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

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Paper 2329

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March 3, 1849

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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 WATER-SUPPLY PAPER 2329

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METRIC CONVERSION FACTORS

For readers who wish to convert measurements from the inch-pound system of units to the metric system of units, the conversion factors are listed below:

Multiply inch-pound unit	By	To obtain metric unit
	Length	
inch (in)	25.4	millimeter (mm)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	.4047	hectare (ha)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	.02832	cubic meter (m^3)
acre foot (acre-ft)	1,233.5	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
	Mass	
ton (short, 2,000 lb)	.9072	megagram (Mg) or metric ton (t)
pound avoirdupois (lb avdp)	.4536	kilogram (kg)
pound (lb)	453.59	gram (g)
	Temperature	
degree Fahrenheit (°F)	5/9 (°F−32)	degree Celsius (°C)
	Specific conductance	
micromho (μmho) per centimeter at 25 °C	1.000	microsiemens (μS) per centimeter at 25 °C

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada; formerly called Sea Level Datum of 1929.

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

Abstract

An evaluation of water-quality data from streams that receive stormwater runoff from a segment of Interstate Highway 85 in North Carolina indicated increased 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 the interstate. The average traffic flow along this section was 25,000 vehicles per day.

During storm runoff, streamflow in basins traversed by the highway rose and fell more rapidly than that in the undeveloped basins. This more rapid response is due to the impervious, paved area of the basins and the manmade drainage systems designed to rapidly move water off 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. Specific conductance and concentrations of dissolved and total nitrogen peaked 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, the pH at all stations decreased during stormflow because the rainfall drained off by the streams had pH values less than 5.7.

High metals concentrations were found in the soils within 100 feet of the highway and in the soil water infiltrating the soil zone. Chromium, copper, nickel, and zinc concentrations in the streams near the highway generally were above the maximum levels recommended by the U.S. Environmental Protection Agency (EPA) for the protection of aquatic life. Lead and cadmium concentrations frequently exceeded the maximum levels recommended by the EPA for drinking water.

The highway is a source of contaminants to surrounding areas. Particulate and metal loads in dustfall and chemical-constituent concentrations in soils decrease exponentially with distance from the highway. The highest concentrations of contaminants were found on the downwind side. Increased concentrations of metals (cadmium, chromium, iron, lead, nickel, and zinc) in rainfall were observed in samples collected near the highway and in samples collected approximately one-half mile away. Material loading due to dustfall was greater than loading due to rainfall. Loading due to saltated particles, those heavier particles bounced along the highway surface, was higher than loading due to dustfall. Saltation loads were greatest during the winter months because of highway deicing and sanding, which supplied an estimated two-thirds of the saltated materials. The remaining one-third of the saltated load came primarily from the deposition of particles from vehicles. Some of the greatest constituent concentrations were measured in the soil water sampled from the lysimeters located adjacent to the highway.

INTRODUCTION

Multiple-lane, controlled-access superhighways are an integral part of modern society. 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 areas near the roads and to remote areas via transport by air and by streams that drain the highways.

Any complete assessment of the effects of development on water quality should include the effects of highways. Although the magnitude of these effects varies, different stretches of highway that have similar climate, topography, and traffic density should have similar kinds of

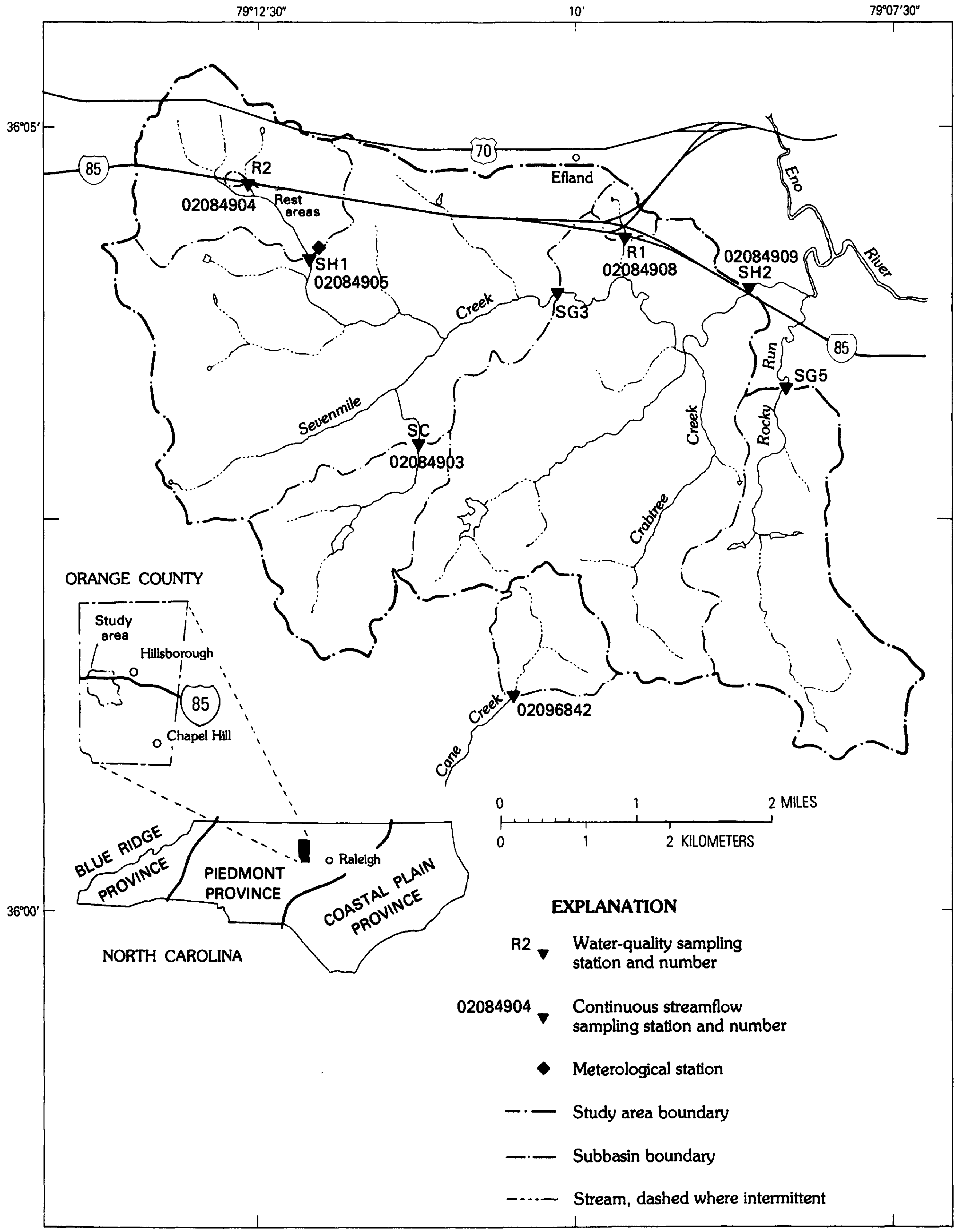


Figure 1. Study area, sampling points, and subbasins, Sevenmile Creek basin, North Carolina.

environmental effects. The superhighway 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, N.C., was one of the basins chosen in a national research study by the Federal Highway Administration (FHA) to identify the sources of pollutants in runoff from major highways and to assess the migration of particulate and chemical substances into the surrounding environment. Four sites were studied: a basin draining a section of I–94 in Milwaukee, Wis.; a basin draining a section of Highway 50 in Sacramento, Calif.; a basin draining a section of I–81 in Harrisburg, Pa.; and the Efland, N.C., I–85 site. The Milwaukee and Sacramento sites are urban, and the Harrisburg and Efland sites are rural. Traffic flow along I–85 near Efland was the lowest of all four sites. A qualitative and quantitative comparison of results determined at the four sites by Kobriger and others (1982) allows general conclusions to be made about pollutant sources and migration. Dupuis and others (1984) presented the results obtained from 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 included the results of biological monitoring that were not available at the time this report was written.

An FHA report series (Gupta and others, 1981) that preceded and precipitated the Kobriger study is another valuable and current source of data and information about the water quality of highway runoff. The Gupta reports examine the body of literature related to highway runoff, describe highway-runoff water-quality characteristics, and outline procedures for monitoring and evaluating these characteristics.

Purpose and Scope

This report describes the effects of storm runoff from a segment of a major highway system, I–85, on the water quality and flow characteristics of Sevenmile Creek, a small rural stream. By defining, in a general manner, the sources and migration of chemical constituents near the highway, comparisons can be made to areas unaffected by highway contaminants.

The study area, in Orange County, N.C., includes the drainage basin of Sevenmile Creek, which drains a 4.8-mi-long segment of I–85 (fig. 1). Two small stream basins, Rocky Run and Cane Creek, are adjacent to the Sevenmile basin and were used as control areas because their flows are unaffected by highway runoff. The combined drainage area of the basins is 17.5 mi^2.

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 October 1973 to September 1981. Data were obtained from measurements of rainfall, streamflow, water temperature, specific conductance, pH, dissolved-oxygen concentration, suspended-sediment concentration, and concentrations of major constituents, metals, and nutrients. Measurements were made of atmospheric deposition quality, chemical quality of the water infiltrating the unsaturated zone, metals in the soils near the highway, wind speed and direction, and the physical and chemical nature of material collected from the road surface.

Biological data were collected but not evaluated in this report because the results were not available at the time this report was written. 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 (USGS) personnel in coordination with REXNORD, Inc., a Milwaukee, Wis., based engineering firm under contract with the Federal Highway Administration (FHA). REXNORD personnel included Thomas Dupuis, N.K. Kobriger, Joseph Kuderski, and William Kreutzberger. The FHA reports for the national study (Kobriger and others, 1982; Dupuis and others, 1984) contain much of the data discussed in this USGS report and were a source for some of the illustrations and tables.

The USGS personnel who were substantially involved in planning the method of study and collecting data for Sevenmile Creek and adjacent basins are R.G. Garrett, J.M. West, C.E. Simmons, S.S. Howe, and N.M. Jackson, Jr.

Helpful 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-mi-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 encompass 17.5 mi^2.

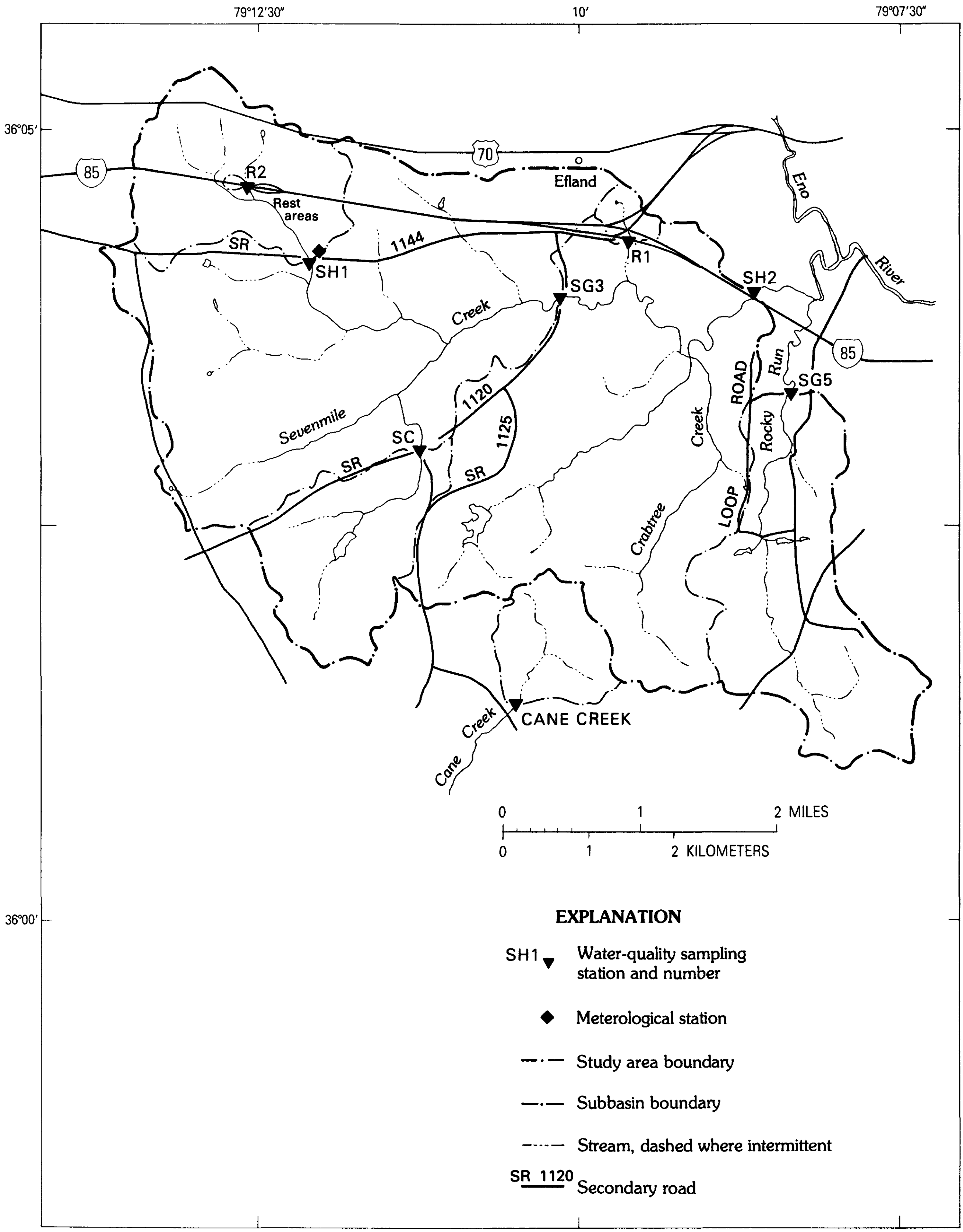


Figure 2. Principal roads in the study area, Sevenmile Creek basin, North Carolina.

