EFFECTS OF LAND USE ON THE WATER QUALITY AND BIOTA OF THREE STREAMS IN THE PIEDMONT PROVINCE OF NORTH CAROLINA

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METRIC CONVERSION FACTORS

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

Multiply inch-pound unit	by	To obtain SI unit
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
	0.4047	hectare (ha)
	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
	0.003785	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
	0.02832	cubic meter per second (m^3/s)
	Temperature	
degree Fahrenheit (°F)	5/9 (°F-32)	degree Celsius (°C)
	Mass	
ton (short, 2,000 pounds)	0.9072	megagram (Mg), or metric ton (t)
pound (lb)	453.59	gram (g)
ounce avoirdupois (oz)	28.35	gram (g)
	Mass per unit area	
ton per acre	36.7144	kilogram per hectare

Sea level: In this report, "sea level" refers to the 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 LAND USE ON WATER QUALITY AND BIOTA OF THREE STREAMS IN THE PIEDMONT PROVINCE OF NORTH CAROLINA

By J. Kent Crawford[1] and David R. Lenat[2]

ABSTRACT

Three streams in North Carolina's northern Piedmont, each having drainage areas of less than 10 square miles, were studied to compare the effects of dominant land use in their watersheds on water-quality characteristics and aquatic biota. The Smith Creek watershed was 75 percent forested, the Devil's Cradle Creek watershed was 53 percent agricultural, and the Marsh Creek watershed was 69 percent urban.

The most striking difference in water quality in the three streams was annual suspended-sediment yield. Devil's Cradle Creek had more than two times the sediment yield of Smith Creek (0.34 tons per acre versus 0.13 tons per acre), and Marsh Creek had more than four times the yield of Smith Creek (0.59 tons per acre). Concentrations of nutrients were consistently higher in Devil's Cradle Creek than in the other two streams. Concentrations of total copper, iron, and lead in samples from each of the three streams at times exceeded State water-quality standards as did concentrations of total zinc in samples from both Smith and Marsh Creeks.

Statistical analyses of aquatic invertebrate collections showed successively lower taxa richness in the streams draining forested, agricultural, and urban watersheds. Shifts in the invertebrate community structure were also noted. Smith Creek was dominated by invertebrates intolerant to stress from pollution, the Ephemeroptera, whereas Devil's Cradle Creek was dominated by the more tolerant Diptera, and Marsh Creek was dominated by the most pollution-tolerant group, the Oligochaeta. Fish communities in the streams draining forested and agricultural watersheds were healthy, whereas there was a limited community in urban Marsh Creek. Healthy aquatic invertebrate communities existed in the stream draining the forested watershed, even though North Carolina water-quality standards for the protection of aquatic life were, at times, exceeded.

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[1] U.S. Geological Survey

[2] The North Carolina Department of Natural Resources and Community Development

INTRODUCTION

In 1984, the U.S. Geological Survey (Survey), in cooperation with the North Carolina Department of Natural Resources and Community Development (NRCD), began an investigation of biological communities (focusing on aquatic invertebrates) in North Carolina Piedmont streams to relate any observed biotic differences to water-quality differences that may have resulted from land-use activities. The Piedmont setting is particularly important because it is the most populated section of the State and is undergoing rapid urbanization. The urbanization brings industrial development, new construction, an increase in impervious area, more automobiles, and higher use of household and lawn and garden chemicals with an accompanying potential for water-quality impairment, as compared to nonurbanized areas. Agriculture also is important in the Piedmont with approximately 30 percent of the land area devoted to cropland and pasture (Ospina and Danielson, 1973). Increased concentrations of pesticides, nutrients, and sediment in receiving waters are associated with agricultural land use.

Purpose and Scope

This report describes the results of the study to define the effects of land use on water quality and aquatic biota in streams of the North Carolina Piedmont. The study spanned a 2-year sampling period from January 1984 through February 1986.

The study involved three watersheds in the northeastern Piedmont province of North Carolina. Each was chosen to be in similar physiographic settings with drainage areas smaller than 10 square miles (mi^2). However, each watershed had a different land-use pattern. One watershed, Smith Creek, was dominated by forested land and was selected to serve as a reference for comparison or as a "control" watershed. The second watershed, Devil's Cradle Creek, was dominated by agricultural land, and the third watershed, Marsh Creek, was dominated by urban land. The three watersheds are within 35 miles of each other (fig. 1).

Sampling for selected water-quality constituents in these streams, suspended-sediment concentrations, chemical quality of interstitial water from stream-bottom sediments, bottom-material particle size and chemistry,

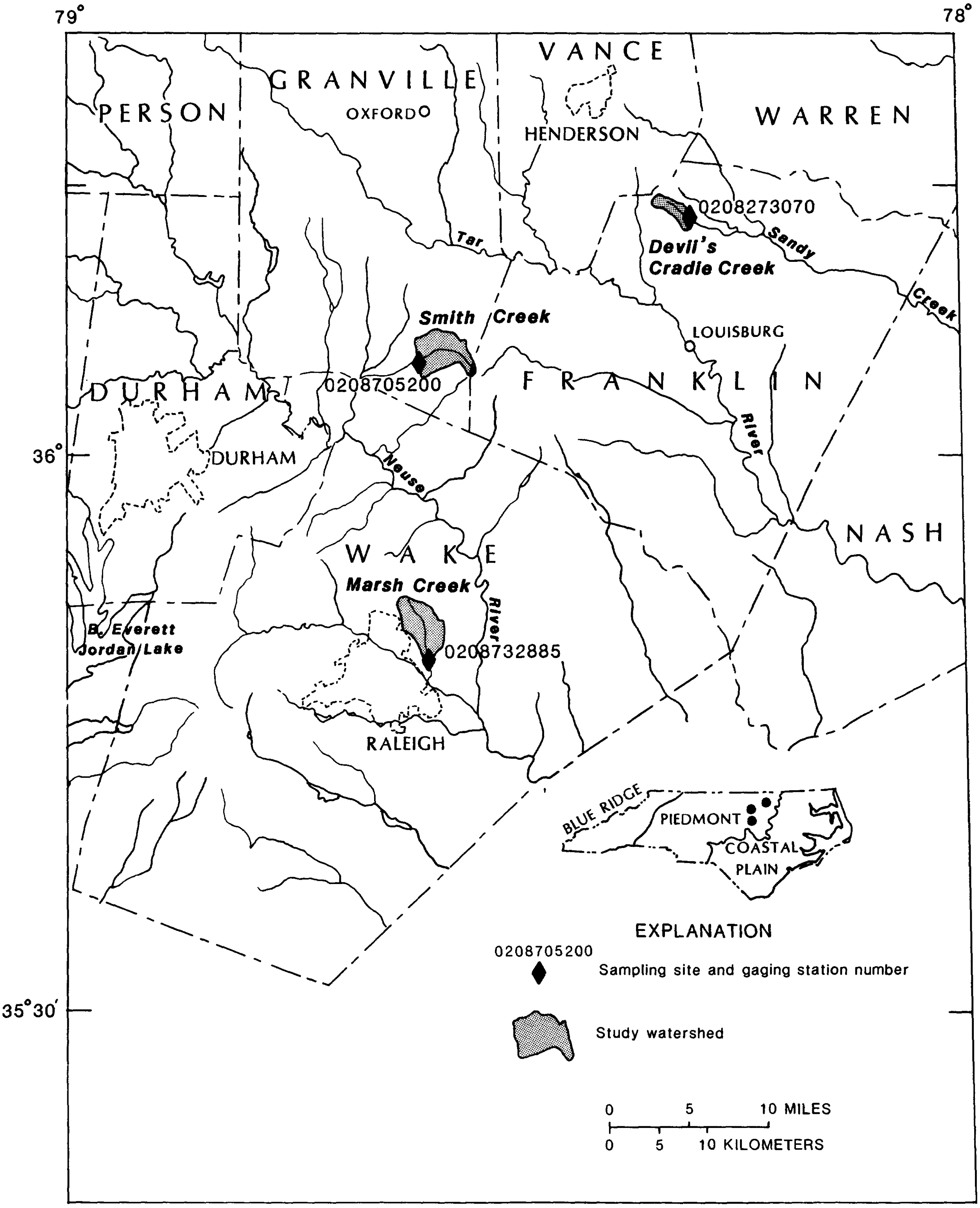

Figure 1.--Location of study watersheds.

