EFFECTS OF HIGHWAY RUNOFF ON STREAMFLOW AND WATER QUALITY IN THE SEVENMILE CREEK BASIN, A RURAL AREA IN THE PIEDMONT PROVINCE OF NORTH CAROLINA, JULY 1981 TO JULY 1982

By Douglas A. Harned

U.S. GEOLOGICAL SURVEY

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DEPARTMENT OF THE INTERIOR

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INTERNATIONAL SYSTEM UNITS

The following factors may be used to convert inch-pound units published herein to the metric (International System) units.

Multiply inch-pound unit	By	To obtain metric unit
Length		
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m^2)
	0.4047	hectare (ha)
	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
gallon (gal)	3.785	liter (L)
	0.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre foot (acre-ft)	1,233.5	cubic meter (m^3)
Flow		
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
gallon per day (gal/d)	0.0038	cubic meter per day (m^3/d)
Flow per area		
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer (m^3/s)/km^2
Temperature		
degree Fahrenheit (^oF)	5/9(^oF-32)	degree Celsius (^oC)
Mass		
ton (short, 2,000 pounds)	0.9072	megagram (Mg), or metric ton (t)
pounds (lbs)	453.59	grams (g)

<u>National Geodetic Vertical Datum of 1929 (NGVD of 1929)</u>: A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada; formerly called, "mean sea level."

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ABSTRACT

An evaluation of water-quality data from streams that receive storm-water runoff from a segment of interstate highway indicated elevated levels of many constituents compared to levels in nearby undeveloped basins. Additional data collected from a network of dry and wet atmospheric deposition collectors, lysimeter samples, soil surveys, wind measurements, and road sweepings helped define the general sources and migration of chemical substances near the highway. The eight study basins, located in a rural area in the Piedmont of North Carolina, had a combined area of 17.5 square miles, and drained a 4.8 mile-long segment of Interstate Highway 85 with an average traffic flow of 25,000 vehicles per day.

During storm runoff, streamflow in basins traversed by the highway rose and fell more rapidly than that in streams in the undeveloped basins. This more rapid response is due to the increased impervious area of the basins and the manmade drainage systems designed to rapidly move water off of the highway.

Alkalinity, specific conductance, and concentrations of calcium, sodium, and chloride were greater at the highway stations than in the undeveloped basins as a result of highway salting for control of ice. Rapid peaks of specific conductance and concentrations of dissolved and total nitrogen occurred at the beginning of each storm event. The data indicated that for the study basins, highway runoff had little or no effect on suspended sediment, water temperature, dissolved oxygen, and pH. However, pH declined during stormflow at all stations as rainfall with pH values less than 5.7 was drained off by the streams.

High metals concentrations were found in the soils near the highway and in the soil water infiltrating through the soil zone. Chromium, copper, nickel, and zinc concentrations in the streams near the highway generally were above U.S. Environmental Protection Agency (EPA) recommended levels for the protection of aquatic life, and lead and cadmium concentrations frequently exceeded levels recommended by the EPA for drinking water.

The highway is a source of contaminants to surrounding areas. Constituent loads in dustfall and constituent concentrations in soils decrease exponentially with distance from the highway, with the highest concentrations on the downwind side. Elevated concentrations of metals (cadmium, chromium, iron, lead, nickel, and zinc) in rainfall were observed in samples collected near the highway and about a half mile away. Material loading from dustfall is greater than from rainfall. Loads of saltated particles, or those heavier particles bounced along the highway surface, were higher than loads from dustfall. Saltation loads peaked during the winter months due to highway deicing and sanding which also supplies an estimated two-thirds of the saltated materials. The remaining third of the saltated load comes primarily from deposition of particles from vehicles. Some of the greatest constituent concentrations were measured in the soil water sampled from the lysimeters located near the highway.

INTRODUCTION

Modern, multiple-lane, controlled-access, super highways are an integral part of modern society. These highway systems move large volumes of traffic rapidly, safely, and effectively. However, once these roads are in place, their use and maintenance continually affect the surrounding environment. Traffic on the highways is a source of chemical substances to the areas near the roads and to more remote areas via transport by streams that drain the highways and transport by air.

Any complete assessment of the effects of development of water quality should account for the effects of highways. Although the magnitude of these effects varies, different stretches of highway with similar climate, topography, and traffic density should have similar kinds of environmental effects. The super highway is an easily identifiable type of land use that may show a range of effects that can be related to measurable independent variables.

Sevenmile Creek, which drains Interstate Highway 85 (I-85) near Efland, North Carolina, was one of the basins chosen in a national research study by the Federal Highway Administration to identify the sources of pollutants in runoff from major highways and to assess the migration of the chemical substances into the surrounding environment. Four sites were studied: a basin draining a section of I-94 in Milwaukee, Wisconsin; a basin draining a section of Highway 50 in Sacramento, California; a basin draining a section of I-81 in Harrisburg, Pennsylvania; and the Efland, North Carolina, I-85 site. Of these basins, the Milwaukee and Sacramento sites are urban, and the Harrisburg and Efland sites are rural. Traffic flow along I-85 near Efland was the least of all four sites. Kobriger and others (1982) qualitatively and quantitatively compare results determined at the four sites that allow general conclusions to be made about pollutant sources and migration. Dupuis and others (1984) present results of field monitoring programs at the Wisconsin I-94 site, the Efland I-85 site, and an additional site in Wisconsin along State Highway 15. The Dupuis and others (1984) study includes results of biological monitoring not available at the time of writing of this report.

A Federal Highway Administration report series (Gupta and others, 1981) that preceded and precipitated the Kobriger study also is a rich up-to-date source of data and information about the water quality of highway runoff. The Gupta report examines the body of literature related to highway runoff, describes highway-runoff water-quality characteristics, and provides procedures for monitoring and evaluating these characteristics.

Purpose and Scope

The purpose of this report is to describe the effects of storm runoff from a segment of a major highway system, I-85, on water-quality and flow characteristics of Sevenmile Creek, a small rural stream. An additional objective is to define, in a general manner, the sources and migration of chemical constituents near the highway.

The study area in Orange County, North Carolina, includes the drainage basin of Sevenmile Creek, which drains a 4.8 mile-long segment of Interstate 85 (fig. 1). Two other small stream basins, Rocky Run and Cane Creek, are adjacent to the Sevenmile basin and are used as control areas because their flows are unaffected by highway runoff. The total drainage area of the basins is 17.5 square miles.

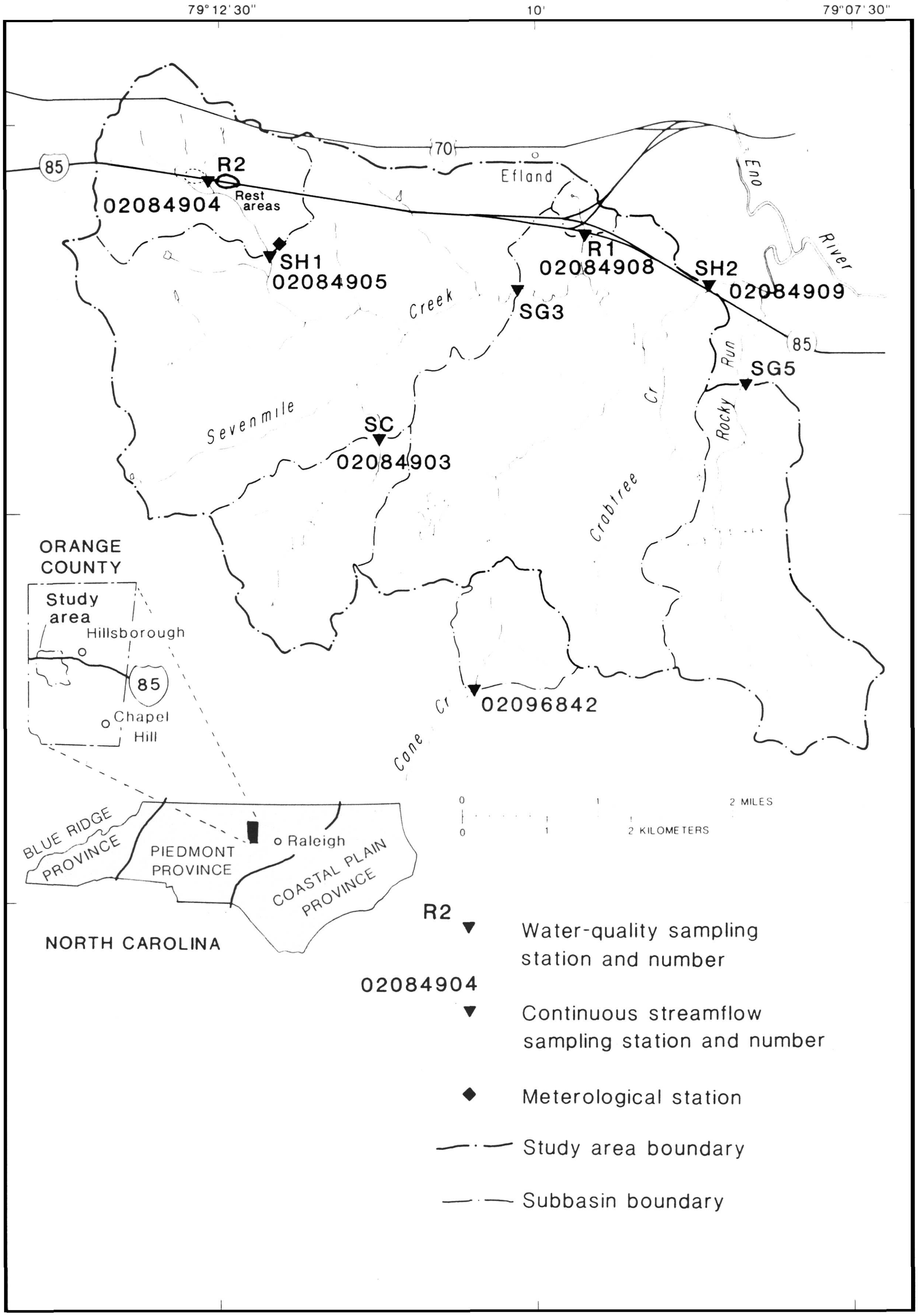

Figure 1.--Study area, sampling points, and subbasins.

Hydrologic data used in this investigation were collected in the Sevenmile Creek and Rocky Run basins from July 1981 to June 1982 and in the upper Cane Creek basin from 1973 to September 1981. Data collected included measurements of rainfall, streamflow, water temperature, specific conductance, pH, dissolved oxygen concentration, suspended-sediment concentration, and concentrations of major constituents, metals, and nutrients. In addition, measurements were made of atmospheric deposition quality, chemical quality of the water infiltrating into the unsaturated zone, metals in the soils near the highway, wind speed and direction, and the physical and chemical nature of road sweeping.

Biological data were collected but not evaluated in this report because the results were not available at the time of writing. In addition, no evaluation was made of water quality of the ground water in the saturated zone in the study basins because no data were available for the saturated zone.

Acknowledgments

The data for this study were collected primarily by U.S. Geological Survey personnel in coordination with REXNORD, Inc., a Milwaukee, Wisconsin, based engineering firm under contract with the Federal Highway Administration. REXNORD personnel included Tom Dupuis, Nick Kobriger, Joe Kuderski, and Bill Kreutzberger. The Federal Highway Administration reports for the national study (Kobriger and others, 1982; Dupuis and others, 1984) contain much of the data discussed in this U.S. Geological Survey report and is a source for some of the illustrations and tables.

The U.S. Geological Survey personnel who were substantially involved in planning and collecting data for Sevenmile Creek and adjacent basins included: R.G. Garrett, J.M., West, C.E. Simmons, S.S. Howe, and N.M. Jackson, Jr.

Technical reviews of this report were received from R.W. Coble, W.C. Meeks, N.M. Jackson, Jr., C.E. Simmons, and S.R. Ellis.

BASIN DESCRIPTION

The study area is located near Efland, Orange County, in the northern Piedmont province of North Carolina (fig. 1) along a 4.8 mile-long segment of I-85. The drainage basin of Sevenmile Creek, which has several small tributaries that drain the highway, is included in the area. Several other tributaries, including Crabtree Creek and Rocky Run, drain rural areas south of the highway. Sevenmile Creek joins the Eno River in the northeastern corner of the study area. Another small basin, the headwater reach of Cane Creek, is in an almost entirely forested area south of the Sevenmile Creek basin. Cane Creek flows south to the Haw River. The combined drainage areas of Sevenmile Creek, tributaries to Sevenmile Creek, and the Cane Creek study area cover 17.5 mi^2.

The study area was divided into eight subbasins to provide data from both developed and undeveloped sections (fig. 1). Two stations, R1 (Road-1; 02084908) and R2 (Road-2; 02084904), were established to record water-quality data from storm-water runoff from the highway. Stations SC (Stream-Control; 02084903) and Cane Creek (02096842) provided background data to compare with data from the runoff stations R1 and R2. Two other stations, SH1 (Stream hydrology-1; 02084905) and SH2 (Stream hydrology-2; 02084909), were located to gather data from larger areas. SH1 is downstream from R2 and drains a large section of I-85. SH2 is on the furthest downstream point on Sevenmile Creek. Water-quality samples were collected periodically at stations SG3 (Stream-grab-3), to provide data for Sevenmile Creek roughly at its midpoint in the study area, and SG5 (Stream-grab-5), to provide data from the Rocky Run basin. Rocky Run is a tributary to Sevenmile Creek and joins it about 0.5 miles downstream from station SH2. The entire study area of 17.5 mi^2 lies upstream of stations SH2 (drainage area 14.5 mi^2), SG5 (2.4 mi^2), and Cane Creek (0.64 mi^2).

The Sevenmile Creek basin is a potential supply source for the regional water-supply system of Orange County and the City of Chapel Hill, North Carolina (Orange County Planning Department, 1981).

Basin Characteristics

Topography

Rolling hills with gentle slopes characterize the landscape of the study area. Land-surface altitudes range from just over 700 feet to slightly less than 550 feet above National Geodetic Vertical Datum of 1929 (NGVD of 1929) in the study basins. As I-85 passes through the basin from east to west, it gains approximately 110 feet of altitude, giving it an overall slope within the basin of about 23 feet per mile.

Stream gradients within the study area range from about 100 feet per mile in headwater reaches (Cane Creek and near station R1) to 15 feet per mile along the downstream segment of Sevenmile Creek. The average stream gradient within the study area is around 48 feet per mile.

Geology

Geology affects natural water quality. In order to better define the significance of geology relative to man-related basin characteristics such as land use, rock type will be used as an independent variable in correlation analysis of the study-basin water-quality data.

Bedrock in the study area is predominately folded and fractured metavolcanic rock and igneous rock intruded into the metavolcanic rock (Allen and Wilson, 1968). Bedrock is generally overlain by the unconsolidated residual material termed regolith, resulting from the weathering of the bedrock. This weathered material has a great effect on the natural quality of ground water. In addition to ground-water quality, rock type influences the yield of wells and the base flow of streams (Simmons and Heath, 1979; Daniel and Sharpless, 1983).

Climate

Weather in the northern Piedmont is relatively mild year-round (National Oceanic and Atmospheric Administration, 1982). The Appalachian mountains in western North Carolina serve as a partial barrier to cold-air masses moving across the Plains States, tempering the severity of winter storms in the Piedmont. The coldest temperatures tend to occur when cold northeastern air moves southward. Overall, more than half of the winter days have sub-freezing temperatures, and the average winter has two snowfalls of over an inch in depth, and an average of four days per year of freezing rain. Maximum temperatures in the summer tend to be between 90 and 100 ^{o}F.

Rainfall generally is evenly distributed throughout the year, with the greatest average rainfall in July and the least in November. Most summer rain falls during convective storms, which can be quite intense. Normal precipitation in the study area, as measured at the National Oceanic and Atmospheric Administration station at the Greensboro-High Point-Winston-Salem Regional Airport, is 42.33 inches per year (period of record 1929-1981). The precipitation measured at the study site rain gages during the study period of July 1981-June 1982 measured 53.91 inches. In other words the study period represented a relatively wet year.

Land Use

Land use is a basin characteristic that can be used to quantify the effect of man on the landscape and will be used as an independent variable in correlation analysis of the water-quality data. The study area is predominantly rural except for development that lines certain roads in the Sevenmile Creek basin and the town of Efland. The principal roads in the basin are shown in figure 2. Road length gives a measure of development and is one independent variable used in correlation analysis of the study-basin water-quality data.

The land-use categories shown in figure 3 were obtained by overlaying a U.S. Geological Survey Land-Use Data Analysis (LUDA) map published in 1977, a USGS topographic map published in 1968, and an unpublished USGS orthophotoquad made from an aerial photograph taken in 1973. Spot field checks were made to verify certain features of the final map. Although the data sources used to compile the map are somewhat outdated, the field checks indicate that, within the range of accuracy possible in this kind of reconnaissance mapping, the resulting land-use breakdown represented in figure 3 is suitable for the purpose of this analysis. The numbers used in figure 3 correspond to the system of land-use categorization used on the USGS LUDA maps (Anderson and others, 1976).

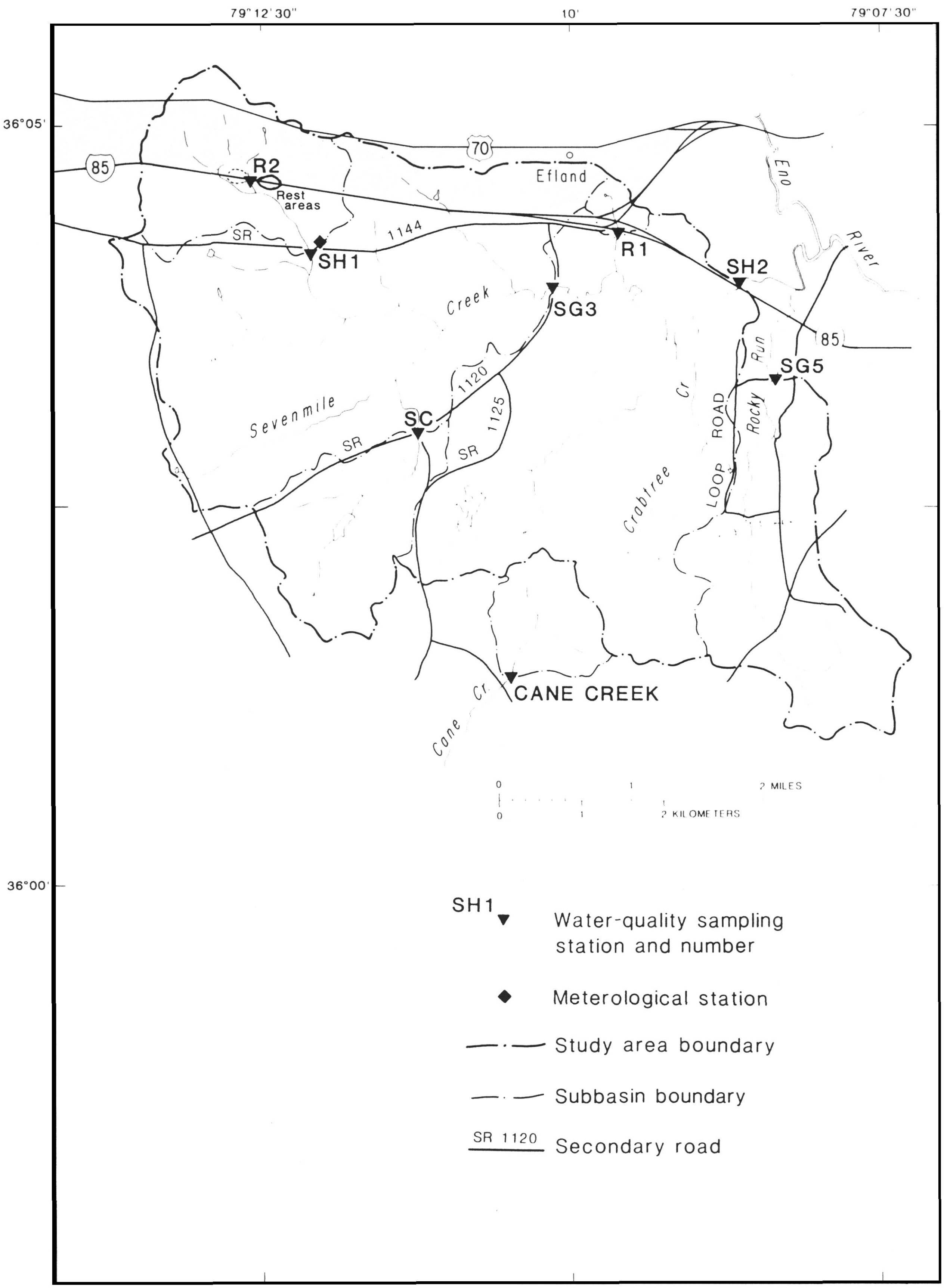

Figure 2.--Principal roads in the study area.