The study area was divided into eight subbasins, each represented by a sampling station, 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 stormwater 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 was placed downstream from R2, where the drainage from a large section of I–85 could be measured. SH2 was placed 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 at its approximate midpoint in the study area, and SG5 (Stream grab-5), to provide data from the Rocky Run basin. Station SH2 was located 0.5 mi upstream from the point at which Rocky Run flows into Sevenmile Creek. SH2 (drainage area 14.5 mi^2), SG5 (2.4 mi^2), and Cane Creek (0.64 mi^2) mark the downstream end points of the entire study area (17.5 mi^2).

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

Basin Characteristics

Topography

Rolling hills characterize the landscape of the study area. Land-surface altitudes range from approximately 770 to 550 ft above the National Geodetic Vertical Datum of 1929 (NGVD of 1929). Traveling from west to east, I–85 loses approximately 110 ft of altitude and, therefore, has an overall slope within the basin of about 23 ft/mi.

The average stream gradient is approximately 48 ft/mi and ranges from about 100 ft/mi in the headwater reaches (Cane Creek and near station R1) to 15 ft/mi along the downstream segment of Sevenmile Creek.

Geology

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

The predominant bedrock in the study area is folded and fractured metavolcanic rock and igneous rock intruded into the metavolcanic rock (Allen and Wilson, 1968). Generally, the bedrock is overlain by unconsolidated residual material, termed regolith, that results from weathering of the bedrock. Regolith has a great effect on the natural quality of ground water.

Climate

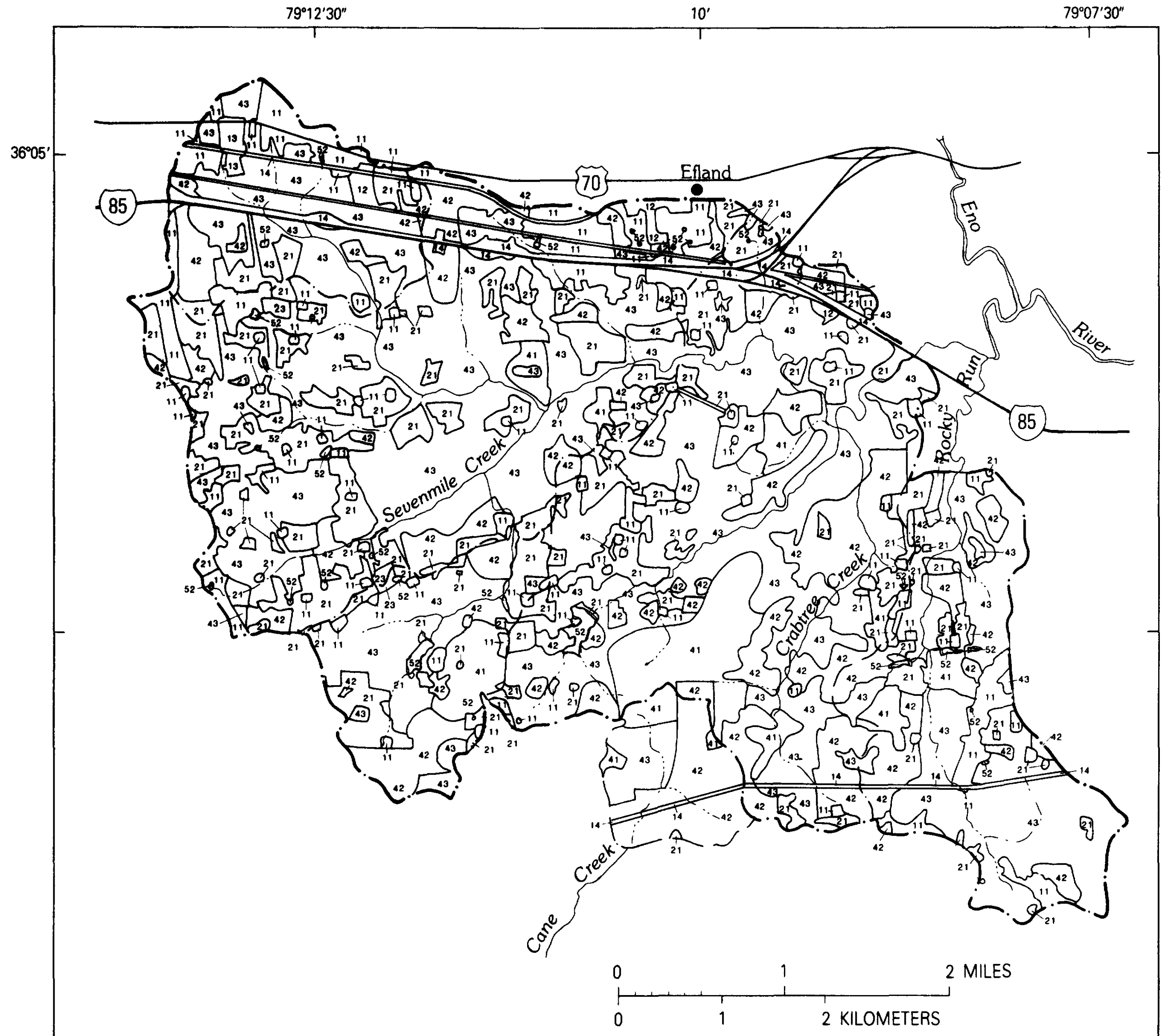
Weather in the northern Piedmont is relatively mild year round (National Oceanic and Atmospheric Administration, 1982). The Appalachian Mountains in western North Carolina serve as a partial barrier to cold-air masses moving across the Plains States, tempering the severity of winter storms in the Piedmont. The coldest temperatures usually occur when cold northeastern air masses move southward. Overall, more than half of the winter days have subfreezing temperatures. An average winter has two snowfalls of more than an inch in depth and an average of 4 days per year of freezing rain. Maximum temperatures in the summer are between 90 and 100 °F.

Rainfall, generally, is evenly distributed throughout the year; the greatest average rainfall is in July, and the least is in November. Most summer rainfall occurs during convective storms, which can be quite severe. Normal precipitation, as measured at the National Oceanic and Atmospheric Administration station at the Greensboro-High Point-Winston-Salem Regional Airport, is 42.33 in/yr (period of record 1929–81). The precipitation measured at the study site rain gages during the study period of July 1981 to June 1982 was 53.91 in; therefore, 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 was used as an independent variable in correlation analysis of the water-quality data. Most of the study area is rural except for development in the town of Efland and along certain roads in the Sevenmile Creek basin. The principal roads in the basin are shown in figure 2. Road length, a measure of development, is one independent variable used in correlation analysis of water-quality data.

The land-use categories shown in figure 3 were obtained by overlaying a USGS 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).



EXPLANATION

LAND USE

11	Residential and farm buildings	23	Confined feeding operations
12	Commercial and services	41	Deciduous forest land
13	Industrial	42	Evergreen forest land
14	Transportation and utilities	43	Mixed forest land
21	Cropland, pasture, and open space	52	Lakes, reservoirs, and ponds

Figure 3. Study area land use compiled from U.S. Geological Survey Land-Use Data Analysis map, topographic map, and orthophoto map.

Table 1. Percentage of land-use types in the eight subbasins of the study area
[Drainage area in square miles for each site is shown in parentheses]

Land-use type		Subbasin								
Number used in figure 3	Description	R1 (0.14)	R2 (0.0032)	SH1 (1.6)	SH2 (14.5)	SG3 (8.8)	SG5 (2.4)	SC (1.4)	Cane Creek (0.64)	Study area[1] (17.5)
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

[1] Study area percentages do not sum to the study area total because of an overlap of drainage areas.

The percent of land-use type within each subbasin is shown in table 1. Forest, cropland, and residential areas are the predominant land uses in all the subbasins except R1 and R2. The predominant land-use types within the subbasin for R1 are pasture and transportation; the subbasin for R2 is completely covered by 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-mi-long section of I-85 that passes through the study area is a four-lane divided highway that has 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.

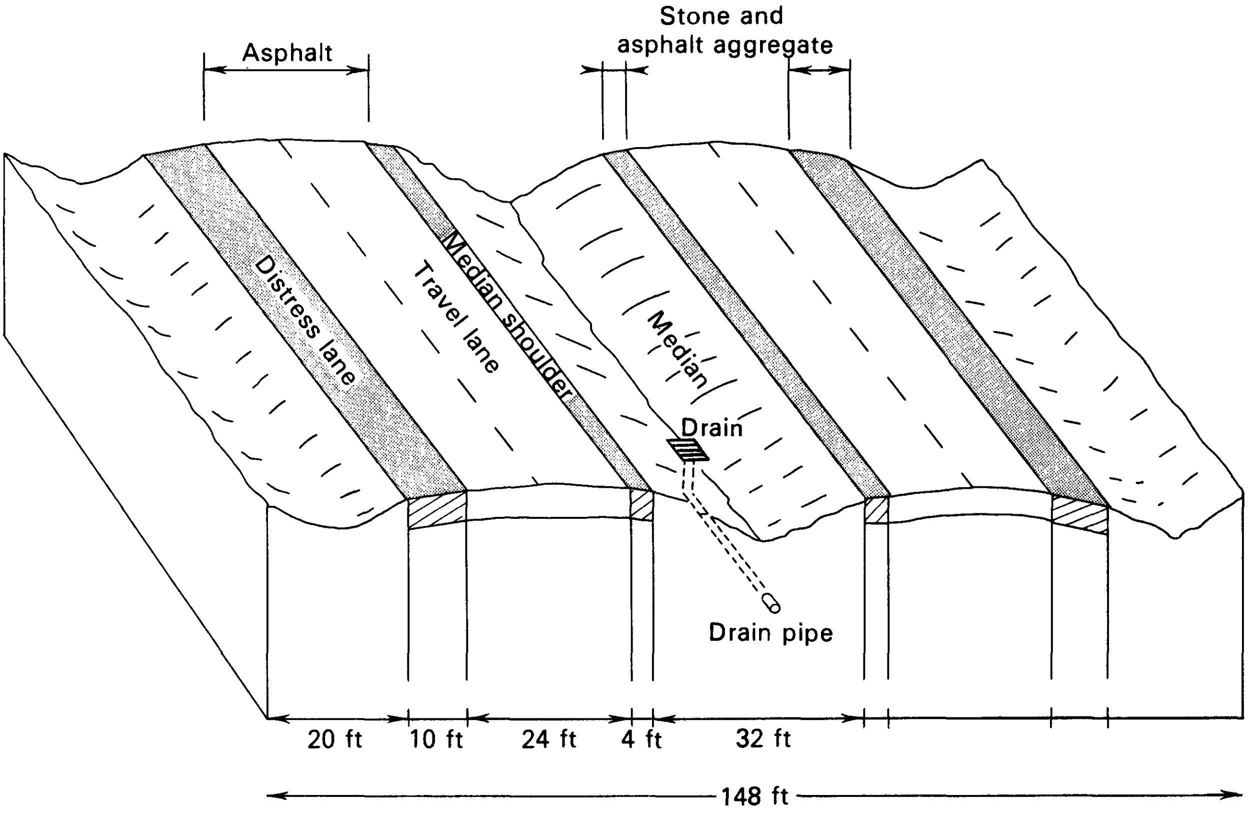


Figure 4. Typical cross section of Interstate 85 near Efland, N.C., showing road design and drainage (Kobriger and others, 1982).

