburg I-81	609-6,630	2,020	609-6,630	1,410	934-2,660	2,140
Efland I-85	203-11,400	633	203-2,060	365	317-11,200	1,280

Site	Total volatile solids, pounds per mile[a] per inch of runoff					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	41.9-2,140	502	41.9-847	352	172-2,140	916
Sacramento Hwy 50	68.8-320	200	68.8-320	200		--
Harrisburg I-81	99.8-968	264	99.8-968	271	230-366	252
Efland I-85	87.2-1,370	155	87.2-218	121	116-1,370	200

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October. Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

Metric units: To convert lb/mi/in to kg/km/cm multiply by 0.111.

Table 49. Suspended solids and volatile suspended solids loadings normalized for runoff volume.

	Suspended solids, pounds per mile[a] per inch of runoff					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
Site	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	71.2-1,080	986	71.2-3,930	659	109-7,790	1,930
Sacramento Hwy 50	41.3-959	366	41.3-959	366		--
Harrisburg I-81	123-5,530	844	123-5,530	683	266-1,290	837
Efland I-85	17.4-166	64.6	20.3-166	67.2	17.4-102	58.4

	Volatile suspended solids, pounds per mile[a] per inch or runoff					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	62.9-1,330	284	62.9-457	158	109-1,330	621
Sacramento Hwy 50	24.1-158	72.8	24.1-158	72.8		--
Harrisburg I-81	15.4-159	43.7	15.3-199	51.7	30.7-87.0	39.5
Efland I-85	11.6-20.3	15.9	11.6-14.5	13.8	14.5-20.3	18.7

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[a] Both direction, irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October
Sacramento - January through December

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

Metric units: To convert lb/mi/in. to kg/km/cm multiply by 0.111.

more total solids than Sacramento. The higher mean total solids loading at Milwaukee compared to Sacramento probably cannot be attributed to a difference in runoff intensity nor to a difference in accumulation periods (dry days between runoff events). Mean runoff intensity for nonwinter quality monitored events was 0.059 in/hr [0.15 cm/hr) at Milwaukee and 0.063 in/hr (0.16 cm/hr)] at Sacramento. Mean dry days between nonwinter events at Milwaukee was 2.2 dry days and mean dry days between events at Sacramento, excluding the long dry period between 4/4 to 11/7/80 during which no runoff events occurred, was 2.5 dry days. The higher mean total solids loading per inch of runoff at Milwaukee can probably be attributed to a larger highway surface washable total solids load which is related to traffic volume (56). Milwaukee's average daily traffic is 116,000 vehicles per day and 85,900 vehicles per day for Sacramento. Harrisburg had the smallest mean total solids loading per event (Table 46) which can probably be attributed to the small mean runoff volume for quality monitored nonwinter events (Table 40). However, the normalized total solids loading value for Harrisburg is less than Milwaukee but greater than Sacramento (Table 48). Also, the suspended solids loading lb/mi/in of runoff, is the highest at Harrisburg and probably reflects drainage channel erosion (Table 49). This is supported by the fact that suspended solids loading for the winter period when ground frost conditions existed is lower than nonwinter periods (Table 48). Efland with the lowest ADT and vegetated drainage ditch had the lowest solids loadings normalized for runoff volume.

Mean solids loading, lb/mi/in of runoff, at Milwaukee was higher during winter periods than nonwinter periods (Table 48). The greatest difference occurred for mean total solids which were approximately 8.6 times higher during winter periods than nonwinter periods. Mean winter suspended solids loading was only twice that observed for nonwinter periods (Table 49). Again the larger increase in total solids is presumably due to dissolved chlorides from winter application of deicing agents. The Harrisburg data show a slight increase of total solids during winter conditions, while Efland had 3.5 times higher loadings during winter periods than nonwinter periods.

Metals--Highway runoff samples from the four sites monitored were analyzed for the metals: lead (Pb), zinc (Zn), iron (Fe), chromium (Cr), copper (Cu), cadmium (Cd), nickel (Ni) and arsenic (As). The sources of these metals were discussed in Section II. Arsenic and cyanide analyses were performed only on a cursory basis. Summary data for these metals concentrations are listed in Tables 50 through 53. Median composite concentrations for lead and zinc (Table 50) were highest at Milwaukee and Sacramento and lowest at Harrisburg and Efland. Median lead concentrations increased during winter periods at Milwaukee and Harrisburg, and mean zinc concentration increased during winter periods at Milwaukee and Efland. Iron, chromium, copper, cadmium and nickel concentrations show no distinct trends (Tables 51 and 53). Based upon concentration values iron was prevalent at all sites, while chromium, cadmium and nickel were not detectable or present in small concentrations. Mercury was generally not detectable at Milwaukee and Sacramento. At Harrisburg mercury was not detectable in the one winter runoff sample analyzed for mercury but was detectable in all three nonwinter samples.

Table 50. Concentration of lead and zinc in highway runoff.

Site	Lead, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	0.10-6.30	0.70	0.10-2.20	0.60	0.10-6.30	2.50
Sacramento Hwy 50	ND-0.70	0.40	ND-0.70	0.40		--
Harrisburg I-81	ND-0.30	0.02	ND-0.30	ND	ND-0.20	0.04
Efland I-85	ND-0.05	0.02	ND-0.03	0.02	ND-0.05	0.02

Site	Zinc, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	0.110-2.90	0.614	0.110-0.770	0.355	0.210-2.90	1.30
Sacramento Hwy 50	0.090-0.800	0.264	0.090-0.800	0.264		--
Harrisburg I-81	0.065-0.450	0.166	0.065-0.450	0.176	0.140-0.220	0.164
Efland I-85	0.036-0.153	0.052	0.038-0.078	0.049	0.036-0.153	0.058

[a] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[b] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.

Table 51. Concentration of iron and chromium in highway runoff.

	Iron, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
Site	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	1.30-46.0	9.37	1.70-13.0	4.92	1.30-46.0	21.2
Sacramento Hwy 50	0.40-10.7	3.95	0.40-10.7	3.95		--
Harrisburg I-81	2.80-115	11.1	2.80-115	16.1	4.40-15.4	11.1
Efland I-85	0.30-5.90	2.53	1.12-5.10	2.13	0.30-5.90	3.25
	Chromium, mg/l x 10^{-2}					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	ND-18.0	2.0	ND-7.0	ND	ND-18.0	5.0
Sacramento Hwy 50	ND-4.0	ND	ND-4.0	ND		--
Harrisburg I-81	ND-19.0	2.9	ND-19.0	5.0	ND-0.8	ND
Efland I-85	ND-3.8	0.3	ND-3.8	0.2	ND-0.5	0.3

[a] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[b] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.

Table 52. Concentration of copper and cadmium in highway runoff.

Site	Copper, mg/l x 10^{-2}					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	5.0-59	15	7.0-37	14	5.0-59	22
Sacramento Hwy 50	ND-16	7.0	ND-16	7.0		--
Harrisburg I-81	3.8-17	8.5	3.8-17	9.5	4.0-4.6	4.3
Efland I-85	2.3-8.1	3.6	2.8-8.1	4.4	2.3-3.1	2.4

	Cadmium, mg/l x 10^{-2}					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	ND-6.0	1.0	ND-4.0	ND	ND-6.0	2.0
Sacramento Hwy 50	ND-4.0	1.5	ND-4.0	1.5		--
Harrisburg I-81	ND-3.0	ND	ND-3.0	ND	ND-0.6	ND
Efland I-85	ND-0.7	ND	ND-0.4	ND	ND-0.7	ND

[a] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October. Sacramento - January through December.

[b] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.

Table 53. Concentration of nickel, mercury, and arsenic in highway runoff.

	Nickel, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
Site	Range	Median	Range	Median	Range	Median
Milwaukee I-94	ND-0.22	0.04	ND-0.22	ND	ND-0.20	0.10
Sacramento Hwy 50	ND-0.20	0.07	ND-0.20	0.07		--
Harrisburg I-81	ND-0.10	ND	ND-0.10	0.05	ND-0.02	ND
Efland I-85	ND-0.03	0.01	ND-0.02	0.01	ND-0.03	ND

	Mercury, mg/l x 10^{-3}					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	ND-0.85	ND	ND-0.85	ND	ND-ND	ND
Sacramento Hwy 50	ND-0.01	ND	ND-0.01	ND		--
Harrisburg I-81	ND-1.30	0.70	0.60-1.3	0.80		ND
Efland I-85		ND		--		ND

	Arsenic, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94		--		--		--
Sacramento Hwy 50	ND-0.03	ND	ND-0.03	ND		--
Harrisburg I-81	ND-ND	ND		ND		ND
Efland I-85	ND-ND	ND		--	ND-ND	ND

[a] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[b] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.

Arsenic was not analyzed for at Milwaukee and the cursory data collected at Sacramento, Efland and Harrisburg show that it is not generally detectable.

A comparison of the metals loadings (Tables 54 through 57), lb/mi/event, indicate that lead, zinc, iron and copper were highest at Milwaukee and lowest at Harrisburg. Winter loadings of these metals were also generally higher than nonwinter loadings at Milwaukee, Efland and Harrisburg. Small or nondetectable loadings were observed at all sites for chromium, cadmium, nickel and arsenic. A median loading value above the detection limit for mercury was observed only at Harrisburg.

Metals data normalized for runoff volume, lb/mi/in of runoff, appear in Tables 58 through 61. Nonwinter lead and zinc loadings, lb/mi/in of runoff, were generally highest at Milwaukee and Sacramento and lowest at Harrisburg and Efland. As previously discussed these metals are directly related to vehicular deposition. Runoff normalized loading values for lead and zinc appear to be related to site average daily traffic; Milwaukee has a mean average daily traffic of 116,000 vehicles per day, 85,900 vehicles per day for Sacramento, 27,800 vehicles per day for Harrisburg and 25,500 vehicles per day at Efland. Iron loading per inch of runoff was highest at Harrisburg. The red clayey soil in the right-of-way area at Harrisburg was high in iron, 32,000 to 80,000 mg/kg, and the high iron loading value is probably related to eroding clay particles. At the Milwaukee I-94 site, winter loadings of lead, zinc, iron, chromium, copper, cadmium, and nickel (lb/mi/in of runoff) were higher than nonwinter. Winter loadings of these metals probably reflect the overall increase in surface pollutant load during the winter period because removal processes which occur on a continuous or frequent basis during nonwinter periods such as maintenance (sweeping), atmospheric removal (blowoff), and runoff are greatly curtailed or do not occur at all during winter periods. Freezing of the surface load prevents blowoff and runoff occurs only during sporadic warm periods. Vehicular deposition of lead and copper may also increase during winter periods due to the stop-and-go traffic characteristic of hazardous driving conditions. Increased winter iron may also be related to increased autobody rusting due to the caustic nature of deicing agents applied to the highway surface.

Cyanide analyses were performed on composite samples obtained from two winter runoff events. On February 15, 1982, 1,700 lb NaCl (765 kg) was applied to the Milwaukee site and cyanide was not detectable (below detection limits) in ~~a~~ baseflow sample collected on February 19, 1982. Fifty percent of the total salt which would be applied during the winter period at the Efland site was applied on January 13, 14, and 15 and totalled 5,480 lb/mi (1,545 kg/km). On January 16, 1982, a snowmelt occurred producing 0.12 in (0.30 cm) of flow. Cyanide could not be detected (below detection limits) in the composite sample obtained for this event.

Deicing chemicals--Deicing chemicals, principally sodium chloride and calcium chloride, are used throughout the United States for snow and ice

Table 54. Loading of lead and zinc in highway runoff.

	Lead, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
Site	Range	Median	Range	Median	Range	Median
Milwaukee I-94	0.034-20.3	0.922	0.084-3.70	0.754	0.034-20.3	1.47
Sacramento Hwy 50	ND-1.95	0.225	ND-1.95	0.225		--
Harrisburg I-81	ND-0.160	0.0004	ND-0.067	ND	ND-0.160	0.099
Efland I-85	ND-0.205	0.008	ND-0.205	0.004	ND-0.061	0.019

	Zinc, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	0.053-7.52	0.888	0.065-1.90	0.578	0.053-7.52	1.45
Sacramento Hwy 50	0.034-1.22	0.357	0.034-1.22	0.357		--
Harrisburg I-81	0.0004-0.345	0.047	0.0004-0.049	0.011	0.005-0.345	0.164
Efland I-85	0.006-0.390	0.114	0.006-0.390	0.122	0.035-0.209	0.103

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.

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

Table 55. Loading of iron and chromium in highway runoff.

	Iron, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
Site	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	0.109-150	13.5	0.402-28.5	8.02	0.109-150	23.6
Sacramento Hwy 50	0.069-23.6	5.35	0.069-23.6	5.35	--	--
Harrisburg I-81	0.012-37.9	3.38	0.012-7.32	0.988	0.099-37.9	11.0
Efland I-85	0.188-20.1	5.50	0.445-20.1	5.32	0.188-17.8	5.73

	Chromium, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	ND-0.556	0.011	ND-0.108	ND	ND-0.556	0.027
Sacramento Hwy 50	ND-0.111	ND	ND-0.111	ND		--
Harrisburg I-81	ND-0.013	0.0005	ND-0.013	0.0005	ND-0.002	ND
Efland I-85	ND-0.135	0.002	ND-0.135	0.002	ND-0.015	0.003

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.

Metric units: To convert lb/mi to kg/km multiply bly 0.2819.

Table 56. Loading of copper and cadmium in highway runoff.

	Copper, lb/mi[a]/event x 10^{-2}					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
Site	Range	Median	Range	Median	Range	Median
Milwaukee I-94	0.8-193	14.7	2.2-105	14.9	0.8-193	14.7
Sacramento Hwy 50	ND-52.8	7.1	ND-52.8	7.1		--
Harrisburg I-81	0.1-5.8	0.6	0.1-1.8	0.6	1.2-5.8	3.5
Efland I-85	0.6-43.1	5.3	0.6-43.1	4.5	0.8-8.02	5.9

	Cadmium, lb/mi[a]/event x 10^{-2}					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	ND-9.8	0.3	ND-8.1	ND	ND-9.8	1.0
Sacramento Hwy 50	ND-5.2	0.9	ND-5.2	0.9		--
Harrisburg I-81	ND-0.2	ND	ND-0.1	ND	ND-0.2	ND
Efland I-85	ND-1.3	ND	ND-1.3	ND	ND-0.2	ND

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.

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

Table 57. Loading of nickel, mercury, and arsenic in highway runoff.

Site	Nickel, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	ND-0.42	0.01	ND-0.41	ND	ND-0.42	0.04
Sacramento Hwy 50	ND-0.66	0.05	ND-0.66	0.05		--
Harrisburg I-81	ND-0.01	ND	ND-0.64	ND	ND-0.01	ND
Efland I-85	ND-0.06	0.004	ND-0.06	0.01	ND-0.03	ND
	Mercury, lb/mi[a]/event x 10^{-3}					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	ND-1.14	ND	ND-1.14	ND	ND-ND	ND
Sacramento Hwy 50	ND-0.04	ND	ND-0.04	ND		--
Harrisburg I-81	ND-0.13	0.07	0.02-0.13	0.12		ND
Efland I-85		ND		--		ND
	Arsenic, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94						
Sacramento Hwy 50	ND-0.13	ND	ND-0.13	ND		--
Harrisburg I-81	ND-ND	ND		ND		ND
Efland I-85	ND-ND	ND		--	ND-ND	ND

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: December

ND = Not detectable.
Metric units: To convert lb/mi to kg/km multiply by 0.2819.

Table 58. Lead and zinc loadings normalized for runoff volume.

	Lead, lb/mi[a]/in of runoff					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
Site	Range	Median	Range	Median	Range	Median
Milwaukee I-94	0.42-26.4	2.93	0.42-9.22	2.51	0.42-26.4	10.5
Sacramento Hwy 50	ND-2.41	1.38	ND-2.41	1.38		--
Harrisburg I-81	ND-0.77	0.05	ND-0.77	ND	ND-0.51	0.10
Efland I-85	ND-0.15	0.06	ND-0.09	0.04	ND-0.15	0.06
	Zinc, lb/mi[a]/in of runoff					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	0.46-12.2	3.23	0.46-3.23	1.64	0.88-12.2	5.32
Sacramento Hwy 50	0.11-2.75	1.03	0.31-2.75	1.03		--
Harrisburg I-81	0.17-1.15	0.43	0.17-1.15	0.44	0.36-0.56	0.42
Efland I-85	0.11-0.45	0.15	0.11-0.23	0.15	0.11-0.45	0.19

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.

Metric units: To convert lb/mi/in to kg/km/cm multiply by 0.111.

Table 59. Iron and chromium loading normalized for runoff volume.

	Iron, lb/mi[a]/in of runoff					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
Site	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	5.45-19.3	39.3	7.12-54.5	20.6	5.45-193	88.7
Sacramento Hwy 50	1.38-36.8	13.6	1.38-36.8	13.6		--
Harrisburg I-81	7.17-294	30.4	7.17-294	41.2	11.3-39.4	28.3
Efland I-85	0.87-17.2	7.36	3.26-14.8	6.19	0.87-17.2	9.44

	Chromium, lb/mi[a]/in of runoff					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	ND-0.754	0.084	ND-0.293	ND	ND-0.745	0.210
Sacramento Hwy 50	ND-0.138	ND	ND-0.138	ND		--
Harrisburg I-81	ND-0.486	0.049	ND-0.486	0.102	ND-0.021	ND
Efland I-81	ND-0.110	0.007	ND-0.110	0.006	ND-0.015	0.009

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October. Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.

Metric units: To convert lb/mi/in to kg/km/cm multiply by 0.111.

Table 60. Copper and cadmium loadings normalized for runoff value.

	Copper, lb/mi[a]/in of runoff					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
Site	Range	Median	Range	Median	Range	Median
Milwaukee I-94	0.21-2.47	0.63	0.29-1.55	0.59	0.21-2.47	0.922
Sacramento Hwy 50	ND-0.55	0.241	ND-0.55	0.24		--
Harrisburg I-81	0.10-0.44	0.22	0.10-0.44	0.24	0.10-0.12	0.111
Efland I-85	0.07-0.24	0.10	0.08-0.24	0.13	0.07-0.09	0.07

	Cadmium, lb/mi[a]/in of runoff					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	ND-0.251	0.042	ND-0.168	ND	ND-0.251	0.084
Sacramento Hwy 50	ND-0.138	0.052	ND-0.138	0.05		--
Harrisburg I-81	ND-0.077	ND	ND-0.077	ND	ND-0.015	ND
Efland I-85	ND-0.020	ND	ND-0.012	ND	ND-0.020	ND

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.

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

Table 61. Nickel, mercury, and arsenic loadings normalized for runoff volume.

Site	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Median	Range	Median	Range	Median
	Nickel, lb/mi[a]/in of runoff					
Milwaukee I-94	ND-0.92	0.17	ND-0.92	ND	ND-0.84	0.42
Sacramento Hwy 50	ND-0.69	0.22	ND-0.69	0.22		--
Harrisburg I-81	ND-0.26	ND	ND-0.26	ND	ND-0.05	ND
Efland I-85	ND-0.09	0.02	ND-0.06	0.03	ND-0.09	ND
	Mercury, lb/mi[a]/in of runoff x 10^{-3}					
Milwaukee I-94	ND-3.56	ND	ND-3.56	ND	ND-ND	ND
Sacramento Hwy 50	ND-0.03	ND	ND-0.03	ND		--
Harrisburg I-81	ND-3.33	1.79	1.54-3.33	2.05		ND
Efland I-85		ND		--		ND
	Arsenic, lb/mi[a]/in of runoff					
Milwaukee I-94		--		--		--
Sacramento Hwy 50	ND-0.10	ND	ND-0.10	ND		--
Harrisburg I-81	ND-ND	ND		ND		ND
Efland I-85	ND-ND	ND		--	ND-ND	ND

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[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.
Metric units: To convert lb/mi/in to kg/km/cm multiply by 0.111.

control on pavements. The anion Cl^- is highly soluble. Much of the chloride from road salting, therefore, eventually enters a receiving watercourse, either as direct runoff or by percolation into the groundwater system. The cations Na^+ and Ca^+ which come in contact with clay particles are captured by their anionic properties (28). Sodium and calcium can reach a watercourse by direct runoff carrying clay particles. Significant migration of sodium and calcium through groundwater percolation occurs only in very sandy soils (28). Sodium and calcium tend to build up in soils of high clay content.

Based upon the large quantities of sodium chloride and calcium chloride applied at Milwaukee during the winter periods monitored (Section II), it is not surprising that mean sodium and chloride concentrations in the nonwinter versus the winter periods were dramatically different (Table 62). Harrisburg and Efland also showed increases in deicing chemical concentration during the winter. The difference between nonwinter and winter periods at Milwaukee would be even more dramatic if the April 1980 data were removed from the nonwinter period. This month was unusually cold, and snow and freezing rain conditions caused hazardous driving conditions on I-94 in Milwaukee. Deicing agents, 8,250 lb/highway mi (2,330 kg/km) of sodium chloride and 8.00 gallons/highway mi (18.8 liters/km) of liquid calcium chloride had to be applied to the monitoring site during April 1980. With the April 1980 data removed, the mean Milwaukee nonwinter concentrations became 25.5 mg/l sodium, 8.4 mg/l calcium, and 26.4 mg/l chloride. Based upon these data, mean nonwinter concentrations for sodium and chloride appear comparable between sites.

Loadings, lb/mi/event, for the deicing agent chemicals are presented in Table 63. Again, if the April 1980 data for Milwaukee are removed, mean nonwinter loading values for this site become 39.2 lb/mi/event (11.1 kg/km/event) for sodium, 12.9 lb/mi/event (3.6 kg/km/event) for calcium, and 34.9 lb/mi/event (9.8 kg/km/event) for chloride. Based upon these data, nonwinter loadings of sodium and chloride for Milwaukee, Efland, and Sacramento are of the same order of magnitude. The low Harrisburg loadings per event are probably a function of the low mean runoff per event (Table 40). Milwaukee again shows a dramatic difference between nonwinter and winter values.

Loadings of deicing chemicals normalized for runoff appear in Table 64. If the April 1980 data for Milwaukee are removed, mean nonwinter loading values normalized for runoff at this site become 107 lb/mi/in of runoff (11.9 kg/km/cm) for sodium, 35.2 lb/mi/in of runoff (3.9 kg/km/cm) for calcium, and 111 lb/mi/in of runoff (12.3 kg/km/cm) for chloride. Based upon these data, Milwaukee had the highest loadings of sodium and chloride per inch of runoff during nonwinter periods, while the values for Sacramento and Harrisburg were quite comparable. Efland had the lowest loadings of the four sites monitored. At Milwaukee, winter values were extremely elevated over nonwinter values, an increase of 57 times for sodium and 89 times for chloride.

Table 62. Concentration of sodium, calcium, and chloride in highway runoff.

Site	Sodium, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	8.0-22,500	852	8.0-1,400	159	9.8-22,500	1450
Sacramento Hwy 50	2.6-60.0	18.6	2.6-60.0	18.6		--
Harrisburg I-81	5.2-125	34.9	5.2-84.0	16.0	28.0-125	43.9
Efland I-85	2.1-1,030	46.5	2.1-9.0	3.1	4.0-1,030	90.4

Site	Calcium, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	5.0-450	38.3	5.0-110	14.0	11.0-450	59.3
Sacramento Hwy 50		19.0		19.0		--
Harrisburg I-81	15.0-20.0	19.4		15.0		20.0
Efland I-85	4.0-135	13.8		--	4.0-135	13.8

Site	Chloride, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	4.0-35,000	809	4.0-2,900	82.9	11.0-35,000	2360
Sacramento Hwy 50	3.0-110	12.6	3.0-110	12.6		--
Harrisburg I-81	8.0-197	47.7	8.0-68.0	22.1	35.0-197	61.1
Efland I-85	2.0-2,250	104	14.5-58.1	19.2	2.0-2,250	202

[a] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October. Sacramento - January through December.

[b] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

Table 63. Loading of sodium, calcium, and chloride in highway runoff.

	Sodium, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
Site	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	3.59-12,600	749	3.59-1,240	171	8.6-12,600	1,100
Sacramento Hwy 50	2.06-167	37.8	2.06-167	37.8		--
Harrisburg I-81	0.02-40.4	6.87	0.02-5.03	1.32	2.26-40.4	25.4
Efland I-85	7.59-358	104	7.59-21.7	15.1	14.0-358	131
	Calcium, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	0.92-202	33.6	0.92-50.3	15.0	2.35-202	45.0
Sacramento Hwy 50		52.9		52.9		--
Harrisburg I-81	2.83-28.9	15.9		2.83		28.9
Efland I-85	3.66-47.1	17.4		--	3.66-47.1	17.4
	Chlorides, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	2.10-13,500	802	2.10-1,630	98.0	10.4-13,500	1740
Sacramento Hwy 50	2.48-227	20.2	2.48-227	20.2		--
Harrisburg I-81	0.07-52.6	7.86	0.07-5.60	1.53	2.78-52.6	35.3
Efland I-85	6.98-785	233	16.9-51.3	32.2	6.98-785	293

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

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

Table 64. Sodium, calcium, and chloride loadings normalized for runoff volume.

Site	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Sodium, lb/mi[a]/in runoff					
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	33.5-94,300	3,570	33.5-5,870	666	41.1-94,300	6,080
Sacramento Hwy 50	8.94-206	64.0	8.94-206	64.0		--
Harrisburg I-81	13.3-320	89.3	13.3-215	41.0	71.7-320	112
Efland I-85	6.13-2,980	135	6.13-262	8.97	11.6-2,980	263
	Calcium, lb/mi[a]/in of runoff					
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	21.0-1,890	160	21.0-460	58.6	46.1-1,890	248
Sacramento Hwy 50		65.3		65.3		--
Harrisburg I-81	38.4-51.2	49.7		38.4		51.2
Efland I-85	11.6-392	40.3		--	11.6-392	40.3
	Chlorides, lb/mi[a]/in of runoff					
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	16.8-147,000	3,390	16.8-12,200	347	461-147,000	9,890
Sacramento Hwy 50	10.3-378	43.5	10.3-378	43.5		--
Harrisburg I-81	20.5-504	122	20.5-174	56.4	89.6-504	156
Efland I-85	5.81-6,540	302	14.5-58.1	19.2	5.81-6,540	587

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

Metric units: To convert lb/mi/in to kg/km/cm multiply by 0.111.

Oil and grease--Section II discusses the sources of the oil, grease, and related petroleum compounds found in highway runoff. Oil and grease data collected as a part of this study appear in Table 65. Oil and grease data were not collected at Harrisburg. Overall concentration and loading values for oil and grease were comparable at Sacramento and Milwaukee. Milwaukee oil and grease values were higher during winter periods than nonwinter periods at Milwaukee.

On August 10, 1979, a semi-tractor overturned and spilled an undetermined amount of fuel oil onto the paved highway surface in the section of I-94 being monitored in Milwaukee. The fuel oil spill was sprayed with a dispersing agent and flushed into the storm sewers by the fire department. The spill was then covered with an oil dry compound. Oil and grease samples were obtained for a storm which occurred on August 9, 1979, the day prior to the oil spills. Composite concentration of oil and grease for this event was 6 mg/l and runoff normalized loading was 25.1 lb/mi/in of runoff (2.79 kg/km/cm). Runoff events on August 13 and 17, 1979, were also sampled for oil and grease. Composite concentrations of oil and grease were 8 and 9 mg/l respectively and runoff normalized loadings were 33.5 and 37.7 lb/mi/in of runoff (3.72 and 4.18 kg/km/cm) respectively. Presumably, the increase in oil and grease values on August 13 and 17, 1979 were the result of residuals left from the oil spill cleanup.

Nutrients--Highway runoff samples were analyzed for total Kjeldahl nitrogen (TKN), nitrate plus nitrite nitrogen (NO_2 + NO_3), and total phosphate (PO_4-P). Nutrient concentrations which were obtained at the sites monitored are summarized in Table 66. A comparison of nutrient concentrations observed in highway runoff at the sites monitored during this study and FHWA's study on highway runoff constituents (35) to urban stormwater runoff concentrations are presented in Table 67. Nutrient concentration values observed for this study are within the range of data from FHWA's initial study (39). Concentration of nutrients in runoff from highway sites are generally in the range of values for urban runoff as demonstrated in Table 67. 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.

Loadings of nutrients, lb/mi/event, observed at the four sites are presented in Table 68. For nonwinter periods, total Kjeldahl nitrogen and nitrate plus nitrite nitrogen loadings were highest at Milwaukee, lowest at Harrisburg, and intermediate at Sacramento, while Sacramento had the highest nonwinter total phosphate loading value. Efland had only one nonwinter nutrient loading value. Runoff normalized loading values, lb/mi/in of runoff, are presented in Table 69. When the loading values are normalized for runoff, Harrisburg has the highest nonwinter values for total phosphate and nitrate plus nitrite nitrogen while Milwaukee has the highest total Kjeldahl nitrogen value. Efland had the lowest nonwinter nutrient loading values in all cases.

Table 65. Concentration and loading of oil and grease in highway runoff.

Site	Oil and grease, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	1-27	8	1-22	5	8-27	13
Sacramento Hwy 50	3-21	11	3-21	11		--
Harrisburg I-81		--		--		--
Efland I-85	1-11	7	1-11	7		--

Site	Oil and grease, lb/mi[c]/event					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	0.7-38	12	0.7-32	7	6-38	22
Sacramento Hwy 50	2-69	17	2-69	17		--
Harrisburg I-81		--		--		--
Efland I-85	0.3-4	1	0.3-4	1		--

Site	Oil and grease, lb/mi[c]/in of runoff					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	4.19-113	34.2	4.19-92.2	22.6	33.5-113	54.2
Sacramento Hwy 50	10.3-72.2	38.5	10.3-72.2	38.5		--
Harrisburg I-81		--		--		--
Efland I-85	2.91-32.0	20.8	2.91-32.0	20.8		--

[a] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[b] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

[c] Both directions irrespective of number of lanes.

Metric units: To convert lb/mi to kg/km multiply by 0.2819.
To convert lb/mi/in to kg/km/cm multiply by 0.111.

Table 66. Concentrations of nutrients in highway runoff.

	Total phosphate, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
Site	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	0.10-1.21	0.39	0.10-0.73	0.33	0.11-1.21	0.54
Sacramento Hwy 50	0.03-4.45	0.44	0.03-4.45	0.44		--
Harrisburg I-81	0.38-3.60	0.79	0.38-3.60	1.18	0.57-0.77	0.60
Efland I-85	0.10-0.16	0.15		0.16	0.10-0.14	0.11

	Total Kjeldahl nitrogen, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Median	Range	Median	Range	Median
Milwaukee 1-94	1.40-9.80	3.03	1.40-9.80	2.88	2.00-6.40	3.41
Sacramento Hwy 50	ND-6.00	2.03	0.30-6.00	2.03		
Harrisburg I-81	1.04-5.00	1.51	1.10-5.00	2.19	1.04-1.90	1.17
Efland I-85	1.18-8.00	2.00		1.18	2.00-8.00	2.00

	Nitrate and nitrite, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	0.22-2.73	0.71	0.38-2.73	0.66	0.22-2.20	0.83
Sacramento Hwy 50	0.04-1.70	0.33	0.04-1.70	0.33		--
Harrisburg I-81	1.27-9.00	5.61	1.27-9.00	4.37	6.00-7.30	6.20
Efland I-85	ND-0.45	0.14		0.08	ND-0.45	0.24

[a] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[b] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.

Table 67. Comparison of nutrient values in urban stormwater runoff to highway runoff.

Area	Ref.	Nitrogen, mg/l			Total phosphate, mg/l	
		Form	Mean	Range	Mean	Range
Urban runoff						
Washington, DC	(50)	Total N	2.1	0.5-6.5	1.3	0.2-4.5
Durham, NC	(51)	--	--	--	0.58	0.15-2.50
Cincinnati, OH	(52)	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	(53)	Kjel-N	0.96	0.1-11.6	2.5	0.6-48
Ann Arbor, MI	(54)	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, OH	(55)	Kjel-N	1.6	--	2.0	--
Highway runoff						
Milwaukee, WI I-794	(39)	Kjel-N	3.43	0.60-10.7	0.50	0.12-1.81
Milwaukee, WI Hwy 45	(39)	Kjel-N	3.28	0.8-11.4	0.52	0.10-1.27
Harrisburg, PA I-81	(39)	Kjel-N	1.58	0.1-8.1	0.34	0.050-0.86
Nashville, IN I-40	(39)	Kjel-N	2.67	0.4-10.0	1.92	0.77-3.55
Denver, CO I-25	(39)	Kjel-N	4.47	1.6-14.0	0.92	0.48-2.36
Milwaukee, WI I-94		Kjel-N	3.03	1.4-9.8	0.39	0.10-1.21
Sacramento, CA Hwy 50		Kjel-N	2.03	ND-6.0	0.44	0.03-4.45
Harrisburg, PA I-81		Kjel-N	1.51	1.0-5.0	0.79	0.38-3.60
Efland, NC I-85		Kjel-N	2.00	1.2-8.0	0.15	0.10-0.16

[a] Hydrolyzable PO_4.

[b] Reported as maximum value.

ND = Not detectable.

Table 68. Loadings of nutrients in highway runoff.

	Total phosphate, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
Site	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	0.01-3.66	0.57	0.02-3.06	0.53	0.01-3.66	0.63
Sacramento Hwy 50	0.03-11.5	0.83	0.03-11.5	0.83		--
Harrisburg I-81	0.01-0.82	0.18	0.01-0.41	0.11	0.21-0.82	0.51
Efland I-85	0.05-1.64	0.52		1.64	0.05-0.22	0.15

	Total Kjeldahl nitrogen, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	0.34-15.1	4.41	0.70-15.1	4.62	0.34-13.1	4.02
Sacramento Hwy 50	ND-15.5	3.56	ND-15.5	3.56		--
Harrisburg I-81	0.01-1.50	0.35	0.01-0.74	0.20	0.51-1.50	1.00
Efland I-85	2.79-12.1	3.55		12.1	2.79-3.72	3.37

	Nitrate & nitrite, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	0.02-2.87	1.03	0.20-2.87	1.06	0.02-2.35	0.98
Sacramento Hwy 50	0.07-2.66	0.62	0.07-2.66	0.62		--
Harrisburg I-81	0.01-8.67	1.29	0.01-2.02	0.40	1.95-8.67	5.31
Efland I-85	ND-0.84	0.45		0.82	ND-0.84	0.08

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.
Metric units: To convert lb/mi to kg/km multiply by 0.2819.

Table 69. Nutrients loadings normalized for runoff volumle.

Total phosphate, lb/mi[a]/in of runoff

Site	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	0.42-5.07	1.62	0.42-3.06	1.37	0.46-5.07	2.24
Sacramento Hwy 50	0.10-15.3	1.51	0.10-15.3	1.51		
Harrisburg I-81	0.97-9.21	2.02	0.97-9.21	3.03	1.46-1.97	1.54
Efland I-85	0.29-0.47	0.38		0.47	0.29-0.41	0.35

Total Kjeldahl nitrogen, lb/mi[a]/in of runoff

Site	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Median	Range	Median	Range	Median
Milwaukee	5.87-41.1	16.8	5.87-41.1	16.8	8.38-26.8	14.3
Sacramento Hwy 50	ND-20.6	6.98	ND-20.6	6.98		-
Harrisburg I-81	2.66-12.8	3.86	2.82-12.8	5.62	2.66-4.86	3.01
Efland I-85	3.43-23.3	5.81		3.43	5.81-23.3	5.81

Nitrate & nitrite, lb/mi[a]/in of runoff

Site	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Median	Range	Median	Range	Median
Milwaukee I-94	0.92-11.4	2.98	1.59-11.4	2.78	0.92-9.22	3.47
Sacramento Hwy 50	0.14-5.84	1.13	0.14-5.84	1.13		-
Harrisburg I-81	3.25-23.0	14.3	3.25-23.0	11.2	15.4-18.6	15.9
Efland I-85	ND-1.31	0.47		0.23	ND-1.31	0.70

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

ND = Not detectable.

Metric units: To convert lb/mi/in to kg/km/cm multiply by 0.111.

Oxygen demand parameters--Biological oxygen demand (BOD_5) and chemical oxygen demand (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 total organic carbon (TOC) determination has also gained acceptance as still another means of characterizing oxygen demand levels. COD and TOC analyses are measures of ultimate oxygen demand but 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 BOD_5.

Colston (53), 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. Inhibitory effect of heavy metals.
2. Presence of other unidentified inhibitory compounds.
3. Inherent problems of the standard BOD test.

For this reason, only COD and TOC analyses were performed on highway runoff samples collected as part of this study. TOC and COD concentrations obtained during this study are summarized in Table 70. A comparison of TOC and COD concentrations observed in highway runoff at the sites monitored during this study and FHWA's initial study on highway runoff constituents (39) to urban stormwater runoff concentrations are presented in Table 71. TOC and COD concentration values observed for this study are within the range observed for FHWA's initial study (39), and also in the range of what would be expected in urban stormwater runoff.

Table 70. Concentration of TOC and COD in highway runoff.

	TOC, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
Site	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	3-182	41	3-82	27	6-182	83
Sacramento Hwy 50	4-46	19	4-46	19		--
Harrisburg I-81	13-23	14	13-23	18		13
Efland I-85	16-26	23		--	16-26	23
	COD, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	46-660	153	46-306	92	61-660	326
Sacramento Hwy 50	16-99	55	16-99	55		--
Harrisburg I-81	21-54	27	33-54	42		21
Efland I-85	26-89	67		--	26-89	67

[a] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October. Sacramento - January through December.

[b] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

Table 71. Comparison of TOC and COD values in urban runoff to highway runoff.

Area	Ref.	COD, mg/l		TOC, mg/l	
		Mean	Range	Mean	Range
Urban runoff					
Washington, DC	(50)	335	29-1514	--	--
Durham, NC	(51)	179	40-600	--	--
Cincinnati, OH	(52)	111	20-610	--	--
Durham, NC	(53)	170	20-1042	42	5.5-384
Ann Arbor, MI	(54)	--	--	--	--
Tulsa, OK	(55)	48	--	--	--
Highway runoff					
Milwaukee, WI I-794	(39)	232	5-1058	50	5-230
Milwaukee, WI Hwy 45	(39)	165	64-774	54	16-290
Harrisburg, PA I-81	(39)	36	21-89	13	6-24
Nashville, TN I-40	(39)	125	13-264	38	12-85
Denver, CO I-25	(39)	191	119-718	54	14-212
Milwaukee, WI I-94		153	46-660	41	3-182
Sacramento, CA Hwy 50		55	16-99	19	4-46
Harrisburg, PA I-81		27	21-54	14	13-23
Efland, NC I-85		67	26-89	23	16-26

Loadings of TOC and COD, lb/mi/event, observed at the sites monitored are presented in Table 72. Milwaukee and Sacramento had comparable values while the values at Harrisburg were an order of magnitude lower. Mean winter loading value at Milwaukee and Harrisburg were higher than nonwinter values. When loading values were normalized for runoff, lb/mi/in of runoff, Milwaukee had the higher mean nonwinter value, Harrisburg the lowest value, and Sacramento the intermediate value (Table 73).

Sulfate--Because sulphuric acid is the major constituent of acid rain and because it is theorized that catalytic converter emissions are conducive to the formation of sulphuric acid, the sulfate ion was measured in the runoff at all sites. Sulfate can also have high concentrations in deicing salts (12) and is a macronutrient required for plant growth. Concentrations and loadings of sulfate are presented in Table 74. The data show a wide range of sulfate concentrations from ND at Sacramento to 180 mg/l at Milwaukee during winter periods. Overall sulfate loadings, lb/mi/event and lb/mi/in of runoff, also show a wide spread in values.

Relationship of total solids to other quality parameters--As previously discussed, analysis of highway runoff quality data collected as part of FHWA's initial study on highway runoff constituents indicated that total solids exhibited the highest degree of association with all other quality parameters (39, 56). To determine if the same relationship existed for runoff quality data collected as part of this study, correlation analysis was performed on the observed nonwinter loadings of total solids to other quality parameters monitored at Milwaukee, Sacramento, and Harrisburg.

A summary of the relationship between total solids and the other highway runoff constituents at Milwaukee, Efland, Harrisburg, and Sacramento are listed in Table 75. Correlation coefficients for the parameters TVS, SS, VSS, Zn, Fe, Cu, Ca, SO_4, O&G, and NO_2+NO_3 indicate a relationship to total solids at all monitoring sites where these analyses were performed. These parameters have a correlation coefficient (r value) greater than the critical value (r crit). On a strict statistical basis, the null hypothesis that r = 0 (ie., that the data is from a population for which no correlation exists) can be rejected at the 95 percent confidence level. COD, Pb, Cd, Ni, TPO_4, and Cl were correlated at all but one of the sites where these analyses were performed while only TOC, Hg, and TKN correlated at one or less of the sites. These results confirm the findings of FHWA's initial study on highway runoff constituents (39, 56) that the loadings of most of the monitored pollutants are highly related to total solids. Therefore, pollutant loadings in highway runoff can be estimated based upon the loading of total solids.

Overall concentrations and loadings of constituents in highway runoff--Runoff data presented thus far have been site specific. A summary of highway runoff composite quality data for all four monitoring sites is presented in

Table 72. Loading of TOC and COD in highway runoff.

Site	TOC, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	2.68-425	66.4	2.68-149	43.2	8.05-425	133
Sacramento Hwy 50	4.26-86.0	42.2	4.26-86.0	42.2		--
Harrisburg I-81	2.45-18.8	7.73	2.45-5.15	3.38		18.8
Efland I-85	5.58-43.8	30.1		--	5.58-43.8	30.1
	COD, lb/mi[a]/event					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	14.1-1,930	244	14.1-386	148	63.0-1,930	523
Sacramento Hwy 50	17.1-271	120	17.1-271	120		--
Harrisburg I-81	4.92-30.3	13.5	4.92-12.1	7.87		30.3
Efland I-85	9.07-166	86.3		--	9.07-166	86.3

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground snow, November through March.

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

Table 73. TOC and COD loadings normalized for runoff volume.

Site	TOC, lb/mi[a]/in of runoff					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	12.6-763	174	12.6-344	113	25.1-763	349
Sacramento Hwy 50	13.8-158	66.3	13.8-158	66.3		--
Harrisburg I-81	33.3-58.9	36.9	33.3-58.9	46.2		33.3
Efland I-85	46.5-75.6	67.4		--	46.5-75.6	67.4

Site	COD, lb/mi[a]/in of runoff					
	Overall monitoring period		Nonwinter periods[b]		Winter periods[c]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	193-2,770	639	193-1,280	387	256-2,770	1,370
Sacramento Hwy 50	55.0-340	189	55.5-340	189		--
Harrisburg I-81	53.8-138	68.8	84.5-138	108		53.8
Efland I-85	75.6-259	193		--	75.6-259	193

[a] Both directions irrespective of number of lanes.

[b] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October.
Sacramento - January through December.

[c] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

Metric units: To convert lb/mi/in to kg/km/cm multiply by 0.111.

Table 74. Concentration and loading of sulfate in highway runoff.

Site	Sulfate, mg/l					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	10-180	40		10	37-180	56
Sacramento Hwy 50	ND-14	6	ND-14	6		--
Harrisburg I-81	8-35	20	8-35	20	19-21	19
Efland I-85	5-24	7	5-12	7	8-24	11

	Sulfate, lb/mi[c]/event					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	10-40	24		10	17-40	28
Sacramento Hwy 50	ND-34	8.2	ND-34	8.2		--
Harrisburg I-81	0.04-27	4.5	0.04-7.8	1.8	5.6-27	17
Efland I-85	8.4-51	29	43-51	47	8.4-15	12

	Sulfate, lb/mi[c]/in of runoff					
	Overall monitoring period		Nonwinter periods[a]		Winter periods[b]	
	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	41.9-754	169		41.9	155-754	233
Sacramento Hwy 50	ND-48.1	11.6	ND-48.1	11.6		--
Harrisburg	20.5-89.6	49.8	20.5-89.6	50.5	48.6-53.8	49.4
Efland I-85	14.5-69.8	21.0	14.5-34.9	19.8	23.3-69.8	30.6

[a] Nonwinter: Milwaukee, Efland, and Harrisburg - April through October. Sacramento - January through December.

[b] Winter: Milwaukee, Efland, and Harrisburg - period with snowfall and ground frost, November through March.

[c] Both directions irrespective of number of lanes.

ND = Not detectable.

Metric units: To convert lb/mi to kg/km multiply by 0.2819.
To convert lb/mi/in to kg/km/cm multiply by 0.111.

Table 75. Correlation between total solids and all other runoff parameters at the four sites monitored - nonwinter data[a].

Parameter	$r > r_{crit}$[b]			
	Milwaukee I-94	Sacramento Hwy 50	Harrisburg I-81	Efland I-85
TVS	Yes	Yes	Yes	NA
SS	Yes	Yes	Yes	Yes
VSS	Yes	Yes	Yes	NA
TOC	Yes	No	No	NA
COD	Yes	Yes	No	NA
Pb	Yes	Yes	No	Yes
Zn	Yes	Yes	Yes	Yes
Fe	Yes	Yes	Yes	Yes
Cr	Yes	Yes	Yes	No
Cu	Yes	Yes	Yes	Yes
Cd	Yes	Yes	No	Yes
Ni	Yes	Yes	No	Yes
Hg	No	NA	No	NA
TPO_4	Yes	No	Yes	NA
TKN	No	No	Yes	NA
NO_2+NO_3	Yes	Yes	Yes	NA
Ca	Yes	NA	NA	NA
Na	Yes	No	No	Yes
Cl	Yes	No	Yes	Yes
SO_4	NA	Yes	Yes	NA
Oil & grease	Yes	Yes	NA	Yes

[a] Nonwinter: Milwaukee and Harrisburg - April through October.
Sacramento - January through December.

[b] Critical value at 95 percent confidence level.

NA = Less than three analyses performed.

Table 76 to provide an overall picture of highway runoff constituent concentrations and loadings. The range of loading values, lb/mi/event, provides an overall idea of the impact of highway runoff as it leaves the highway drainage system and discharges to the surrounding environment. For example, the lead loading for a single event was not detectable at the low end of the range to as high as 20.3 lb/mi/event (5.72 kg/km) during a winter runoff event at Milwaukee. The data also show that during a winter period at Milwaukee, 26,100 lb/mi (7,300 kg/km) of sodium chloride were discharged to the environment during a single runoff event. Oil and grease also showed a wide loading range of 0.7 to 69 lb/mi/event (0.2 to 19 kg/km).

Discrete quality data--The pattern of pollutant discharge during a runoff event was defined by discrete samples collected at selected time intervals throughout the event. Pollutant concentrations and flow measurements were utilized to determine loadings of various constituents during each sampling time interval. One event from the Milwaukee I-94 site and Sacramento Hwy 50 site were selected to characterize rainfall intensity (in/hr), runoff flow (cfs), constituent concentrations (mg/l), and loadings (lb/min) with time. Quality parameters selected to demonstrate discharge patterns were total solids (carrier constituent), suspended solids, lead, and zinc.

Rain and flow data for the June 28-29, 1979, storm at the Milwaukee I-94 site are presented in Figure 21. The rainfall pattern for this storm event, relatively high intensity and short duration, is characteristic of the Milwaukee site. The 15-minute lag time between rainfall start and flow start is also characteristic for this site and would be expected for a 100 percent paved drainage area. Peak rainfall intensity and peak flow intensity show a similar lag time.

In discussion 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. 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.

The total solids discharge pattern for the June 28-29, 1979, storm event at the Milwaukee I-94 site is presented in Figure 22. The first flush phenomenon is clearly evident on the total solids loading graph (lb/min). At the beginning of the runoff event (2100 hrs), total solids concentration (mg/l) is the highest for the event but the low flow at that time results in a low loading value (lb/min). However, the relatively high total solids concentration (mg/l) at 2110 hours and the corresponding peak flow (Figure 21) results in a total solids loading (lb/min) which is extremely high compared to the other points on the graph (first flush). After the first flush, which removes the major portion of the load for this event, total solids loading tapers off with time into the runoff event even though the total solids

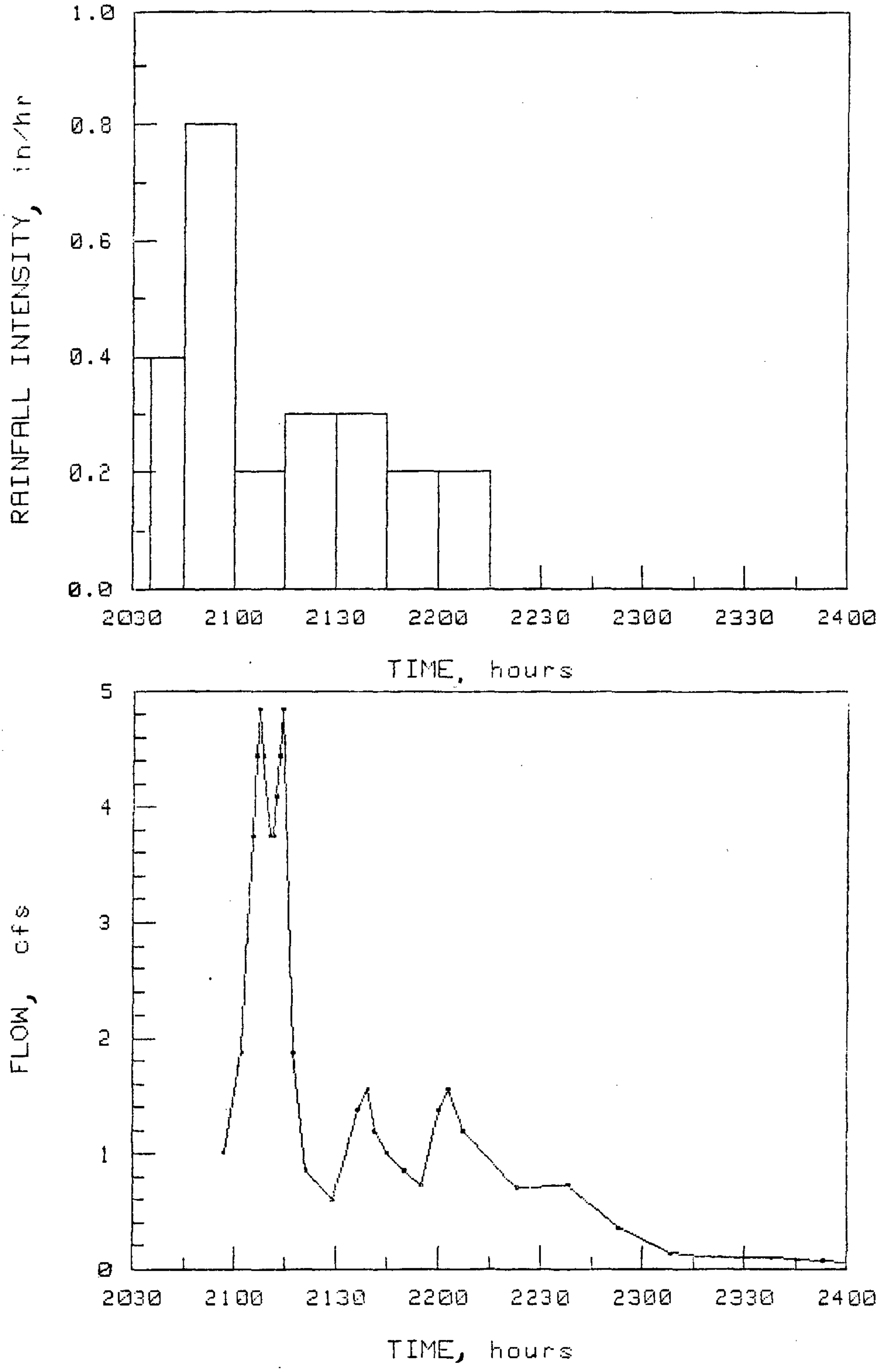
Table 76. - Summary of highway runoff composite quality data for all four monitoring sites - overall monitoring period (winter and nonwinter).

Parameter	Pollutant concentration, mg/l		Pollutant loading, lb/mi[a]/event	
	Minimum	Maximum	Minimum	Maximum
pH	4.90	7.95		
TS	68	57,400	0.85	17,400
VTS	10	510	0.25	1,200
SS	6	2,160	0.22	6,080
VSS	4	317	0.04	915
Pb	ND	6.30	ND	20.3
Zn	0.036	2.90	0.0004	7.52
Fe	0.30	115	0.012	150
Cr	ND	0.19	ND	0.556
Cu	ND	0.59	ND	1.93
Cd	ND	0.06	ND	0.010
Ni	ND	0.22	ND	0.66
Hg	ND	0.001	ND	0.001
As	ND	0.03	ND	0.13
Na	2.1	22,500	0.02	12,600
Ca	4.0	450	0.92	202
Cl	2.0	35,000	0.07	13,500
Oil & grease	1	21	0.3	69
PO_4-P	0.03	4.45	0.01	11.5
TKN	ND	9.80	ND	15.5
NO_2+NO_3	ND	9.00	ND	8.67
TOC	4	182	2.45	425
COD	16	660	4.92	1930
SO_4	ND	180	ND	51

[a] Both directions irrespective of number of lanes.

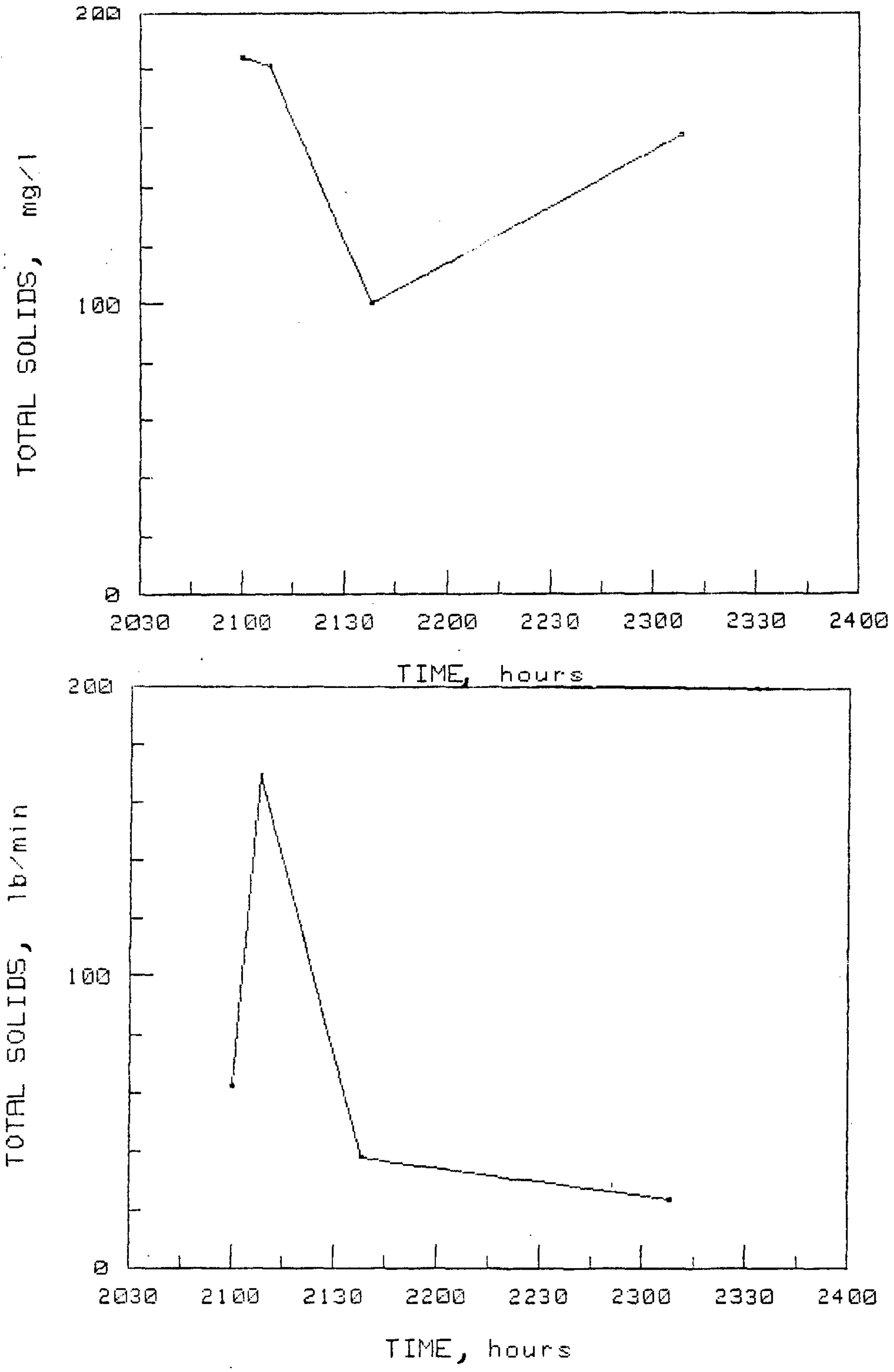
ND = Not detectable.