macroinvertebrate communities, and fish populations at each site was scheduled for a 1-year period. During January and February of 1984, stream-gaging stations were installed at each site for continuous monitoring of stream discharge. Water-quality sampling began in February 1984. Most of the needed data were on hand at the end of the 1-year sampling period, but interstitial water sampling, bottom-material sampling, and high-flow suspended-sediment sampling could not be completed until the fall of 1985. The final sampling of fish populations at the three sites was conducted in February 1986.

For this study, NRCD collected all the biological data and the Survey collected the data on water quality, sediments, interstitial water, and stream discharge. Biological laboratory work was handled by NRCD; the Survey conducted laboratory chemical analyses.

Previous Investigations

As land use in Piedmont watersheds changes from a pristine, forested setting to agricultural and urban uses, stream-water quality and the biological community of the streams change. Various researchers have examined relations between land use and stream-water quality. Previous investigations summarized in the paragraphs that follow will consider, in turn, studies dealing with sediment, those dealing with agricultural effects, and those focusing on urban effects. None of the studies to date have integrated land use, water quality, and biota in a detailed examination of the relations between these three components.

Sediment has received most of the attention given to studies of water-quality changes resulting from land use changes. Many studies have shown that land use is a major determinant of stream sediment. For example, the Soil Conservation Service (U.S. Department of Agriculture, 1977) has shown that erosion in North Carolina is strongly influenced by land use, with the highest erosion rates being associated with construction activities. They found that erosion rates from highway construction sites were 300 times greater than those from forested land. Erosion rates from roadsides and general construction activities were more than 50 times greater than those from forested land; rates from cropland and general urban areas were, respectively, about 10 and 4 times greater than those from forested land. Pasture land had erosion rates slightly less than general urban areas.

Other investigators have related land use to the quantity of sediment delivered to streams. Simmons (1976, p. 18) estimated that "... about 30 to 40 percent of these eroded soils become waterborne sediment in streams." He showed that basins in the North Carolina Piedmont with a higher percentage of forest cover than other basins have lower annual suspended-sediment yields. Lietman and others (1983) showed that suspended-sediment concentrations during storms were higher in drainage from a cornfield than in drainage from a residential area or pasture land. Therefore, it has been established that land use is a major factor in determining sediment concentrations in streams.

Unstable sand deposits are not suitable substrate for most stream life. When sediment blankets the normal rocky substrate, diversity and productivity of benthic macroinvertebrates is reduced. Fish are also affected, especially through a reduction in suitable habitat for reproduction and survival (Karr, 1981).

The clay soils typical of the Piedmont are highly erodible. Once eroded, the fine clay-sized particles stay in suspension longer than larger sand particles. They also adsorb trace metals (Wilber and Hunter, 1979; Horowitz, 1985; Demas and Curwick, 1986) and organic compounds (Sartor and others, 1974; Feltz, 1980; Hites and Lopez-Avila, 1980) and can dominate the transport of these substances, some of which are potentially harmful.

Erosion control measures and best-management practices can reduce the amount of sediment reaching streams. Agricultural operations have been shown to be particularly amenable to erosion and sediment reduction. For example, Atkins (1984) reported dramatic reductions in mobilization and delivery of both coarse and fine suspended sediment at a farm site where best management practices were used compared to a nearby farm without best-management practices. Lenat (1984) found lower erosion rates and healthier macroinvertebrate communities in well managed versus poorly managed agricultural watersheds. Both of these studies included data from areas in the Piedmont of North Carolina.

The North Carolina Department of Natural Resources and Community Development has declared sediment and its effects on stream environments to be the most widespread water-quality problem in North Carolina (North Carolina Department of Natural Resources and Community Development, 1979).

However, our understanding of the chemical quality of sediments and the effects of sediment on water quality and aquatic biota needs to be strengthened.

Although sediment has been the most widely studied aspect of stream-water quality that is influenced by land use, it may not always be the most important. Land-use activities also can result in elevated concentrations of nutrients, metals, and organic compounds in receiving streams.

In comparison with streams in forested drainage areas, streams in agricultural settings typically have greater concentrations of nutrients, particulate organics, sediment, and toxic organic compounds (especially pesticides) (Loehr, 1974, 1979; Baker, 1983; Lenat, 1984). Streams in agricultural settings also may have higher temperatures than streams in forested settings due to reduced shading because of cleared areas and greater flow variability attributed to channelization and land drainage. Several investigators (Welch and others, 1977; Hirose and Kuramoto, 1981; Lenat, 1984) reported elevated specific-conductance levels associated with streams draining agricultural areas; this reflects high concentrations of dissolved chemicals in the streams.

In addition, croplands may be heavily fertilized, and excess nutrients (nitrogen and phosphorus) may be washed into nearby streams. A nationwide survey by Omernick (1977) indicated that concentrations of nitrogen and phosphorus in agricultural watersheds were almost an order of magnitude greater than those in forested watersheds. The combination of these increased nutrients with a reduced amount of shading commonly stimulates periphyton production (Schlosser and Karr, 1981; Cook and others, 1983).

There have been several studies of the effects of agricultural runoff on stream fauna. A review by Baker and Johnson (1983) found that the relationship between chemical concentrations in agricultural runoff and the health of the aquatic fauna in receiving streams is very poorly understood. Most studies indicate a reduction in the taxa richness of the most intolerant groups: Ephemeroptera, Plecoptera, and Trichoptera (Welch and others, 1977; McCafferty, 1978; Dance and Hynes, 1980; Cook and others, 1983; Lenat, 1984). Effects of agricultural runoff on other groups are more variable, but some studies indicate increases in either the taxa richness or abundance of Odonata (Dance and Hynes, 1980), Trichoptera (Brooks, 1983;

Freeman and Wallace, 1984), Coleoptera (Dance and Hynes, 1980; Brooks, 1983), and Diptera (Baker, 1983; Lenat, 1984; Cooper, 1987). Total density, or abundance, may either increase (Cook and others, 1983; Lenat, 1984) or decrease (Welch and others, 1977; Bratton and others, 1980). Most studies indicate that sediment is a major problem (Lenat, 1984; Cooper, 1987), but other studies suggest that chemical changes in water quality also may have affected stream biota (Welch and others, 1977; Cook and others, 1983; Lenat, 1984). No clear picture emerges from the existing literature about how agricultural land use will affect the fauna of a given stream.