There are two rest areas, one for each side of the highway. Each rest area contains a small, self-contained sewage-treatment facility that processes wastewater from the restrooms. The effluent from these facilities enters the tributary to Sevenmile Creek that is 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 usually was lowest during the winter months.

Highway maintenance activities included repairing the roadway; sanding, salting and snowplowing for the removal of ice and snow; applying herbicide and fertilizer; and roadside mowing. Of these practices, only data from road sanding and salting and herbicide application could be obtained for this analysis.

DATA COLLECTION

Data-collection efforts were coordinated between the USGS and REXNORD, Inc. Day-to-day operation and maintenance of the equipment, periodic water-quality and meteorological sampling, stream gaging, and storm-event sampling were conducted by the USGS staff. The USGS staff also performed field analyses, when appropriate, for pH, water temperature, conductivity, and dissolved oxygen. Samples collected by the USGS were mailed to REXNORD's laboratory in Milwaukee, Wis., for analysis. The REXNORD staff made several sampling trips to collect biological specimens and to vacuum segments of I–85 to obtain samples of the material on the road surface. This report was based on the data available at the time the report was written and, in particular, the data that the USGS staff collected.

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

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

Water-quality sampling was conducted at SH1, SH2, SC, R1, and R2 by using automated stage-activated samplers. Samples from the automatic samplers were supplemented with periodic, manually collected samples and field water-quality analyses. Samples were collected manually at sites SG3 and SG5. Specific conductance and water temperature were continuously monitored at SH1, SH2, and SC. Analyses of fecal coliform bacteria, fecal streptococcus bacteria, specific conductance, pH, water temperature, suspended-sediment concentration, and dissolved oxygen concentration were determined by the USGS. All other analyses, including analyses of major ionic constituents, metals, nutrients, and organics, were conducted by REXNORD, Inc.

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.

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.

Analysis of the effects of the highway on water quality is complicated by background levels of constituents and highway maintenance operations. Truly natural pollution effects are difficult to separate from ambient background water and air-quality data, making pollution-source identification more difficult. The Cane Creek station was used in an earlier study of the natural or background water quality of North Carolina streams (Simmons and Heath, 1979). Because no station in the Sevenmile Creek basin provides data representative of an undeveloped area, Cane Creek data were used. The samples collected at Cane Creek were analyzed at the USGS laboratory in Doraville, Ga.

SOURCES AND TRANSPORT MECHANISMS OF CONSTITUENTS

The principal sources of materials commonly found in highway-runoff water are vehicles, atmospheric fallout, highway maintenance, and road structure degradation. Vehicles contribute materials from fluid leaks and spills; automobile body rust; and the wear of brake linings, tires, bearings, and moving engine parts. Atmospheric sources are fallout from vehicle exhaust and other air pollution. Highway maintenance, such as road deicing, spraying of roadsides with pesticides, and using fertilizers, also affects runoff water quality. Finally, degeneration of the road itself, including pavement wear, the rusting of steel highway structures, and the leaching of petroleum from asphalt, contributes to the material deposited in nearby streams. A

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

Station	Equipment							Sampling frequency						
	Continuous stage recorder	Automatic sampler	Temperature and conductivity monitor	Precipitation gage number	Weather station	Lysimeter	Staff gage	Gage height, automatic sampler, and temperature and conductivity	Wet-dry collector	Weather station	Dry weather survey	Storm event	Bulk precipitation	Lysimeter
SH1 Sevenmile Creek tributary at SR 1144 near Miles (02084905)	●	●	●	[1]P1	●		●	M	BW	W	M	[2,3]~6		
SH2 Sevenmile Creek at I-85 near Efland (02084909)	●	●	●	P2			●	M			M	[2,3]~6		
SC Sevenmile Creek tributary at SR 1120 near Buckhorn (02084903)	●	●	●	[1]P3			●	M	BW		M	[2,3]~6		
R1 Sevenmile Creek tributary at I-85 near Efland (02084908)	●	●					●	M				[3]~6-8		
R2 Sevenmile Creek tributary at I-85 near Miles (02084904)	●	●				●	●	M				[3]~25	BW	~25 events
Cane Creek 0.1 mi upstream from SR 1126 near Buckhorn (02096842)	●		●				●	M						
SG3 Sevenmile Creek at SR 1120 near Efland							●					[2]~6		
SG5 Rocky Run at Loop Road near Efland							●					[2]~6		

[1] Includes wet-dry collector.
[2] Includes 5–6 manual samples for oil, bacteria, pesticides, and wet-sieve separations.
[3] Includes automated and manual multiple-sample collection during storms.

list of constituents commonly found in highway runoff and associated sources of the substances is shown in table 3.

Another source of chemical constituents in runoff in the Sevenmile Creek basin is development unrelated to the highway system, such as minor industrial and residential development in Efland (see Land Use), the two small wastewater treatment plants serving the highway rest areas, and two intensive feed-lot operations located in the western section of the SG3 subbasin and the northern section of the SC subbasin. Geological influences also contribute to constituent loads in streams, as discussed in Basin Characteristics.

The principal transport mechanisms include stormwater washoff and solution, entrainment in the air, and saltation along the ground. Stormwater washes and dissolves the material accumulated from the road and median

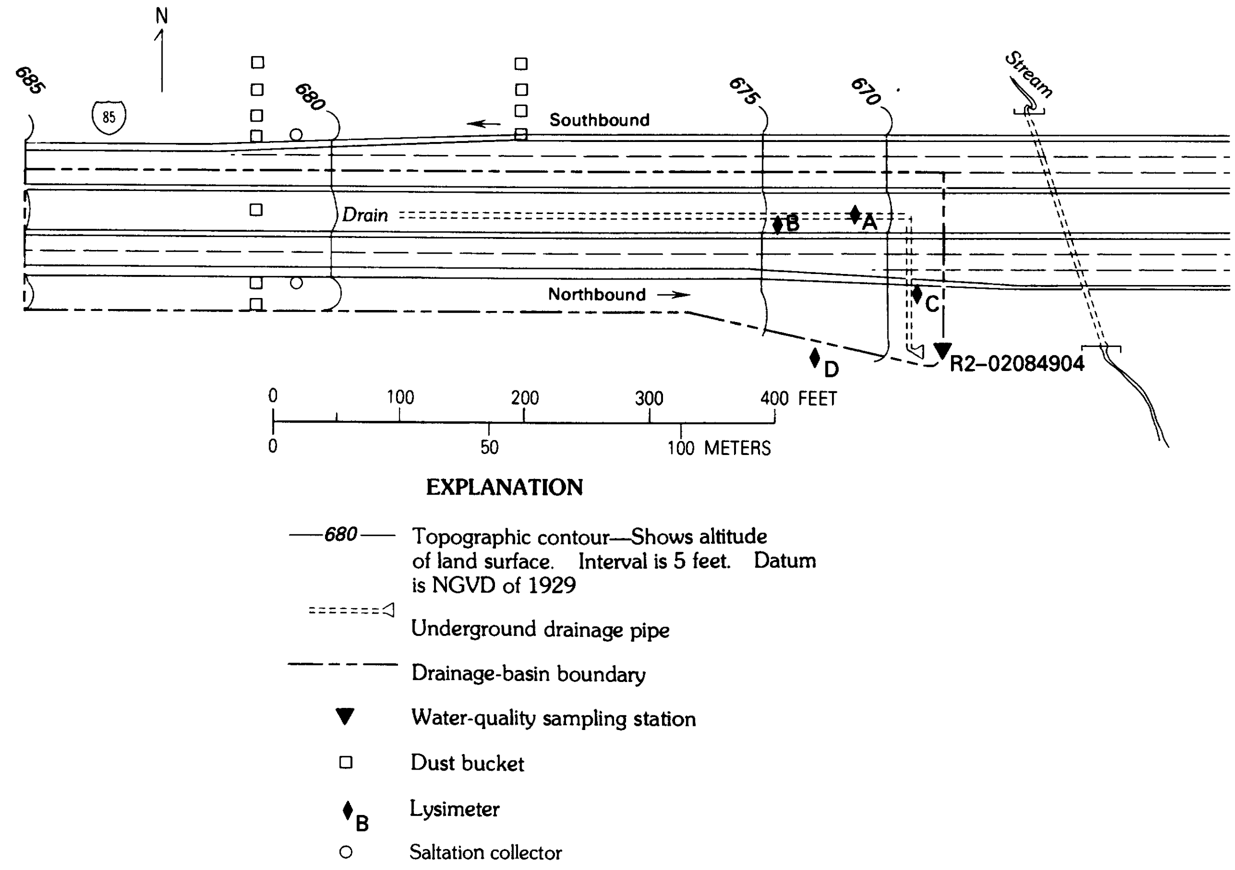


Figure 5. Locations of dust buckets, saltation collectors, and lysimeters at site R2.

Table 3. Sources of common highway-runoff chemical constituents

[Modified from Kobriger and others, 1982, v. I, p. IV–1–2]

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 keep deicing salt granular.
Iron	Autobody rust, steel highway structures (guard rails, and so on), 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, trucks hauling livestock and stockyard waste.
Particulates	Pavement wear, vehicles, atmosphere, road maintenance.
Petroleum	Spills, leaks, and blow-by of motor lubricants, antifreeze and hydraulic fluids, asphalt surface leachate.
Pesticides	Spraying of highway rights-of-way, atmosphere.
Manganese	Moving engine parts.
Nickel	Diesel fuel and gasoline (exhaust), lubricating oil, metal plating, bushing wear, brake-lining wear, asphalt pavement.
Rubber	Tire wear.
Sulfate	Roadway beds, fuel.
Zinc	Tire wear (filler material), motor oil (stabilizing additive), grease.

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, gives a measure of the role of stormwater transport. Lysimeters give an estimate of the quality of water that moves through the soil zone.

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 that 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.

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 determine because some materials may have been transported long distances. Statistical analysis of the chemical characteristics of precipitation collected at the SH1 station from 14 storms indicates that the atmosphere is a major source of metals and nitrogen and that the rainwater is acidic (table 4). All pH values were below 5.7, which is the theoretical pH of pure water in equilibrium with atmospheric carbon dioxide concentrations (Interagency Task Force on Acid Precipitation, 1981).

Highway Sources

Materials derived from highway activities were collected at the R2 site by using dust buckets and saltation collectors (see location map, fig. 5) and from road-sweep material and soil samples.