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



Metric units: To convert in to cm multiply by 2.54.
To convert cu ft to liters multiply by 28.32.

Figure 21. Rain and flow pattern, Milwaukee I-94, June 28-29, 1979.



Metric units: To convert lb to kg multiply by 0.4536.

Figure 22. Total solids discharge pattern, Milwaukee I-94, June 28-29, 1979.

concentration rises sharply at storm end. Except for the rise in concentration at the beginning and end of the storm, suspended solids (Figure 23), lead (Figure 24), and zinc (Figure 25) show the same discharge pattern as total solids.

Rain and flow patterns observed on January 17, 1980, at the Sacramento Hwy 50 site are presented in Figure 26. The rainfall pattern for this storm event, long duration and relatively low intensity except for a brief high intensity period, is characteristic of the Sacramento site. This site is 100 percent paved and similar to the Milwaukee site; the lag time between rainfall start and flow start is approximately 15 minutes.

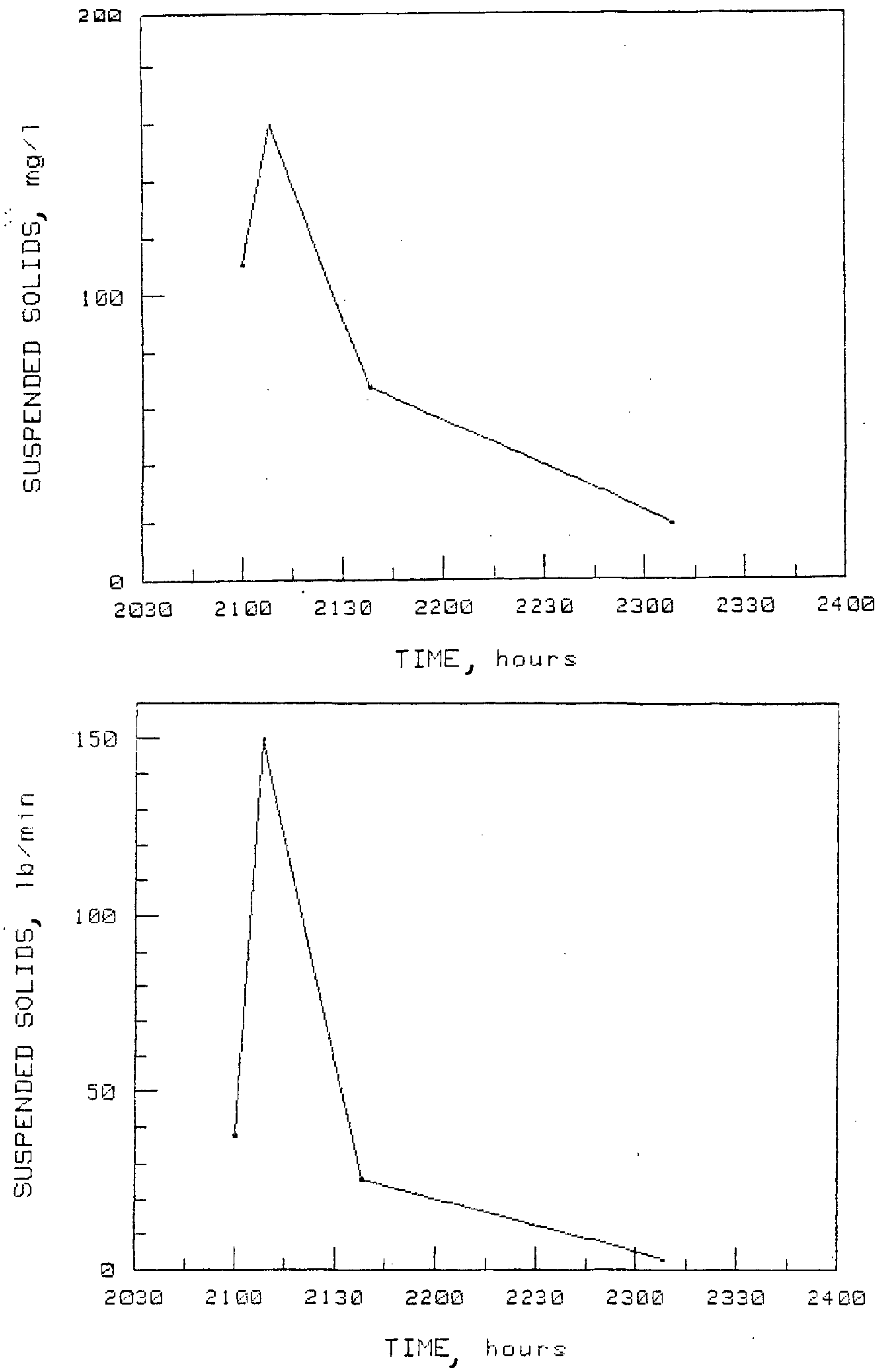
Discharge patterns for total solids (Figure 27) and suspended solids (Figure 28) were comparable. Because of the low flow intensity (Figure 26) during the first seven hours of the storm event, the first flush phenomenon was delayed until 1100 hours when flow intensity exceeded one cfs. Lead and zinc discharge patterns (Figures 29 and 30) were also comparable. Lead and zinc loadings (lb/min) followed the same pattern as total and suspended solids. Concentration of lead and zinc (mg/l) peaked just prior to peak discharge while the peak concentration of total solids and suspended solids coincided with peak flow discharge.

Unpaved Runoff--During the periods monitored at the Milwaukee I-94, Sacramento Hwy 50, and Harrisburg I-81 sites all unpaved runoff events were monitored for quality data. Efland was the last site to be monitored. Unpaved runoff was not monitored at this site because the contribution of the unpaved area to the total pollutant load was determined to be negligible at Milwaukee and Sacramento and 14 percent at Harrisburg. Distribution of unpaved runoff events at the three sites monitored is as follows:

Site	Number of runoff events	Monitoring period
Milwaukee I-94	13	8/16/78 - 5/15/80
Sacramento Hwy 50	1	12/19/79 - 1/22/81
Harrisburg I-81	5	6/15/80 - 6/10/81

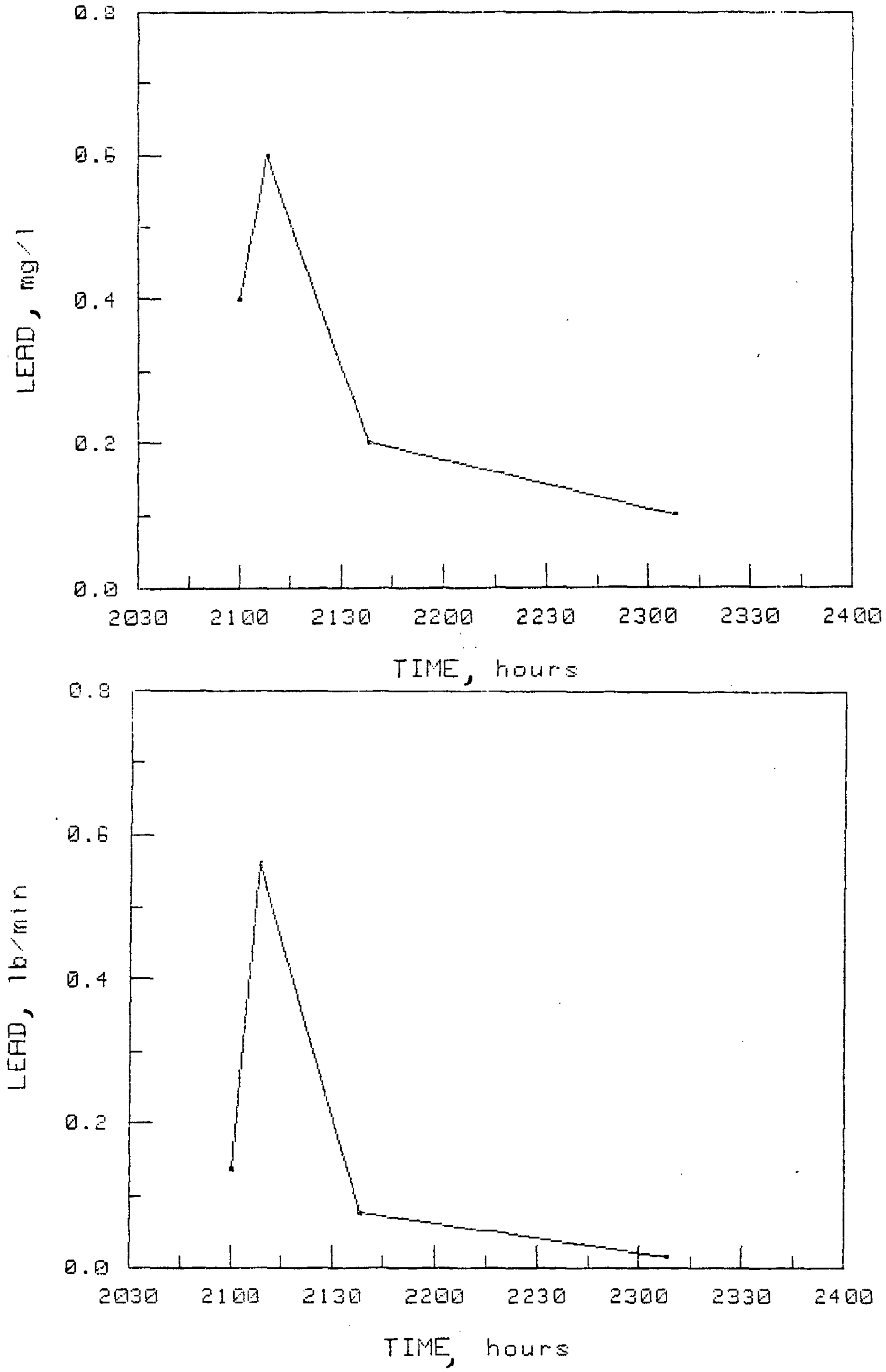
Accumulated data from these quality monitored events at the three sites are presented and discussed in the ensuing subsections.

Rainfall runoff relationships--A complete listing of hydraulic data for unpaved runoff at all sites monitored is presented in Volume IV - Appendix. A summary of the calculated runoff coefficients is presented in Table 77.



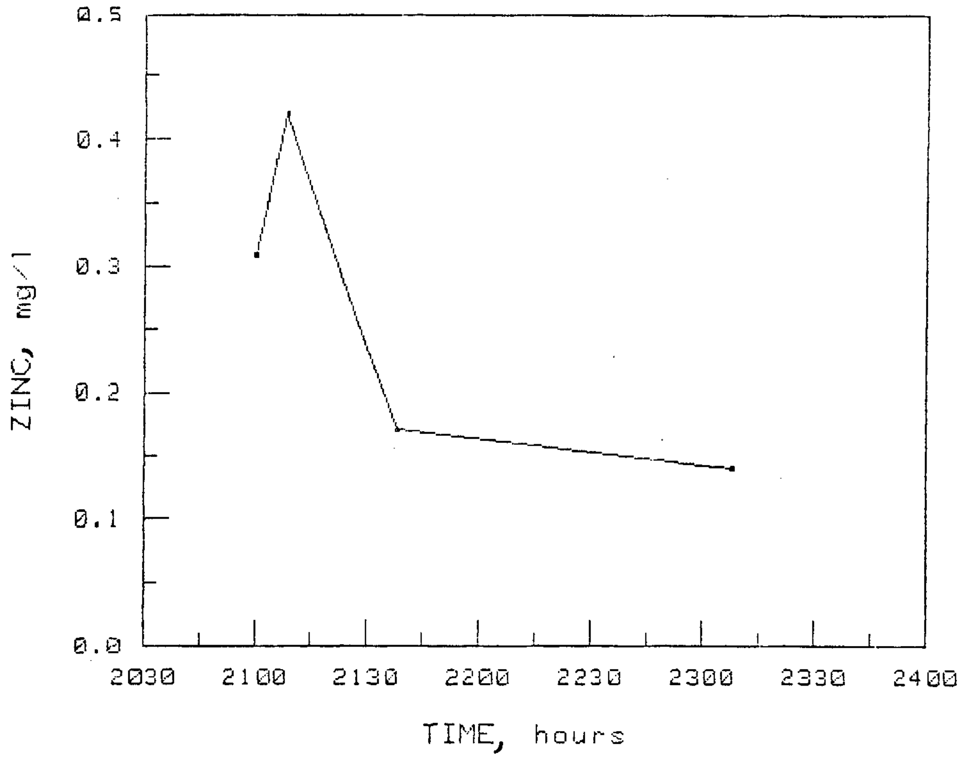
Metric units: To convert lb to kg multiply by 0.4536.

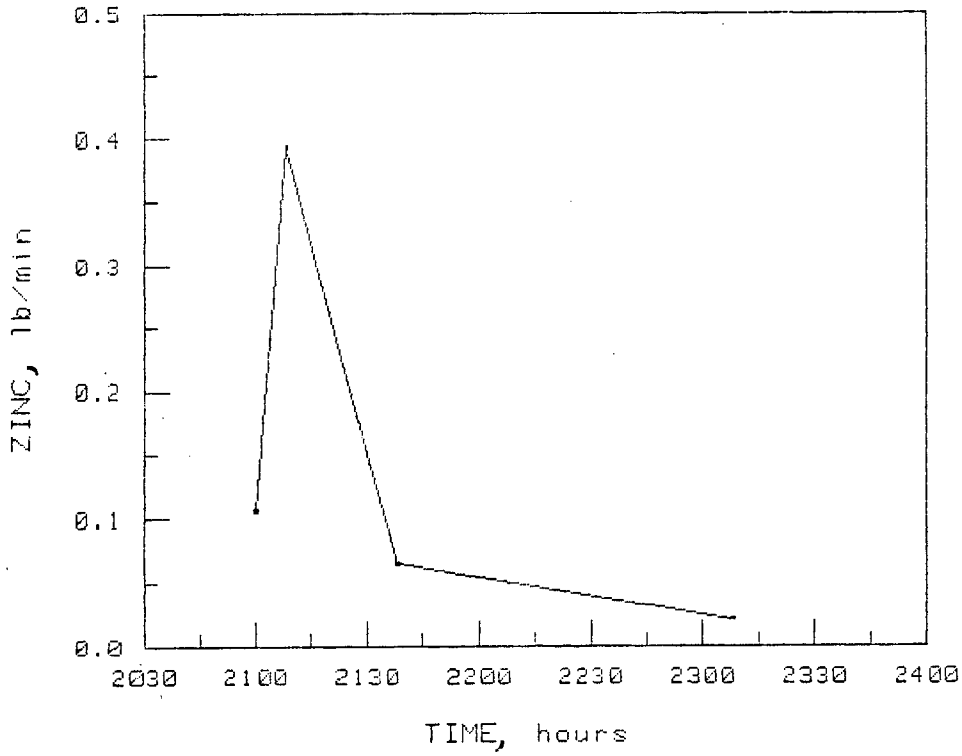
Figure 23. Suspended solids discharge pattern, Milwaukee I-94, June 28-29, 1979.



Metric units: To convert lb to kg multiply by 0.4536.

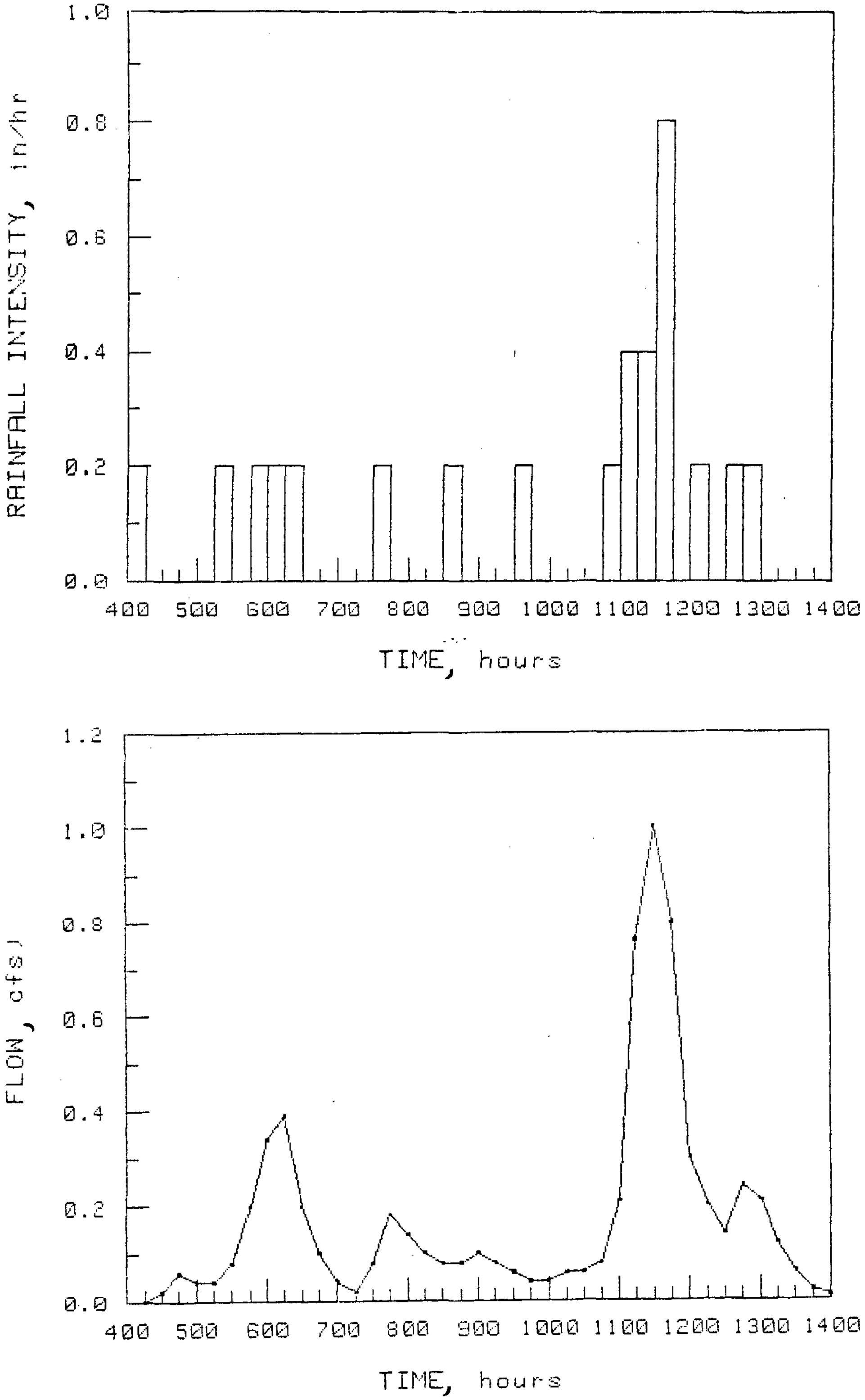
Figure 24. Lead discharge pattern, Milwaukee I-94, June 28-29, 1979.





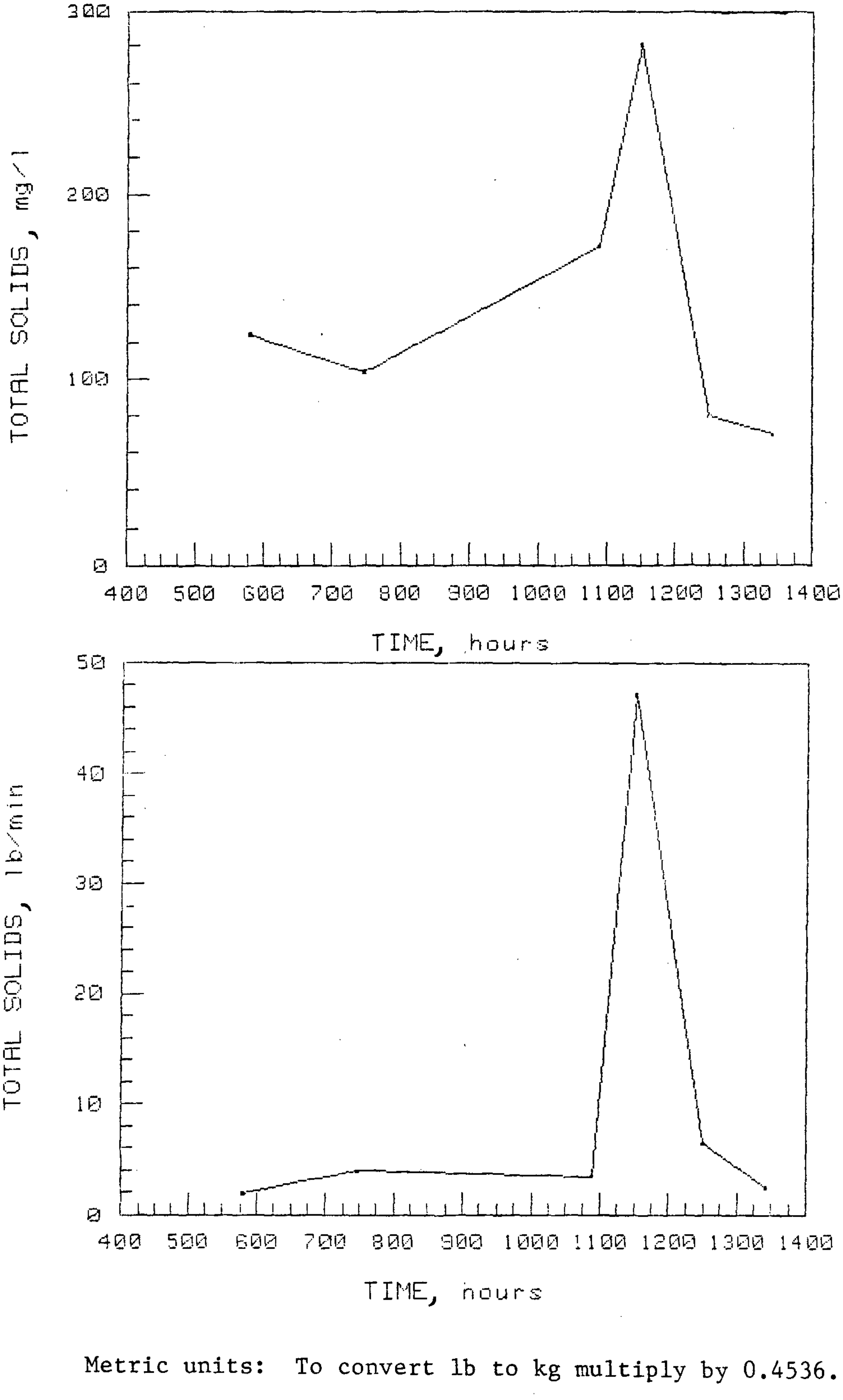
Metric units: To convert lb to kg multiply by 0.4536.

Figure 25. Zinc discharge pattern,
Milwaukee I-94, June 28-29, 1979.



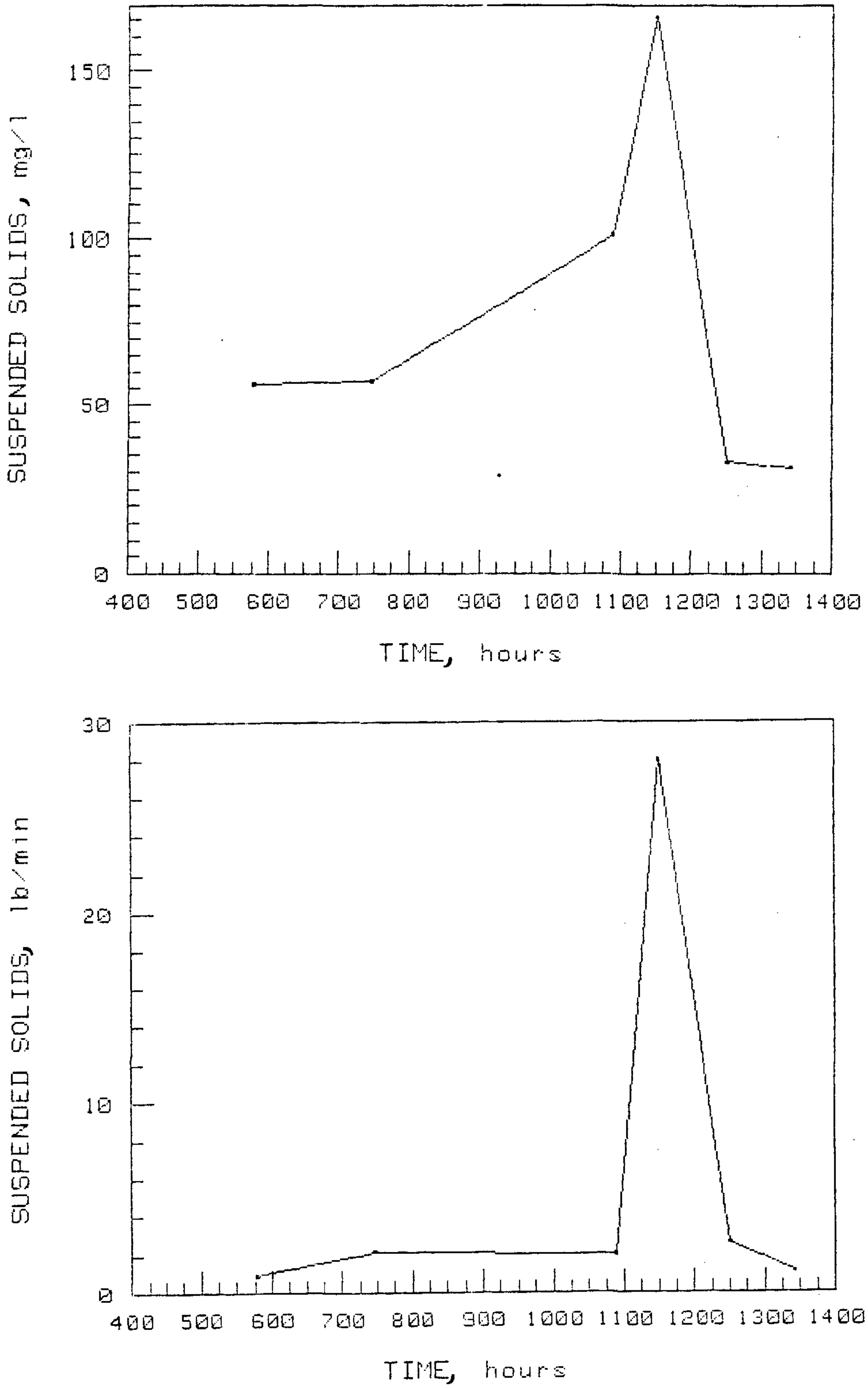
Metric units: To convert in to cm multiply by 2.54.
To convert cu ft to liters multiply by 28.32.

Figure 26. Rain and flow pattern, Sacramento Hwy 50, January 17, 1980.



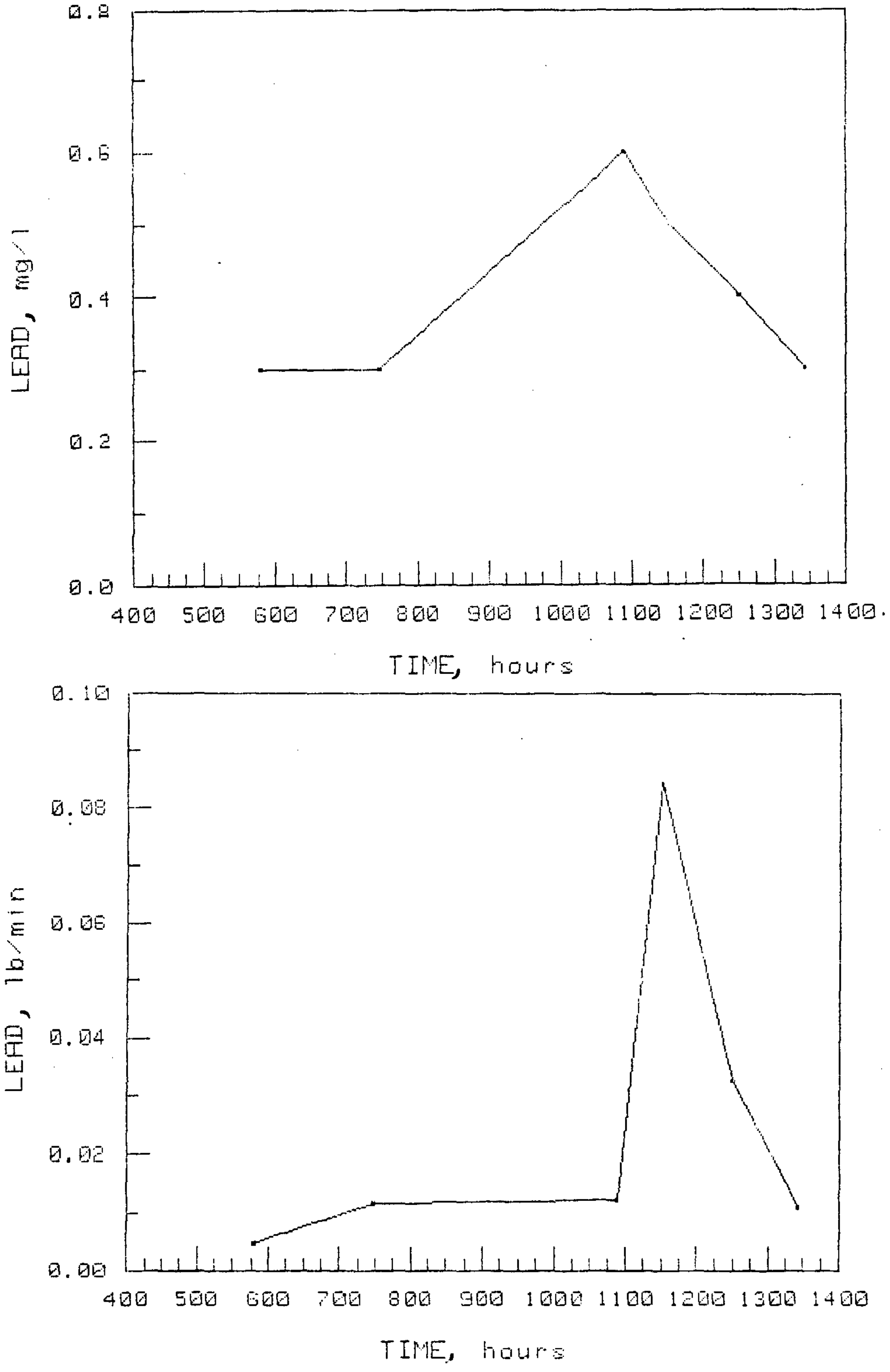
Metric units: To convert lb to kg multiply by 0.4536.

Figure 27. Total solids discharge pattern, Sacramento Hwy 50, January 17, 1980.



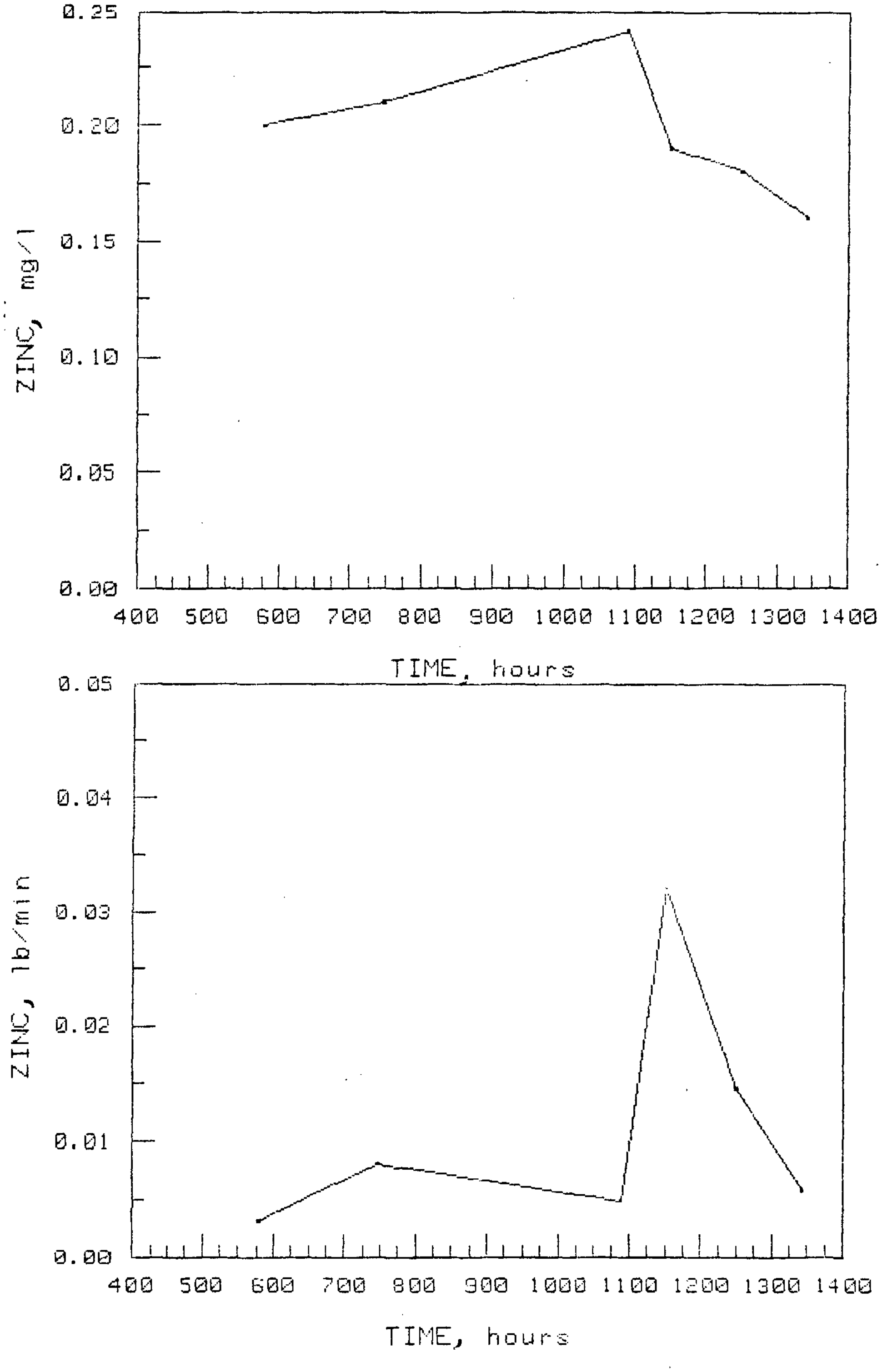
Metric units: To convert lb to kg multiply by 0.4536.

Figure 28. Suspended solids discharge pattern, Sacramento Hwy 50, January 17, 1980.



Metric units: To convert lb to kg multiply by 0.4536.

Figure 29. Lead discharge pattern, Sacramento Hwy 50, January 17, 1980.



Metric units: To convert lb to kg multiply by 0.4536.

Figure 30. Zinc discharge pattern, Sacramento Hwy 50, January 17, 1980.

Table 77. Summary of runoff (Q) rainfall (R) coefficients (Q/R)-unpaved areas.

		Rainfall, in		Runoff, in		Runoff coefficient	
Site	n	Range	Mean	Range	Mean	Range	Mean
Milwaukee I-94	6	0.14-1.22	0.66	0.0007-0.06	0.02	0.002-0.11	0.02
Sacramento Hwy 50	1	--	1.62	--	0.15	--	0.09
Harrisburg I-81	5	1.02-2.02	1.59	0.004-0.84	0.30	0.004-0.43	0.19

n = Number of observations

Metric units: To convert in to cm multiply by 2.54.

The 13 runoff events from the unpaved area at Milwaukee occurred either during winter months when the ground was frozen (2 events in January, 1 event in February, and 8 events in March) or during early spring when the soil was saturated (2 events in April). Seven of the runoff events were due to snowmelt and six were associated with precipitation events. These precipitation events had a mean rainfall of 0.66 in (1.68 cm) and produced a mean runoff coefficient of 0.02 (Table 77). Rainfalls for the two April runoff events were 1.20 and 1.22 in (3.05 to 3.10 cm). Runoff was produced from the unpaved area at Milwaukee only when the following two conditions existed:

1. Precipitation or snowmelt producing flow on frozen ground.
2. Large rainfall events producing flow on spring saturated soils.

The single unpaved runoff event at Sacramento occurred on February 10, 1980. Total rainfall for this event was 1.62 in (4.11 cm) and produced a runoff coefficient of 0.09 (Table 77). Rainfall for the period February 14-19, 1980, totalled 3.57 in (9.07 cm) indicating that the ground was saturated.

The five unpaved runoff events monitored at Harrisburg were associated with rainfall events. One event occurred in late November, three in February, and one in July. An unpaved runoff event due to snowmelt did not occur during the period monitored. This was probably due to the unusual winter period monitored at Harrisburg. Only 24.9 in (63.2 cm) of snow fell during the period monitored as compared to 39.5 in (100 cm) and 70.6 in (179 cm) that fell in the two previous years. Another factor was the unusually warm temperature which occurred during the winter monitored. For these two reasons, a true ground snow cover never existed. In all cases, unpaved runoff at Harrisburg during the monitoring period resulted from large rainfall events flowing on saturated ground. Mean rainfall for these events was 1.59 in (4.03 cm) producing a runoff coefficient of 0.19.

Unpaved runoff quality data--A complete listing of quality data for unpaved runoff at all sites monitored is presented in Volume IV - Appendix. The objective of monitoring unpaved runoff quality was to determine the contribution of the unpaved area to the total pollutant load leaving the paved highway surface and right-of-way areas. A comparison of constituent loadings (lb/event) from paved and unpaved runoff events during the period monitored at each site is presented in Table 78 for Milwaukee, Table 79 for Sacramento, and Table 80 for Harrisburg. Median value (m) was used to characterize data sets which included ND (not detectable) values and the mean value was used to characterize all other data sets.

At the Milwaukee I-94 site, runoff from both the eastbound and westbound travel lanes was collected by the inlets existing in each of these highway sections. The inlets were connected to a common sewer system whose outfall was located north of the westbound lanes (Volume II - Methods). Water quality

Table 78. Comparison of constituent loadings (lb/event) from paved and unpaved runoff events - Milwaukee I-94.

	Paved		Unpaved	
Parameter	Range	Mean median, m	Range	Mean median, m
TS	4.04-4,610	288	0.12-20.5	5.68
TVS	3.07-319	46.6	0.31-6.21	1.55
SS	0.58-1,610	57.5	0.005-1.93	0.34
VSS	1.42-243	26.5	0.05-0.93	0.17
TOC	0.71-113	1.76	0.14-0.58	0.36
COD	3.73-511	64.8	0.38-1.82	0.84
Pb	0.009-5.37	0.24	ND-0.007	0.0008
Zn	0.01-1.99	0.24	0.00007-0.005	0.002
Fe	0.03-39.8	3.59	0.0004-0.116	0.02
Cr	ND-0.15	0.003	ND-0.001	ND
Cu	0.002-0.51	0.07	0.0001-0.003	0.001
Cd	ND-0.03	0.0009	ND-0.0002	ND
Ni	ND-0.11	0.003	ND-0.001	ND
Hg	ND-0.0003	ND	ND-0.0008	ND
PO_4-P	0.002-0.97	0.15	0.0003-0.02	0.007
TKN	0.09-4.01	1.17	0.007-0.11	0.04
NO_2+NO_3	0.005-0.76	0.27	0.00008-0.02	0.006
Na	0.95-334	198	0.86-4.22	2.31
Cl	0.56-357	213	0.04-6.06	1.65
Ca	0.24-53.4	8.91	0.05-0.57	0.36
SO_4	2.67-10.5	6.46	0.11-0.33	0.20
O&G	0.18-9.95	3.10		
Number of runoff events		228		13

Metric units: To convert lb to kg multiply by 0.4536.

Table 79. Comparison of constituent loadings (lb/event) from paved and unpaved runoff events - Sacramento Hwy 50.

Parameter	Paved Range	 Mean median, m	Unpaved Mean median, m
TS	1.62-202	36.7	2.96
TVS	1.79-53.0	13.3	0.81
SS	0.27-106	19.1	1.68
VSS	0.76-14.7	4.86	0.28
TOC	0.56-11.4	5.59	0.42
COD	2.26-35.9	15.9	0.69
Pb	ND-0.26	0.03	0.003
Zn	0.005-0.16	0.05	0.002
Fe	0.009-3.13	0.71	0.15
Cr	ND-0.01	0.005	ND
Cu	ND-0.07	0.02	ND
Cd	ND-0.007	0.001	ND
Ni	ND-0.09	0.006	0.003
Hg	ND-0.000006	ND	ND
PO_4-P	0.005-1.52	0.11	0.01
TKN	ND-2.05	0.47	0.03
NO_2+NO_3	0.009-0.35	0.05	ND
Cl	0.33-30.1	2.67	0.07
SO_4	ND-4.56	0.68	0.04
Number of runoff events		57	1

ND - Not detectable.

Metric units: To convert lb to kg multiply by 0.4526.

Table 80. Comparison of constituent loadings (lb/event) from paved and unpaved runoff events - Harrisburg I-81.

	Paved		Unpaved	
Parameter	Range	Mean median, m	Range	Mean median, m
TS	0.11-327	28.7	0.31-81.7	28.7
TVS	0.03-16.6	2.64	0.10-12.2	6.17
SS	0.03-158	12.0	0.13-33.7	13.9
VSS	0.06-2.21	0.44	0.27-1.16	0.59
TOC	0.31-2.39	0.92		2.21
COD	0.63-3.87	1.72		2.95
Pb	ND-0.02	0.0005 m	ND-0.007	0.0003 m
Zn	0.00005-0.04	0.006	0.0002-0.02	0.009
Fe	0.002-4.84	0.43	0.003-1.02	0.36
Cr	ND-0.002	0.00007 m	ND-0.0006	ND m
Cu	0.00007-0.007	0.001	0.00006-0.008	0.003
Cd	ND-0.0002	ND m	ND-0.005	0.00002 m
Ni	ND-0.0008	ND m	ND-0.0006	ND m
Hg	ND-0.00002	0.000009 m	--	ND
PO_4-P	0.0007-0.11	0.02	0.0002-0.05	0.02
TKN	0.002-0.19	0.04	0.002-0.21	0.08
NO_2+NO_3	0.001-1.11	0.17	0.005-0.57	0.20
Cl	0.008-6.70	1.00	0.04-1.98	1.01
Na	0.002-5.16	0.88	0.02-0.83	0.42
Ca	0.36-3.68	2.02		0.74
SO_4	0.005-3.50	0.57	0.01-1.32	0.67
Number of runoff events		30		5

Metric units: To convert lb to kg multiply by 0.4536.

samples were obtained just beyond the point at which all trunk sewers joined the main sewer. Thus, constituent loadings for the paved runoff at the Milwaukee site represent both sides of the highway. Runoff from the unpaved area north of the westbound lanes normally included inlets in the grassy area which entered the sewer system carrying paved runoff. As explained in Volume II - Methods, these inlets were sealed and unpaved runoff was diverted to a separate monitoring point. The unpaved area south of the eastbound lanes was not a part of the drainage scheme at Milwaukee I-94. Thus, constituent loadings for the unpaved runoff at the Milwaukee site represent only the area north of the westbound lanes.

Although the loadings (lb/event) in Table 78 are for segregated paved and unpaved runoff, they represent the as-built drainage scheme for this site. The total constituent loading normally reaching the outfall is reflected in these data. At Milwaukee, the mean or median loading value for paved runoff was generally several orders of magnitude higher than loading values for unpaved runoff. The number of runoff events during the period monitored at Milwaukee was 228 paved runoff events and 13 unpaved runoff events. These data indicate that the contribution of the unpaved area to the total constituent loading reaching the outfall is negligible. For example, the total lead loading from the unpaved area during the period monitored for all 13 events was approximately 0.01 lb (4.5 g), which is less than 0.2 percent of the highest lead load [5.37 lb (2,440 g)] monitored for a single paved runoff event (Table 78). Because the ground was frozen for 11 of the 13 unpaved runoff events at Milwaukee, the source of pollutants in unpaved runoff was mainly from the pollutant load held in the ground snow. As will be discussed in the section on pollutant storage and migration in areas adjacent to the highway, ground snow accumulates pollutants over winter due to splashoff and blowoff from the paved highway surface. The pollutant load stored in the soil and litter (dead vegetation) of the area adjacent to I-94 at Milwaukee, appears to be relatively unaffected by unpaved runoff.

At the Sacramento Hwy 50 site, runoff from the westbound lanes was contained by an asphalt berm (curb) installed the length of the highway section monitored and diverted to the monitoring point via an asphalt channel (Volume II - Methods). Essentially, these site modifications transformed the drainage scheme at Sacramento from a flush shoulder to a curb and gutter drainage design. The unpaved area north of the westbound lanes which was normally a part of the drainage scheme was monitored separately for its contribution to the total constituent loading. Therefore, the loading data (lb/event) in Table 79 represent the modified drainage scheme for westbound lanes and the associated unpaved runoff. To obtain estimates of loadings (lb/event) from the entire highway system at Sacramento (both directions), the values in Table 79 would have to be doubled.

The Sacramento data for the period monitored (Table 79) show that the mean or median loading value for the 57 paved runoff events was generally an order of magnitude higher than the loading value for the single unpaved runoff event. These data indicate that the contribution of the unpaved area to the total constituent loading is negligible. For example, the total lead loading from the unpaved area during the period monitored was approximately 0.003 lb (1.36 g), which is less than 1.2 percent of the highest lead load [0.26 lb (118 g)] monitored for a single runoff event (Table 79). The source of constituents in unpaved runoff at Sacramento would be from the pollutant load associated with the soil system (atmospheric deposition) and constituents leached from the vegetation.

At the Harrisburg I-81 site, runoff from the northbound travel lanes was channeled through a drainage ditch (flush shoulder drainage design) located in the southern right-of-way area before reaching the monitoring point (Volume II - Methods). As previously discussed, a large portion of the unpaved runoff was lost to groundwater seepage through a gravel sub-base which existed beneath the soil cover. The unpaved area in the southern right-of-way which was normally a part of the drainage scheme was monitored separately for its contribution to the total constituent loading. A half-cut PVC pipe located at the base of the elevated terrain, which constituted the area contributing unpaved runoff, diverted unpaved runoff to a monitoring point segregated from paved runoff (Volume II - Methods).

Although the loadings (lb/event) in Table 80 are for segregated paved and unpaved runoff, they represent the as-built drainage for the northbound travel lanes at this site. The total constituent loading from the northbound highway section normally reaching the point monitored is reflected in these data. To obtain estimates of loadings (lb/event) from the entire highway system at Harrisburg (both directions), the values in Table 80 would have to be doubled.

The Harrisburg data for the period monitored (Table 80) show that generally the mean or median value for paved and unpaved runoff loadings are comparable. During the period monitored, there were 30 paved runoff events and 5 unpaved runoff events. These data indicate that the contribution of the unpaved area to the total constituent loading may be significant, approximately 14 percent for most constituents. The source of constituents in unpaved runoff monitored at Harrisburg would be mainly from the pollutant load associated with the soil system (atmospheric deposition) and constituents leached from the vegetation. An important factor to consider when comparing paved and unpaved constituent loadings at Harrisburg is that the constituent loading associated with paved runoff (Table 80) is extremely low compared to Milwaukee (Table 78) and Sacramento (Table 79). For example, the mean zinc loading for the entire paved area at Milwaukee is 0.24 lb/event (109 g), 0.10 lb/event (45 g) at Sacramento, and 0.01 lb/event (4.5 g) at Harrisburg.

As previously discussed, precipitation at the three monitoring sites was characterized as acid; median pH was 3.8 at Milwaukee, 4.3 at Harrisburg, and 5.0 at Sacramento. Table 81 summarizes the unpaved runoff pH monitored at all sites. The ranges and median pH values at all sites were comparable. The data indicate that the soil system and/or ground snow cover had a large capacity to buffer the acid precipitation. Hornbeck, et.al., have demonstrated that acidity declines in snow stored in snowpack (57).

Table 81. Unpaved area runoff pH.

Site	Overall monitoring period	
	Range	Median
Milwaukee I-94	6.9-7.4	7.0
Sacramento Hwy 50	-	6.9
Harrisburg I-81	6.4-7.4	7.3

Highway Surface Constituents

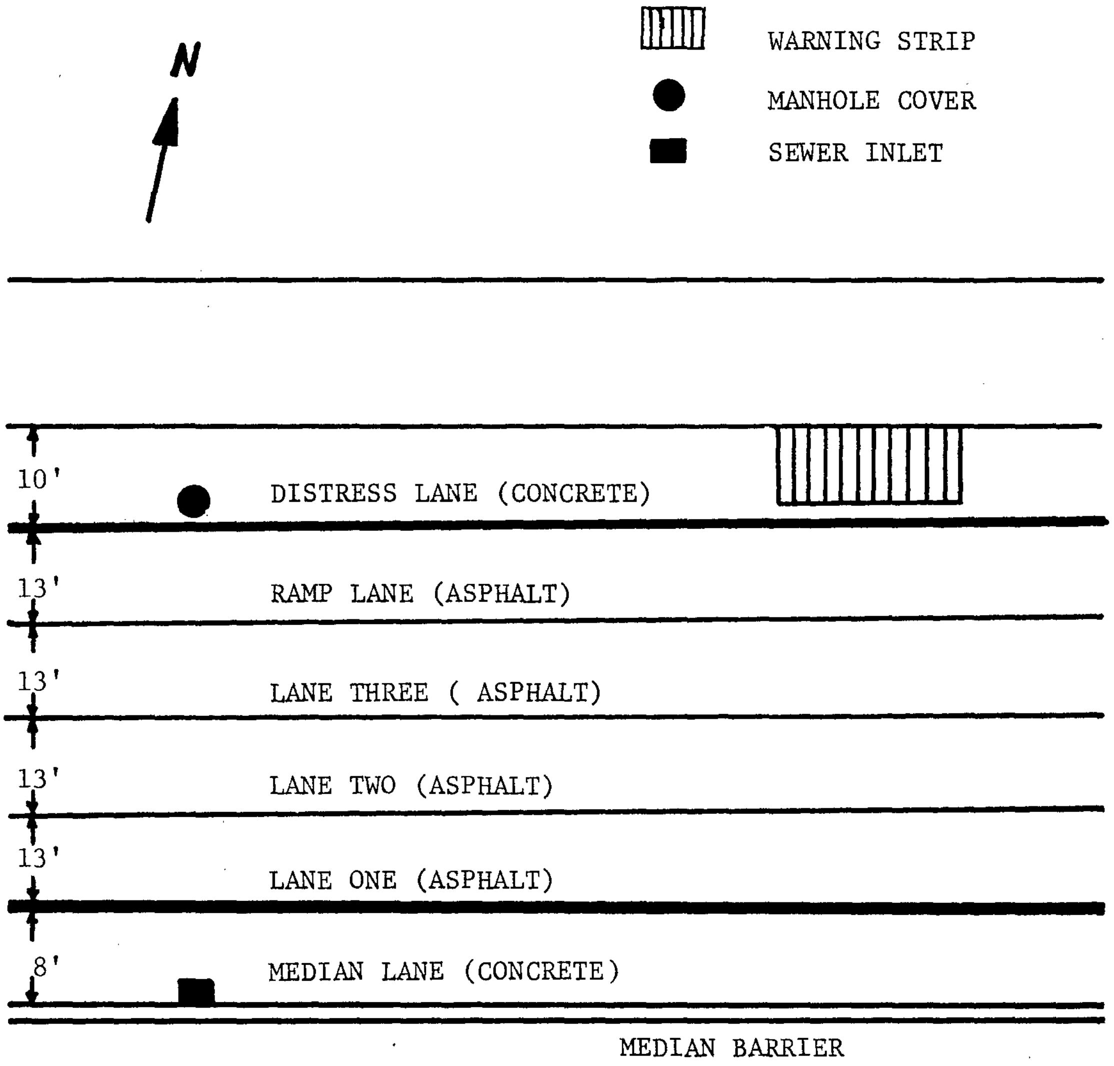
In order to understand the processes of highway pollutant deposition and removal, it was necessary to characterize highway surface pollutants. Sweeping/flushing studies were conducted at each site monitored to quantify highway surface pollutant loads and to characterize their composition and distribution on the paved surface. Studies were also performed at the Milwaukee I-94 site to determine commercial sweeper efficiency. The results of these studies are presented and discussed in the ensuing subsections.

Distribution of Constituent Load on Highway Surface--

The highway surface at each of the four sites monitored was swept/flushed to determine the distribution of the surface pollutant load across the width of the highway. Highway surface configurations at each site, including lane widths and surface composition, are presented in Figures 31 through 34. At the Milwaukee I-94 site the westbound highway lanes were sampled (Figure 31). The westbound lanes included four asphalt travel lanes, a concrete median lane, and a concrete distress lane. The distress lane was curbed and contained sewer inlets and warning strips (grooves cut into the concrete surface). The median lane was bordered by a GM impact barrier and also contained sewer inlets. At the Sacramento Hwy 50 site (Figure 32), four concrete travel lanes and an asphalt distress and median lane in the westbound highway section was sampled. The highway section sampled at Sacramento was a flush shoulder drainage design. Northbound lanes at the Harrisburg I-81 site were sampled (Figure 33). The asphalt distress lane and two concrete travel lanes were sampled. The median shoulder at Harrisburg was approximately 2.5-ft-wide (0.76-m) and consisted of unconsolidated material (loose gravel). Therefore, sweeping/flushing techniques were not used to determine pollutant accumulation on the median shoulder. The section of highway sampled at Harrisburg was flush shoulder drainage design. At the Efland I-85 site, the northbound lanes were sampled (Figure 34). The northbound lanes included two asphalt travel lanes, and an asphalt median and distress lane (flush shoulder drainage design).

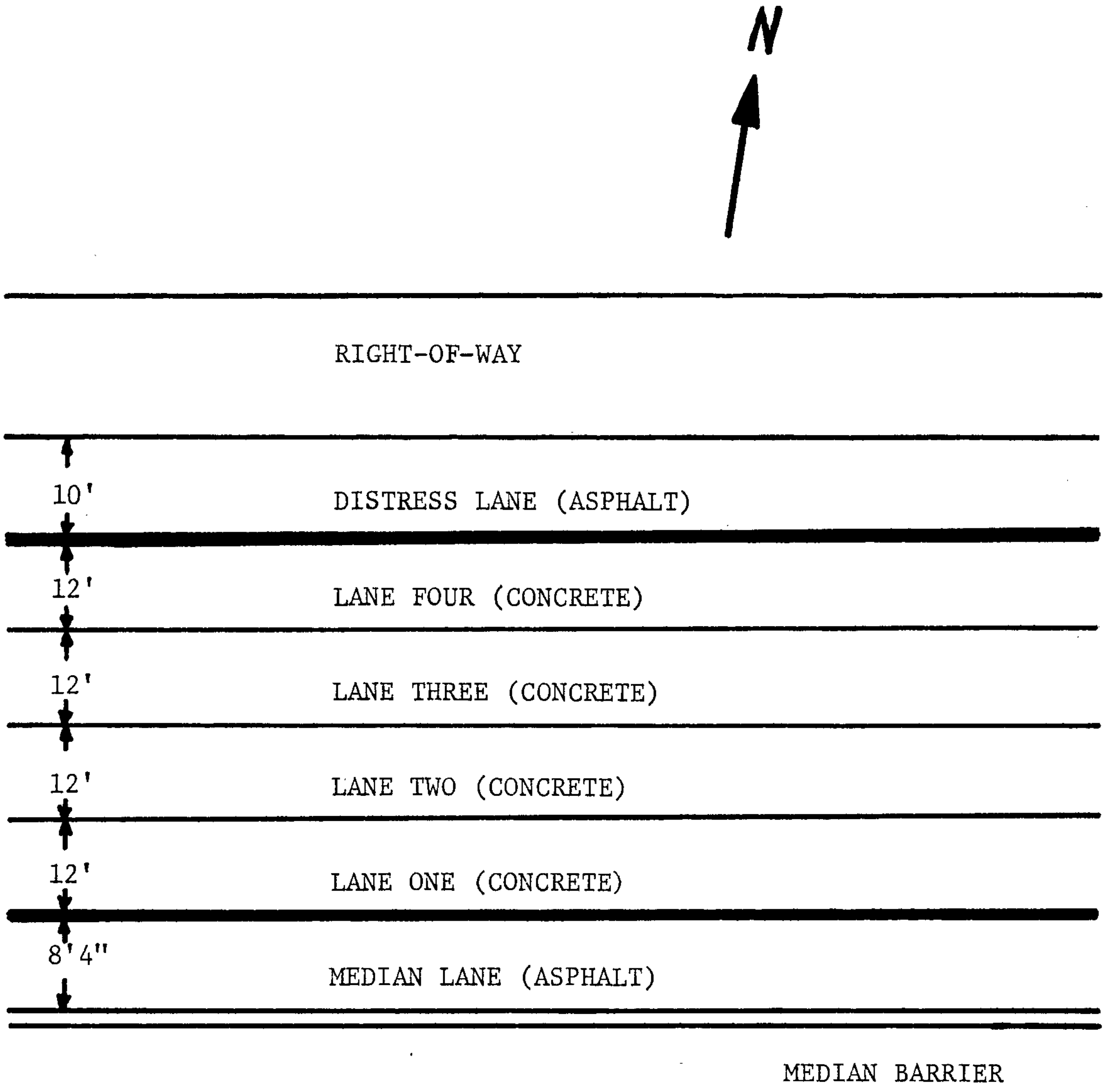
A 50-ft-(15-m-) test section in each of the lanes at the four sites monitored was swept/flushed to estimate the pollutant load on the highway surface and to determine the distribution of pollutants across the width of the highway. The samples collected in each of the lanes were analyzed for solids and associated constituents. The dry solids collected during these studies were divided into three categories as shown in the following:

1. Gross material - very large litter which could easily be collected by hand. Examples of the material found in the gross material component of the highway surface load for the three sites monitored are presented in Table 82.