Of particular concern to those studying the effects of agriculture on stream fauna is the concentration of pesticides. In at least two investigations (Heckman, 1982; Penrose and Lenat, 1982), pesticide runoff was believed to be a problem. However, these studies looked at runoff from orchards, where there were heavy applications of pesticides. In another pesticide runoff study, Wauchope (1978) indicated that pesticide losses are usually less than 1 percent of the amount applied, unless heavy rainfall occurs within 2 weeks of application. However, another survey of agricultural watersheds in southern Ontario, Canada, (Frank and others, 1982) indicated that pesticides entered stream water both from storm runoff and from carelessness. They found a number of pesticides in stream water, five of which were at levels exceeding water-quality criteria. Many of these pesticides had not been in use for several years, and their detection reflects the persistence of chlorinated hydrocarbon pesticides.

The chlorinated hydrocarbons are being replaced by a more biodegradable class of compounds, especially organophosphates. Ramande and others (1984) characterized these as "extremely noxious, but labile compounds." Such compounds have a great potential to affect stream life (especially aquatic insects), but are hard to detect chemically. Some research (Streit and Schwoerbel, 1976; Besch and others, 1977) indicates that sublethal effects may be observed at very low concentrations.

Many streams draining urban watersheds have been shown to contain a wide variety of contaminants (see review by Klein, 1985). For example, a survey of Ellerbe Creek (Durham, N.C.) indicated potential problems due to runoff from impervious surfaces (paved surfaces, roofs, and so forth), nutrient inputs (a fertilized golf course), erosion, a leaking toxic-waste dump, small sporadic point sources (gas stations, car washes, and so forth), sewer overflows, and a permitted discharge from a wastewater treatment plant (Edward A. Holland, Triangle J Council of Governments, oral commun., 1983). This mixture of problems is typical of most streams draining urban watersheds. A review of "priority pollutants" in storm-water runoff indicated a number of toxic materials, especially heavy metals, may enter streams draining urban watersheds (Cole and others, 1984).

Urban runoff may be directly toxic to stream invertebrates during storms (Medeiros and others, 1983). However, toxic conditions may also exist during periods of base flow. Pratt and others (1981) and Medeiros and others (1983) suggest that materials in the stream bed may affect stream life. Many studies have indicated that streams draining urban watersheds are characterized by high levels of sediment metals (Wilber and Hunter, 1979; Duda and others, 1982; Kelly and Hite, 1984).

Changes in the fauna of streams draining urban areas have been associated with both point-source and nonpoint-source inputs. The effects of nonpoint runoff from impervious surfaces can be more severe than the effects from point-source discharges. In localized studies, Klein (1979) concluded that the effects of urban runoff on biological communities in streams will be noticed when the percent of impervious surface exceeds 15 percent of the watershed; and Benke and others (1981) found changes in the benthos if the amount of developed land is greater than 30 percent of the watershed. The effects of nonpoint-source input from impervious and developed areas make any analysis of the effects of point-source discharges more difficult. Additionally, many small point-source discharges can have an effect similar to nonpoint discharges and complicate attempts to resolve the source of impairment of streams in urban areas (Duda and others, 1982).

Taxa richness, especially for Ephemeroptera, Plecoptera, Trichoptera, and Coleoptera, is drastically reduced in some streams draining urban watersheds relative to control sites (Benke and others, 1981; Cook and others, 1983). Diptera and Oligochaeta become dominant, with the most abundant Chironomidae usually belonging to the "toxic assemblage" described by Simpson and Bode (1980) and Winner and others (1980). These species are known to be tolerant of many heavy metals. Total abundance of invertebrates in streams also is reduced, except in some cases where sewer overflows and (or) cross connections between storm sewers and sanitary sewers exist. This situation may produce a classic organic pollution assemblage, with low taxa richness and high abundance of a few species (Duda and others, 1982). Such buildups of organic indicator species, such as tubificid worms or Chironomidae, are highly unstable and may be washed out by storms. Studies of the fauna of streams draining urban areas of large North Carolina cities have consistently found low organism densities, low taxa richness, low diversity, and low biotic index values (Lenat and others, 1979; Penrose and others, 1980; Lenat and Eagleson, 1981).

Studies of urban runoff in small towns, or in lightly developed watersheds, have indicated less severe pollution than in large cities. In towns with a population of less than 20,000, Lenat and others (1981) found that sediment impacts were of greater significance than toxic or organic problems. Similarly, Benke and others (1981) found that in watersheds with housing densities of 100-500 houses per mi^2, streams had higher invertebrate taxa richness than streams in watersheds with a housing density of greater than 500 houses per mi^2.

Acknowledgments

The authors express their appreciation to their many colleagues in the Survey and NRCD who assisted in the data collection and analysis and the preparation of this report. Frank McBride and his staff from the North Carolina Division of Inland Fisheries assisted in fish collections to support the study. Vince Schneider of the Division of Environmental Management (DEM), NRCD, did the fish identifications.

METHODS OF INVESTIGATION

In this section, methods will be presented that cover the rationale for selection of the study watersheds, suspended-sediment sampling and analysis, bottom-material sampling and analysis, water-column sampling and analysis, interstitial water sampling and analysis, aquatic invertebrate collection methods, and fish collection and preservation. Two different invertebrate collection techniques were used concurrently and methodology for both is presented.

Watershed Selection

At the outset of the study, a search was made to select watersheds of less than 10 mi^2 and no permitted point-source discharges in the Piedmont where land use was dominated by one of the three different types: forested, agricultural, and urban. Selection of watersheds having appropriate land uses and verification of the land use in each watershed was made by using a 4-step process involving map reconnaissance, field reconnaissance, aerial photography, and digitized data. U.S. Geological Survey topographic maps were used to identify potential study sites and then field reconnaissance was used to verify existing conditions. Smith Creek in southern Granville County was selected as the forested watershed, Devil's Cradle Creek in northern Franklin County as the agricultural watershed, and Marsh Creek in central Wake County as the urban watershed (fig. 1). Smith Creek is a second-order stream with a drainage area of 6.23 mi^2; Devil's Cradle Creek is a second-order stream with a drainage area of 2.89 mi^2; and Marsh Creek is a third-order stream with a drainage area of 6.84 mi^2.

Further verification of the land use within each watershed was taken from U.S. Department of Agriculture aerial photographs. Basin boundaries were outlined on aerial photos and land-use types within each basin were planimetered and the areas summed. A second calculation of land use was used for the Smith Creek watershed where the U.S. Soil Conservation Service has mapped agricultural land-use types, and the information has been digitized by the NRCD's Land Resources Information Service. Watershed boundaries were digitized at the same scale as the land-use data and a computer overlay technique used to calculate the areas of various land-use types within each watershed. The Survey's land use and land cover maps were also examined in an attempt for quantitative verification of the land use within each watershed. However, the watersheds in question are so small in comparison to the 1:250,000 scale of the land-use maps that useful quantitative data could not be obtained.

Suspended Sediment

Suspended-sediment samples were collected manually and with automated sampling equipment. Manual samples were collected using either a hand-held depth-integrating US DH-48TM sampler or a hand-held, depth-integrating US DH-59TM sampler. Both of these suspended-sediment samplers use a 1-pint glass bottle as the sample container. Manual suspended-sediment samples were collected at multiple vertical sampling points across the stream using the equal-width increment method with equal transit rates (Guy and Norman, 1970; International Hydrological Program, 1977) or by depth integrating at the centroid of flow or by depth integrating at quarter points in the stream. Automated samples for suspended-sediment analyses were collected from a fixed intake point using an Instrumentation Specialties Company (ISCO)[3] model 1680 automated water sampler equipped with an ISCO model 1640 liquid level sample actuator.