A comparison of highway dustfall conditions to 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, about one-half mile from the highway (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 factions together shows that (table 5, column 10) the proportion of the total loading rate attributable to background conditions is unexpectedly high, ranging from a low of 42 percent of the total zinc loading rate to a high of 93 percent of the total particulate loading

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

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

Characteristic	Mean	Standard deviation	Range	Statistical median load (mg/m^2)	Number of samples
Precipitation (in.)	1.35	0.93	0.22–3.7	—	14
pH[1]	4.0	.57	3.4–5.4	—	14
Total dissolved solids (mg/L)	9	9	0–24	272	6
Total suspended solids (mg/L)	14	11	2–33	36	13
Total organic carbon (mg/L)	11	7.8	5–16	260	2
Chemical oxygen demand (mg/L)	13	6.4	8–17	505	2
Chloride (mg/L)	2.9	2.4	0–6	108	8
Sodium (mg/L)	.5	.7	0–2	7.3	8
Sulfate (mg/L)	1.0	2.2	0–5	—	5
Total phosphorus (as P, mg/L)	.003	.01	0–0.03	—	9
Total Kjeldahl nitrogen (mg/L)	1.0	.91	0–2.0	42	7
Total nitrate+nitrite (as N, mg/L)	.27	.28	.03–0.81	6.6	7
Total cadmium (µg/L)	.8	1.4	0–4	—	13
Total chromium (µg/L)	2.6	3.8	0–10	.04	11
Total copper (µg/L)	32	22	10–90	.7	13
Total iron (µg/L)	240	400	50–1500	3.1	13
Total lead (µg/L)	3.8	7.7	0–20	—	13
Total nickel (µg/L)	3.9	6.5	0–20	—	13
Total zinc (µg/L)	30	14	0–50	.8	13

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

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

[Columns are numbered for reference in the text; (mg/m²)/d, milligrams per square meter per day; ND, not detected; —, no data]

Particulate matter and metals	R2 dust bucket			SH1 wet-dry collectors						Background² loading rate	Saltation collectors		
	Median load (mg/m²)/d	Range (mg/m²)/d	Number of samples	Mean or median load (mg/m²)/d			Range (mg/m²)/d		Number of samples		Mean load¹ (mg/m²)/d	Range¹ (mg/m²)/d	Number of samples
				Wet	Dry	Wet+Dry	Wet	Dry					
	1	2	3	4	5	6	7	8	9	10	11	12	13
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–0.0007	7	ND	ND	ND	ND	ND–0.001	6	—	ND	ND	4
Total chromium	.002	.00002–0.005	7	ND	.001	.001	ND–0.001	.00002–0.002	6	50	.002	.001–0.003	4
Total iron	.424	.024–0.672	7	.041	.320	.320	ND–0.159	.024–0.626	6	75	1.45	.83–2.08	4
Total lead	.006	.001–0.015	7	ND	.004	.004	NC–0.002	.0001–0.007	6	66	.07	.05–0.10	4
Total nickel	ND	ND–0.002	7	ND	ND	ND	ND–0.001	ND–0.001	6	—	ND	ND–0.001	4
Total zinc	.007	.00004–0.018	7	ND	.003	.003	ND–0.015	.0004–0.011	6	42	.02	.017–0.024	4

[1] Calculated by using means of samples from both collectors. Because each of the two saltation collectors was located on the outside median strip, saltation material in the central median strip was not collected.

[2] Calculated as (column 6)−(column 1)×100.

rate at the highway station. The high percentage of background dustfall may indicate high ambient dust levels from widespread sources or, more likely, load contribution to the SH1 wet-dry collector from the highway system.

A distinct relation exists between the constituent levels measured in the dust buckets and the distance of the bucket from the highway. This relation, when plotted, takes the form of an exponential die-off curve (fig. 6). In this diagram, both total particulate material and total lead content of the samples are high next to the road, and just 30 ft away, the totals are much lower. The metals concentration of the uppermost centimeter of soil (fig. 7), as with the levels measured in the dust buckets, is highest in samples taken nearest to the highway. Also, the highest concentrations of iron, lead, and zinc are found on the north side of the freeway, probably because the predominant wind direction is to the north.

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

The summary of saltation-collector data shown in table 5 allows a comparison of highly localized material loading near the highway system to the diffused dustfall loadings near and one-half 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 the loading rate of total particulates collected by the saltation collectors (fig. 8). The highest total particulate loads, observed during the winter months, correspond to a general decrease in traffic flow and rainfall and a slight increase in average wind speed. The seasonality probably is a result of road deicing operations, including road sanding that occurred during the winter months.

EFFECTS OF THE HIGHWAY ON STREAM DISCHARGE

Discharge measured during sampling usually was 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, SC, Cane Creek, R1, and R2. Logically, the greater the size of the drainage area, the greater the discharge, as shown in table 6. However, the catchment area of site R2 was the smallest of all the stations. The high discharge per square mile at site R2 resulted because approximately one-half of this area is paved.

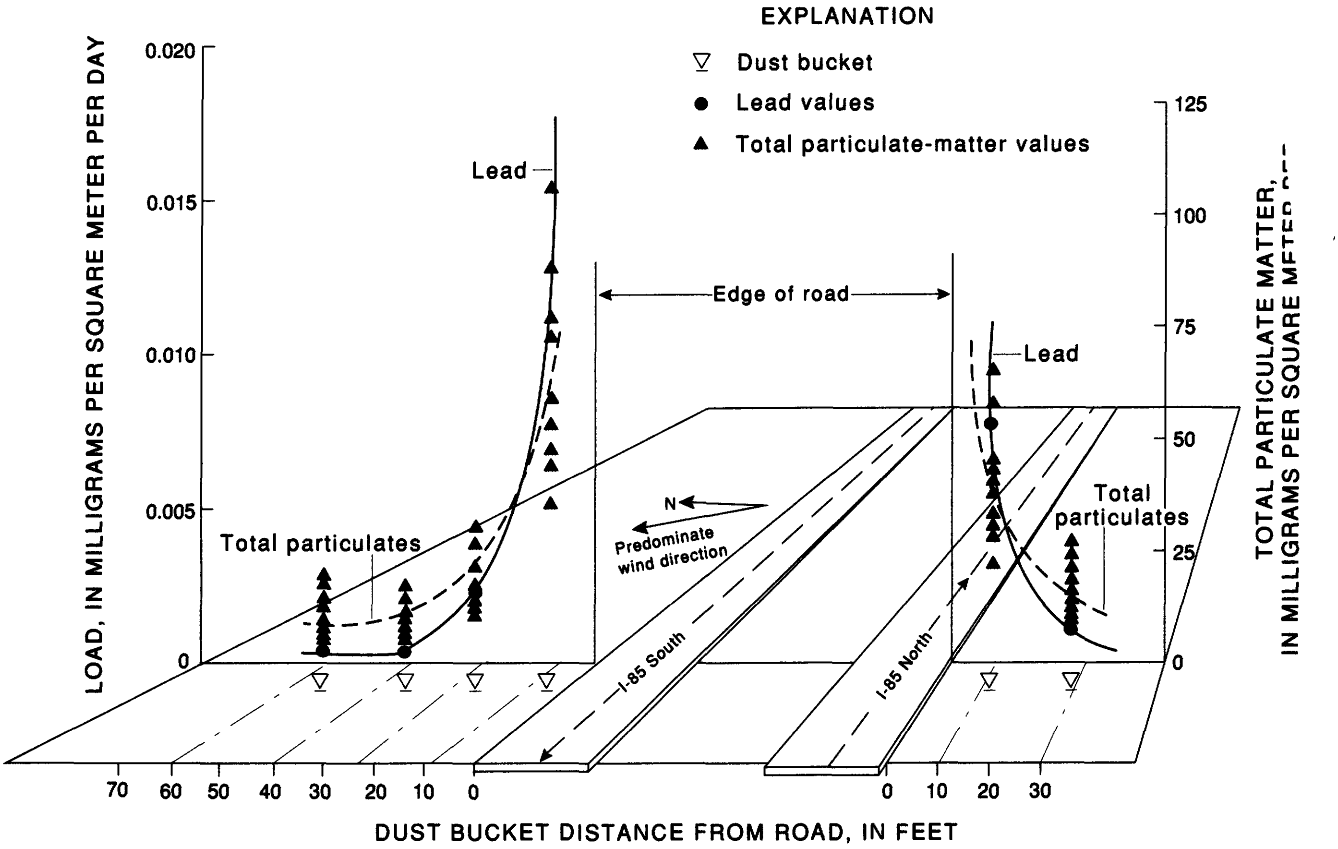


Figure 6. Lead and particulate fallout near highway station R2 (Kobriger and others, 1982).

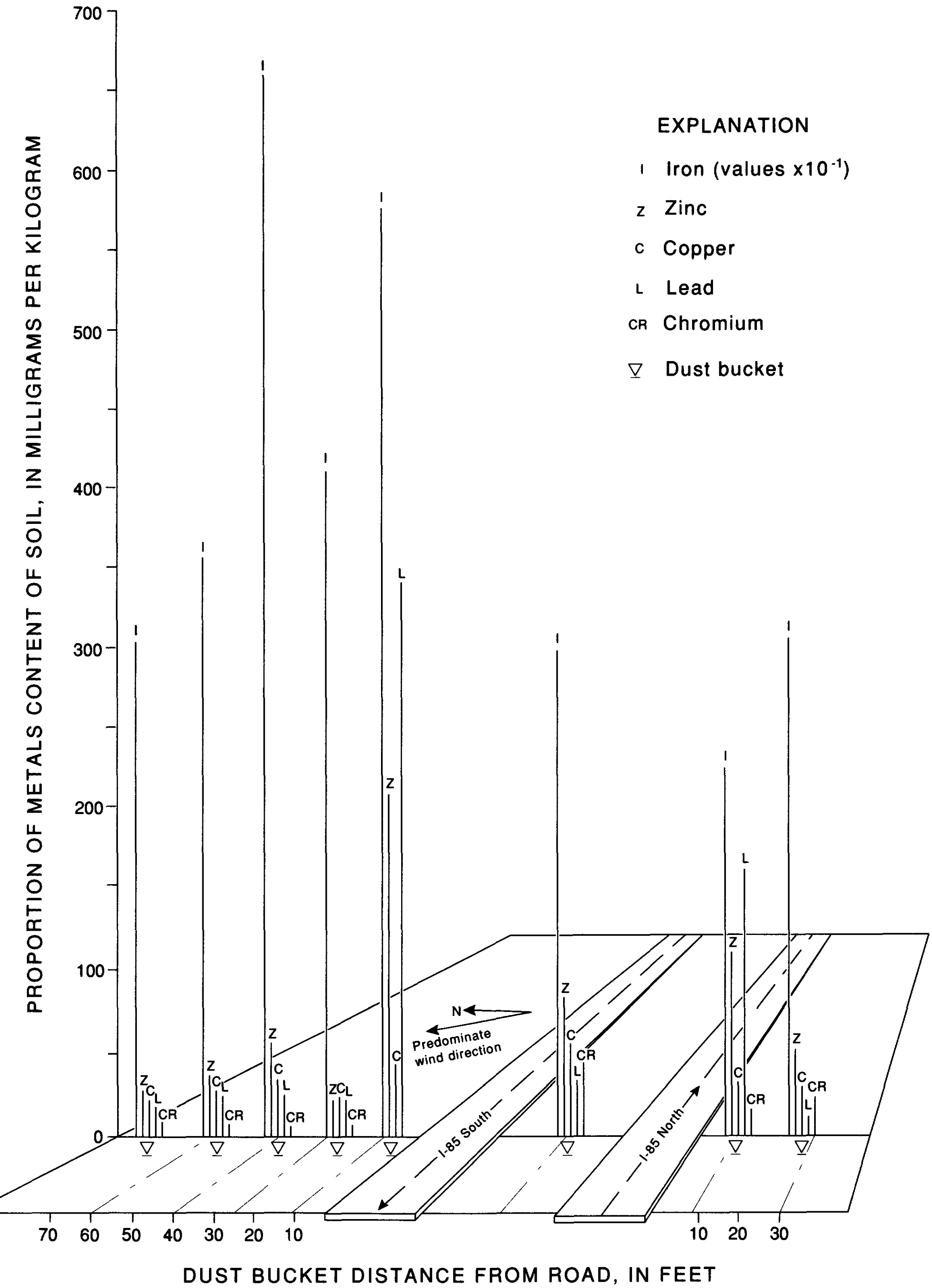


Figure 7. Proportion of metals content in soil near highway station R2 (Kobriger and others, 1982).

Comparisons among stations for a single storm event show the relative hydrologic responses of the streams and demonstrate 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 in of rainfall were measured during a 5-h period. Graphical representations of hourly rainfall (hyetographs)

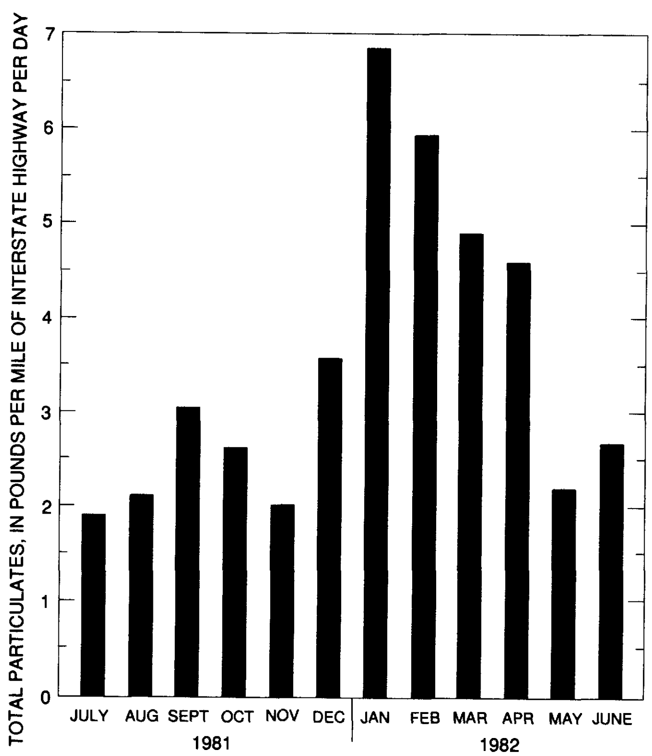


Figure 8. Seasonal loading rate of total particulates near highway station R2.