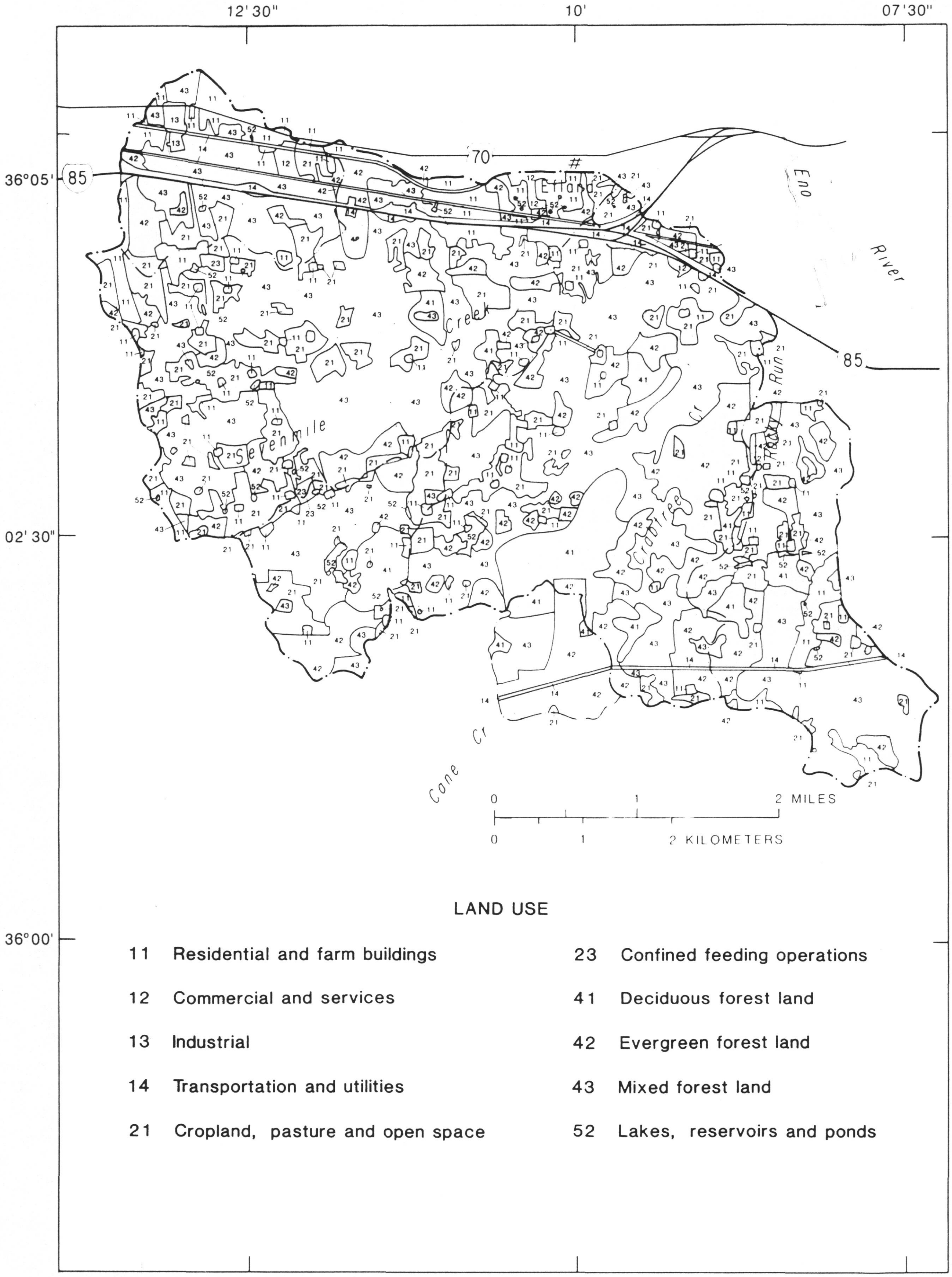

Figure 3.--Study area land use.

The percent of land-use type within each subbasin is shown in table 1. Forest, cropland, and residential areas are the dominant land uses in all the subbasins except R1 and R2. The subbasin for R1 is predominantly pasture and transportation, whereas that for R2 is completely road area. The most highly developed basins are SH1 (which includes R2) and R1. The Cane Creek subbasin, which is 97 percent forest, is the least developed area.

Highway Characteristics

The 4.8 mile-long section of I-85 that passes through the study area is a four-lane divided highway with a grass median strip. The pavement is asphalt in the travel lanes and stone and asphalt aggregate in the distress lane and median shoulders. A typical cross section of the highway, showing the road design, is given in figure 4.

There are two rest areas, one for each side of the highway. Each rest area contains a small, self-contained sewage treatment facility to handle wastewater from the restrooms. The effluent from these facilities enters the tributary to Sevenmile Creek just downstream from the R2 station.

An average of 25,000 vehicles per day traveled through the basin during the study period. Monthly averages ranged from a low of 22,000 vehicles per day in January 1982, to a high of 28,000 vehicles per day in August 1981, November 1981, and June 1982. Traffic flow along I-85 tends to be the lowest during the winter months.

Table 1.--Percentage of land-use types in subbasins

Map number	Land use	Percent area								
		R1	R2	SH1	SH2	SG3	SG5	SC	Cane Creek	Study area
11	Residential and farm buildings	2.1	0	16.8	7.5	10.3	9.1	3.8	0	7.4
12	Commercial and services	0	0	2.2	.9	1.2	0	0	0	.7
13	Industrial	0	0	2.8	.3	.5	0	0	0	.3
14	Transportation and utilities	38.2	100	7.9	3.0	3.4	1.2	0	3.0	2.7
21	Cropland, pasture, and open space	52.6	0	11.6	17.6	19.6	7.0	18.5	.4	15.4
23	Confined feeding operations	0	0	0	.3	.5	0	1.2	0	.2
41	Deciduous forest land	0	0	0	6.2	2.9	6.1	12.1	13.6	6.5
42	Evergreen forest land	.5	0	9.9	17.1	12.5	15.6	18.7	59.0	18.7
43	Mixed forest land	5.4	0	48.6	46.1	48.7	60.4	44.2	24.0	47.6
52	Lakes, reservoirs, and ponds	1.2	0	.2	.5	.4	.6	1.5	0	.5
	Drainage area (mi^2)	.14	0.0032	1.6	14.5	8.8	2.4	1.4	.64	17.5

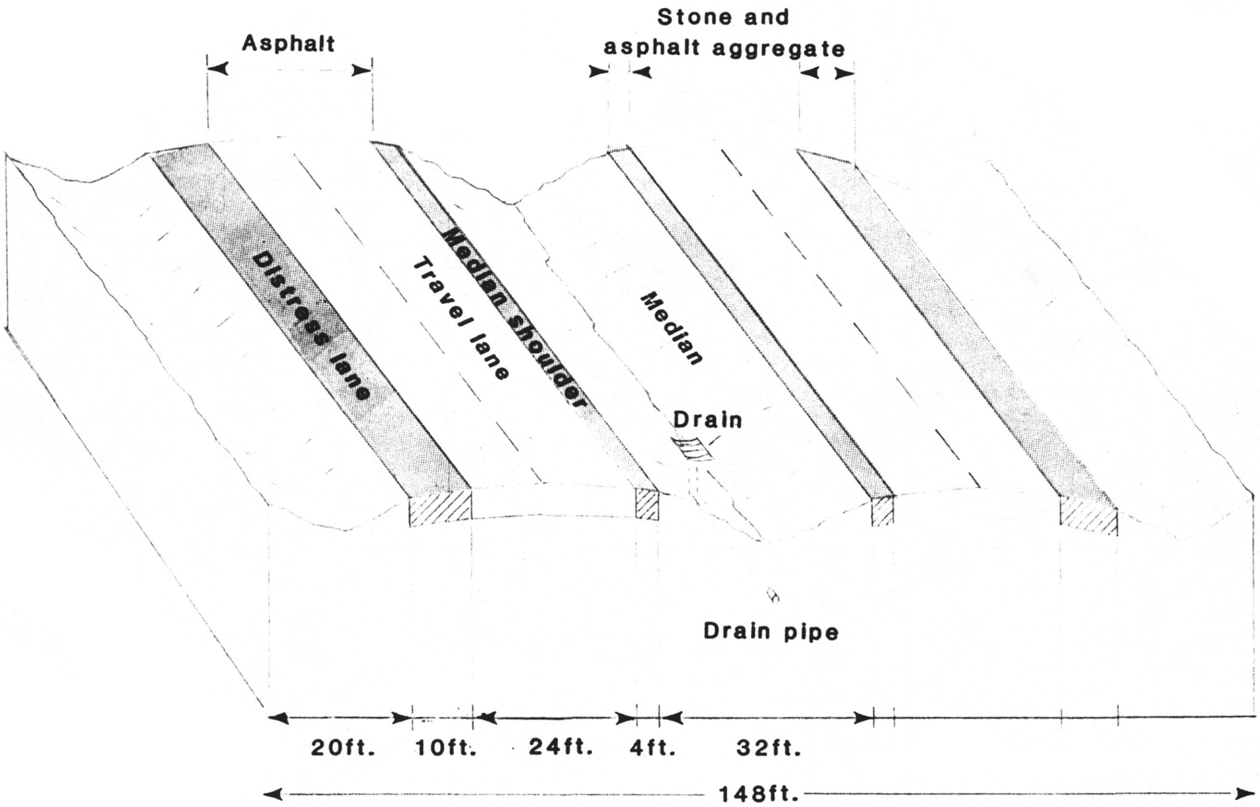

Figure 4.--Typical cross section of Interstate Highway 85 near Efland, showing road design and drainage (Kobriger and others, 1982).

Highway maintenance activities on the stretch of I-85 that passes through the study area include: repair, sanding and salting for ice and snow removal, snowplowing, roadside mowing, and herbicide and fertilizer application. Of these practices, only data on road sanding and salting were available for this analysis.

DATA COLLECTION

The data-collection effort was coordinated jointly between the Geological Survey and REXNORD, Incorporated. Day-to-day operation and maintenance of the equipment, periodic water-quality and meteorological sampling, stream gaging, and storm-event sampling were handled by the Geological Survey staff. Samples collected by the Geological Survey were mailed to REXNORD's laboratory in Milwaukee, Wisconsin, for analysis. The Geological Survey staff also performed field analyses when appropriate for pH, water temperature, conductivity, and dissolved oxygen. REXNORD staff made several special sampling trips to collect biological samples and to vacuum segments of I-85 to obtain samples of the material on the road surface. The emphasis of this report will be placed on the available data at the time of writing and, in particular, the data which the Geological Survey staff collected.

A summary of the equipment and sampling frequency for each site is presented in table 2. The instrumentation included analog-to-digital recorders (ADR) for gage height, temperature and specific conductance, automatic water samplers that would activate with each rise in stream stage, recording rain gages, a recording anemometer, and atmospheric deposition samplers that collected dustfall during dry periods in one container and precipitation during wet periods in another. Other collectors were used to gather dustfall at all times or from specific sources. Water-quality samples were also collected by hand. Lysimeters were used to collect samples of water infiltrating through the soil zone.

Table 2.--Equipment at stations and sampling frequency
[M = monthly; BW = biweekly; W = weekly]

STATION	EQUIPMENT							TRIP/SAMPLE FREQUENCY						
	Continuous stage recorder (ADR)	Automatic sampler	Temperature and conductivity monitor	Precipitation gage and gage number	Weather station	Lysimeters	Staff gage	Gage height Automatic sampler Temperature and conductivity	Wet/dry collectors	Weather station	Dry weather survey	Wet weather survey	Bulk precipitation	Lysimeters
SH1 - Sevenmile Creek tributary at SR 1144 near Miles (02084905)	✓	✓	✓	P1[a]	✓		✓	M	BW	W	M	~6[b,c]		
SH2 - Sevenmile Creek at I-85 near Efland (02084909)	✓	✓	✓	P2			✓	M			M	~6[b,c]		
SC - Sevenmile Creek tributary at SR 1120 near Buckhorn (02084903)	✓	✓	✓	P3[a]			✓	M	BW		M	~6[b,c]		
R1 - Sevenmile Creek tributary at I-85 near Efland (02084908)	✓	✓					✓	M				~6-8		
R2 - Sevenmile Creek tributary at I-85 near Miles (02084904)	✓	✓				✓	✓	M				~25 events	BW	~25 events
Cane Creek - 0.1 mile upstream from SR 1126 near Buckhorn (02096842)	✓		✓				✓	M						
SG3 - Sevenmile Creek at SR 1120 near Efland							✓					~6[b]		
SG5 - Rocky Run at Loop Road near Efland							✓					~6[b]		

[a] Includes wet/dry collector
[b] Includes 5-6 manual samples for oil, bacteria, pesticides and wet sieve
[c] Includes automated and intensive surveys

The variety of devices used to collect atmospheric deposition included: recording rain gages, plastic buckets on mounts used to collect dustfall (dust buckets), wet/dry collectors, and a saltation catcher--a bucket capped by a section of slotted pipe set at road-surface level. The locations of these devices at station R2 are shown in figure 5. Wet/dry collectors were also located at the SC and SH1 sites.

Factors which complicate analysis of effects of the highway on water quality include background levels of constituents and highway maintenance. It is difficult to separate from ambient background water and air-quality data what are truly natural pollution effects. This complication makes source identification more difficult.

Data collected at the Cane Creek station have been used in a study of natural or background water quality of North Carolina streams (Simmons and Heath, 1979), and because no station in the Sevenmile Creek basin provides data representative of an undeveloped area, Cane Creek data were used. The station at Cane Creek is operated by the Geological Survey, and the samples collected there were analyzed at the Geological Survey laboratory in Doraville, Georgia.

All of the stations, except SG3 and SG5, were equipped with ADRs which are used to record the stream stage data. The stages measured at each station were related to discharge by use of weirs and flow meters. Stage-discharge relations defined in this process were then applied to the stage data to determine discharge.

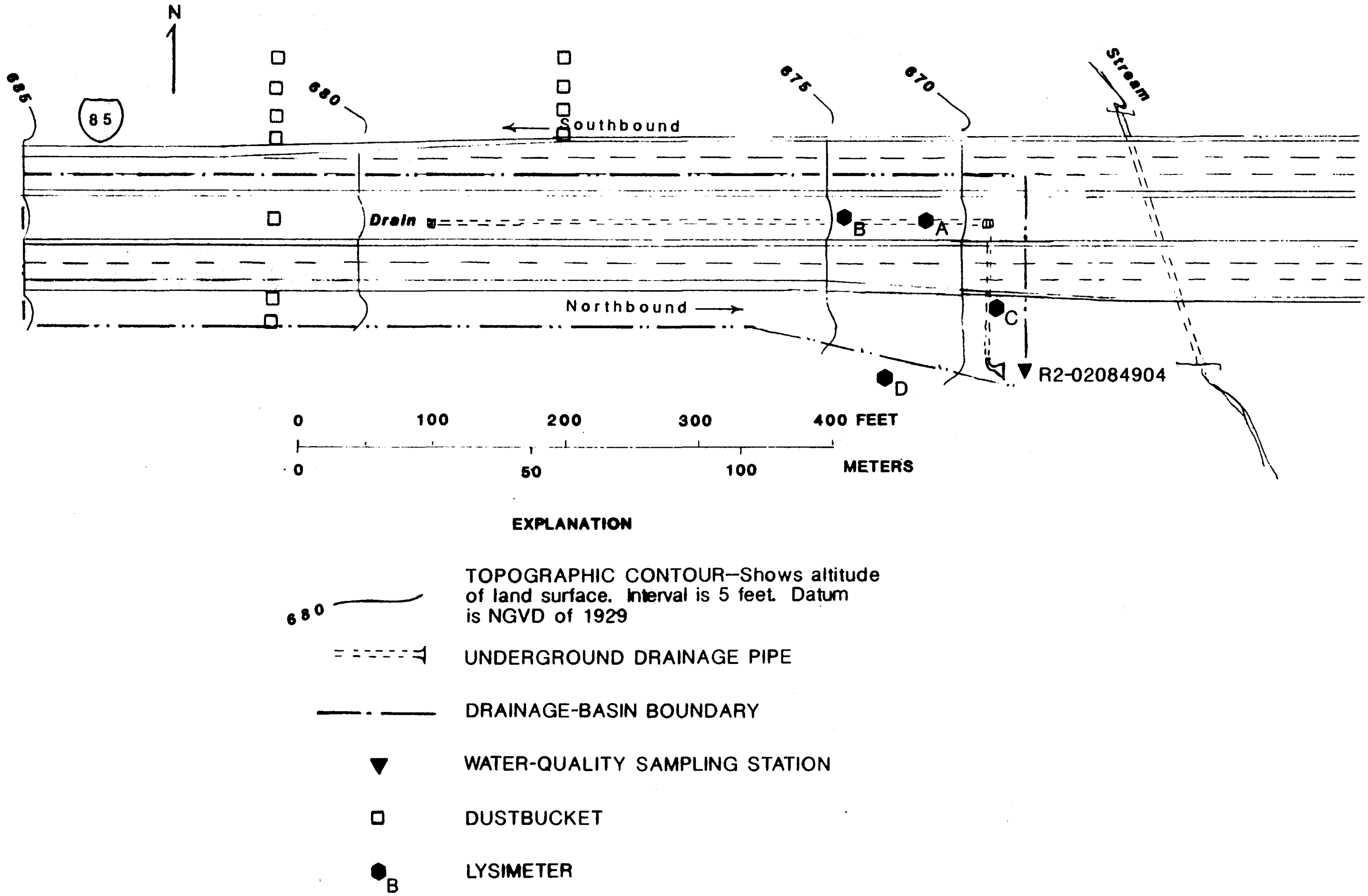

Figure 5.--Locations of dust buckets, saltation collectors, and lysimeters at site R2 .

Water-quality sampling was conducted at SH1, SH2, SC, R1, and R2 using an automated stage-activated sampler. Samples from the automatic samplers were supplemented with periodic manually collected samples and field water-quality analyses. The samples obtained were either shipped to REXNORD, Inc. in Milwaukee, Wisconsin, for analysis or analyzed in the laboratory at the Geological Survey in Raleigh, North Carolina. Only analysis of fecal coliform bacteria, fecal streptococcus bacteria, and specific conductance, pH, water temperature, suspended-sediment concentration, and dissolved oxygen concentration were determined by the Geological Survey; all other analyses were conducted by REXNORD, Inc.

Samples were collected manually at sites SG3, SG5, and Cane Creek. The samples from SG3 and SG5 were shipped to REXNORD, Inc. All analyses of samples from Cane Creek were performed at the Geological Survey laboratory in Doraville, Georgia.

Specific conductance and water temperature were continuously monitored at SH1, SH2, SC, and Cane Creek. These parameter values were measured and stored by using in-stream probes and ADRs; these data were processed with the Geological Survey computer system.

Lysimeters designed to collect samples of soil water were installed at the R2 site. The locations of these four lysimeters are shown in figure 5.