The filtration method (Guy, 1969; International Hydrological Program, 1977) was used to determine suspended-sediment concentrations. Regression equations between concentrations from manual and automated samples were developed for each stream, and concentrations from the automated, single point samples were adjusted to correspond with the concentration expected from a manual, depth-integrated sample.

Bottom Material

Samples of bottom material for particle-size analysis and chemical analyses were collected in October 1985. A sampling device was fashioned by cutting the bottom from an acid-rinsed 250-ml polyethylene bottle (approximate inside diameter, 1.75 inches). Samples were collected by gently working the sampling device into the stream bed to a depth of approximately 2 inches (in.). Once the sampler had been inserted into the stream bed, a small hole was scooped out in the sediments adjacent to the sampler and an acid-rinsed watch glass was inserted under the bottom of the sampler with the 2-inch core of bottom material trapped inside. The sampler was then removed along with the 2-inch sample core of bottom material. Bed material sampling sites for each stream were selected by drawing three numbers between zero and 99 from a random number table (Steel and Torrie, 1980) and using these three numbers as sampling distances (in meters) downstream from the gaging station. At the distances indicated by the random numbers, five samples were taken at equal intervals along a tag line stretched across the stream for a total of 15 samples per stream.

For chemical analyses, the sample bed material from 15 sites per stream was sieved through a 2-millimeter mesh size nalgene sieve and composited in an acid-rinsed nalgene pan. Material larger than 2 millimeters (mm) in

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[3] Use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey or the North Carolina Department of Natural Resources and Community Development.

diameter was discarded. Subsamples were taken from the composite by gently working the barrel of a 20-cubic-centimeter (cc) disposable sterile syringe into the pan of composited and mixed sample bed material. As the barrel of the syringe was worked into the bottom material, the plunger was slowly withdrawn to create a partial vacuum that helped hold the subsample in the barrel of the syringe. Subsamples were composited and then separated into two size fractions by passing the sample through 0.063-millimeter screen. Only native water was used to rinse the sample during the screening process. Thus, two samples of sediment were obtained from each stream for chemical analysis, one containing material between 0.063 mm and 2 mm (the sand fraction) and one containing material less than 0.063 mm in diameter (the silt/clay fraction). Samples were sent to the Survey's central laboratory in Doraville, Georgia, for chemical analysis.

Cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc were analyzed in bottom material samples. Prior to analysis, each sample was subjected to a strong oxidizing agent (hydrogen peroxide) to destroy any organic matter present, followed by digestion in hot, dilute (approximately 0.3 Molar) hydrochloric acid (Malo, 1977; Skougstad and others, 1979). The digestion releases sorbed metals but does not break down the mineral components of the sediment. Analysis for individual metals was done by direct atomic absorption spectrometry (Skougstad and others, 1979).

For particle-size analysis, samples within each transect were composited, but samples from the various transects were kept separate. Thus, there were three samples for particle size from each of the three sampling sites.

Particle-size analysis of bottom material was done in the Survey sediment laboratory, Raleigh, N.C., by splitting the sample into subsamples of 50 to 100 grams (g) each using a laboratory sample splitter. Subsamples were then dried overnight at 110 degrees Celsius (^{o}C) and passed through a series of U.S. standard sieves, ranging in mesh size from 2 mm to 0.063 mm. A portable sieve shaker was used to speed the sieving process. Individual sieved samples were weighed on an analytical balance and percent composition for each particle-size class was determined.

Water Chemistry

Stream water was sampled for chemical analysis approximately monthly for a 1-year period from February 1984 through January 1985. An additional water-quality sample from Smith Creek was collected in November 1985 at the time when high-flow sampling for suspended sediment was completed. Samples were collected over a wide range of flow conditions using depth-integrating methods at the centroid of flow. Analyses focused on nutrients and trace elements. Table 1 presents the constituents analyzed during the study, the methods used for analysis, and the detection limit for each constituent.

Several quality-assurance checks were included in the study. Field results for pH and specific conductance were checked by comparing field measurements against laboratory measurements of these two properties. Also, total and dissolved fractions for the various constituents were compared; total concentrations should always be equal to or greater than dissolved concentrations. The one exception to this generalization is chromium. The method used for total chromium is more sensitive than the method for dissolved chromium. Therefore, when concentrations for this element are near the detection limit, reported concentrations may be greater for the dissolved fraction than for the total fraction.

All the water-quality data collected for this study have been placed in the Survey's computerized national data bank called WATSTORE, and the data are published in the annual data report for the North Carolina District of the U.S. Geological Survey (U.S. Geological Survey Water Resources Data for North Carolina, Water Year 1986).

Interstitial Water

Samples of interstitial water from stream-bottom sediments were collected once during the study at each of the three stations. A diffusion-controlled sampler (Simon and others, 1985) was used to sample from 6 depths--2 in. and 0.4 in. above the sediment-water interface and 0.4 in., 1.2 in., 2 in., and 4 in. below the sediment-water interface. Samples were analyzed for the nutrients ammonia-nitrogen, nitrite- plus nitrate-nitrogen, and orthophosphate-phosphorus. Interstitial water samples taken for metals analyses were accidently discarded in the laboratory prior to conducting the analyses; and, therefore, no metals data are available for interstitial water.

Table 1.--*Chemical analyses performed on stream samples during this study*
[mg/L, milligrams per liter; µg/L, micrograms per liter;
µS/cm, microsiemens per centimeter]

Constituent	Laboratory method	Detection limit	Reference
	Nutrients		
Dissolved nitrite and nitrate-nitrogen	Automated cadmium reduction-diazotization, colorimetric	0.1 mg/L	Skougstad and others, 1979
Total nitrite and nitrate-nitrogen	Automated cadmium reduction-diazotization, colorimetric	.1 mg/L	Skougstad and others, 1979
Dissolved ammonia-nitrogen	Automated hypochlorite and alkaline phenol extraction, colorimetric	.01 mg/L	Skougstad and others, 1979
Total ammonia-nitrogen	Automated hypochlorite and alkaline phenol extraction, colorimetric	.01 mg/L	Skougstad and others, 1979
Dissolved ammonia and organic-nitrogen	Automated sulfuric acid and mercuric sulfate digestion, reaction with sodium salicylate, sodium nitroprusside, and sodium hypochlorite, colorimetric	.1 mg/L	Skougstad and others, 1979
Total ammonia and organic-nitrogen	Automated sulfuric acid and mercuric sulfate digestion, reaction with sodium salicylate, sodium nitroprusside, and sodium hypochlorite, colorimetric	.1 mg/L	Skougstad and others, 1979
Dissolved orthophosphate-phosphorus	Automated phosphomolybdate, colorimetric	.01 mg/L	Skougstad and others, 1979
Total orthophosphate-phosphorus	Automated phosphomolybdate, colorimetric	.01 mg/L	Skougstad and others, 1979
Dissolved phosphorus	Automated phosphomolybdate with acid-persulfate digestion, colorimetric	.01 mg/L	Skougstad and others, 1979
Total phosphorus	Automated phosphomolybdate with acid-persulfate digestion, colorimetric	.01 mg/L	Skougstad and others, 1979