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 during the entire study period.

The hyetographs for stations SC (P3) and SH1 (P1) on figure 9 and 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 of rainfall 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, nearly half of which is covered by impervious highway pavement, responded within minutes to the rainfall, and the maximum discharge coincided with periods of most intensive rain. The stormflow recession was brief after the rain stopped (fig. 9). This response is expected because most of the precipitation runs off quickly in a small basin that has a large proportion of impervious cover and has a manmade drainage system. Relatively little water is stored in surface pools or in soil that would later drain out of the basin and create a prolonged recession.

The runoff response at station R1 was similar to that at R2, as evidenced by the runoff peaks in the hydrograph that nearly match the spikes in the hyetograph. The response at R1 was delayed somewhat in comparison to R2 because R1 is a larger basin having less basin area that is impervious. The streamflow recession at R1 also was 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 the floodflow of a stream can be 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 initial response to the storm. Streamflow in Cane Creek only began to increase 2 h after rainfall began, peaking slowly and having 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 more than four times that of R1. The slow rise and long recession observed at Cane Creek are characteristic of an undeveloped forested basin having no impervious area. The rapid rises and recessions observed at R1 and R2 and the high peak flows observed at R1 are characteristic of small, developed or urban basins containing substantial impervious areas.

A comparison between the hydrographs for stations SH1 and SH2 (fig. 10) demonstrates an attenuated response for SH2, which is typical of the larger drainage areas that have greater streamflow traveltimes. The imprint of the storm hyetograph, as well as effects of impervious area, shows in the SH1 hydrograph but does not show in the hydrograph of the downstream SH2 station. The SH2 hydrograph is the cumulative response of flows from numerous smaller tributaries. These tributaries flow through basins that have different basin characteristics but which are predominantly cropland and forest. The resultant

Table 6. Summary of stream discharge at selected sites

[mi^2, square mile; 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 daily discharge
		Mean (ft^3/s)	Range (ft^3/s)	Drainage area [(ft^3/s)/mi^2]
R1	0.14	0.12	0–4.30	0.86
R2	.00324	.0090	0–0.370	2.78
SH1	1.62	1.82	.01–63.0	1.12
SH2	14.54	15.18	.01–437	1.04
SC	1.39	1.49	0–20.0	1.07
Cane Creek[1]	.64	.29	0–11.0	.45

[1] Period of record, October 1973 to October 1981. The period of record for the Sevenmile Creek stations was July 1981 to July 1982.

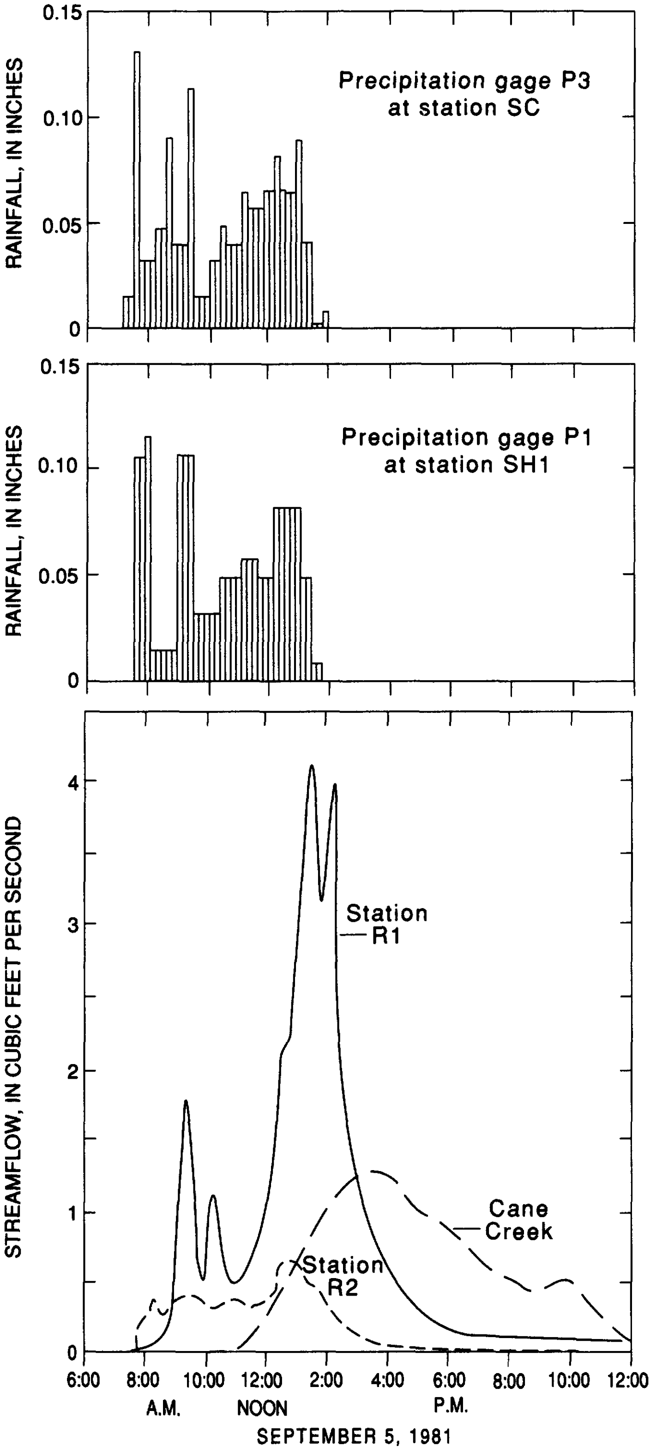


Figure 9. Rainfall hyetographs for stations SC and SH1 and streamflow hydrographs for stations R1, R2, and Cane Creek for the storm of September 5, 1981.

hydrograph for SH2 represents an average flow response from the tributaries and has a general shape that is between those of the Cane Creek and R2 stations.

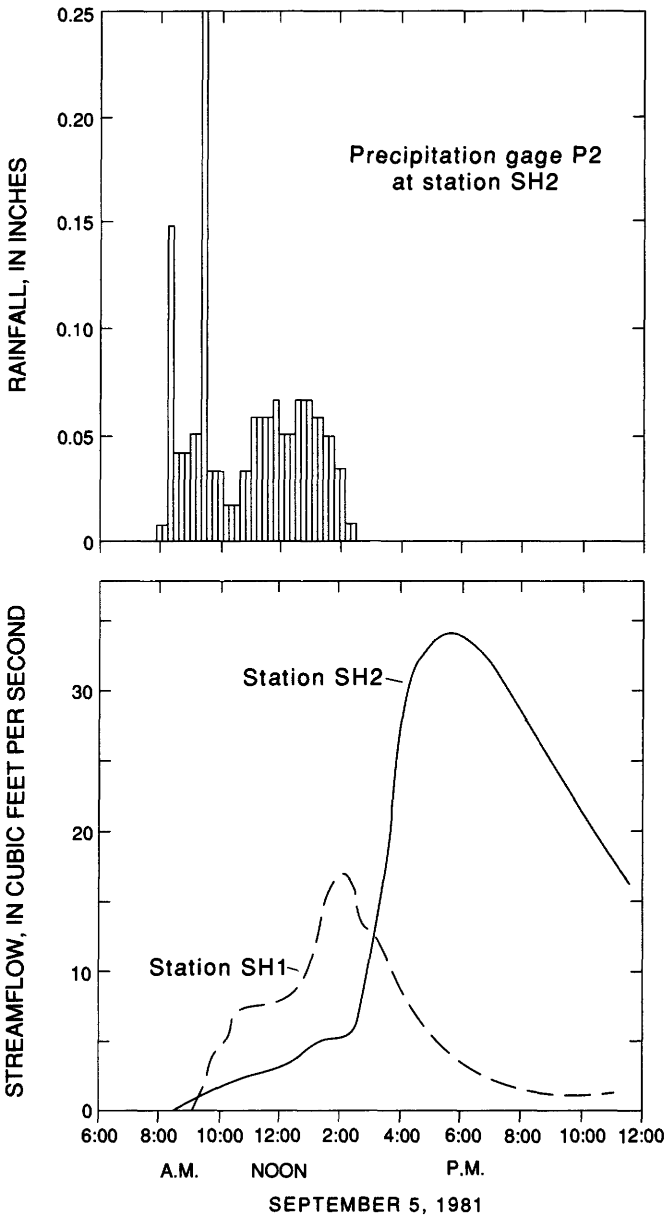


Figure 10. Rainfall hyetograph for station SH2 and streamflow hydrographs for stations SH1 and SH2 for the storm of September 5, 1981.

A correlation analysis was used to test for relations among 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, is discussed later in the section on major dissolved constituents. In all tables of water-quality characteristics, the chemical and physical characteristics for the Sevenmile Creek stations are primarily representative of higher flow conditions than conditions for Cane Creek. The physical and chemical characteristics for Cane Creek represent a full range of flow conditions.

Suspended Sediment

The statistical summaries for suspended sediment presented in tables 7–10 do not conclusively show any effects from the highway system. In fact, other variables probably are more important 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, the station that should show the greatest highway effect, had quite low concentrations. Stations SC and SH2 had 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 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 did not reveal any correlations.

A comparison of the data derived from the stations during storm events indicates that land use 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 shown in figures 11–13. The sediment concentration responses at both R1 and SH1 show rapid peaks at the beginning of the event 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 the 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 that have no extensive development (Overton and Meadows, 1976) and is similar to the response observed at Cane Creek for other storms. There were not enough data for SH2 to demonstrate whether the peak sediment concentration occurred before the streamflow peak, which is what would be expected for a basin that contains some development.

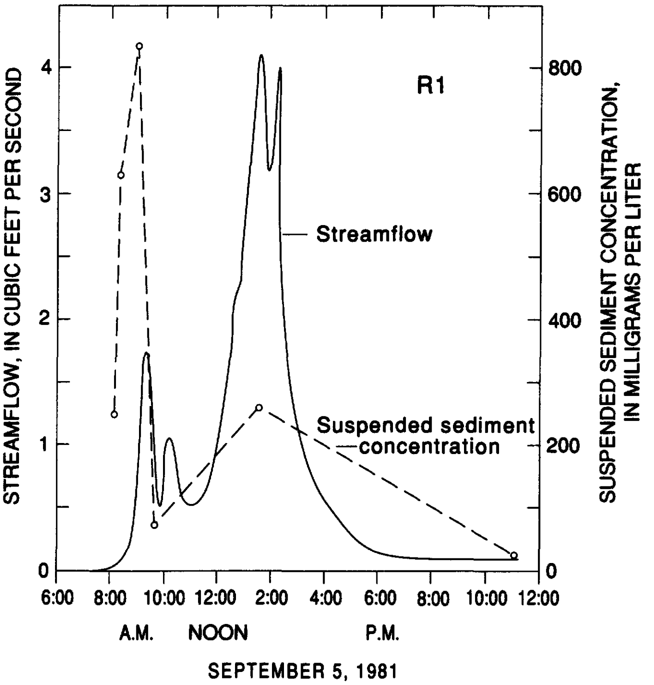


Figure 11. Suspended-sediment concentration at station R1 during the rainstorm of September 5, 1981.