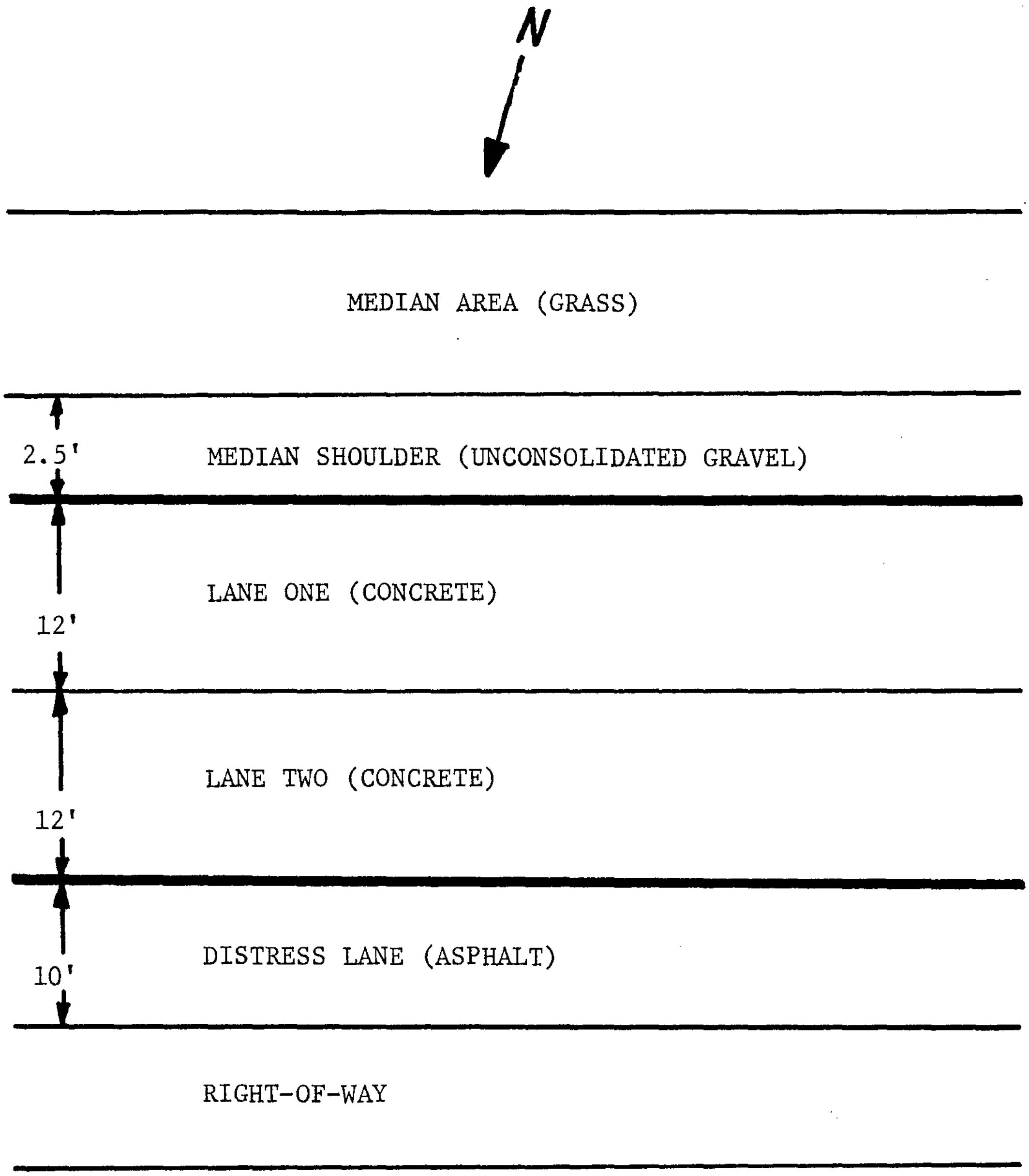
Metric units: To convert ft to m multiply by 0.3048.

Figure 31. Schematic of test area for sweeping/flushing studies at the Milwaukee I-94 site - westbound lanes.



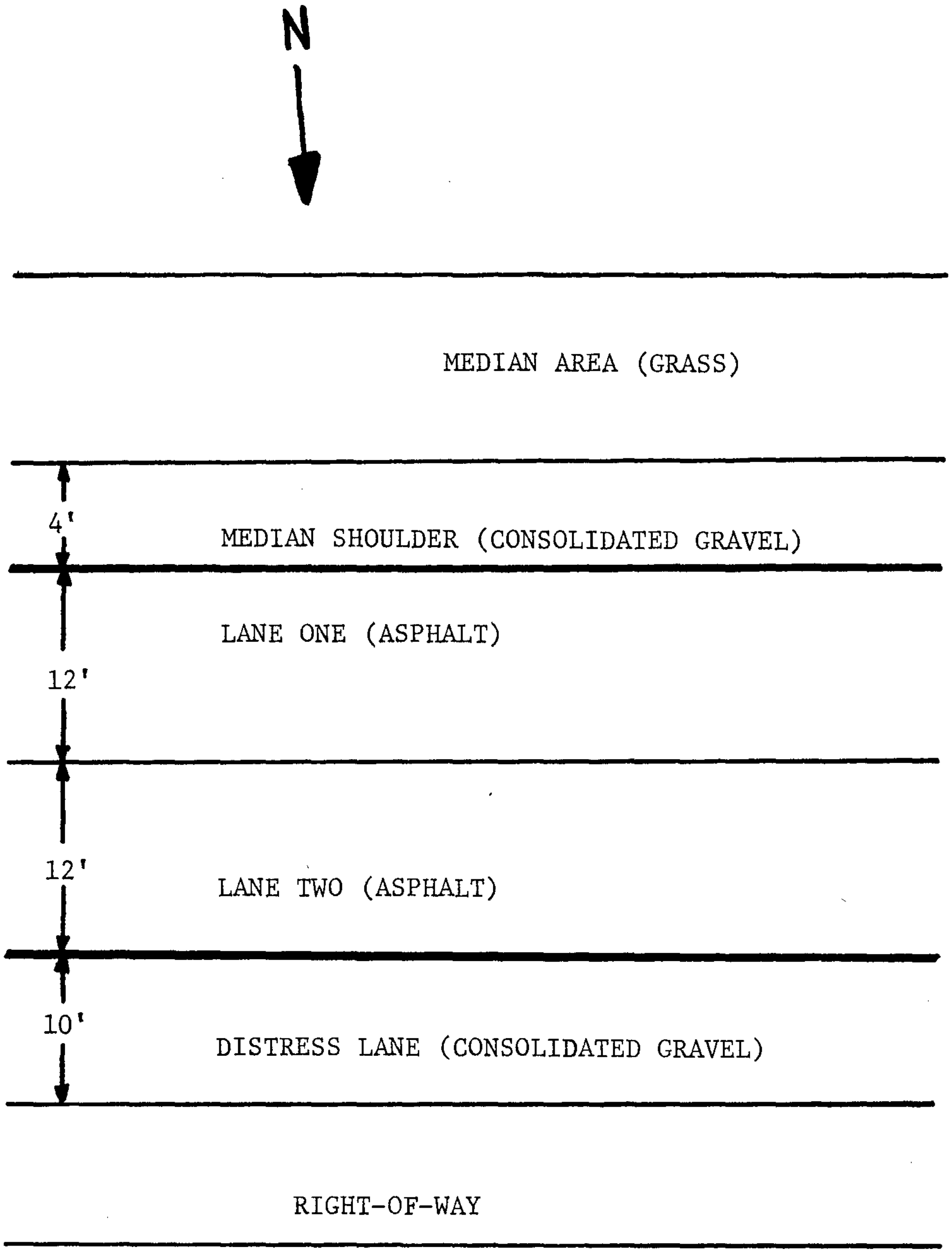
Metric units: To convert ft to m multiply by 0.3048.

Figure 32. Schematic of test area for sweeping/flushing studies at the Sacramento Hwy 50 site - westbound lanes.



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

Figure 33. Schematic of test area for sweeping/flushing studies at the Harrisburg I-81 site - northbound lanes.



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

Figure 34. Schematic of test area for sweeping/flushing studies at the Efland I-85 site - northbound lanes.

Table 82. Materials commonly found in the gross material component of the highway surface load for the three monitoring sites.

Gross material constituents
Rocks
Sticks
Tire fragments
Hub caps
Scrap metal
Pulley belts
Plastic fragments
Glass fragments
Articles of clothing
Dead animals
Asphalt chunks
Wood
Paper
Beer and soda cans
Bottle caps
Chrome trim
Chunks of coal
Nuts and bolts
License plates
Tools
Children's toys
Section of exhaust systems
Stockyard waste (manure & straw)
Mud flap
Bicycle pedal

2. Litter - Particles larger than 3.35 mm (U.S.A. No. 6 sieve) but not including gross material. Common constituents of this solids class include gravel, corn, glass fragments, etc.

3. Total solids - particles smaller than 3.35 mm (passing through a U.S.A. No. 6 sieve).

The distinction between total solids and litter is similar to that used by Shaheen (5) in his study on the contribution of urban roadway usage to water pollution.

Data for distribution of pollutant load on the paved highway surface at each site monitored are presented in Tables 83 through 86. Two studies to determine the distribution of pollutants on the highway surface were conducted at Milwaukee (September 26, 1978, and July 17, 1980), one at Sacramento (December 12, 1979), two at Harrisburg (May 28, 1980, and September 17, 1980), and all four studies at Efland. The data presented in Tables 83 through 86 include the mean total pollutant load (lb/mi) for the studies conducted and the mean loading intensity (percent of total pollutant load) for the combined travel lanes and combined distress and median lanes. At all four sites, gross material and litter were present exclusively in the distress and/or median lanes. At Milwaukee, the major portion of the total pollutant load, except NO_2+NO_3, accumulated in the distress and median lanes. At the Milwaukee site, pollutants such as NO_2+NO_3, Cl, and sulfate which are highly soluble tend to be more uniformly distributed across the paved surface than pollutants associated with solids which tend to accumulate near curbs or barriers. At Sacramento, the major portion of the total pollutant load, except Hg, SO_4, Na, and Cl, also accumulated in the distress and median lanes. At Harrisburg, the pollutant load appears to be more evenly distributed between the distress lane and travel lanes. At Efland, 98 percent of the total solids accumulated in the distress and median lanes; this is probably a function of the extremely porous pavement of these lanes which effectively traps the solids. Percent pollution accumulation in the distress and median lanes at Milwaukee is significantly higher than at Sacramento or Harrisburg. Presumably, the higher accumulation in the distress and median lanes at Milwaukee is due to the larger surface load at this site being retained by the curb and warning grooves in the distress lane and GM barrier in the median lane. Both Sacramento and Harrisburg have flush shoulder drainage designs.

A comparison of surface constituent loads in the distress and median lanes at Milwaukee and Sacramento is presented in Table 87. At Milwaukee, the constituent surface load data are presented for spring and nonspring conditions. Spring loadings were sampled prior to the first commercial sweeping of the highway surface performed for that year and represent pollutant buildup from the preceding winter. Spring values represent the mean for 3 monitoring events while the nonspring values represent data from 11 monitoring events. Data for the Milwaukee I-94 site indicate that spring and nonspring constituent loads were generally higher in the median lane than in the distress lane. Total solids were 2.1 times higher in the median lane for nonspring conditions and 1.85 times higher in the median lane for spring

Table 83. Distribution of pollutant load on the paved highway surface - Milwaukee I-94.

Parameter	Westbound load[a] lb/mi	Loading intensity, % of westbound load: Distress plus median lanes	Loading intensity, % of westbound load: Travel lanes
Gross material[b]	337	100	ND
Litter[c]	763	100	ND
TS[d]	2,810	98	2
VTS	118	93	7
TOC	18.7	83	17
COD	86.9	88	12
Pb	12.5	99	1
Zn	2.23	98	2
Fe	233	99	1
Cu	1.00	96	4
Cr	0.216	96	4
Cd	0.015	97	3
Ni	0.175	92	8
Hgx10^{-3}	0.275	91	9
As	0.012	100	ND
TKN	1.04	75	25
NO_2+NO_3	0.125	31	69
TPO4	0.867	98	2
SO_4	3.25	61	39
Na	12.4	93	7
Cl	9.18	63	37
Oil & grease	11.4	98	2
Rubber	31.1	99	1

[a] Mean for two dates - September 26, 1978, and July 17, 1980.

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

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

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

ND = Not detectable

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

Table 84. Distribution of pollutant load on the paved highway surface - Sacramento Hwy 50.

Parameter	Westbound load[a] lb/mi	Loading intensity % of westbound load: Distress plus median lanes	Travel lanes
Gross material[b]	13.0	100	ND
Litter[c]	190	100	ND
TS[d]	187	87	13
VTS	18.2	70	30
TOC	6.05	77	23
COD	28.4	73	27
Pb	1.12	96	4
Zn	0.171	87	13
Fe	6.85	95	5
Cu	0.020	82	18
Cr	0.037	96	4
Cd	0.001	100	ND
Ni	0.011	81	19
Hg $\times 10^{-3}$	0.011	27	73
As	0.003	92	8
TKN	0.365	57	43
NO_2+NO_3	0.088	54	46
TPO_4	0.088	85	15
SO_4	3.02	32	68
Ca	2.87	51	49
Na	0.467	41	59
Cl	0.910	36	64
Oil & grease	2.05	62	38
Rubber	21.5	91	9

[a] December 12, 1979.

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

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

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

ND = Not detectable.

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

Table 85. Distribution of pollutant load on the paved highway surface - Harrisburg I-80.

		Loading intensity, % of northbound load	
Parameter	Northbound load[a] lb/mi	Distress lane	Travel lanes
Gross material[b]	26.9	100	ND
Litter[c]	1.86	100	ND
TS[d]	18.3	56	44
VTS	6.25	53	47
TOC	1.89	54	46
COD	4.06	80	20
Pb	0.022	66	34
Zn	0.024	50	50
Fe	0.214	80	20
Cu	0.004	50	50
Cr	0.002	48	52
Cd	0.001	25	75
Ni	0.009	26	74
Hg x 10^{-3}	ND	--	--
As	ND	--	--
TKN	0.161	42	58
NO_2+NO_3	0.114	32	68
TPO4	0.012	42	58
SO_4	1.32	29	71
Ca	1.66	33	67
Na	0.405	27	63
Cl	0.800	39	61
Oil & grease	0.585	45	55
Rubber	0.690	53	47

[a] Mean for two dates - May 28, 1980, and September 17, 1980.

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

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

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

ND = Not detectable

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

Table 86. Distribution of pollutant load on the paved highway surface - Efland I-85.

Parameter	Northbound load[a] lb/mi	Loading intensity, % of northbound load: Distress plus median lanes	Loading intensity, % of northbound load: Travel lanes
Gross material[b]	112	100	ND
Litter[c]	2020	100	ND
TS[d]	283	98	2
VTS	20.6	91	9
TOC	2.14	45	55
COD	7.15	48	52
Pb	0.297	96	4
Zn	0.104	90	10
Fe	6.10	99	1
Cu	0.018	89	11
Cr	0.007	93	7
Cd	0.001	83	17
Ni	0.005	91	9
Hg x 10^{-3}	ND	--	--
As	ND	--	--
TKN	0.387	86	14
NO_2+NO_3	0.025	29	71
TPO_4	0.184	96	4
SO_4	0.386	23	77
Ca	0.207	48	52
Na	0.249	42	58
Cl	0.413	42	58
Oil & grease	0.292	68	32
Rubber	0.635	49	51

[a] Mean for all four events.

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

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

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

ND = Not detectable

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

Table 87. Comparison of surface constituent loads (lb/mi) in the distress and median lanes - Milwaukee I-94 and Sacramento Hwy 50.

	Milwaukee I-94				Sacramento Hwy 50	
	Winter buildup		Remaining months		Entire monitoring period	
Parameter	Distress lane	Median lane	Distress lane	Median lane	Distress lane	Median lane
Gross material[a]	140	609	68.0	182	ND	30.0
Litter[b]	2,460	2,440	521	743	56.4	65.9
TS[c]	9,750	18,000	1,260	2,650	94.1	79.6
VTS	549	929	122	359	6.25	5.66
TOC	198	119	10.6	20.6	1.92	2.09
COD	629	884	34.1	68.6	8.39	6.53
Pb	25.3	69.4	5.61	9.81	0.253	0.459
Zn	7.52	21.7	1.29	2.34	0.049	0.058
Fe	425	1,350	106	215	3.02	3.08
Cr	0.637	1.45	0.143	0.353	0.012	0.009
Cu	2.87	8.23	0.458	0.808	0.009	0.009
Cd	0.054	0.105	0.013	0.019	0.0004	0.0003
Ni	0.535	1.94	0.091	0.156	0.005	0.005
As	0.012	0.010	0.002	0.006	0.0002	0.001
NO_2+NO_3	0.024	0.048	0.032	0.036	0.025	0.022
TKN	3.93	8.35	0.625	1.39	0.129	0.092
PO_4-P	2.76	5.71	0.407	0.755	0.052	0.047
Ca	638	956	103	246	0.784	0.626
Na	8.78	22.1	1.94	4.10	0.106	0.087
Cl	7.20	17.9	3.70	3.51	0.180	0.135
SO_4	2.52	4.36	1.30	2.08	0.317	0.292
Oil & grease	113	226	5.84	21.1	0.315	0.334
Rubber	132	192	8.71	36.9	8.24	11.3

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

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

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

ND = Not detectable.

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

conditions. The concrete GM barrier (0.9-m-high) next to the median lane appears to effectively trap and/or re-entrain most of the constituents which accumulate there, while wind and vehicular turbulence may blow some of the distress lane constituent load into the grassy right-of-way area (Figure 31). This observation appears to be especially true for those constituents associated with solids. Surface loading values for the more soluble constituents, NO +NO and Cl, are comparable for the distress and median lanes during nonspring conditions.

At the Sacramento Hwy 50 site, a distinct pattern for surface constituent load buildup in the distress and median lanes for the four monitoring events is not evident (Table 87). Generally, the loading values between the distress and median lanes are comparable. Apparently, the flush shoulder design is conducive to a more even distribution of the surface load.

The data presented in Table 83 showed that the major portion of the total pollutant load at Milwaukee accumulated in the distress and median lanes. A study was conducted at the Milwaukee site to establish the distribution of the pollutants within the distress and median lanes. The median lane (Table 88) was divided into three 2-ft-(0.6-m-) sections and one section 2.7-ft-(0.8 m-) wide, while the distress lane (Table 89) was divided into five 2-ft-(0.6-m-) sections. In the median lane, pollutant distribution decreased rapidly with distance from the GM barrier toward the travel lanes. Gross material was found exclusively in the test section nearest the GM barrier. Except for NO_2 $+NO_3$, 87 to 95 percent of the pollutants were located within the first 2 ft (0.6 m). The $NO_2$$+NO_3$ load located in the 2-ft- section closest to the GM barrier accounted for 51 percent of the total median load, while the remaining 48 percent was uniformly distributed in the other three test sections of the median lane.

Pollutant load distribution in the distress lane (Table 89) did not show the same trends observed for the median lane. The percentage of pollutant load within the first 2 ft of distress lane was lower than the median lane. The distress lane had an additional test section [8-10 ft (2.4-3.0 m)] which lowers the percentage of pollutant load in the distress curb section by approximately two to three percent when compared to the median lane. However, the major difference is probably due to the warning strip [8.7 x 5.8 ft (2.7 x 1.8 m)] located mostly in test sections 2-10 ft (0.6 - 3.0 m) from edge of curb in the distress lane which traps some of the pollutant load that would normally migrate into the curb section. Another factor that probably contributes to the higher percentage of pollutant load in the median curb section than the distress curb section is the GM barrier of the median lane which appears to effectively trap and/or re-entrain most of the particles which accumulate in the median curb section. The warning strip in the distress lane may also account for the fact that the pollutant load within the distress lane was more uniformly distributed in test sections located 2-10 ft (0.6-3.0 m) from edge of curb than was observed for the median lane.

Table 88. Distribution of total pollutant load (percent) from edge of GM barrier within the median lane at the Milwaukee I-94 site - test section

Parameter	Test section from edge of GM barrier 0-2 ft	2-4 ft	4-6 ft	6-8.7 ft
Gross material[b]	100	ND	ND	ND
Litter[c]	78	13	7	2
TS[d]	92	4	12	2
VTS	87	5	4	4
Pb	89	6	3	2
Zn	91	4	3	2
Fe	92	4	2	2
Cr	89	6	3	2
Cu	91	5	2	2
Cd	96	5	ND	ND
Ni	92	8	ND	ND
NO_2+NO_3	51	16	18	15
TKN	92	4	2	2
TPO4	93	5	1	1

[a] Data normalized for a 2-ft-section.

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

[c] Litter is defined as particles larger than 3.35 mm (USA No. 6 Sieve) not including gross material.

[d] Total solids data represents the fraction passing through a USA No. 6 Sieve (below 3.35 mm).

ND = Parameter was not present in detectable quantities.
Metric units: To convert ft to m multiply by 0.3048.

Table 89. Distribution of total pollutant load (percent) from edge of curb within the distress lane at the Milwaukee I-94 site.

	Test section from edge of curb				
Parameter	0-2 ft	2-4 ft	4-6 ft	6-8 ft	8-10 ft
Gross material[a]	59	ND	41	ND	ND
Litter[b]	58	16	12	9	5
TS[c]	78	6	5	5	6
VTS	84	4	4	4	4
Pb	70	8	7	6	9
Zn	66	8	7	8	11
Fe	74	6	6	6	8
Cr	60	8	8	13	11
Cu	71	6	7	7	9
Cd	65	10	13	ND	12
Ni	63	16	5	5	11
NO_2+NO_3	25	52	11	6	6
TKN	65	6	18	5	6
TPO4	77	4	11	4	4

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

[b] Litter is defined as particles larger than 3.35 mm (USA No. 6 Sieve) not including gross material.

[c] Total solids data represents the fraction passing through a USA No. 6 Sieve (below 3.35 mm).

ND = Parameter was not present in detectable quantities.
Metric units: To convert ft to m multiply by 0.3048.

In summary, the highway design at Harrisburg apparently allowed pollutants to quickly migrate to adjacent grassy areas. At Milwaukee, Sacramento, and Efland, highway design was such that the major portion of pollutants, especially those associated with solids, accumulate in nontravel lanes (distress and/or median lanes). The GM barrier of the median lane at Milwaukee appeared to be especially effective in retaining pollutant surface load. Data collected at the Milwaukee site also indicate that the major portion of pollutants were located within the first 2 ft (0.6 m) of the median lane and within the warning strip grooves of the distress lane. At sites where highway design is conducive to the buildup of pollutants in nontravel lanes, periodic sweeping of the highway surface, especially after periods of long buildup (winter in the north or summer drought in the south), appears to be an effective mitigation strategy.

Highway Surface Constituent Load--

The highway surface at each of the four sites monitored was swept/flushed to determine the highway surface constituent load. Preliminary studies at each site indicated that because of surface load and distribution, good estimates of total pollutant load could be obtained by sampling the distress and median lanes at Milwaukee and Sacramento, while all lanes at Harrisburg and Efland had to be sampled to estimate total pollutant load. The distribution of monitored events at the four sites is as follows:

	Monitored events		
Site	Distress & median only	All lanes	Total
Milwaukee I-94	12	2	14
Sacramento Hwy 50	3	1	4
Harrisburg I-81	0	2	2
Efland I-85	0	4	4

A complete listing of highway surface constituent loads monitored at each site is presented in Volume IV - Appendix. A summary of the 24 monitoring events to determine highway surface constituent loads is presented in Table 90. Data for each site is summarized using the range and mean or median for each of the 24 parameters. The median value was used in lieu of a mean value to characterize any parameter data set which had a large number of observations reported as ND, not detectable. Constituent loading values are presented as lb/highway mi (both directions).

Mean highway surface constituent loads were generally highest at Milwaukee, lowest at Harrisburg, and intermediate at Sacramento and Efland (Table 90). Constituent loading values for the two studies conducted at Harrisburg were comparable. The range of loading values at Sacramento and Efland showed more variability than at Harrisburg, while order of magnitude differences existed between the minimum and maximum constituent loading values at Milwaukee. The differences in the magnitude of surface loads and

Table 90. Surface constituent loadings at the sites monitored (lb/highway mi) - all lanes.

Parameter	Milwaukee I-94 8 lanes (116,000 ADT) Range	Mean	Sacramento Hwy 50 8 lanes (85,900 ADT) Range	Mean	Harrisburg I-81 4 lanes (27,800 ADT) Range	Mean	Efland I-85 4 lanes (25,000 ADT) Range	Mean
Gross material[c]	112-1,900	669	ND-214	ND[b]	31.6-75.8	53.7	3.86-747	224
Litter[d]	746-13,400	4,070	93.2-379	245	2.46-4.98	3.72	1600-7090	4,040
TS[e]	2,440-66,400	18,100	282-433	360	32.9-40.0	36.5	40.5-1940	566
VTS	146-6,550	1,400	22.0-36.4	26.6	12.3-12.6	12.5	7.24-122	41.3
TOC	25.1-1140	228	5.98-12.1	8.72	--	3.77	--	4.28
COD	106-3,660	1,020	16.5-56.8	33.8	--	8.11	--	14.3
Pb	3.64-293	64.8	0.914-2.23	1.43	0.032-0.056	0.044	0.058-1.90	0.593
Zn	1.74-96.1	18.2	0.158-0.342	0.23	0.042-0.054	0.048	0.024-0.646	0.208
Fe	8.86-4,290	1200	9.70-13.8	12.4	0.324-0.532	0.428	0.722-41.6	12.2
Cr	0.026-5.46	1.68	0.026-0.075	0.043	0.002-0.004	0.003	0.002-0.036	0.013
Cu	0.138-36.1	6.75	0.032-0.040	0.037	0.006-0.010	0.008	0.004-0.112	0.036
Cd	0.008-0.426	0.115	0.0005-0.002	0.001	0.0006-0.0009	0.0008	0.002-0.004	0.003
Ni	0.032-6.05	1.45	0.008-0.026	0.020	0.006-0.012	0.008	0.002-0.030	0.010
As	0.004-0.044	0.017	0.0002-0.004	0.002	--	ND[b]	--	ND[b]
Hg x 10^{-3}	0.1-4.0	0.3	0.01-0.02	0.02	--	ND[b]	--	ND[b]
NO_2+NO_3	0.050-0.318	0.170	0.018-0.176	0.117	0.138-0.316	0.227	0.042-0.064	0.049
TKN	1.45-36.8	8.53	0.366-0.730	0.521	0.296-0.348	0.322	0.194-1.36	0.773
PO_4-P	1.02-23.7	5.46	0.176-0.228	0.205	0.022-0.024	0.023	0.042-1.18	0.368
Ca	666-4,130	1,930	0.694-5.74	3.76	--	3.32	--	0.414
Na	6.35-110	37.2	0.264-0.934	0.521	0.720-0.899	0.810	0.394-0.624	0.497
Cl	4.75-91.4	25.4	0.408-1.82	0.922	1.44-1.76	1.60	0.646-1.00	0.826
SO_4	3.82-16.8	9.79	0.542-6.04	2.25	2.45-2.80	2.63	0.688-0.854	0.771
Oil & grease	17.0-730	167	0.720-4.09	1.73	0.614-1.72	1.17	0.478-0.690	0.584
Rubber	60.7-648	206	--	43.0	--	1.38	--	1.27

[a] Both directions.

[b] Median.

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

[d] Litter is defined as particles larger than 3.35 mm (USA No. 6 sieve) not including gross material.

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

ND = Not detectable. Metric units: To convert lb/mi to kg/km multiply by 0.2819.

variability in the range of loadings values are probably attributable to differences in site drainage, traffic characteristics, seasonal variations, and maintenance activities.

Because Harrisburg and Sacramento have the same drainage design (flush shoulder) and similar pavement characteristics (concrete travel lanes and asphalt distress lane), the difference in surface loads may be due largely to a difference in average daily traffic (27,800 vehicles per day at Harrisburg and 85,900 vehicles per day at Sacramento) and surface area (number of lanes) available to hold the load (three lanes at Harrisburg and six lanes at Sacramento for each travel direction). Although Efland had a flush shoulder drainage design, travel lanes were asphalt paved and median and distress lanes consisted of consolidated gravel which was extremely porous. High litter values at Efland are due to gravel which worked loose from the distress and median lanes. High total solids values at Efland are a result of the trapping ability of the porous distress and median lanes. Milwaukee has both the pollutant source (116,000 vehicles per day) and capacity (curbs, warning grooves, and GM barrier) to maintain high surface constituent loads.

The lack of surface load variability for most constituents at Harrisburg is probably due to the relatively small surface area, low average daily traffic, and flush shoulder drainage design. Apparently, a steady state condition usually exists for the highway surface load at Harrisburg where a constant surface load is held in pavement cracks, pores, etc. Because of the relatively small surface area, flush shoulder drainage design, and low vehicular deposition rate, atmospheric removal processes can easily maintain a steady state load. Large fluctuations of surface load at this site probably occur only as a function of removal due to runoff and increased holding capacity during the winter season (pollutants held in ice and snow). The variability in the Sacramento surface load is somewhat greater than Harrisburg, but does not approach the variability observed at Efland and Milwaukee. Although both Sacramento and Harrisburg have a flush shoulder drainage design, the higher vehicular deposition rate and larger surface area at Sacramento make atmospheric removal of the surface load and subsequent attainment of a steady state more difficult.

Variability in surface constituent loadings observed at the Milwaukee I-94 site (Table 90) can be attributed to its capacity to hold a large load (curb and gutter design) which provides the potential for wide fluctuations when removal or deposition processes conducive to these fluctuations exist. Deposition processes which caused large increases of the surface load at Milwaukee include deicing agent application, winter buildup, and accidental spills; removal processes included large runoff events and commercial sweeping activities by the Wisconsin Department of Transportation. Variability in surface load at the Efland I-85 site can probably also be attributed to its capacity to hold a relatively large load in the porous surface at the distress and median lanes.

During winter periods, the surface load can be greatly increased by deicing agent application. During the first winter period monitored at Milwaukee (1978 to 1979), total deicing agents applied were approximately 137,000 lb/highway mi (38,600 kg/km) of sodium chloride, 2,600 lb/highway mi (730 kg/km) of calcium chloride, 660 gallons/highway mi (1,550 liters/km) of liquid calcium chloride (30 percent $CaCl_2$ solution), and 1,760 lb/highway mi (500 kg/km) of sand. During the second winter period monitored at Milwaukee (1979 to 1980), total deicing agents applied were approximately 115,000 lb/highway mi (32,500 kg/km) of sodium chloride and 129 gallons/highway mi (305 liters/km) of liquid calcium chloride. Solid calcium chloride and sand were not applied during this winter period. On February 5, 1980, salt application for that day totalled 13,600 lb/highway mi (3,900 kg/km). These data indicate the potential for large increases in surface load during the winter period.

The surface load increases during the winter period at Milwaukee because removal processes which occur on a continuous or frequent basis during nonwinter periods such as maintenance (sweeping), atmospheric removal (blow out) and runoff are greatly curtailed or do not occur at all during winter periods. Freezing of the surface load prevents blow off and runoff occurs only during sporadic warm periods. Vehicular deposition may also increase during winter periods due to the stop-and-go traffic characteristics of hazardous driving conditions (increased exhaust emissions) and due to increased autobody rusting from salt. The effect of winter buildup was evident for the April 1979 and 1980 and May 1981 surface constituent studies. Table 91 compares the loading values obtained for these studies with the mean nonspring loading values. Total solids loadings obtained for the two April studies are very similar and are approximately eight times greater than nonspring values. Spring loading values for the other parameters were also elevated. However, the sodium and chloride loading values for the April 1980 study are approximately twice as high as those observed for the April 1979 study. Presumably, the higher sodium and chloride loadings for the April 1980 study are due to the deicing salt applications which occurred late in spring 1980. Deicing salts were applied on April 5, 14, and 15 in 1980, while the last salt application for 1979 occurred on March 25.

The spring study for 1981 occurred on May 19-20 which is over a month later than the spring studies for 1979 and 1980. The effect of performing the study later in spring is demonstrated by the fact the total solids loading was almost half that observed for the two April studies. Presumably, the runoff events that occurred prior to the May study and blowoff account for part of this difference. That runoff removed a portion of the total solids level is supported by the fact that although the total solids loading on May 19-20, 1981, was still extremely elevated over nonspring loadings (Table 91), the chloride loading for May 19-20, 1981, was below the nonspring mean. As discussed in the paved runoff section, chlorides removed by spring runoff events are considerable at the Milwaukee site.

The quality data presented for winter paved runoff events (November through March) at Milwaukee demonstrate that large constituent loadings were

Table 91. Comparison of spring surface loadings (lb/highway mi[a]) for selected parameters - Milwaukee I-94 site.

Parameter	April 17, 1979	April 17, 1980	May 19-20, 1981	Mean nonspring
Gross material[b]	1,900	1,520	1,070	443
Litter[c]	13,400	11,100	4,860	2,510
TS[d]	64,200	66,400	36,100	7,870
Pb	166	293	109	31.0
Zn	45.9	96.1	33.1	7.28
Na	51.2	110	24.3	12.7
Cl	52.2	91.4	7.28	16.2
Oil & grease	730	622	NA	54.2

[a] Both directions.

NA = No analyses performed.

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

b, c, and d; Refer to appropriate footnotes in Table 88.

removed during these events. Another major mechanism for the removal of winter surface buildup is the commercial sweeping performed each spring at the Milwaukee I-94 site. The spring commercial sweeping was always conducted on the same day the surface load was sampled (Volume IV - Appendix). The spring loading values presented in Table 91 represent the surface load just prior to sweeping. Loading values for the month after spring sweeping were always near the nonspring mean (Volume IV - Appendix). Another indication of the effect of commercially sweeping the paved surface is demonstrated by the low loading values for the October 16, 1979, study (Volume IV - Appendix). The majority of the minimum surface loading values reported in Table 90 are from this study. One week prior to this study, the surface was swept by the Wisconsin Department of Transportation (Volume IV - Appendix).

On August 10, 1979, a semi-tractor overturned and spilled an undetermined amount of fuel oil onto the paved highway surface in the section of I-94 being monitored in Milwaukee. The fuel oil spill was sprayed with a dispersing agent and flushed into the storm sewers by the fire department. The spill was then covered by 500 lb (227 kg) of an oil dry compound. Table 92 compares loading values for selected parameters obtained for a study conducted on August 16, 1979, (six days after the oil spill) to mean loading values for nonspring events. Compared to mean nonspring loading values, constituent loading values for the August study were especially high for total solids, TVS, TOC, TKN, and oil and grease. The fuel oil, dispersing agent, and oil dry compound probably account for these high values.

A summary of the relationship between highway surface total solids and the other constituents at Milwaukee, Efland, and Sacramento is listed in Table 93. Correlation analyses were not possible at Harrisburg due to the small number of data points (two monitoring events). At Milwaukee, most parameters indicate a relationship to total solids. These parameters have a correlation coefficient (r value) greater than the critical values. On a strict statistical basis, the null hypothesis that $r = 0$ (i.e., that the data is from a population for which no correlation exists) can be rejected at the 95 percent confidence level. Two of the parameters which did not show a correlation to total solids are NO_2+NO_3 and SO_4. This would be expected based upon analysis results for the distribution of constituents on the paved highway surface which showed that these parameters did not follow the accumulation patterns of total solids i.e., that these parameters were not associated with total solids. Correlation coefficients for all parameters at Sacramento did not exceed the critical values. This is probably due to the large quantities of sand present which would have negligible affinity for most of the constituents tested for. At Efland, a relationship exists between total solids and volatile total solids, most metals, and phosphorus.

Lateral Variation of Highway Surface Constituents--

Three studies were performed at the Milwaukee I-94 site to quantify the lateral variation of highway surface pollutant loadings. The grade profile within the site boundaries varied from relatively flat to a 3-percent slope.

Table 92. Effect of an oil spill (August 10, 1979) on surface load (lb/highway mi[a]) for selected parameters - August 16, 1979 study at Milwaukee I-94 site.

Parameter	August 16, 1979	Mean value for nonspring events
Gross material[b]	112	476
Litter[c]	5,820	2,180
TS[d]	12,300	7,430
VTS	6,550	408
TOC	124	51.3
TKN	14.4	3.15
Oil & grease	176	39.0

[a] Both directions

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

b, c, and d; Refer to appropriate footnotes in Table 88.

Table 93. Correlation between highway surface total solids with other parameters at Milwaukee, Efland, and Sacramento.

	r greater than r_{crit}[a]		
Parameter	Milwaukee I-94	Sacramento Hwy 50	Efland I-85
VTS	Yes	No	Yes
TOC	No	No	NA
COD	Yes	No	NA
Pb	Yes	No	Yes
Zn	Yes	No	Yes
Fe	Yes	No	Yes
Cr	Yes	No	Yes
Cu	Yes	No	Yes
Cd	Yes	No	No
Ni	Yes	No	Yes
As	No	NA	NA
Hg	No	No	NA
NO_2+NO_3	No	No	No
TKN	Yes	No	No
TPO_4	Yes	No	Yes
Ca	Yes	No	NA
Na	Yes	No	No
Cl	Yes	No	No
SO_4	No	No	NA
Oil & grease	Yes	No	NA
Rubber	Yes	NA	NA

[a] Critical value at 95 percent confidence level.
NA = Less than three analyses performed.

During the 1979-80 spring studies, it was noted that the accumulated materials on the Milwaukee I-94 site highway surface were not evenly distributed. However, visual inspection of this site during summer and fall indicated relatively even distribution of the surface load, at least within the boundaries of the site. The purpose of the lateral variation studies was to investigate the manner in which the spring load (winter buildup) is distributed laterally on the highway surface and to put the observed summer and fall surface loading values into perspective by quantifying the lateral variation, or lack of, during this period.

Four highway test sections were sampled on I-94 during these studies (Figure 35). Test areas one, two, and three were within the site boundaries, while test area four was located approximately 2 mi (3 km) west of the I-94 monitoring site. The three test areas within the site were chosen to include a high point, mid-point, and low point in the drainage scheme. The test outside the site boundaries (test area four) was chosen to determine lateral variation over a wider expanse of highway. The locations for these test sections and the existing grade profile for the four test areas appear in Figure 35. Test area one was located near the top of a 3-percent grade, test area two near the bottom of a 3-percent grade, test area three near the bottom of a 1-percent grade, and test area 4 near the bottom of a 600 ft (183 m) section with a slope of 0.5 percent. Test area two is the section of I-94 where all previous sweeping/flushing studies were conducted. All distress lane test areas contained a warning strip.

For the spring study (May 19-20, 1981) the section of I-94 that encompasses test areas one, two, and three had not been commercially swept since the previous fall, while the section of I-94 containing test area four had been commercially swept twice during the spring period prior to the May sweeping/flushing study. Surface contaminant loadings (lb/highway mile) as detected by the May 19-20 sweeping/flushing study appear in Table 94. Test area four had significantly lower surface loadings (for most parameters more than five times lower) than test areas one, two, and three. The lower loadings at test area four probably reflect the two commercial sweepings performed prior to the sweeping/flushing study.

The total solids loading for test area two (original sweeping/flushing test area) was 36,100 lb/highway mi (10,200 kg/km) (Table 94) and this value was lower than the spring values obtained during the previous two spring sweeping/flushing studies [66,400 lb/highway mi (18,700 kg/km) on April 17, 1980, and 64,200 lb/highway mi (18,000 kg/km) on April 17, 1979)]. Although this area had not been commercially swept during the spring period prior to the sweeping/flushing study, a portion of total solids was probably lost from the paved highway surface due to atmospheric removal and runoff [spring rainfall prior to the study totalled 7.45 in (18.9 cm), including two events that exceeded 1.5 in (3.8 cm) of rainfall]. Gross material and litter loadings for test area two were also lower than the spring values obtained during previous two spring sweeping/flushing studies, while metals, NO_2+NO_3, and TPO_4 loading values were more comparable.

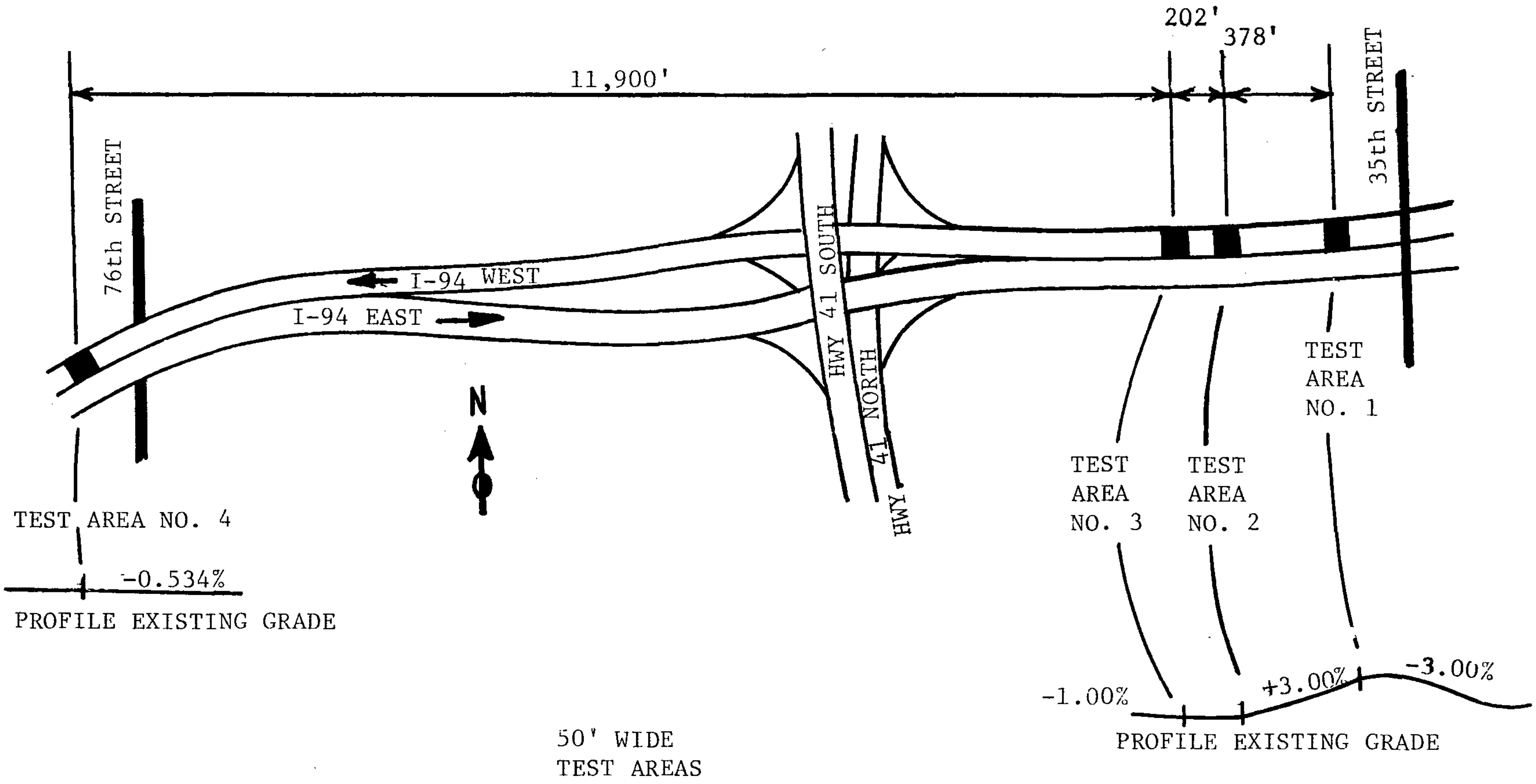


Figure 35. Lateral sweeping/flushing test area locations with profile grade - Milwaukee I-94.

Table 94. Results of the May 19-20, 1981, lateral sweeping/ flushing study conducted at the Milwaukee I-94 site - total of wet and dry[a] fractions for highway surface.[b]

	Highway test area[b]			
Parameter	One, lb/mi	Two, lb/mi	Three, lb/mi	Four, lb/mi
Gross material[c]	1030	1070	830	488
Litter[d]	4330	4860	4750	1270
TS[e]	30,200	36,100	40,900	6550
VTS	1150	1420	1640	247
Pb	129	109	129	28.4
Zn	26.3	33.1	43.2	5.97
Fe	3100	3290	3920	676
Cr	3.14	4.42	3.91	0.560
Cu	11.3	15.9	18.6	3.11
Cd	0.196	0.209	0.242	0.033
Ni	3.41	6.05	2.94	0.562
NO_2+NO_3	0.185	0.128	0.122	0.174
TKN	6.30	9.30	10.1	1.96
PO_4-P	12.9	13.2	19.7	2.33
SO_4	10.2	10.8	10.3	4.68
Ca	2310	2200	3080	435
Na	228	24.3	26.9	5.94
Cl	6.47	7.28	7.58	2.48

[a] All pollutant loading values for the dry fraction are based solely upon total solids (particles less than 3.35 mm).

[b] Addition of pollutant load for median and distress lanes times two (both directions).

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

[d] Litter is defined as particles larger than 3.35 mm (USA No. 6 sieve) not including gross material.

[e] Total solids data represents the fraction passing through USA No. 6 sieve (below 3.35 mm).

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

The total solids loading (lb/highway mi) for test area two (original sweeping/flushing test area) was approximately midpoint to the total solids loading for test areas one and three (Table 94). Considering the location of the test areas relative to profile grade (Figure 35) this result is somewhat surprising. Based upon existing profile grade alone, test area one (top of the three percent grade) should have had the lowest total solids loading, test area two (bottom at the three percent grade) the highest loading, and test area three (bottom at the one percent grade) the midpoint loading. When the highway total solids load is separated into distress lane and median lane loads (Tables 95 and 96), the distress lane does appear to accumulate total solids as a function of profile grade: 1,020 lb/highway mi (288 kg/km) total solids for test area one, 6,260 lb/highway mi (1760 kg/km) total solids for area two, and 3870 lb/highway mi (1090 kg/km) total solids for test area three. However, this correlation does not exist in the median lane. In fact, test area two has the lowest total solids loading value (Table 96). Sewer inlet locations (Figure 36) relative to median test area one may help to explain the high total solids loading observed at this point compared to median test area two. The entire median lane on the 3-percent slope drains into an inlet just above test area two (Figure 36). With the large solids load present at this time of year due to winter accumulation, the removal of total solids through runoff from median test area one may be a longer process than the other test areas due to the lack of inlets relative to the other test areas. The high total solids load in the median test area three cannot readily be explained. However, lateral variation of total solids during the spring period at the Milwaukee I-94 monitoring site appears to be a function of existing profile grade, inlet placement, the quantity of solids accumulated during the winter period, and spring thaw and runoff characteristics. These data show the effect of highway design and maintenance practices on the accumulation of highway surface pollutants.

A comparison of surface constituent loads in the distress and median lanes at Milwaukee was discussed earlier in this section and the data were presented in Table 87. The spring data indicated that constituent loads were generally higher in the median lane than in the distress lane. All four test areas monitored during the May 19-20, 1981, lateral study show the same trend (Tables 95 and 96).

Surface contaminant loadings (lb/highway mile) as detected by the August 19-20, 1981, (summer) sweeping/flushing study appear in Table 97. The total solids loading value for test area two, 10,600 lb/highway mi (2,990 kg/km), was in the range of values observed for the August 26 and September 24, 1980, studies performed in this test section, 12,300 lb/highway mile (3,470 kg/km) and 10,200 lb/highway mile (2,880 kg/km) respectively (Volume IV - Appendix). Overall, constituent loadings observed for the summer study in the four test sections were generally much lower than the winter influenced surface loads observed during the spring studies (Table 94).

Total solids loadings were highest for test area two (located at the bottom of a 3-percent slope), were highest, slightly lower for test area one (located at the bottom of 1-percent slope), and lowest for test area three

Table 95. Results of the May 19, 1981, lateral sweeping/flushing study conducted at the Milwaukee I-94 site - total of wet and dry[a] fractions for distress lane.[b]

	Distress lane test area[b]			
Parameter	One, lb/mi	Two, lb/mi	Three, lb/mi	Four, lb/mi
Gross material[c]	42.2	61.2	71.8	32.7
Litter[d]	634	1270	792	317
TS[e]	1020	6260	3870	785
VTS	34.7	261	152	33.8
Pb	7.08	21.9	1.77	2.51
Zn	1.26	6.75	0.717	0.673
Fe	132	584	382	82.0
Cr	0.099	0.531	0.363	0.057
Cu	0.594	3.52	1.73	0.303
Cd	0.004	0.045	0.023	0.005
Ni	0.083	0.394	0.298	0.055
NO_2+NO_3	0.019	0.024	0.019	0.026
TKN	0.289	1.30	1.02	0.326
PO_4-P	0.240	2.21	1.77	0.265
SO_4	1.15	2.03	1.10	1.13
Ca	73.1	410	279	81.7
Na	1.01	4.94	3.24	1.14
Cl	0.575	1.31	1.00	0.512

[a] All pollutant loading values for the dry fraction are based solely upon total solids (particles less than 3.35 mm).

[b] One direction.

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

[d] Litter is defined as particles larger than 3.35 mm (USA No. 6 sieve) not including gross material.

[e] Total solids data represents the fraction passing through USA No. 6 sieve (below 3.35 mm).

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

Table 96. Results of the May 20, 1981, lateral sweeping/flushing study conducted at the Milwaukee I-94 site - total of wet and dry[a] fractions for median lane.[b]

	Median lane test area[b]			
Parameter	One, lb/mi	Two, lb/mi	Three, lb/mi	Four, lb/mi
Gross material[c]	475	475	343	211
Litter[d]	1531	1162	1580	317
TS[e]	14,100	11,800	16,600	2490
VTS	540	447	668	89.6
Pb	57.5	32.6	62.6	11.7
Zn	11.9	9.80	20.9	2.31
Fe	1420	1060	1580	256
Cr	1.47	1.68	1.59	0.223
Cu	5.05	4.45	7.57	1.25
Cd	0.0936	0.060	0.098	0.012
Ni	1.62	2.63	1.17	0.226
NO_2+NO_3	0.0733	0.040	0.042	0.061
TKN	2.86	3.35	4.05	0.654
PO_4-P	6.22	4.40	8.10	0.901
SO_4	3.94	3.35	4.03	1.21
Ca	1080	692	1260	136
Na	10.4	7.20	10.2	1.83
Cl	2.66	2.33	2.79	0.726

[a] All pollutant loading values for the dry fraction are based solely upon total solids (particles less than 3.35 mm).

[b] One direction.

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

[d] Litter is defined as particles larger than 3.35 mm (USA No. 6 sieve) not including gross material.

[e] Total solids data represents the fraction passing through USA No. 6 sieve (below 3.35 mm).

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

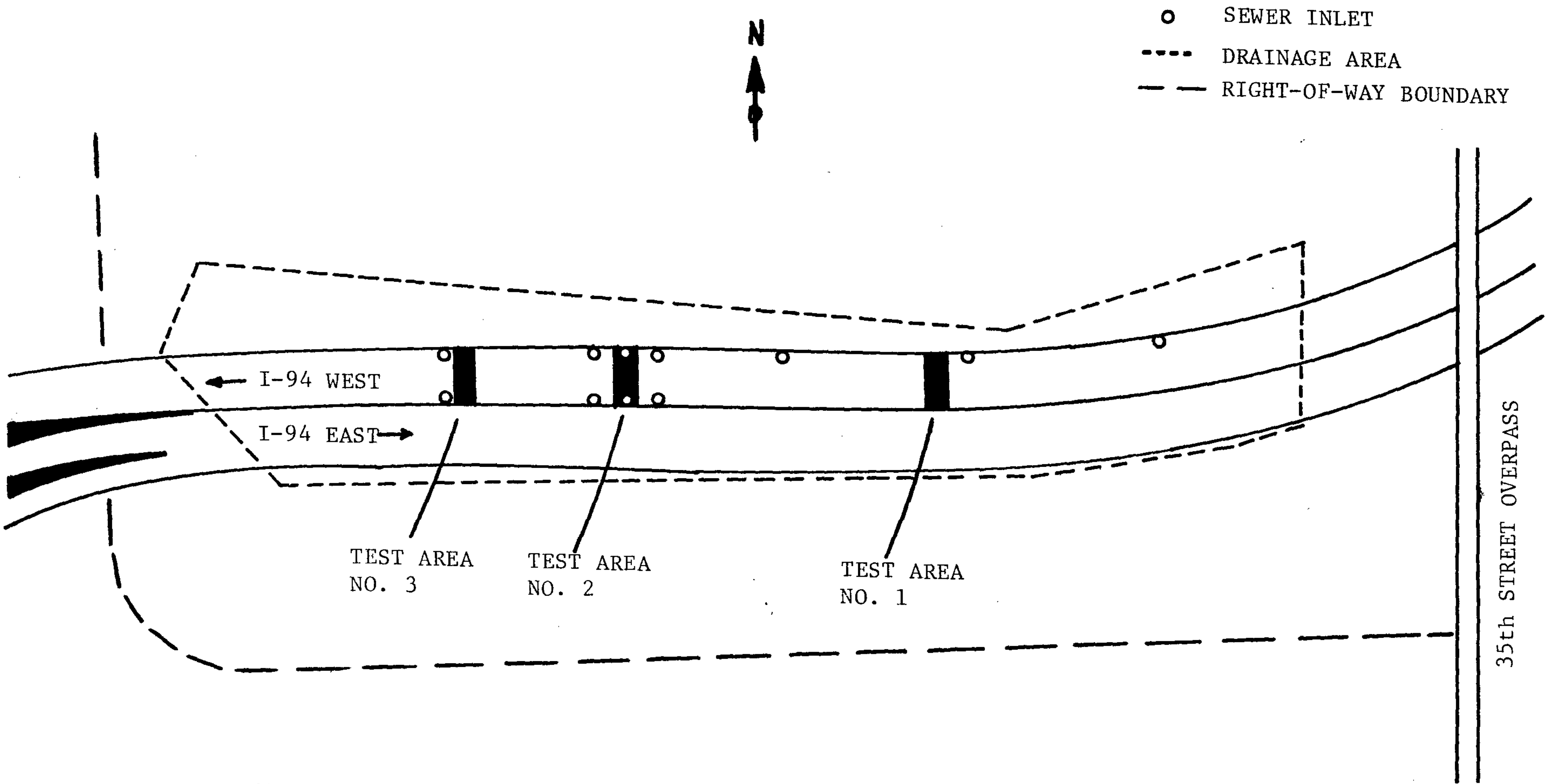


Figure 36. Lateral sweeping/flushing test areas relative to sewer inlets - Milwaukee I-94.