SOURCES AND TRANSPORT MECHANISMS OF CONSTITUENTS

The principal sources of materials commonly found in highway runoff water are vehicles, atmo pheric fallout, highway maintenance, and road structure degradation. Vehicles contribute materials from tire wear, fluid leaks or spills, automobile body rust, brake lining wear, and wear of moving engine parts and bearings. The atmospheric contribution includes fallout from vehicle exhaust and other air pollution. Road maintenance such as road deicing, spraying of right-of-ways with pesticides, and fertilizers also affect runoff water quality. Finally, degeneration of the road itself, with pavement wear, rusting of steel highway structures, and leaching of petroleum from asphalt, contributes to the material that makes its way to nearby streams. A list of constituents commonly found in highway runoff and associated sources of the substances is shown in table 3. Although inferences can be made in some cases about the sources of constituents measured, the emphasis of this report will be the comparative differences between areas affected by the highway system and unaffected areas.

Other sources of constituents within the Sevenmile Creek basin include development unrelated to the highway system and geological influences. There is some minor industrial and residential development in Efland (see Land Use section). Two small wastewater treatment plants serving the highway rest areas flank I-85. Two intensive feed-lot operations are located in the western section of the SG3 subbasin and northern section of the SC subbasin.

Table 3.--Sources of common highway runoff chemical constituents
[from Kobriger and others, 1982]

Constituent	Source
Asbestos	Clutch and brake lining wear
Bromide	Exhaust
Cadmium	Tire wear (filler material), insecticide application
Chloride	Deicing salts (NaCl, $CaCl_2$)
Chromium	Metal plating, moving engine parts, brake lining wear
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides applied by maintenance operations
Cyanide	Anticake compound (ferric ferrocyanide, Prussian Blue or sodium ferrocyanide, Yellow Prussiate of Soda) used to deep deicing salt granular
Iron	Autobody rust, steel highway structures (guard rails, etc.) moving engine parts
Lead	Leaded gasoline (exhaust), tire wear (lead oxide filler material), lubricating oil and grease, bearing wear
Nutrients	Atmosphere, roadside fertilizer application, bird droppings, trucks hauling livestock and stockyard waste
Pathogenic bacteria (indicators)	Soil, litter, bird droppings, and trucks hauling livestock and stockyard waste
Particulates	Pavement wear, vehicles, atmosphere, maintenance
Petroleum	Spills, leaks or blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate
Pesticides	Spraying of highway right-of-ways, atmosphere
Manganese	Moving engine parts
Nickel	Disel fuel and gasoline (exhaust) lubricating oil, metal plating, bushing wear, brake lining wear, asphalt paving
Rubber	Tire wear
Sulfate	Roadway beds, fuel
Zinc	Tire wear (filler material), motor oil (stabilizing additive), grease

The principal transport mechanisms include storm-water washoff and solution, entrainment in the air, and saltation along the ground. Storm-water washes and dissolves accumulated material from road and median surfaces, carries particles and dissolved constituents in surface runoff, or transports dissolved material through the soils by infiltration. The array of devices designed to sample surface water, such as stage-activated automatic samplers, combined with manual sampling schemes, give a measure of the role of storm-water transport. Lysimeters give an estimate of quality of water that moves through the soil zone.

Winds and air currents caused by moving vehicles may either briefly blow materials short distances or entrain them for longer periods in the atmosphere. Dry atmospheric deposition collectors, including dust buckets and wet/dry collectors, measure the effect air movement has on material transport. Measurements of rainwater quality are particularly important because of the air-cleansing effect rain has on entrained dust particles and gases. Saltation collectors measure the fraction of larger-sized particles that bounce off the road surface.

Table 4.--Statistical summary of chemical concentrations in rainfall samples collected at the SH1 station from July 1981 to July 1982

[mg/m^2, milligrams per square meter; -, no data; mg/L, milligrams per liter; µg/L, micrograms per liter]

Characteristic	Mean	Standard deviation	Range	(Statistical) Median load mg/m^2	Number of samples
Precipitation, in inches	1.35	0.93	0.22-3.7	-	14
pH [1/]	4.0	.57	3.4-5.4	-	14
Total dissolved solids, in mg/L	9	9	0-24	272	6
Total suspended solids, in mg/L	14	11	2-33	36	13
Total organic carbon, in mg/L	11	7.8	5-16	260	2
Chemical oxygen demand, in mg/L	13	6.4	8-17	505	2
Chloride, in mg/L	2.9	2.4	0-6	108	8
Sodium, in mg/L	.5	.7	0-2	7.3	8
Sulfate, in mg/L	1.0	2.2	0-5	-	5
Total phosporous (as P), in mg/L	.003	.01	0-.03	-	9
Total Kjeldahl nitrogen, in mg/L	1.0	.91	0-2.0	42	7
Total nitrate + nitrite (as N), in mg/L	.27	.28	.03-.81	6.6	7
Total cadmium, in µg/L	.8	1.4	0-4	-	13
Total chromium, in µg/L	2.6	3.8	0-10	.04	11
Total copper, in µg/L	32	22	10-90	.7	13
Total iron, in µg/L	240	400	50-1500	3.1	13
Total lead, in µg/L	3.8	7.7	0-20	-	13
Total nickel, in µg/L	3.9	6.5	0-20	-	13
Total zinc, in µg/L	30	14	0-50	.8	13

[1/] pH mean calculated using hydrogen-ion concentrations.

Atmospheric Sources

Dust particles carried by air currents and atmospheric gases combine and react with precipitation and affect rainwater quality. The sources of these materials in the air are difficult to define because some materials may have been transported long distances. Statistical analysis of the chemical characteristics of precipitation from 14 storms collected at the SH1 station, indicates that the atmosphere is a major source of metals and nitrogen and that the rainwater is very acidic (table 4). All pH values were below 5.7, which is the theoretical pH of pure water in equilibrium with atmospheric CO_2 concentrations (Interagency Task Force on Acid Precipitation, 1981).

Highway Sources

Materials derived from highway activities were collected at the R2 sites by using dust buckets, saltation collectors (see location map, figure 5), and road sweeps and soil samples.

A comparison of highway dustfall conditions with background conditions is shown by the summary of loading rates of particulates and metals measured near the R2 station at the highway and the wet/dry collector located near the SH1 station located about a half mile from the highway (see table 5). Background dustfall conditions, represented by data from the wet/dry collector, can be compared to the highway conditions measured by data from the R2 dust buckets. Adding the wet and dry fractions together, we find that (column 10, table 5) the proportion of the total loading rate attributable to background conditions is unexpectedly high, ranging from around 40 percent of the total zinc load to over 90 percent of the total particulate loading rate at the highway station. This may indicate high ambient dust levels from widespread sources or, more likely, load contribution to the SH1 wet/dry collector from the highway system.

Table 5.--Summary of loading rates of particulates and metals measured near the R2 (highway) and at the SH1 (background) stations from July 1981 to July 1982

[$mg/m^2/d$, milligrams per square meter per day; ND, not detected; -, no data]

	R2 Dust Bucket			SH1 Wet/Dry Collectors						Saltation Collectors			
Column:	1	2	3	4	5	6	7	8	9	10	11	12	13
	Mean load ($mg/m^2/d$)	Range ($mg/m^2/d$)	Number of samples	Mean or median load in ($mg/m^2/d$) Wet	Dry	Wet+Dry	Range ($mg/m^2/d$) Wet	Dry	Number of samples	(Col. 6) - (Col. 1) x 100	Mean load 1/ ($mg/m^2/d$)	Range 1/ ($mg/m^2/d$)	Number of samples
Total particulate matter	40.3	8.7-103	27	11.0	26.5	37.5	0.047-39.9	4.05-68.9	23	93	69.5	25.4-146	24
Total cadmium	ND	ND-.0007	7	ND	ND	ND	ND	ND-.001	6	-	ND	ND	4
Total chromium	.002	.00002-.005	7	ND	.001	.001	ND-.001	.00002-.002	6	50	.002	.001-.003	4
Total iron	.424	.024-.672	7	.041	.320	.320	ND-.159	.024-.626	6	75	1.45	.83-2.08	4
Total lead	.006	.001-.015	7	ND	.004	.004	ND-.002	.0001-.007	6	66	.07	.05-.10	4
Total nickel	ND	ND-.002	7	ND	ND	ND	ND-.001	ND-.001	6	-	ND	ND-.001	4
Total zinc	.007	.00004-.018	7	ND	.003	.003	ND-.015	.0004-.011	6	42	.02	.017-.024	4

1/ Calculated using means of samples from both collectors. Because there were only two saltation collectors, and each was located on the outside median, saltation material in the central median was not accounted for.

There is a distinct relation between constituent levels measured in the dust buckets and bucket distance from the highway. This relation, which takes the form of an exponential die-off curve, is illustrated in figure 6. In this diagram both total particulate material and total lead content are high next to the road and much lower just 30 feet away from the road. This kind of relation also exists for the metals concentration of the uppermost centimeter of soil, illustrated in figure 7. Again, as with dust buckets, high concentrations in the soil generally are found nearest to the highway. The highest concentrations of iron, lead, and zinc are also found on the north side of the freeway. This is probably because the predominant wind direction is to the north.

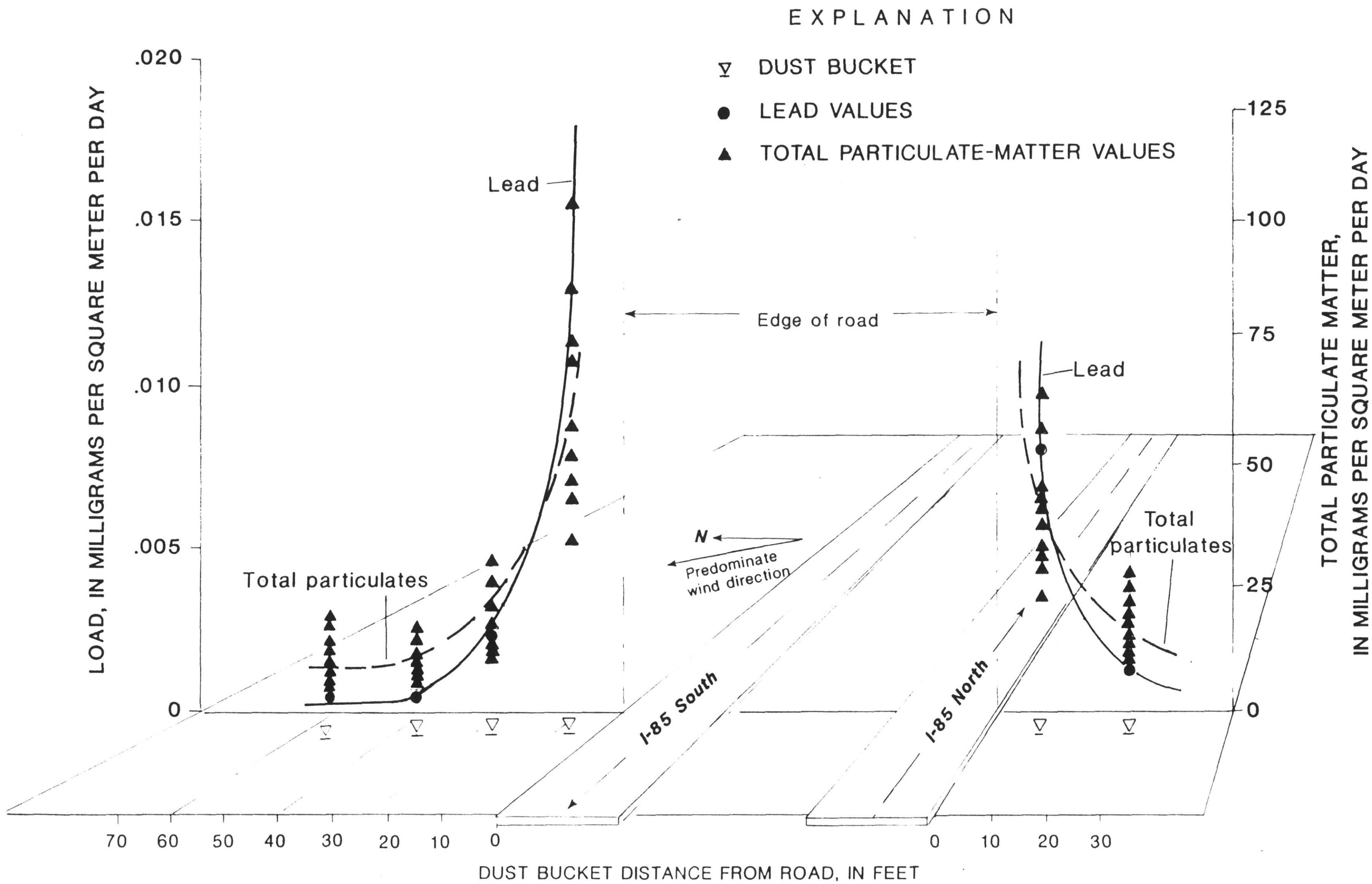

Figure 6.--Lead and particulate fallout near highway station R2 (Kobriger and others, 1982).

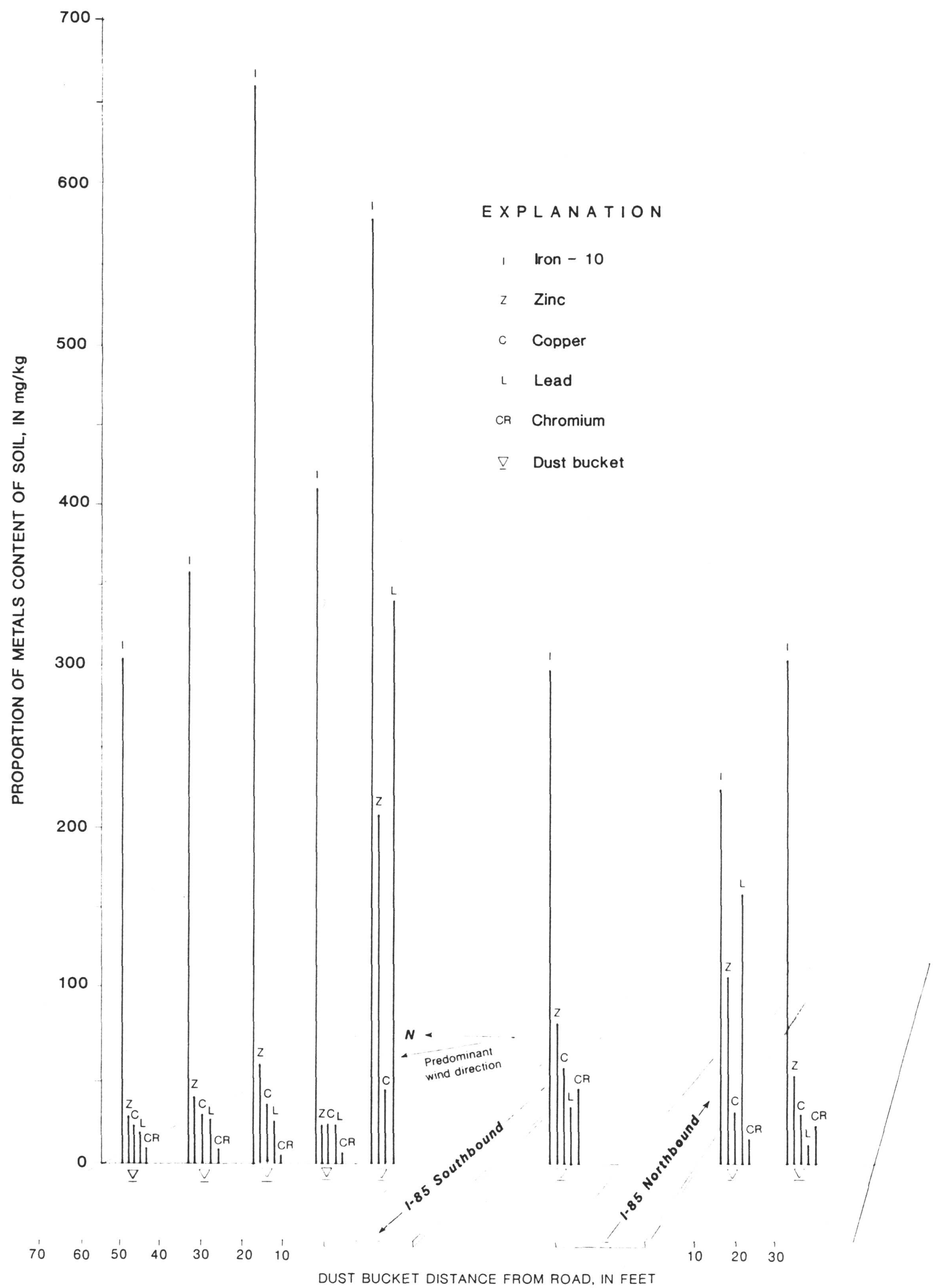

Figure 7.--Proportion of metals content in soil near the highway station R2 (Kobriger and others, 1982).

The results of a comparison of wet deposition to dry deposition reveal that material loading is greater during dry periods than wet periods. As shown in table 5 (columns 4 and 5), this is particularly evident for metals.

The summary of saltation-collector data shown in table 5 allows comparison of highly localized material loading near the highway system, due to saltating particles, to the diffused dustfall loadings near and a half of a mile away from the highway. The loads caught by the saltation collectors are higher than those measured from dustfall and wet atmospheric deposition.

There is a seasonal pattern in loading rate of total particulates collected by the saltation collectors (figure 8). The peaks of total particulate load observed during winter months corresponds to a general decrease in traffic flow and rainfall, and a slight increase in average wind speed. The seasonality probably is due to road deicing operations, including road sanding that occurred during the winter months.

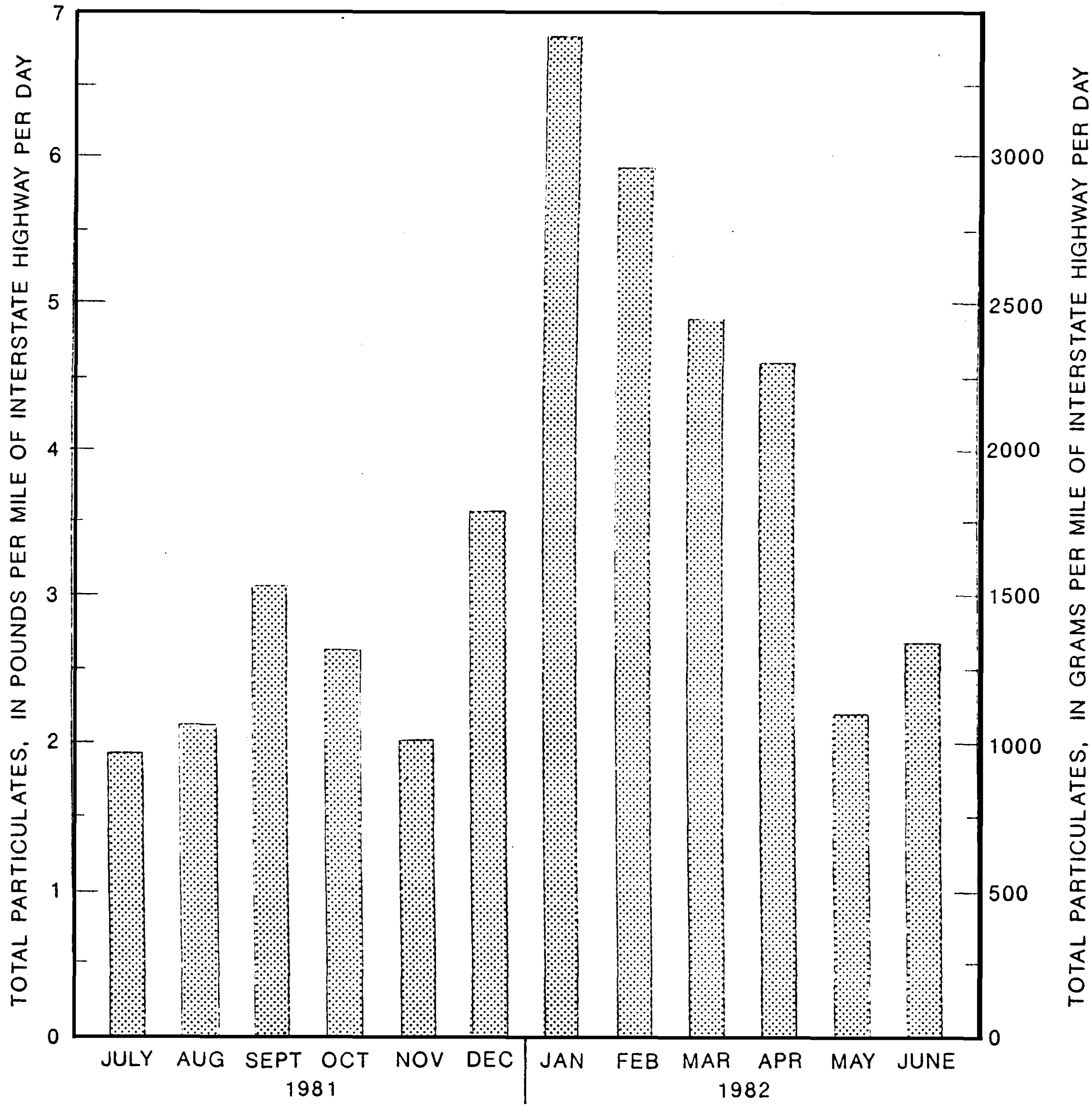

Figure 8.--Seasonal loading rate of total particulates near the highway station R2.