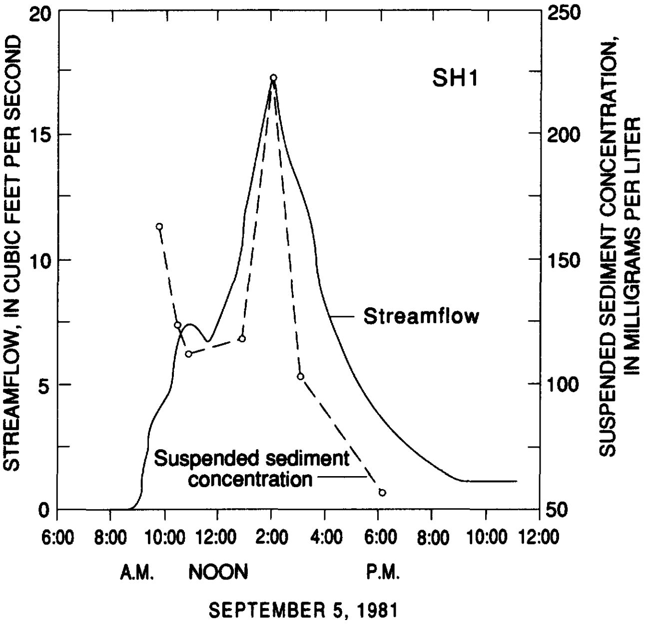


Figure 12. Suspended-sediment concentration at station SH1 during the rainstorm of September 5, 1981.

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

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

Physical characteristic	R1				R2			
	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
Discharge at time of sampling (ft^3/s)	0.620	0.974	0.001–4.1	51	0.112	0.19	0.01–0.98	31
Discharge, daily values (ft^3/s)	.11	.39	0–4.3	384	.009	.036	0–0.37	390
Temperature at time of sampling (°C)	11.2	6.5	1.0–20.0	12	12.8	8.2	2.5–20.0	5
Temperature, daily values (°C)	—	—	—	—	—	—	—	—
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 by using hydrogen-ion concentrations.

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

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

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 (°C)	12.7	6.4	1.0–24.0	18	10.8	6.5	0–23.0	17
Temperature, daily values (°C)	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 by using hydrogen-ion concentrations.

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

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

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 by using hydrogen-ion concentrations.

Table 10. Statistical summary of physical characteristics of water at the background stations SC, July 1981 to July 1982, and Cane Creek, October 1973 to October 1981

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

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 by using hydrogen-ion concentrations.

Water Temperature and Dissolved Oxygen

No difference among stations that could be related to highway runoff effects was observed for dissolved-oxygen concentrations and water temperatures. Water temperatures were measured and used to determine the percent saturation of dissolved oxygen. A comparison of dissolved-oxygen water-temperature relations among stations indicates that the sample values generally are near or just below dissolved-oxygen saturation values (tables 7–10). Station SC had consistently lower dissolved-oxygen levels than the other stations but was still approximately 76 percent saturated. These lower values can be explained by the relatively stagnant and, therefore, poorly aerated segment of the stream at the SC station. Runoff from the highway probably 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 (tables 7–10) of the streams yields no significant differences among the highway, rural, and background stations. In addition, no seasonal patterns were evident. However, during storms, a substantial decrease in pH was evident at the R1, R2, and SH1 stations because low pH rainfall collected in the streams. A slight peak in pH occurred at R1 and R2 at the beginning of a storm, possibly representing 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

Material derived from the highway causes detectable differences in levels of dissolved constituents, nutrients, and minor elements and materials in the 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 table 11. Analyses for the Sevenmile Creek stations (sites R1, R2, SH1, SH2, SG3, SG5, and SC) were made for calcium, sodium, sulfate, chloride, and alkalinity. In addition to these constituents, analyses for the Cane Creek station were made for silica, magnesium, potassium, bicarbonate, sulfate, fluoride, dissolved solids, and hardness.

The highest mean values for all the constituents measured (except sulfate) were at station R2. The statistics shown in table 11 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 reflected in the specific conductance results as well (tables 7–10). The highest mean-sample specific conductance was 3,530 μS/cm at R2, and the lowest was 44 μS/cm at the Cane Creek station. Clearly, the practice of road salting has a dramatic effect on the water quality of streams that receive drainage from the road. In addition to the major components of the salt, the deicing agents used on the stretch of highway near R2 included detectable amounts of copper, cyanide, iron, lead, and zinc (table 12).

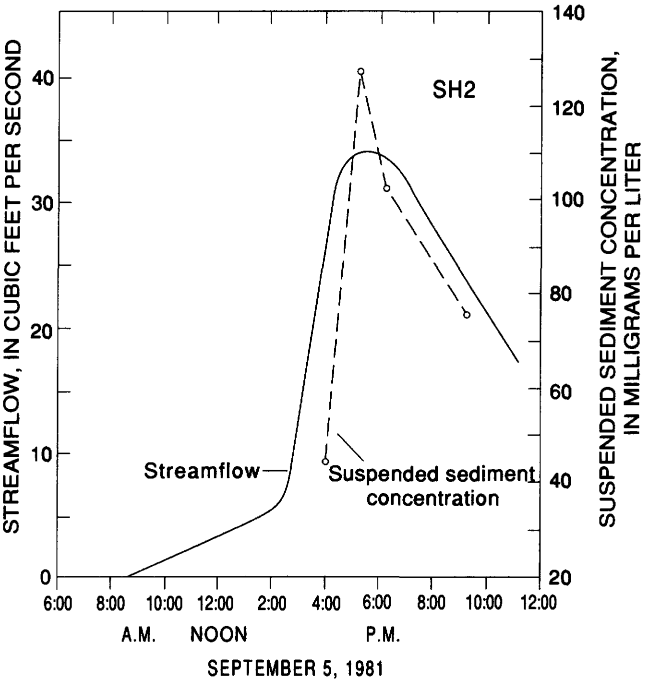


Figure 13. Suspended-sediment concentration at station SH2 during the rainstorm of September 5, 1981.

Station R1 had the second highest concentrations (table 11) of dissolved calcium, sodium, and chloride. High concentrations also were measured downstream at SH1 and even at SH2. The other stations had concentrations approximately equal to or slightly higher than the background levels detected at the Cane Creek station.

Not surprisingly, dissolved calcium, sodium, and chloride correlate (regression coefficient (r^2)≥0.72, at a probability (pr)=0.05) with the transportation and utilities category of land use (table 1, transportation and utilities) and with discharge per unit of drainage area (r^2≥0.90). All stations were used in the correlation analysis.

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)

Table 11. Statistical summary of major dissolved constituents, hardness, and alkalinity at stations R1, R2, SH1, SH2, SG3, SG5, and SC, July 1981 to July 1982, and at Cane Creek, October 1973 to October 1981

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

Constituent (mg/L)	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
			R1				R2	
Calcium (Ca^{+2})	13	12	1.7–35	10	135	—	—	1
Sodium (Na^{+})	25	27	3.4–110	36	510	420	2.1–1,100	20
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
Alkalinity (mg/L as $CaCO_3$)	54	39	9–150	20	—	—	—	—
			SH1				SH2	
Calcium (Ca^{+2})	10	14	1.8–66	19	5.2	2.3	1–9.1	13
Sodium (Na^{+})	18.8	25	1.2–110	44	15	57	1.7–340	35
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
Alkalinity (mg/L as $CaCO_3$)	27	16	8–60	22	29	9	15–55	23
			SG3				SG5	
Calcium (Ca^{+2})	5.6	0.7	4.6–6.3	6	5.5	1.5	3.6–7.5	6
Sodium (Na^{+})	4.6	1.5	1.9–7	8	4.2	1.2	1.5–6	9
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
Alkalinity (mg/L as $CaCO_3$)	29	3	25–34	6	26	8	16–38	8
			SC				Cane Creek	
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	.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

had the same pattern as the dissolved sodium, calcium, and chloride concentrations (table 11); station R2 had the highest specific-conductance levels, followed by R1, SH1, and SH2. Stations SH1, SG3, SG5, and SC had specific-conductance levels near the background levels at the Cane Creek station.

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

Nutrients

Summaries of nutrient statistics for the Sevenmile Creek stations and the Cane Creek station are shown in table 13. The few analyses of nitrogen and phosphorous concentrations do not show any clear effects of highway runoff on

Table 12. Chemical analysis of deicing agents used on I–85 near Efland

[mg/kg, milligrams per kilogram; ND, not detected; modified from Kobriger and others, 1982, v. 1, p. V–44–B]

Constituent	Deicing agents	
	NaCl (mg/kg)	[1]Sand:CaCl$_2$ mixture (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 ranged from 40:1 to 50:1.

the surrounding streams. Organic carbon analyses 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, obscuring the effects of highway runoff on nutrient concentrations.

Nitrogen

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

To aid in the comparisons among stations, Kjeldahl nitrogen was considered to be the total of organic nitrogen plus ammonia nitrogen (table 13). Therefore, organic nitrogen for the Sevenmile Creek stations can be calculated by subtracting ammonia nitrogen from Kjeldahl nitrogen. For Cane Creek, Kjeldahl nitrogen can be approximated by adding the ammonia nitrogen concentration to the organic nitrogen concentration. The measure of total nitrogen for the Sevenmile Creek stations can be obtained by adding Kjeldahl nitrogen to the nitrite-plus-nitrate nitrogen.

Table 13. Statistical summary of nutrients at stations R1, R2, SH1, SH2, SG3, SG5, and SC, July 1981 to July 1982, and at Cane Creek, October 1973 to October 1981

[mg/L, milligrams per liter; —, no data]

Nutrient (mg/L)	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
			R1				R2	
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, total	2.4	.75	1.5–3.0	4	4.6	4.8	1.2–8.0	2
Organic nitrogen (as N), total	[2]2.3	—	—	—	—	—	—	—
Ammonia nitrogen (as N), total	.15	—	—	1	—	—	—	—
Nitrate nitrogen (as N), total	—	—	—	—	—	—	—	—
NO$_2$+NO$_3$ nitrogen (as N), total	.12	.05	.08–0.18	3	.14	.15	.03–0.24	2
Phosphate (as PO$_4$), total	—	—	—	—	—	—	—	—
Orthophosphate (as PO$_4$), dissolved	.12	—	—	1	—	—	—	—
Phosphorus (as P), dissolved	.22	—	—	1	—	—	—	—
Phosphorus (as P), total	.17	.14	.02–26	5	.15	.01	.14–0.16	3
			SH1				SH2	
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, total	2.1	2.0	1.0–9.0	15	1.4	1.1	.2–4.4	11
Organic nitrogen (as N), total	[2]1.9	—	—	—	—	—	—	—
Ammonia nitrogen (as N), total	.25	.38	.02–1.3	9	.03	.02	.01–0.07	7
Nitrate nitrogen (as N), total	—	—	—	—	—	—	—	—
NO$_2$+NO$_3$ nitrogen (as N), total	1.4	1.7	.03–4.7	14	.23	.12	.03–0.40	1
Phosphate (as PO$_4$), total	—	—	—	—	—	—	—	—
Orthophosphate (as PO$_4$), dissolved	.19	.13	.02–0.45	8	.02	.004	.02–0.03	6
Phosphorus (as P), dissolved	.22	.17	.02–0.49	9	.03	.01	.02–0.04	7
Phosphorus (as P), total	.28	.27	.01–0.96	19	.05	.06	.02–0.17	13

Ammonia is a reduced form of nitrogen that, in streams, is readily oxidized to nitrite and then to nitrate by aerobic aquatic bacteria. Algae use ammonia 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 nitrogen is considered indicative of contamination by human or animal wastes or by fertilizers (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 has been diluted by increased flows. This pattern is seen in the decrease of mean nitrite-plus-nitrate concentrations as well. The highest basinwide levels of nitrite-plus-nitrate occurred at SH1, and a considerable reduction was recorded downstream at SG3 and even more at SH2.