Table 1.--*Chemical analyses performed on stream samples during this study*--Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter]

Constituent	Laboratory method	Detection limit	Reference
	Trace elements		
Dissolved cadmium	ICP[1]	1 µg/L	Fishman and Friedman, 1985
Total cadmium	AAS[2] following chelation with APDC[3] and extraction with MIBK[4]	1 µg/L	Skougstad and others, 1979
Dissolved chromium	AAS	10 µg/L	Skougstad and others, 1979
Total chromium	AAS following chelation with APDC, oxidation with potassium permanganate, and extraction with MIBK	1 µg/L	Skougstad and others, 1979
Dissolved copper	AAS following chelation with APDC and extraction with MIBK	1 µg/L	Skougstad and others, 1979
Total copper	AAS following chelation with APDC and extraction with MIBK	1 µg/L	Skougstad and others, 1979
Dissolved iron	ICP	3 µg/L	Fishman and Friedman, 1985
Total iron	AAS following digestion with dilute hydrochloric acid	10 µg/L	Skougstad and others, 1979
Dissolved lead	AAS following chelation with APDC and extraction with MIBK	1 µg/L	Skougstad and others, 1979
Total lead	AAS following chelation with APDC and extraction with MIBK	1 µg/L	Skougstad and others, 1979
Dissolved manganese	ICP	1 µg/L	Fishman and Friedman, 1985
Total manganese	AAS	10 µg/L	Skougstad and others, 1979

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[1] ICP = Induction-coupled plasma used as excitation source for atomic emission spectirometric technique.

[2] AAS = Atomic absorption spectrometry.

[3] APDC = Ammonium pyrrolidine dithiocarbamate.

[4] MIBK = Methyl isobutyl ketone.

Table 1.--*Chemical analyses performed on stream samples during this study*--Continued

[mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter]

Constituent	Laboratory method	Detection limit	Reference
	Trace elements--Continued		
Dissolved nickel	AAS following chelation with APDC and extraction with MIBK	1 µg/L	Skougstad and others, 1979
Total nickel	AAS following chelation with APDC and extraction with MIBK	1 µg/L	Skougstad and others, 1979
Dissolved zinc	ICP	3 µg/L	Fishman and Friedman, 1979
Total zinc	AAS	10 µg/L	Skougstad and others, 1979
	General constituents		
pH (field)	Electrometric, glass electrode	0.05 pH units	Skougstad and others, 1979
pH (lab)	Electrometric, glass electrode, automated	.05 pH units	Fishman and Friedman, 1985
Specific conductance (field)	Wheatstone bridge	1 µS/cm	Skougstad and others, 1979
Specific conductance (lab)	Wheatstone bridge, automated	1 µS/cm	Fishman and Friedman, 1985
Dissolved oxygen	Membrane electrode	.1 mg/L	U.S. Environmental Protection Agency, 1983a
Dissolved solids	Gravimetric, following evaporation	1 mg/L	Skougstad and others, 1979
Suspended sediment	Gravimetric, following filtration	1 mg/L	Guy, 1969
Dissolved chloride	Colorimetric, ferric thiocyanate, automated	.1 mg/L	Fishman and Friedman, 1985

Aquatic Invertebrates

Two different collection techniques, kick nets and standardized qualitative collections, were used to sample benthic macroinvertebrates. This "double sampling" was intended both as a test of the techniques and as a way of independently verifying results.

Kick-Net Sampling

Kick nets (one square meter) were constructed of mesh netting with approximately 1-millimeter openings (Hornig and Pollard, 1978). Smaller mesh netting is available, but it has a greater tendency to become clogged with organic debris and silt, causing flow to be diverted around the net and reducing collection efficiency. A double layer of netting was used to obtain a smaller opening, but without the clogging effect of the smaller mesh.

The net was positioned upright on the streambed while the substrate was physically disrupted (kicked) to a depth of approximately 4 in. in an upstream area of 1 m^2. Kick-net samples were then rinsed into a wash bucket (brass wire cloth mesh no. 30, 0.56-millimeter mesh openings) and preserved with 95 percent ethanol in plastic quart freezer containers. After carefully washing all specimens, large pieces of organic debris were removed to increase preservation efficiency.

All samples were stained with rose Bengal (Mason and Yevich, 1967). Species identifications and enumerations were done in the laboratory of the NRCD's Biological Monitoring Group. Duplicate samples from each of the three stream-sampling sites were collected in January, April, June, and November 1984.

The kick-net technique is less quantitative than other collection techniques, including Surber samples (Welch, 1948) or artificial substrates, such as Hester-Dendy multiplates (Hester and Dendy, 1962) and rock-filled baskets (Henson, 1965). However, it can be used across a wider range of habitats. Hornig and Pollard (1978) found that the kick-net technique was superior to both Surber samples and artificial substrates because it obtained more consistent results.

Standardized Qualitative Sampling

The standardized qualitative-sampling procedure (North Carolina Division of Environmental Management, 1983) uses a variety of collection techniques and mesh sizes to sample as much of the macroinvertebrate community as possible. The three sampling devices used (kick net, sweep net, and wash bucket) had a fairly coarse mesh (0.5 mm) and were intended to sample the larger macroinvertebrates. In addition, two kinds of fine-mesh (0.3 mm) samplers were used to sample the smaller macroinvertebrates, especially Chironomidae. These collection techniques were supplemented by visual inspection of larger rocks and logs. A total of 10 separate samples were included in each qualitative collection. Collections were made at each site in January, April, June, and November. At the sampling site, macroinvertebrate organisms were separated from the rest of the material collected. During lab identification, organisms from each sample were tabulated as rare (1-2 specimens), common (3-9 specimens), or abundant ($\geq$10 specimens).

For both types of collections, species identifications and enumerations were done in the laboratory of the Biological Monitoring Group of NRCD. Most invertebrates were identified using a dissecting microscope. However, representative Chironomids and Oligochaetes were mounted in CMC-10 mounting media and identified using a compound microscope.

Fish

Fish were collected from each stream site in September 1984 by personnel from the North Carolina Division of Inland Fisheries. Rotenone was used to sample all fish in a 328-foot stream reach, which included the water chemistry sampling point and the stream discharge gaging station. A second fish collection was conducted by NRCD's Department of Environmental Management (DEM) personnel in February 1986 to confirm results of the first. For this second collection, because rotenone is less effective in cold water and because equipment and personnel needed to use rotenone were not available, electroshocking, supplemented by active seining, was used to sample the same stream sections. All fish collected were preserved in 10-percent formalin and taken to the laboratory where identifications, enumerations, and measurements were made by DEM staff.

LAND USE AND SOILS IN THE STUDY WATERSHEDS

Land Use

Land-use percentages for each of the study basins as calculated from aerial photographs taken in 1981 and 1982 are presented in table 2. Agricultural land-use data for the Smith Creek watershed (table 2) also were compiled from an on-site inventory conducted by the Soil Conservation Service (U.S. Soil Conservation Service, 1983). These inventories are prior to the study period but land uses in the basins changed only slightly in the interim.