EFFECTS OF THE HIGHWAY ON STREAM DISCHARGE

The instantaneous discharge measured during the time of sampling at the study stations tends to be greater than the daily mean discharge because most samples were collected during high rates of runoff during storm events. Both measures of discharge indicate that station SH2 had the greatest streamflow followed by SH1 and SC Cane Creek, R1, and R2. Logically, the greater the size of the drainage area the greater the discharge, as shown in table 6. The discharge per square mile at site R2, the station with a catchment area that is about one-half paved, is particularly high.

A comparison among stations for a single storm event shows the relative hydrologic responses of the streams and demonstrates a common effect of development on those responses. The storm of September 5, 1981, was monitored for discharge at all of the stations, except SC, and for water quality at all of the stations, except SC and Cane Creek. About 1.5 inches total rainfall was measured during a 5-hour period. Graphical representations of hourly rainfall (hyetographs) and continuous streamflow (hydrographs) for this storm are shown in figures 9 and 10. The runoff response observed for this storm was typical of storm events observed throughout the study period.

Table 6.--Summary of stream discharge at selected sites

[mi^2, square miles; ft^3/s, cubic feet per second; $ft^3/s/mi^2$, cubic feet per second per square mile]

Station (number)	Drainage area (mi^2)	Daily discharge Mean (ft^3/s)	Daily discharge Range (ft^3/s)	Mean daily discharge - drainage area ($ft^3/s/mi^2$)
R1 (02084908)	0.14	0.12	0-4.30	0.86
R2 (02084904)	.00324	.0090	0-.370	2.78
SH1 (02084905)	1.62	1.82	.01-63.0	1.12
SH2 (02084909)	14.54	15.18	.01-437.	1.04
SC (02084903)	1.39	1.49	0-20.0	1.07
Cane Creek 1/ (02096842)	.64	.29	0-11.0	.45

1/ Period of record, October 1971 to October 1981. The period of record for the Sevenmile Creek stations was July 1981 to July 1982.

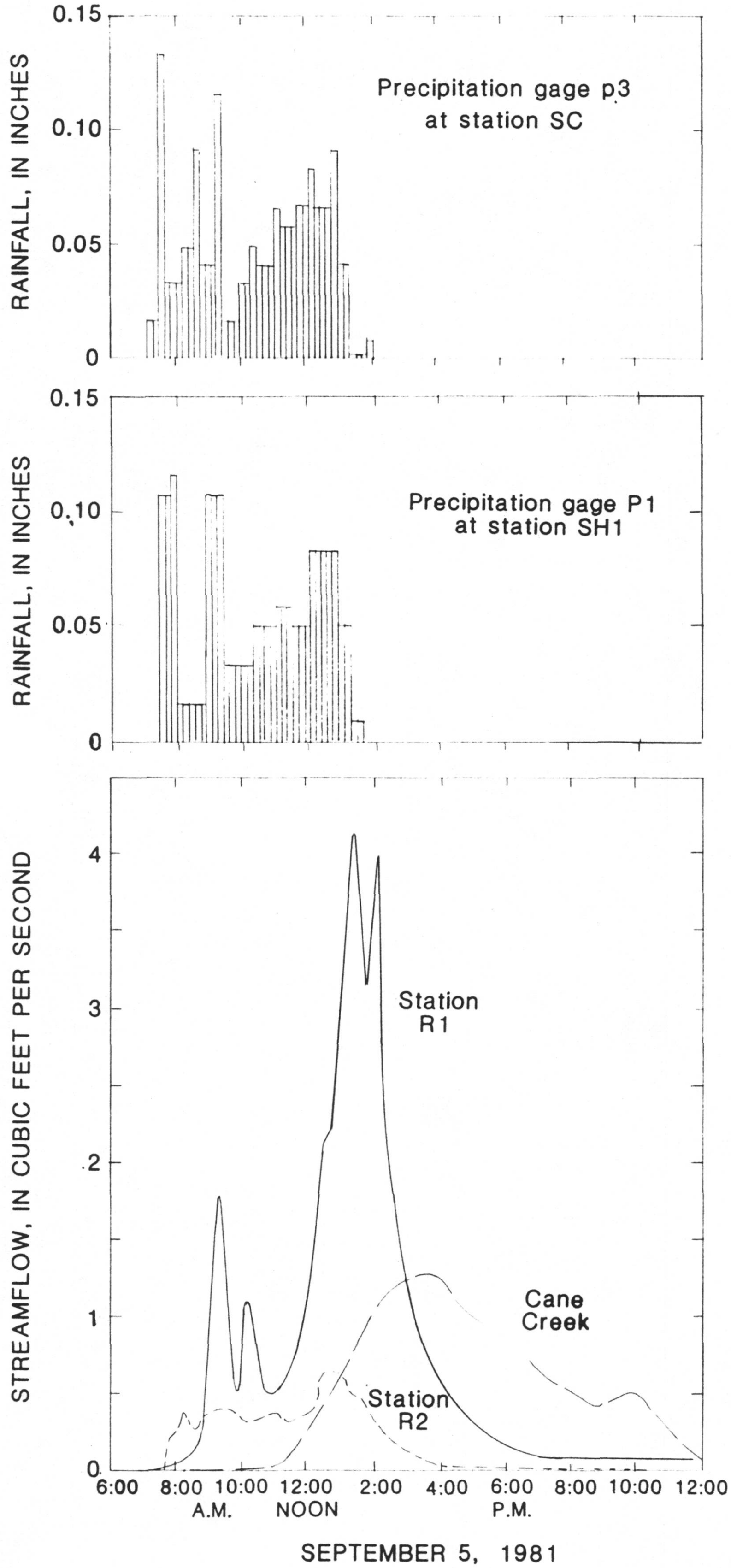

Figure 9.--Rainfall at stations SC and SH1, and streamflow hydrographs for stations R1, R2, and Cane Creek for the storm of September 5, 1981.

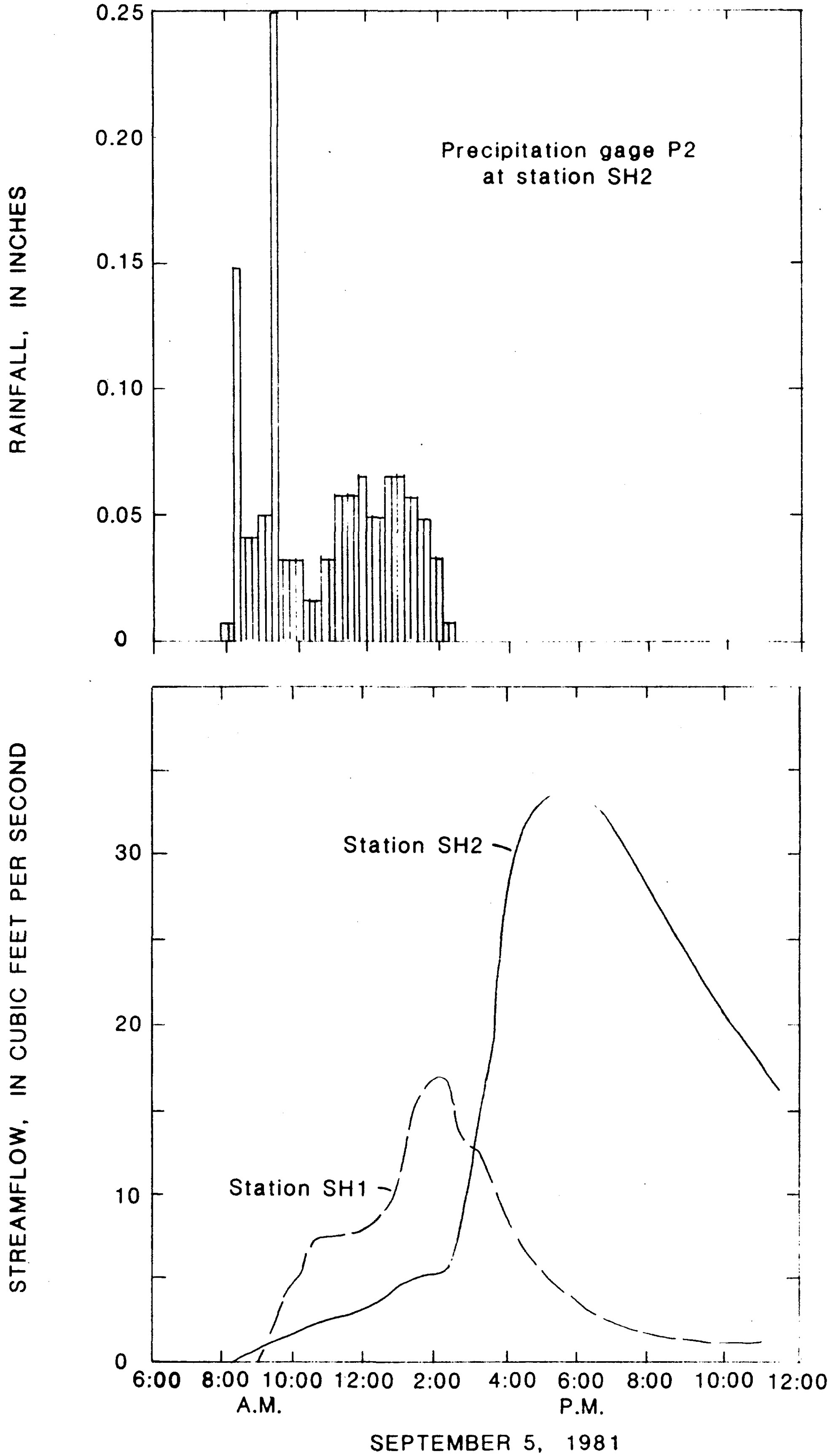

Figure 10.--Rainfall at station SH2, and hydrographs for stations SH1 and SH2 for the storm of September 5, 1981.

The hyetographs for stations SC (P3) and at station SH1 (P1) on figure 9 and at station SH2 (P2) on figure 10 generally are similar in overall form; the only difference is the distribution of rainfall at the beginning of the storm. In particular, the intensity observed at station SH2 was greater than at the other two rainfall stations. The stream responses to the rainfall, shown in figures 9 and 10, are dramatically different from each other.

Runoff in the smallest basin, R2, which is nearly half covered with impervious highway pavement, responded within minutes to the rainfall; its discharge peaks coincided with the periods of most intense rain, and the stormflow recession was brief after the rain stopped (fig. 9). This response is expected because most of the precipitation in a small basin that has a large proportion of impervious cover and a manmade drainage system runs off quickly with relatively little water stored in surface pools or in soil to later drain out of the basin.

The runoff response at station R1 was similar to that at as R2; the runoff peaks in the hydrograph nearly matched the spikes in the hyetograph. The response at R1 was delayed somewhat in comparison to R2 because R1 is a larger basin with less impervious area than R2. The streamflow recession at R1 also is longer in duration than that observed at R2 because of the greater surface and ground-water storage area in the R1 basin.

The relative effect of impervious area on a stream's flood flow can be easily seen by comparing the Cane Creek hydrograph to those of R1 and R2. The Cane Creek basin, which has a much greater drainage area than either R1 or R2, showed a much more subdued response to the storm. Streamflow in Cane Creek only began to increase two hours after rainfall began, peaking slowly with a long recession period. The total volume of runoff for the period shown was greatest at R1 even though the drainage area of the Cane Creek basin is over four times that of R1. The response observed at Cane Creek, with its slow rise and long recession, is characteristic of an undeveloped forested basin with no impervious area. The response observed at R1 and R2, with their rapid rises and recessions and with the high peak flows as observed at R1, is characteristic of small, developed or urban basins with substantial impervious areas.

A comparison between the hydrographs for stations SH1 and SH2 demonstrates an attenuated response for SH2, which is typical of the larger drainage areas with greater streamflow travel times. The imprint of the storm hyetograph, as well as effects of impervious area, show in the SH1 hydrograph but not downstream at SH2. This is because the SH2 hydrograph is the cumulative response of flows from numerous smaller tributaries, each with different basin characteristics but 80 percent cropland and forest. The resultant hydrograph at SH2 represents an average flow response from the tributaries and takes a general shape that is between that observed at Cane Creek and that observed at station R2.

A correlation analysis was used to test for relations between streamflow, land use, and geology. No statistically significant relations were found.

EFFECTS OF HIGHWAY RUNOFF ON WATER QUALITY

Physical Characteristics

A statistical summary of water-quality characteristics of water discharge, water temperature, dissolved oxygen, pH, and suspended sediment for the Sevenmile Creek stations and the Cane Creek station is shown in tables 7-10. Specific conductance, which is included in these tables, also is discussed later under major dissolved constituents. In these and other following tables of water-quality characteristics, the chemical and physical characteristics for the Sevenmile Creek stations are primarily representative of higher flow conditions than those for Cane Creek. The physical and chemical characteristics for Cane Creek represent the full range of flow conditions.

Suspended Sediment

The statistical summaries for suspended sediment presented in tables 7-10 do not conclusively show any effects of the highway system. In fact, other variables probably play more important roles in controlling sediment concentrations and loads in the stream than the highway system. Stations SH1 and R1 had the highest mean suspended-sediment concentrations, yet R2 had quite low concentrations. Stations SC and SH2 also have suspended-sediment concentrations greater than the background levels observed at Cane Creek and station SG5. In all subbasins, the elevated concentrations of suspended sediment can be accounted for by an examination of land use near the sampling station. For example, the R1 station is located just downstream from a dirt and gravel access road that is a sediment source for the stream. Stations SH1 and SC are near farm fields that may provide considerable sediment in overland runoff. However, these observations are not supported by the statistical correlations. No statistically significant relation between suspended-sediment concentrations and basin land use was found. Apparently, land-use effects on sediment concentrations in the stream are either so localized or so variable that the general analysis used was not able to show the relations.

Table 7.--Statistical summary of water physical characteristics at the highway runoff stations R1 and R2, July 1981 to July 1982

[ft^3/s, cubic feet per second; ^oC, degrees Celsius; -, no data; mg/L, milligrams per liter; JTU, Jackson turbidity units; µS/cm, microsiemans per centimeter at 25° Celsius]

Physical characteristic	R1 Mean	R1 Standard deviation	R1 Range	R1 Number of samples	R2 Mean	R2 Standard deviation	R2 Range	R2 Number of samples
Discharge at time of sampling (ft^3/s)	0.620	0.974	0.001-4.1	51	0.112	0.19	0.01-.98	31
Discharge, daily values (ft^3/s)	.11	.39	0-4.3	384	.009	.036	0-.37	390
Temperature at time of sampling (^oC)	11.2	6.5	1.0-20.0	12	12.8	8.2	2.5-20.0	5
Temperature, daily values (^oC)	-	-	-	-	-	-	-	-
Dissolved oxygen (mg/L)	10.3	2.8	6.8-14.8	12	10	2.9	7.9-14.8	5
Dissolved oxygen saturation (percent)	93	16	67-119	11	91	10	82-108	5
pH, field (units)1/	6.5	.7	6.0-7.9	14	6.4	.8	5.5-7.2	5
pH, lab (units)1/	6.6	.3	6.1-7.4	45	6	.3	6.0-7.2	26
Suspended sediment (mg/L)	65	150	4-806	45	17	15	6-65	30
Volatile suspended sediment (mg/L)	12	14	2-69	28	5	.6	4-5	3
Turbidity (JTU)	53	50	7.3-190	20	-	-	-	-
Specific conductance, field (µS/cm)	256	129	72-475	13	591	1,206	33-3,050	6
Specific conductance, lab (µS/cm)	289	216	80-1,020	45	3,530	2,077	450-6,400	17
Specific conductance, daily values (µS/cm)	-	-	-	-	-	-	-	-

1/ pH mean calculated using hydrogen-ion concentrations.

Table 8.--Statistical summary of water physical characteristics at the Sevenmile Creek stream-hydrology stations SH1 and SH2, July 1981 to July 1982

[ft^3/s, cubic feet per second; ^oC, degrees Celsius; mg/L, milligrams per liter; JTU, Jackson turbidity units; µS/cm, microsiemens per centimeter at 25^o Celsius]

Physical characteristic	SH1				SH2			
	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Discharge at time of sampling (ft^3/s)	7	9.5	0.06-50	61	46	90	0.05-425	47
Discharge, daily values (ft^3/s)	1.8	5.4	.01-63	392	15	36	.01-437	383
Temperature at time of sampling (^oC)	12.7	6.4	1.0-24.0	18	10.8	6.5	0-23.0	17
Temperature, daily values (^oC)	13.8	6.6	.5-25.2	385	13.5	6.8	0-25.5	352
Dissolved oxygen (mg/L)	9.5	2.2	6.1-13.6	18	10.1	2.4	6.9-14.5	16
Dissolved oxygen saturation (percent)	88	13	72-113	18	91	12	69-109	16
pH, field (units)[1/]	6.4	.5	5.8-7.9	18	6.4	.6	5.8-7.8	17
pH, lab (units)[1/]	6.2	.4	5.6-7.1	52	6.3	.4	5.5-7.1	38
Suspended sediment (mg/L)	76	86	2-369	52	48	70	2-273	39
Volatile suspended sediment (mg/L)	14	11	2-41	36	9	9	2-34	30
Turbidity (JTU)	56	39	4-125	30	41	39	3.8-125	22
Specific conductance, field (µS/cm)	113	47	43-200	18	90	27	61-161	15
Specific conductance, lab (µS/cm)	179	172	46-820	52	88	24	54-160	35
Specific conductance, daily values (µS/cm)	121	43	41-332	385	82	13	46-155	364

[1/] pH mean calculated using hydrogen-ion concentrations.

Table 9.--Statistical summary of water physical characteristics at the Sevenmile Creek grab-sample stations SG3 and SG5, July 1981 to July 1982

[ft^3/s, cubic feet per second; -, no data; °C, degrees Celsius; mg/L, milligrams per liter; JTU, Jackson turbidity units; µS/cm, microsiemens per centimeter of 25° Celsius]

Physical characteristic	SG3				SG5			
	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Discharge at time of sampling (ft^3/s)	-	-	-	-	-	-	-	-
Discharge, daily values (ft^3/s)	-	-	-	-	-	-	-	-
Temperature at time of sampling (°C)	12.8	6.7	1.5-23.5	14	13.7	6.4	3.5-25	15
Temperature, daily values (°C)	-	-	-	-	-	-	-	-
Dissolved oxygen (mg/L)	9.8	2.4	7.2-14.0	13	10.6	2.0	7.4-14.8	15
Dissolved oxygen saturation (percent)	94	17	66-124	11	101	12	87-131	14
pH, field (units)[1/]	6.5	.6	6.1-8.1	14	6.6	.6	6.0-8.5	15
pH, lab (units)[1/]	6.3	.3	5.9-6.9	11	6.3	.4	5.5-7.0	12
Suspended sediment (mg/L)	20	50	2-166	11	12	22	2-83	12
Volatile suspended sediment (mg/L)	4	5	2-20	11	4	3	1-12	11
Turbidity (JTU)	21	29	6.7-93	8	11	11	3.2-40	9
Specific conductance, field (µS/cm)	84	20	5-129	14	58	16	26-83	15
Specific conductance, lab (µS/cm)	-	-	-	-	68	15	50-98	12
Specific conductance, daily values (µS/cm)	-	-	-	-	-	-	-	-

[1/] pH mean calculated using hydrogen-ion concentrations.