Although R1 and R2 are upstream and SH1 is downstream from the wastewater-treatment plants, R1 and R2 had mean concentrations of all nitrogen species, except nitrite-plus-nitrate, equal to or greater than the nitrogen levels observed at SH1. These increased nitrogen levels were probably caused by deposition from vehicles and deposition of sewage mist entrained in the air by the treatment-plant aerators. The only statistically significant correlation ($r^2=0.88$) found between nitrogen and basin characteristics was between mean total ammonia concentration and road length, supporting the observation that the

Table 13. Statistical summary of nutrients at stations R1, R2, SH1, SH2, SG3, SG5, and SC, July 1981 to July 1982, and at Cane Creek, October 1973 to October 1981—Continued

Nutrient (mg/L)	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
		SG3				SG5		
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, total	.9	.17	.70–1	3	1.9	.54	1.0–2.1	6
Organic nitrogen (as N), total	[2]1.9	—	—	—	[2]1.3	—	—	—
Ammonia nitrogen (as N), total	.05	.06	.02–0.12	3	.03	.02	.01–0.05	4
Nitrate nitrogen (as N), total	—	—	—	—	—	—	—	—
NO_2+NO_3 nitrogen (as N), total	.36	.25	.10–0.60	3	.19	.13	.01–0.32	6
Phosphate (as PO_4), total	—	—	—	—	—	—	—	—
Orthophosphate (as PO_4), dissolved	.02	—	—	3	.02	—	—	3
Phosphorus (as P), dissolved	—	—	—	—	.02	.01	.01–0.02	3
Phosphorus (as P), total	.02	.01	.02–0.03	3	.02	.01	.01–0.02	6
		SC				Cane Creek		
Organic carbon, dissolved	—	—	—	—	14	2.7	12–17	3
Organic carbon, 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, total	1.3	.40	.90–2.0	12	[3].69	—	—	—
Organic nitrogen (as N), dissolved	—	—	—	—	.38	.25	0–0.83	23
Organic nitrogen (as N), total	[2]1.2	—	—	—	.68	.53	.08–2.7	28
Ammonia nitrogen (as N), dissolved	—	—	—	—	.01	—	—	4
Ammonia nitrogen (as N), total	.05	.05	.01–0.17	8	.01	—	—	1
Nitrate nitrogen (as N), total	—	—	—	—	.06	.06	0–0.22	29
NO_2+NO_3 nitrogen (as N), dissolved	—	—	—	—	.07	.06	.01–0.21	28
NO_2+NO_3 nitrogen (as N), total	.07	.09	.01–0.35	12	.07	.07	.01–0.24	30
Phosphate (as PO_4), total	—	—	—	—	.03	.05	0–0.12	19
Orthophosphate (as PO_4), dissolved	—	—	—	—	.02	.04	0–0.21	26
Phosphorus (as P), dissolved	—	—	—	—	.01	—	—	1
Phosphorus (as P), total	.06	.07	.01–0.24	12	.01	—	—	1

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

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

[3] Calculated value: Ammonia nitrogen plus organic nitrogen.

road does indeed have an impact on nitrogen concentrations.

Some nutrient data were collected for stations SH1 and SH2 during the September 5, 1981, rainstorm. As observed earlier in suspended-sediment concentrations (figs. 12 and 13), the data from these stations indicate that total nutrient concentrations (table 13) show a pattern of rapid increase in concentration with the initial runoff flush of rainfall. The nutrient concentrations peak just before the maximum stream discharge and decline in concentration during the recession. Because nutrients can attach to sediment, total nutrient concentrations may vary similarly to the sediment concentrations in response to changing streamflow, and dissolved nutrient concentrations may be diluted by floodflows. 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 of total and dissolved nitrogen concentrations to changing streamflow at Cane Creek is shown in figure 14. The peak in total nitrogen concentrations probably was caused by the flushing of nutrient-rich material, which builds up during low flow, from the streambed. The source of this nutrient-rich material probably was the rest-stop wastewater-treatment plants. The peak in dissolved nitrogen concentrations may be related to the atmospheric contribution of nitrogen during rainfall (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, is thought to be sufficient for high algal productivity (Crawford, 1983).

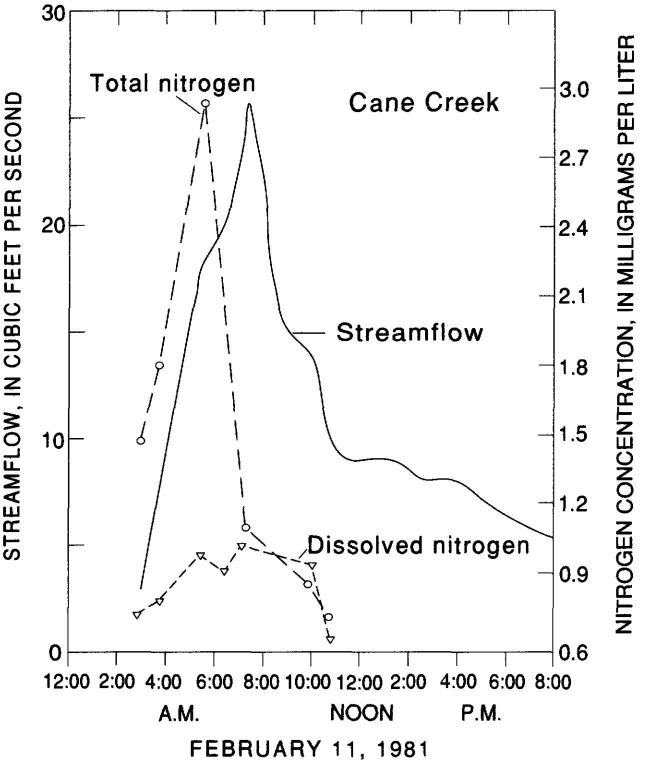


Figure 14. Hydrograph and dissolved- and total-nitrogen concentrations for the storm of February 11, 1981, at Cane Creek.

Phosphorus

A comparison of mean total phosphate (as PO_4), dissolved orthophosphate, and total phosphorus among stations shows a concentration pattern similar to that found for nitrogen. Stations R1 and R2, which are close to the highway, and station SH1, which is located just downstream from the rest-stop sewage-treatment plants, had relatively high concentrations of phosphorus 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, having means almost twice as great as at stations R1 and R2, and at least six times as great as at 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 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 considered to be great 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

Statistical summaries for trace elements and oil and grease concentrations in highway runoff at the study stations are given in table 14. Trace-element analysis for the Sevenmile Creek stations included total cadmium, chromium, copper, iron, lead, nickel, and zinc. Cane Creek samples were analyzed for these elements and for arsenic, cobalt, manganese, mercury, and selenium. Oil and grease concentrations were not determined for station R2 or Cane Creek. Samples taken at R1, SC, and SH2 during one storm event were analyzed for a suite of synthetic organic substances.

Trace Elements

As discussed in the Highway Sources section, data indicate that the highway system is a source of metals contamination to the surrounding air and soil. 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 levels to 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, do the data show substantial metals contamination of the streams that drain the highway?

The answer to this question is a qualified yes. In a comparison of the mean values shown in table 14, chromium, copper, and zinc showed patterns of greater concentrations in stations R1, R2, and SH1, which were affected by the highway, than in the rural and background stations SG5, SC, and Cane Creek. Surprisingly, no patterns were apparent in the cadmium and lead concentrations. Although highway runoff commonly affects lead concentrations (Kobriger and others, 1982), only a slight increase above background concentration was noted at the stations affected by the highway. In addition, although stations R2, SH1, and SH2 showed higher concentrations of nickel than stations SG5 and SC, station R1 showed a seemingly anomalously low nickel concentration. The concentration of chromium at Cane Creek also seems anomalously high compared to the other station data. The relatively high concentration of chromium may be attributed to the difference in laboratory procedures used by the USGS, which analyzed the Cane Creek data, and REXNORD, which analyzed the Sevenmile Creek data.

Water-quality criteria established by the U.S. Environmental Protection Agency (1980) can be used to compare the observed concentrations of metals to levels recommended for water supply and protection of aquatic life. Two sets of maximum contaminant levels generally are given; the first establishes levels suitable for the protection of freshwater aquatic life, and the second establishes 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. A sliding scale of criteria values is used because toxicity to aquatic life of metals and other constituents is greater if water hardness is lower. Unfortunately, hardness was not measured at any of the Sevenmile Creek stations. The hardness measured at Cane Creek (table 11) averaged 15 mg/L (as $CaCO_3$) and had a standard deviation of 5.1 and a range of 9 to 30 mg/L (31 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 15. The percentages of samples containing metals concentrations that exceeded the recommended criteria levels for drinking water are given in table 16. Many of the metals concentrations at all the stations exceeded criteria levels for protection of aquatic life; only nickel did not exceed the criteria levels at any station. Few metals 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 were higher than the criteria recommended for the protection of aquatic life. Although the percentages of sample concentrations that exceed criteria levels tended to be high in several samples from stations R1, R2, and SH1, the stations affected by the highway, distinguishing these percentages from the percentages that exceeded criteria at the other stations is difficult. Not surprisingly, no statistically significant correlations were found between mean metals concentration and basin characteristics. Finally, the use of the Piedmont streams hardness values in this analysis yields more moderate criteria than those that would be calculated by using the Cane Creek hardness value.

Oil and Grease

Mean-total oil and grease concentrations for the Sevenmile Creek stations are listed in table 14. 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 rural stations. Station SH1 also had somewhat increased concentrations in comparison to those at the 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 17). Two discrete samples from station R1 were examined: one sample was collected 3 h before the peak in streamflow, and one was collected 4 h 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. An herbicide-2,4-D concentration of 19 μg/L was measured in the postpeak sample at station R1; the composited sample had a concentration of 3.8 μg/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).

Soil-Water Quality

Samples from the four lysimeters (A, B, C, and D) shown in figure 5 were collected after about 25 storm events monitored at station R2. Lysimeters provide a gross estimate of the quality of the water as it drains through the first 6 in of topsoil. A summary of the results of chemical analyses of the water that had moved through the soil zone is given in table 18.

Only lysimeter C, on the northbound right-of-way 6 ft 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 lysimeters A and B in the median area were inundated during storms because of runoff in the median and splashing from passing vehicles. Although splashing was also a minor problem at lysimeter C, the lysimeter was inundated only a few times.

Virtually all of the chemical-constituent concentrations were 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, these results do not show whether the water sampled was a representation of soil-water quality or a worst-case representation of surface runoff.

Table 14. Statistical summary of trace elements and oil and grease concentrations at stations R1, R2, SH1, SH2, SG3, SG5, and SC, July 1981 to July 1982, and at Cane Creek, October 1973 to October 1981

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

Constituent	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
			R1				R2	
Cadmium (μg/L), total	1.6	1.3	0.5–4.0	7	2.4	2.3	0.5–7.0	7
Chromium (μg/L), total	5.7	6.2	2.0–19	7	7.3	14	1.0–30	7
Copper (μg/L), total	39	22	7.0–69	7	38	12	23–56	6
Iron (μg/L), total	2,300	2,100	760–6,700	7	—	—	—	—
Lead (μg/L), total	18	10	5.0–30	7	11	14	.5–50	15
Nickel (μg/L), total	6	6	1–18	7	13	10	3–30	7
Zinc (μg/L), total	100	120	20–360	7	80	40	40–150	15
Oil and grease (mg/L), total	14	17.4	2–53	8	—	—	—	—
			SH1				SH2	
Cadmium (μg/L), total	1.5	1.5	0.5–6.0	22	2.3	2.6	0.5–12	18
Chromium (μg/L), total	5.3	5.3	.5–19	22	3.3	2.8	.5–9.0	18
Copper (μg/L), total	54	67	15–340	22	39	21	8.0–83	18
Iron (μg/L), total	—	—	—	—	2,300	2,600	400–9,200	22
Lead (μg/L), total	18	19	2.5–80	23	9.8	8.7	2.5–30	21
Nickel (μg/L), total	12	13	3–65	22	11	9	3–30	18
Zinc (μg/L), 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
			SG3				SG5	
Cadmium (μg/L), total	1.5	0.87	0.5–2.0	3	2.3	1.6	0.5–4.0	6
Chromium (μg/L), total	2.5	2.3	.5–5.0	3	1.5	1.3	.5–1.0	6
Copper (μg/L), total	29	1.5	22–25	3	27	16	8.0–56	6
Iron (μg/L), total	1,100	280	550–1,400	3	1,000	85	460–2,900	7
Lead (μg/L), total	35	26	5–50	3	19	19	5–50	7
Nickel (μg/L), total	8	7	3–16	3	8	5	3–15	6
Zinc (μg/L), 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 14. Statistical summary of trace elements and oil and grease concentrations at stations R1, R2, SH1, SH2, SG3, SG5, and SC, July 1981 to July 1982, and at Cane Creek, October 1973 to October 1981—Continued

Constituent	Mean	Standard deviation	Range	Number of samples	Mean	Standard deviation	Range	Number of samples
	SC				Cane Creek			
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	0–0.1	11
total	—	—	—	—	.3	.2	.1–0.5	6
Nickel (μg/L), 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	—	—	—	—

Table 15. Percentage of samples from each station having concentrations that exceeded recommended criteria levels for the protection of aquatic life

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

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 16. Percentage of samples from each station having 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.