Table 97. Results of the August 19-20, 1981, lateral sweeping/ flushing study conducted at the Milwaukee I-94 site - total of wet and dry[a] fractions for highway surface.[b]

	Highway test area[b]			
Parameter	One, lb/mi	Two, lb/mi	Three, lb/mi	Four, lb/mi
Gross material[c]	574	182	84.5	63.4
Litter[d]	3320	2410	1710	676
TS[e]	9,950	10,600	6,940	3,310
VTS	457	412	298	128
Pb	38.9	32.8	24.6	13.9
Zn	11.4	10.0	5.56	5.88
Fe	1020	1040	726	393
Cr	0.938	0.788	0.544	0.550
Cu	2.32	4.72	2.32	1.21
Cd	0.042	0.052	0.030	0.016
Ni	0.724	0.696	0.452	0.388
NO_2+NO_3	0.090	0.050	0.068	0.102
TKN	6.06	2.94	2.71	1.38
PO_4-P	4.83	3.21	2.71	1.69
SO_4	5.85	3.82	3.53	3.48
Ca	735	729	466	211
Na	13.7	7.52	5.64	3.47
Cl	8.73	4.75	4.76	2.54
Oil and grease	13.6	56.9	33.3	16.6

[a] All pollutant loading values for the dry fraction are based solely upon total solids (particles less than 3.35 mm).

[b] Addition of pollutant load for median and distress lanes times two (both directions).

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

[d] Litter is defined as particles larger than 3.35 mm (USA No. 6 sieve) not including gross material.

[e] Total solids data represents the fraction passing through USA No. 6 sieve (below 3.35 mm).

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

(located at the top of 3-percent slope). This total solids distribution pattern would be expected based upon existing profile grade. However, the other constituent parameters did not always follow the same pattern as total solids. Test area four near 76th Street (Figure 35) had the lowest total solids loading of the four test areas (Table 97). The low total solids loading for test area four compared to test areas one, two, and three may be partially due to a difference in ADT. Average traffic count for test area four during the monitoring period (May through November 1981) was 52,000 vehicles per day while average daily traffic for the highway section which included test areas one, two, and three was 59,200 vehicles per day.

Loadings for the four distress lane test sections are presented in Table 98. Loadings were generally highest in test area two at the bottom of the 3-percent grade (Figure 35). Although summer total solids loadings in the distress lane were lower than spring distress lane values (Table 95), the same distribution pattern between test areas one, two, and three was observed for both studies. Loadings for the four median lane test sections are presented in Table 99. Test areas one and two, located in the lowest areas (Figure 35), have constituent loading values which are comparable, while test area three, located on a high point in the highway section (Figure 35), had loading values significantly lower than test areas one and two. Summer total solids loading distribution for median test areas one, two and, three did not follow the same pattern observed for spring. Similar to spring, the summer median constituent loading values were higher than distress values for all four test sections.

The fall lateral variation study was conducted on November 3-4, 1981. This study was interrupted on the morning of November 4 by dense fog which produced hazardous driving conditions which posed a safety problem for the study. Once the fog lifted, the study resumed. However, due to the fog delay, there was not enough time to complete the study on November 4. The study could not be resumed on November 5 because of a thunderstorm which occurred on the evening of November 5. All sections were sampled except distress lane test areas one and three. Surface contaminant loadings (lb/highway mile) as detected by the November 3-4 sweeping/flushing study for test areas two and four appear in Table 100. The data indicate that total constituent loadings for test areas two and four are comparable to those observed for the summer study (Table 97). Summer (Table 98) and fall (Table 101) constituent loading values for distress lane test area two also appear comparable for most constituents, while summer and fall data for test area four shows more variability. Summer (Table 99) and fall (Table 102) total solids loadings for median test areas two and three are comparable, while the total solids load in median test section one was significantly lower in fall compared to summer. Considerable variation occurs for the other constituent parameters between summer and fall data.

The data collected as part of the surface load lateral variation studies indicate the following:

Table 98. Results of the August 19-20, 1981, lateral sweeping/flushing study conducted at the Milwaukee I-94 site - total of wet and dry[a] fractions for distress lane.[b]

Parameter	Distress lane test area[b] One, lb/mi	Two, lb/mi	Three, lb/mi	Four, lb/mi
Gross material[c]	84.5	35.2	28.9	27.2
Litter[d]	389	547	394	129
TS[e]	715	1340	1160	224
VTS	31.7	55.9	49.1	12.7
Pb	3.07	5.22	4.59	1.14
Zn	0.591	1.39	1.06	1.53
Fe	96.9	145	134	42.6
Cr	0.085	0.126	0.098	0.156
Cu	0.149	0.850	0.501	0.132
Cd	0.005	0.006	0.005	0.003
Ni	0.071	0.118	0.080	0.106
NO_2+NO_3	0.013	0.010	0.013	0.017
TKN	0.238	0.461	0.373	0.093
PO_4-P	0.366	0.517	0.286	0.067
SO_4	0.743	0.682	0.766	0.820
Ca	48.7	96.4	81.0	17.9
Na	1.29	1.04	0.971	0.664
Cl	0.547	0.985	0.820	0.678
Oil & grease	4.63	6.03	4.94	1.12

[a] All pollutant loading values for the dry fraction are based solely upon total solids (particles less than 3.35 mm).

[b] One direction.

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

[d] Litter is defined as particles larger than 3.35 mm (USA No. 6 sieve) not including gross material.

[e] Total solids data represents the fraction passing through USA No. 6 sieve (below 3.35 mm).

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

Table 99. Results of the August 19-20, 1981, lateral sweeping/flushing study conducted at the Milwaukee I-94 site - total of wet and dry[a] fractions for median lane.[b]

	Median lane test area[b]			
Parameter	One, lb/mi	Two, lb/mi	Three, lb/mi	Four, lb/mi
Gross material[c]	203	55.7	13.6	4.35
Litter[d]	1270	657	461	209
TS[e]	4260	3940	2310	1430
VTS	197	150	100	51.2
Pb	16.4	11.2	7.73	5.80
Zn	5.12	3.63	1.72	1.41
Fe	414	375	229	154
Cr	0.384	0.268	0.174	0.119
Cu	1.01	1.51	0.659	0.473
Cd	0.016	0.020	0.010	0.005
Ni	0.291	0.230	0.146	0.088
NO_2+NO_3	0.032	0.015	0.021	0.034
TKN	2.79	1.01	0.980	0.598
PO_4-P	2.05	1.09	1.07	0.778
SO_4	235	1.23	1.00	0.920
Ca	319	268	152	87.6
Na	5.57	2.72	1.85	1.07
Cl	3.82	1.29	1.56	0.590
Oil & grease	2.18	22.4	11.7	7.17

---

[a] All pollutant loading values for the dry fraction are based solely upon total solids (particles less than 3.35 mm).

[b] One direction.

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

[d] Litter is defined as particles larger than 3.35 mm (USA No. 6 sieve) not including gross material.

[e] Total solids data represents the fraction passing through USA No. 6 sieve (below 3.35 mm).

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

Table 100. Results of the November 3-4, 1981, lateral sweeping/ flushing study conducted at the Milwaukee I-94 site - total of wet and dry[a] fractions for highway surface.[b]

	Highway test area[b]	
Parameter	Two, lb/mi	Four, lb/mi
Gross material[c]	548	260
Litter[d]	4,010	812
TS[e]	10,500	2,960
VTS	553	160
Pb	31.7	10.2
Zn	9.44	2.09
Fe	662	276
Cr	0.334	0.126
Cu	4.15	1.42
Cd	0.046	0.016
Ni	0.396	0.208
NO_2+NO_3	0.162	0.132
TKN	4.99	2.93
PO_4-P	4.51	2.69

[a] All pollutant loading values for the dry fraction are based solely upon total solids (particles less than 3.35 mm).

[b] Addition of pollutant load for median and distress lanes times two (both directions).

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

[d] Litter is defined as particles larger than 3.35 mm (USA No. 6 sieve) not including gross material.

[e] Total solids data represents the fraction passing through USA No. 6 sieve (below 3.35 mm).

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

Table 101. Results of the November 3-4, 1981, lateral sweeping/flushing study conducted at the Milwaukee I-94 site - total of wet and dry[a] fraction for distress lane.[b]

	Distress lane test area[b]	
Parameter	Two, lb/mi	Four, lb/mi
Gross material[c]	717	27.9
Litter[d]	130	235
TS[e]	1400	421
VTS	72.6	24.0
Pb	6.36	1.35
Zn	1.18	0.222
Fe	107	48.7
Cr	0.043	0.027
Cu	1.08	0.129
Cd	0.008	0.001
Ni	0.059	0.035
NO_2+NO_3	0.038	0.035
TKN	0.934	0.354
PO_4-P	0.577	0.156

[a] All pollutant loading values for the dry fraction are based solely upon total solids (particles less than 3.35 mm).

[b] One direction.

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

[d] Litter is defined as particles less than 3.35 mm (USA No. 6 sieve) not including gross material.

[e] Total solids data represents the fraction passing through USA No. 6 sieve (below 3.35 mm).

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

Table 102. Results of the November 3-4, 1981, lateral sweeping/flushing study conducted at the Milwaukee I-94 site - total of wet and dry[a] fraction for median lane.[b]

	Median lane test area[b]			
Parameter	One, lb/mi	Two, lb/mi	Three, lb/mi	Four, lb/mi
Gross material[c]	95.9	144	249	102
Litter[d]	694	1290	459	171
TS[e]	2080	3840	2350	1060
VTS	109	204	131	56.1
Pb	9.34	9.48	9.36	3.77
Zn	4.52	3.54	2.04	0.824
Fe	159	224	247	89.4
Cr	0.071	0.124	0.135	0.036
Cu	0.736	0.994	0.813	0.582
Cd	0.007	0.015	0.009	0.007
Ni	0.143	0.139	0.166	0.069
NO_2+NO_3	0.037	0.043	0.030	0.031
TKN	1.46	1.56	1.54	1.11
PO_4-P	0.701	1.68	0.778	1.19

[a] All pollutant loading values for the dry fraction are based solely upon total solids (particles less than 3.35 mm).

[b] One direction.

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

[d] Litter is defined as particles less than 3.35 mm (USA No. 6 sieve) not including gross material.

[e] Total solids data represents the fraction passing through USA No. 6 sieve.

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

1. Test area two, the area of I-94 where all surface constituent load studies were conducted (Volume IV - Appendix), provides good estimates of the spring surface load present within the monitoring site boundaries.

2. Based upon data from test area two, estimates of summer surface constituent loads within the monitoring site boundaries may be slightly high.

3. Data collected from test area four indicate that over a relatively large expanse of I-94 in Milwaukee there exists considerable variation in surface load constituents.

4. Lateral variation in surface load at a given point in time appears to be a function of profile grade and other factors including: inlet placement, seasonable characteristics, maintenance activities (highway sweeping), and average daily traffic.

Data collected as a part of this study indicate that highway design is an important factor in the magnitude and pattern of pollutant accumulation on the highway surface. The data again indicate that sweeping the highway surface is an important mitigation strategy where highway design is conducive to the buildup of pollutants. This is especially true for solids and pollutants associated with solids. The data indicate the importance of removing the highway surface pollutant load which accumulates after long buildup periods, as in the case of the Milwaukee site after the winter buildup period.

Surface Load Particle Size Distribution--

Studies were conducted to determine the particle size distribution of solids and associated metals in the highway surface load at the Milwaukee I-94 site and Sacramento Hwy 50 site. Fractionation studies were not feasible at the Harrisburg site due to a lack of dry solids on the highway surface. The solids portion of the dry material collected in the distress and median lanes at Milwaukee, Efland, and Sacramento was fractionated into the litter component (particles larger than 3.35 mm excluding gross material) and total solids (particles less than 3.35 mm). The total solids portion was further fractionated in a sonic sieve using six different openings. The solids portion of the dry material was divided into eight particle size ranges as follows:

1. Greater than 3350 microns
2. 1410-3350 microns
3. 841-1410 microns
4. 420-841 microns
5. 250-420 microns
6. 74-250 microns
7. 44-74 microns
8. Less than 44 microns

This breakdown of particle size ranges allows direct comparison with work previously done on roadway surface contaminants by Sartor, et. al. (58), and Shaheen (5).

For selected samples, each of the eight fractions was then analyzed for Pb, Zn, Fe, Cu, Cr, Cd, and Ni to determine what portion of these metals are associated with each fraction.

Dry solids collected during the June 17, 1980, and August 19-20, 1981, studies at Milwaukee, the October 22, 1980, study at Sacramento, and the September 24, 1980, study at Efland were fractionated and selected metal analyses performed. Metal concentrations associated with the selected particle size classes appear in Tables 103 through 106. In general, the Milwaukee data (Tables 103 and 104) show that the lowest metal concentrations were associated with the largest particle size class (greater than 3350 microns), while the highest metal concentrations were associated with the 44 to 841 micron particle size classes. The exception to this trend was iron which appears to be associated with the larger particle size classes. In fact, increasing iron concentration is highly correlated to increasing particle size up to 1410 microns, decreasing somewhat in the 1410 to 3350 micron particle size class with the lowest concentration being associated with the litter (greater than 3350 micron particle size class). At Sacramento, the lowest metal concentrations were also associated with the largest particle size class (greater than 3350 microns). However, the highest metal concentrations were associated with the less than 44 to 841 micron particle size class (Table 105). Also, the iron concentration pattern observed at Milwaukee was not evident. At Sacramento, the iron concentrations were relatively uniform over the less than 44 to 1410 micron size range with a decrease in concentration for particles greater than 1410 microns. At Efland, the highest concentrations were always associated with the smallest particle size classes. The high iron concentration in the 74 to less than 44 micron particle size group may be due to the iron enriched clay particles from areas adjacent to the highway. The dry fraction obtained from the paved surface of the distress lane for this study was visibly high in red clay particles.

Metal loadings (lb/mi) at Milwaukee, Efland, and Sacramento were calculated for each particle size class (Tables 107 through 110) based upon metal concentrations (Tables 103 through 106) and the total solids loading obtained for each particle size class. Total solids and metal loadings calculated for the liquid fraction (flush sample) are also listed in Tables 107 through 110. To facilitate comparisons, the loading values for each of the fractions were converted to a percentage of the total load (Tables 111 through 114). The Milwaukee data (Tables 111 and 112) indicate that the metals loading for the liquid fraction is, in most cases, low (approximately 1 to 12 percent) when compared to the total load. The same is true for Efland where metals loading for the liquid fraction was approximately 4 to 14 percent of the total load. For the dry fraction, the 74 to 841 micron particle size class contains the major portion of the total metals loading (approximately 50 to 85 percent). The data also show that the distress lane contains a greater percentage of large size particles (greater than 1410 microns) than the median

Table 103. Metal concentrations for selected particle size classes of the dry solids[a] obtained in the distress and median lanes for the June 17, 1980, sweeping/flushing study at the Milwaukee I-94 site.

Lane	Particle size, microns	Concentration, mg/kg[b]						
		Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	>3350	41.9	20.9	1,290	5.0	5.6	1.3	8.9
	1410-3350	116	73	95,400	111	34	2.1	54
	841-1410	1300	794	132,000	157	120	4.3	60
	420-841	2840	774	102,000	118	59	3.5	90
	250-420	4320	597	77,700	355	74	15.6	64
	74-250	5060	999	67,400	426	96	7.0	67
	44-74	4680	936	60,200	552	117	11.4	97
	<44	2830	745	41,700	396	92	7.1	137
Median	>3350	41.5	20.8	1,970	7.8	6.2	1.3	9.3
	1410-2250	436	66	108,000	290	36	2.2	196
	841-1410	1100	858	151,000	180	97	3.1	88
	420-841	2620	888	119,000	230	89	4.2	64
	250-420	4700	750	81,700	163	52	2.7	37
	74-250	5070	948	73,000	458	65	6.3	67
	44-74	6250	1430	67,300	729	108	11.1	123
	<44	4220	884	48,400	474	84	10.4	104

[a] Litter is defined as solids whose particle size is greater than 3350 microns and total solids are particles whose size is less than 3350 microns.

[b] Dry weight basis.

Table 104. Metal concentrations for selected particle size classes of the dry solids[a] obtained in the distress and median lanes for the August 19-20, 1981, sweeping/flushing study at the Milwaukee I-94 site.

Lane	Particle size, microns	Concentration, mg/kg[b]						
		Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	>3350	66.5	27.8	30.1	5.6	9.5	1.3	7.8
	1410-3350	192	209	107,000	88.7	87.7	1.5	56.1
	841-1410	2970	659	159,000	138	94.9	8.8	86.9
	420-841	5530	1010	127,000	553	93.8	2.9	164
	250-420	5090	923	83,900	588	64.7	3.5	98.8
	74-250	5490	836	59,500	430	62.6	5.1	63.0
	44-74	7130	1300	71,300	646	115	9.0	126
	<44	4490	1000	47,500	444	89.8	7.4	79.2
Median	>3350	31.7	18.3	154	5.2	4.7	1.1	6.7
	1410-3350	269	231	89,500	102	76.9	1.6	44.8
	841-1410	1920	1210	128,000	116	81.6	5.3	64.2
	420-841	2230	792	107,000	279	81.2	2.8	66.0
	250-420	2980	845	63,200	276	59.2	5.2	54.2
	74-250	4340	849	51,400	338	60.1	3.7	61.1
	44-74	7860	1420	68,500	700	104	9.4	101
	<44	5800	1090	47,800	512	85.3	7.2	102

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[a] Litter is defined as solids whose particle size is greater than 3350 microns and total solids are particles whose size is less than 3350 microns.

[b] Dry weight basis.

Table 105. Metal concentrations for selected particle size classes of the dry solids[a] obtained in the distress and median lanes for the October 22, 1980, sweeping/flushing study at the Sacramento Hwy 50 site.

Lane	Particle size, microns	Concentration, mg/kg[b]						
		Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	>3350	4.0	12.1	4,740	11.8	3.6	0.2	5.6
	1410-3350	55.8	26.3	13,500	24.9	17.2	0.9	37.2
	841-1410	1460	92.3	22,800	30.8	39.6	1.0	43.7
	420-841	5110	216	32,300	34.7	60.9	0.9	60.9
	250-420	4410	174	26,700	28.2	58.4	1.5	56.4
	74-250	4230	423	38,600	94.1	76.7	2.4	56.4
	44-74	3260	498	33,200	124	71.7	13.0	97.7
	<44	2550	612	35,700	230	102	ND	255
Median	>3350	8.4	6.2	3,730	9.5	12.0	0.2	5.4
	1410-3350	432	33.4	33,400	20.4	40.4	0.6	39.2
	841-1410	2440	65.7	58,700	41.8	48.1	1.2	68.1
	420-841	9600	250	40,600	31.7	48.7	0.9	37.9
	250-420	11,600	846	46,800	202	76.4	0.9	101
	74-250	10,900	473	53,000	256	78.8	4.3	62.7
	44-74	6420	882	41,700	93.0	83.4	5.2	72.2
	<44	7770	2370	45,500	141	99.4	2.8	94.7

[a] Litter is defined as solids whose particle size is greater than 3350 microns and total solids are particles whose size is less than 3350 microns.

[b] Dry weight basis.

ND = Not detectable.

Table 106. Metal concentrations for selected particle size classes of the dry solids[a] obtained in the distress lane for the September 24, 1981, sweeping/flushing study at the Efland I-85 site.

Lane	Particle size, micron	Concentration, mg/kg[b] Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	>3350	16.9	95.5	12,800	32.8	0.98	0.22	7.6
	1410-3350	217	118	28,500	34.1	19.2	0.37	14.2
	841-1410	451	245	27,400	43.6	25.0	0.78	15.2
	420-841	1170	263	30,200	30.2	23.9	0.93	15.6
	250-420	1530	483	26,700	76.1	23.3	1.53	15.9
	74-250	1820	527	27,000	89.9	26.6	2.19	20.0
	44-74	1970	752	42,300	118	29.6	3.29	25.9
	<44	1840	904	45,200	132	34.8	3.50	34.8

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[a] Litter is defined as solids whose particle size is greater than 3350 microns and total solids are particles whose size is less than 3350 microns.

[b] Dry weight basis.

Table 107. Solids and metals loadings associated with the liquid fraction[a] and selected particle size classes of the total solids and litter fraction[b] for the June 17, 1980, sweeping/flushing study at the Milwaukee I-94 site.

		Loading, lb/mi[c]							
Lane	Fraction	Solids	Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	Dry, microns								
	>3350	440	0.018	0.009	0.568	0.002	0.002	0.001	0.004
	1410-3350	332	0.039	0.024	31.7	0.037	0.011	0.001	0.018
	841-1410	222	0.289	0.176	29.3	0.034	0.027	0.001	0.013
	420-841	360	1.02	0.279	36.7	0.042	0.021	0.001	0.032
	250-420	234	1.01	0.140	18.2	0.083	0.017	0.004	0.015
	74-250	292	1.48	0.292	19.7	0.124	0.028	0.002	0.020
	44-74	38.0	0.178	0.036	2.29	0.021	0.004	0.0004	0.004
	<44	30.8	0.087	0.023	1.28	0.012	0.003	0.0002	0.004
	Liquid	70.8	0.222	0.074	2.65	0.021	0.004	0.001	0.006
	Total	2020	4.34	1.05	142	0.376	0.117	0.012	0.116
Median	dry, microns								
	>3350	307	0.013	0.006	0.605	0.002	0.002	0.0004	0.003
	1410-3350	160	0.070	0.011	17.3	0.046	0.006	0.0004	0.031
	841-1410	236	0.260	0.202	35.6	0.042	0.023	0.001	0.021
	420-841	478	1.25	0.424	56.9	0.110	0.043	0.002	0.031
	250-420	450	2.12	0.338	36.8	0.073	0.023	0.001	0.071
	74-250	476	2.41	0.451	34.7	0.218	0.031	0.003	0.032
	44-74	53.9	0.337	0.077	3.63	0.039	0.006	0.001	0.007
	<44	39.8	0.168	0.035	1.93	0.019	0.003	0.0004	0.004
	Liquid	45.9	0.184	0.054	1.80	0.014	0.003	0.001	0.004
	Total	2250	6.81	1.60	189	0.563	0.140	0.010	0.204

[a] Sample obtained by wet vacuuming the highway surface.

[b] Litter is defined as solids whose particle size is greater than 3350 microns and total solids are particles whose size is less than 3350 microns.

[c] One direction.

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

Table 108. Solids and metals loadings associated with the liquid fraction[a] and selected particle size classes of the total solids and litter fraction[b] for the August 19-20, 1981, sweeping/flushing study at the Milwaukee I-94 site.

		Loading, lb/mi[c]							
Lane	Fraction	Solids	Pb	Zn	Fe	Cu	Cr	Cd	Ni
	Dry, microns								
Distress	>3350	547	0.036	0.015	0.016	0.003	0.005	0.001	0.004
	1410-3350	220	0.042	0.044	23.5	0.020	0.019	0.0003	0.012
	841-1410	158	0.469	0.104	25.1	0.022	0.015	0.001	0.014
	420-841	241	1.33	0.243	30.6	0.133	0.023	0.001	0.040
	250-420	230	1.17	0.212	19.3	0.135	0.015	0.001	0.023
	74-250	323	1.77	0.270	19.2	0.139	0.020	0.002	0.020
	44-74	54.4	0.388	0.071	3.88	0.035	0.006	0.0005	0.007
	<44	42.4	0.190	0.042	2.01	0.019	0.004	0.0003	0.003
	Liquid	71.7	0.345	0.111	3.96	0.033	0.007	0.001	0.006
	Total	1890	5.74	1.11	128	0.539	0.114	0.008	0.129
Median	Dry, microns								
	>3350	394	0.012	0.007	0.061	0.002	0.002	0.0004	0.003
	1410-3350	502	0.135	0.116	44.9	0.051	0.039	0.001	0.022
	841-1410	405	0.778	0.490	51.8	0.047	0.033	0.002	0.026
	420-841	729	1.63	0.577	78.0	0.203	0.059	0.002	0.048
	250-420	824	2.46	0.696	52.1	0.227	0.049	0.004	0.045
	74-250	1150	4.99	0.976	59.1	0.389	0.069	0.004	0.070
	44-74	148	1.16	0.210	10.1	0.104	0.015	0.001	0.015
	<44	108	0.626	0.118	5.16	0.055	0.009	0.001	0.011
	Liquid	66.4	0.298	0.095	2.70	0.034	0.005	0.001	0.005
	Total	4330	12.1	3.29	304	1.11	0.280	0.0164	0.245

[a] Sample obtained by wet vacuuming the highway surface.

[b] Litter is defined as solids whose particle size is greater than 3350 microns and total solids are particles whose size is less than 3350 microns.

[c] One direction.

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

Table 109. Solids and metals loadings associated with the liquid fraction[a] and selected particle size classes of the total solids and litter fraction[b] for the October 22, 1980, sweeping/flushing study at the Sacramento Hwy 50 site.

		Loading, lb/mi[c]							
Lane	Fraction	Solids	Pb	Zn	Fe	Cu	Cr	$Cd x 10^{-3}$	Ni
Distress	Dry, microns								
	>3350	35.9	0.0001	0.0004	0.170	0.0004	0.0001	0.01	0.0002
	1410-3350	11.5	0.001	0.0003	0.155	0.0003	0.0002	0.01	0.0004
	841-1410	3.90	0.006	0.0004	0.089	0.0001	0.0002	0.004	0.0002
	420-841	3.53	0.018	0.001	0.114	0.0001	0.0002	0.003	0.0002
	250-420	1.39	0.006	0.0002	0.037	0.00004	0.0001	0.002	0.0001
	74-250	1.51	0.006	0.001	0.058	0.0001	0.0004	0.004	0.0001
	44-74	0.23	0.001	0.0001	0.009	0.00003	0.00002	0.003	0.00002
	<44	0.05	0.0001	0.00003	0.002	0.00001	0.00001	ND	0.00001
	Liquid	49.6	0.155	0.034	1.96	0.006	0.006	0.4	0.005
	Total	108	0.193	0.037	2.59	0.007	0.007	0.4	0.006
Median	Dry, microns								
	>3350	10.7	0.0001	0.0001	0.040	0.0001	0.0001	0.002	0.0001
	1410-3350	9.76	0.004	0.0003	0.326	0.0002	0.0004	0.01	0.0004
	841-1410	6.71	0.016	0.0004	0.394	0.0003	0.0003	0.01	0.0004
	420-841	7.88	0.076	0.002	0.320	0.0002	0.0004	0.01	0.0003
	250-420	4.02	0.047	0.003	0.188	0.001	0.0003	0.004	0.0004
	74-250	5.30	0.058	0.003	0.281	0.001	0.0004	0.02	0.0003
	44-74	0.855	0.005	0.001	0.036	0.0001	0.0001	0.004	0.0001
	<44	0.373	0.003	0.001	0.017	0.0001	0.00004	0.001	0.00004
	Liquid	34.2	0.202	0.035	1.73	0.009	0.005	0.2	0.004
	Total	79.8	0.411	0.046	3.33	0.012	0.007	0.3	0.006

[a] Sample obtained by wet vacuuming the highway surface.

[b] Litter is defined as solids whose particle size is greater than 3350 microns and total solids are particles whose size is less than 3350 microns.

[c] One direction.

ND = Not detectable. Metric units: To convert lb/mi to kg/km multiply by 0.2819.

Table 110. Solids and metals loadings associated with the liquid fraction[a] and selected particle size classes of the total solids and litter fraction[b] for the September 24, 1981, sweeping/flushing study at the Efland I-85 site.

		Loading, lb/mi[c]							
Lane	Fraction	Solids	Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	Dry, microns,								
	>3350	643	0.011	0.061	8.23	0.021	0.001	0.0001	0.005
	1410-3350	291	0.063	0.034	8.29	0.010	0.006	0.0001	0.004
	841-1410	149	0.067	0.037	4.08	0.006	0.004	0.0001	0.0002
	420-841	176	0.206	0.046	5.32	0.005	0.004	0.0002	0.003
	250-420	103	0.158	0.050	2.75	0.008	0.002	0.0002	0.002
	74-250	155	0.282	0.082	4.19	0.014	0.004	0.0003	0.003
	44-74	26.3	0.052	0.020	1.11	0.003	0.001	0.0001	0.001
	<44	17.5	0.032	0.016	0.791	0.002	0.001	0.0001	0.001
	Liquid	43.8	0.092	0.035	1.28	0.006	0.002	0.0002	0.001
	Total	1600	0.963	0.381	36.0	0.075	0.005	0.0014	0.020

[a] Sample obtained by wet vacuuming the highway surface.

[b] Litter is defined as solids whose particle size is greater than 3350 microns and total solids are particles whose size is less than 3350 microns.

[c] One direction.

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

Table 111. Percent solids and metals loadings for the liquid fraction[a] and selected particle size classes of the total solids and litter fraction[b] for the June 17, 1980, sweeping/flushing study at the Milwaukee I-94 site.

Lane	Fraction	Percent of total load							
		TS	Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	Dry, microns								
	>3350	21.78	0.41	0.85	0.40	0.53	1.71	8.62	3.45
	1410-3350	16.44	0.90	2.28	22.26	9.84	9.40	8.62	15.52
	841-1410	10.99	6.65	16.71	20.58	9.04	23.08	8.62	11.21
	420-841	17.82	23.49	26.50	25.77	11.17	17.95	8.62	27.58
	250-420	11.59	23.26	13.30	12.78	22.07	14.53	34.49	12.93
	74-250	14.46	34.08	27.73	13.84	32.98	23.93	17.24	17.24
	44-74	1.88	4.10	3.42	1.61	5.59	3.42	3.45	3.45
	<44	1.53	2.00	2.18	0.90	3.19	2.56	1.72	3.45
	Liquid	3.51	5.11	7.03	1.86	5.59	3.42	8.62	5.17
Median	Dry, microns								
	>3350	13.67	0.19	0.38	0.32	0.36	1.43	3.92	1.47
	1410-3350	7.12	1.03	0.69	9.14	8.17	4.29	3.92	15.20
	841-1410	10.50	3.82	12.64	18.81	7.46	16.43	9.80	10.29
	420-841	21.28	18.35	26.53	30.07	19.54	30.71	19.62	15.20
	250-420	20.03	31.12	21.15	19.44	12.97	16.43	9.80	34.80
	74-250	21.19	35.37	28.22	18.33	38.71	22.14	29.42	15.69
	44-74	2.40	4.95	4.82	1.92	6.93	4.29	9.80	3.43
	<44	1.77	2.47	2.19	1.02	3.37	2.14	3.92	1.96
	Liquid	2.04	2.70	3.38	0.95	2.49	2.14	9.80	1.96

[a] Sample obtained by wet vacuuming the highway surface.

[b] Litter is defined as solids whose particle size is greater than 3350 microns and total solids are particles whose size is less than 3350 microns.

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

Table 112. Percent solids and metals loadings for the liquid fraction[a] and selected particle size classes of the total solids and litter fraction for the August 19-20, 1981, sweeping/flushing study at the Milwaukee I-94 site.

		Percent of total load							
Lane	Fraction	TS	Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	Dry, microns								
	>3350	2.89	0.627	1.35	0.013	0.557	4.39	12.5	3.10
	1410-3350	11.6	0.732	3.96	18.6	3.71	16.7	3.73	9.30
	841-1410	8.39	8.17	9.31	19.7	4.08	13.2	12.4	10.9
	420-841	12.9	23.2	21.8	23.9	24.7	20.1	12.4	31.0
	250-420	12.2	20.4	19.1	15.1	25.0	13.2	12.5	17.8
	74-250	17.1	30.8	24.3	15.0	25.8	17.5	24.0	15.5
	44-74	2.88	6.75	6.40	3.03	6.50	5.26	6.25	5.43
	<44	2.24	3.31	3.78	1.57	3.53	3.51	3.72	2.33
	Liquid	3.79	6.01	10.0	3.09	6.12	6.14	12.5	4.64
Median	Dry, microns								
	>3350	9.10	0.099	0.213	0.020	0.180	0.714	2.44	1.22
	1410-3350	11.6	1.12	3.53	14.8	4.59	13.9	6.09	8.97
	841-1410	9.36	6.44	14.9	17.0	4.25	11.8	12.2	10.6
	420-841	16.8	13.5	17.6	25.8	18.3	21.1	12.2	19.6
	250-420	19.0	20.3	21.2	17.1	20.3	17.5	24.4	18.4
	74-250	26.7	41.3	29.7	19.4	35.0	24.6	24.4	28.6
	44-74	3.42	9.59	6.38	3.30	9.37	5.39	6.09	6.10
	<44	2.49	5.18	3.59	1.69	4.95	3.21	6.09	4.47
	Liquid	1.53	2.47	2.89	0.888	3.06	1.79	6.09	2.04

[a] Sample obtained by wet vacuuming the highway surface.

[b] Litter is defined as solids whose particle size is greater than 3350 microns and total solids are particles whose size is less than 3350 microns.

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

Table 113. Percent solids and metals loadings for the liquid fraction[a] and selected particle size classes of the total solids and litter fraction[b] for the October 22, 1980, sweeping/flushing study at the Sacramento Hwy 50 site.

Lane	Fraction	Percent of total load							
		TS	Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	Dry, microns								
	>3350	33.37	0.05	1.07	6.55	5.65	1.44	2.29	3.21
	1410-3350	10.69	0.52	0.80	5.98	4.24	2.89	2.29	6.42
	841-1410	3.62	3.11	1.07	3.43	1.41	2.89	0.92	3.21
	420-841	3.28	9.32	2.67	4.39	1.41	2.89	0.69	3.21
	250-420	1.29	3.11	0.53	1.43	0.56	1.44	0.46	1.61
	74-250	1.40	3.11	2.67	2.24	1.41	1.44	0.92	1.61
	44-74	0.21	0.52	0.27	0.35	0.42	0.29	0.69	0.32
	<44	0.05	0.05	0.08	0.08	0.14	0.14	ND	0.16
	Liquid	46.09	80.21	90.84	75.55	84.76	86.58	91.74	80.26
Median	Dry, microns								
	>3350	13.41	0.02	0.22	1.20	0.83	1.42	0.77	1.66
	1410-3350	12.23	0.97	0.66	9.78	1.67	5.68	3.83	6.62
	841-1410	8.41	3.89	0.87	11.83	2.50	4.26	3.83	6.62
	420-841	9.87	18.49	4.37	9.60	1.67	5.68	3.83	4.97
	250-420	5.04	11.43	6.55	5.64	8.33	4.26	1.53	6.62
	74-250	6.64	74.11	6.55	8.43	8.33	5.68	7.66	4.97
	44-74	1.07	1.22	2.18	1.08	0.83	1.42	1.53	1.66
	<44	0.47	0.73	2.18	0.51	0.83	0.57	0.38	0.66
	Liquid	42.86	49.14	76.42	51.93	75.01	71.03	76.64	66.22

[a] Sample obtained by wet vacuuming the highway surface.

[b] Litter is defined as solids whose particle size is greater than 3350 microns and total solids are particles whose size is less than 3350 microns.

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

Table 114. Percent solids and metals loadings for the liquid fraction[a] and selected particle size classes of the total solids and litter fraction for the September 24, 1981, sweeping/flushing study at the Efland I-85 site.

		Percent of total load							
Lane	Fraction	TS	Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	Dry, microns								
	>3350	40.06	1.14	16.01	22.84	28.00	4.00	7.14	24.76
	1410-3350	18.14	6.54	8.92	23.00	13.33	24.00	7.14	19.80
	841-1410	9.29	6.96	9.71	11.32	8.00	16.00	7.14	0.99
	420-841	10.97	21.39	12.07	14.76	6.67	16.00	14.29	14.85
	250-420	6.42	16.41	13.12	7.63	10.67	8.00	14.29	9.90
	74-250	9.66	29.29	21.53	11.63	18.67	16.00	21.43	14.85
	44-74	1.64	5.40	5.25	3.08	4.00	4.00	7.14	4.95
	<44	1.09	3.32	4.20	2.19	2.67	4.00	7.14	4.95
	Liquid	2.73	9.55	9.19	3.55	8.00	8.00	14.29	4.95

[a] Sample obtained by wet vacuuming the highway surface.

[b] Litter is defined as solids whose particle size is greater than 3350 microns and total solids are particles whose size is less than 3350 microns.

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

lane. Wind and vehicular turbulence may blow some of the finer material into the grassy right-of-way next to the distress lane, while the GM barrier next to the median lane appears to effectively trap and/or re-entrain most of the particles which accumulate there. The data also show that although the litter fraction (greater than 3350 microns) is approximately 28 percent of the solids load in the distress lane and 14 percent in the median lane, the metals load contributed by the litter fraction is less than 9 percent and usually less than 2 percent.

Unlike Milwaukee and Efland, the metals loading associated with the liquid fraction at Sacramento were high (approximately 49 to 94 percent) when compared to the total load (Table 113). The difference between the percent metals loading for the liquid fraction at the Sacramento, Milwaukee, and Efland sites can probably be attributed to a difference in solids loadings. Solids loadings at Milwaukee and Efland were approximately 16 to 20 times higher than Sacramento for the fractionation studies. Therefore, the percent metals loading in the liquid (flush fraction) was lower at Milwaukee and Efland because of the larger quantity of dry solids which accumulated. However, when actual metal loading values were compared (lb/mi) for Sacramento, Efland, and Milwaukee, metals loading associated with the liquid fraction (flush sample) were quite comparable (Tables 108 through 110). Metal loadings associated with the liquid fraction were also comparable for the distress and median lanes at the Sacramento and Milwaukee sites. These data suggest that once an area of distress or median lane is swept (by hand with a broom), the metals load that remains (that which can be collected by flushing) is essentially the same regardless of drainage design, pavement type, or traffic characteristics.

The data for Sacramento (Table 113) indicate that for the dry fraction, the 74 to 1410 micron particle size class contains the major portion of the metals loading. The data also show that although the litter fraction (greater than 3350 micron) is approximately 33 percent of the solids load in the distress lane and 13 percent in the median lane, the metals load contributed by the litter fraction is less than 7 percent and usually less than 2 percent. The Efland data (Table 114) show that the litter fraction is 40 percent of the solids load in the distress lane and contained 1 percent of the lead load and 4 to 28 percent of the load for all other metals.

Tables 115 through 118 compare the metal loading values for Milwaukee, Efland, and Sacramento obtained by summing the loading values for each of the eight particle size classes for the dry fraction (sieved) to the metal loadings obtained by analyzing the single aliquot of the entire total solids sample (unsieved). For Milwaukee and Efland (Tables 115, 116 and 118), the metal loading values in most cases were comparable between the sieved and unsieved samples, indicating that the aliquots chosen for analysis were representative of the entire sample. The Sacramento data (Table 117) show that the sieved and unsieved samples were not as consistently similar as those observed for the Milwaukee data, but in many cases the values were close. These data indicate that representative solids samples could be obtained from the large quantity of dry material collected during a sweeping/flushing study.

Table 115. Comparison of metals loadings calculated for the sieved[a] and unsieved[b] dry total solids sample - June 17, 1980, sweeping/ flushing study at the Milwaukee I-94 site.

Lane	Sample type	Loading, lb/mi[c]						
		Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	Sieved	4.10	0.970	139	0.353	0.111	0.010	0.106
	Unsieved	6.45	1.56	119	0.438	0.122	0.009	0.081
Median	Sieved	6.62	1.54	187	0.547	0.135	0.009	0.197
	Unsieved	5.52	1.77	190	0.429	0.132	0.007	0.095

[a] Sum of the loading values for each of the eight particle size classes (sample fractionated in a sonic sieve).

[b] Loading value based on the concentration obtained from the analysis of an aliquot of the entire total solids sample (particles less than 3.35 mm).

[c] One direction.

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

Table 116. Comparison of metals loadings calculated for the sieved[a] and unsieved[b] dry total solids sample - August 19-20, 1981, sweeping/flushing study at the Milwaukee I-94 site.

Lane	Sample type	Loading, lb/mi[c]						
		Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	Sieved	5.36	0.986	124	0.503	0.102	0.006	0.119
	Unsieved	4.87	1.28	141	0.817	0.119	0.005	0.112
Median	Sieved	11.8	3.18	301	1.08	0.273	0.015	0.237
	Unsieved	10.9	3.54	373	1.48	0.263	0.019	0.225

[a] Sum of the loading values for each of the eight particles size classes (sample fractionated in a sonic sieve).

[b] Loading value based on the concentration obtained from the analysis of an aliquot of the entire total solids sample (particle less than 3.35 mm).

[c] One direction.

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

Table 117. Comparison of metals loadings calculated for the sieved[a] and unsieved[b] dry total solids sample - October 22, 1980, sweeping/ flushing study at the Sacramento Hwy 50 site.

Lane	Sample type	Loading, lb/mi[c]						
		Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	Sieved	0.038	0.003	0.464	0.001	0.001	0.00003	0.001
	Unsieved	0.139	0.011	0.980	0.004	0.003	0.00005	0.001
Median	Sieved	0.209	0.011	1.56	0.003	0.002	0.0001	0.002
	Unsieved	0.170	0.020	1.43	0.005	0.004	0.00005	0.002

[a] Sum of the loading values for each of the eight particle size classes (sample fractionated in a sonic sieve).

[b] Loading value based on the concentration obtained from the analysis of an aliquot of the entire total solids sample (particles less than 3.35 mm).

[c] One direction.

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

Table 118. Comparison of metals loadings calculated for the sieved[a] and unsieved[b] dry total solids sample - September 24, 1981, sweeping/ flushing study at the Efland I-85 site.

Lane	Sample type	Loading, lb/mi[c]						
		Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	Sieved	0.952	0.320	27.8	0.054	0.024	0.001	0.015
	Unsieved	0.934	0.312	20.7	0.055	0.017	0.002	0.015

[a] Sum of the loading values for each of the eight particle size classes (sample fractionated in a sonic sieve).

[b] Loading value based on the concentration obtained from the analysis of an aliquot of the entire total solids sample (particles less than 3.35 mm).

[c] One direction.

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

Runoff composite samples collected on October 1, 1979, and August 7, 1981, at the Milwaukee I-94 site, on January 22-23, 1981, at the Sacramento Hwy 50 site, on June 10, 1981, at the Harrisburg I-81 site, and on April 26, 1982, at the Efland I-85 site were wet sieved into four particle size classes. Wet sieve analyses of composite runoff samples from the Milwaukee (Tables 119 and 120), Sacramento (Table 121), Harrisburg (Table 122), and Efland (Table 123) sites show that 92 to 95, 99, 98.5, and 98 percent respectively of the total solids in runoff were less than 250 microns in size. An estimate of washable total solids on the highway surface at Milwaukee on June 17, 1980, (Table 124) and August 19-20, 1981, (Table 125), at Sacramento on October 22, 1980, (Table 126) and at Efland on September 24, 1981, (Table 127) was calculated by assuming that the washable fraction is those total solids less than 250 microns in size and that the majority of solids in the flush fraction are less than 250 microns in size. Wet sieve analyses performed on the flush samples obtained at Milwaukee on August 19-20, 1981, showed that approximately 85 (distress lane) to 89 (median lane) percent of the total solids were less than 250 microns in size.

The Milwaukee data (Table 124 and 125) show that the washable total solids were approximately 33 percent of the entire total solids load and that the metals associated with the washable total solids were approximately 19 to 50 percent of the total metals load. Of the metals analyzed for, iron had the lowest percentage of association with washable total solids. The Efland data (Table 127) was comparable to the Milwaukee data. The percentage of total solids and metals in the highway surface load associated with the washable fraction at the Sacramento site (Table 126) was considerably higher than those estimated for the Milwaukee and Efland sites. Data for Sacramento show that washable total solids were approximately 50 percent of the entire total solids load and that the metals associated with the washable total solids were approximately 62 to 97 percent of the total metals load. The difference in percent washable total solids and metals between these sites can probably be attributed to the difference in highway drainage design and average daily traffic. The curb and gutter drainage design and median lane GM barriers at Milwaukee appear to effectively retain highway generated material, especially those in the larger particle size classes, compared to the flush shoulder design at Sacramento and Efland where the majority of the highway generated material is blown into the right-of-way. However, although Milwaukee had a lower percentage of washable total solids and metals than Sacramento and Efland, the loadings (lb/mi) of washable total solids and metals at Milwaukee were generally an order of magnitude higher than at Sacramento and Efland (Table 128). Again, this can probably be attributed to the differences in drainage design and average daily traffic.

Commercial Sweeper Efficiency--

At the Milwaukee I-94 site (urban, curb and gutter drainage design), the highway surface is normally swept six to eight times per year (once per month during nonwinter conditions), while at the Sacramento Hwy 50 site (urban, flush shoulder drainage design) the highway surface is swept only if the paved surface is extremely dirty (at most once per year). Commercially sweeping the

Table 119. Wet sieving analysis on runoff composite samples collected October 1, 1979, at the Milwaukee I-94 site.

Particle size, microns	Total solids, percent	Suspended solids, percent
>250	4.99	15.32
88-250	1.10	3.37
44-88	1.58	4.84
<44	92.34	77.47

Note: Rainfall totalled 0.21 inches in 4.5 hr.

Metric units: To convert in to cm multiply by 2.54.

Table 120. Wet sieving analysis on runoff composite samples collected August 7, 1981, at the Milwaukee I-94 site.

Particle size, microns	Total solids, percent	Suspended solids, percent
>250	7.59	13.79
88-250	2.07	10.63
44-88	3.10	6.84
<44	87.24	68.74

Note: Rainfall totalled 0.29 inches in 1.0 hr.

Metric units: To convert in to cm multiply by 2.54.

Table 121. Wet sieving analysis on runoff composite samples collected January 22-23, 1981, at the Sacramento Hwy 50 site.

Particle size, microns	Total solids, percent	Suspended solids, percent
>250	1.06	1.54
88-250	6.24	9.07
44-88	7.36	10.70
<44	85.34	78.69

Note: Rainfall totalled 1.14 inches in 19 hr.

Metric units: To convert in to cm multiply by 2.54.

Table 122. Wet sieving analysis on runoff composite samples collected June 10, 1981, at the Harrisburg I-81 site.

Particle size, microns	Total solids, percent	Suspended solids, percent
>250	1.50	6.70
88-250	1.60	6.70
44-88	2.60	11.70
<44	94.30	75.50

Note: Rainfall totalled 0.52 inches in 2.6 hr.

Metric units: To convert in to cm multiply by 2.54.

Table 123. Wet sieving analysis on runoff composite samples collected April 26, 1982, at the Efland I-85 site.

Particle size, microns	Total solids, percent	Suspended solids, percent
>250	0.51	3.58
88-250	0.18	1.30
44-88	1.15	8.06
<44	98.16	87.06

Note: rainfall totalled 0.31 inches in 6.5 hr.

Metric units: To convert in to cm multiply by 2.54.

Table 124. Percent of total solids[a] and metals in highway surface load associated with the washable fraction[b] - June 17, 1980, sweeping/flushing study at the Milwaukee I-94 site.

	Percent of total highway surface load							
Lane	TS	Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	27.33	45.47	40.71	18.27	47.60	33.91	33.96	30.36
Median	31.74	45.58	38.76	22.28	51.69	31.15	55.10	31.97

[a] Total solids data represent the fraction passing through USA No. 6 sieve (below 3.55 mm).

[b] Washable fraction includes the dry fraction in the particle size class less than 250 micron plus the liquid (flush) fraction.

Table 125. Percent of total solids[a] and metals in highway surface load associated with the washable fraction - August 19-20, 1981, sweeping/flushing study at the Milwaukee I-94 site.

	Percent of total highway surface load							
Lane	TS	Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	36.60	47.21	34.98	22.70	42.16	33.94	54.29	28.80
Median	37.41	58.52	42.61	25.35	52.53	35.25	43.75	41.74

[a] Total solids data represent the fraction passing through USA Sieve No. 6 (below 3.35 mm).

[b] Washable fraction includes the dry fraction in the particle size class 250 micron plus the liquid (flush) fraction.

Table 126. Percent of total solids[a] and metals in highway surface load associated with the washable fration - October 22, 1980, sweeping/flushing study at the Sacramento Hwy 50 site.

	Percent of total highway surface load							
Lane	TS	Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	47.58	83.93	97.22	78.34	91.92	89.75	95.54	85.07
Median	51.04	65.21	88.89	61.98	85.71	79.83	93.36	74.75

[a] Total solids data represents the fraction passing through USA Sieve No. 6 (below 3.55 m).

[b] Washable fraction includes the dry fraction in the particle size class less than 250 micron plus the liquid (flush) fraction.

Table 127. Percent of total solids[a] and metals in highway surface load associated with the washable fraction - September 24, 1981, sweeping/flushing study at the Efland I-85 site.

	Percent of total highway surface load							
Lane	TS	Pb	Zn	Fe	Cu	Cr	Cd	Ni
Distress	25.22	48.11	47.81	26.50	46.30	33.33	53.85	40.00

[a] Total solids data represents the fraction passing through USA Sieve no. 6 (below 3.55 m).

[b] Washable fraction includes the dry fraction in the particle size class less than 250 micron plus the liquid (flush) fraction.

Table 128. Comparison of washable solids[a] loadings and associated metals calculated for the sweeping/flushing studies at Sacramento, Milwaukee, and Efland.

Location	Date	Lane	Loading, lb/mi[b]							
			Ts	Pb	Zn	Fe	Cu	Cr	Cd	Ni
Sacramento	10/22/80	Distress	51.4	0.162	0.035	2.03	0.006	0.006	0.0004	0.005
		Median	40.7	0.268	0.040	2.06	0.010	0.006	0.0002	0.004
Milwaukee	6/17/80	Distress	432	1.97	0.425	25.9	0.178	0.039	0.004	0.034
		Median	616	3.10	0.617	42.1	0.290	0.040	0.005	0.047
Milwaukee	8/19-20/81	Distress	492	2.69	0.494	29.1	0.226	0.037	0.004	0.036
		Median	1470	7.07	1.40	77.1	0.582	0.098	0.007	0.101
Efland	9/26/81	Distress	243	0.458	0.153	7.37	0.025	0.008	0.001	0.006

[a] Washable fraction includes the dry fraction in the particle size class less than 250 micron plus the liquid (flush) fraction.

[b] One direction.

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

highway pavement was not a maintenance practice performed at the Harrisburg I-81 and Efland I-85 sites (rural, flush shoulder drainage design). Four studies were conducted at the Milwaukee I-94 site to determine commercial sweeper efficiency. To meet this objective, a 50-ft (15-m)-test section of the distress and/or median lanes was swept/flushed to determine the surface contaminant load present. A commercial sweeper then cleaned the distress and/or median lanes for the entire length of the site. After the commercial sweeping, a 50-ft (15-m)-test section adjacent to the test section used to determine surface contaminant load present was swept/flushed to recover residuals from the commercial sweepings. These samples were analyzed for selected pollutant parameters, and the data was used to calculate commercial sweeper efficiency for each parameter [(surface load present - residual load) divided by surface load present]. Results of these studies appear in Table 129.

The data show that generally all gross material (very large litter which can be picked up by hand) is removed by commercially sweeping the highway surface. Overall, the efficiency values obtained for summer (May) studies are higher than the values obtained for spring (April) studies. Presumably, the pickup efficiency by commercial sweepers during summer months is higher than spring months due to the lower surface load present during summer months. Also, the surface load in the distress and median lanes is more compacted in the spring than in summer due to spring thaw characteristics, i.e., surface material in the spring can be removed in sheets with a shovel. This compacted material (spring load) is more difficult to remove than the loose material present during summer months.

The commercial sweeper used for the April 17, 1979, study had a worn broom and was operating at half-vacuum power. To compensate for the low operating efficiency of the commercial sweeper, the test site was swept twice which is the normal WI DOT maintenance practice when a commercial sweeper is operating at less than 100 percent. The commercial sweeper used for the April 17, 1980, study had a newer broom and was operating at full vacuum power. The test site was swept once for this study. The data from these two studies indicate that the practice of double sweeping adequately compensates for the lower pickup efficiency of a commercial sweeper operating at less than 100 percent.

Efficiency of pickup by commercial sweepers was generally highest for solids and those constituents associated with solids including metals, calcium, sodium, oil and grease, TKN, PO_4-P, and rubber. Efficiency was lowest for the more soluble constituents including NO_2+NO_3, chloride, and sulfate. The commercial sweeper used by WI DOT utilized a misting system which wet the surface load which was then removed by a brushing action and vacuum. The sweeper cleaned an area approximately five feet (1.5-m)-wide from the curb or GM barrier. The data presented earlier in Tables 65 and 66 (distribution of surface load in distress and median lanes) showed that this area (1.5 m) contains the major portion of the total highway surface load (especially solids and associated constituents) at Milwaukee. These data

Table 129. Results of commercial sweeper efficiency study at Milwaukee I-94 site.

	April 17, 1979[a]		May 23, 1979[a]		April 17, 1980[b]		May 21, 1980[b]	
Parameter	Surface load, lb/mi	Commercial sweeper pickup efficiency, percent	Surface load, lb/mi	Commercial sweeper pickup efficiency, percent	Surface load, lb/mi	Commercial sweeper pickup efficiency, percent	Surface load, lb/mi	Commercial sweeper pickup efficiency, percent
Gross material[c]	687	100	359	100	1,520	100	149	79
Litter[d]	2,540	47	437	91	11,100	77	1,490	82
TS[e]	18,900	72	3,320	90	66,400	74	8,160	89
VTS	1,270	74	103	84	2,920	74	396	87
TOC	194	42	27.2	83	124	26	NA	--
COD	909	77	72.6	76	2,390	68	NA	--
Pb	50.7	75	9.24	87	2.93	86	58.7	91
Zn	15.1	76	2.47	86	96.1	86	14.0	91
Fe	903	70	227	90	4,290	84	966	91
Cr	0.894	72	0.139	50	4.78	76	1.47	87
Cu	4.74	78	0.717	83	36.1	80	3.59	85
Cd	0.088	67	0.012	92	0.426	77	0.202	96
Ni	1.33	74	0.198	90	4.83	85	0.902	89
As	0.010	50	0.001	100	NA	--	NA	--
Hg	0.0001	100	0.00005	100	0.0002	100	NA	--
NO_2+NO_3	0.061	49	0.036	56	0.110	65	0.088	18
TKN	11.4	71	0.927	80	27.6	74	4.14	66
PO_4-P	3.36	71	0.407	86	23.7	69	4.33	90
Ca	1,200	70	223	92	NA	--	NA	--
Na	17.4	74	2.27	81	110	63	NA	--
Cl	21.2	70	3.65	76	91.4	68	4.84	27
SO_4	NA	--	NA	--	168	48	NA	--
Oil & grease	230	80	20.3	87	622	61	41.0	91
Rubber	192	86	NA	--	NA	--	NA	--

[a] Median lane. [b] Distress and median lane.

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

[d] Litter is defined as particles larger than 3.35 mm (USA No. 6 sieve) not including gross material.

[e] Total solids data represents the fraction passing through USA Sieve no. 6 (below 3.35 mm).

NA = No analysis performed. Metric units: To convert lb/mi to kg/km multiply by 0.2819.

indicate why commercial sweeper pick-up efficiency at Milwaukee is high, especially for those pollutants associated with the solids fraction.

HIGHWAY SURFACE MASS BALANCE

Pollutants which accumulate on highway surfaces originate from highway use, maintenance, and ambient atmospheric deposition. Pollutants accumulate on the highway surface between major removal events, such as runoff and highway sweeping, when deposition exceeds removal rates. One of the objectives of this study is to quantify the deposition, accumulation, and removal processes, providing the necessary information to evaluate abatement and/or control measures for objectionable constituents.

To meet this objective and to facilitate interpretation of the data collected as part of the field monitoring effort and literature search, a mass balance for selected pollutants associated with the paved highway surface load was performed for two of the sites monitored: Milwaukee I-94 and Efland I-85. A mass balance was not feasible for Harrisburg because of the paved runoff hydraulics (groundwater seepage due to gravel sub-base and drain tile). At Sacramento, the long drought period and sand storms made the atmospheric deposition data impossible to assess for mass balance calculations. The mass balance includes the following three components:

1. Deposition - processes which contribute to highway surface load including deposition from vehicles, atmosphere, and highway maintenance activities.
2. Highway surface load - highway surface load which accumulates due to the above deposition processes.
3. Removal - processes which remove highway surface load including runoff, blowoff, and, where performed, highway sweeping.

Vehicle deposition is essentially a continuous process which contributes to the highway surface load through tire and pavement wear; exhaust emissions, clutch and brake lining wear; mud and dirt accumulated on the vehicle body, engine and undercarriage; wear from mechanical parts; oil and other fluid leaks; and rust and spilled loads such as sand, salt, gravel, grain, etc. Contaminants are also contributed on a continuous basis to the highway surface load through atmospheric deposition due to rainfall and dustfall. Intermittent contributions to the highway surface load include maintenance activities such as pavement repair, painting lane markers, deicing agent application, etc. The types and intensities of maintenance activities vary from area to area depending on climatological, topographical, traffic, and drainage system design considerations.