Table 10.--Statistical summary of water physical characteristics at the background stations SC (July 1981 to July 1982) and Cane Creek (October 1971 to October 1981)

[ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; -, no data; JTU, Jackson turbidity units; µS/cm, microsiemens per centimeter at 25° Celsius]

Physical characteristic	SC				Cane Creek			
	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Discharge at time of sampling (ft^3/s)	6	11.0	0.01-55	45	6.0	6.2	0.01-26	61
Discharge, daily values (ft^3/s)	1.5	3.2	0-20	372	.29	.89	.0-11	731
Temperature at time of sampling (°C)	12.5	6.2	1.1-23.0	18	11.5	5.9	2.0-23.0	21
Temperature, daily values (°C)	14.1	6.7	0-25.2	391	11.6	6.9	.3-24.6	590
Dissolved oxygen (mg/L)	8.3	2.6	3.4-12.7	18	10.3	2.1	7.0-14.0	16
Dissolved oxygen saturation (percent)	77	18	31-96	18	-	-	-	-
pH, field (units)[1/]	6.2	.6	5.5-8.2	19	6.0	.6	5.2-7.3	24
pH, lab (units)[1/]	6.1	.4	5.1-7.3	37	5.7	.4	5.5-6.6	8
Suspended sediment (mg/L)	47	89	3-450	37	33	33	2-120	49
Volatile suspended sediment (mg/L)	10	10	2-44	26	-	-	-	-
Turbidity (JTU)	41	46	3-140	17	-	-	-	-
Specific conductance, field (µS/cm)	69	20	40-105	19	44	13	27-80	41
Specific conductance, lab (µS/cm)	75	20	52-130	37	-	-	-	-
Specific conductance, daily values (µS/cm)	79	21	43-128	388	58	13	29-106	657

[1/] pH mean calculated using hydrogen-ion concentrations.

A comparison between stations during storm events suggests that land use also has an effect on sediment discharge response. The suspended-sediment concentrations at stations R1, SH1, and SH2 during the rainstorm of September 5, 1981, are s own in figures 11, 12, and 13. The sediment concentration response at both R1 and SH1 show very rapid peaks at the beginning of the event, probably as a result of the early intense rainfall, and just before the first peak in streamflow. At both sites, the first early peak was followed by another sediment concentration rise associated with a second peak in streamflow. The first rapid sediment peak observed at both R1 and SH1 probably represents flushing of readily available sediment from local land uses. On the other hand, the sediment response observed at station SH2 showed one peak in sediment concentration that nearly coincided with the peak in streamflow. This response could be expected for basins without extensive development (Overton and Meadows, 1976), and is similar to the response observed at Cane Creek for other storms. There was not enough data for SH2 to demonstrate if the peak sediment concentration occurs before the streamflow peak, which is what would be expected for a basin that contains some development.

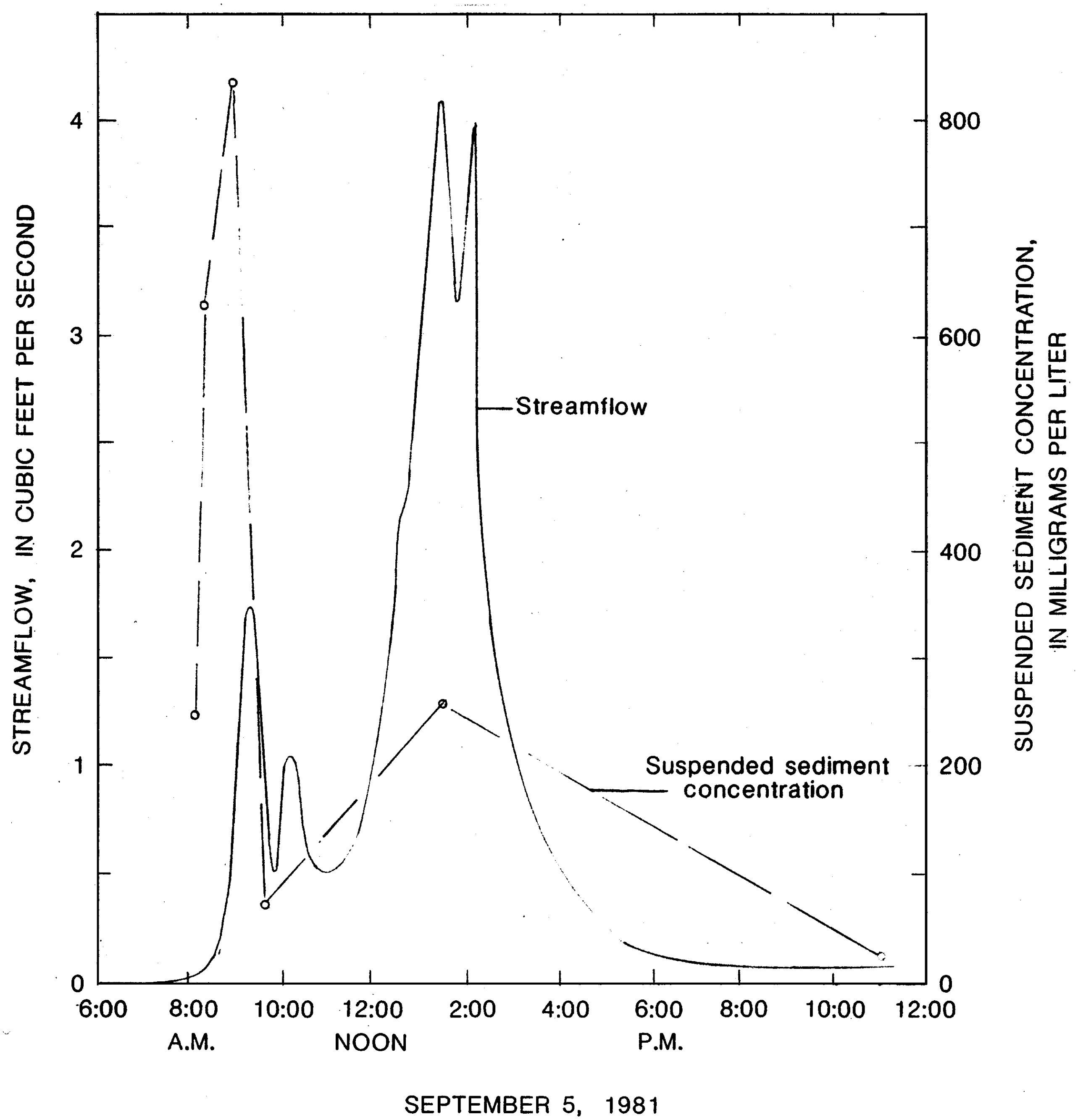

Figure 11.--Suspended-sediment concentration at station R1 during the rainstorm of September 5, 1981.

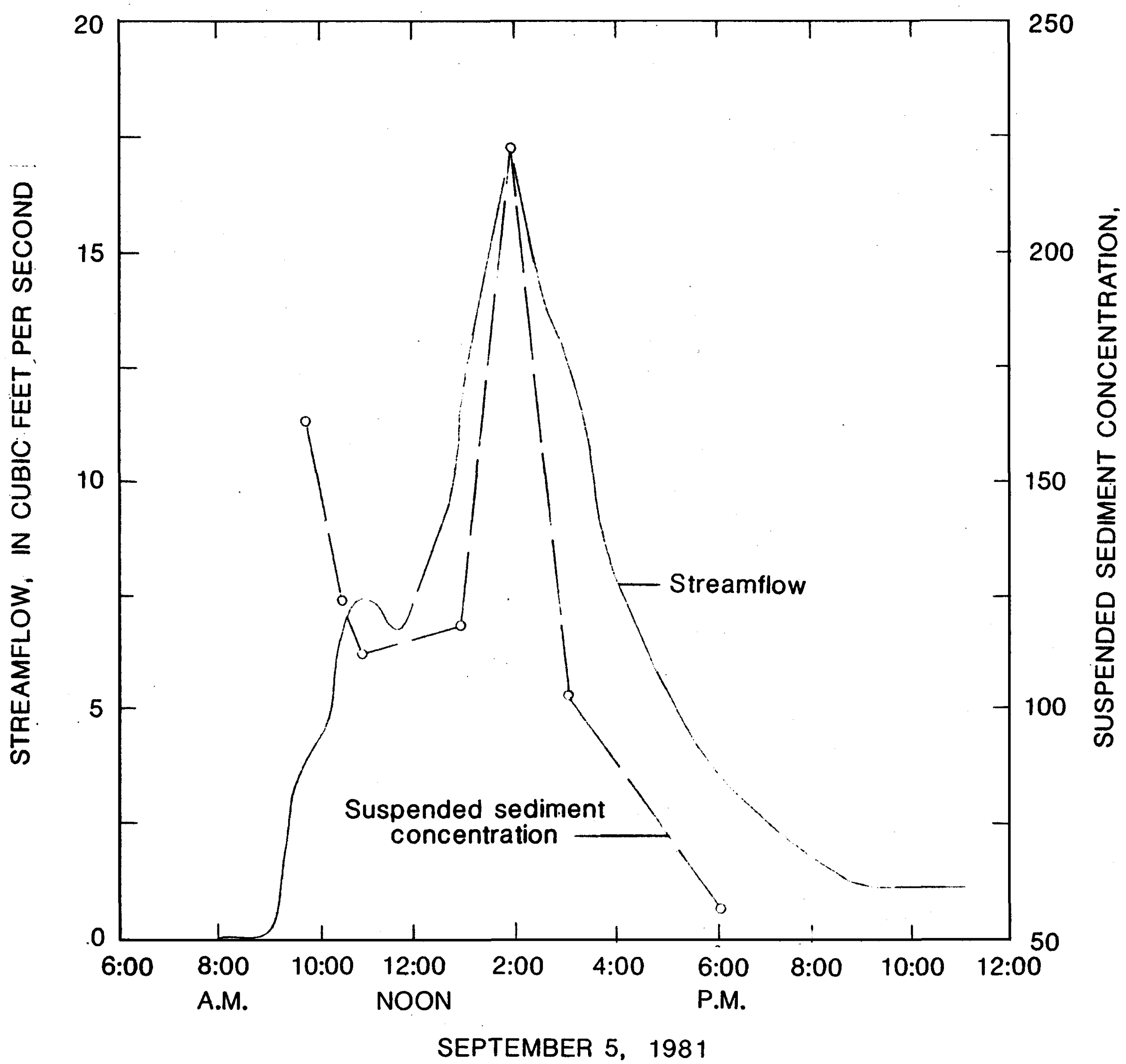

Figure 12.--Suspended-sediment concentration at station SH1 during the rainstorm of September 5, 1981.

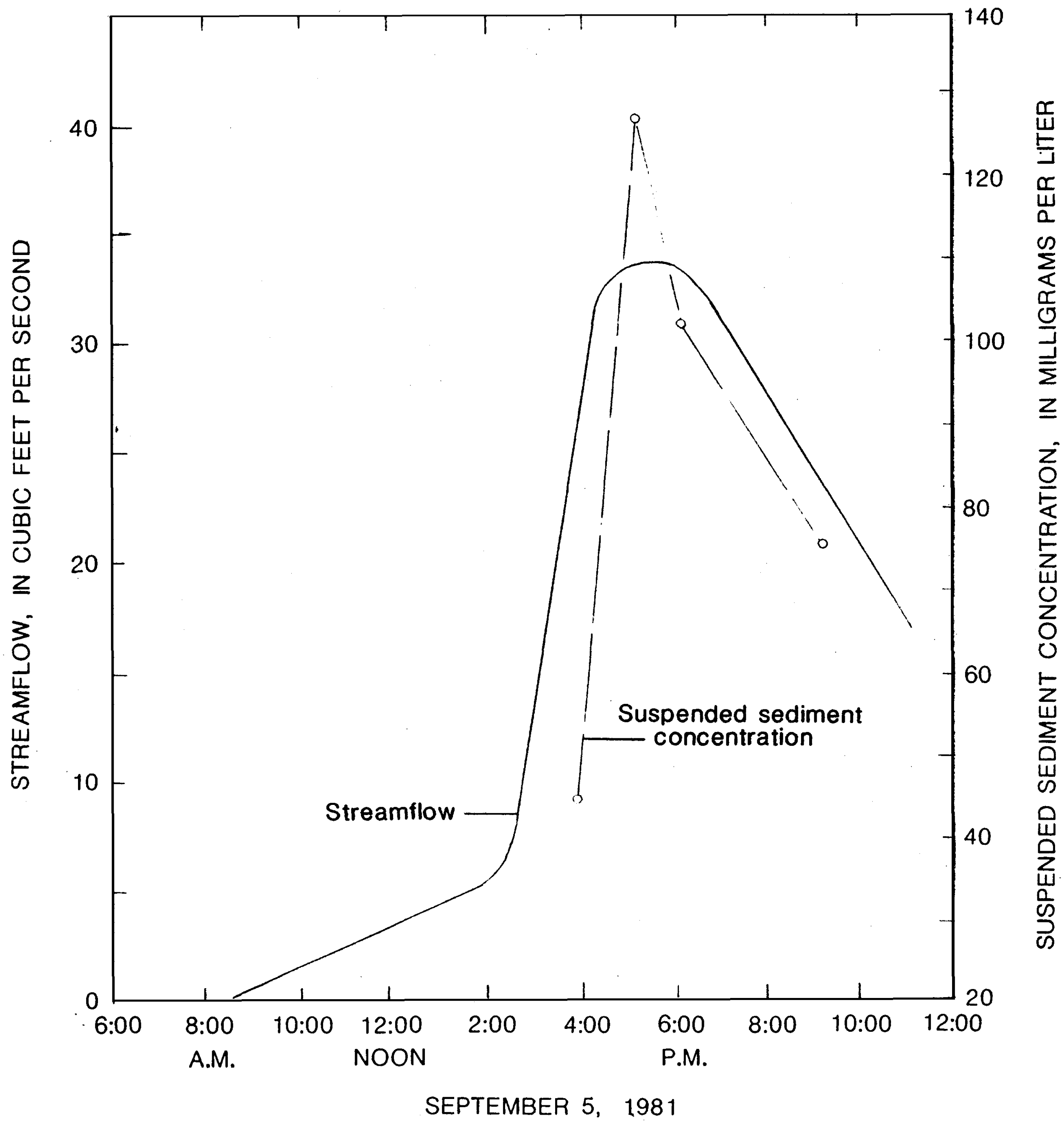

Figure 13.--Suspended-sediment concentration at station SH2 during the rainstorm of September 5, 1981.

Water Temperature and Dissolved Oxygen

No difference between stations that could be related to highway runoff effects was observed for dissolved-oxygen concentrations and water temperatures. Water temperatures were collected and used to determine percent saturation of dissolved oxygen. A comparison between stations of dissolved oxygen/water-temperature relations indicates that the sample values generally are near or just below dissolved-oxygen saturation values (see tables 7-10). Station SC had consistently lower dissolved-oxygen levels than the other stations but was still at around 76 percent saturation. These lower values can be explained by the relatively stagnant and, therefore, poorly aerated segment of the stream at the SC station. In general, it can be concluded that runoff from the highway did not introduce enough oxygen-demanding material into the surrounding streams to make a noticeable difference in dissolved-oxygen concentrations.

pH

A comparison of pH values of the stations yields no significant differences between the highway, rural, and background stations. In addition, no seasonal patterns are evident. However, during storms, a substantial decrease in pH is evident at the R1, R2, and SH1 stations as the low pH rainfall is collected in the streams. There is also a hint of a slight peaking in pH at the beginning of a storm at R1 and R2. This peak may represent the effect of material washed off the road. No significant statistical correlations were found between pH and basin geology, land use, or stream discharge.

Chemical Characteristics

The highway causes detectable differences in levels of dissolved constituents, nutrients, and minor elements and materials in streams near the road system compared to the streams in the rural and forested basins.

Major Dissolved Constituents

A summary of water-quality statistics of major dissolved constituents for the Sevenmile Creek stations and the Cane Creek station is shown in tables 12-15. Analyses for the Sevenmile Creek stations (sites R1, R2, SH1, SH2, SG3, SG5, and SC) were made for calcium, sodium, sulfate, chloride, and alkalinity, whereas the Cane Creek analyses included all these same constituents and silica, magnesium, potassium, bicarbonate, sulfate, fluoride, dissolved solids, and hardness.

Table 11.--Statistical summary of major dissolved constituents at the highway runoff stations R1 and R2, July 1981 to July 1982

[mg/L, milligrams per liter; -, no data; °C, degrees Celsius]

Constituent (mg/L)	R1				R2			
	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Silica (SiO_2)	-	-	-	-	-	-	-	-
Calcium (Ca^{+2})	13	12	1.7-35	10	135	-	-	1
Magnesium (Mg^{+2})	-	-	-	-	-	-	-	-
Sodium (Na^{+})	25	27	3.4-110	36	510	420	2.1-1,100	20
Potassium (K^{+})	-	-	-	-	-	-	-	-
Bicarbonate (HCO_3^{-})	-	-	-	-	-	-	-	-
Sulfate (SO_4^{-2})	16	5.4	7-22	6	10	10	.04-24	4
Chloride (Cl^{-})	70	79	9.3-320	30	1,100	860	5.0-2,500	20
Fluoride (F^{-})	-	-	-	-	-	-	-	-
Dissolved solids (residue at 180° C)	-	-	-	-	-	-	-	-
Hardness (as $CaCO_3$)	-	-	-	-	-	-	-	-
Alkalinity (mg/L as $CaCO_3$)	54	39	9-150	20	-	-	-	-

Table 12.--Statistical summary of major dissolved constituents at the Sevenmile Creek stream-hydrology stations SH1 and SH2, July 1981 to July 1982

[mg/L, milligrams per liter; -, no data; °C, degrees Celsius]

Constituent (mg/L)	SH1				SH2			
	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Silica (SiO_2)	-	-	-	-	-	-	-	-
Calcium (Ca^{+2})	10	14	1.8-66	19	5.2	2.3	1-9.1	13
Magnesium (Mg^{+2})	-	-	-	-	-	-	-	-
Sodium (Na^{+})	18.8	25	1.2-110	44	15	57	1.7-340	35
Potassium (K^{+})	-	-	-	-	-	-	-	-
Bicarbonate (HCO_3^{-})	-	-	-	-	-	-	-	-
Sulfate (SO_4^{-2})	13	8.0	2.0-30	13	5.0	2.3	2.0-8.0	8
Chloride (Cl^{-})	40	59	4.9-260	46	12	8.0	5.0-34	35
Fluoride (F^{-})	-	-	-	-	-	-	-	-
Dissolved solids (residue at 180° C)	-	-	-	-	-	-	-	-
Hardness (as $CaCO_3$)	-	-	-	-	-	-	-	-
Alkalinity (mg/L as $CaCO_3$)	27	16	8-60	22	29	9	15-55	23

Table 13.--Statistical summary of major dissolved constituents at the Sevenmile Creek grab-sample stations SG3 and SG5, July 1981 to July 1982

[mg/L, milligrams per liter; -, no data; ^{o}C, degrees Celsius]

Constituent (mg/L)	SG3				SG5			
	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Silica (SiO_2)	-	-	-	-	-	-	-	-
Calcium (Ca^{+2})	5.6	0.7	4.6-6.3	6	5.5	1.5	3.6-7.5	6
Magnesium (Mg^{+2})	-	-	-	-	-	-	-	-
Sodium (Na^{+})	4.6	1.5	1.9-7	8	4.2	1.2	1.5-6	9
Potassium (K^{+})	-	-	-	-	-	-	-	-
Bicarbonate (HCO_3^{-})	-	-	-	-	-	-	-	-
Sulfate (SO_4^{-2})	3.5	2.1	2.0-5.0	2	3.5	2.1	2.0-5.0	2
Chloride (Cl^{-})	10	2.4	6.0-14	8	5.7	1.4	3.0-8.0	9
Fluoride (F^{-})	-	-	-	-	-	-	-	-
Dissolved solids (residue at 180° C)	-	-	-	-	-	-	-	-
Hardness (as $CaCO_3$)	-	-	-	-	-	-	-	-
Alkalinity (mg/L as $CaCO_3$)	29	3	25-34	6	26	8	16-38	8

Table 14.--Statistical summary of major dissolved constituents at the background stations SC (July 1981 to July 1982) and Cane Creek (October 1971 to October 1981)

[mg/L, milligrams per liter; -, no data; °C, degrees Celsius]

Constituent (mg/L)	SC				Cane Creek			
	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Silica (SiO_2)	-	-	-	-	10	5.5	3.1-24	31
Calcium (Ca^{+2})	6.1	2.2	3.9-10	11	3.8	1.2	2.4-7.2	31
Magnesium (Mg^{+2})	-	-	-	-	1.4	.5	.7-3	31
Sodium (Na^+)	3.7	1.3	1.7-7.7	29	3.1	1.1	1.5-5.9	31
Potassium (K^+)	-	-	-	-	.6	.4	.1-1.7	31
Bicarbonate (HCO_3^-)	-	-	-	-	20	14	5-48	21
Sulfate (SO_4^{-2})	9.0	-	-	1	5.2	2.4	0.9-9.2	31
Chloride (Cl^-)	7.8	3.9	2.9-21	27	2.9	1.3	1.4-5.9	32
Fluoride (F^-)	-	-	-	-	.1	-	-	7
Dissolved solids (residue at 180° C)	-	-	-	-	61	12	23-80	32
Hardness (as $CaCO_3$)	-	-	-	-	15	5.1	9-30	31
Alkalinity (mg/L as $CaCO_3$)	28	13	4-60	19	14	11	3-39	28

Station R2 had the highest mean values for all the constituents measured except sulfate. The statistics shown in tables 12-15 include samples taken during a winter snowstorm when the highway was salted for ice control. The runoff from melting snow and ice carried much of this salt to surrounding streams, resulting in large concentrations of dissolved calcium, sodium, and chloride as measured at R2. The effect of road salting is also reflected in the specific conductivity results (tables 7-10). The highest mean sample specific conductance was 3,530 uS/cm at R2 and the lowest was 44 uS/cm at the Cane Creek station. It is clear that the practice of road salting has a dramatic effect on the water quality of streams that receive drainage from the road. This effect is not limited just to the major components of the salt. As shown in table 16, the deicing agents used along the stretch of highway near R2 also include detectable amounts of copper, cyanide, iron, lead, and zinc.