Table 2.--*Land use in the study watersheds, 1981-82*
[On-site inventory data from U.S. Soil Conservation Service, 1983; values in percent; --, no data]

	Watershed			
	Smith Creek		Devil's Cradle Creek	Marsh Creek
Land use	Aerial photograph data 1982	On-site inventory data 1982	Aerial photograph data 1982	Aerial photograph data 1981
Row crops	11.2	8.3	48.0	2.6
Grasslands and pasture	9.9	10.7	5.1	2.6
Farm buildings and other	1.6	--	1.8	1.3
Residential	.1	--	6.5	41.1
Commercial, industrial, and highways	2.0	--	5.4	27.5
Forests	74.6	--	31.0	24.1
Ponds	.6	--	2.2	.7

Several significant points about the land-use data should be noted. First, calculated land-use patterns for the three watersheds generally matched the original selection criteria. That is, the Smith Creek watershed is mostly forested (75 percent); the Marsh Creek watershed is mostly urban (69 percent residential and commercial, including highways), and the Devil's Cradle Creek watershed is mostly agricultural (53 percent row crops and grasslands/pasture combined). However, both the urban watershed (Marsh Creek) and the agricultural watershed (Devil's Cradle Creek) contain substantial forested areas. Most of these forested areas are adjacent to the streams. Also, the forested watershed (Smith Creek) includes 21 percent agricultural land, a high percentage for the watershed that is to serve as the control for the study. However, almost none of the agricultural land in the Smith Creek basin is adjacent to the stream.

Forested land along a stream can act as a filter and attenuate the effects of land use in parts of the basin that do not border stream channels. Therefore, all of the streams in the study may not receive the full impact of runoff from land-use activities in their watersheds. This is especially true for the forested watershed where agricultural land use in the basin is relatively far removed from the stream.

Second, the Smith Creek watershed had some development activities in the watershed during the study. About 30 acres of land in the south central part of the basin were cleared and a trailer park was established on the cleared land. The cleared land does not border Smith Creek, but it lies on both sides of an intermittent stream that is tributary to Smith Creek. Also, during the study, a gravel road through the upper one-third of the watershed was regraded and paved. These activities may have an effect on the water quality of Smith Creek and need to be considered in the analysis of the data.

Furthermore, for the entire duration of the study, a beaver dam located about 0.25 mi upstream from the Smith Creek sampling site, may have had an effect of trapping suspended-sediment, thus reducing suspended sediment downstream.

The search for a totally forested watershed to serve as the control revealed that, in the northeastern Piedmont province of North Carolina, no such undisturbed basins apparently exist. The Smith Creek watershed represents the best choice identified during the search for suitable watersheds.

The agricultural watershed had few agricultural best-management practices in place. Some field borders existed, but they were narrow. Grass waterways were almost nonexistent, and plowing was seldom done on the contour. Similarly, most agricultural land in the forested and urban watersheds did not have progressive land-management practices in place.

Finally, the stream draining the urban watershed, Marsh Creek, is paralleled by a sanitary sewer line. The line was constructed several years prior to the study, so any effects of land disturbance from construction have subsided. However, the chemistry of Marsh Creek could be affected if this sewer line leaks.

Soils

Daniels and others (1984) categorized the land area for all three study watersheds as having soils belonging to the felsic crystalline system of the Piedmont. These soils are found in a large area of the eastern Piedmont north of Raleigh and in a broad band about 60 miles wide in the western Piedmont from Virginia to South Carolina. Soils of this system are derived from granite, granite gneiss, mica gneiss, and mica schist parent material. Because all three study watersheds are classified in the same soil system, the soils in the three watersheds probably have similar and fairly uniform characteristics and affect stream chemistry similarly.

Although the three watersheds are overlain by the same regional soil system, individual soil associations within them are variable because of differences in organic content, mineralogy, permeability, and other factors. The forested watershed, Smith Creek, contains two different soil associations: the Cecil association in the southern part of the watershed and the Creedmoor-White Store association in the northern part of the watershed (U.S. Department of Agriculture, 1971). Cecil soils are sandy loams with kaolinitic clay B horizons. The soil erodibility factor (K) is a measure of the susceptiblity of the soil to be eroded by water (U.S. Department of Agriculture, 1983). The higher the value of K, the more susceptible a soil is to erosion. Values of 0.25 to 0.30 are typical for clay loam type soils; values over 0.40 are characteristic of silt loams, very fine sandy loams, and loamy sands. For Cecil soils, K is 0.28. The Creedmoor-White Store soils usually occur in association with Creedmoor soils on upland sites and White Store soil in the valley slopes. Both soil associations have K values of approximately 0.40 and are moderately well-drained, clay-textured soils with firm, clayey B horizons of mixed clays. The General Soil Map of Granville County (U.S. Department of Agriculture, 1971) indicates about 30 percent of the Smith Creek watershed is of Creedmoor-White Store soils.

The agricultural watershed, Devil's Cradle Creek, is approximately equally divided between soils of the Appling-Louisburg association, the Appling association, and Appling-Durham association (U.S. Department of Agriculture, 1972). Like the Cecil soils of the Smith Creek watershed, these soils are well drained and have sandy loam textured surface layer and clay textured B Horizon of kaolinitic clay mineralogy. Appling soils have a K value of 0.24.

In the urban Marsh Creek watershed, soils of the Cecil-Appling association predominate (Cawthorn, 1970). Again, these soils have sandy loam surface layers, with a clayey B horizon of kaolinite clay. K values are about 0.25.

WATER QUALITY

Results from water-quality sampling are presented in the following sections. All segments of the aquatic environment are included; the water column, sediments suspended in the water, sediments on the stream bottoms, and water within the interstices of the bottom material.

Suspended Sediment

Suspended-sediment concentrations for this study were sampled by two methods, manual and automated. Manual sampling is the preferred method because it produces a sample that is both depth-integrated and width-integrated and, therefore, presumed to be representative of the cross section of the stream. Automated samples are collected at a single, fixed point in the stream and are likely to be less representative of concentrations throughout the entire cross section. Indeed, figure 2 shows the bias of the samples collected by the automatic sampler--consistently higher concentrations are found in samples collected by the automatic sampler than in samples collected manually. Therefore, automated samples from each sampling site were related by a least-squares regression equation to concurrently collected manual samples. The relation between automated and manual samples is statistically significant (fig. 2) for each stream with correlation coefficients of 0.79 for Smith Creek, 0.87 for Devil's Cradle Creek, and 0.97 for Marsh Creek. Concentrations of suspended sediment from samples collected by the automatic sampler were then adjusted to match the corresponding value which would have been expected from a manual sample taken at the same time. Adjustments were made by substituting suspended-sediment concentrations from automatically collected samples into the regression equation from each station and calculating the corresponding concentration as if the sample had been collected manually. Both adjusted concentrations from automated samples and unadjusted concentrations from manual samples are used in this report.