Paved surface runoff due to rain or melting snow is an intermittent process which removes accumulated highway surface pollutants. Contaminants are picked up from highway surface by the stormwater which is then collected by a sewer system (curb and gutter highway drainage design) or channeled through right-of-way areas (flush shoulder highway drainage design). Another process is atmospheric removal where pollutants are continually blown off the highway surface due to wind and vehicular turbulence. The final removal process considered in this mass balance is highway sweeping. As previously discussed, the efficiency of contaminant pickup by commercial sweepers is related to the quantity and quality of the surface load, and the type of sweeper used and its state of mechanical repair. Highway surface sweeping was performed extensively at the Milwaukee I-94 site (urban, curb and gutter drainage design), was performed once during the monitoring year at the Sacramento Hwy 50 site (urban, flush shoulder drainage design), and was not a maintenance practice performed at the Harrisburg I-81 and Efland I-85 sites (rural, flush shoulder drainage design).

Total solids was the first constituent for which a mass balance was attempted because in FHWA's original study on highway runoff constituents, the carrier pollutant in highway runoff was determined to be total solids (56). Carrier pollutant is that pollutant exhibiting the highest degree of association with all other pollutants. In fact, a predictive procedure (model) was developed as part of FHWA's original study for determining the runoff quantity and quality from highway systems, and this model used the carrier pollutant, total solids, to estimate the quantity of all other quality parameters. Total solids data from FHWA's original study was "end-of-the-pipe" wash-off data, and, before a mass balance could be calculated, the particle size class of the "end-of-the-pipe" total solids had to be defined. Wet sieve analysis of composite runoff samples from the Milwaukee, Sacramento, Harrisburg, and Efland sites show that 92 to 95, 99, 98.5, and 98 percent respectively of the total solids in runoff were less than 250 microns in size. For mass balance calculation, only dustfall data based upon elevated dust buckets [30 in (76.2 cm) above the ground] were used. The elevated buckets eliminate the inclusion of saltating particles, sand sized particles [less than 30 in (76.2 cm) in height] which bounce off the paved surface due to vehicular turbulence. Saltating particles are not considered part of the atmospheric dust emissions from a fugitive dust source (59). Under most conditions, dust sized particles are less than 250 microns. Particulate matter larger than 200 microns in diameter does not remain suspended for any significant period of time except with high windspeeds (greater than 20 mph) (59).

The solids constituent of the highway surface load includes the dissolved form and particulate form which varies over a wide particle size range including: gross material, the extremely large material such as tire fragments, hub caps, etc.; litter, solids (usually composed of loose gravel and glass) which are larger than 3350 microns but not including gross material; and total solids, particles whose sizes are less than 3350 microns. Gross material and litter were not used in mass balance calculations because the pollution potential, other than aesthetics, is generally very low for litter (Table 130) and is difficult to assess for gross material because of

Table 130. Percent of litter[a] and metals associated with litter to the total highway surface load.[b]

Parameter	Milwaukee 6/17/80	Milwaukee 8/21/81	Sacramento 10/22/80	Efland[c] 9/26/81
Litter[a]	17.49	15.13	24.81	40.06
Pb	0.28	0.27	0.03	1.14
Zn	0.57	0.50	0.60	16.01
Fe	0.35	0.01	3.55	22.84
Cu	0.43	0.30	2.63	28.00
Cr	1.56	1.78	1.43	4.00
Cd	6.36	5.74	1.71	7.14
Ni	2.19	1.87	2.50	24.76

[a] Solids greater than 3350 microns but not including gross material.
[b] Surface load includes total solids (particles less than 3350 microns) and litter (particles greater than 3350 microns but not including gross material).
[c] Distress lane only.

Table 131. Fraction of contaminants associated with the less than 250 micron particle size range (percent of total) (5).

Parameter	I-495[a]	Baltimore-Washington Parkway[b]
VTS	66.3	69.5
COD	68.1	70.8
Pb	67.7	58.9
Zn	72.9	59.1
Cr	60.0	60.6
Cu	56.2	84.7
TPO_4	74.5	69.2
NO_2	59.6	56.8
NO_3	74.5	69.8
TKN	54.9	32.3
Cl	51.7	71.7
Grease	69.4	69.7
Rubber	84.8	83.1

[a] Interstate route 495 is an expressway in the Washington, DC metropolitan area - average daily traffic is 109,000 axles/day in one direction.

[b] Baltimore-Washington Parkway is an expressway in the Washington, DC metropolitan area - average daily traffic is 73,000 axles/day in one direction.

the diversified nature of this component (Table 82). Also, the major mechanisms for the removal of highway surface pollutants, runoff and atmospheric removal, do not directly involve particles of the size found in litter and gross material (particles greater than 3350 microns).

Because the major mechanisms for the removal of highway surface pollutants, runoff and atmospheric removal, involve particles whose sizes are less than 250-microns, only the less than 250-micron particle size group of the highway surface load total solids was considered in mass balance calculations. Accordingly, the selected pollutant mass balances were calculated for the pollutants associated with the less than 250-micron particle size fraction. Data collected as part of this study and similar studies show that a large portion of the pollutants are associated with the less than 250-micron particle size group. Sartor et. al. state that between 40 to 90 percent of street surface pollutants are associated with particles less than 246-micron in diameter (58). The results of Shaheen's study (Table 131) also show that a large portion of pollutants from two highway systems are associated with the less than 250-micron particle size group (5). Pitt and Amy (60) fractionated street surface solids collected in four cities and analyzed for the metals associated with selected particle size ranges. Their results also show that a major portion of the metals (32 to 88 percent) are associated with the less than 246 micron particle size range.

Highway surface solids (litter plus total solids) collected at the Sacramento, Efland, and Milwaukee sites were fractionated in a sonic sieve and metals analyses were performed on the solids in each of the selected particle size classes (Table 132). Fractionation studies were not feasible at the Harrisburg site due to a lack of dry solids on the highway surface. The data show that approximately 21 to 55 percent of the total metals load at the Milwaukee site, 69 to 91 percent of the total metals load at the Sacramento site, and 27 to 54 percent of the total metals load at the Efland site are associated with the less than 250-micron particle size group.

Mass balance calculations were performed using total solids less than 250 microns because the total solids removed from the highway surface by the major removal mechanisms, runoff and atmospheric deposition, appear to be in this particle size group. For the remainder of this section, mass balance total solids will be referred to as "TS_{250}". Mass balances for selected constituent parameters such as metals, include only that fraction which is associated with TS_{250}, because only that fraction has the potential for removal from the highway surface through runoff and atmospheric removal processes. However, the fractionation studies discussed above show that the major portion of most constituents are associated with this particle size group. The results of attempting a mass balance for two of the sites monitored, Milwaukee and Efland, are described below.

Table 132. Percent of total solids less than 250 microns and associated metals to the total highway surface load.[a]

	Milwaukee		Sacramento	Efland
Parameter	6/17/80	8/21/81	10/22/80	9/26/81
TS[b]	24.52	31.57	49.05	25.22
Pb	45.43	54.75	71.21	48.11
Zn	39.32	56.65	90.52	47.81
Fe	20.54	24.56	69.14	26.50
Cu	49.84	49.00	86.00	46.30
Cr	31.91	34.26	83.36	33.33
Cd	40.91	44.26	90.29	53.85
Ni	25.31	36.63	79.75	40.00

[a] Surface load includes total solids (particles less than 3350 microns) and litter (particles greater than 3350 microns but not including gross material).

[b] Less than 250 microns.

Milwaukee I-94 Site

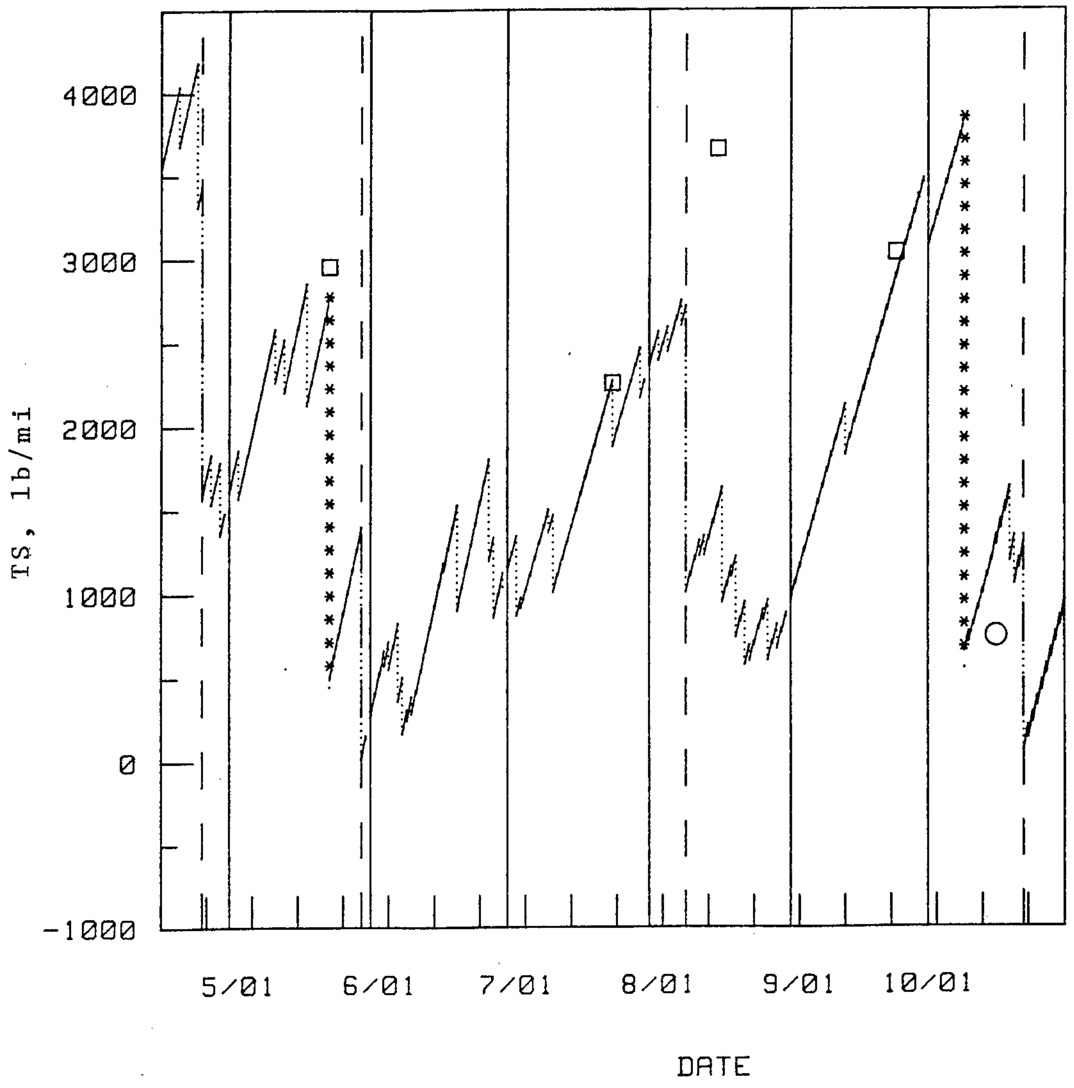
Climate in Milwaukee, Wisconsin is characterized by two distinct seasons; moderate summers and cold winters [average of 132 days of 32°F (0°C) or lower], with considerable snow accumulation [average annual snowfall of 46 inches (117 cm)]. Because seasonal characteristics affect many of the processes involved in the accumulation and removal of highway surface constituents, a mass balance was calculated for two periods: April 17 through October 31, 1979 (summer period), and November 1, 1979 through May 1, 1980 (winter-influenced period). These two consecutive periods covered a total of 401 days. TS_{250} and metals mass balances were developed for the summer period, while TS_{250}, sodium, and chloride mass balances were developed for the winter/spring period. A computer program was written to organize and evaluate the large volume of data required to develop each mass balance. A plotting routine was used in conjunction with the computer program for graphic display of the data.

The TS_{250} mass balance for the summer period, April 17 through October 31, 1979, is graphically displayed in Figure 37. The increasing slope on the graph represents the daily TS_{250} accumulation on the highway surface. The squares and circles represent the highway surface load for dates when the surface load was measured using sweeping/flushing techniques. Total solids loads (particles less than 3350 microns) monitored on those dates were adjusted to reflect TS_{250} loads based upon fractionation data for June 17, 1980 (squares), and for October 16, 1979 (circle). Vertical drops in the graph represent TS_{250} removal from the highway surface through runoff and maintenance as monitored throughout the period. TS_{250} removal through the maintenance practice of sweeping the highway surface is differentiated from runoff events using asterisks (*). All data corresponding to this graph can be found in Volume IV - Appendix.

The summer mass balance was started on April 17, 1979. On this date the highway surface was swept by the Wisconsin Department of Transportation (WI DOT) and the remaining surface load was determined to be 3530 lb/mi (995 kg/km) through sweeping/flushing techniques. This highway surface load was used as the initial load for the mass balance period (Figure 37) because it represents an experimentally known point and because the majority of the winter-influenced load was removed [sweeper removed 22,650 lb/mi (6,435 kg/km) of TS_{250}].

The increasing slope on the graph (Figure 37) represents the daily TS_{250} accumulation on the highway surface which is the difference between continuous deposition from vehicular and atmospheric sources and continuous removal through atmospheric processes (blowoff due to wind and vehicular turbulence). The daily TS_{250} accumulation rate (lb/mi/day) was developed by quantifying the following two components:

1. Daily accumulation rate based on runoff data.
2. Daily accumulation rate based on atmospheric data.



Legend

* TS_{250} removal by sweeping.

□ Monitored TS_{250} highway surface load - fractionation data from June 17, 1980.

○ Monitored TS_{250} highway surface load - fractionation data from October 16, 1979.

Large vertical dashed lines denote events with rainfall ≥ 1.0 in.

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

Figure 37. TS_{250} mass balance model for the Milwaukee I-94 site - April 17 through October 31, 1979.

The K_1 factor, accumulation rate based on runoff, for the Milwaukee I-94 site was developed using the technique described in "Predictive Procedures for Determining Pollutant Characteristics in Highway Runoff" (56). The technique calculates K_1 by summing all total solids removed by runoff (monitored and estimated values) between two large storm events which remove essentially all of the surface total solids available for wash-off. A large storm event is defined as an event with greater than 1 in (2.54 cm) of total rainfall and having at least 1 hour in which the average intensity is 0.5 in/m (1.27 cm/hr). Because the large storm events at the beginning and end of the period washoff essentially all of the available surface total solids, the sum of the total solids removed by runoff between these events and the event ending the period should account for all the total solids (TS_{250}) accumulated during this period except those lost through atmospheric processes. The K_1 accumulation rate [lb/mi/day (kg/km/day)] is the sum of the total solids divided by both the length of the specified highway section and the number of days between the two large storm events.

Two periods were used for K_1 development, April 17 to May 30, 1979 (43 days), and May 31 to August 9, 1979 (71 days). For the April 17 to May 30, 1979, period a modification to the technique described in "Predictive Procedures for Determining Pollutant Characteristics in Highway Runoff" (56) had to be used because some of the winter accumulated load was still present during this time [3530 lb/mi (995 kg/km) remained after highway sweeping by WI DOT on April 17, 1979]. On April 25, 1979, 1.30 in (3.30 cm) of rain fell on the monitoring site and the largest 1-hour intensity was 0.24 in per hour (0.61 cm/hr). The 1-hour intensity for this storm does not meet the criteria for a large storm event and this storm event could not be used in K_1 development. On May 30, 1979, 1.09 in (2.77 cm) of rain fell and the largest 1-hour intensity was 0.45 in per hour (1.14 cm/hr). Although the 1-hour intensity for this storm was slightly less than the criteria for a large storm event, the majority of the highway surface TS_{250} was probably removed because on May 23, 1979, WI DOT swept the highway surface and removed 2462 lb/mi (694 kg/km) of TS_{250}. Assuming the storm on May 30, 1979, removed essentially all of the TS_{250} surface load and knowing that the TS_{250} load on April 17, 1979, was 3530 lb/mi (995 kg/km), the accumulation rate, K_1 factor, could be determined for this period by summing the TS_{250} removed through runoff and the May 23, 1979, highway surface sweeping and subtracting from this total the TS_{250} surface load on April 17, 1979. During the 43 day period between April 17 through May 30, 1979, continuous runoff quantity records were maintained, and total solids quality monitored events accounted for 95 percent of the total runoff volume. To account for the total solids removed by unmonitored runoff, the total solids load from monitored events with similar total runoff and runoff duration were used for unmonitored events. K_1 was calculated for the period as follows:

6183 lb/mi TS_{250} - monitored runoff events (Volume IV - Appendix)
349 lb/mi TS_{250} - estimate for unmonitored runoff events
+2462 lb/mi TS_{250} - commercial sweeper removal on May 23, 1979
=8994 lb/mi TS_{250} - removed during period
-3530 lb/mi TS_{250} - initial load on April 17, 1979
=5464 lb/mi TS_{250} - accumulated load during period

5464 lb/mi TS_{250} (accumulated load) divided by 43 days (period duration) = 127 lb/mi/day (35.8 kg/km/day) daily accumulation rate, K_1 factor.

The second period for K development was May 31 to August 9, 1979 (71 days). On August 9, 1979, 1.44 in (3.667 cm) of rain fell on the monitoring site and the largest 1-hour intensity was 1.29 in/m (3.28 cm/hr). During the 71 day period between May 31 to August 9, 1979, continuous runoff quantity records were also maintained, and total solids quality monitored events accounted for 95 percent of the total runoff volume. Removal of TS_{250} from the paved highway surface during this period was monitored to be 6402 lb/mi (1805 kg/km) (Volume IV - Appendix). To account for the TS_{250} removed by unmonitored runoff, the total solids load from monitored events with similar total runoff and runoff durations were used for unmonitored events. Total solids estimated for unmonitored events was 433 lb/mi (122 kg/km). The K_1 factor for this period, 95 lb/mi/day (27 kg/km/day), was calculated by summing monitored and estimated total solids [6835 lb/mi (1927 kg/km)] and dividing by the days in the period (71 days).

Results from FHWA's original study on highway runoff constituents (56) showed that the accumulation rate (K_1 factor) was highly correlated to average daily traffic (ADT). K_1 for the spring period (April 17 to May 30, 1979) was 127 lb/mi/day (35.8 kg/km/day6) which is 31 lb/mi/day (8.7 kg/km/day) higher than the K_1 for the summer period (May 31 to August 9, 1979), 96 lb/mi/day (27 kg/km/day). ADT during the spring period was 120,300 vehicles per day while the ADT for the summer period was 118,000 vehicles per day. Monthly ADT for the monitoring period are presented in Table 133. For the mass balance, the K_1 of 127 lb/mi/day (35.8 kg/km/day) was used for April through June, months with high ADT, while the K_1 of 96 lb/mi/day (27 kg/km/day) was used for July through October, months with low ADT.

The developed accumulation rates (K_1 factors) were applied to the predictive model (an end-of-pipe model) developed during FHWA's Phase I study (56) to determine how well predicted pollutant loadings compared to monitored pollutant loadings. Table 134 compares predicted and monitored total solids loads and associated pollutants for the period August 17 through October 31, 1979. The K_1 of 127 lb/mi/day (35.8 kg/km/day) was used for April 17 through June and 96 lb/mi/day (27 kg/km/day) was used for July through October. The predictive procedure was set up to account for TS_{250} removed through commercial sweeping of the highway surface by WI DOT. Predicted and monitored values for TS_{250} and associated pollutants appearing in Table 134 represent only those pollutants removed by runoff.

Predicted and monitored total solids loads were similar, the predicted loading being only 7.7 percent higher than the monitored loading. The comparativeness of predicted and monitored total solids indicates that the developed K_1's provided reasonable estimates of total solids accumulations. Predicted and monitored loads for most pollutant parameters were also comparable. Notable exceptions are the parameters for volatile suspended solids (55.9 percent overpredicted), lead (146.7 percent overpredicted),

Table 133. Monthly average daily traffic at the Milwaukee I-94 site during the study performance period.

Month	Average daily traffic, vehicles/day[a]
1978	
August	124,138
September	123,583
October	116,510
November	117,808
December	110,897
1979	
January	100,119
February	116,434
March	120,670
April	118,389
May	120,154
June	123,771
July	115,439
August	116,996
September	103,304
October	114,929
November	114,546
December	109,619
1980	
January	109,267
February	112,507
March	114,636
April	117,411
May	118,154
June	118,752
Average	115,567

[a] Both directions.

Table 134. Monitored and predicted[a] pollutant loadings for the Milwaukee I-94 site - April through October, 1979.

Parameter	Monitored, lb	Predicted, lb
TS	4390	4730
SS	1960	2340
VTS	890	983
VSS	358	558
TOC	250	177
COD	850	685
Pb	6.36	15.7
Zn	3.58	2.78
Fe	48.5	57.7
Cr	0.100	0.493
Cu	1.27	0.860
Cd	0.094	0.373
NO_2+NO_3	6.39	6.48
TKN	28.0	12.8
TPO_4	3.03	2.51
Cl	312	222

[a] Predicted values (56) were obtained using a K_1 of 127 lb/mi/day (35.8 kg/km/day) for August 17 through June 30, 1979, and 96 lb/mi/day (27 kg/km/day) for July 1 through October 31, 1979.

Metric units: To convert lb to kg multiply by 0.454.

chromium (393.0 percent overpredicted), cadmium (296.8 percent overpredicted) and TKN (54.3 percent overpredicted). Many chromium and cadmium concentrations for monitored runoff events were not detectable. Monitored events were considered to have zero loadings when concentrations were not detectable. However, regression equations in the predictive procedure would estimate concentration values below the detection limits for these events. In many cases, these small predicted chromium and cadmium concentrations were applied to relatively large total solids loadings, producing a predicted loading value for events where monitored loadings were considered zero. This probably accounts for the overprediction of chromium and cadmium as compared to monitored data. The predicted lead loading was approximately 2.5 times higher than the monitored loading. Regression equations incorporated into the predictive model (56) which estimate lead loadings from total solids loadings are based on data collected in 1976-77. The shift from leaded to unleaded fuels may account for some of the overprediction. Table 135 presents data for leaded and unleaded gasoline sales for the State of Wisconsin during the period 1975-1980. The data show a decrease in leaded gas sales of approximately 22 percent from 1976-77 to 1979. Gas sales data specific to the Milwaukee area, which would have provided better data relative to I-94, was unavailable. However, yearly traffic data for the I-94 site and annual gasoline sales for Wisconsin appear to be highly correlated (Table 135).

The developed K_1 factors account for the accumulated load as detected by washoff data but do not reflect the accumulated load which was lost through atmospheric processes. Atmospheric deposition of TS_{250} to the highway surface for the period April 17 through October 31, 1979, was calculated from the bulk precipitation data (dustfall plus rainfall) collected at the background monitoring station. The TS_{250} load removed from the highway surface through the atmosphere by blowoff due to wind and vehicular turbulence during this period was calculated from the bulk precipitation data collected in the area adjacent to the highway. The difference between monitored atmospheric deposition and removal represents that part of the total accumulated load which is not accounted for by the K_1 factors. The total daily TS_{250} accumulation rate was obtained by adding the difference to the appropriate K_1 factor (Volume IV - Appendix).

The mass balance model graphically displayed in Figure 37 incorporates all atmospheric, runoff, surface load, and maintenance TS_{250} data collected during the period April 17 through October 31, 1979, at the Milwaukee I-94 site.

The graph shows that the individually monitored components fit well into the overall mass balance. The May 23, July 24, and September 25, 1979, monitored surface loads were on or close to the deposition/removal line. The August 16, 1979, monitored load is high due to the oil dry compound which was applied to an accidental oil spill on August 10, 1979. The oil dry particles were in the 841 to 3350 micron range. For this reason, when the TS_{250}/TS_{250} ratio developed from the June 17, 1980, data was applied to the total solids load monitored on August 16, 1979, the result was an overprediction of TS_{250}. The October 16, 1979, monitored TS_{250} highway surface load was low compared to

Table 135. Comparison of leaded and unleaded gasoline sales for Wisconsin and yearly traffic at the Milwaukee I-94 site during the period 1975-1980.

Year	Total gasoline sales[a], gal x 10^6	Leaded gasoline[b], gal x 10^6	Unleaded gasoline[b], gal x 10^6	I-94 traffic, vehicles/year
1980	2,149	1,261	888	42,897,000
1979	2,326	1,442	884	42,066,000
1978	2,401	1,683	718	44,088,000
1977	2,319	1,742	577	42,933,000
1976	2,243	1,828	415	38,362,000
1975	2,150	1,909	241	40,151,000

[a] Data obtained from the State of Wisconsin Revenue Department - Motor Fuel Division.

[b] Leaded to unleaded gasoline sales ratios for Wisconsin obtained from "Yearly Report of Gasoline Sales by State," prepared and published by the Ethyl Corporation; 1979 ratio estimated from Clark Oil and Refining Corporation data.

Metric units: To convert gal to ℓ multiply by 3.785.

that indicated by the deposition/removal line. The ability of rainfall events larger than 1 in (2.54 cm) (vertical dashed lines) to remove large quantities of TS_{250} from the highway surface is shown on the graph. The effectiveness of sweeping the highway surface to remove TS_{250} is also evident. The mass balance indicates that the surface load peaked on April 24, 1979 [4,188 lb/mi (1,181 kg/km)], and again on October 9, 1979 [3,852 lb/mi (1,086 kg/km)], and that the highway surface was relatively clean on May 30, 1979, and October 22, 1979. Both of these low surface load points on the mass balance graph were preceded by maintenance sweeping of the highway and a rainfall event greater than 1 in (2.54 cm). The data represented by the mass balance graph (Figure 37) are summarized in Figure 38. The data displayed in Figure 38 are divided into three mass balance components: deposition processes, highway surface load, and removal processes.

Atmospheric deposition of TS_{250} to the highway surface for the period April 17 through October 31, 1979, was obtained from the bulk precipitation data (dustfall plus rainfall) collected at the background monitoring station. The loadings monitored by the dustfall buckets (mg/bucket) at the background station were converted to reflect deposition on the highway surface [lb/mi (kg/km)]. Total atmospheric deposition of TS_{250} for this period was 3668 lb/mi (1034 kg/km) of highway surface (Figure 38).

A continuous rainfall quantity record was maintained throughout the study. However, rainfall quality was monitored for selected events. Therefore, TS_{250} deposition due to rainfall alone was estimated using two techniques. The first method used data from quality monitored rainfall events and estimated values for the unmonitored events from regression analysis of the monitored data. Fourteen data points from monitored rainfall events were used to develop a polynomial regression equation from which a TS_{250} loading, lb/site area, could be estimated from total rainfall volume for unmonitored events. The developed polynomial regression equation is as follows:

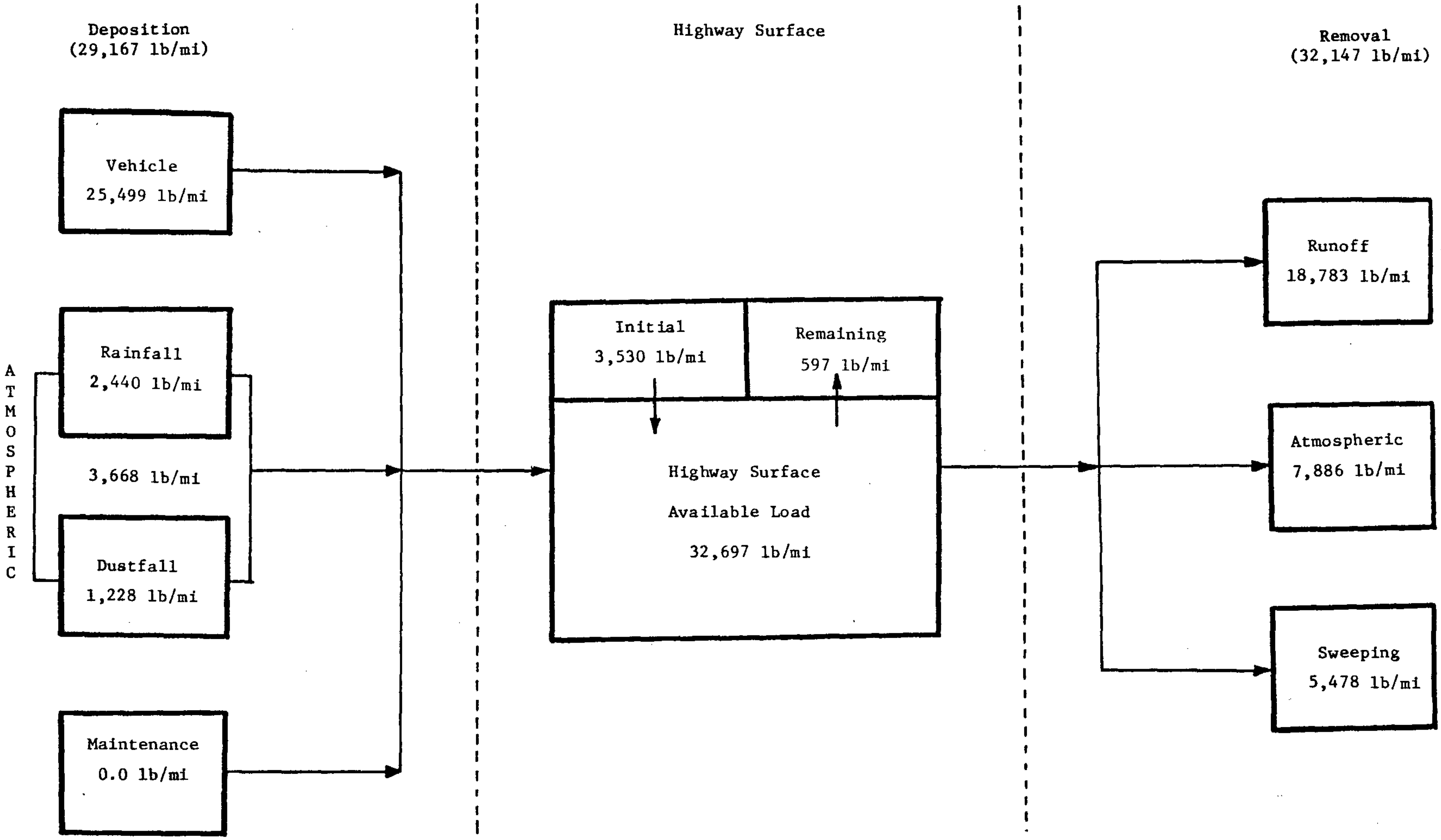
$$TS_{250} = 0.0052 + (155.7 * R) - (385.8 * R^2) + (487.5 * R^3) - (332.3 * R^4) + (116.2 * R^5) - (16.3 * R^6).$$

Where:

TS_{250} = lb (kg) of TS_{250} deposited on the paved highway surface of the site [4.9 ac (1.98 ha)].

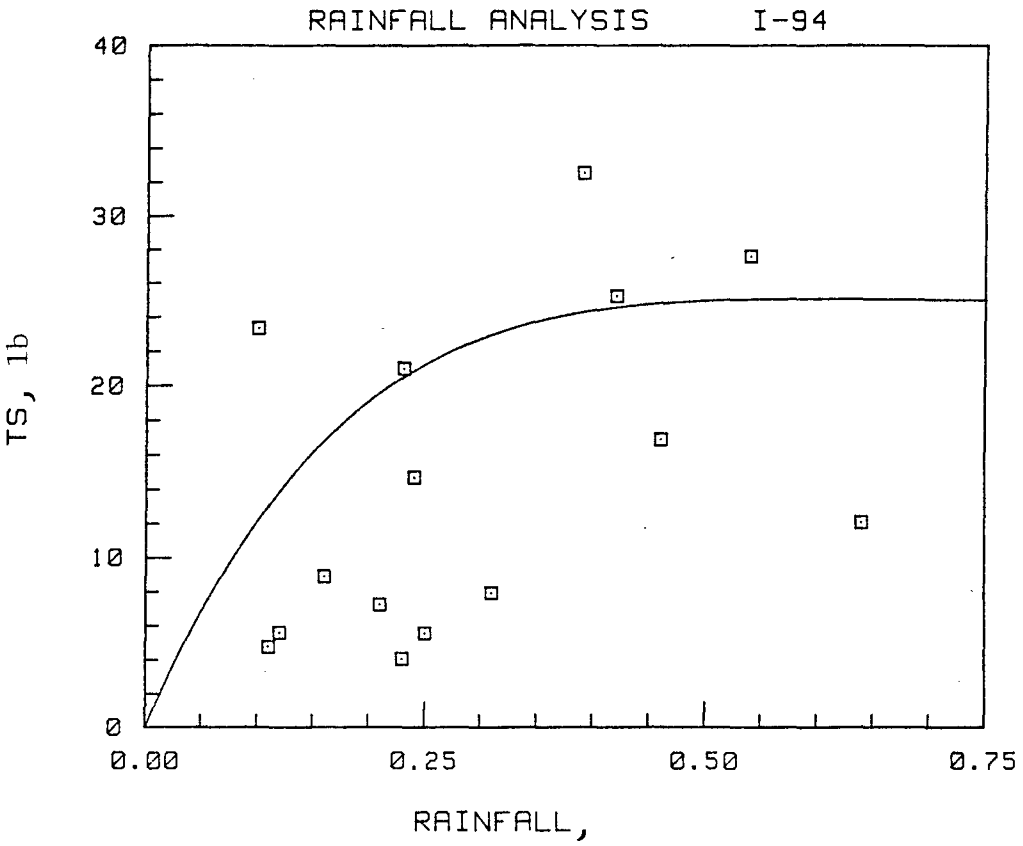
R = rainfall volume [in (cm)].

Figure 39 shows the monitored rainfall quality data points and the developed regression line. This plot indicates that as rainfall volume increases, TS_{250} loadings increase asymtotically to 0.47 in. (1.19 cm) of rainfall to a maximum TS_{250} loading of approximately 25 lb/site area (11 kg/site area). Therefore, the maximum estimated loading for any unmonitored event was 25 lb/site area (11 kg/site area). Using the monitored TS_{250} loadings and those values estimated from the polynomial equation, the TS_{250} loading for the period April 17 through October 31, 1979, was calculated to be 3075 lb/mi (867 kg/km). However, comparison of monitored values to predicted values indicated an overestimate of 34 percent.



Metric units: To convert lb/mi to kg/km multiply by 0.2819

Figure 38. TS_{250} mass balance for the Milwaukee I-94 site - April 17 through October 31, 1979.



Metric units: To convert lb to kg multiply by 0.454.
To convert in to cm multiply by 2.54.

Figure 39. Scatterplot of rainfall volume and total solids loading with developed regression line.

The second method of calculating TS_{250} deposition due to rainfall used data from quality monitored rainfall events and estimated values for the unmonitored event. TS_{250} values for the unmonitored events were obtained by allowing the computer to select the loading value from the quality monitored events which best fit the rainfall volume for the unmonitored event. Using this method, the TS_{250} loading for the period April 17 through October 31, 1979, was calculated to be 2440 lb/mi (688 kg/km). This estimate is 21 percent lower than the estimate obtained from the first method. Based upon the analysis of predicted and monitored values for the first method, the loading value obtained by the second method, 2240 lb/mi (688 kg/km), appears to be the better estimate and was used in the mass balance (Figure 38). Once the loading due to rainfall was calculated, the contribution of atmospheric deposition from dustfall alone was calculated by subtracting the rainfall loading, 2440 lb/mi (688 kg/km) from the total atmospheric load, 3668 lb/mi (1034 kg/km), to obtain a TS_{250} dustfall loading of 1228 lb/mi (346 kg/km) (Figure 30).

During the period April 17 through October 31, 1979, monthly records received from the Wisconsin Department of Transportation revealed no maintenance activities, accidents, or construction which might have contributed to the TS_{250} highway surface load. One accident did occur during this period on August 19, 1979, in which a semi-tractor overturned spilling diesel fuel onto the section of highway monitored for this study. Five hundred pounds (227 kg) of oil dry was applied from the highway surface and essentially all of the oil dry particles were in the 841 to 3350 micron range. Therefore, deposition of TS_{250} due to maintenance during this period was 0.0 lb/mi (0.0 kg/km) (Figure 38).

Direct measurement of vehicular deposition was not within the scope of this study. The value for vehicular deposition of TS_{250}, 25,499 lb/mi (7188 kg/km) (Figure 38), was obtained by subtracting the load due to maintenance plus atmospheric deposition from the accumulated load (available load minus initial load). The average daily traffic (ADT) monitored during the period April 17 through October 31, 1979, was 116,323 vehicles per day. Using this ADT, the average vehicular deposition rate was calculated to be 0.0011 lb/mi/vehicle (0.31 g/km/vehicle). Vehicular deposition of TS_{250} would include the processes of tire and pavement wear; exhaust emissions; clutch and brake lining wear; mud, dirt, and rust from the vehicle body, engine, and under-carriage; wear from mechanical parts; and oil and other fluid leaks.

Dannis (36) has reported that tire wear rate at highway driving speeds of 75 mph (120 km/hr) is 0.096 g/km/vehicle (passenger car) and that those particles were in the size range of 5 to 100 microns. Pierson and Brachaczek (61) reported that of the material worn from tires, 5 percent is airborne particulate matter and 95 percent is non-suspendable, indicating that the majority of the tire wear rate reported by Dannis (36), 0.096 g/km/vehicle, is probably deposited directly on the highway surface. Highway driving speeds at the Milwaukee site are probably closer to 55-60 mph (88-99 km/hr). Therefore, deposition from tire wear at Milwaukee is probably somewhat lower than 0.096 g/km/vehicle because tire wear decreases with speed (62). Loadings to street surfaces from vehicle related deposition processes were identified through a literature search performed by PEDCO (13). Of the vehicle related deposition processes contributing to street surface loadings, approximately 37 percent was attributed to tire wear, 37 percent to pavement wear, 18.5 percent to brake and engine component wear, and 7.5 percent to settleable exhaust (13).

An order of magnitude estimate for total vehicular deposition, 0.26 g/km/vehicle, can be obtained by multiplying Dannis' value for tire wear (36), 0.096 g/km/vehicle, by the ratio of tire wear to total vehicular deposition, 2.7, developed from the values reported by PEDCO (13). Other order of magnitude estimates can be calculated from other values reported in the literature. Pierson and Brachaczek (61) reported that the rate of tire wear in the United States is 600,000 metric tons/yr, while exhaust particles from gas powered vehicles are estimated at 270,000 metric tons/yr. Assuming 90 million cars on the road in the United States (1970) and assuming each car is driven about 14,000 mi/yr [22,500 km/yr)] (36), rates of deposition can be calculated from Pierson and Brachaczek's (61) values for total tire wear and exhausted particulates, 0.30 g/km/vehicle for tire wear and 0.13 g/km/vehicle for exhausted particulates. These values represent both city and highway driving, and would, therefore, represent higher deposition rates than highway driving alone because deposition due to city driving which is characterized by "stop and go" driving (36), cold cycle operation (13), cornering (36), etc., is higher than highway driving. However, the above literature values indicate that the vehicular deposition rate, calculated from the mass balance load (Figure 37) and average daily traffic for the Milwaukee site, is within the correct order of magnitude. The data (Figure 38) also show that the largest source of TS_{250} deposition is vehicle related.

As previously discussed, the summer mass balance was started on April 17, 1979. On this date, the highway surface was swept by WI DOT and the remaining TS_{250} load was determined to be 3530 lb/mi (1003 kg/km). This highway surface load was used as the initial TS_{250} load for the mass balance period (Figure 38). The available highway surface load for the period was calculated to be 32,697 lb/mi (9,217 kg/km) using the accumulation rates based on runoff and atmospheric data. The mass balance model indicated that 597 lb/mi (168 kg/km) TS_{250} remained on the highway surface at the end of the mass balance period.

The data (Figure 38) show that the major portion of the TS_{250} highway surface load was removed by runoff, 18,783 lb/mi (5,295 kg/km). Atmospheric removal by blowoff due to wind and vehicular turbulence was 7886 lb/mi (2223 kg/km), while the maintenance practice of sweeping the highway surface removed 5478 lb/mi (1544 kg/km).

A mass balance sheet for TS_{250} and associated metals (April 17 through October 31, 1979) is presented in Table 136. The data show that for the TS_{250} mass balance a negative 47 lb/mi (13.2 kg/km) was unaccounted for, i.e., that more TS_{250} was removed than was available during the mass balance period. However, the error associated with the TS_{250} mass balance was only 0.1 percent.

Table 136. Mass balance for TS_{250} and associated metals - April 17 through October 31, 1979, at the Milwaukee I-94 site.

Balance component	Balance symbol	Parameter, lb/mi[a]							
		TS_{250}	Pb	Zn	Fe	Cr	Cu	Cd	Ni
Initial load	+	3,530	17.4	3.76	235	0.450	1.64	0.032	2.91
Deposition									
Vehicle	+	25,499	62.5		1079	1.53		0.125	8.09
Rainfall	+	2,440	0.0		4.16	0.0		0.0	0.0
Dustfall	+	1,228	0.012		2.88	0.039		0.0005	0.00003
Maintenance	+	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Highway surface load	=	32,697	79.9	49.2	1321	2.02	12.4	0.158	11.0
Removal									
Runoff	-	18,783	37.8	27.2	280	1.12	8.63	0.110	4.81
Atmospheric	-	7,886	0.038		660	0.003		0.006	2.29
Sweeping	-	5,478	35.3	3.96	362	0.854	3.27	0.040	3.46
Remaining load	-	597	6.37	2.67	20.0	0.031	0.460	0.002	0.394
Surface load unaccounted for	=	-47	+0.392		-1.00	0.012		0.0	0.046
Percent error		0.1	0.5		0.1	0.6		0.0	0.4

[a] Both directions.

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

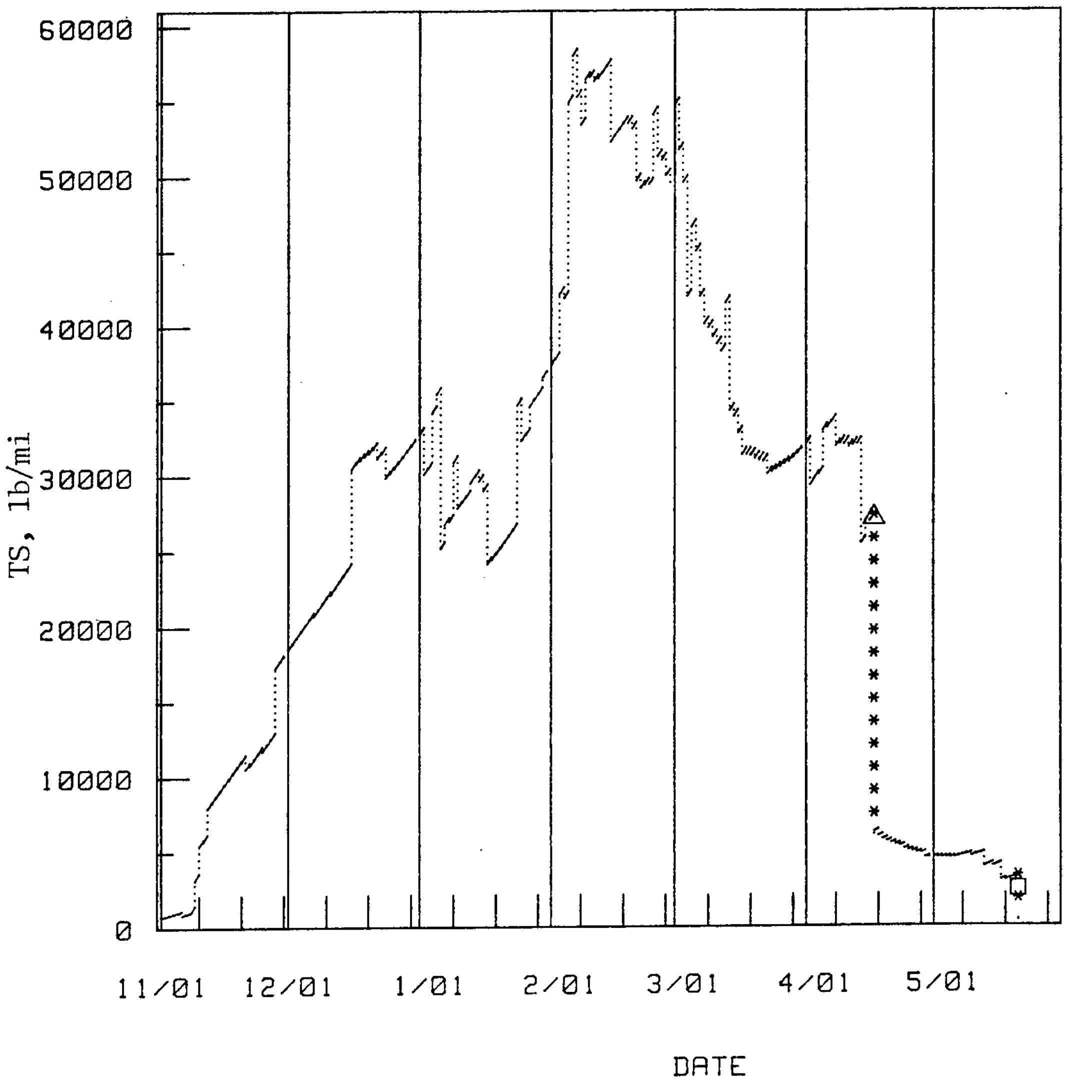
Complete mass balance calculations were performed for Pb, Fe, Cr, Cd, and Ni (Table 136). Atmospheric deposition and removal could not be calculated for Zn and Cu, but data for the other mass balance components were calculated for these two parameters (Table 136). Copper analyses on bulk precipitation samples were not possible because copper sulfate was added to the distilled water in dustfall buckets to eliminate algal growth which would have caused elevated solids values. Zinc interference from the filter pad stock used to filter bulk precipitation samples for the Milwaukee I-94 site was high and extremely variable. Background interference ran as high as 80 percent of the total zinc value. The accuracy of the zinc data corrected for the interference could not be evaluated and the data was therefore not used.

The lead mass balance show that 99.98 percent of the lead deposition, 62.5 lb/mi (17.6 kg/km), was attributable to vehicular sources. The remaining 0.02 percent was due to atmospheric deposition. The data also show that 51.68 percent of the lead was removed by runoff, 48.26 percent by maintenance activities (sweeping), and 0.05 percent through atmospheric processes. The percent error of the lead mass balance was 0.5 percent. The parameters chromium and cadmium followed the same general pattern displayed by lead.

The iron mass balance shows that 99.35 percent of the iron deposition was attributable to vehicular sources. The iron deposition pattern was similar to lead. However, the removal pattern of iron from the highway system was dramatically different than the pattern observed by lead. The data show that 21.50 percent of the iron was removed by runoff, 50.69 percent by atmospheric processes, and 27.80 percent by sweeping. The nickel data also show that a large portion, 21.69 percent, of the nickel is removed through atmospheric processes.

The TS_{250} mass balance for the winter/spring period, November 1, 1979, through May 21, 1980, is graphically displayed in Figure 40. The increasing slope on the graph represents the daily TS_{250} accumulation on the highway surface. Sharp vertical increases in slope represent the application of deicing agents to the road surface. The square and triangle represent the highway surface load for dates when surface load was measured using sweeping/flushing techniques. Total solids loads (particles less than 3350 microns) monitored on those dates were adjusted to reflect TS_{250} loads based upon fractionation data for June 17, 1980 (squares), and for April 17, 1980 (triangle). Vertical drops in the graph represent TS_{250} removal from the highway surface through runoff, baseflow, and maintenance as monitored throughout the period. TS_{250} removal through the maintenance practice of sweeping the highway surface is differentiated from runoff events and baseflow by asterisks (*). All data corresponding to the graph can be found in Volume IV - Appendix.

The winter-influenced mass balance was started on November 1, 1979. The remaining TS_{250} load for the summer mass balance (ending October 31, 1979), 597 lb/mi (168 kg/km) (Table 136) was used as the initial load for the winter/spring mass balance (starting November 1, 1979) (Figure 85).



Legend

* TS_{250} removal by sweeping.

▲ Monitored TS_{250} highway surface load - fractionation data from April 17, 1980.

☐ Monitored TS_{250} highway surface load - fractionation data from June 17, 1980.

Figure 40. TS_{250} mass balance model for the Milwaukee I-94 site - November 1, 1979, through May 21, 1980.

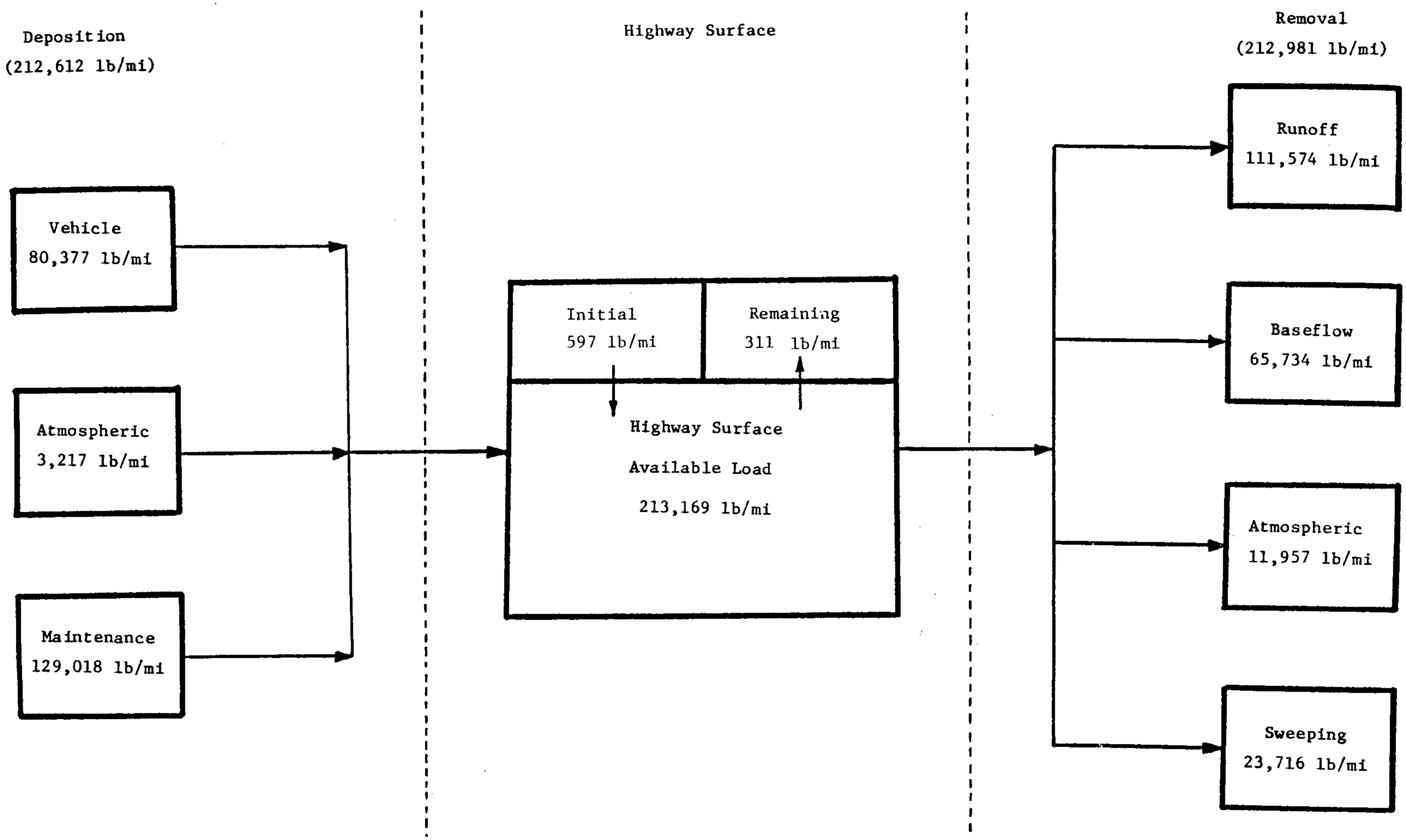
Three K_1 factors were used to develop the daily TS_{250} accumulation rates. For the period November 1 to 8, 1979, a K_1 factor of 96 lb/mi/day (27 kg/km/day) was used. This is the same K_1 used for the July through October period of the summer mass balance. On November 9, 1979, the first deicing agents were applied to the highway surface, marking the beginning of the winter-influenced surface load. The highway surface was swept by WI DOT on April 17, 1980, marking the end of the winter-influenced surface load. A K_1 factor which characterized this period, November 9, 1979, to April 17, 1980, was developed by balancing the inputs to the highway system due to deicing agent application with the outputs from the highway system due to runoff and baseflow. The K1 factor for this period was calculated to be 410 lb/mi/day (116 kg/km/day). For the period April 18 to May 21, 1980, a K_1 factor of 127 lb/mi/day (35.8 kg/km/day) was used. This is the same K_1 used for the April through June period of the summer mass balance.

Again, the developed K_1 factors do not reflect the accumulated load which was lost through atmospheric processes. As previously discussed, bulk precipitation was not monitored throughout the winter period at the Milwaukee I-94 site. Atmospheric deposition to and removal from the highway surface for the period November 1, 1979, to April, 1980, was based upon data collected during November, 1979. The difference between atmospheric deposition and removal represents that part of the total accumulated load which is not accounted for by the K_1 factors. The total daily TS_{250} accumulation rate was obtained by adding this difference to the appropriate K_1 factor (Volume IV - Appendix).

The data displayed on Figure 40 indicate that the winter surface load peaked on February 7, 1980, at 58,068 lb/mi (16,369 kg/km). The peak winter surface load was over an order of magnitude higher than the peak summer load, 4,188 lb/mi (1,189 kg/km). The effectiveness of sweeping the highway surface in spring is also apparent. The data represented by the mass balance graph (Figure 32) are summarized in Figure 41. The data displayed in Figure 41 are divided into the three mass balance components: deposition processes, highway surface load, and removal processes.

Data for the deposition processes (Figure 41) indicate that the largest source of TS_{250} to the highway surface during the winter period was maintenance related. Monthly records received from WI DOT showed that 129,018 lb/mi (36,360 kg/km) of deicing agents were applied. WI DOT estimated the quantity of material applied by prorating the spreader rate for the distance and the number of lanes covered. Deicing agents applied to the Milwaukee I-94 site during the 1979-80 winter included sodium chloride and liquid calcium chloride. The liquid calcium chloride is sprayed directly on the solid salt just prior to spreading on the roadway surface. Because of the soluble nature of these deicing agents, they were considered as TS_{250}.

The data (Figure 41) also indicate that the second largest source of TS_{250} to the highway surface during the winter period was vehicle related, 80,377 lb/mi (22,658 kg/km). The average daily traffic (ADT) monitored during the



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

Figure 41. TS_{250} mass balance for the Milwaukee I-94 site, November 1, 1979, through May 21, 1980.

period November 1, 1979, through May 21, 1980, was 114,389 vehicles per day. Using this ADT, the average winter vehicular deposition rate was calculated to be 0.035 lb/mi/vehicle (9.93 g/km/vehicle). The winter vehicular deposition rate was higher than the summer vehicular deposition rate of 0.0011 lb/mi/vehicle (0.31 g/km/vehicle). The higher winter vehicular deposition rate is probably due to increased exhaust emissions from stop-and-go driving during hazardous driving conditions, increased autobody rusting from caustic deicing agents, and "carry on" deposition.

Data for the removal processes (Figure 41) indicate that runoff and baseflow removed the largest quantity of the TS_{250} surface load. Runoff removed 111,574 lb/mi (31,453 kg/km) of TS_{250} while baseflow removed 65,734 lb/mi (18,530 kg/km). The two processes combined accounted for 83 percent of the TS_{250} removal. Runoff and baseflow are probably the major removal mechanisms during the winter period because a large portion (approximately 61 percent) of the surface load consists of the highly soluble deicing agents. TS_{250} removed by runoff was calculated from quantity and quality data collected throughout the period monitored. Baseflow quantity was monitored throughout the winter period as was specific conductivity. Continuous specific conductivity was recorded on a Beckman conductivity meter strip chart. Grab samples were obtained weekly and analyzed for total solids. During the winter period, total solids consist mostly of dissolved solids. Because of this fact, regression analyses were performed to determine the relationship between total solids (mg/l) and specific conductance (micro-mhos/cm at 25°C). A scatter plot of the total solids and conductivity data and the resulting best fit line appear in Figure 42. The data in Figure 42 indicate that a strong relationship exists between winter total solids concentrations and conductivity. Regression analyses indicate that 95.4 percent (R^2 value) of the variance in winter total solids concentrations can be explained by conductivity. Baseflow total solids for the winter period were calculated using continuous flow data, continuous conductivity measurements, and the developed regression equation. Total solids concentrations were calculated using the following equation:

$$\text{Total solids concentration (mg/l)} = 0.9082 \text{ specific conductance (micro-mhos/cm at 25°C)} - 1858.$$

The data presented on Figure 41 also show that atmospheric processes removed 11,957 lb/mi (3371 kg/km), while the maintenance practice of sweeping the highway surface removed 23,716 lb/mi (6686 kg/km).