Station R1 showed the second highest concentrations of dissolved sodium, calcium, and chloride, and high concentrations are seen downstream at SH1 and even SH2. The other stations show concentrations around or slightly higher than the background levels detected at the Cane Creek station.

Not surprisingly, dissolved calcium, sodium, and chloride are highly correlated ($r^2 \geq 0.72$, pr=0.05) with the transportation and utilities category of land use (Transportation and utilities, table 1) and with discharge per unit of drainage area ($r^2 \geq 0.90$). All stations were used in the correlation analysis.

Table 15.--Chemical analysis of de-icing agents used on Interstate Highway 85 near Efland (from Kobriger and others, 1982)
[mg/kg, milligrams per kilogram; ND = not detected]

	Deicing agents	
Constituent	NaCl mg/kg	$CaCl_2$/sand mixture[1/] mg/kg
Calcium	550	500
Chloride	626,000	2,300
Sodium	370,000	750
Cadmium	ND	ND
Copper	1.2	3.2
Cyanide	1.8	ND
Iron	41	9,200
Lead	1.6	1.0
Nickel	ND	ND
Zinc	ND	20

1/ Sand to $CaCl_2$ ratio varied 40:1 to 50:1

Specific conductance, a measure of the ability of water to conduct an electric current, is an approximation of the amount of ionic material dissolved in water. The mean specific-conductance values at each station (tables 7-10) had the sa e pattern as the dissolved sodium, calcium, and chloride concentrations (tables 12-17); station R2 had the highest specific-conductance levels followed by R1, SH1, and SH2. The other stations had specific-conductance levels near the background levels at the Cane Creek station.

Concentrations of dissolved materials in streams generally are diluted by flood flows and, therefore, specific-conductance values usually vary inversely with discharge. However, peaks in specific-conductance values are observed at R1 and R2 during the earliest flush of runoff from storm events well before the peaks in discharge occur.

Nutrients

A summary of nutrient statistics for the Sevenmile Creek stations and the Cane Creek station is shown in tables 17-20. The few analyses of nitrogen and phosphorous concentrations do not show any clear effects of the highway on the surrounding streams. Although there are a substantial number of organic carbon analyses, they also do not demonstrate any clear relation to the highway system or any other land uses. Further, samples collected at SH1 and SH2 were affected by effluent from the two sewage-treatment plants serving the rest areas on both sides of I-85.

Table 16.--Statistical summary of nutrients in highway runoff at stations R1 and R2, July 1981 to July 1982
[mg/L, milligrams per liter; -, no data]

Nutrient (mg/L)	R1				R2			
	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Organic carbon, total (TOC)	15	5.2	5.0-29	31	16	-	-	1
Nitrogen (as N), total	[1]2.5	-	-	-	[1]4.8	-	-	-
Nitrogen, Kjeldahl	2.4	.75	1.5-3.0	4	4.6	4.8	1.2-8.0	2
Organic nitrogen (as N), dissolved	-	-	-	-	-	-	-	-
total	[2]2.3	-	-	-	-	-	-	-
Ammonia nitrogen (as N), dissolved	-	-	-	-	-	-	-	-
total	.15	-	-	1	-	-	-	-
Nitrate nitrogen (as N), total	-	-	-	-	-	-	-	-
$NO_2 + NO_3$ nitrogen (as N), dissolved	-	-	-	-	-	-	-	-
total	.12	.05	.08-.18	3	.14	.15	.03-.24	2
Phosphate (as PO_4), total	-	-	-	-	-	-	-	-
Orthophosphate (as PO_4), dissolved	.12	-	-	1	-	-	-	-
Phosphorus (as P), dissolved	.22	-	-	1	-	-	-	-
total	.17	.14	.02-26	5	.15	.01	.14-.16	3

[1]Calculated value: Kjeldahl nitrogen plus nitrate-plus-nitrite nitrogen.

[2]Calculated value: Kjeldahl nitrogen minus ammonia nitrogen.

Table 17.--Statistical summary of nutrients in Sevenmile Creek at stations SH1 and SH2, July 1981 to July 1982
[mg/L, milligrams per liter; -, no data]

Nutrient (mg/L)	SH1				SH2			
	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Organic carbon, total (TOC)	15	7.6	4.0-50	41	12	5.3	5.0-21	32
Nitrogen (as N), total	3.5	-	-	-	1.7	-	-	-
Nitrogen, Kjeldahl	2.1	2.0	1.0-9.0	15	1.4	1.1	.2-4.4	11
Organic nitrogen (as N),								
dissolved	-	-	-	-	-	-	-	-
total	1/ 1.9	-	-	-	-	-	-	-
Ammonia nitrogen (as N),								
dissolved	-	-	-	-	-	-	-	-
total	.25	.38	.02-1.3	9	.03	.02	.01-.07	7
Nitrate nitrogen (as N), total	-	-	-	-	-	-	-	-
NO_2 + NO_3 nitrogen (as N),								
dissolved	-	-	-	-	-	-	-	-
total	1.4	1.7	.03-4.7	14	.23	.12	.03-.40	1
Phosphate (as PO_4), total	-	-	-	-	-	-	-	-
Orthophosphate (as PO_4),								
dissolved	.19	.13	.02-.45	8	.02	.004	.02-.03	6
Phosphorus (as P),								
dissolved	.22	.17	.02-.49	9	.03	.01	.02-.04	7
total	.28	.27	.01-.96	19	.05	.06	.02-.17	13

1/ Calculated value: Kjeldahl nitrogen minus ammonia nitrogen.

Table 18.--Statistical summary of nutrients in Sevenmile Creek at stations SG3 and SG5, July 1981 to July 1982
[mg/L, milligrams per liter; -, no data]

Nutrient (mg/L)	SG3				SG5			
	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Organic carbon, total (TOC)	9.8	4.8	6.0-21	9	8.6	5.6	4.0-22	10
Nitrogen (as N), total	1.3	-	-	-	1.5	-	-	-
Nitrogen, Kjeldahl	.9	.17	.70-1	3	1.9	.54	1.0-2.1	6
Organic nitrogen (as N), dissolved	-	-	-	-	-	-	-	-
total	[1/]1.9	-	-	-	[1/]1.3	-	-	-
Ammonia nitrogen (as N), dissolved	-	-	-	-	-	-	-	-
total	.05	.06	.02-.12	3	.03	.02	.01-.05	4
Nitrate nitrogen (as N), total	-	-	-	-	-	-	-	-
NO_2 + NO_3 nitrogen (as N), dissolved	-	-	-	-	-	-	-	-
total	.36	.25	.10-.60	3	.19	.13	.01-.32	6
Phosphate (as PO_4), total	-	-	-	-	-	-	-	-
Orthophosphate (as PO_4), dissolved	.02	-	-	3	.02	-	-	3
Phosphorus (as P), dissolved	-	-	-	-	.02	.01	.01-.02	3
total	.02	.01	.02-.03	3	.02	.01	.01-.02	6

[1/]Calculated value: Kjeldahl nitrogen minus ammonia nitrogen.

Table 19.--Statistical summary of nutrients at stations SC (July 1981 to July 1982) and Cane Creek (October 1971 to October 1981)
[mg/L, milligrams per liter; -, no data]

Nutrient (mg/L)	SC				Cane Creek			
	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Organic carbon, dissolved	-	-	-	-	14	2.7	12-17	3
total (TOC)	14.5	5.0	6-26	30	10.5	7.4	2.7-21	9
Nitrogen (as N), total	1/ 1.4	-	-	-	.77	.58	.16-2.9	29
Nitrogen, Kjeldahl	1.3	.40	.90-2.0	12	2/ .69	-	-	-
Organic nitrogen (as N), dissolved	-	-	-	-	.38	.25	0-.83	23
total	3/ 1.2	-	-	-	.68	.53	.08-2.7	28
Ammonia nitrogen (as N), dissolved	-	-	-	-	.01	-	-	4
total	.05	.05	.01-.17	8	.01	-	-	1
Nitrate nitrogen (as N), total	-	-	-	-	.06	.06	0-.22	29
NO_2 + NO_3 nitrogen (as N), dissolved	-	-	-	-	.07	.06	.01-.21	28
total	.07	.09	.01-.35	12	.07	.07	.01-.24	30
Phosphate (as PO_4), total	-	-	-	-	.03	.05	0-.12	19
Orthophosphate (as PO_4), dissolved	-	-	-	-	.02	.04	0-.21	26
Phosphorus (as P), dissolved	-	-	-	-	.01	-	-	1
total	.06	.07	.01-.24	12	.01	-	-	1

1/ Calculated value: Kjeldahl nitrogen plus nitrate-plus-nitrite nitrogen.

2/ Calculated value: Ammonia nitrogen plus organic nitrogen.

3/ Calculated value: Kjeldahl nitrogen minus ammonia nitrogen.

Nitrogen

Ammonia nitrogen, Kjeldahl nitrogen, and nitrate-plus-nitrite nitrogen analyses were made for samples from most Sevenmile Creek stations. At Cane Creek, total nitrogen, organic nitrogen, ammonia nitrogen, nitrate nitrogen, and nitrate-plus-nitrite nitrogen analyses were made.

To allow easier comparison between stations, certain values in tables 17-20 were approximated as follows: Kjeldahl nitrogen is the total of organic and ammonia nitrogen. Therefore, organic nitrogen for the Sevenmile Creek stations can be calculated as the remaining concentration when the ammonia nitrogen is subtracted from the Kjeldahl nitrogen. For Cane Creek, Kjeldahl nitrogen can be approximated by adding the ammonia nitrogen concentration to the organic nitrogen concentration. A measure of total nitrogen for the Sevenmile Creek stations also can be obtained by adding Kjeldahl nitrogen to the nitrate-plus-nitrite nitrogen.

Ammonia is a reduced form of nitrogen that is readily oxidized in streams by aquatic aerobic bacteria to nitrite and then to nitrate; it also is used by algae first in preference to other forms of nitrogen. Because of the transiency of ammonia nitrogen, the presence of concentrations greater than 0.5 mg/L as N is considered indicative of contamination by human or animal wastes or by fertilizer (Weiss and others, 1973). The only station that periodically had total ammonia nitrogen concentrations above 0.5 mg/L was SH1. The average dissolved ammonia concentration for SH1 was 15 times greater than that of Cane Creek. The reason for the high concentration of ammonia at SH1 is the upstream rest area sewage-treatment plants. By the time water flows from SH1 downstream to station SG3, and later to SH2, most of the ammonia has been removed or converted to other forms of nitrogen and diluted by increased flows. This same pattern is seen with mean nitrite-plus-nitrate concentrations: the highest basin-wide levels are seen at SH1, with a considerable reduction downstream at SG3 and even more at SH2.

The highway stations R1 and R2, except for nitrite-plus-nitrate, had mean concentrations near to, or greater than, the nitrogen levels observed for the SH1 station, even though R1 and R2 are upstream from the wastewater treatment plant discharge points and SH1 is downstream from them. This probably is due to a combination of factors, including deposition from vehicles and entrainment of sewage mist in the air by the treatment-plant aerators with subsequent deposition. The only statistically significant correlation found between nitrogen and basin characteristics was between mean total ammonia concentration and road length (r^2=0.88).

Some nutrient data was collected for stations SH1 and SH2 during the September 5, 1981 rainstorm. As observed earlier with suspended-sediment concentrations, the data from these stations indicate that total nutrient concentrations show a pattern of rapid increase in concentration with the initial runoff flush of rainfall. The nutrient concentrations peak just before the peak in stream discharge and decline in concentration during the recession. Because nutrients can attach to sediment, it would be expected that total nutrient concentrations vary similarly to the sediment in response to changing streamflow, and that dissolved nutrient concentrations are diluted by flood flows. However, a rainstorm that occurred February 11, 1981, clearly showed a peak and recession for concentrations of virtually all the nitrogen species examined. The response at Cane Creek of total and dissolved nitrogen concentrations in response to changing streamflow is shown in figure 14. The peak in total nitrogen concentrations probably was caused by the flushing of nutrient-rich material from the streambed that builds up during low flow. The source of this nutrient-rich material probably is the rest-stop wastewater treatment plants. The peak in dissolved nitrogen concentrations may be related to the atmospheric contribution of nitrogen during rainfall (see table 4).

The nitrogen concentrations present at all stations are high enough to allow abundant algal growth. A total nitrogen concentration of 0.5 mg/L, or greater, generally is thought to allow a high algal productivity level (Crawford, 1983).

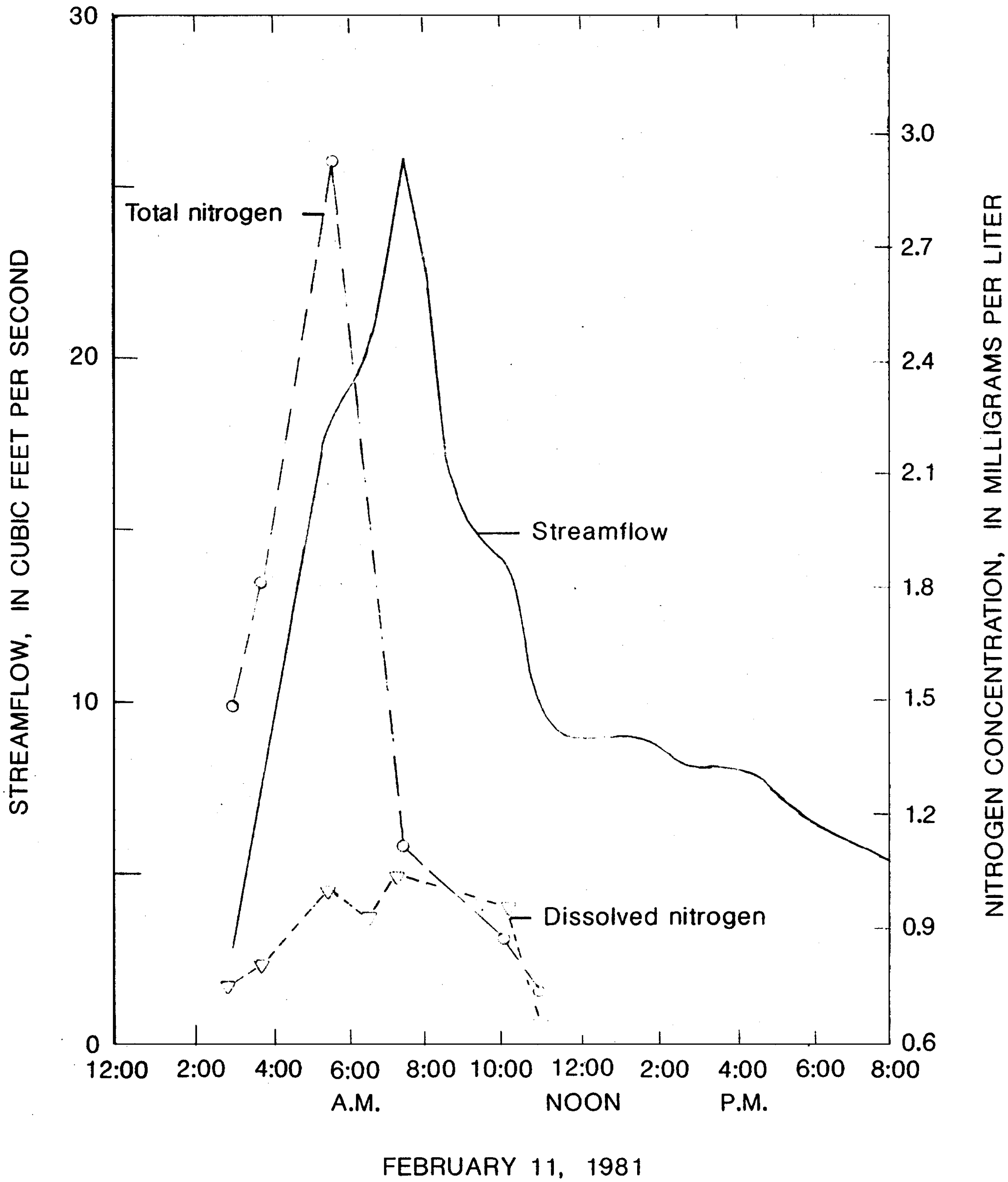

Figure 14.--Hydrograph and dissolved and total nitrogen concentrations for the storm of February 11, 1981, at Cane Creek.

Phosphorus

A comparison of mean total phosphate (as PO_4), dissolved orthophosphate, and total phosphorus between stations show a similar concentration pattern as found for nitrogen. The stations affected by the highway, R1 and R2 and station SH1 which are just downstream from the rest stop sewage-treatment plants, had relatively high concentrations compared to stations SH2, SG3, SG5, SC, and Cane Creek. Even so, the phosphorus concentrations measured at the highway stations are low compared to levels commonly found in North Carolina Piedmont rivers (Harned, 1980; Harned and Meyer, 1981; Crawford, 1983). Phosphorus concentrations at station SH1 were the greatest, with means almost twice as great as stations R1 and R2, and at least six times greater than stations SH2, SG3, SG5, SC, and Cane Creek. These comparisons indicate that the effect of the sewage-treatment plants is more important than the role the highway roadway may play as a source of phosphorus.

The phosphorus concentrations observed at stations R1, R2, and SH1 are sufficient to support a high algal-productivity level. Total phosphorus concentrations of 0.1 mg/L, or greater, are generally considered enough to allow abundant algal growth (Crawford, 1983). The phosphorus concentrations observed at the other stations are sufficient for moderate to low algal productivity. No significant statistical correlations were found between basin characteristics and total phosphate, dissolved orthophosphate, and total phosphorus.