CONSTITUENT LOADS

Mass Balance for Constituent Sources

A mass balance, including the major sources of material accumulated on the highway surface and the principal 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 illustrated in figure 15.

The mass balance was derived by using a series of approximations in a modeling process (Kobriger and others, 1982) that did not take full consideration of the possible errors and uncertainty involved. Three components were examined: material deposition, highway-surface load, and material removal. Mean daily rates of deposition were determined from loads calculated from surface-water runoff data and atmospheric deposition data. The deposition rate was the mean daily rate of deposition for the 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. The deposition 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-bucket and wet-dry collector data. The highway-surface load was determined by considering measurements of the amount of

Table 17. List of trace synthetic organic substances tested and their detection limits

[All values are reported in micrograms per liter]

Constituent	Detection limit
PCB	0.5
Alpha-BHC	.01
Gamma-BHC (Lindane)	.01
Beta-BHC	.01
Delta-BHC	.01
Heptachlor	.01
Aldrin	.01
Heptachlor epoxide	.01
p,p-DDE	.05
o,p-DDD	.05
o,p-DDT	.05
p,p-DDD	.05
p,p-DDT	.05
Dieldrin	.05
Endrin	.05
Hexachlorobenzene	.01
2,4-D	2.0
2,4,5-T	.5
Silvex	.5

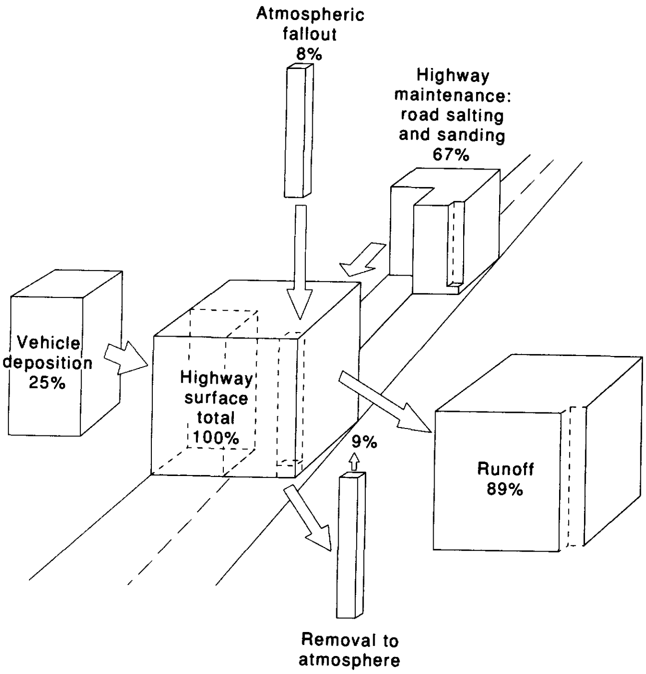


Figure 15. Mass balance of total dissolved-solids load at station R2 for the period of June 30, 1981, through April 2, 1982 (Kobriger and others, 1982). (Load unaccounted for is model error.)

material found on the road surface and data from road salting and sanding. Vehicular deposition was calculated as the difference between the highway surface load and the salting-sanding and atmospheric load.

As in the analysis of lysimeter results, some of the material load probably moved into the ground-water system. However, no accounting for removal through the ground-water system was made in this analysis.

The resultant mass balance, as shown in figure 15, emphasizes the relative impact of road salting and sanding and vehicle deposition as sources of material available on the highway surface for washoff into streams. Road maintenance accounted for 67 percent of the material that was washed into nearby streams during the period studied (Kobriger and others, 1982). The remaining material came mainly from deposition of particles from vehicles.

Constituent Loads in Streams

Daily loads of dissolved solids and a suite of metals were computed by first defining linear relations (regression equations) between instantaneous discharge and constituent load and then by using the known daily discharges. Regression equations having slopes statistically different from zero ($pr = 0.05$) were used to estimate the loads. The estimated annual loads are listed in table 19, and the annual loads per

Table 18. 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	Mean 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	.15–0.85	.73	.18–1.8
Phosphorus as PO_4 (mg/L)	1.1	.06–2.7	.20*	ND–0.61	.27	.06–0.69	.37	.26–0.46
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

Table 19. Annual subbasin loads, in tons

[—, no data]

Constituent	Highway stations			Sevenmile Creek	Rural station
	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

square mile are shown in table 20. The dissolved-solids loads for stations R1, R2, SH1, and SH2, listed in table 20, are shown in figure 16, which shows 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 were insufficient to test this relation statistically. The total-metals loads listed in table 20 are shown in figure 17.

An examination of loads verifies the results of the constituent-concentration comparisons among 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 19). 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.

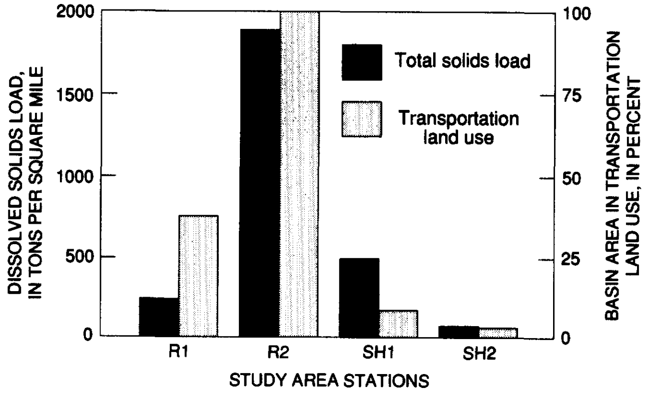


Figure 16. Annual dissolved-solids loads for the study stations and the percentage of basin area in the transportation land-use category.

SUMMARY

An evaluation of the water quality of streams that receive stormwater runoff from a segment of Interstate Highway 85 indicated increased levels of many constituents when compared to nearby undeveloped basins. The study area included eight sampling stations: R1 and R2 were near the highway; SC and SG5 received no runoff from the highway but represented rural land uses; Cane Creek drained an undeveloped, almost completely forested basin; SH1 was located downstream from R2 and included a highway rest-stop area and minor residential and urban land uses; SG3 was located downstream from R2, SH1, and SC; and SH2 was located downstream from SG3 and R1. The basins had a combined drainage area of 17.5 mi^2 and drained a 4.8-mi-long segment of I–85. The asphalt highway consisted of two northbound and two southbound lanes and, on each side of the road, entry and exit lanes for highway rest-stop areas. 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, rain gages were located at sites SH1, SH2, and SC, wet-dry atmospheric-deposition collectors were located near sites R2 and SC, and a weather station having a recording anemometer and thermometer was located at site SH1. The particulate 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 the quality of water in the soil. Road surface material, obtained from soil samples and highway sweepings, also was 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

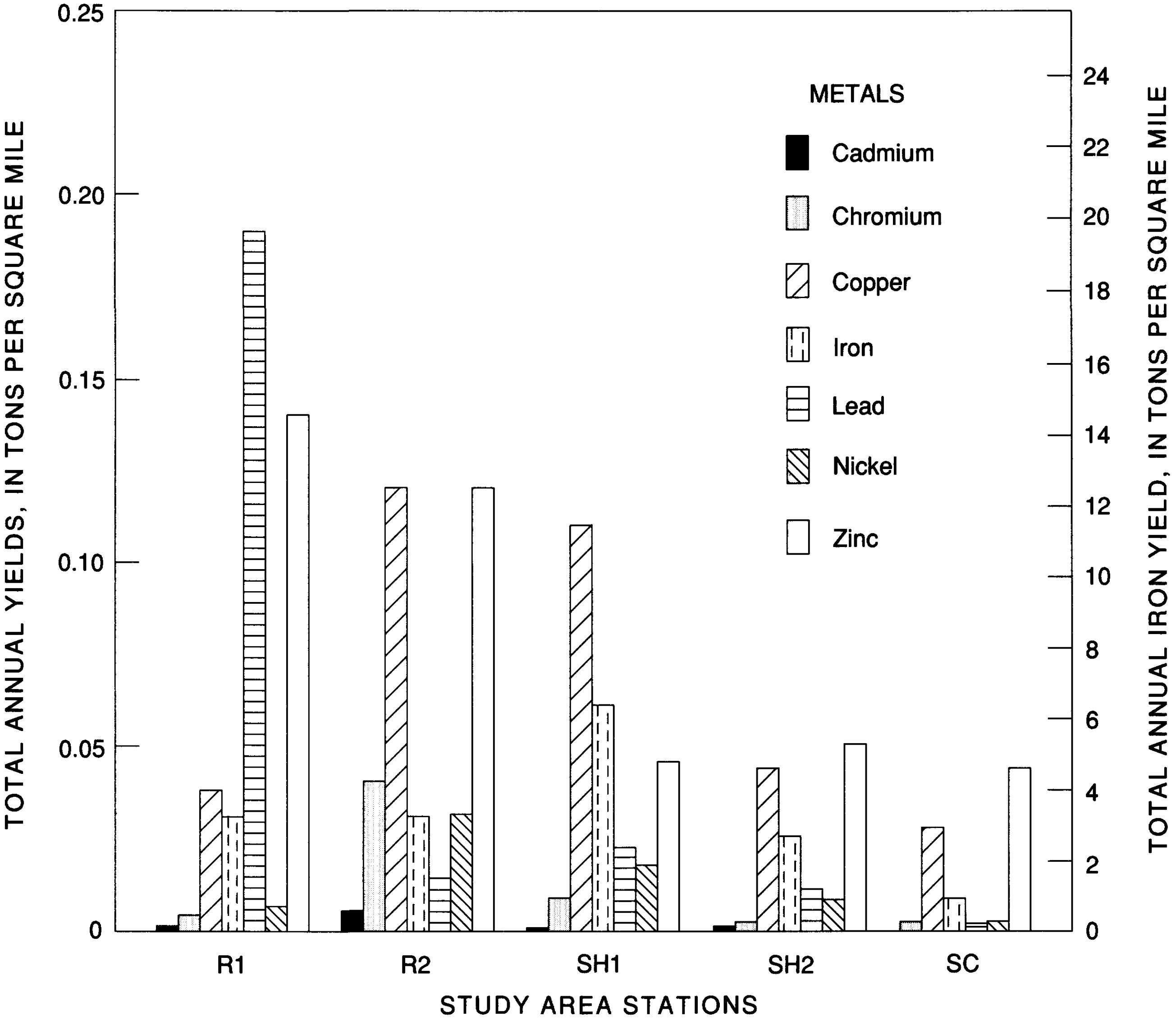


Figure 17. Total annual metals loads for the study stations.

Table 20. Annual subbasin loads, in tons per square mile

[—, no data]

Constituent	Highway stations			Sevenmile Creek	Rural station
	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

and Cane Creek). This rapid runoff response results from the impervious nature of the highway and the manmade drainage system that was designed to move water quickly off the highway. Station R2, which gaged the discharge from an area that is approximately one-half paved, had the highest discharge per square mile (2.78 $(\mathrm{ft}^3/\mathrm{s})/\mathrm{mi}^2$), and Cane Creek, a forested basin, showed the lowest discharge per square mile (0.45 $(\mathrm{ft}^3/\mathrm{s})/\mathrm{mi}^2$).

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

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

Increased metals concentrations, as much as 10 times greater than background levels, were found in the soils near the highway at station R2 and in the water that infiltrates the soil zone. Chromium, copper, nickel, and zinc concentrations observed at the stations that were affected by the highway (R1, R2, and SH1) generally were 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 the maximum recommended levels for the protection of aquatic life, and lead and cadmium concentrations frequently exceeded the maximum 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 those of stations SH2, SG3, SG5, and SC. The effects of highway runoff on suspended sediment, water temperature, dissolved oxygen, and pH could not be determined. However, pH declined during stormflow at all stations because rainfall having 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 nitrite-plus-nitrate, 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, located approximately one-half mile from the highway, suggests that dust from the highway can be carried considerable distances. However, the constituent levels observed in dustfall and in soil samples generally decreased exponentially with increased distance from the highway. Dust constituent loads and constituent concentrations in the soil were greater on the downwind side of the highway. Material loading from dustfall was greater than loading from wet precipitation. Saltated particle loads were higher than loads from other particle deposition probably because of the greater size of saltated particles. Saltation loads were highest during the winter months because of highway salting and sanding. About two-thirds of the materials washed off into the surrounding areas were from highway deicing and sanding. The remaining one-third of material came mainly from deposition of particles from vehicles.

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