A mass balance sheet for TS_{250}, sodium, and chloride (November 1, 1979, through May 21, 1980) is presented in Table 137. The data show that for the TS_{250} mass balance a negative 83 lb/mi (23.4 kg/km) was unaccounted for, i.e., that more TS_{250} was removed than was available during the mass balance period. The error associated with TS_{250} mass balance was 0.03 percent.

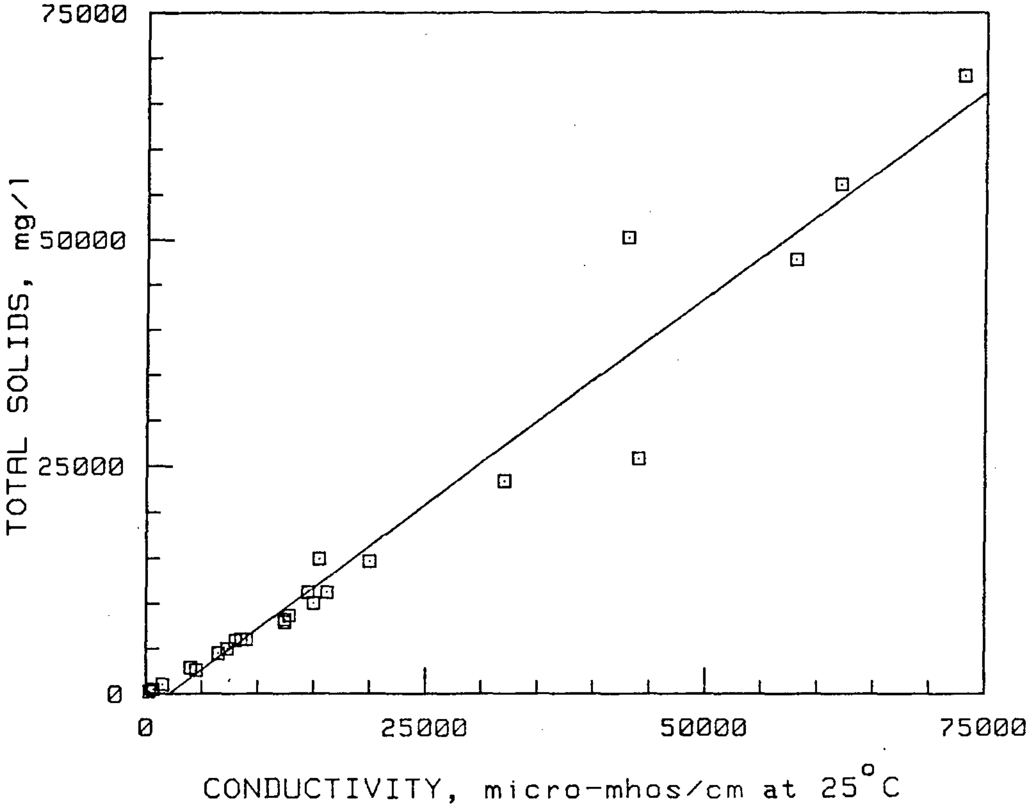


Figure 42. Scatterplot of winter baseflow total solids and conductivity data at the Milwaukee I-94 site.

Table 137. Mass balance for TS_{250}, sodium, and chloride - November 1 through May 21, 1980. at the Milwaukee I-94 site.

Balance component	Balance symbol	Parameter, lb/mi[a]		
		TS_{250}	Cl	Na
Initial load	+	597	0.636	0.970
Deposition				
Vehicle	+	80,377	111	
Atmospheric	+	3,217		
Maintenance	+	129,018	78,301	48,665
Highway surface load	=	213,169	78,413	48,730
Removal				
Runoff	-	111,574	90,400	43,513
Baseflow	-	65,734	8,941	5,583
Atmospheric	-	11,957		
Sweeping	-	23,716	82	66
Remaining load	-	311	1.06	0.667
Surface load unaccounted for	=	-123	-21,011	-433
Percent error		0.1	27.0	0.9

[a] Both directions.

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

Deposition of the chloride anion to the highway surface from the deicing agents, sodium chloride and calcium chloride, was calculated using atomic weight ratios. The data (Table 138) show that chloride application was highest during the months of January and February. In fact, these 2 months accounted for 66 percent of the total chloride application. Chloride removed by runoff was calculated from quantity and quality data collected throughout the period monitored. Similar to total solids, chloride removed by baseflow was calculated using continuous baseflow and specific conductance measurements. Baseflow grab samples for chloride analysis were obtained a minimum of one per week. A scatter plot of chloride (mg/l) and conductivity data (micro-mhos/cm at 25°C) and the resulting best fit line appear in Figure 43. The data presented in Figure 43 indicate that a strong relationship exists between chloride concentrations and conductivity. Regression analyses indicate that 97.1 percent (R^2 value) of the variance in chloride concentrations can be explained by conductivity. Chloride concentrations were calculated using the following equation:

$$\text{Chloride concentration (mg/l)} = 0.4785 \text{ specific conductance (micro-mhos/cm at } 25^\circ\text{C)} - 943$$

The data (Table 137) show that a negative 21,011 lb/mi (5,923 kg/km) of chloride was unaccounted for (a 27 percent error). More chlorides were removed than were available in the highway surface load during the winter period. The mass balance error may have occurred for several reasons. WI DOT estimated the quantity of deicing agents applied by prorating a spreading rate over the site length and number of lanes covered. The accuracy of these estimates is difficult to assess. A value for atmospheric deposition could not be made. Although the precipitation data for the Milwaukee I-94 site indicated that chloride loading values (mg/m^2) were higher during winter periods than summer periods, the atmospheric deposition of chlorides is probably small compared to the deposition from maintenance activities. Chloride deposition from vehicular sources (carry on) appears negligible compared to maintenance inputs.

The data presented in Table 137 also indicate that chloride removal by the maintenance practice of sweeping the highway surface is insignificant compared to removal by runoff and baseflow. This is probably due to the following:

1. WI DOT swept the highway surface on April 17 and May 21, 1980. Data presented in Table 139 indicate that 99 percent of the chloride load as detected in runoff and baseflow had already been removed by April 17, 1980. By the time the first commercial sweeping was performed the chloride load was very small.

2. The data presented on commercial sweeper efficiency indicated that pickup efficiency for soluble constituents was generally lower than constituents associated with solids.

Table 138. De-icing agent application data (lb/mi[a]) - November 1979, through May 1980 at the Milwaukee I-94 site.

Month	Chloride	Sodium
November	6212	4029
December	3808	2334
January	18,654	11,468
February	33,078	20,507
March	10,971	6847
April	5578	3480
Total	78,301	48,665

[a] Both directions.

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

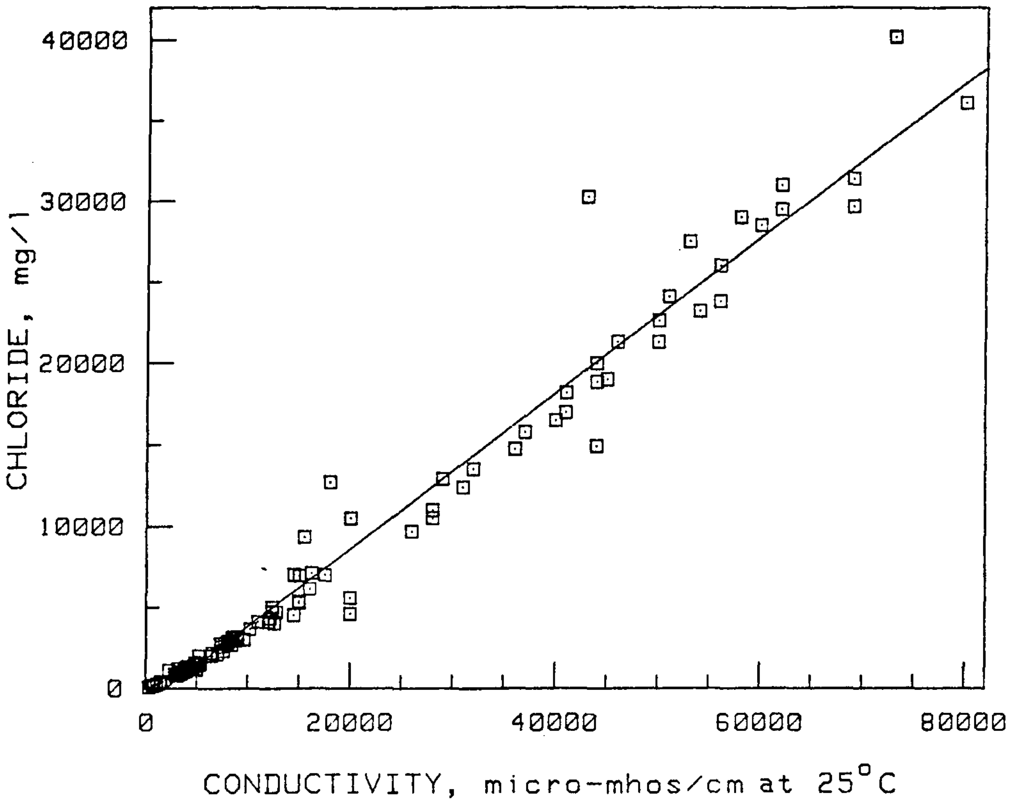


Figure 43. Scatterplot of winter baseflow chloride and conductivity data at the Milwaukee I-94 site.

Table 139. Chloride and sodium removal (lb/mi[a]) from the Milwaukee 1-94 highway surface through runoff and baseflow - November 1979 through May 1980.

	Runoff events[b]		Base flow		Total	
Month	Cl	Na	Cl	Na	Cl	Na
November	711	376	36	42	747	418
December	2,982	2,301	222	144	3,204	2,445
January	20,129	10,491	1,097	723	21,226	11,214
February	27,980	12,063	3,070	1,785	31,050	13,848
March	33,585	14,397	3,322	2,063	36,907	16,460
April (1st to 16th)	4,742	3,680	606	405	5,348	4,085
April (17th to 30th)	230	147	431	297	661	444
May	81	61	158	127	239	188
Total	90,440	43,513	8941	5583	99,381	49,096

[a] Both directions.

[b] Runoff events are defined as periods of runoff resulting from rainfall, snowfall, or snowmelt.

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

Sodium mass balance values were obtained in the same manner as chloride. A scatter plot of sodium (mg/l) and conductivity data (micro-mhos/cm at 25°C) and the resulting best fit line appear in Figure 44. The data indicate that a good relationship exists between sodium concentrations and conductivity; however, the scatter of data about the best fit line is greater than that observed for chloride (Figure 43). Regression analysis indicated that 79.5 percent (R^2 value) of the variance in sodium concentrations can be explained by conductivity. Sodium concentrations were calculated using the following equation:

$$\text{Sodium concentration (mg/l)} = 0.2652 \text{ specific conductance (micro-mhos/cm at } 25^\circ\text{C)} - 185$$

The data (Table 137) show that a negative 433 lb/mi (122 kg/km) of sodium was unaccounted for (a 0.9 percent error). Reasons for the error are probably similar to those discussed for the chloride data.

Efland I-85 Site

A TS_{250} mass balance was calculated for the period June 30, 1981, through April 22, 1982 (297 days), at Efland. The TS_{250} balance is graphically displayed in Figure 45. The same calculations and assumptions used in the Milwaukee mass balance were used in the Efland mass balance. The increasing slope on the graph represents the daily TS_{250} accumulation on the highway surface. Total accumulation rate varied from 4 to 35 lb/mi/day (1.1 to 9.9 kg/km/day) at Efland compared to 10 to 464 lb/mi/day (2.8 to 131 kg/km/day) at Milwaukee. The difference in accumulation rate is probably attributable to differences in ADT, drainage design, and atmospheric and climatic variables. Sharp vertical increases in slope during the winter period represent the application of deicing agents to the road surface. The squares represent the highway surface TS_{250} load for dates when the surface load was measured using sweeping/flushing techniques. The mass balance begins and ends on sweeping/flushing events, experimentally known points. Vertical drops in the graph represent TS_{250} removal from the highway surface through runoff. All data corresponding to the graph can be found in Volume IV - Appendix.

The mass balance model graphically displayed in Figure 45 incorporates all atmospheric, runoff, surface load, and maintenance TS_{250} data during the period June 30, 1981, through April 22, 1982, at the Efland I-85 site. The graph shows that the last two surface monitored loads are low, but that overall the individually monitored components fit well into the mass balance. The mass balance indicates that the summer surface load peaked on September 4, 1981 [1506 lb/mi (425 kg/km)], and the winter surface load peaked on January 15, 1982 [5459 lb/mi (1540 kg/km)]. Milwaukee's peak summer surface load was 4,188 lb/mi (1,180 kg/km), and the peak winter surface load was 58,068 lb/mi (16,370 kg/km). The difference in peak surface load is probably due largely to differences in ADT and drainage design.

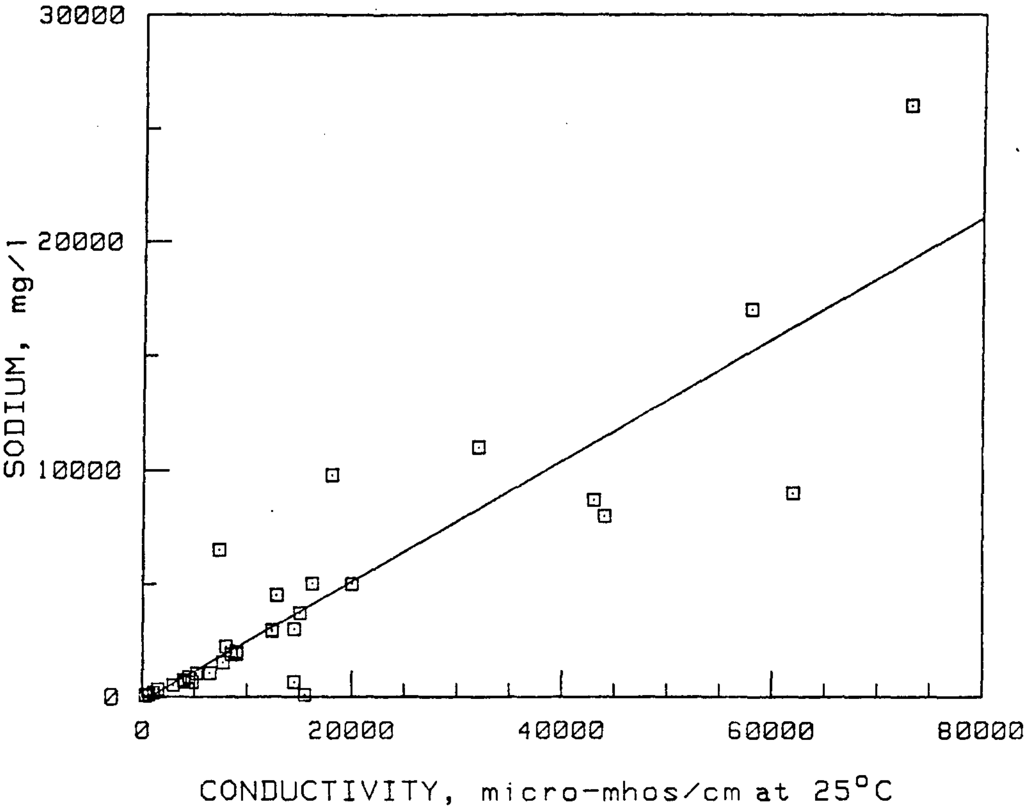
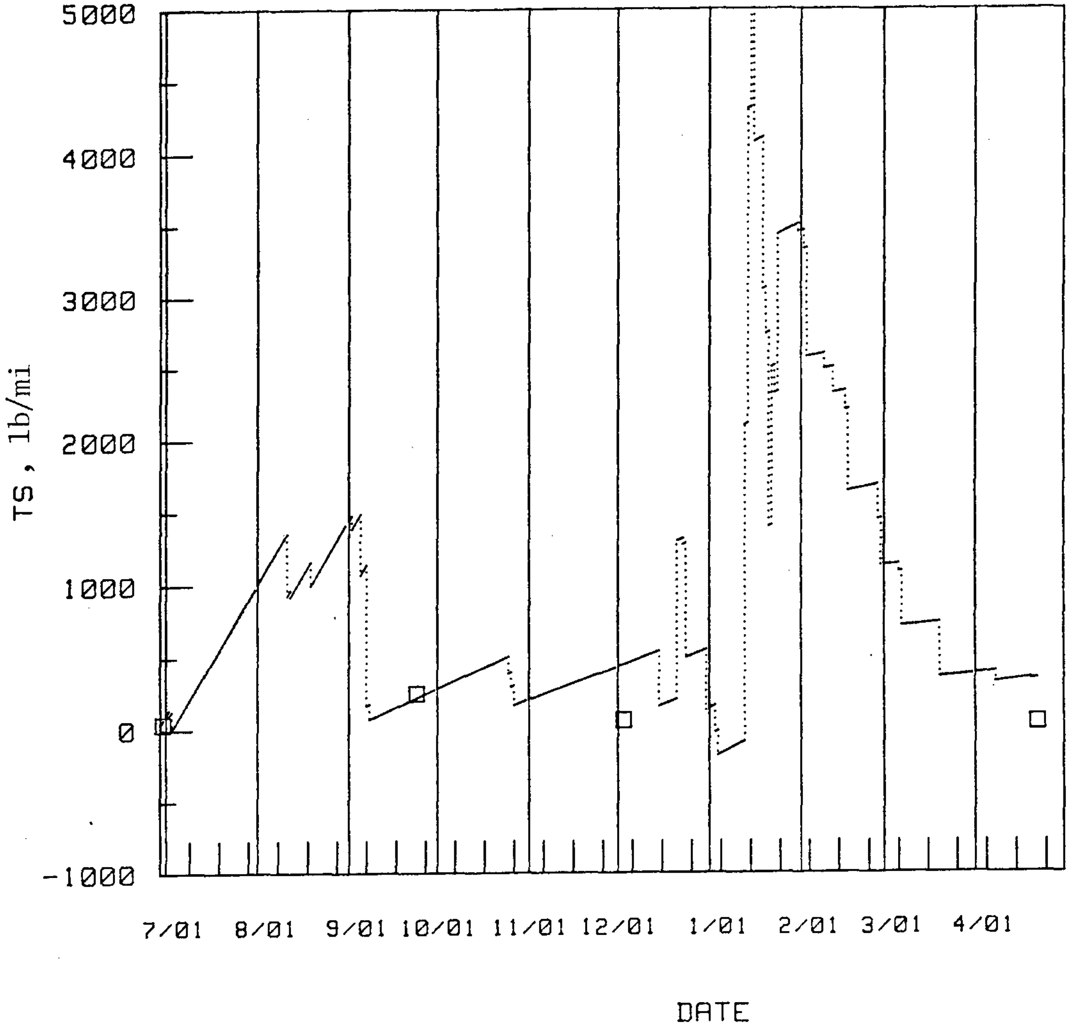


Figure 44. Scatterplot of winter baseflow sodium and conducivity data at the Milwaukee I-94 site.



Legend

□ Monitored TS_{250} highway surface load

Figure 45. TS_{250} mass balance model for Efland I-85 site - June 30, 1981, through April 22, 1982.

The data represented by the mass balance graph (Figure 45) are summarized in Figure 46. The data displayed in Figure 46 are divided into three mass balance components: deposition processes, highway surface load, and removal processes. Atmospheric deposition of TS_{250} to the highway surface for the period June 30 through April 22, 1982, was obtained from wet/dry collector data which monitored background precipitation and dustfall separately. Total atmospheric deposition for the period was 1276 lb/mi (360 kg/km) with rainfall accounting for 32 percent of the total deposition. During the period, monthly maintenance records were received from the North Carolina Department of Transportation. These records indicated that 10,980 lb/mi (3095 kg/km) of TS_{250} were associated with deicing agent application. However, the data also indicated that there was no other occurrence of maintenance activities, accidents, or construction, which might have contributed to the TS_{250} highway surface load. Vehicular deposition during the mass balance period was 4,061 lb/mi (1145 kg/km), and the ADT during the period was 25,300 vehicles/day. Using this loading and ADT, the average vehicular deposition rate was calculated to be 0.00054 lb/mi/vehicles (0.15 g/km/vehicle). The average vehicular deposition rate at Efland was approximately half that observed at Milwaukee, 0.011 lb/mi/vehicle (3.12 g/km/vehicle).

Sweeping of the highway surface is not a maintenance activity performed at Efland and therefore is not a removal mechanism. Similar to Milwaukee, the major removal mechanism of TS_{250} at Efland is runoff. Runoff removed 91 percent of the available load while the remaining 9 percent was removed by atmospheric processes.

A mass balance sheet for TS_{250}, Pb, Zn, and Fe (June 30, 1981, through April 22, 1982) is presented in Table 140. Mass balance calculations were not made for Cr, Cu, Cd, and Ni because loadings for these parameters were very small or not detectable for many of the mass balance components. The data show that for the TS_{250} mass balance a positive 180 lb/mi (50.7 kg/km) was unaccounted for, i.e., that more TS_{250} accumulated than was removed during the mass balance period. The error associated with the TS_{250} mass balance was 1.1 percent. The mass balance also shows that the major source of Pb, Zn, and Fe is the vehicle, while runoff is the major removal mechanism. Percent error of the selected metals mass balance ranged from 2.9 to 4.3 percent.

A mass balance sheet for TS_{250}, sodium, and chloride for the period when deicing agents were applied to the highway surface at Efland (December 3, 1981, through March 30, 1982) is presented in Table 141. The data show that during this period, the maintenance practice of deicing agent application accounted for 89 percent of the total TS_{250} deposition. The data also show that the major portion (96 percent) of the accumulated TS_{250} load was removed by runoff. A positive 280 lb/mi (78.9 kg/km) of TS_{250} was unaccounted for by the mass balance for an error of 2.2 percent. Mass balance errors for chloride and sodium were 0.3 and 0.2 percent respectively.

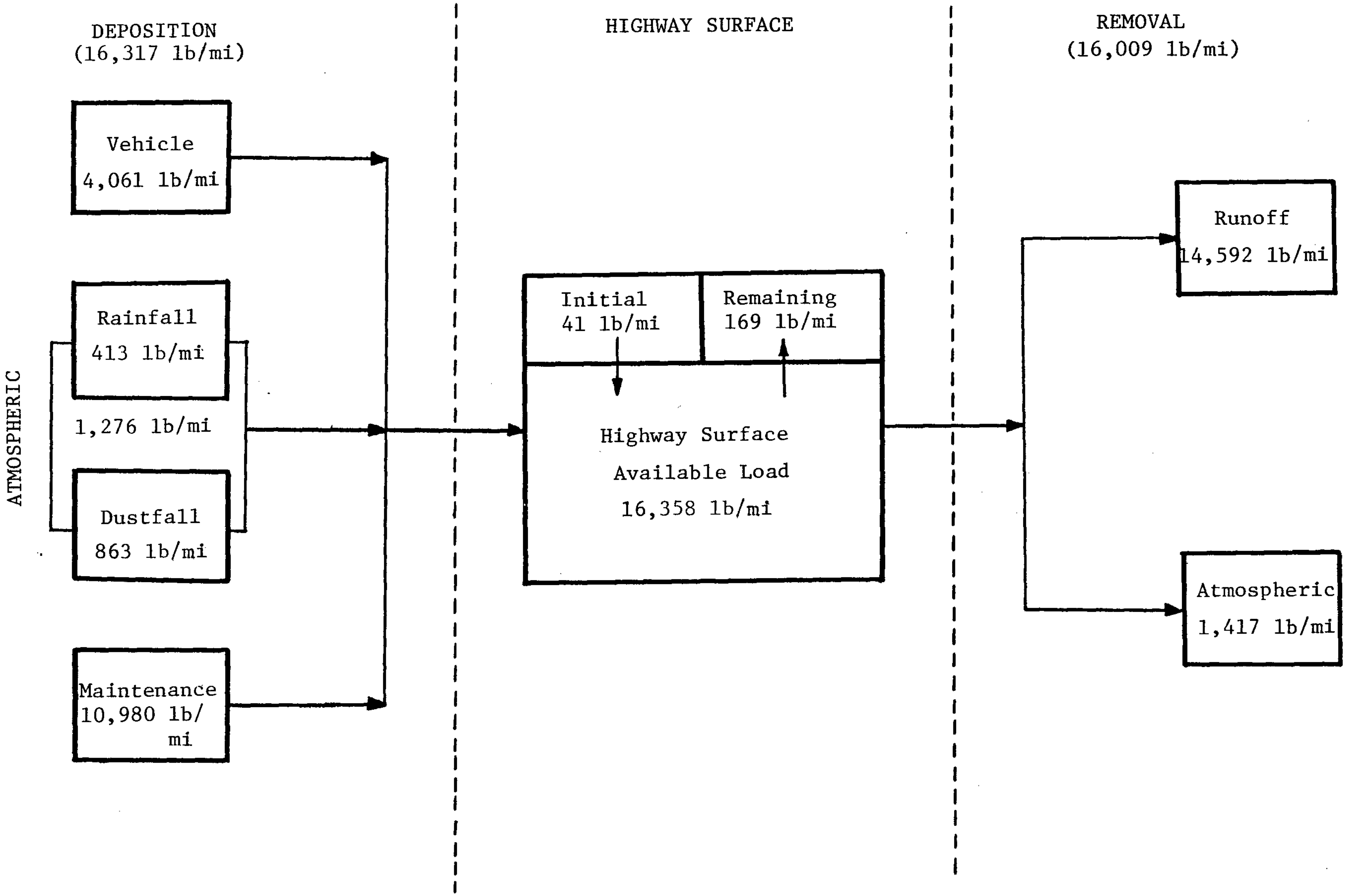


Figure 46. TS$_{250}$ mass balance for the Efland I-85 site - June 30, 1981, through April 22, 1982.

Table 140. Mass balance for TS_{250}, lead, zinc, and iron - June 30, 1981, through April 22, 1982, at the Efland I-85 site.

Balance component	Balance symbol	Parameter, lb/mi[a]			
		TS_{250}	Pb	Zn	Fe
Initial load	+	41	0.100	0.058	0.72
Deposition					
Vehicle	+	4.061	0.836	3.289	147.98
Atmosphere	+	1,276	0.368	0.168	16.78
Maintenance	+	10,980	0.018	0.0	0.45
Highway surface load	=	16,358	1.322	3.515	165.93
Removal					
Runoff	-	14,592	0.820	2.779	144.38
Atmospheric	-	1,417	0.425	0.223	15.62
Remaining load	-	169	0.021	0.412	0.0
Surface load unaccounted for	=	180	0.056	0.101	5.93
Percent error		1.1	4.2	2.9	3.6

[a] Both directions.

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

Table 141. Mass balance for TS_{250} sodium, and chloride - December 3, 1981, through March 20, 1982 at the Efland I-85 site.

Balance component	Balance symbol	Parameter, lb/mi[a]		
		TS_{250}	Cl	Na
Initial load	+	449	1	1
Deposition				
Vehicle	+	893	57	37
Atmospheric	+	432		
Maintenance	+	10,980	6796	4058
Highway surface load	=	12,754	6854	4,096
Removal				
Runoff	-	11,751	6314	3,342
Atmospheric	-	540		
Remaining load	-	183	518	745
Surface load unaccounted for	=	280	22	9
Percent error		2.2	0.3	0.2

[a] Both directions.

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

POLLUTANT ACCUMULATION AND MIGRATION IN AREAS ADJACENT TO THE HIGHWAY

Studies were performed to determine pollutant accumulation and migration in areas adjacent to the highway. These studies included the sampling of soil and vegetation and the monitoring of groundwater seepage and snow cover. These studies are discussed in the ensuing subsections.

Soils

Soil studies were conducted to quantify pollutant loads in areas adjacent to the highway and to evaluate possible effects on plant uptake and runoff and groundwater seepage characteristics. Soil cores were obtained along a transect crossing the highway right-of-way at selected distances from the paved highway surface to define the pattern of contaminant accumulation in the soil with distance from the highway. Soil core sampling included background samples as points for comparison to highway-influenced samples. Topsoil and substrate layers of each soil core were separated and analyzed as individual samples to quantify contaminant storage and migration within the soil profile. Wherever soil cores were obtained, a corresponding vegetation sample was collected.

Figure 47 shows the soil and vegetation sampling scheme for the Milwaukee I-94 site. Soil samples were obtained north of the paved highway surface in the area where unpaved runoff was monitored. Samples were obtained for eight locations: three near the highway, three near the edge of right-of-way, and two at background locations. Samples obtained in the right-of-way area included both the depressed and hill sections.

The soil and vegetation sampling schemes for the Sacramento Hwy 50 site are presented in Figure 48. Soil samples were obtained both north and south of the paved highway surface in the power line right-of-way. Samples were obtained from six locations; two near the highway, one in each of the two drainage ditches, one near the edge of the right-of-way, and one at a background location.

Figure 49 shows the soil and vegetation sampling scheme for the Harrisburg I-81 site. Soil samples were obtained north and south of the northbound highway section. Samples were obtained from six locations: two near the highway, one in the median area, one on a berm bordering the southern right-of-way drainage ditch, one near the edge of right-of-way, and one at a background location.

The soil and vegetation sampling scheme for the Efland I-85 site is presented in Figure 50. Soil samples were obtained in an open area north and south of the paved highway surface. A total of six locations were sampled at the Efland site.

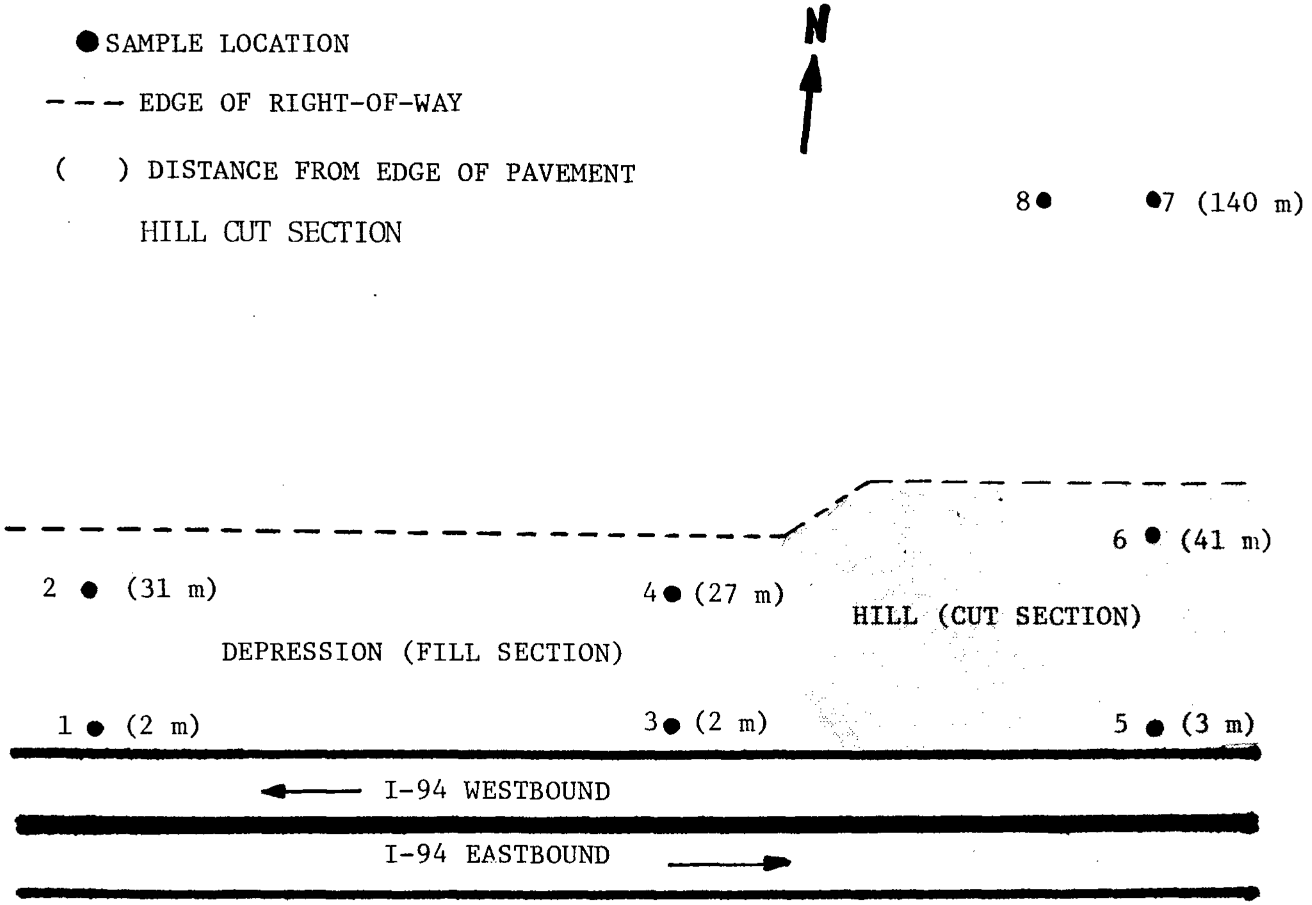


Figure 47. Soil and vegetation sampling scheme for the Milwaukee I-94 site.

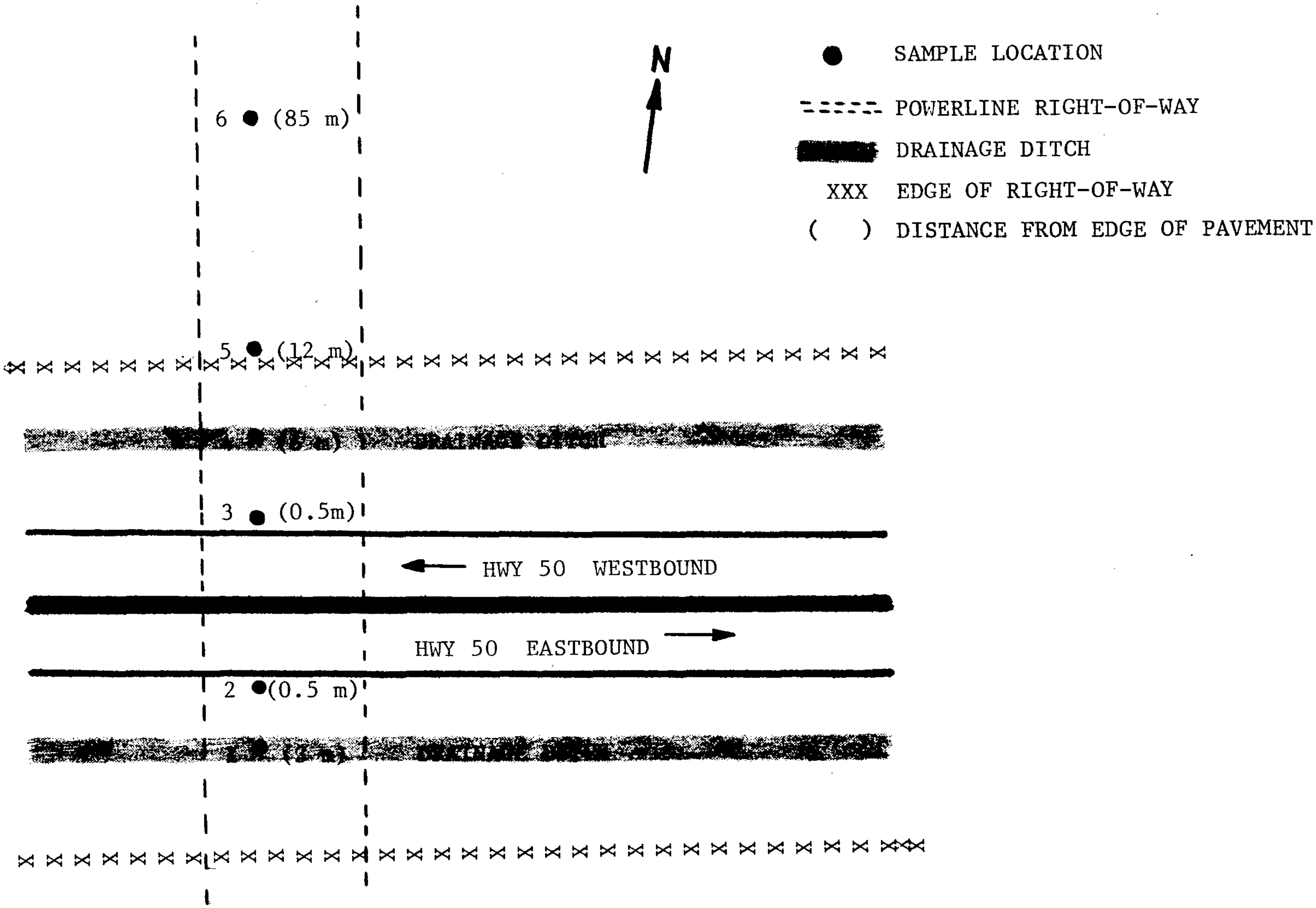


Figure 48. Soil and vegetation sampling scheme at the Sacramento Hwy 50 site.

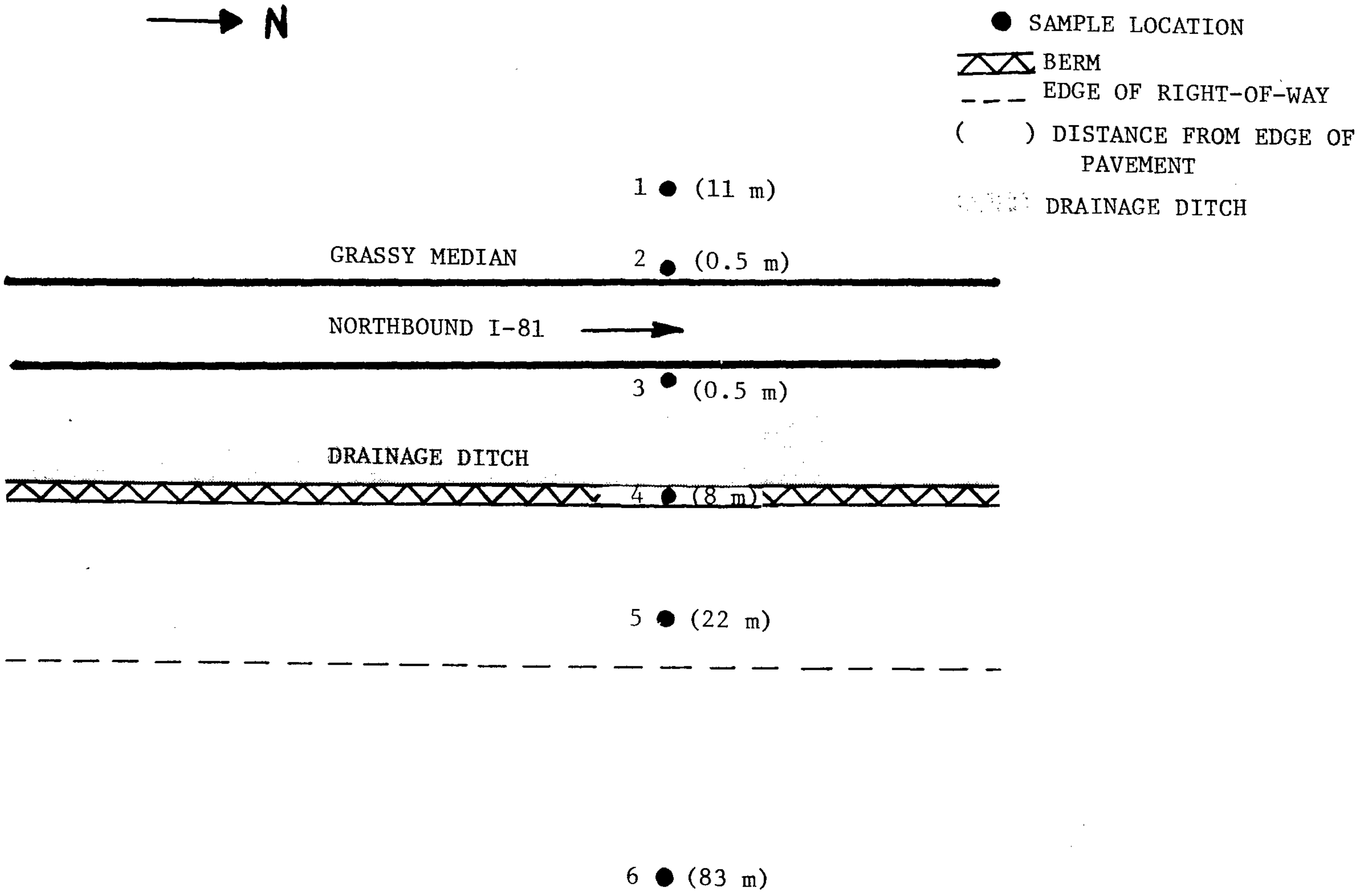


Figure 49. Soil and vegetation sampling scheme at the Harrisburg I-81 site.

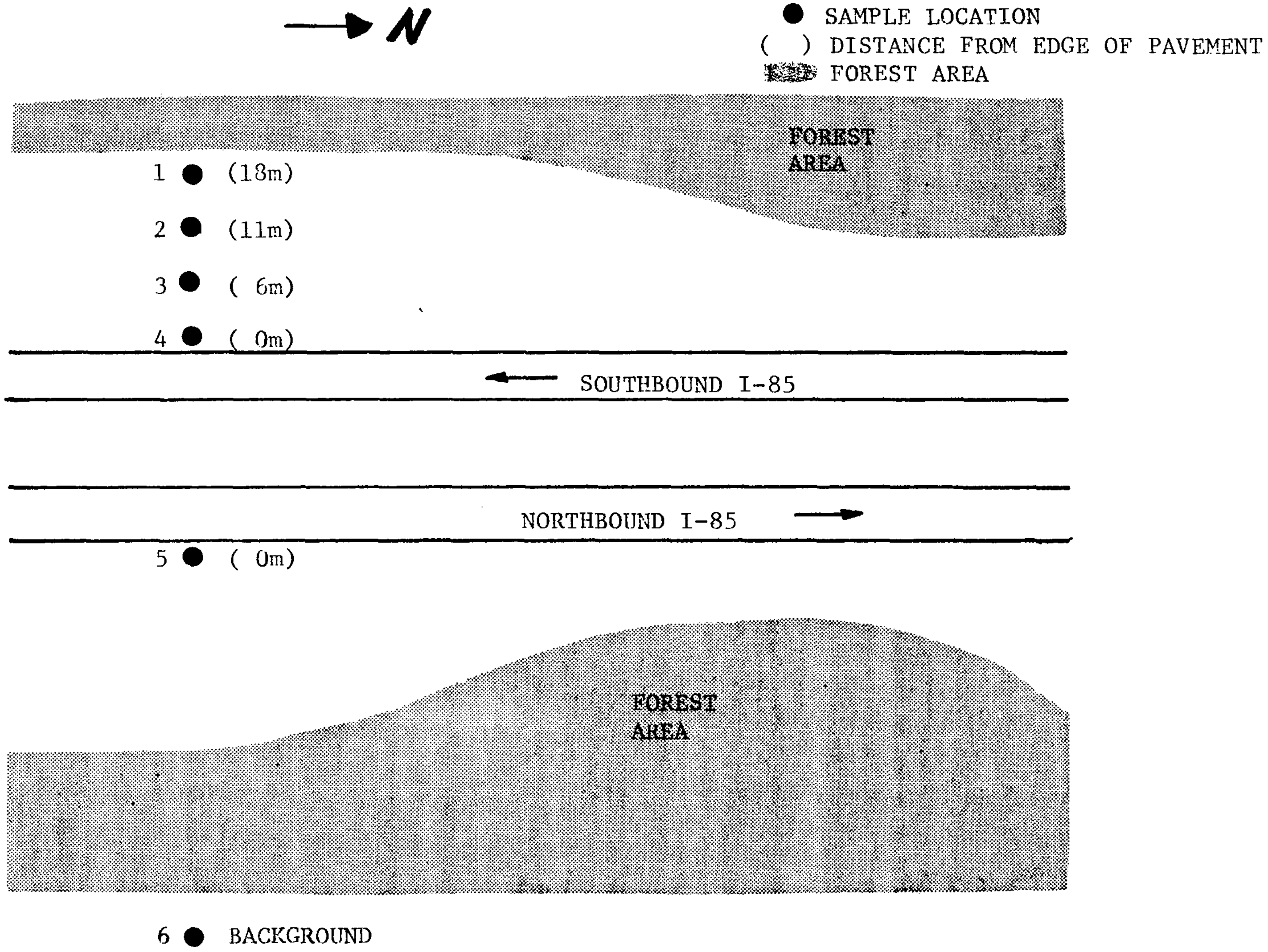


Figure 50. Soil and vegetation sampling scheme at the Efland I-85 site.

Physical soil characteristics--

The physical characteristics of the soil profile at each monitoring site (Tables 142 through 145) were determined because these characteristics can affect the manner in which pollutants accumulate and migrate in the soil system. Soils high in organic matter and clay tend to accumulate pollutants, while soils high in sand tend to allow pollutants to migrate downward in the soil profile. For example, Hildebrand and Blum (63) stated that the major mechanism in lead soil retention is organic matter content. Particle size distribution was determined for each soil sample. The results are reported as percent sand, silt, and clay, where sand includes particles in the 0.5 to 2.0 mm range, silt the 0.002 to 0.05 mm range, and clay the 0.00008 to 0.002 mm range. Bulk density, a measure of soil weight per specified volume, was also measured for each soil sample.

The Milwaukee data (Table 142) indicate that the topsoil layers were generally higher in silt and organic matter than the substrate layer, indicating that most pollutants (except those which are highly soluble) would tend to accumulate in the topsoil layer. Substrate layers at Milwaukee were generally high in sand and low in organic matter. Bulk densities ranged from 0.94 to 1.67 gm/cc. The physical data indicate no distinct pattern between near highway, right-of-way, or background soils.

The Sacramento data (Table 143) indicate that both the topsoil and substrate layers are high in sand-sized particles and extremely low in organic matter, indicating a soil system conducive to pollutant migration. Particle size data indicate no distinct pattern between sampling locations. Organic matter was higher in topsoil layers compared to substrate layers. Organic matter in the topsoil of sampling locations 2, 3, and 5 on the crests of the drainage ditch were lower than sampling locations 2 and 4 in the bottom of the drainage ditch, indicating some soil erosion into the ditch. Bulk densities ranged from 1.07 to 2.01 gm/cc.

At Harrisburg, only topsoil samples could be obtained at the near highway sampling locations (nos. 2 and 3). The substrate at these locations consisted of the gravel sub-base. As discussed in the section describing runoff characteristics, a large portion of the paved surface runoff was lost to the sub-base before reaching the monitoring point. Because the sub-base is so near the soil surface at the highway pavement, most of the paved runoff is probably lost just as it leaves the pavement. The topsoil nearest the highway pavement (nos. 2 and 3) was also the highest in sand-sized and lowest in clay-sized particles (Table 144) facilitating drainage to the gravel sub-base. The near-highway topsoil samples were also highest in organic matter which is difficult to explain. However, Harrisburg soils are generally low in organic matter compared to Milwaukee soils. Bulk densities ranged from 1.04 to 1.82 gm/cc.

The Efland data (Table 145) indicate the soils near the highway (nos. 3, 4, and 5) were generally higher in silt and clay than the soils away from the

Table 142. Physical properties of soils at the Milwaukee I-94 site.

Plot location	Soil layer depth, cm	Sand, percent[a]	Silt, percent[a]	Clay, percent[a]	Organic matter, mg/kg[b]	Dry bulk density[b], gm/cc
Near-highway						
Site 1						
Topsoil	17.8	47	40	13	60,000	1.27
Substrate	12.7	58	26	16	23,300	1.61
Site 3						
Topsoil	6.4	35	46	19	78,800	1.53
Substrate	24.1	59	29	12	27,500	1.31
Site 5						
Topsoil	22.9	37	42	21	101,000	0.94
Substrate	7.6	48	38	14	37,500	1.12
Right-of-way						
Site 2						
Topsoil	11.4	48	36	16	68,300	1.24
Substrate	19.1	39	45	16	12,800	1.57
Site 4						
Topsoil	10.2	28	53	19	78,800	1.53
Substrate	20.3	46	37	17	12,500	1.07
Site 6						
Topsoil	7.6	24	53	23	46,800	1.30
Substrate	22.9	43	44	13	14,000	1.31
Background						
Site 7						
Topsoil	12.7	43	44	13	69,500	
Substrate	17.8	41	41	18	11,800	1.67
Site 8						
Topsoil	10.2	57	34	9	95,000	1.52
Substrate	20.3	55	32	13	18,000	1.28

[a] Average of two samples.

[b] Average of four samples.

Table 143. Physical properties of soils at the Sacramento Hwy 50 site.

Plot location	Soil layer depth, cm	Sand, percent	Silt, percent	Clay, percent	Organic matter, mg/kg	Dry bulk density, gm/cc
Near-highway						
Site 2						
Topsoil	10.2	79	12	9	23,000	1.12
Substrate	20.3	61	32	7	13,000	1.46
Site 3						
Topsoil	10.2	57	34	9	11,000	1.72
Substrate	20.3	57	36	7	9,000	2.01
Right-of-way						
Site 1						
Topsoil	10.2	51	40	9	30,000	1.69
Substrate	20.3	47	48	5	20,000	1.80
Site 4						
Topsoil	10.3	51	40	9	37,000	1.07
Substrate	20.3	55	38	7	12,000	1.70
Site 5						
Topsoil	10.2	59	34	7	20,000	1.21
Substrate	20.3	61	32	7	11,000	1.46
Background						
Site 6						
Topsoil	10.2	59	36	5	33,000	1.08
Substrate	20.3	44	46	10	15,000	1.68

Table 144. Physical properties of soils at the Harrisburg I-81 site.

Plot locations	Soil layer depth, cm	Sand, percent	Silt, percent	Clay, percent	Organic matter, mg/kg[a]	Dry bulk density, gm/cc[a]
Near-highway[b]						
Site 2						
Topsoil	10.2	53	34	13	45,000	1.26
Site 3						
Topsoil	10.2	53	32	15	50,000	1.40
Median						
Site 1						
Topsoil	10.2	45	37	18	30,000	1.37
Substrate	20.3	41	42	17	15,000	1.61
Right-of-way						
Site 4						
Topsoil	10.2	38	43	19	45,000	1.09
Substrate	20.3	38	33	29	7,000	1.82
Site 5						
Topsoil	10.2	51	33	16	29,500	1.04
Substrate	20.3	63	24	13	85,00	1.81
Background						
Site 6						
Topsoil	10.2	35	44	21	33,000	1.04
Substrate	20.3	37	43	20	11,000	1.48

[a] Average of two samples.
[b] Substrate consisted of the gravel sub-base.

Table 145. Physical properties of soils at the Efland I-85 site.

Plot location	Soil layer depth, cm	Sand, percent	Silt, percent	Clay, percent	Organic matter, mg/kg	Dry bulk density, gm/cc
Site 1						
Topsoil	10.2	53	39	8	22,000	1.79
Substrate	20.3	49	40	11	13,000	1.35
Site 2						
Topsoil	10.2	59	34	7	21,000	1.34
Substrate	20.3	51	30	19	7,000	1.47
Site 3						
Topsoil	10.2	11	70	19	15,000	1.42
Substrate	20.3	37	18	45	5,000	1.27
Site 4						
Topsoil	10.2	49	20	31	58,000	1.07
Substrate	20.3	5	49	46	9,000	1.95
Site 5						
Topsoil	10.2	9	49	42	16,000	1.53
Substrate	20.3	25	50	25	2,000	1.75
Site 6						
Topsoil	10.2	41	53	6	28,000	1.28
Substrate	20.3	61	36	3	12,000	1.34

highway (nos. 1, 2, and 4) which were high in sand. Except for the topsoil at site 4, the soils in general were low in organic matter. Bulk densities ranged from 1.07 to 1.95 gm/cc.

Chemical soil characteristics--

Chemical analyses were performed on soil samples at the sites monitored to determine accumulation and migration patterns. Analyses included cation exchange capacity (CEC) which is defined as the sum of the exchangeable cations of the soil. Exchangeable cations are those which are held on the surface of soil minerals and within the crystal framework of some mineral species plus those which are a part of certain organic compounds and can be reversibly replaced by cations of salt solutions and acids (64). The higher the CEC value (milliequivalents/100 grams), the greater the capacity to exchange cations. For example, Zimdahl (65), Hasett (66), and Zimdahl and Skigerboe (67) have shown that lead immobilization in the soil is directly correlated to soil CEC and inversely related to pH. However, U.S. EPA considers CEC only a first approximation of the ability of a soil to immobilize metals and not the controlling factor (68). Soluble salts were also measured and are defined as the inorganic constituents which are appreciably soluble in water. The soluble salt measurement is used to indicate the osmotic pressure of the soil solution which is important in defining the availability of water for plant growth (64). Other soil analyses included pH, nutrients, metals, sodium, chloride, and sulfate.

At the Milwaukee I-94 site, soil samples were obtained on September 15, 1978, May 23, 1979, September 18, 1979, and May 9, 1980. Mean constituent concentrations for the fall samples are presented in Table 146, while mean spring values appear in Table 147. The fall data show that the soils at the Milwaukee site were slightly basic (pH 7.6 to 8.8). CEC's were highest at the base of the hills (no. 2, 4, and 5). Nutrients (TKN, NH_4, NO_3, P, K, Ca, and Mg) were generally higher in the topsoil layers but showed no definite pattern when values near the highway are compared to values near the edge of the right-of-way and background values.

Sodium concentrations were an order of magnitude higher near the highway, while chlorides did not display this pattern. Both of these constituents originate from deicing applications during winter periods. Apparently, the chlorides are easily leached from the soil during the spring and summer through runoff and groundwater percolation, while sodium tends to accumulate in the soil at a higher rate. These findings appear consistent with those previously reported (32, 69). Patenaude (31) conducted an investigation of road salt content of soil, water, and vegetation adjacent to highways in Wisconsin. Data collected from many sites within the state showed little tendency for development of a pattern of calcium accumulation. The author believed this could be attributed to the fact that calcium chloride generally constitutes no more than a few percent of the total road salt used in Wisconsin, and the variability of the calcium content in most soils, particularly the glacial tills, obscures the effect of any calcium from road

Table 146. Chemical properties of soils at the Milwaukee I-94 site - mean values for fall 1978 and 1979.