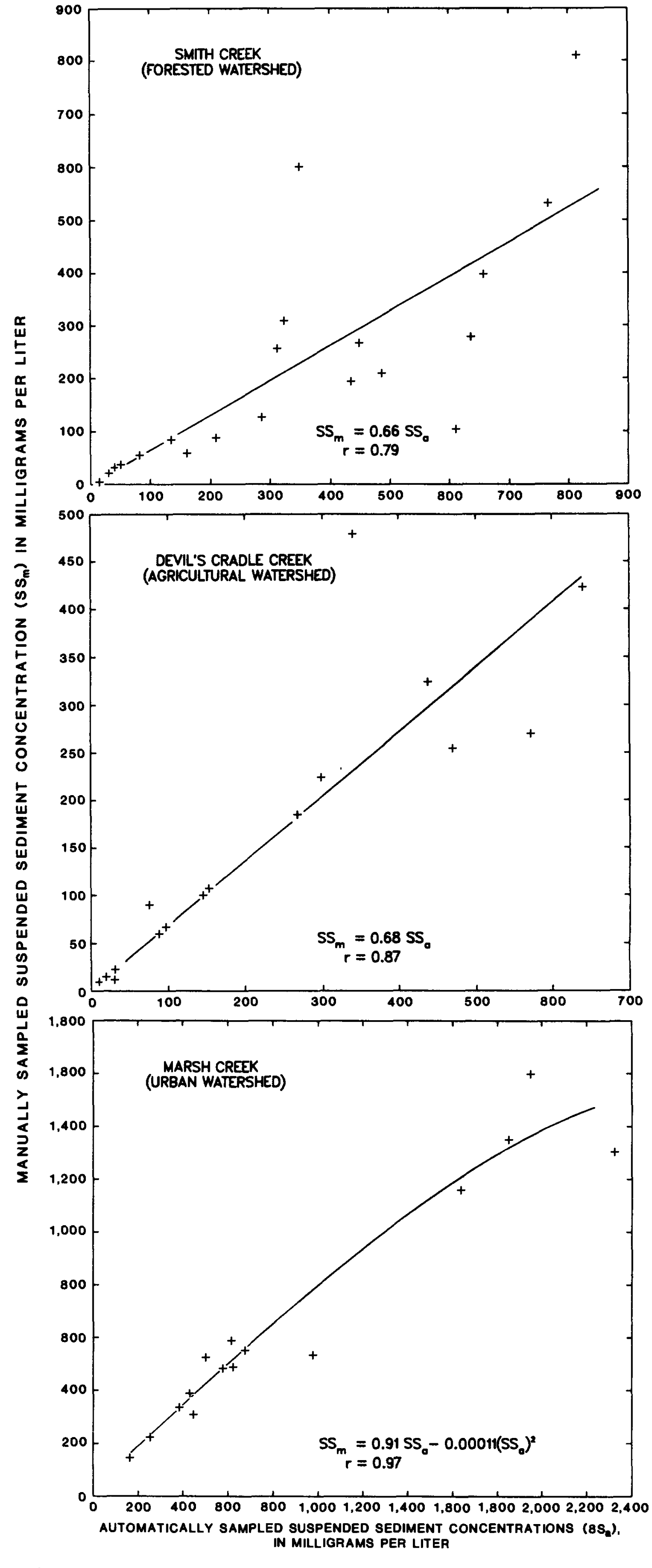

Figure 2. The relations between manually sampled and automatically sampled suspended-sediment concentrations in the study watersheds.

Instantaneous suspended-sediment discharge, in tons per day, is computed by multiplying suspended-sediment concentration by stream discharge at the time the suspended-sediment concentration was sampled, or:

$$Q_s = 0.0027\ Q_w\ C_s, \qquad (1)$$

where: Q_s = instantaneous suspended-sediment discharge, in tons per day,
Q_w = instantaneous water discharge, in cubic feet per second, and
C_s = concentration of suspended sediment, in milligrams per liter.

At each of the three study sites, instantaneous suspended-sediment discharge is statistically related to stream discharge (fig. 3). Because this relation is well defined for each stream, annual suspended-sediment discharge values (loads) can be calculated. Regression equations developed between instantaneous suspended-sediment discharge and instantaneous stream discharge are used to predict daily suspended-sediment loads from daily average stream discharges. Daily loads are summed for a 1-year period to yield an annual load. For Smith Creek, Devil's Cradle Creek, and Marsh Creek, annual suspended-sediment loads for the 1-year period, February 1984 through January 1985, are presented in table 3. Dividing each of the calculated loads by the drainage area of the study watershed gives a measure of suspended-sediment load expressed on a per-unit area basis. These load-per-unit area values, or yields, can be directly compared among watersheds. The annual yields from Smith, Devil's Cradle, and Marsh Creeks indicate that the forested basin yields about 0.13 tons of suspended sediment per year for each acre of land. The agricultural basin yields more than twice (0.31 tons per acre) the suspended-sediment load of the forested basin, and the urban basin yields more than four times (0.59 tons per acre) the load of the forested basin (table 3). These results are in line with previously reported yields from streams in the North Carolina Piedmont (Simmons, 1987).

Bottom Material

There is a strong association between sediment suspended in the water of a stream and the sediment on a stream bottom. Any individual sediment particle is carried in suspension until the water velocity slows to the point that it can no longer provide the force needed to carry the particle. The particle then settles and changes from suspended sediment to bottom material. During some future period of increased streamflow, that particle

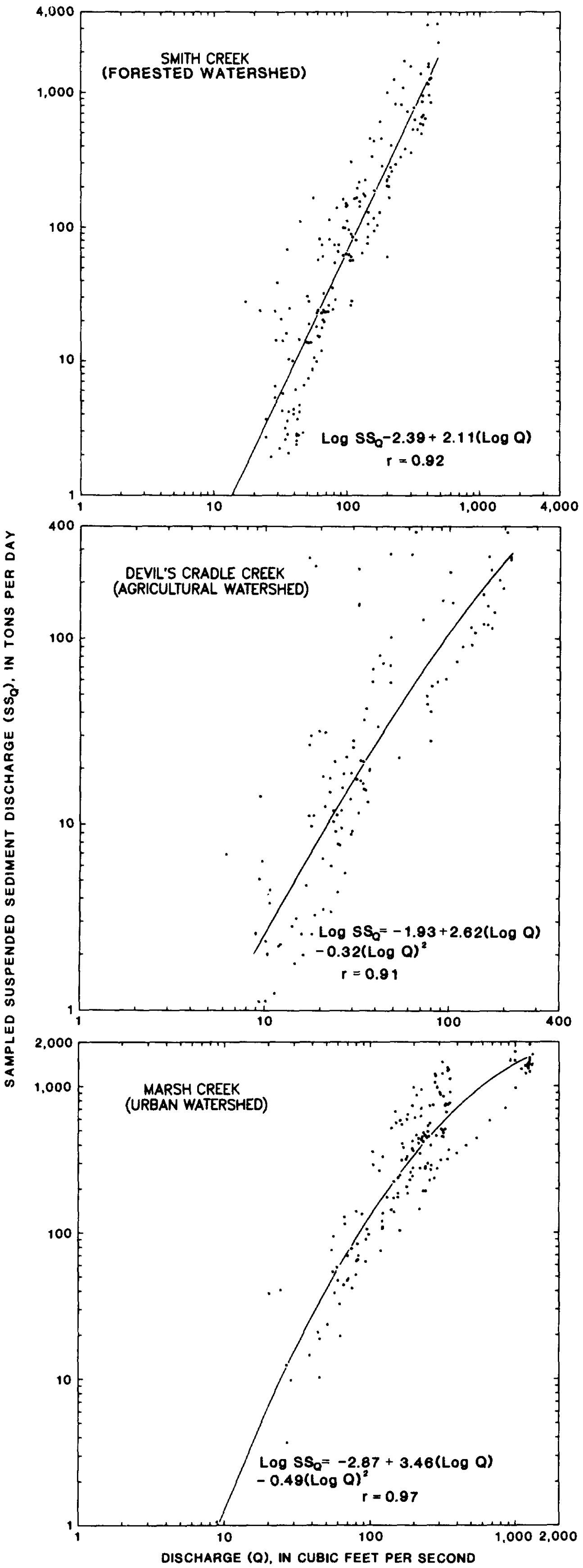

Figure 3.--The relations between suspended-sediment discharge and stream discharge for the study watersheds.