Minor Constituents

Trace elements

Statistical summaries for trace elements and oil and grease concentrations in highway runoff at the study stations are given in tables 20-23. Trace-element analysis for the Sevenmile Creek stations included total cadmium, chromium, copper, iron, lead, nickel, and zinc. These elements also were analyzed at Cane Creek in addition to arsenic, cobalt, manganese, mercury, and selenium. Oil and grease concentrations were not determined for station R1 or Cane Creek.

As discussed earlier in the Highway Sources section, data indicate that the highway system is a source of metal contamination. Measurable concentrations of cadmium, chromium, iron, lead, nickel, and zinc were found in the dust buckets and wet/dry collectors (table 5). The fallout of these metals on the land surface near the road shows a strong relation of concentration with distance from the road. This relation can readily be observed in both the fallout data (fig. 6) and in the proportion of metal content in the surface soil near the highway (fig. 7). However, we have yet to address the question: Does the data show substantial metal contamination in the streams that drain the highway?

Table 20.--Statistical summary of trace element and oil and grease concentrations in highway runoff at stations R1 and R2, July 1981 to July 1982

[µg/L, micrograms per liter; -, no data; mg/L, milligrams per liter]

Constituent		R1 Mean	R1 Standard deviation	R1 Range	R1 Number of samples	R2 Mean	R2 Standard deviation	R2 Range	R2 Number of samples
Arsenic (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Cadmium (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	1.6	1.3	0.5-4.0	7	2.4	2.3	0.5-7.0	7
Chromium (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	5.7	6.2	2.0-19	7	7.3	14	1.0-30	7
Cobalt (µg/L),	Dissolved	-	-	-	-	-	-		-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Copper (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	39	22	7.0-69	7	38	12	23-56	6
Iron (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	2,300	2,100	760-6,700	7	-	-	-	-
Lead (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	18	10	5.0-30	7	11	14	.5-50	15
Manganese (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Mercury (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Nickel (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	6	6	1-18	7	13	10	3-30	7
Selenium (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Zinc (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	100	120	20-360	7	80	40	40-150	15
Oil and grease (mg/L),	Total	14	17.4	2-53	8	-	-	-	-

Table 21.--Statistical summary of trace element and oil and grease concentrations in Sevenmile Creek at stations SH1 and SH2, July 1981 to July 1982

[µg/L, micrograms per liter; -, no data; mg/L, milligrams per liter]

Constituent		SH1				SH2			
		Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Arsenic (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Cadmium (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	1.5	1.5	0.5-6.0	22	2.3	2.6	0.5-12	18
Chromium (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	5.3	5.3	.5-19	22	3.3	2.8	.5-9.0	18
Cobalt (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Copper (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	54	67	15-340	22	39	21	8.0-83	18
Iron (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	2,300	2,600	400-9,200	22
Lead (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	18	19	2.5-80	23	9.8	8.7	2.5-30	21
Manganese (µg/L),	Dissolved	-							
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Mercury (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Nickel (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	12	13	3-65	22	11	9	3-30	18
Selenium (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Zinc (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	60	30	20-140	22	50	30	10-132	20
Oil and grease (mg/L),	Total	6.9	3.8	2.0-15	10	4.5	3.6	1.0-14	13

Table 22.--Statistical summary of trace element and oil and grease concentrations in Sevenmile Creek at stations SG3 and SG5, July 1981 to July 1982
[µg/L, micrograms per liter; -, no data; mg/L, milligrams per liter]

Constituent		SG3 Mean	SG3 Standard deviation	SG3 Range	SG3 Number of samples	SG5 Mean	SG5 Standard deviation	SG5 Range	SG5 Number of samples
Arsenic (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Cadmium (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	1.5	0.87	0.5-2.0	3	2.3	1.6	0.5-4.0	6
Chromium (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	2.5	2.3	.5-5.0	3	1.5	1.3	.5-1.0	6
Cobalt (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Copper (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	29	1.5	22-25	3	27	16	8.0-56	6
Iron (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	1,100	280	550-1,400	3	1,000	85	460-2,900	7
Lead (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	35	26	5-50	3	19	19	5-50	7
Manganese (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Mercury (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-					
Nickel (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	8	7	3-16	3	8	5	3-15	6
Selenium (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	-	-	-	-	-	-	-	-
Zinc (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	40	9	25-42	3	30	20	15-73	7
Oil and grease (mg/L),	Total	5	1.7	3.0-6.0	-	2	1.4	1.0-3.0	2

Table 23.--Statistical summary of trace element and oil and grease concentrations at stations SC (July 1981 to July 1982) and Cane Creek (October 1971 to October 1981)
[µg/L, micrograms per liter; -, no data; mg/L, milligrams per liter]

Constituent		SC				Cane Creek			
		Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Arsenic (µg/L),	Dissolved	-	-	-		1.5	0.9	0-3	11
	Suspended	-	-	-		.2	.4	0-1	11
	Total	-	-	-	-	1.0	-	-	1
Cadmium (µg/L),	Dissolved	-	-	-	-	.7	.9	0-2.0	11
	Suspended	-	-	-	-	0	0	-	11
	Total	2.4	3.0	0.5-12	15	.1	.3	0-1.0	11
Chromium (µg/L),	Dissolved	-	-	-	-	0	0	-	2
	Suspended	-	-	-	-	6	5.7	2.0-10	2
	Total	3.0	2.7	.5-9.0	15	13	5	10-20	9
Cobalt (µg/L),	Dissolved	-	-	-	-	.9	1.8	0-5.0	11
	Suspended	-	-	-	-	.6	1.0	0-3.0	11
	Total	-	-	-	-	.9	1.0	0-3.0	11
Copper (µg/L),	Dissolved	-	-	-	-	4.0	3.6	1.0-13	20
	Suspended	-	-	-	-	1.8	2.8	0-12	20
	Total	28	7.6	12-40	15	5.2	5.3	1.0-18	21
Iron (µg/L),	Dissolved	-	-	-	-	300	180	100-770	21
	Suspended	-	-	-	-	2,100	3,240	60-12,000	18
	Total	2,900	3,800	530-16,400	20	2,200	3,000	530-12,000	21
Lead (µg/L),	Dissolved	-	-	-	-	1	1.4	0-2	2
	Suspended	-	-	-	-	2.6	3.7	0-15	21
	Total	6.5	8.2	.5-30	18	3.9	5.0	0-18	21
Manganese (µg/L),	Dissolved	-	-	-	-	38	26	10-90	11
	Suspended	-	-	-	-	43	60	0-200	11
	Total	-	-	-	-	80	55	40-220	11
Mercury (µg/L),	Dissolved	-	-	-	-	.1	0		3
	Suspended	-	-	-	-	.01	.03	0-.1	11
	Total	-	-	-	-	.3	.2	.1-.5	6
Nickel (µg/L),	Dissolved	-	-	-	-	-	-	-	-
	Suspended	-	-	-	-	-	-	-	-
	Total	9	6	3-22	15	-	-	-	-
Selenium (µg/L),	Dissolved	-	-	-	-	0	0	0	11
	Suspended	-	-	-	-	0	0	0	11
	Total	-	-	-	-	1	0	-	3
Zinc (µg/L),	Dissolved	-	-	-	-	10	10	0-20	3
	Suspended	-	-	-	-	40	70	0-270	20
	Total	60	20	19-71	20	10	20	0-20	2
Oil and grease (mg/L),	Total	4.5	8.7	1-8	9	-	-	-	-

The answer to this question is a qualified yes. In a comparison of the mean values shown in tables 20-23, chromium, copper, and zinc show patterns of greater concentrations in stations R1, R2, and SH1 that are affected by the highway than in the rural and background stations SG5, SC, and Cane Creek. Surprisingly, no patterns are apparent in the cadmium and lead concentrations. Although highway runoff commonly affects lead concentrations (Kobriger and others, 1982), only a slight elevation above background concentration was noted at the stations affected by the highway. In addition, although stations R2, SH1, and SH2 show higher concentrations of nickel than stations SG5, and SC, station R1 shows a seemingly anomalously low nickel concentration. The concentration of chromium at Cane Creek also seems anomalously high compared to the other station data. In the case of the Cane Creek data, the high concentration may be due to procedures used to determine chromium by the REXNORD laboratory. Procedures used by REXNORD laboratory, which analyzed the Sevenmile Creek data, are different from procedures used by the Geological Survey laboratory, which analyzed Cane Creek data.

Water-quality criteria established by the U.S. Environmental Protection Agency (1980) can be used to assess the relevance of the observed concentrations of metals to water use. Two sets of criteria are generally given: one giving levels suitable for protection of freshwater aquatic life and the other suggesting levels recommended for domestic water supply to protect human health. Many of the aquatic-life criteria are set to vary depending on the water hardness. The reason for this sliding scale of criteria values is that toxicity to aquatic life of metals and other constituents tends to be greater with lower water hardness. Unfortunately, hardness was not measured at any of the Sevenmile Creek stations. The hardness measured at Cane Creek averaged 8.44 mg/L (as $CaCO_3$) with a standard deviation of 3.5 and a range of 4 to 13 mg/L (9 samples). These are relatively low hardness values even for streams in the North Carolina Piedmont which have mean concentrations of about 23 mg/L ($CaCO_3$) (Harned, 1980; Harned and Meyer, 1981; and Crawford, 1983).

A hardness value of 23 mg/L for Piedmont streams was used to devise water-quality criteria according to U.S. Environmental Protection Agency guidelines (1980). The percentages of samples that had cadmium, chromium, copper, lead, nickel, and zinc concentrations greater than criteria levels for protection of aquatic life are given in table 24. The percentages of samples with metals that exceeded recommended criteria levels for drinking water are given in table 25. Many of the metal concentrations at all stations exceeded criteria levels for protection of aquatic life; only nickel did not exceed the criteria levels at any station. Few metal concentrations exceeded levels set for drinking water; lead and cadmium concentrations were higher than the drinking-water criteria for several stations. Even metals concentrations for cadmium, chromium, copper, and zinc found in rainwater sampled at SH1 are higher than the criteria recommended for the protection of aquatic life. Finally, although the percentages of sample concentrations that exceed criteria levels tended to be high in several samples from stations R1, R2, and SH1 that are affected by the highway, it is difficult to distinguish them from the percentages that exceeded criteria at the other stations. Not surprisingly, no meaningful correlations were found between mean metal concentration and basin characteristics.

Table 24.--Percentage of samples with concentrations that exceeded criteria levels for protection of aquatic life

[μg/L, micrograms per liter; -, no data; mg/L, milligrams per liter]

Constituent	R1	R2	SH1	SH2	SG3	SG5	SC	Cane Creek	Criterion[1/]
Cadmium	29	43	32	89	67	83	40	9	0.65 μg/L
Chromium	100	100	91	94	67	67	93	100	.29 μg/L
Copper	100	100	100	100	100	100	100	46	5.5 μg/L
Lead	29	13	22	10	67	29	6	0	27.9 μg/L
Nickel	0	0	0	0	0	0	0	-	593 mg/L
Zinc	57	100	68	50	67	14	50	0	37.9 mg/L

[1/]Derived from U.S. Environmental Protection Agency (1980) guidelines. Hardness was assumed to be 23 mg/L. All values are the recommended maximum, not to be exceeded at any time.

Table 25.--Percentage of samples with concentrations that exceeded recommended criteria levels for drinking water
[µg/L, micrograms per liter; mg/L, milligrams per liter]

Constituent	R1	R2	SH1	SH2	SG3	SG5	SC	Cane Creek	Criterion[1/]
Cadmium	0	0	0	5	0	0	7	0	10 µg/L
Chromium	0	0	0	0	0	0	0	0	170 µg/L
Copper	0	0	0	0	0	0	0	0	1 µg/L
Lead	0	7	9	0	67	14	0	0	50 µg/L
Nickel	0	0	0	0	0	0	0	0	13.4 mg/L
Zinc	0	0	0	0	0	0	0	0	5 mg/L

1/ U.S. Environmental Protection Agency (1980) recommendations.

Oil and grease

Mean total oil and grease concentrations for the Sevenmile Creek stations are listed in tables 20-23. Although no data were collected for the R2 and Cane Creek stations, the effect of highway runoff on water quality is quite apparent. Station R1 had much higher concentrations than the other rural stations. Station SH1 also had somewhat elevated concentrations in comparison to those at the other rural stations.

Synthetic organics

During the rainstorm of April 8-10, 1982, samples were collected at stations R1, SC, and SH2 and later analyzed for a variety of synthetic organic substances (table 26). Two discrete samples from station R1 were examined: one sample was collected 3 hours before the peak in streamflow and one was collected 4 hours after the peak. A sample was composited from several stream samples collected during the storm at stations SC and SH2. The only organic substance detected was the herbicide 2,4-D. A herbicide 2,4-D concentration of 19 ug/L was measured in the post-peak sample at station R1; the composited sample from station SH2 had a concentration of 3.8 ug/L. Herbicide 2,4-D had been applied along the road 2 weeks prior to the rainstorm of April 8-10, 1982. The measured concentrations of herbicide 2,4-D are well below the 100 mg/L interim standard established by the State of North Carolina for raw water supply (North Carolina Environmental Management Commission, 1986).

Table 26.--List of trace synthetic organic substances tested for and their detection limits
[All values are reported in micrograms per liter (µg/L)]

Constituent	Detection limit
PCB	0.5
Alpha - BHC	0.01
Gamma - BHC (Lindane)	0.01
Beta - BHC	0.01
Delta - BHC	0.01
Heptachlor	0.01
Aldrin	0.01
Heptachlor epoxide	0.01
p,p - DDE	0.05
o,p - DDD	0.05
o,p - DDT	0.05
p,p - DDD	0.05
p,p - DDT	0.05
Dieldrin	0.05
Endrin	0.05
Hexachlorobenzene	0.01
2,4 - D	2.0
2,4,5 - T	0.5
Silvex	0.5

Soil-Water Quality

Samples from four lysimeters (A, B, C, and D) shown in figure 5 were collected after about 25 storm events monitored at station R2. These lysimeters provide a gross estimate of the quality of the water as it drains through the first 6 inches of topsoil. A summary of the results of chemical analyses of water that was collected after it had moved through the soil zone is given in table 27.

Only lysimeter C, on the northbound right-of-way 6 feet from the edge of the pavement, and lysimeter D, at the edge of the woods on the northbound right-of-way, operated satisfactorily during the study. The sample collection bottles for the lysimeters in the median area were inundated during storms because runoff in the median and splashing from passing vehicles. Although splashing was also something of a problem at lysimeter C, the lysimeter was inundated only a few times.

Virtually all of the chemical concentrations are greater than concentrations observed in the water of the nearby streams. Furthermore, no relation between distance from the road and soil-water quality was found; in fact, some of the highest concentrations in nitrogen, copper, and iron were observed at lysimeter D, the furthest away from the pavement. The high concentrations of constituents in the soil water, and those in the soil (fig. 7), indicate that the soil system surrounding the highway accumulated and retained many of the pollutants derived from the use and maintenance of the highway. However, because the lysimeters malfunctioned, it is not clear from these results if the water sampled is a representation of soil-water quality or a worst-case representation of surface runoff.

Table 27.--Summary of water-quality analyses of samples from lysimeters A, B, C, and D near station R2
[mg/L, milligrams per liter; µg/L, micrograms per liter; ND, not detected]

Constituent	A: 15 feet from pavement		B: 2 feet from pavement		C: 6 feet from pavement		D: 35 feet from pavement	
	Mean or median*	Range	Mean or median*	Range	Mean or median*	Range	ean or median*	Range
pH (units)	6.3*	5.8-7.8	6.6*	5.0-7.7	6.5*	5.8-7.9	6.4*	1.7-7.2
Total solids (mg/L)	838	267-3,350	982	226-3,570	504	145-1,140	1,330	355-3,330
Chloride (mg/L)	250	58-850	480	14-1,900	90	13-370	12*	ND-810
Sodium (mg/L)	100	7-420	230	11-950	47	9-210	28	20-130
Total Kjeldahl nitrogen (mg/L)	8.6	3.5-17	6.0	3.0-13	3.0	2.0-4.0	8.0	4.0-10
Nitrite plus nitrate (mg/L)	.46	.11-1.1	1.6	.63-4.5	.39	.15-.85	.73	.18-1.8
Phosphorus as PO4 (mg/L)	1.1	.06-2.7	.20*	ND- .61	.27	.06-.69	.37	.26-.46
Cadmium (µg/L)	ND*	ND-6	ND*	ND-2	ND	ND-4	ND	ND-4
Chromium (µg/L)	3*	ND-50	10*	ND-40	10*	ND-20	30	ND-50
Copper (µg/L)	50	20-90	40	20-90	60	2-210	80	30-120
Iron (µg/L)	18,100	900-130,000	16,000	1,900-43,000	12,000	600-39,000	51,000	23,000-85,000
Lead (µg/L)	ND*	ND-60	20*	ND-180	40	ND-250	ND	ND-120
Nickel (µg/L)	20	ND-100	10*	ND-100	ND*	ND-100	ND	ND-100
Zinc (µg/L)	120	40-500	100	50-260	100	40-310	110	60-140

CONSTITUENT LOADS

Mass Balance for Constituent Sources

A mass balance that gives the relative contributions of the various sources to the total amount of material accumulated on the highway surface and the means of removal of the material from the highway was calculated by Kobriger and others (1982). The mass balance for total dissolved solids for station R2 is represented by the diagram on figure 15.

The mass balance was derived by using a series of approximations in a modeling process (Kobriger and others, 1982) without full consideration of possible errors and uncertainty involved. Three components were examined: deposition, highway-surface load, and removal. Deposition was determined by defining mean daily accumulation rates based on loads calculated from surface-water runoff and atmospheric data. The accumulation rate is the mean daily rate of accumulation for time period from the end of a major storm to the beginning of the next major storm. It was assumed that each storm washed the highway surface clean. This rate was calculated as the load washed out during the second storm divided by the number of days between the first and second storms. Atmospheric fallout was estimated from dust buckets and wet/dry collector data. The highway-surface load was determined by considering results from highway sweeping surveys and road salting and sanding data. Vehicular deposition was calculated as the difference between the highway surface load and the salting/sanding and atmospheric load.

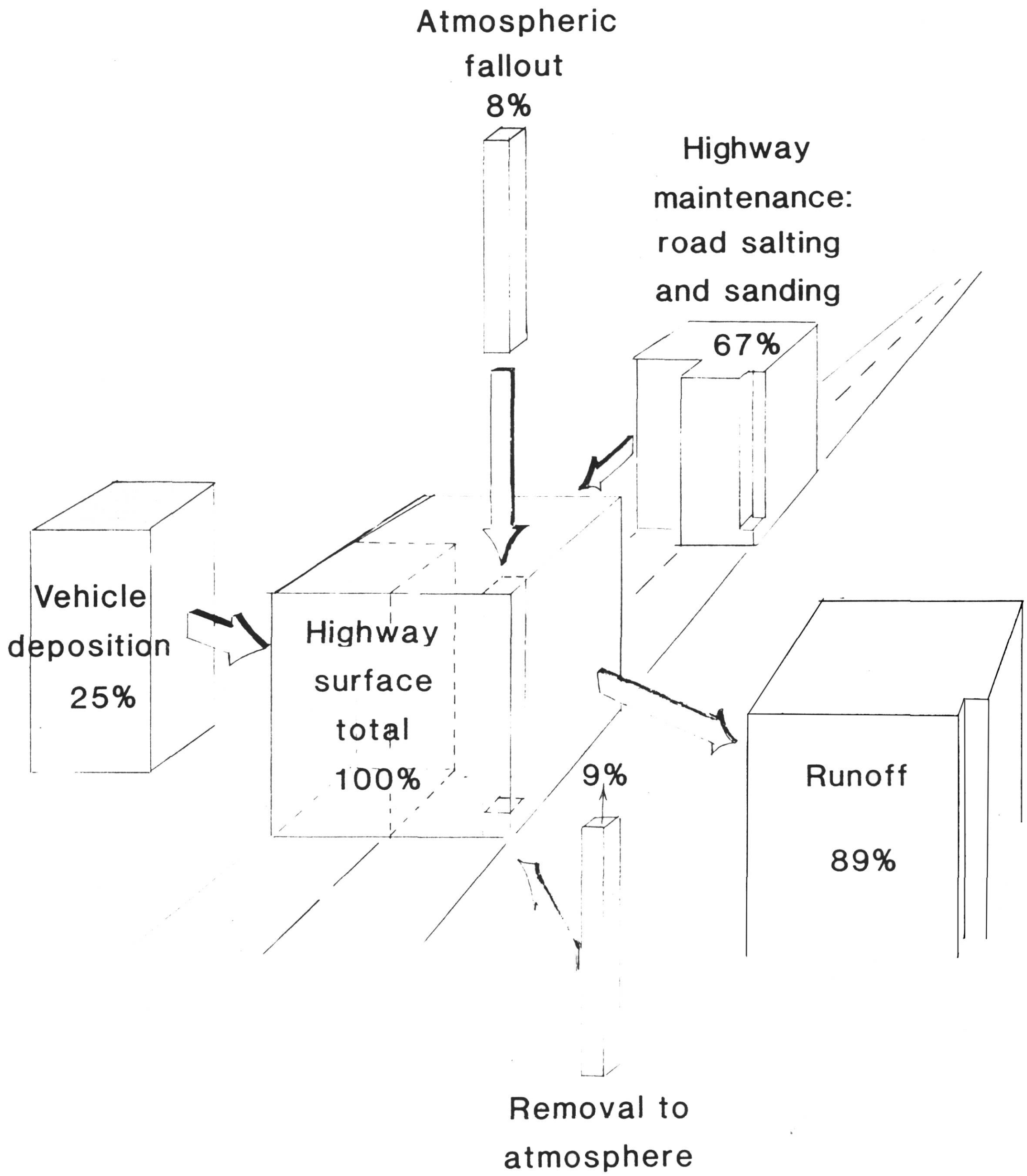

Figure 15.--Mass balance of total dissolved solids load at station R2 for the period of June 30, 1981, through April 2, 1982 (Kobriger and others, 1982). (Load unaccounted for is model error.)