Plot location	Soil layer depth, cm	pH	CEC, me /100 g	Soluble salts, mhos x10^{-5} /cm	Concentration, mg/kg dry weight																	
					TKN	NH_4	NO_3	P	K	Ca	Mg	Na	Cl	SO_4-S	Pb	Zn	Fe	Cr	Cu	Cd	Ni	As[a]
Near-highway																						
Site 1																						
Topsoil	17.8	8.0	24	34	2820	ND	7.6	20	106	3,720	250	430	18	65.3	1020	370	25,600	45	78	3.3	33	3.90
Substrate	12.7	8.6	19	20	580	ND	1.6	8.3	46.3	3,400	150	173	8.0	58.7	59	58	9,700	13	25	2.3	23	0.26
Site 3																						
Topsoil	6.4	8.2	22	30	2210	2.5	23	23	165	3,630	188	228	33	65.8	1800	342	23,700	56	87	4.0	41	2.60
Substrate	24.1	8.8	23	34	460	ND	3.2	6.5	85.0	4,080	175	530	25	65.0	67	91	17,400	28	24	2.0	28	0.47
Site 5																						
Topsoil	22.9	8.2	83	48	4400	ND	7.9	11	111	5,900	288	620	48	86.3	511	149	28,600	41	53	2.6	31	6.80
Substrate	7.6	8.5	24	30	1030	ND	ND	9.0	52.5	4,480	175	240	29	62.2	35	83	16,000	18	19	1.8	24	0.09
Near edge of right-of-way																						
Site 2																						
Topsoil	11.4	7.8	31	25	1710	ND	ND	15	133	4,180	375	45	23	31.2	125	107	24,600	32	28	1.5	26	1.50
Substrate	19.1	8.2	23	18	260	ND	ND	1.0	75.0	4,050	213	33	11	54.2	32	87	17,800	16	20	2.5	28	0.16
Site 4										4,690												
Topsoil	10.2	7.8	41	33	3820	ND	2.4	18	133	4,690	375	45	19	41.5	111	108	24,100	36	32	1.9	27	2.90
Substrate	20.3	8.2	23	17	510	ND	ND	3.0	67.5	4,050	188	38	12	49.0	29	89	14,400	22	22	2.2	32	0.20
Site 6																						
Topsoil	7.6	7.7	19	25	1810	ND	12	23	178	2,880	388	30	33	18.2	93	132	21,100	37	24	0.9	27	1.60
Substrate	22.9	7.9	22	15	580	ND	ND	8.0	77.5	3,780	325	28	9.0	17.2	25	95	20,700	30	28	1.1	27	0.44
Background																						
Site 7																						
Topsoil	12.7	7.6	21	35	1740	1.6	17	28	120	3,500	375	20	26	27.8	51	77	13,000	18	17	1.0	21	0.66[b]
Substrate	17.8	7.8	23	25	680	0.5	2.6	8.0	75.0	4,000	300	25	6.5	11.5	58	75	13,100	18	18	1.3	23	
Site 8																						
Topsoil	10.2	7.7	25	25	2260	1.0	2.1	47	100	3,950	300	25	5.5	43.5	330	210	15,300	22	37	1.5	20	
Substrate	20.3	8.0	22	20	560	ND	ND	2.0	67.5	4,050	225	25	3.5	60.0	46	80	12,800	16	19	1.2	22	

[a] 10/5/78 only.

[b] Topsoil and substrate combined.

ND = Not detectable.

Table 147. Chemical properties of soils at the Milwaukee I-94 site - mean values for spring 1979 and 1980.

					Concentration, mg/kg dry weight																	
Plot location	Soil layer depth, cm	pH	CEC me /100 g	Soluble salts, mhos $x10^{-5}$ /cm	TKN	NH_4	NO_3	P	K	Ca	Mg	Na	Cl	SO_4-S	Pb	Zn	Fe	Cr	Cu	Cd	Ni	As[a]
Near-highway																						
Site 1																						
Topsoil	16.5	8.4	20	34	1,850	1.3	7.5	19	110	3,430	213	700	28	125	1.260	821	25,150	35	95	3.5	38	0.56
Substrate	14.0	8.5	14	30	850	ND	1.5	8.8	56.3	2,530	175	335	64	61.9	288	58	8,330	7.1	55	1.5	15	0.06
Site 3																						
Topsoil	8.3	8.3	57	25	1,250	ND	7.6	20	126	3,500	188	333	19	74.7	2,180	364	26,700	28	74	3.4	31	0.34
Substrate	22.2	8.6	20	29	900	ND	ND	9.8	72.5	3,580	213	368	44	46.7	104	129	16,900	12	21	1.4	21	0.04
Site 5																						
Topsoil	22.9	8.2	87	45	4,650	1.3	9.9	10	119	5,750	350	620	85	125	385	177	36,000	24	45	2.2	34	2.30
Substrate	7.6	8.2	24	33	1,450	0.8	2.6	7.0	62.5	4,230	275	363	73	74.3	63	113	23,200	15	21	1.7	26	0.05
Right-of-way																						
Site 2																						
Topsoil	10.8	7.7	34	22	2,700	4.7	9.7	12	143	4,900	425	49	18	33.4	119	103	26,700	19	23	1.4	31	0.54
Substrate	19.7	8.1	21	18	700	ND	ND	1.8	76.3	3,730	250	29	17	63.2	29	125	23,700	11	14	1.4	23	0.05
Site 4																						
Topsoil	10.2	7.7	47	25	2,050	5.7	8.2	15	124	4,800	525	63	20	31.6	161	141	27,300	22	28	1.6	31	1.40
Substrate	20.3	8.1	20	10	500	ND	ND	3.0	47.5	3,500	225	25	13	53.7	33	85	15,900	11	21	1.7	24	0.05
Site 6																						
Topsoil	12.7	7.7	19	21	1,950	1.2	6.5	13	153	2,830	488	30	36	11.7	130	176	24,100	20	20	1.1	28	0.44
Substrate	17.8	8.0	19	10	700	ND	ND	4.5	90.0	3,130	413	28	12	5.8	31	92	23,300	26	20	1.0	31	0.05
Background																						
Site 7																						
Topsoil	7.6	7.3	75	34	300	9.4	8.2	5.0	250	4,750	600	30	57	54.8	51	99	14,700	16	15	1.9	28	0.01[b]
Substrate	22.9	7.8	23	24	3,500	ND	ND	1.0	168	3,900	425	20	21	129	28	81	20,200	38	13	1.2	32	
Site 8																						
Topsoil	10.2	7.3	84	23	2,400	ND	13.0	113	218	2,950	450	20	34	27.5	172	110	15,800	30	14	1.6	26	NA
Substrate	20.3	7.9	21	10	500	ND	ND	4.0	72.5	3,750	300	15	9.0	33.8	48	76	15,800	55	12	1.5	22	NA

[a] 5/22/79 only.

[b] Topsoil and substrate combined.

ND - Not detectable.

NA - No analysis.

salt. However, sodium commonly displayed a pattern of accumulation, with the highest rate of accumulation in finer grained soils. Calcium and sodium ions are subject to retention on negatively charged soil exchange sites, especially clay particles, while chloride, which is negatively charged, is not attracted to soil particles but remains in soil solution. Chlorides tend to flush from soils, especially those which are coarse-grained (sand) with low storage capacities. Patenaude (31) found that the pattern of chloride concentrations in Wisconsin soils is characteristically seasonal in nature because of the tendency of chloride to remain in solution with higher chloride concentrations in spring and lower concentrations in fall. Total rainfall can also vary soil chloride concentrations with lower chloride content during wet years and higher concentrations during dry years.

The spring soils data at the Milwaukee I-94 site (Table 147) are generally comparable to fall data. Chlorides appear to have reached background levels (fall levels) for most sampling locations by the time the spring samples were obtained (May 23, 1979, and May 9, 1980). This fact is supported by the lysimeter chloride data (Table 148) which shows that the "slug" load of chlorides had migrated out of the topsoil layer by mid-April 1979.

Sulfate concentrations were also higher in the topsoil layers near the highway compared to right-of-way and background samples (Table 147). Metal concentrations were generally higher in the topsoil layers than substrate layers. Of the four sites, Milwaukee had highest concentration of lead, 2180 mg/kg. However, lead concentrations as high as 7000 mg/kg near roadways have been reported (70). The difference was most dramatic for near-highway samples and least for background samples. Of the near-highway topsoil samples, site no. 5 had the lowest metals concentrations. Site no. 5 was further from the highway than the other two sites, and this fact probably accounts for the lower metal concentrations.

At the Sacramento Hwy 50 site, soil samples were obtained on October 3, 1979. The soils data (Table 149) show that the pH was near neutral at all sampling locations (pH 6.6 to 7.9). CEC's were highest for the topsoil samples obtained in the drainage ditch and at the background location. Soluble salts were very high in the topsoil layer for the near-highway samples. Except for calcium and magnesium, nutrients were generally higher in the topsoil layer compared to substrate layers. TKN, NH_4, P, and K concentrations in the topsoil layers for mean-highway samples were low compared to right-of-way and background location. Although deicing agents are not applied to the highway surface at Sacramento, elevated sodium and chloride concentrations were evident at the near-highway and drainage ditch sampling locations. Apparently, the low concentrations observed in the paved runoff (mean sodium concentration was 18.6 mg/l and 12.6 mg/l for chloride) combined with the high evaporation rates at Sacramento (warm dry climate) account for the buildup of sodium, chloride, and total soluble salts in areas carrying highway runoff. This is analogous to salt buildup in soils for arid regions using extensive irrigation. Lead and zinc concentrations were extremely high for topsoil layers near the highway and in the drainage ditches.

Table 148. Chloride migration out of the topsoil layer as monitored by the zero tension lysimeters at the Milwaukee I-94 site.

Date, 1979	Chlorides, mg/m^2
3/2	915
3/5	2,660
3/13	2,360
3/15	3,270
3/19	7,400
3/30	185
3/31	247
4/3	97.2
4/16	522
4/25	17.4
4/26	ND
4/30	14.0
6/8	21.1
7/3	61.5

Note: ND = Not detectable.

Table 149. Chemical properties of soils at the Sacramento Hwy 50 site - fall 1979.

Plot location	pH	CEC, me /100 g	Soluble salts, mhos x10^{-5} /cm	Concentration, mg/kg dry weight																	
				TKN	NH_4	NO_3	P	K	Ca	Mg	Na	Cl	SO_4-S	Pb	Zn	Fe	Cr	Cu	Cd	Ni
Near-highway																				
Site 2																				
Topsoil	7.1	5	40	440	1.0	23	50	100	2,200	225	35	21	65	510	110	24,000	46	34	0.4	54
Substrate	7.1	5	10	480	ND	7.6	70	118	2,000	300	25	4.0	12	72	75	30,000	52	39	0.4	63
Site 3																				
Topsoil	7.5	6	65	560	3.2	94	70	118	2,530	300	50	63	65	480	81	28,500	48	37	0.4	59
Substrate	7.9	8	25	440	ND	21	53	100	3,900	275	40	12	91	31	69	30,000	51	38	0.4	60
Right-of-way																				
Site 1																				
Topsoil	6.6	5	30	1,300	18	13	70	170	2,450	175	60	127	12	340	152	30,000	53	44	0.6	67
Substrate	6.8	5	10	840	3.7	4.2	53	115	2,250	250	40	43	8.0	40	84	31,000	52	45	0.4	71
Site 4																				
Topsoil	6.8	6	25	1,500	ND	9.6	85	335	2,450	250	25	26	24	270	113	32,300	52	41	0.5	65
Substrate	7.2	5	10	600	ND	3.2	48	173	2,030	300	20	3.0	6.8	27	71	29,000	54	41	0.2	67
Site 5																				
Topsoil	6.7	4	20	1,060	8.2	9.2	88	405	1,500	325	15	38	14	68	74	27,000	50	36	0.5	56
Substrate	7.0	5	10	560	ND	2.1	113	325	1,700	325	15	3.5	5.8	41	82	29,000	54	40	0.4	59
Background																				
Site 6																				
Topsoil	6.8	5	25	1,480	4.1	14	118	630	1,700	275	15	14	9.3	32	77	27,000	53	35	0.4	62
Substrate	6.9	4	20	760	1.0	5.2	113	370	1,700	275	15	1.5	7.5	21	83	33,000	58	48	0.5	68

ND = Not detectable.

Concentrations for the remaining metals showed no distinct pattern between near highway, right-of-way, and background soil samples.

At the Harrisburg I-81 site, soil samples were obtained on September 5, 1979, and on May 29, 1980. The fall data (Table 150) show that pH for the near-highway and median soil samples were neutral to slightly basic (pH 6.9 to 8.2), while right-of-way and background samples were slightly acid (pH 5.3 to 6.5). CEC's showed no distinct pattern, while soluble salts were higher near the highway. Nutrients were generally higher in the topsoil layer. Except for calcium, no definite pattern is apparent when values near the highway are compared to right-of-way and background samples. Calcium concentrations were elevated for topsoil layers near the highway. Similar to Milwaukee, sodium concentrations were an order of magnitude higher near the highway while chlorides did not display this pattern. Metals concentrations were generally higher in the topsoil layers than substrate layers and were higher for near-highway samples compared to median, right-of-way, and background samples.

The spring soils data at the Harrisburg I-81 site (Table 151) are generally comparable to the fall data. Similar to the Milwaukee results, chlorides appeared to have reached background levels (fall levels) for most sampling locations by the time the spring samples were obtained (May 29, 1980).

At the Efland I-85 site, soil samples were obtained on September 24, 1981. The soils data (Table 152) show that the pH was slightly acid at all sampling locations (5.0 to 6.5). CEC's and soluble salts showed no distinct pattern. Except for TKN, nutrient concentrations appeared low compared to the other three sites. Similar to the other sites, calcium and chloride showed no accumulation pattern, while sodium was an order of magnitude higher near the paved highway surface. Lead and zinc concentrations were highest for the near- highway topsoil samples. The remaining metals showed no distinct accumulation pattern, and most values appeared to be close to background.

In general, the soil metals data are consistent with those observed by other researchers. Getz, et al. (71) observed that lead concentrations were highest in topsoil layers (10 cm) and decreased sharply with distance from the edge of the pavement, with lead concentrations approaching background levels at 20-50 m for high ADT sites and 5-10 m for low ADT sites (less than 2,000 vehicles/day) along Illinois highways. Motto, et al. (72) also observed that the accumulation of lead in topsoil layers (15 cm) was approximately twice that in substrate layers (15-30 cm), and that concentrations of lead in the topsoil layer decreased with distance from the edge of the pavement for several New Jersey highways. Scanlon (63) observed that Pb, Zn, Cd, and Ni approached background levels at the 48 m for most highway sites which were sampled in Virginia.

Results of the one centimeter soil study (Figures 14 through 19) were discussed earlier in this section in relationship to defining the area

Table 150. Chemical properties of soils at the Harrisburg I-81 site - fall 1979.

Plot location	Soil layer depth, cm	pH	CEC, me/100 g	Soluble salts, mhos 10^{-5}/cm	Concentration, mg/kg dry weight																	
					TKN	NH_4	NO_3	P	K	Ca	Mg	Na	Cl	SO_4-S	Pb	Zn	Fe	Cr	Cu	Cd	Ni
Near-highway																					
Site 2																					
Topsoil	10.2	8.0	14	22	1,640	16.0	15.0	1	103	3450	125	280	35.0	27.8	380	176	33,900	39	41	1.5	35
Site 3																					
Topsoil	10.2	8.2	15	24	1,720	19.7	17.5	9	90.0	3870	125	645	65.0	28.3	336	202	34,900	28	40	2.3	36
Median																					
Site 1																					
Topsoil	10.2	7.5	16	24	1,260	21.4	22.5	11	105	2650	225	33	48.0	10.8	47	87	33,800	21	18	0.5	31
Substrate	20.3	6.9	15	10	560	17.5	17.5	17	82.5	2750	100	65	31.0	3.5	23	74	31,500	18	15	0.4	28
Right-of-way																					
Site 4																					
Topsoil	10.2	6.5	14	20	1,920	17.7	25.5	9	138	2500	250	50	31.5	10.3	40	87	37,000	21	24	0.4	30
Substrate	20.3	5.5	14	10	560	16.4	18.1	21	11	2250	250	40	26.0	11.0	23	86	44,500	28	39	0.4	35
Site 5																					
Topsoil	10.3	5.3	10	10	1,180	18.4	17.3	26	163	1500	150	30	32.0	7.8	39	105	45,000	19	20	0.4	29
Substrate	20.3	5.3	6	10	360	15.6	15.1	34	105	1280	150	33	21.0	3.3	27	69	33,000	18	230	0.4	26
Background																					
Site 6																					
Topsoil	10.2	5.4	9	10	1,540	16.8	16.2	10	87.5	1525	100	20	21.0	10.8	37	89	33,000	18	14	0.4	27
Substrate	20.3	5.5	8	10	720	16.2	15.6	30	45.0	1200	125	18	14.0	6.3	24	82	32,000	17	15	0.4	25

[a] Substrate consisted of the gravel sub-base.

Table 151. Chemical properties of soils at the Harrisburg I-81 site - spring 1980.

Plot location	Soil layer depth, cm	pH	CEC, me/100g	Soluble salts, mhosx10^{-5}/cm	Concentration, mg/kg dry weight																	
					TKN	NH_4	NO_3	P	K	Ca	Mg	Na	Cl	SO_4-S	Pb	Zn	Fe	Cr	Cu	Cd	Ni
Near-highway[a]																					
Site 2																					
Topsoil	10.2	7.6	21	20	1,390	ND	1.6	17	103	3900	175	265	41.0	23.8	146	114	42,400	37	79	1.5	35
Site 3																					
Topsoil	10.2	7.8	20	37	1,840	ND	1.1	19	90	3600	200	630	144	35.3	379	271	50,100	61	68	2.7	49
Median																					
Site 1																					
Topsoil	10.2	7.1	13	10	1,180	0.6	ND	21	90	2250	225	30	13.0	0.5	69	117	45,100	38	43	1.0	41
Substrate	20.3	6.9	10	10	1.860	1.7	ND	6.5	75	1750	150	75	10.0	3.25	32	91	36,000	38	27	1.0	33
Right-of-way																					
Site 4																					
Topsoil	10.2	6.3	13	25	1,830	8.5	25	37.5	185	2100	275	30	67.0	19.5	49	116	52,300	48	50	0.9	44
Substrate	20.3	6.0	14	10	420	0.6	2.3	4	100	2250	250	40	15.5	57.5	16	102	62,500	49	51	1.1	43
Site 5																					
Topsoil	10.2	5.7	9	10	1,510	ND	ND	8	190	1500	175	15	9.5	3.5	43	189	42,000	39	32	1.1	32
Substrate	20.3	5.8	11	10	140	ND	ND	2.5	125	1900	200	20	7.0	2.0	26	123	63,800	51	49	1.0	57
Background																					
Site 6																					
Topsoil	10.2	5.4	7	10	1,490	ND	ND	7.5	97.5	1200	150	15	9.0	5.75	66	170	79,600	53	47	1.5	65
Substrate	20.3	5.5	6	10	670	ND	ND	2.5	52.5	1050	125	15	4.5	5.75	29	36	43,800	36	25	1.1	36

[a] Substrate consisted of the gravel sub-base.

ND = Not detectable.

Table 152. Chemical properties of soils at the Efland I-85 site - fall 1981.

Plot location	pH	CEC, me/ 100 g	Soluble salts, mhos $\times10^{-5}$ /cm	Concentration, mg/kg																	
				TKN	NH_4	NO_3	P	K	Ca	Mg	Na	Cl	SO_4-S	Pb	Zn	Fe	Cr	Cu	Cd	Ni
Site 1																					
Topsoil	6.4	7.9	15	1,340	1.0	5.0	3.0	53.0	1000	340	30.0	15.5	2.5	16	53	46,500	27	30	0.37	7.8
Substrate	5.4	5.9	10	605	1.0	1.5	1.5	35.0	675	295	40.0	7.5	8.0	12	78	37,000	9.3	22	0.17	4.6
Site 2																					
Topsoil	6.5	6.2	15	1,080	2.0	1.5	2.5	100	700	300	20.0	26.5	7.5	13	24	90,000	6.5	35	0.20	6.0
Substrate	5.3	3.4	10	315	1.0	1.5	1.5	65.0	325	190	12.5	23.0	23.8	9.6	20	84,000	6.9	34	0.24	5.1
Site 3																					
Topsoil	5.4	3.9	10	550	3.0	3.0	3.0	82.5	400	200	25.0	17.5	23.8	18	27	82,000	8.8	32	0.33	8.3
Substrate	5.1	2.8	10	240	1.5	1.5	1.5	57.5	275	160	32.5	47.0	19.3	12	34	99,000	9.4	36	0.41	7.0
Site 4																					
Topsoil	6.4	6.2	15	1,720	1.5	2.0	12	85.0	900	175	200	13.5	9.5	1200	235	41,500	18	38	0.80	20
Substrate	5.0	4.3	25	245	0.5	ND	3.0	65.0	625	125	70.0	20.5	74.5	45	99	59,000	17	41	0.50	7.4
Site 5																					
Topsoil	6.5	10.6	10	540	1.5	3.5	6.0	55.0	1250	510	225	14.0	5.8	85	74	33,000	15	27	0.41	12
Substrate	5.5	11.2	20	65	ND	2.0	2.5	47.5	1030	725	220	36.0	36.8	12	57	39,000	19	31	0.24	14
Site 6																					
Topsoil	5.7	5.3	15	1,450	3.0	7.0	40	165	600	225	5.0	5.0	3.3	16	34	56,000	45	25	0.33	14
Substrate	6.3	4.3	10	635	2.0	1.0	4.0	90	500	190	5.0	2.5	5.5	14	33	61,000	39	28	0.25	16

ND = Not detectable.

impacted by atmospheric deposition of metals originating from the highway surface. This data is consistent with the soil core data discussed above and showed that the area impacted by atmospheric deposition of metals was approximately 35 m from the edge of the pavement at Milwaukee and Sacramento (116,000 and 85,900 vehicles/day respectively), 15 m at Harrisburg (27,800 vehicles/day) and 12 m at Efland (25,300 vehicles/day). Laxen and Harrison (8) observed that lead deposition from highway sources is confined to a strip of land roughly 30 m wide to either side of the highway. They also observed that lead is effectively immobilized within the top few centimeters of soil and that this lead causes an insignificant contribution to water pollution. Zimdahl (65) also found that lead in the top centimeter of soil along I-25 in Colorado approached background at 30 m. Wang, *et al.* (73) performed surface soil (upper 1 cm) studies of metal concentrations at three highway sites in the State of Washington. Their data suggested that there is little movement of metals once they are deposited on the ground and that background levels were approached at 15 m from the edge of the pavement at all three sites.

Vegetation

Vegetation studies were performed to determine pollutant accumulation in roadside vegetation. A vegetation sample was obtained at each soil core sampling location (Figures 46 through 49). Vegetation samples were divided into three components:

1. Above ground vegetation - those vegetative structures which were removed by clipping at ground level.
2. Litter - those vegetative structures which have abscised from the plant and accumulated on the ground surface but which had not decomposed to the point of being incorporated into the soil profile.
3. Belowground vegetation - those vegetative structures which were removed by excavating the soil.

Table 153 lists the predominant species found at each sampling location for the sites monitored. At the Milwaukee I-94 site, near-highway sampling locations no. 1 and 3, which were closest to the paved highway surface, were predominantly inhabited by squirreltail grass (*Hordeum jubatum*), quack grass (*Agropyron repens*), bindweed (*Convolvulus arvensis*), and chickory (*Cichorium intybus*). These species are frequently found along roadsides in Wisconsin (74) and are considered pioneer species. Pioneer species are those which initially inhabit disturbed or harsh environments. The predominance of these four species in near highway sampling locations indicates the existence of a harsh environment. The Milwaukee soils data (Table 146 and 147) showed that these sampling locations were high in metals. The predominant species at the remaining sampling locations was blue grass (*Poa pratensis*). Sampling location no. 6 at the Milwaukee site contained several herbaceous species including: lamb's quarters (*Chenopodium album*), bird's-foot trefoil (*Lotus*

Table 153. Predominant of species vegetation at the sites monitored.

	Milwaukee I-94
Plot location	Species
Near-highway	
Site 1	Squirreltail grass, quack grass, bindweed, chickory
Site 3	Squirreltail grass, quack grass, bindweed, chickory
Site 5	Blue grass
Right-of-way	
Site 2	Blue grass
Site 4	Blue grass
Site 6	Blue grass, mixed herbaceous species
Background	
Site 7	Blue, quack grass
Site 8	Blue, quack grass

	Sacramento Hwy 50
Plot location	Species
Near-highway	
Site 2	No vegetation
Site 3	No vegetation
Right-of-way	
Site 1	Mixed grass
Site 4	Mixed grass, star thistle
Site 5	Mixed grass
Background	
Site 6	Mixed grasses, star thistle

Table 153. Predominant of species vegetation at the sites monitored (continued).

Harrisburg I-81	
Plot location	Species
Near-highway	
Site 2	Quack grass
Site 3	Quack grass
Median	
Site 1	Blue, quack grass
Right-of-way	
Site 4	Vetch
Site 5	Mixed herbaceous
Background	
Site 6	Mixed herbaceous

Efland I-85	
Plot location	Species
Near-highway	
Site 4	Mixed grass
Site 5	Mixed grass
Right-of-way	
Site 1	Mixed grass
Site 2	Mixed grass
Site 3	Mixed grass
Background	
Site 6	Mixed grass

corniculatus), butter and eggs (Linaria vulgaris), wild aster (Aster parviceps), and goat's beard (Tragopogon dubius).

At the Sacramento Hwy 50 site no vegetation grew near the highway (Table 153). This would be expected based upon the soils data (Tables 143 and 149) which indicated that the soils next to the highway were sandy, low in organic matter, high in soluble salts, low in nutrients, and high in lead and zinc. Predominant species at the remaining sampling locations were mixed grass species and star thistle (Centaurea sp.).

At the Harrisburg I-81 site, the predominant near highway species was quack grass (Table 153). The median area was inhabited by a blue grass and quack grass mixture. The berm next to the drainage ditch (Figure 49) was covered by vetch (Vicia sp.). The near edge of right-of-way location (no. 5) and background location contained similar species including: goldenrod (Solidago sp.), wild strawberry, poison ivy (Rhus radicans), and wild onion (Allium tricoccum).

At the Efland I-85 site, all sampling locations consisted of mixed grass species (Table 153).

Biomass--

Biomass is the oven-dried weights of the aboveground and belowground vegetation samples/unit area. Biomass data for the vegetation samples collected at the monitoring sites are presented in Table 154. At the Milwaukee I-94 site, spring values were generally lower than fall. This would be expected because peak standing crop occurs in the fall. No distinct pattern is evident when near-highway samples are compared to right-of-way and background samples. Biomass values for fall samples ranged from 4.4 to 10.9 metric tons/hectare (Tm/ha). The biomass production at the Milwaukee I-94 site, including the near-highway vegetation, is similar to an old field community of tallgrass prairie, 3.12 to 10.03 Tm/ha/yr (75, 76, 77). Biomass production at the Sacramento Hwy 50 site was very high. At Harrisburg, no distinct pattern was observed between near-highway and right-of-way or background biomass values and the values were also in the range for old field communities or tall grass prairies. At Efland, near-highway samples had approximately twice the biomass as background and right-of-way samples.

Litter--

Litter is the dead vegetation which accumulates on the ground surface but has not decomposed to the point of being incorporated into the soil profile. The litter load (Tm/ha) at the sites monitored is presented in Table 155. Although biomass production at the Milwaukee I-94 site was slightly higher in the right-of-way samples, litter load was highest near the highway. The

Table 154. Vegetation biomass[a] (Tm/ha) at sites monitored.

Milwaukee I-94				
Plot location	Fall, 1978	Spring, 1979	Fall, 1979	Spring, 1980
Near-highway				
Site 1	6.7	2.6	5.2	2.5
Site 3	7.0	6.0	5.6	4.5
Site 5	8.2	5.8	8.3	4.2
Right-of-way				
Site 2	10.9	4.7	6.1	3.1
Site 4	7.7	7.5	7.7	5.1
Site 6	9.2	6.2	10.8	5.8
Background				
Site 7	NA	4.6	4.8	7.8
Site 8	NA	NA	4.4	4.4

Sacramento Hwy 50	
Plot location	Fall, 1979
Near-highway	
Site 2	No vegetation
Site 3	No vegetation
Right-of-way	
Site 1	10.8
Site 4	10.3
Site 5	14.3
Background	
Site 6	10.5

[a] Aboveground and belowground production.

NA = Samples were not obtained.

Table 154. Vegetation biomass[a] (Tm/ha) at sites monitored (continued).

Plot location	Harrisburg I-81 Fall, 1979	Spring, 1980
Near-highway		
Site 2	3.9	4.3
Site 3	5.7	5.3
Median		
Site 1	5.5	3.0
Right-of-way		
Site 4	8.5	2.3
Site 5	3.9	2.9
Background		
Site 6	4.3	5.6

Plot location	Efland I-85 Fall, 1981
Near-highway	
Site 4	8.9
Site 5	10.6
Right-of-way	
Site 1	4.9
Site 2	5.1
Site 3	4.8
Background	
Site 6	5.0

[a] Aboveground and belowground production.

NA = Samples were not monitored.

Table 155. Litter load (Tm/ha) at the sites monitored.

Milwaukee I-94				
Plot location	Fall, 1978	Spring, 1979	Fall, 1979	Spring, 1980
Near-highway				
Site 1	3.7	1.5	5.3	3.0
Site 3	6.6	1.7	3.5	2.6
Site 5	3.1	1.8	1.6	3.5
Right-of-way				
Site 2	1.4	1.2	0.8	0.8
Site 4	1.0	1.3	1.4	1.5
Site 6	1.2	1.4	1.3	1.7
Background				
Site 7	NA	1.5	1.6	1.2
Site 8	NA	NA	2.0	2.1

Sacramento Hwy 50	
Plot location	Fall, 1979
Near-highway	
Site 2	No vegetation
Site 3	No vegetation
Right-of-way	
Site 1	8.6
Site 4	6.7
Site 5	6.0
Background	
Site 6	7.8

NA = Samples were not obtained.

Table 155. Litter load (Tm/ha) at the sites monitored (continued).

Harrisburg I-81		
Plot location	Fall, 1979	Spring, 1980
Near-highway		
Site 2	0.0	0.0
Site 3	1.8	0.0
Median		
Site 1	1.8	2.9
Right-of-way		
Site 4	5.2	0.0
Site 5	3.7	0.0
Background		
Site 6	2.9	3.4

Efland I-85	
Plot location	Fall, 1981
Near-highway	
Site 4	10.0
Site 5	11.5
Right-of-way	
Site 1	9.9
Site 2	6.5
Site 3	5.7
Background	
Site 6	7.7

difference in litter buildup is probably due to a difference in litter decomposition rates between the two areas. A possible explanation would be that high levels of pollutants in the soil and plant tissue near the highway's edge, especially heavy metals and soluble salts, may decrease the number and activity of the microorganisms involved in the decomposition of plant tissue. As previously discussed, no vegetation grew near the paved highway surface at Sacramento. However, biomass production and associated litter production at the remaining sampling locations was high. Soils data for Sacramento (Table 143) indicated low organic matter content. Either total decomposition of the litter occurs during the winter and summer periods or wind erosion removes the litter before it can be incorporated into the soil profile as organic matter. In general, litter values at the Harrisburg I-81 site were low (Table 155), and the data are difficult to interpret. At Efland, litter load was high and showed no distinct pattern.

Pollutant accumulation--

Mean concentrations for nutrients, metals, sodium, and chlorides in fall vegetation samples obtained at the Milwaukee I-94 site are presented in Tables 156 through 158. For aboveground vegetation (Table 156), no distinct pattern of nutrient concentration (TKN, PO_4-P, Ca, Mg, and K) is apparent except that background levels are slightly higher. These nutrient concentrations are generally in the range of values reported for Wisconsin grass and prairie species growing in relatively unpolluted environments (Table 159). The average to high nutrient concentrations for plants growing at the Milwaukee I-94 site are not surprising since the vegetation growing there appeared dense [high biomass (Table 154)] and healthy. Metal concentrations, except for cadmium, copper, and nickel, were generally higher for aboveground vegetation samples taken near the highway (Table 156). In a review article, Smith (78) reported that lead concentration in grasses strongly varied inversely with sampling distance normal to the roadway. Concentrations for Fe, Cu, and Zn were generally in the range of values reported for Wisconsin grass and prairie species (Table 159). Lead concentrations for aboveground vegetation at the Milwaukee I-94 site are in the lower region of values for grasses growing close to the roadway reported by Smith (Table 159). Only the aboveground samples obtained from sampling location no. 5 exceeded the range of sodium values reported for Wisconsin prairie species (Table 159). Sodium values for aboveground vegetation were also generally lower than the range of sodium values for an Ohio highway, 450 to 5,450 mg/km (July values), reported by Drysdale and Brenner (79). Chloride values for near-highway and right-of-way samples were within the range of values reported for Wisconsin grass and prairie species, while background values were somewhat higher. Arsenic was detectable in one sample.

Data for belowground vegetation at Milwaukee (Table 157) show no distinct pattern for nutrient concentration for samples taken near the highway versus right-of-way and background samples. Near-highway metals concentrations were generally higher than right-of-way or background values. Sodium concentrations were highest for near-highway samples while chlorides showed no distinct pattern. Metal and sodium concentrations in belowground samples were

Table 156. Chemical analyses of aboveground vegetation at the Milwaukee I-94 site - mean values for fall 1978 and 1979.

Plot location	Concentration, mg/kg dry weight																VTS, percent	Ash content, percent
	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Al	As[a]	Na	Cl	Ni[b]		
Near-highway																		
Site 1	14,200	2,140	3,790	1,460	14,500	601	69	75	ND	2.0	9.1	188	ND	300	7,500	ND	91.9	8.1
Site 3	16,500	1,820	4,670	1,680	14,600	785	82	120	0.4	2.4	15.0	215	0.26	222	6,100	ND	91.5	8.5
Site 5	10,600	3,110	3,000	1,020	10,800	539	37	110	ND	1.7	9.5	158	ND	730	5,650	ND	91.5	8.5
Right-of-way																		
Site 2	6,930	2,500	5,150	1,350	10,400	274	21	31	ND	1.2	5.1	106	ND	62	4,600	ND	90.5	9.5
Site 4	9,430	2,420	4,690	1,340	12,600	458	47	60	0.4	1.6	9.6	146	ND	126	5,900	1.5	89.3	10.7
Site 6	11,600	3,320	3,550	2,650	18,900	345	23	32	ND	1.1	5.8	111	ND	256	7,780	1.3	87.9	12.1
Background																		
Site 7[b]	24,600	3,260	5,600	2,300	25,000	410	41	19	0.3	0.7	13.0	170	NA	110	10,400	1.7	89.0	11.0
Site 8[b]	20,600	3,750	8,900	2,400	21,000	1200	64	31	0.5	2.1	13.0	930	NA	79	8,500	2.4	84.9	15.1

[a] Fall 1978 only.

[b] Fall 1979 only.

NA = No analysis.
ND = Not detectable.

Table 157. Chemical analyses of belowground vegetation at the Milwaukee I-94 site - mean values for the fall 1978 and 1979.

Plot location	Concentration, mg/kg dry weight																VTS, percent	Ash content, percent
	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Al	As[a]	Na	Cl	Ni[b]		
Near-highway																		
Site 1	16,700	3,030	7,500	2,730	6,150	2,530	322	219	2.0	5.9	50	1,880	0.41	1,980	2,350	4.7	86.4	13.6
Site 3	14,800	2,750	8,950	2,900	5,650	2,200	385	383	3.1	4.9	89	1,030	0.89	1,230	2,200	5.1	90.6	9.4
Site 5	8,550	2,770	3,800	1,150	6,550	1,440	77	58	0.7	2.8	22	1,140	ND	2,530	2,850	2.3	89.1	10.9
Right-of-way																		
Site 2	7,060	2,520	6,230	1,330	6,200	1,530	69	28	ND	2.5	24	1,270	0.65	100	1,000	1.7	91.3	8.7
Site 4	7,700	2,040	6,950	1,400	5,350	1,570	72	45	0.9	2.6	25	1,480	0.94	175	1,010	1.6	89.1	10.9
Site 6	8,250	2,260	5,800	1,990	7,650	1,920	73	14	0.3	3.2	43	1,680	ND	248	2,950	3.6	87.6	12.4
Background																		
Site 7[b]	16,500	2,230	5,100	1,300	9,300	960	63	18	0.4	1.8	16	870	NA	84	2,300	3.3	90.1	9.9
Site 8[b]	10,800	2,300	4,900	1,500	8,700	970	87	40	0.4	3.2	84	760	NA	81	2,800	3.1	89.2	10.8

[a] Fall 1978 only.

[b] Fall 1979 only.

NA = No analysis.
ND = Not detectable.

Table 158. Chemical analyses of litter at the Milwaukee I-94 site - mean values for fall 1978 and 1979.

	Concentration, mg/kg dry weight																	
Plot location	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Al	As[a]	Na	Cl	Ni[b]	VTS, percent	Ash content, percent
Near-highway																		
Site 1	14,900	1620	13,700	2260	6240	5900	319	815	4.7	14	71	2940	1.63	341	3200	5.0	82.0	18.0
Site 3	16,200	2130	46,700	10,500	6950	7200	380	1060	2.3	16	95	1800	1.94	320	3000	5.2	77.6	22.4
Site 5	7900	1740	8200	3670	3770	3110	119	494	1.1	6.8	38	1230	1.71	353	1550	1.7	86.9	13.1
Right-of-way																		
Site 2	9550	1330	8250	2620	3690	3050	84	265	ND	5.9	19	1620	0.51	100	1380	2.2	82.7	17.3
Site 4	9950	1660	10,300	3130	4320	4050	111	332	0.53	7.1	28	2110	1.22	104	1900	5.2	79.7	20.3
Site 6	9550	1780	6060	3130	5500	2750	56	116	0.61	4.7	13	1760	1.03	149	2450	4.2	82.7	17.3
Background																		
Site 7[b]	21,900	3000	7000	2400	22,000	900	44	24	ND	1.5	14	510	NA	112	8200	1.7	88.0	12.0
Site 8[b]	14,700	2100	19,000	3500	10,000	2600	60	42	ND	2.5	13	1500	NA	94	3100	4.2	83.0	17.0

[a] Fall 1978 only.

[b] Fall 1979 only.

NA = No analysis.
ND = Not detectable.

Table 159. Literature values for concentrations of selected parameters in aboveground vegetation.

	Range of reported concentrations, mg/kg dry weight										
Vegetation type	TKN	TPO_4	Ca	Mg	K	Fe	Cu	Zn	Cl	Na	Pb	Ref. no.
Wisconsin grass species	2,500-21,100	800-2,800	1,500-5,800	700- 4,000	4,400-12,300	27-215	1.1-6.8	10.2-53.3	380-3,978	-		85
Wisconsin prairie species	9,700-22,800	900-2,800	1,500-14,800	1,300-11,800	6,100-37,300	54-2,818	1.8-10.0	12.4-157.6	32-7,522	10-697		85
Grass unpolluted											1-5	86
Grass close to roadway											50-1,000	

higher than aboveground samples, while chloride concentrations were higher in aboveground samples.

Earlier, it was hypothesized that high levels of pollutants in the soil and plant tissue near the highway's edge may decrease the number and/or activity of the microorganisms involved in the decomposition of plant tissue. Both the soils data (Tables 146 and 147) and the litter data (Table 158), especially for Pb, Zn, Cu, Cd, and Na, appear to support this hypothesis. Also, the arsenic concentrations of the litter collected near the highway was higher than the litter samples collected near the edge of the right-of-way (Table 158).

Mean concentrations for selected parameters in fall vegetation samples obtained at the Milwaukee I-94 site are presented in Tables 160 through 162. In general, fall and spring concentration values are similar. Notable exceptions were TKN and K which were higher in spring aboveground vegetation (Table 160). This would be expected because larger quantities of most nutrients are needed to support the rapid spring growth. Elevated chloride values were also observed in the aboveground vegetation sampled in spring (Table 160). Apparently the new spring growth assimilated large quantities of chlorides which are readily available in the early spring soils. As the growing season progresses and the soil chloride concentration drops, the highly soluble chlorides are probably removed from the plant through transpiration and/or root exudation.

Results of the analyses of vegetation samples collected at the Sacramento Hwy 50 site during the fall, 1979 are presented in Tables 163 through 165. As previously discussed, the near-highway sampling locations were void of vegetation. This would be expected based upon the soils data (Tables 143 to 149) which indicated that the soils next to the highway were sandy, low in organic matter, high in soluble salts, low in nutrients, and high in lead and zinc. Concentrations of aboveground vegetation obtained from the drainage ditch (no. 1 and 4) had elevated Zn, Pb, and Cu concentrations compared to right-of-way location no. 5 and the background location. Except for Cu, this pattern was consistent with the soils data (Table 149). Above-ground vegetation samples obtained in the right-of-way had higher chloride concentrations than the background samples. All metals concentrations of belowground vegetation obtained from the drainage ditch (no. 1 and 4) were high compared to the remaining locations (Table 164). For litter, the concentrations of Pb, Zn, and Cd were highest for drainage ditch samples (Table 165).

Data for the fall vegetation collected at the Harrisburg I-81 site are presented in Tables 166 through 168. Data for aboveground vegetation (Table 166) show no distinct pattern for nutrient concentrations. Metal concentrations were generally higher for the near-highway and median samples than for the right-of-way and background samples. All zinc concentrations for aboveground vegetation, including the background sample, were higher than the near-highway samples at Milwaukee (Table 156). This is surprising because the

Table 160. Chemical analyses of aboveground vegetation at the Milwaukee I-94 site - mean values for spring 1979 and 1980.

	Concentration, mg/kg dry weight																	Ash
Plot location	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Al	As[a]	Na	Cl	Ni	VTS, percent	content, percent
Near-highway																		
Site 1	20,700	2,260	5,580	773	54,800	368	55	58	1.0	1.8	8.6	187	0.04	295	12,600	ND	85.7	14.3
Site 3	25,100	2,320	5,630	905	44,600	560	67	109	1.8	3.0	13.0	253	0.05	581	13,500	ND	85.3	14.7
Site 5	15,500	2,270	4,800	1,290	32,600	902	50	128	ND	3.5	13.7	450	0.40	1,020	11,400	6.8	87.0	13.0
Right-of-way																		
Site 2	16,500	1,970	4,750	1,070	15,000	705	42	56	0.6	2.3	11.6	379	0.18	122	6,140	ND	90.1	9.9
Site 4	16,600	1,870	16,000	2,010	21,400	1890	52	97	ND	3.5	10.2	1740	0.13	132	5,700	8.0	83.4	16.6
Site 6	17,500	2,250	6,680	1,380	26,000	628	39	65	ND	2.4	7.8	382	0.12	224	7,250	8.2	86.6	13.4
Background																		
Site 7	23,700	3,150	5,440	1,360	27,000	474	41	32	ND	1.5	11.3	188	1.10	123	10,500	ND	90.0	10.0
Site 8	22,800	2,960	21,800	1,370	38,100	670	60	40	1.4	2.5	3.0	480	NA	70	6,200	2.5	84.0	16.0

[a] Spring 1979 only.

[b] Spring 1980 only.

Table 161. Chemical analyses of vegetation belowground at the Milwaukee I-94 site - mean values for spring 1979 and 1980.

	Concentration, mg/kg dry weight																	Ash
Plot location	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Al	As[a]	Na	Cl	Ni	VTS, percent	content, percent
Near-highway																		
Site 1	8,650	1,370	7,850	3,740	5,700	5,050	326	237	1.4	11	76	2,710	1.61	2,340	3,390	10	85.2	14.8
Site 3	10,500	1,660	19,400	7,920	5,980	8,460	420	630	4.7	19	139	3.150	1.67	2,190	3,750	ND	78.8	21.2
Site 5	8,900	1,700	7,330	3,150	6,070	3,780	113	108	1.1	6.4	82	2,030	0.75	2,040	4,140	8.1	88.6	11.4
Right-of-way																		
Site 2	7,450	1,600	11,100	4,050	5,920	5,660	75	54	1.5	5.9	30	3,760	1.28	215	1,980	11	83.4	16.6
Site 4	7,800	1,220	13,500	1,690	5,130	10,400	107	144	1.8	11	43	6,650	3.37	251	1,810	13	71.8	28.2
Site 6	11,500	1,410	8,960	4,040	7,150	7,360	89	50	0.9	9.1	27	2,520	2.62	228	2,540	9.5	74.0	26.0
				6,570														
Background				11,500														
Site 7	11,300	1,930	10,200	6,570	10,500	5,750	114	88	1.2	12	14	7,270	0.93	208	2,050	15	69.2	30.8
Site 8	8,200	1,670	22,400	11,500	4,700	11,500	160	160	1.5	12	35	7,500	NA	224	1,130	14	58.6	41.4

[a] Spring 1979 only.

[b] Spring 1980 only.

NA = No analysis.
ND = Not detectable.

Table 162. Chemical analyses of litter at the Milwaukee I-94 site - mean values for spring 1979 and 1980.

Plot location	Concentration, mg/kg dry weight																	VTS, percent	Ash content, percent
	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Al	As[a]	Na	Cl	Ni			
Near-highway																			
Site 1	14,400	1090	15,800	2950	4630	2830	207	528	6.2	11	62	1790	0.76	457	2500	14		83.4	16.6
Site 3	13,100	1180	23,100	5330	6840	5300	270	568	2.6	15	90	2220	1.52	448	3100	ND		78.9	21.1
Site 5	10,900	995	29,300	5540	3720	5640	217	790	18	16	90	2810	2.74	506	2250	12		77.8	22.2
Right-of-way																			
Site 2	9700	1040	10,500	4550	3160	7520	92	210	1.1	9.7	29	4630	1.10	152	1410	13		75.3	24.7
Site 4	8550	1070	11,500	5790	3730	8970	130	290	1.7	13	48	6930	2.01	177	1770	14		71.9	28.1
Site 6	17,700	1010	15,100	1930	5020	3020	75	134	ND	6.2	14	2800	1.33	107	2050	11		80.5	19.5
Background																			
Site 7	17,300	2400	33,600	4500	12,600	3140	113	137	2.7	9.9	16	3030	1.95	164	2350	7.0		80.3	19.7
Site 8[b]	16,000	1630	72,400	10,500	17,500	7350	135	175	1.6	19	11	7000	NA	175	1850	14		55.7	44.3

[a] Spring 1979 only.

[b] Spring 1980 only.

NA = No analysis.
ND = Not detectable.

Table 163. Chemical analyses of aboveground vegetation at the Sacramento I50 site - fall 1979.

Plot location	Concentration, mg/kg dry weight														VTS, percent	Ash content, percent
	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Ni	Al	Na	Cl	
Near-highway																
Site 2[a]																
Site 3[a]																
Right-of-way																
Site 1	7100	1000	4170	7820	7920	750	71.0	63.0	0.28	2.64	3.47	4.2	646	292	5700	74.9	25.1
Site 4	8100	1900	8420	2210	11,300	1620	64.9	155	0.46	5.10	5.41	6.2	1700	201	2800	79.3	20.7
Site 5	12,600	1100	4270	2860	9900	1050	27.1	44.0	0.31	3.75	2.19	4.2	1290	750	7700	72.6	27.4
Background																
Site 6	8500	1800	6780	1550	11,600	1130	25.5	18.6	0.32	3.30	2.89	5.0	1360	100	1900	78.2	21.8

[a] No vegetation.

Table 164. Chemical analyses of belowground vegetation at the Sacramento I-50 site - fall 1979.

	Concentration, mg/kg dry weight																
Plot location	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Ni	Al	Na	Cl	VTS, percent	Ash content, percent
Near-highway																	
Site 2[a]																	
Site 3[a]																	
Right-of-way																	
Site 1	5,600	1,200	2,370	1,820	5,490	5,220	70.0	144	0.82	13	26.1	14.4	5,180	309	1400	65.4	34.6
Site 4	12,400	1,500	947	3,660	2,850	11,500	247	1180	2.04	28	18.2	33.3	12,900	247	400	55.0	45.0
Site 5	11,300	1,100	1,610	1,210	5,320	2,870	18.5	18.5	0.36	6.5	1.19	7.2	2,540	346	1300	69.2	30.8
Background																	
Site 6	7,000	1,200	4,080	677	9,240	698	23.6	11.8	0.43	1.9	2.00	3.2	924	355	2500	78.3	21.7

[a] No vegetation.

Table 165. Chemical analyses of litter at the Sacramento I-50 site - fall 1979.

	Concentration, mg/kg dry weight																
Plot location	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Ni	Al	Na	Cl	VTS, percent	Ash content, percent
Near-highway																	
Site 2[a]																	
Site 3[a]																	
Right-of-way																	
Site 1	9,300	1,000	5,430	3,000	4,240	10,200	213	554	1.81	26.6	16.4	30.5	9,960	3.7	1,900	53.7	46.3
Site 4	8,600	1,600	9,990	3,630	6,510	10,400	128	633	1.24	23.6	6.86	26.0	10,200	284	1,300	48.8	51.2
Site 5	7,400	1,300	3,680	4,060	4,640	15,600	67.7	155	0.64	30.0	4.50	29.7	13,540	309	1,350	38.7	61.3
Background																	
Site 6	6,900	1,700	4,870	4,190	4,680	14,400	52.4	44.2	0.52	31.1	7.00	32.9	15,700	225	1,200	38.3	61.7

[a] No litter.

Table 166. Chemical analyses of aboveground vegetation at the Harrisburg I-81 site - fall 1979.

Plot location	Concentration, mg/kg dry weight															VTS, percent	Ash content, percent
	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Ni	Al	Na	Cl		
Near-highway																	
Site 2	14,700	3,900	9,900	2,700	19,800	700	120	70	0.7	2.0	13	3.6	450	395	7,400	89.8	10.2
Site 3	17,300	3,790	5,900	2,400	26,700	535	103	29	0.6	1.3	6.3	1.9	380	2500	16,900	87.4	12.6
Median																	
Site 1	13,200	2,700	5,700	1,300	13,600	650	60	75	0.3	1.6	4.6	3.0	570	35	7,600	92.4	7.6
Right-of-way																	
Site 4	17,600	1,120	17,600	3,950	22,900	86	95	19	0.4	0.9	4.1	1.8	53	71	5,100	88.9	11.1
Site 5	6,800	730	12,700	2,200	14,800	313	89	24	0.5	0.9	4.9	1.7	365	40	3,200	90.8	9.2
Background																	
Site 6	6,000	2,040	11,700	2,300	19,100	125	99	11	1.0	0.9	7.3	1.7	113	40	5,000	93.2	6.8

Table 167. Chemical analyses of belowground vegetation at the Harrisburg I-81 site - fall 1979.

Plot location	Concentration, mg/kg dry weight															VTS, percent	Ash content, percent
	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Ni	Al	Na	Cl		
Near-highway																	
Site 2	9,200	1,810	11,000	2,300	10,200	4,400	176	130	1.6	10	45	7.0	2,500	630	2,800		
Site 3	9,800	2,230	7,900	1,900	7,500	1,450	189	51	2.0	2.7	60	4.6	1,300	1600	5,600	89.8	10.2
Median																	
Site 1	8,900	1,510	8,900	1,500	5,800	2,200	133	70	0.9	2.9	20	3.5	2,700	115	1,300	91.9	8.1
Right-of-way																	
Site 4	23,000	1,060	8,900	1,800	13,600	820	61	7.2	0.3	1.5	9.4	4.4	1,150	82	1,400	92.4	7.6
Site 5	9,400	850	13,600	1,600	13,600	2,050	106	29	2.7	2.6	22	5.1	2,600	100	2,600	91.1	8.9
Background																	
Site 6	7,100	1,120	8,100	1,700	1,100	1,900	110	16	1.2	2.2	33	4.3	2,400	190	2,200	91.6	8.4

Table 168. Chemical analyses of litter at the Harrisburg I-81 site - fall 1979.

Plot location	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Ni	Al	Na	Cl	VTS, percent	Ash content, percent
	Concentration, mg/kg dry weight																
Near-highway																	
Site 3	17,900	2,380	12,800	2,900	9,400	4,000	200	177	1.3	7.2	26	9.0	2,900	920	41,600	85.2	14.8
Median																	
Site 1	8,000	1,350	6,600	1,700	5,100	6,600	82	440	0.6	8.0	16	7.7	5,900	69	1,100	79.5	20.5
Right-of-way																	
Site 4	11,200	430	12,000	1,200	4,400	1,100	103	90	0.7	2.2	9.0	4.4	1,100	24	6,100	92.1	7.9
Site 5	3,600	310	11,200	1,700	3,900	3,400	131	76	2.1	3.6	8.7	4.5	3,500	41	9,100	86.5	13.5
Background																	
Site 6	3,100	620	11,400	3,200	5,200	760	108	28	0.8	1.2	9.2	2.0	780	30	1,800	93.4	6.6

[a] No litter.

Table 169. Chemical analyses of aboveground vegetation at the Harrisburg I-81 site - spring 1980.

Plot location	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Ni	Al	Na	Cl	VTS, percent	Ash content, percent
	Concentration, mg/kg dry weight																
Near-highway																	
Site 2	15,100	3,010	6,050	1,260	39,400	181	26	21	23	2.5	3.4	2.6	171	2100	15,400	78.9	21.1
Site 3	13,300	2,300	5,350	1,160	26,100	340	30	21	1.2	1.7	4.6	1.3	391	2870	15,200	79.1	20.9
Median																	
Site 1	15,700	2,840	10,400	1,370	23,800	465	29	48	3.7	2.1	82	2.0	550	96	9,990	78.8	21.2
Right-of-way																	
Site 4	40,600	4,570	31,000	6,580	55,900	435	53	11	0.9	3.1	16	6.2	273	225	20,900	72.7	27.3
Site 5	19,300	1,290	18,600	4,350	45,600	890	153	25	3.3	3.1	13	6.2	870	83	9,190	82.5	17.5
Background																	
Site 6	9,900	1,600	14,500	2,300	71,600	490	53	12	1.3	2.2	14	3.0	228	87	11,000	90.5	9.5

background zinc concentrations in soils at both sites were comparable (Table 146 and 150), and the zinc concentration of near-highway soil samples were approximately three times higher at Milwaukee. Lead concentrations in fall near-highway samples at Milwaukee ranged from 75 to 120 mg/kg and were higher than those observed at Harrisburg, 29 to 70 mg/kg. This is consistent with the soils data (Tables 146 and 150) which showed that lead concentrations were approximately three to four times higher in the near-highway soil samples at Milwaukee. At Harrisburg, sodium concentrations for aboveground vegetation were highest for near-highway samples, while chloride concentrations were highest for near-highway and median samples.

Concentration of metals in belowground vegetation for near-highway and median samples was generally higher than aboveground vegetation (Table 167). Metal concentrations were generally higher in belowground samples obtained near the highway and in the median, compared to right-of-way and background samples. Sodium and chloride concentrations for below ground samples were also elevated. Similar to aboveground and belowground vegetation, metal and sodium concentrations in litter were generally higher for near-highway and median sampling locations (Table 168).

Results of the spring sampling of vegetation at the Harrisburg I-81 site are presented in Tables 169 through 171. Zinc and lead concentrations for spring aboveground vegetation samples obtained near the highway were very low (Table 169) compared to fall values (Table 166). These data indicate that lead and zinc are accumulated throughout the growing season. Similar to Milwaukee, elevated sodium and chloride concentrations were observed in the spring aboveground vegetation. However, the belowground vegetation at Harrisburg did not show elevated sodium and chloride values (Table 170). Litter was absent during spring at many of the sampling locations at Harrisburg (Table 171). However, similar to the fall results, the metal and sodium concentrations for median litter samples were higher than background samples.

Vegetation was sampled in fall 1981 at the Efland I-85 site. Concentrations of selected parameters for aboveground and belowground vegetation, and litter are presented in Tables 180 through 174. For all three vegetative components, nutrient accumulation showed no distinct pattern, while accumulation for most metals and sodium was highest near the highway and decreased with distance from the highway. Metal concentrations for near-highway samples were highest for belowground, lowest for aboveground and intermediate for litter. Sodium for near-highway samples was highest for aboveground and belowground samples and lowest for litter.

Groundwater Percolation

Zero tension lysimeters were installed beneath the topsoil layer in areas adjacent to the highway at all sites monitored. Lysimeters installed just beneath the topsoil layer (major rooting zone) provide estimates of the loss

Table 170. Chemical analyses of belowground vegetation at the Harrisburg I-81 site - spring 1980.

Plot location	Concentration, mg/kg dry weight															VTS, percent	Ash content, percent
	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Ni	Al	Na	Cl		
Near-highway																	
Site 2	6,000	1,430	53,900	12,400	10,800	18,900	377	512	7.0	49	121	26	17,500	1280	3,150	41.7	58.3
Site 3	6,500	770	74,000	17,000	5,600	14,600	470	716	8.5	35	145	31	13,100	940	2,030	35.7	64.3
Median																	
Site 1	5,900	740	25,500	8,400	13,100	17,200	116	131	5.0	28	31	26	26,800	190	975	42.4	57.6
Right-of-way																	
Site 4	23,300	1,770	21,700	5,250	47,400	385	40	26	7.8	7.4	17	15	11,300	576	1,770	68.0	32.0
Site 5	7,600	575	17,000	3,280	17,000	8,500	243	39	2.2	10.4	22	13	12,100	182	4,280	57.3	42.7
Background																	
Site 6	6,500	760	9,880	3,470	19,300	12,200	94	49	3.1	17	32	22	85,000	205	35,900	49.3	50.7

Table 171. Chemical analyses of litter at the Harrisburg I-81 site - spring 1980.

Plot location	Concentration, mg/kg dry weight															VTS, percent	Ash content, percent
	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Ni	Al	Na	Cl		
Near-highway																	
Site 2[a]																	
Site 3[a]																	
Median																	
Site 1	11,500	1,090	7,150	1,675	9,270	5,140	72	201	4.0	9	15	9	10,500	112	2,740	68.1	31.9
Right-of-way																	
Site 4[a]																	
Site 5[a]																	
Background																	
Site 6	9,200	520	12,900	1,700	13,600	2,720	68	41	5.4	4.2	9.7	7.0	4,250	68	23,500	81.0	19.0

[a] No litter.

Table 172. Chemical analysis of aboveground vegetation at the Efland I-85 site - fall 1981.

Plot location	Concentration, mg/kg dry weight															VTS, percent	Ash content, percent
	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Ni	Al	Na	Cl		
Near-highway																	
Site 4	17,800	1,810	4,660	2,170	17,500	466	79	39	0.8	1.3	7.8	1.0	310	393	11,500	89.18	10.82
Site 5	16,100	2,920	3,490	2,980	18,600	308	31	13	0.5	0.8	4.6	0.7	144	268	14,900	88.22	11.78
Right-of-way																	
Site 1	15,900	1,900	2,290	2,600	2,000	364	10	3.6	2.0	0.4	5.7	ND	447	312	15,100	86.44	13.56
Site 2	14,800	1,830	3,620	2,890	17,600	424	18	7.8	1.1	0.6	7.1	0.8	424	119	12,100	89.04	10.96
Site 3	15,100	1,120	5,370	2,170	12,300	1440	37	14	0.7	1.1	9.9	ND	2060	103	6,300	89.04	10.96
Background																	
Site 6	11,600	2,470	3,510	2,680	16,000	887	20	2.4	0.4	1.3	6.2	1.7	1030	155	8,260	86.72	13.24

Table 173. Chemical analysis of belowground vegetation at the Efland I-85 site - fall 1981.

Plot location	Concentration, mg/kg dry weight															VTS, percent	Ash content, percent
	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Ni	Al	Na	Cl		
Near-highway																	
Site 4	12,100	1,530	5,430	2,260	6,560	12,600	543	584	3.5	6.4	39	9.2	13,900	461	3,970	74.94	25.06
Site 5	7,460	1,370	4,320	3,300	5,150	9,270	175	154	1.2	9.6	33	8.1	8,750	340	2,440	61.71	38.29
Right-of-way																	
Site 1	8,370	1,270	2,590	1,550	5,070	8,590	97	7.0	1.3	5.2	25	3.9	8,280	280	3,500	76.11	23.89
Site 2	7,310	1,230	2,480	1,650	6,600	11,400	71	8.5	0.6	2.5	20	4.2	13,800	330	3,500	80.10	19.90
Site 3	8,520	901	3,090	1,340	5,040	13,200	78	35	0.4	3.6	21	3.9	13,700	185	2,700	74.34	25.66
Background																	
Site 6	6,250	1,230	3,090	1,320	5,880	8,670	75	6.9	0.8	1.2	19	4.8	7,840	101	2,320	76.92	23.08

Table 174. Chemical analysis of litter at the Efland I-85 site - fall 1981.

Plot Location	Concentration, mg/kg dry weight															VTS, percent	Ash content, percent
	TKN	PO_4-P	Ca	Mg	K	Fe	Zn	Pb	Cd	Cr	Cu	Ni	Al	Na	Cl		
Near-highway																	
Site 4	17,000	1,280	5,970	2,060	5,760	3,910	185	278	2.0	4.4	17	3.3	3,400	165	3,860	84.51	15.49
Site 5	13,700	1,370	3,920	2,580	4,960	3,920	86	95	0.9	7.0	11	3.8	2,680	145	4,000	79.24	10.76
Right-of-way																	
Site 1	13,600	1,020	4,470	1,870	3,820	2,700	23	24	0.4	1.4	9.2	1.8	3,950	78	3,900	82.34	17.66
Site 2	16,700	1,060	6,330	2,390	3,420	6,640	34	47	0.8	2.1	0.3	ND	7,680	70	2,590	82.15	17.85
Site 3	10,900	711	5,260	1,750	3,610	8,760	63	77	3.9	9.3	15	3.3	9,180	56	2,320	78.84	25.16
Background																	
Site 6	11,300	1,050	7,920	2,080	3,330	5,210	45	16	0.5	5.7	12	5.2	5,420	69	1,180	78.79	21.21

of various chemical constituents from the highway system due to groundwater percolation. Since plant roots are the major mechanisms for "pumping" chemical constituents back to the soil surface, chemical constituents leaving the rooting zone are essentially lost to the surface system. Lysimeter installations at each monitoring site are presented in Figures 51 through 54. At Milwaukee (Figure 51), two lysimeters were installed at each of three locations. Lysimeter pairs were installed 2 m, 12 m, and 24.5 m from edge of pavement. At Sacramento (Figure 52), two lysimeter pairs were installed at 3 m and 19 m from the edge of the pavement. As previously discussed, most of the paved runoff at Harrisburg was lost to groundwater seepage through a gravel sub-base which existed beneath the soil cover next to the highway shoulder. An extensive lysimeter network (ten lysimeters) was installed at the Harrisburg site (Figure 53) to monitor this groundwater seepage. Six lysimeters were installed in the drainage ditch and two lysimeters were installed at a background location. At Efland (Figure 54), two lysimeters were installed in the median area and two lysimeter pairs in the northbound right-of-way.

Lysimeter quality data collected at the Milwaukee I-94 site are presented in Table 175. As previously discussed, precipitation at Milwaukee was acid (median pH was 3.8). Acid rain percolating through the topsoil layer appears to be effectively neutralized by the buffering capacity of the soil system. Percolation water leaving the topsoil layer had a pH range of 6.85 to 8.1. The data also show that metal concentrations were inversely related to distance from edge of pavement. One sample at the midpoint lysimeter installation (12 m from the edge of the pavement) was analyzed for arsenic and mercury; however, these constituents were not detected. Chloride concentrations were highest for the near-highway sample (2 m from the edge of the pavement).

At the Sacramento Hwy 50 site (Table 176), the background monitoring point located 19.4 m from edge of pavement did not flow during the monitoring period. Again, the acid rain at Sacramento (median pH 5.0) appears to be neutralized by the topsoil layer (pH range 6.3 to 7.3 for percolation water). However, the median percolation water pH at Sacramento (Table 176) was not as basic as the pH values observed at Milwaukee, indicating a lower buffering capacity for Sacramento soils. Metal, sodium, and chloride concentrations in percolation water were considerably lower for the near-highway installation at Sacramento than at Milwaukee.

Lysimeter quality data collected at the Harrisburg I-81 site are presented in Table 177. Similar to Milwaukee and Sacramento, Harrisburg precipitation was characterized as acid (median pH 4.3). Again, acid rain percolating through the topsoil layer appears to be neutralized by the buffering capacity of the soil system. Percolation water leaving the topsoil layer had a pH range of 5.6 to 9.1. Some samples were slightly acid indicating a limited soil buffering capacity. In fact, Harrisburg and Efland were the only sites at which several soil samples had an acid pH (Tables 150 and 151). Metal concentrations for percolation water were generally higher for the drainage ditch samples than for the background samples. Mean lead

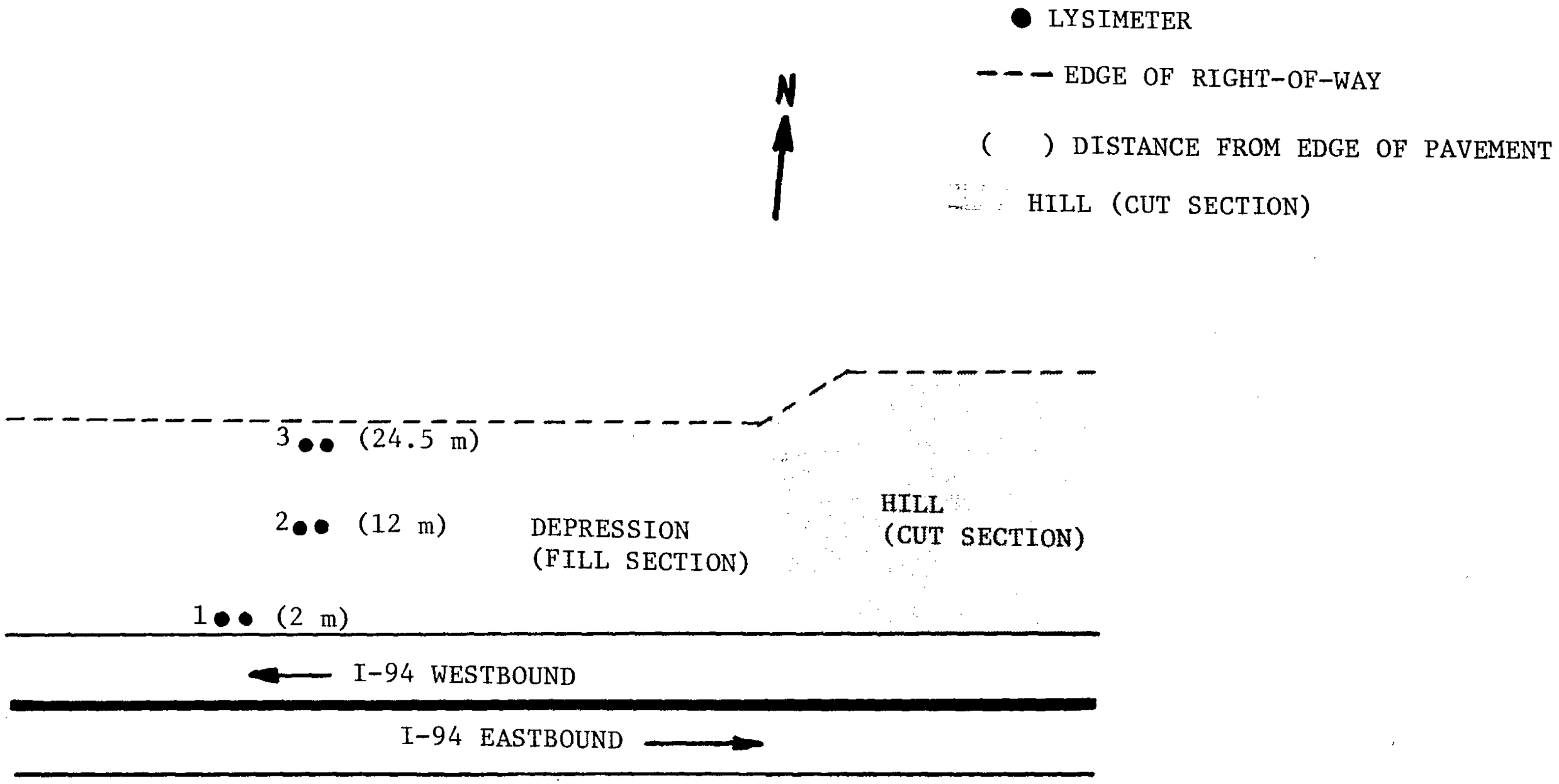


Figure 51. Lysimeter locations at the Milwaukee I-94 site.

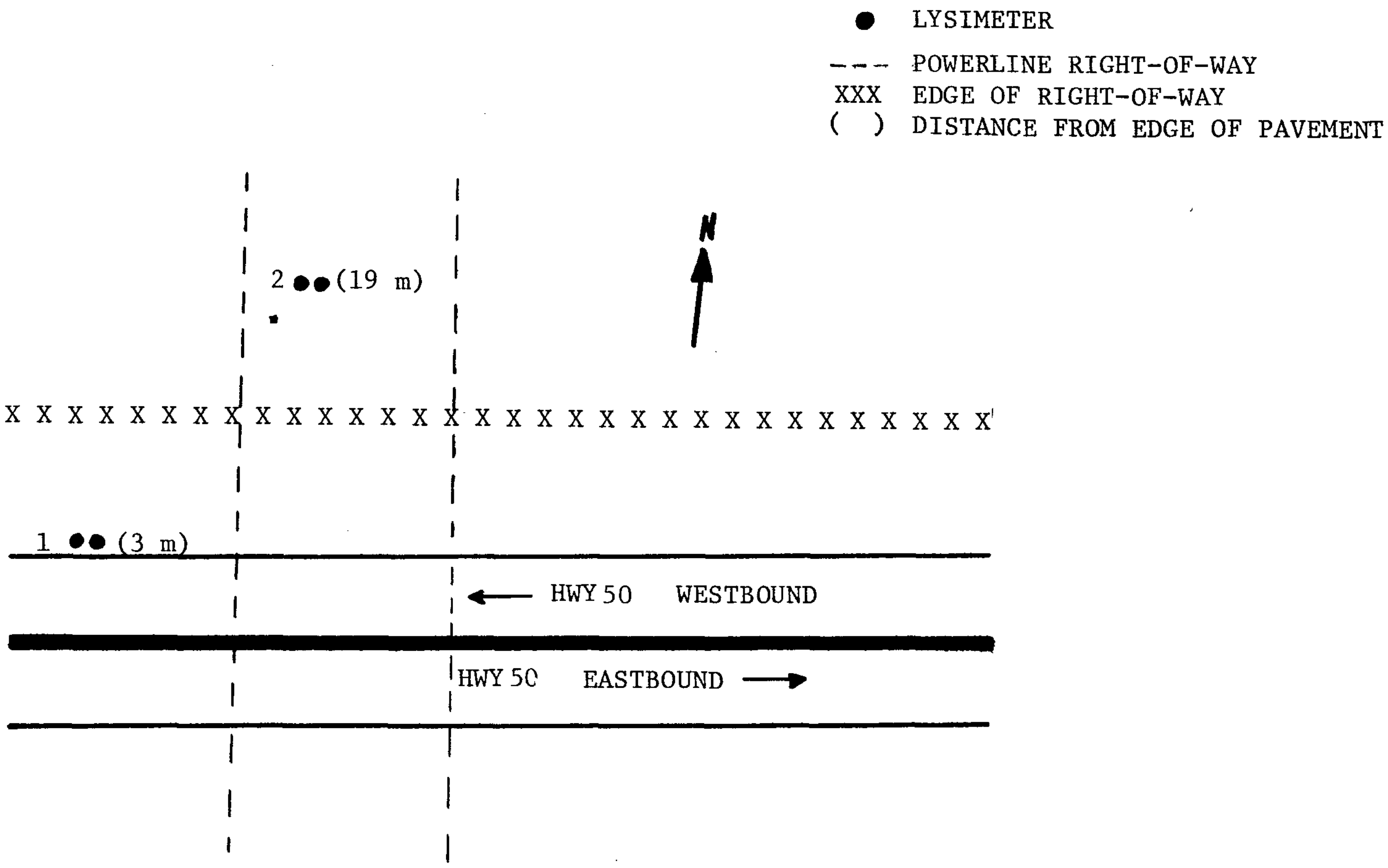


Figure 52. Lysimeter locations at the Sacramento Hwy 50 site.

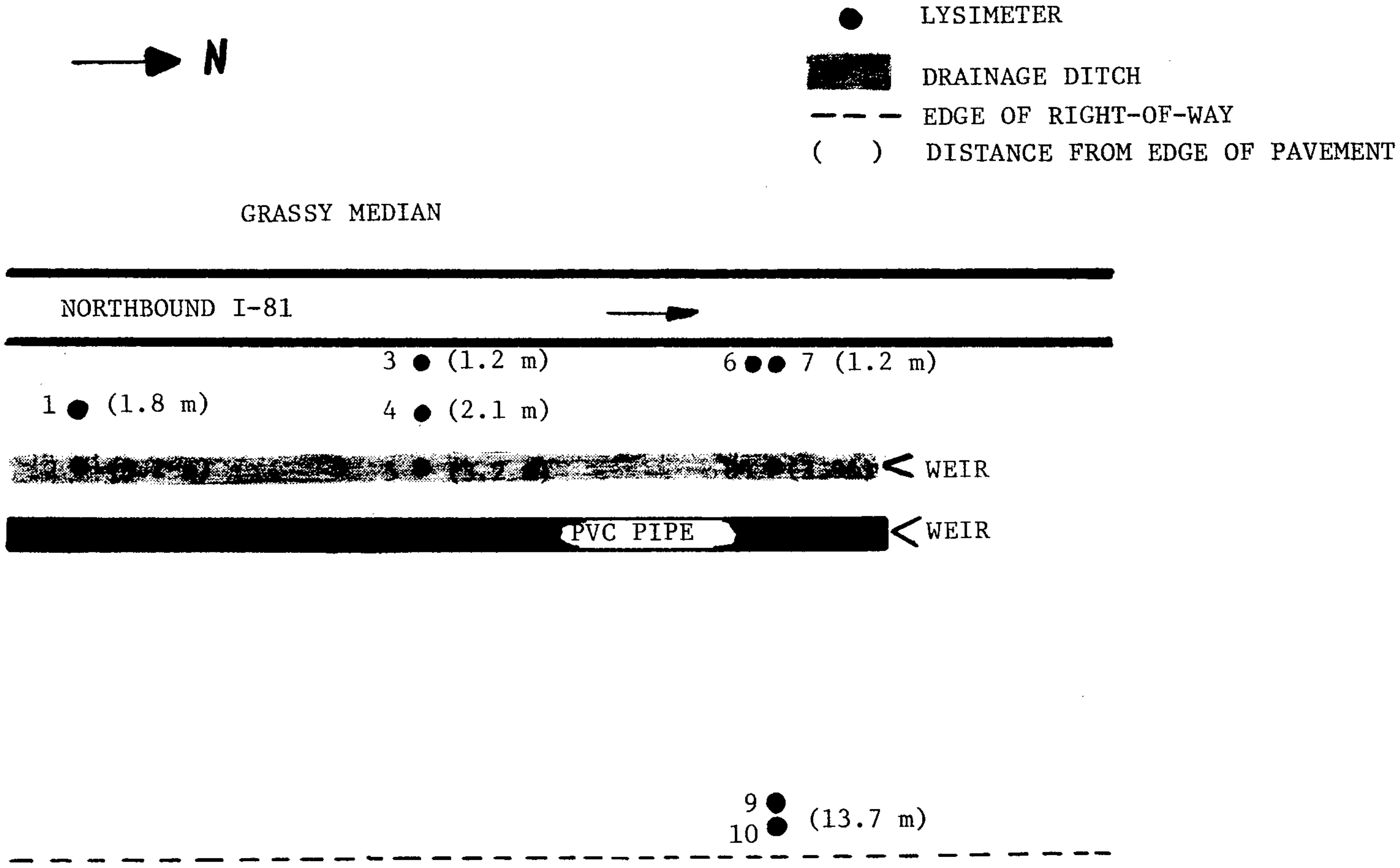


Figure 53. Lysimeter locations at the Harrisburg I-81 site.

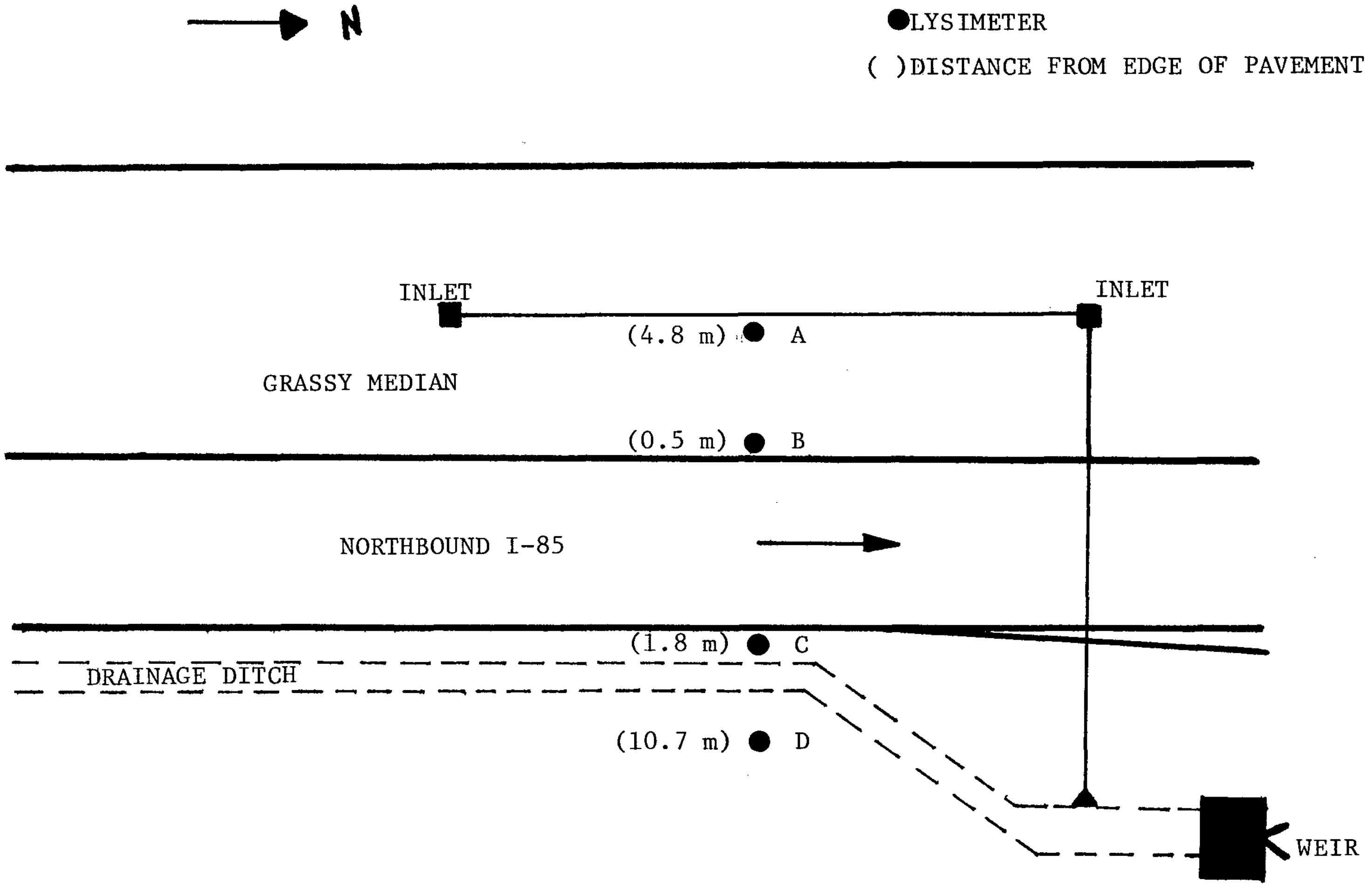


Figure 54. Lysimeter locations at the Efland I-85 site.

Table 175. Lysimeter quality data (mg/l) - Milwaukee I-94 site.

Parameter	Distance from the edge of the pavement					
	2 m		12 m		24.5 m	
	Range	Mean median, m	Range	Mean median, m	Range	Mean median, m
pH	7.5-8.0	7.8	6.85-8.1	7.5	7.2-8.1	7.7
TS	733-3570	2150	218-440	326	308-418	379
TVS	--	NA	--	61	--	NA
SS	--	NA	10-98	33	3-11	7
Pb	0.2-3.5	1.5	ND-4.1	0.2	ND-0.1	ND
Zn	0.19-2.0	0.88	0.06-5.7	0.80	0.03-0.11	0.08
Fe	3.6-102	41.2	0.05-4.3	2.0	0.3-1.6	0.76
Cr	0.03-0.20	0.10	ND-0.06	0.03	0.01-0.02	0.02
Cu	0.49-2.2	1.15	0.06-0.43	0.16	0.01-0.04	0.03
Cd	ND-0.04	0.02	ND-0.08	ND	ND-0.02	ND
Ni	ND-0.2	ND	ND-0.20	ND	ND-0.1	ND
As	--	NA	--	ND	--	NA
Hg	--	NA	--	ND	--	NA
NO_2+NO_3	--	NA	0.04-0.34	0.21	ND-0.04	0.02
TKN	--	NA	1.8-3.2	2.6	ND-2	1
PO_4	--	NA	0.21-1.93	0.60	ND-0.04	0.03
Sulfate	ND-110	ND		NA	18-26	24
Na	80-860	470	12-80	38	5-37	20
Cl	100-825	362	ND-262	20	42-125	87
Ca	14-98	56	2.8-38	14.5	21-78	59

ND = Not detectable.
NA = No analysis performed due to limited sample quantity.

Table 176. Lysimeter quality data[a] (mg/l) - Sacramento Hwy 50 site.

Near highway (3 m from the edge of the pavement)		
Parameter	Range	Mean median, m
pH	6.3-7.3	6.5
TS	193-625	341
SS	23-194	97
Pb	ND-0.6	0.4
Zn	0.06-0.40	0.27
Fe	1.5-16	7.8
Cr	0.03-0.18	0.09
Cu	0.04-0.20	0.11
Cd	ND-0.05	0.03
Ni	0.1-0.4	0.2
PO_4	0.72-4.48	2.04
TKN	2-11.9	6.0
NO_2+NO_3	5.9-20.0	9.1
Cl	6-25	14
SO_4	13-50	35
Ca	11-27	19
Na	2.5-14	6.8

[a] Background monitoring point located 19.4 m from the edge of the pavement did not flow during the monitoring period.

ND = Not detectable.

Table 177. Lysimeter quality data (mg/l) - Harrisburg I-81 site.

	Distance from the edge of the pavement							
	1.2-1.8 m		2.1 m		3.2-3.9 m		13.7 m	
Parameter	Range	Mean median, m	Range	Mean median, m	Range	Mean median, m	Range	Mean median, m
pH	5.6-8.4	6.6	6.95-9.1	7.0	5.90-8.0	7.5	5.6-7.8	6.3
TS	66-3550	587	918-1370	1140	101-3190	751	28-422	158
SS	6-1550	201	112-1040	574	40-2430	381	8-50	25
Pb	ND-0.6	0.1	ND-0.2	ND	ND-0.6	0.04	ND-0.50	ND
Zn	0.04-1.5	0.24	0.12-0.76	0.44	0.07-0.83	0.30	0.06-2.0	0.27
Fe	0.3-130	11.2	9.5-40.3	24.9	1.3-95.8	16.6	0.4-14	2.1
Cr	ND-0.07	0.01	--	0.08	ND-0.14	0.005	ND-0.07	ND
Cu	0.02-0.26	0.09	--	0.16	0.037-0.21	0.09	0.029-0.20	0.09
Cd	ND-0.05	ND	--	0.02	ND-0.02	0.004	ND-0.08	0.01
Ni	ND-0.3	ND	--	ND	ND-0.3	0.02	ND-0.2	ND
Cl	6-2060	114	40-110	75	5-130	45	ND-41	10
NO_2+NO_3	0.46-27.5	7.0	--	NA	5.8-23.0	15.0	0.03-1.36	0.17
TKN	0.78-5.6	3.0	--	NA	2.62-3.60	3.01	ND-2.85	2.3
PO_4	0.77-3.20	1.59	--	NA	0.53-0.86	0.70	0.02-5	1.2
Na	3-1300	81	25.6-125	75.3	13.8-88	29.6	1.2-8.2	3.9
Ca	10-74	30	--	NA	--	NA	2-11	7
Hg	0.0005-0.0014	0.0010	--	NA	--	NA	--	0.0005
SO_4	ND-133	30	--	61	10-104	48	ND-22	7
O&G	2-3	3	--	NA	--	NA	--	NA

ND = Not detectable.
NA = No analysis performed due to limited sample quantity.

concentration for the near-highway samples at Milwaukee were an order of magnitude higher than at Harrisburg. Sodium and chloride concentrations in percolation water were inversely related to distance from edge of pavement.

Lysimeter quality data collected at the Efland I-85 site in the median area are presented in Table 178 and the northbound right-of-way data are presented in Table 179. Similar to Harrisburg, the lysimeter and soil data (Table 152) indicate a limited soil buffering capacity. Except for sodium and chloride, no distinct pattern of concentration with distance appears in the data. Mean sodium and chloride concentrations were highest near the highway.

Groundsnow

Groundsnow was sampled at the Milwaukee I-94 and Harrisburg I-81 sites to determine contaminant content and to determine the variation in concentration with distance from the highway. Samples were collected at Milwaukee on January 3, 1979, March 5, 1979, and February 8, 1980, and at Harrisburg on March 6, 1981. The Milwaukee data (Table 180) indicate that cadmium, nickel, and mercury are generally not detectable, and that the remaining parameters, except NO_2 and NO_3, decrease in concentration with distance from the highway. The results at Harrisburg (Table 181) were similar to those observed at Milwaukee.

LaBarre, et al. (80) studied the lead contamination of snow in Ottawa, Canada. The range of lead concentrations in snow along major highways in Ottawa was 86-113 mg/l. In a study conducted in Stockholm, Sweden (81), Soderlund et al. found up to 100 mg/l of lead in snow and attributed this to motor vehicular emissions. These values are much higher than those observed in this study, 0.28 to 7.2 mg/l at 0.5 m from the edge of the highway pavement. Labarre, et al. (80) stated that the levels of lead in snow along city roads which they studied was roughly proportional to the traffic volume. They also noted that the majority of lead in the snow samples collected was associated with particulate matter.

SUMMARY AND CONCLUSIONS

Field studies were conducted at the four sites monitored to evaluate the quantitative and qualitative aspects of background pollutant deposition to the highway system (discussed in Section II), pollutant accumulation within the highway system due to background and highway related sources, and the mechanism of pollutant dispersion within and without the highway system.

Bulk precipitation data (wet and dry deposition) were collected at each site to establish the level of pollutants migrating from the highway to the surrounding environment through atmospheric processes. The area adjacent to the highway receiving TPM (total particulate matter) and associated metals

Table 178. Lysimeter quality data (mg/l) - Efland I-85 site median area.

	Distance from the edge of the pavement			
	0.5 m		4.8 m	
Parameter	Range	Mean median, m	Range	Mean median, m
pH	5.0-7.7	6.6	5.8-7.8	6.3
TS	226-3570	982	267-3350	838
SS	22-3510	583	14-568	103
Pb	ND-0.18	0.02	ND-0.06	ND
Zn	0.05-0.26	0.10	0.04-0.5	0.12
Fe	1.9-43.0	16.0	0.9-130	18.1
Cu	0.02-0.09	0.04	0.02-0.09	0.05
Cr	ND-0.04	0.01	ND-0.05	0.003
Cd	ND-0.002	ND	ND-0.006	ND
Ni	ND-0.10	0.01	ND-0.10	0.02
Cl	14-1875	475	58-850	252
Na	11-950	233	7.2-420	105
PO_4	ND-0.61	0.2	0.06-2.66	1.12
TKN	3-13	6	3.5-17	8.6
NO_2+NO_3	0.63-4.45	1.64	0.11-1.06	0.46

ND = Not detectable.

Table 179. Lysimeter quality data (mg/l) - Efland I-85 site northbound right-of-way area.

	Distance from the edge of the pavement			
	1.8 m		10.7 m	
Parameter	Range	Mean median, m	Range	Mean median, m
pH	5.8-7.9	6.5	1.7-7.2	6.4
TS	145-1140	504	355-3330	1330
SS	21-260	87	40-1550	567
Pb	ND-0.25	0.04	ND-0.12	ND
Zn	0.04-0.31	0.10	0.06-0.14	0.11
Fe	0.6-39	12	23-85	51
Cu	0.002-0.21	0.06	0.03-0.12	0.08
Cr	ND-0.02	0.01	ND-0.05	0.03
Cd	ND-0.004	ND	ND-0.004	ND
Ni	ND-0.10	ND	ND-0.10	ND
Cl	13-370	91	ND-810	12
Na	9-210	47	20-130	28
PO_4	0.06-0.69	0.27	0.26-0.46	0.37
TKN	2-4	3	4-10	8
NO_2+NO_3	0.15-0.85	0.39	0.18-1.80	0.73

ND = Not detectable.

Table 180. Ground snow concentrations (mg/l) - Milwaukee I-94 site.

	Distance from the edge of the pavement							
	0.5 m		15 m		35 m		140 m	
Parameter	Range	Mean median, m	Range	Mean median, m	Range	Mean median, m	Range	Mean median, m
pH	7.1-8.4	7.4	6.3-7.4	6.9	5.4-7.0	6.8	4.5-5.8	5.2
TS	922-8350	3660	290-300	295	166-261	199	88-106	97
TVS	64-506	259	26-29	28	16-66	41	13-38	26
SS	108-1350	810	52-54	53	43-162	85	22-45	34
VSS	211-225	218	14-17	16	12-13	13		9
Pb	0.38-7.2	3.9	0.4-0.4	0.4	0.2-1.2	0.5	0.1-0.3	0.2
Zn	0.21-3.5	1.6	0.57-0.82	0.70	0.11-0.45	0.26	0.05-0.25	0.15
Fe	2.9-70	35	4.9-4.9	4.9	3.2-7.0	4.5	2.0-2.3	2.2
Cr	0.02-0.19	0.14	0.02-0.02	0.02	ND-0.04	0.03	ND-0.03	ND
Cu	0.15-1.11	0.64	0.17-0.20	0.19	0.03-0.15	0.11	0.02-0.12	0.07
Cd	ND-0.14	0.02	0.08-0.09	0.09	ND-0.08	ND	ND-0.08	ND
Ni	ND-0.4	ND	0.2-0.2	0.2	ND-0.4	ND	ND-0.3	ND
Hg[a]	ND-0.0016	ND	ND-0.0004	ND	ND-0.0003	ND	ND-ND	ND
TPO_4	0.10-1.30	0.64	0.02-0.04	0.03	0.03-0.15	0.08	ND-0.03	ND
TKN	2.0-6.0	4.4	3.0-3.0	3.0	2.0-2.3	2.1	1.8-2.0	1.9
NO_2+NO_3	0.02-1.22	0.49	0.92-0.93	0.93	0.08-0.92	0.50	0.18-0.88	0.53
Ca	13-83	37	3-3	3	2-4	3	1.4-2.0	1.7
Na	5.2-8400	2340	500-1500	1000	3.3-300	139	2.6-300	151
Cl	15-4350	1520	128-130	129	5-73	36	10-18	14
SO_4	13-16	32	8-9	9	ND-5	ND	ND-4	ND

[a] micrograms/liter.

ND - Not detectable.

Table 181. Ground snow concentrations (mg/l) - Harrisburg I-81 site.

Parameter	Distance from the edge of the pavement 0.5 m	 20 m	 69 m
pH	8.1	6.6	6.5
TS	683	55	46
TVS	137	37	21
SS	372	14	7
Pb	0.28	ND	ND
Zn	0.230	0.042	0.064
Fe	7.3	0.24	0.29
Cr	0.026	0.002	0.007
Cu	0.090	0.018	0.027
Cd	0.007	0.002	0.007
Ni	0.003	0.002	0.003
Hg	ND	ND	ND
TPO_4	0.18	ND	ND
TKN	1.6	1.0	0.6
NO_2+NO_3	0.28	0.53	0.46
Ca	35	ND	ND
Na	87	4.3	1.5
Cl	123	9	4
SO_4	15	ND	ND

ND = Not detectable.

(impacted area) was defined using bulk precipitation and 1 cm soils data. One cm soils data was used because accumulation of highway related metals from atmospheric deposition should be reflected in the topsoil layer of areas adjacent to the highway. Based upon TPM and associated metals deposition and upon data from the one centimeter soil study, the impact area was defined to be approximately 35 m from the edge of pavement at Milwaukee, 35 m at Sacramento, 15 m at Harrisburg, and 12 m at Efland. The smaller impact areas at Harrisburg and Efland compared to Milwaukee and Sacramento are probably functions of average daily traffic (27,800 and 25,500 vehicles/day at Harrisburg and Efland compared to 116,000 and 85,900 vehicles/day at Milwaukee and Sacramento). Mean TPM transport rate for the period monitored was 29.6 kg/km/day at Milwaukee, 29.8 kg/km/day at Sacramento, 12.3 kg/km/day at Harrisburg, and 1.14 kg/km/day at Efland. TPM transport from the highway system was seasonal at all sites. At sites with winter seasons, TPM rates were generally highest during the winter period. At Sacramento, the drought period produced the highest TPM rates.

Atmospheric deposition of highway-generated TPM and associated metals onto areas adjacent to the highway surface appears to be related to:

1. Average daily traffic.
2. Wind speed and direction.
3. Available surface load.
4. Terrain and landscape features.

Studies were performed at Milwaukee to determine the precision (closeness of repeated measurements of the same quantity) of bulk precipitation measurements. The data indicated that generally bulk precipitation as monitored during this study provided precise measurements of TPM deposition. However, the data also showed that these measurements can be affected by:

1. Localized effects due to vehicular turbulence.
2. Severe meteorological conditions.

Another mechanism for the removal of pollutants from the highway through the atmosphere is saltation. Data collected at the four sites monitored indicate that the quantity of saltating particles (sand-sized particles injected into the atmosphere by vehicular turbulence) reaching areas adjacent to the highway appears to be related to:

1. Average daily traffic.
2. Windspeed and direction.
3. Available surface load (seasonal variation).
4. Highway drainage design.
5. Proximity of travel lanes to right-of-way area.
6. Landscape features near the highway affecting wind patterns.

Milwaukee, Harrisburg, and Efland had higher average monthly saltation rates during winter and spring. This period was generally characterized by high surface loads and high average windspeeds.

Monitoring of runoff from the paved and unpaved areas was segregated to determine pollution loadings leaving the highway drainage system and to develop insights into the hydraulics of pollutant movement and strengths at various points in the drainage scheme. At the Milwaukee and Sacramento sites (curb and gutter drainage design), the contribution of the unpaved area to the total constituent load removed via runoff was negligible, while at Harrisburg (flush shoulder drainage design), the unpaved area contributed approximately 17 percent of the total load for most constituents. However, the overall constituent load at Harrisburg was extremely low compared to Milwaukee and Sacramento.

Precipitation at the four sites monitored can be characterized as acid; median pH was 3.8 at Milwaukee, 4.3 at Harrisburg, 4.2 at Efland, and 5.0 at Sacramento. However, runoff data indicated that the highway systems at all sites had a large capacity to neutralize the runoff of acid precipitation before it reached the surrounding environment. Groundwater percolation data also indicated that the soil system adjacent to the highway sections monitored at Milwaukee and Sacramento had considerable buffering capacity against acid rain while the Harrisburg soil system had limited buffering capacity. The prevalence of acid rain in the United States (49) and the apparent ability of highway systems to neutralize this acid rain may have important implications when considering pollutant migration from the highway through the areas adjacent to the highway. For example, the solubility of metals is a function of pH (generally higher solubilities occur at the extremes of the pH scale) and the quantity of anionic complexing agents and organic matter present. Soluble metals would be easier to remove from the highway surface, would tend to migrate further, and would be readily accessible for bioaccumulation.

Highway runoff at Milwaukee, the site with the highest average daily traffic, had the highest solids loadings and generally the highest loadings for most parameters. Sites where deicing agents were applied showed increases in total solids, sodium, and chloride loadings during winter periods. The deicing salt used at Milwaukee was analyzed for contaminants. The salt analyzed contained lead, zinc, chromium, copper, cadmium, nickel, and cyanide. Cyanide is an anticake compound used to keep salt granular. The loading of cyanide to the highway surface from rock salt was approximately 0.79 kg/km/yr. Based upon loading values, rock salt was also an important source of cadmium and nickel. At Efland, deicing agents (rock salt and calcium chloride/sand mixture) were also analyzed for contaminants. Lead, iron, chromium, copper, and cyanide were found to be present in the rock salt sample analyzed. However, the salt used at Efland was generally lower in contaminants than the salt used at Milwaukee. Whereas, the salt applied at Milwaukee was an important source of cadmium and nickel, it was not detectable in the salt used at Efland. The contaminants associated with deicing agents appears to vary with the source of the deicing agent and additives used.

Correlation analysis between total solids (TS) and other runoff quality constituents indicate that TS is a good carrier parameter (parameter showing the highest degree of association with all other quality parameters). This is consistent with the results of FHWA's Phase 1 study (56).

Mean highway surface constituent loads were generally highest at Milwaukee, lowest at Harrisburg, and intermediate at Sacramento and Efland. The range of loading values at the Sacramento Hwy 50 site showed more variability than at Harrisburg, while order of magnitude differences existed between the minimum and maximum constituent values at Milwaukee. The differences in the magnitude of surface loads and variability in the range of loading values are probably attributable to differences in site drainage and traffic characteristics, seasonal variations, and maintenance activities.

Solids and pollutants associated with solids tend to accumulate in the distress and median lanes, while pollutants which are more soluble tend to be more uniformly distributed across the distress, median, and travel lanes. Apparently, vehicular turbulence tends to move any solids deposited on travel lanes to the outer lanes. Lateral variation in surface load at a given point in time appears to be a function of profile grade and other factors including: inlet placement, seasonal characteristics, maintenance activities, and average daily traffic.

Commercial sweeper efficiency studies performed at Milwaukee showed that efficiency of pickup by commercial sweepers was generally highest for solids and those constituents associated with solids and lowest for the more soluble constituents. Sweeper efficiency was also higher in summer than in spring. The surface load was more compacted in the spring than in summer. Presumably, the compacted spring surface load was more difficult to remove by surface sweeping.

At the sites monitored, the major removal mechanisms, runoff and atmospheric removal, appear to involve particles whose size are generally less than 250 microns. Approximately 21 to 57 percent of the total highway surface metals load at the Milwaukee site, 69 to 91 percent at the Sacramento site, and 27 to 54 percent at the Efland site are associated with the less than 250 micron particle size class. A mass balance was calculated for total solids less than 250 microns (TS_{250}) and associated metals at the Milwaukee site for the period April 17 through October 31, 1979) (summer period). The mass balance indicated that in all cases, vehicles were the largest source of TS_{250} and associated metals. Vehicular deposition during the summer period was calculated to be 0.31 g/km/vehicle. The quantity of surface load removed by runoff, atmospheric processes, and maintenance activities (sweeping the highway surface) varied by constituent parameter. A mass balance was also calculated for TS_{250}, sodium, and chloride at the Milwaukee site for the period November 1 through May 21, 1980 (winter and spring period). The mass balance for this period indicated that the major source of these constituents was maintenance (deicing agent application), and that the major removal mechanism was runoff and baseflow. Vehicular deposition during the winter period was calculated to be 0.98 g/km/vehicle, approximately three times higher than the summer period. The highest winter vehicular deposition rate is probably due to increased exhaust emissions from stop-and-go driving during hazardous driving conditions, increased autobody rusting from caustic deicing agents, and "carry on" deposition.

Mass balances for TS_{250}, selected metals, sodium, and chloride were also calculated for the period June 30, 1981, through April 22, 1982 at the Efland site. Average vehicular deposition rate for this period was calculated to be 0.15 g/km/vehicle. Similar to Milwaukee, the mass balance indicated that vehicles were the largest source of TS_{250} and associated metals. A mass balance was also calculated for TS_{250}, sodium, and chloride at the Efland site for the period when deicing agents were applied to the highway surface at Efland (December 3, 1981, through March 30, 1982). During this period the majority of the TS_{250} deposited on the highway was due to deicing agent application. The data also showed that runoff was the major removal mechanism.

Soils data at the four sites monitored indicated that metals and sodium concentrations were generally higher in the topsoil layers (major rooting zone usually 10 cm deep) than substrate layers and were highest for the near-highway samples, decreasing with distance from the highway.

Accumulation of metals and sodium by vegetation was generally related to the concentration of these constituents in the topsoil layer. At the Milwaukee site, litter was highest for the near-highway samples although biomass production was slightly higher for samples obtained further from the highway. A possible explanation would be that high levels of pollutants in the soil and plant tissue near the highway's edge, especially heavy metals and soluble salts, may decrease the number and activity of the microorganisms involved in the decomposition of plant tissue. At the Sacramento site, no vegetation grew near the highway. This would be expected based upon the soils data which indicated that the soils next to the highway were sandy, low in organic matter, high in soluble salts, low in nutrients, and high in lead and zinc. The vegetation and soils data indicate that normal ecosystem processes may be affected in areas immediately adjacent to the highway (1 to 2 m), especially near highways with high ADT (greater than 85,000 vehicles/day).

SECTION IV
PRIORITY POLLUTANTS

In June 1976, out of concern for the detrimental effects of toxic pollutants on public health and the environment and in settlement of suit with the Natural Resources Defense Council (NRDC), EPA agreed to devote more attention to the discharge of potentially toxic substances in industrial wastewaters. The resulting NRDC Consent Decree required EPA to promulgate regulations for 65 classes of toxic pollutants associated with 21 industrial categories, updated in 1979 to 34 industrial categories. The 65 classes represent 129 specific substances referred to, simply, as "priority pollutants". A list of the priority pollutants is presented in Table 182.

In cooperation with the U.S. EPA, runoff samples were obtained at the Milwaukee I-94 and Sacramento Hwy 50 sites for analysis of priority pollutants. A discussion with the various aspects of this project task are presented in the following paragraphs.

MILWAUKEE I-94 SITE

A 5-gallon composite runoff sample (paved area only) was obtained at Milwaukee I-94 site during a storm on May 13, 1980. Aliquots of this sample were submitted to the following laboratories for analysis:

1. EPA (Edison, NJ) for priority pollutant analyses.
2. Rexnord laboratory for routine analysis.

The background information regarding the storm event is as follows:

1. Prestorm rainfall history:

Date	Total rain, in	Rain duration, hr
April 28, 1980	0.27	6.0
April 29, 1980	trace	3.0
May 10, 1980	0.06	1.5
May 12, 1980	0.11	3.3

Metric units: To convert in to cm multiply by 2.54.

Also, the Wisconsin Department of Highways swept the entire study site on April 17, 1980, using commercial sweepers.

Table 182. Priority toxic pollutants.

PURGEABLE ORGANICS

Acrolein
Acrylonitrile
Benzene
Toluene
Ethylbenzene
Carbon tetrachloride
Chlorobenzene
1,2-Dichloroethane
1,1,1-Trichloroethane
1,1-Dichloroethane
1,1-Dichloroethylene
1,1,2-Trichloroethane
1,1,2,2-Tetrachloroethane
Chloroethane
2-Chloroethyl vinyl ether
Chloroform
1,2-Dichloropropane
1,3-Dichloropropene
Methylene chloride
Methyl chloride
Methyl bromide
Bromoform
Dichlorobromethane
Trichlorofluoromethane
Dichlorodifluoromethane
Chlorodibromomethane
Tetrachloroethylene
Trichloroethylene
Vinyl chloride
1,2-trans-Dichloroethylene
bis (Chloromethyl) ether

BASE/NEUTRAL EXTRACTABLE ORGANICS

1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Hexachloroethane
Hexachlorobutadiene
Hexachlorobenzene
1,2,4-Trichlorobenzene
bis(2-Chloroethoxy) methane
Naphthalene
2-Chloronaphthalene
Isophorone
Nitreobenzene
2,4-Dinitrotoluene
2,6-Dinitrotoluene
4-Bromophenyl phenyl ether
bis(2-ethylhexyl) phthalate
Di-n-octyl phthalate
Dimethyl phthalate
Diethyl phthalate
Di-n-butyl phthalate
Acenaphthylene
Acenaphthene
Butyl benzyl phthalate
Fluorene
Fluorathene
Chrysene
Pyrene
Phenanthrene
Anthracene
Benzo (a) anthracene
Benzo (b) fluoranthene
Benzo(k)fluroanthese
Benzo(a)pyrene
Indeno(1,2,3-c,d)pyrene
Dibenzo(a,h) anthracene
Benzo(g,h,i) perylene
4-Chlorophenyl phenyl ether
3,3'-Dichlorobenzidine
Benzidine
bis(2-Chloroethyl) ether
1,1-Diphenylhydrazine
Hexachlorocyclopentadiene
N-Nitrosodiphenylamine
N-Nitrosodimethylamine
N-Nitrosodi-n-propylamine
bis(2-Chloroisopropyl) ether

Table 182. Priority toxic pollutants (continued).

ACID EXTRACTABLE ORGANICS

Phenol
2-Nitrophenol
4-Nitrophenol
2,4-Dinitrophenol
4,6-Dinitro-o-cresol
Pentachlorophenol
p-Chloro-m-cresol
2-Chlorophenol
2,4-Dichlorophenol
2,4,6-Trichlorophenol
2,4-Dimethylphenol

PESTICIDES/PBC'S

α-Endosulfan
β-Endosulfan
Endosulfan sulfate
α-BHC
β-BHC
δ-BHC
γ-BHC
Aldrin
Dieldrin
4,4'-DDE
4,4'-DDD
4,4'-DDT
Endrin
Endrin aldehyde
Heptachlor
Heptachlor epoxide
Chlordane
Toxaphene
Aroclor 1016
Aroclor 1221
Aroclor 1232
Aroclor 1342
Aroclor 1248
Aroclor 1254
Aroclor 1260
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)

METALS

Antimony
Arsenic
Beryllium
Cadmium
Chromium
Copper
Lead
Mercury
Nickel
Seleniumn
Silver
Thallium
Zinc

MISCELLANEOUS

Asbestos (fibrous)
Total Cyanides
Total Phenols

2. Rainfall intensity and duration:

Date, 1980	Total rain, in	Rain duration, hr	Rainfall intensity, in/hr
May 13	0.31	0.05	0.62

3. Rainfall start time - 1305 on May 13, 1980.
4. Sample shipped to EPA (Edison, NJ) for arrival at Newark Airport at 1502, May 14, 1980.

The sample submitted to EPA (Edison, NJ) was analyzed for all priority pollutants except asbestos and cyanides. The sample sent to the Rexnord laboratory was analyzed for heavy metals in addition to analysis for other routine constituents.

The results for priority pollutant analysis showed that 94 priority pollutants were looked for but not found. Of the 32 priority pollutants that were detected, the phenol result was not obtained per EPA protocol for that analysis; the results for arsenic and nickel were estimated values; for trichlorofluoromethane, the reported value was less than the criterion for detection; six of the metals detected were of less concentration than the value reported.

The data obtained for the 32 detected priority pollutants are presented in Table 183. Also shown in Table 183 are the metal determinations analyzed by Rexnord Inc. on an identical sample aliquot. Between the two sets of metals data shown in Table 183, discrepancies appear to exist for the analyses of arsenic, cadmium, chromium, mercury, and nickel. It was pointed out previously that the EPA values for arsenic and nickel were only estimates. The lower values reported by EPA for cadmium, chromium, and mercury may be due to the use of different approved methods and/or instruments. For the analytical methods used by Rexnord, their values for cadmium, chromium, and mercury were very near the detection limits.

From Table 183, it may be seen that a significant number (over 25 percent in those listed in Table 183) of different priority pollutants were observed in the highway runoff. Although the priority pollutant concentrations shown in Table 183 appear relatively low, the mass loading of priority pollutants transported from the highway are significant. For example, the total runoff measured for this storm event was 4256 ft^3 (120,530 liters) or 265,509 lbs (120,435 kg). The corresponding total weight of priority pollutants in the measured runoff was about 1.01 lbs (0.46 kg). Inasmuch as the length of the monitored area was 0.26 mi (0.42 km), the priority pollutant load transported off the highway environment was 3.88 lb/mi (1.09 kg/km). By far, the greater portion (95 percent) of this load was contributed by the deposition of lead, zinc, and copper on the highway.

Table 183. Priority pollutants - Milwaukee I-94 site
May 13, 1980, runoff sample.

	EPA analysis		Rexnord analysis
Priority pollutant	g/l	SD or RSD*	g/l
Phenol	1.9	9.0	
Acenaphthene	0.5	20.0	
Fluoranthene	12.0	20.0	
Naphthalene	1.8	20.0	
N-Nitrosodiphenylamine	0.8	20.0	
Bis (2-Ethyhexyl) phthalate	19.0	20.0	
Butyl benzyl phthalate	5.0	20.0	
Di-n-butyl phthalate	2.8	20.0	
Diethyl phthalate	0.3	20.0	
1,2-benzanthracene	3.4	20.0	
3,4-benzofluoranthene	8.6	20.0	
11,12-benzofluoranthene	8.6	20.0	
Chysene	3.4	20.0	
Acenaphthylene	0.2	20.0	
Anthracene	0.6	20.0	
Fluorene	0.6	20.0	
Phenanthrene	6.9	20.0	
Pyrene	8.0	20.0	
Trichlorofluoromethane	0.2	20.0	
Silver	<2.0	20.0	
Arsenic	1.0	61.7	<20.0
Beryllium	<3.0	20.0	
Cadmium	9.8	21.4	30.0
Chromium	43.0	14.2	70.0
Copper	280.0	13.5	280.0
Mercury	<0.2	23.9	0.5
Lead	2600.0	29.1	2200.0
Nickel	40.0	13.0	100.0
Antimony	<20.0	20.0	
Selenium	<0.8	20.0	
Thallium	<0.4	20.0	
Zinc	780.0	9.5	770.0

*SD or RSD - Standard deviation or relative standard deviation based on all previous analyses for that parameter. The number in this column is ± percent of the detected parameter value.

SACRAMENTO HWY 50 SITE

Composite runoff samples (paved area only) were collected at this site on January 22 and 23, 1981. Aliquots of these samples were submitted to the following laboratories for analysis:

1. California Analytical Laboratories, Inc., Sacramento, California.
2. Rexnord laboratory for routine analyses.

The background information regarding the storm event is as follows:

1. Prestorm rainfall history:

Date	Total rain, in	Rain duration, hr
December 3, 1980	0.05	1.50
December 3, 1980	0.03	2.75
December 3, 1980	0.40	4.00
December 3, 1980	0.24	1.50
December 3-4, 1980	0.35	3.50
December 21, 1980	0.50	7.25

Metric units: To convert in to cm multiply by 2.54.

2. Rainfall intensity and duration for sampled storm:

Date, 1980	Total rain, in	Rain duration, hr	Rainfall intensity, in/hr
January 22-23	1.27	16.5	0.08

3. Rainfall start time - 1250 on January 22, 1981.

The samples submitted to the California laboratory were analyzed for all priority pollutants except asbestos, cyanides, and bis (chloromethyl) ether. The sample sent to the Rexnord laboratory was analyzed for heavy metals in addition to analyses for other routine constituents.

The results obtained for priority pollutant analysis showed that 107 priority pollutants were looked for but not found. The data obtained for the 19 detected priority pollutants are shown in Table 184.

Also presented in Table 184 are the metals results obtained by Rexnord Inc. Comparison of the Rexnord results with the other metals data in Table 184 shows that the lead, zinc, and copper values are in reasonable agreement.

Table 184. Priority pollutants - Sacramento Hwy 50 site January 22-23, 1981, runoff samples.

Priority pollutant	California lab analysis Sample 1, g/1	California lab analysis Sample 2, g/1	Rexnord analysis Sample 1, g/1
Phenol	18	19	
Bis (2-Ethylhexyl) phthalate	13	16	
Di-n-butyl phthalate	<10	<10	
Di-n-octyl phthalate	<10	ND	
Anthracene	<10	ND	
Phenanthrene	<10	ND	
Silver	<20	<20	
Arsenic	<10	<10	30
Beryllium	<2	<2	
Cadmium	<5	<5	10
Chromium	29	30	8
Copper	67	44	80
Mercury	<1		10
Lead	370	440	380
Nickel	47	45	30
Antimony	<20	<20	
Selemium	<10	<10	
Thallium	<10	<10	
Zinc	210	210	245

ND = Not detected.

The discrepancy in the other metals values are again attributed to the use of different approved methods and/or instruments.

Comparison of the nonmetal data in Table 183 and 184 shows that 18 organic priority pollutants were found at the Milwaukee I-94 site as opposed to only 6 organic priority pollutants found at the Sacramento Hwy 50 site. However, common to both sites were the presence of five organic priority pollutants: phenol, bis (2-ethyhexyl) phthalate, di-n-butyl phthalate, anthracene, and phenanthrene.

The total flow sampled for priority pollutants during the January 22 to 23, 1981, storm event was 6000 ft^3 (169,920 liters) or 374,299 lbs (169,780 kg). The corresponding total weight of priority pollutants in the measured runoff was approximately 0.30 lbs (0.14 kg). The length of the study site was 0.27 mi (0.43 km); therefore, the priority pollutant load transported off the highway environment was 1.11 lb/mi (0.31 kg/km). This figure compares with 3.88 lb/mi (1.09 kg/km) for the Milwaukee I-94 site. Again, the major portion (76 percent) of the priority pollutant load at the Sacramento Hwy 50 site was contributed by the deposition of lead, zinc, and copper on the highway.

SUMMARY AND CONCLUSIONS

In summary, this study has demonstrated, through field surveys at four separate sites, that priority pollutants were present in the highway environment and that they migrated from that environment via the runoff from storm events. It was also indicated that highway sweeping methods presently used are not totally successful in removing all of the priority pollutants from the highway surfaces. In addition, it was observed that a significant number or organic priority pollutants were present in the highway environment, however, the major portion of the priority pollution load in highway runoff was attributed to the metal priority pollutants; lead, zinc and copper.

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