No accounting for removal through the ground-water system was made in this analysis. As in the analysis of lysimeter results, it is likely that some of the material moves into the ground-water system.

The resultant mass balance, as shown in figure 15, emphasizes the relative importance of road maintenance operations, which consists primarily of highway deicing by use of a mix of salt and sand, and vehicle deposition as sources of material available on the highway surface for washoff into streams. Road maintenance supplied 67 percent of available material over the period studied (Kobriger and others, 1982).

Constituent Loads in Streams

Daily loads were obtained by first defining linear relations (regression equations) between insta taneous discharge and constituent load and then using the known daily discharges to compute loads on a daily basis. Regression equations with slopes statistically different from zero (pr=0.05) were used to estimate loads for dissolved solids and a suite of metals. The estimated annual loads are listed in table 28, and the annual loads per square mile are shown in table 29. The dissolved-solids loads for selected stations listed in table 29 are shown in figure 16 with the percentage of basin area in the transportation and utilities land-use category. The bar plots shown in figure 16 suggest that there may be a relation between the transportation and utilities land use and dissolved-solids load; however, available data are insufficient to test this relation statistically. The total-metals loads listed in table 29 are shown in figure 17.

An examination of loads verifies the results of the constituent concentration comparisons between stations. As noted in the earlier comparison of constituent concentrations, the stations affected by highway runoff (R1, R2, and SH1) show high total metals and total dissolved solid loads relative to those at station SH2, which are indicative of water quality of most of the Sevenmile Creek basin, and to those of station SC, which are from a basin that is predominately rural (table 28). In particular, station R1 had relatively high total lead, iron, and zinc loads, and station R2 had high dissolved-solids, copper, iron, and zinc loads.

Table 28.--Annual loads, from subbasins, in tons
[-, no data]

Constituent	R1	R2	SH1	SH2	SC
Dissolved solids	33	5.8	730	880	-
Cadmium	.00019	.00018	.0023	.025	-
Chromium	.00076	.00013	.016	.048	0.0049
Copper	.0053	.00037	.17	.62	.039
Iron	.43	.010	9.9	38	1.3
Lead	.0026	.000047	.037	.18	.0038
Nickel	.0010	.00010	.028	.13	.0048
Zinc	.019	.00039	.074	.74	.062

Table 29.--Annual loads, from subbasins, in tons per square mile
[-, no data]

Constituent	R1	R2	SH1	SH2	SC
Dissolved solids	240	1,800	460	61	-
Cadmium	.0014	.0056	.0014	.0017	-
Chromium	.0054	.041	.010	.0033	0.0035
Copper	.038	.12	.11	.043	.028
Iron	3.1	3.1	6.2	2.6	.93
Lead	.19	.015	.023	.012	.0027
Nickel	.0071	.031	.018	.0090	.0034
Zinc	.14	.12	.046	.051	.044

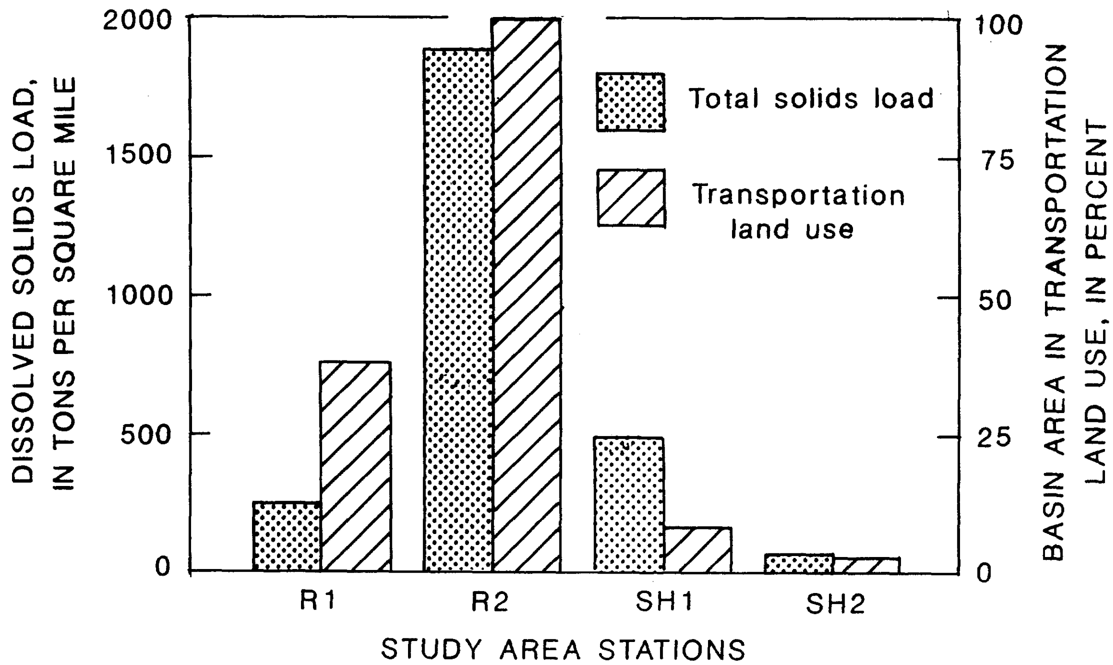

Figure 16.--Annual dissolved-solids loads for the study stations and the percentage of basin area in the transportation land-use category.

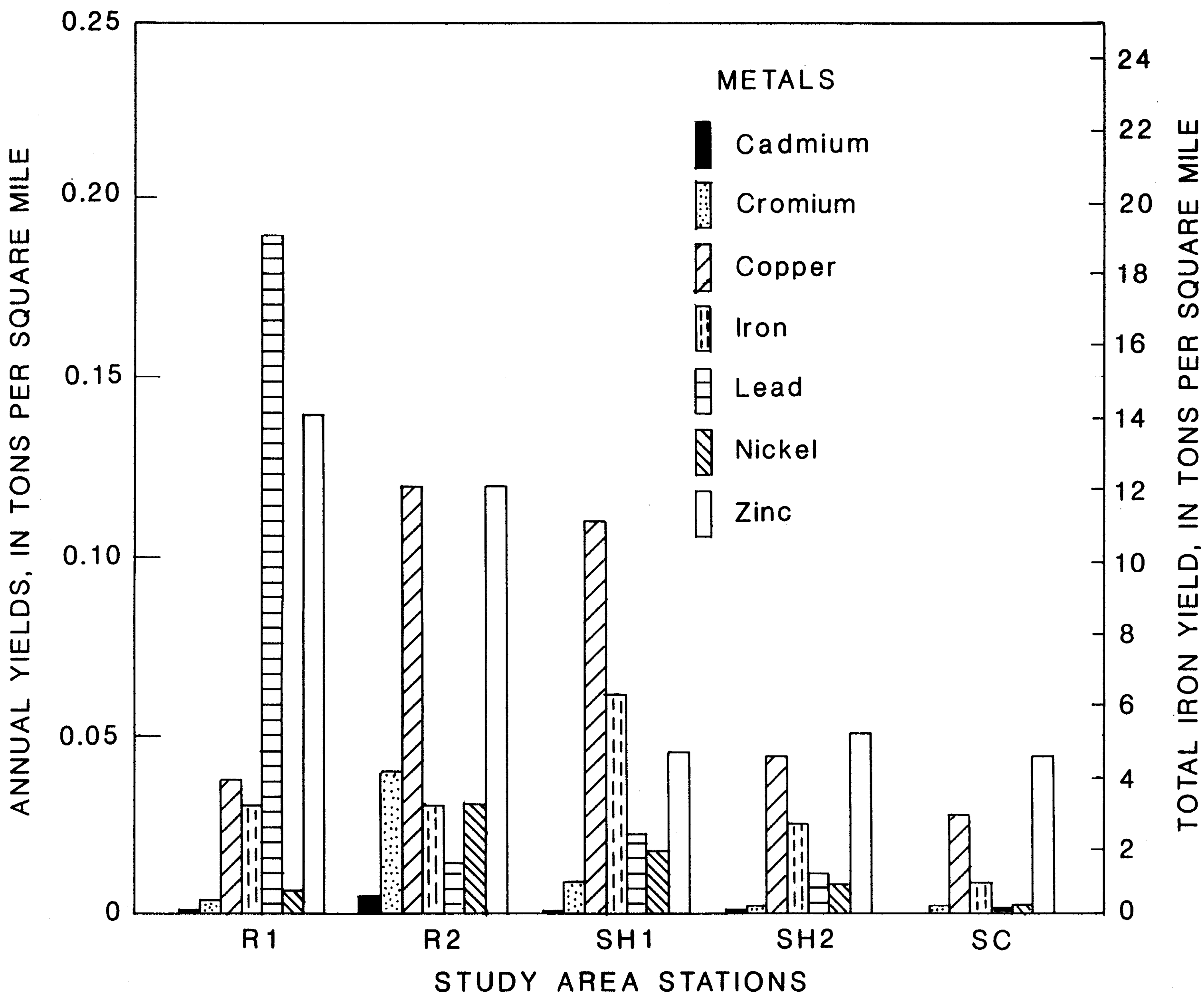

Figure 17.--Total annual metals loads for the study stations.

SUMMARY

An evaluation of water quality of streams that receive storm-water runoff from a segment of Interstate Highway 85 indicated elevated levels of many constituents compared to nearby undeveloped basins. The study area included eight sampling stations: R1 and R2, which were near the highway; SC and SG5, which received no runoff from the highway but represented rural land uses; Cane Creek, which drained an undeveloped, almost completely forested basin; SH1, which was downstream from R2 and included a highway rest-stop area and some residential and urban land uses; SG3, which was downstream from R2, SH1, and SC; and SH2, which was downstream from SG3 and R1. The basins had a combined drainage area of 17.5 square miles and drained a 4.8 mile-long segment of Interstate Highway 85. The asphalt highway consisted of two northbound and two southbound lanes, with entry and exit lanes for highway rest stop areas on both sides of the road. The daily mean traffic flow along the highway was greatest during August 1981 at 28,000 vehicles per day and least during January 1982 at 22,000 vehicles per day. The yearly mean traffic flow was 25,000 vehicles per day.

In addition to the stream sampling stations, there were rain gages at SH1, SH2, and SC, wet/dry atmospheric deposition collectors near R2 and SC, and a weather station with a recording anemometer and thermometer at SH1. The dry-fall samplers near R2 included devices designed specifically to measure saltation particle loads bounced along the highway surface. Four lysimeters were located near the road at station R2 to sample quality of water in the soil. Soil sampling and highway sweeping to collect road surface material also were part of the study. Areal data on geology and land use for each basin were compiled to allow testing for correlation of basin characteristics with water quality.

During storm runoff, streamflow affected by the highway (stations R1, R2, and SH1) rose and fell more rapidly than in the streams in the undeveloped basins (SC, Cane Creek). This rapid runoff response results from increased impervious area of the basin and the manmade drainage system designed to rapidly move water off of the highway. Station R2, which gaged discharge from an area that is approximately one-half paved, had the highest discharge per square mile (2.78 $[(ft^3/s)/mi^2]$) and Cane Creek, a forested basin, showed the lowest discharge per square mile (0.45 $[(ft^3/s)/mi^2]$).

The highway stations (R1 and R2) had the greatest values of specific conductance, calcium, sodium, chloride, and alkalinity primarily due to road salting. The highest mean sample specific conductance was 3,530 uS/cm at R2 and the lowest was 44 uS/cm at the background station at Cane Creek. In general, highway station R2 had the highest constituent concentration levels followed by highway station R1, mid-basin station SH1, the station furthest downstream SH2, and the other stations. This pattern reflects the effect of the road--the further away the station was from the highway and the more dilution, the less the effects in water-quality downstream.

No conclusive effects from highway wash-off were observed for nutrients. However, mean nitrate-plus-nitrite, phosphorus, total organic carbon, and ammonia concentrations were high at stations SH1 and SH2, probably because of rest area wastewater treatment plant effluent upstream from station SH1. Nitrogen and phosphorus concentrations were at levels sufficient to allow abundant algae growth, although phosphorus concentrations were low compared to larger Piedmont rivers. During storms, stations SH1 and SH2 had dissolved- and total-nitrogen concentrations that rapidly peaked with stormflow. The peaks probably are caused by the flushing of nutrient-rich material from the streambed that accumulates during low flow. The source of this nutrient-rich material probably is the rest-stop wastewater treatment plants.

Elevated metals concentrations as much as 10 times greater than background were found in the soils near the highway at station R2 and in the water that infiltrates through the soil zone. Chromium, copper, nickel, and zinc concentrations observed at the stations (R1, R2, and SH1) which are affected by the highway generally are higher than concentrations observed at the background stations SG5, SC, and Cane Creek. Many of the concentrations of cadmium, chromium, copper, lead, nickel, and zinc exceeded recommended levels for the protection of aquatic life, and lead and cadmium concentrations frequently exceeded levels recommended for drinking water. Concentrations of cadmium, chromium, copper, and zinc in rainwater, collected at SH1, exceeded the criteria recommended for the protection of aquatic life.

Stations R1 and SH1 showed high concentrations of oil and grease compared to stations SH2, SG3, SG5, and SC. The effects of highway washoff on suspended sediment, water temperature, dissolved oxygen, and pH were inconclusive. However, pH declined during stormflow at all stations because rainfall with pH values less than 5.7 entered the streams.

Some of the highest constituent concentrations were measured in the soil water sampled from the lysimeters located near the highway. The highest concentrations of iron, chromium, zinc, total nitrate-plus-nitrite, total Kjeldahl nitrogen, and total phosphorus in water were found in the soil-water samples. The source of these constituents is the use and maintenance of the highway.

The highway is a source of chemical constituents to surrounding areas. The high proportion of the total dustfall loading rate at SH1, about a half-mile from the highway, suggests that dust from the highway can move considerable distances. However, constituent levels observed in dustfall and in soils generally decreased exponentially with distance from the highway. Dust constituent loads and constituent concentrations in soil are greater on the downwind side of the highway. Material loading from dustfall was greater than from wet precipitation. Loads of saltated particles were higher than loads from other particle deposition due, probably, to the greater size of saltated particles. Saltation loads peaked during the winter months due to highway deicing and sanding. About two-thirds of the available materials washed off into the surrounding areas were from highway deicing and sanding. The remaining one-third of available material came mainly from deposition of particles from vehicles.

SELECTED REFERENCES

Allen, E.P., and Wilson, W.F., 1968, Geology and mineral resources of Orange County, North Carolina: N.C. Department of Conservation and Development, Division of Mineral Resources, Bulletin 81.

Anderson, J.R., Hardy, E.E., Roach, J.T., and Witmer, R.E., 1976, A land use and land cover classification system for use with remote sensor data: U.S. Geological Survey Professional Paper 964, 28 p.

Crawford, J.K., 1983, Water-quality characteristics for selected sites on the Cape Fear River, North Carolina, 1955-88--Variability, loads, and trends of selected constituents: U.S. Geological Survey Open-File Report 83-526, also to be published as Chapter F of U.S. Geological Survey Water-Supply Paper 2185.

Daniel, C.C., III, and Sharpless, N.B., 1983, Ground-water supply potential and procedures for well-site selection, Upper Cape Fear River basin, North Carolina: North Carolina Department of Natural Resources and Community Development, Raleigh, N.C., 73 p.

Dupuis, T., Kaster, J., Bertram, P., Meyer, J., Smith, M., Kobriger, N., 1984, Effects of highway runoff on receiving waters, Volume II--Results of field monitoring program: Federal Highway Administration, FHWA-RD-841063.

Gupta, M.K., Agnew, R.W., and Kobriger, N.P., 1981, Constituents of highway runoff; Volume I--State of the art report; Volume II--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; Volume V--Highway runoff data storage program and computer users manual; Volume VI--Executive summary: Federal Highway Administration, report nos.: Vol. I, FHWA-RD-81/042; Vol. II, FHWA-RD-81/043; Vol. III, FHWA-RD-81-044; Vol. IV, FHWA-RD-81/045; Vol. V, FHWA-RD-81/046; Vol. VI, FHWA-RD-81-047.

Harned, D.A., 1980, Water quality of the Neuse River, North Carolina--Variability, pollution loads, and long-term trends: U.S. Geological Survey Water-Resources Investigations 80-36, also published as Chapter D of U.S. Geological Survey Water-Supply Paper 2185.

Harned, D.A., and Meyer, D., 1981, Water quality of the Yadkin-Pee Dee River system, North Carolina--Variability, pollution loads, and long-term trends: U.S. Geological Survey Open-File Report 81-643, also published as Chapter E of U.S. Geological Survey Water-Supply Paper 2185.

Interagency Task Force On Acid Precipitation, 1981, National acid precipitation assessment plan: Council on Environmental Quality, Washington, D.C.

Kobriger, N.K., Gupta, M.K., and Geinopolos, A., 1982, Sources and migration of highway runoff pollutants--Research report: Federal Highway Administration report no. FHWA-RD, Vols. I-III.

National Oceanic and Atmospheric Administration, 1982, Local climatological data, Raleigh and Greensboro, N.C., Environmental Data and Information Service, National Climatic Center, Asheville, N.C.

North Carolina Environmental Management Commission, 1986, Classifications and water quality standards applicable to surface waters of North Carolina: North Carolina Administrative Code, Title 15, Chapter 2, p. 2B-23.

Orange County Planning Department, 1981, Existing and potential reservoir sites and watersheds: Map by the Orange County Planning Department.

Overton, D.E., and Meadows, M.E., 1976, Storm-water modeling: Academic Press, New York, pp. 123-126.

Simmons, C.E., and Heath, R.C., 1979, Water-quality characteristics of streams in forested and rural areas of North Carolina: U.S. Geological Survey Water-Resources Investigations, 79-108, also published as Chapter B of U.S. Geological Survey Water-Supply Paper 2185.

U.S. Environmental Protection Agency, 1980, Water quality criteria documents: Federal Register, vol. 45, no. 231, Friday, Nov. 28, 1980, notices, p. 79318-79379.

Weiss, C.M., Francisco, D.E., and Lenat, D.R., 1973, Preimpoundment studies-Falls project--water-quality characteristics: U.S. Army Corps of Engineers draft environmental statement, Falls Lake, Neuse River basin, N.C., Appendix I, U.S. Army Engineers District, Wilmington, N.C.