Table 3.--*Annual suspended-sediment loads and yields for the period February 1984 to January 1985 for the study watersheds*

Stream	Suspended-sediment load (tons)	Drainage area (acres)	Suspended-sediment yield (tons per acre)
Smith Creek (Forested watershed)	510	3,987	0.13
Devil's Cradle Creek (Agricultural watershed)	566	1,850	.31
Marsh Creek (Urban watershed)	2,603	4,378	.59

may again be placed in suspension if the velocity of the water becomes sufficient to dislodge the particle. Thus, a particle alternates between the suspended phase and the settled phase with the stream velocity dictating in which phase the particle is at a given time.

An examination of the particle-size distribution of bottom material reveals some striking differences between the three streams. The forested site had the highest percentage (35 percent) of gravel-size particles and the lowest percentage (0.4 percent) of silt-clay size particles (table 4). The agricultural site had the largest percentage of the sand fraction (85 percent) and the largest percentage of the silt-clay fraction (7.7 percent) (table 4). The urban site had intermediate percentages of gravel, sand, and silt-clay size bottom material (table 4).

Table 4.--*Size distribution of bottom material in the study watersheds*
[Values in percent; mm, millimeter]

Particle size	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
Greater than 2.0 mm (gravel)	35.0	7.5	27.0
Between 2.0 mm and 0.63 mm (sand)	64.6	84.8	71.6
Less than 0.63 mm (silt-clay)	.4	7.7	1.4

Bottom material from each of the three sampling sites was collected in late October 1985. Material greater than 2 mm in diameter was discarded because chemicals contained in the gravel-sized sediments of this fraction are largely unavailable to biological organisms. The sand and silt-clay fractions were analyzed in the Survey laboratory in Atlanta, Georgia, for total recoverable cadmium, total recoverable chromium, total recoverable copper, total recoverable iron, total recoverable lead, total recoverable manganese, total recoverable nickel, and total recoverable zinc. Results from the laboratory analyses are presented in table 5.

Table 5.--*Chemical analyses of stream-bottom material*
[Results are from a single sample taken at each site in October 1985; μg/g, micrograms per gram; mm, millimeters; <, less than]

Constituent	Smith Creek (forested watershed) (μg/g)	Devil's Cradle Creek (agricultural watershed (μg/g)	Marsh Creek (urban watershed) (μg/g)
Particle size less than 0.063 mm (silt-clay fraction)			
Cadmium	2	1	5
Chromium	30	3	10
Copper	92	8	6
Iron	33,000	6,000	12,000
Lead	10	10	<100
Manganese	1,700	2,100	2,500
Nickel	40	<10	<10
Zinc	120	13	52
Particle size between 2 mm and 0.063 mm (sand fraction)			
Cadmium	1	<1	<1
Chromium	30	3	3
Copper	7	2	3
Iron	6,600	2,500	17,000
Lead	<100	<100	<100
Manganese	14,000	5,800	7,800
Nickel	<10	<10	<10
Zinc	16	5	14

Concentrations of most metals analyzed were greater in the smaller-sized fraction of the bottom material. This pattern of greater concentrations of metals associated with small-sized particles has previously been identified by other researchers (Wilber and Hunter, 1979; Horowitz, 1985; Demas and Curwick, 1986). Manganese was the only constituent that consistently deviated from this pattern. At each of the three sampling sites, higher concentrations of manganese were found in the sand fraction than in the silt-clay fraction. This pattern is common and occurs because manganese-oxide coatings bind small particles together to make them appear as larger particles (Whitney, 1975).

North Carolina has no standards for concentrations of metals sorbed on bottom material against which the results from this study can be compared. However, Kelly and Hite (1984) developed a classification scheme for sediments of Illinois streams that may apply to other areas as well. Their classification scheme (table 6) includes five categories: "nonelevated," "slightly elevated," "elevated," "highly elevated," and "extremely elevated." On the basis of their classification, total recoverable chromium, copper, iron, and zinc are elevated at the forested site in the silt-clay fraction. Chromium also is elevated at the forested site (30 micrograms per gram (μg/g)) in the sand fraction. Manganese is elevated at the agricultural site (2,100 μg/g) and at the urban site (2,500 μg/g) in the silt-clay fraction. Manganese is extremely elevated at all three sites in the sand fraction (up to 14,000 μg/g).

Table 6.--*Classification scheme for metals in stream sediments* (modified from Kelly and Hite, 1984)
[Results in milligrams per kilogram of sediment;
<, less than; >, greater than]

Parameter	Non-elevated	Slightly elevated	Elevated	Highly elevated	Extremely elevated
Arsenic	<8.0	>8.0	>11.0	>17.0	>28.0
Cadmium	< .5	> .5	>1	>2	>20
Chromium	<16	>16	>23	>38	>60
Copper	<38	>38	>60	>100	>200
Iron	<18,000	>18,000	>23,000	>32,000	>50,000
Lead	<28	>28	>38	>60	>100
Manganese	<1,300	>1,300	>1,800	>2,800	>5,000
Mercury	< .07	> .07	> .10	> .17	> .30
Zinc	<80	>80	>100	>170	>300

General interpretations concerning relative concentrations of metals associated with the bottom material from the different watersheds could not be made. For the silt-clay fraction, total recoverable concentrations of chromium, iron, nickel, and zinc were greater in the stream draining the forested watershed, Smith Creek, than in either of the streams draining the agricultural or the urban watersheds, Devil's Cradle Creek and Marsh Creek, respectively. The greatest concentrations of cadmium and manganese were found in the stream draining the urban watershed. For the sand fraction, chromium, copper, and manganese were highest in the stream draining the forested watershed, but the highest concentrations of iron were found in the stream draining the urban watershed.

Wilber and Hunter (1977) found that metals loadings to the Saddle River, New Jersey, decrease as the percentage of residential land increases. Other research (Wilber and Hunter, 1979; Cole and others, 1984) indicates that a significant source of metals loadings in streams draining urban watersheds is automobile related. Pitt and Bozeman (1980) point to automobile tirewear as a substantial source of zinc, auto exhausts as contributors of many heavy metals, especially lead, and fluid losses and mechanical wear as contributors of still more heavy metals. Therefore, a watershed with a large percentage of impervious area and (or) with a high volume of traffic would be expected to have high loadings of metals in its stream sediments.

On the basis of previous research (Loehr, 1974; Sartor and others, 1974; Wilber and Hunter, 1979; U.S. Environmental Protection Agency, 1983b; Garie and McIntosh, 1986), highest metal concentrations would be expected in streams draining urban watersheds. The generally lower concentrations found in Marsh Creek may be somewhat atypical for streams draining urban watersheds. The lack of heavy industrial activity in the watershed may account for this. The Marsh Creek watershed is dominated by residential development (41.1 percent) and commercial establishments (27.5 percent commercial, industrial, and highway), with virtually no manufacturing. The high percentage of residential land and the lack of manufacturing activity both tend to decrease metals loadings to urban streams and may account for low concentrations of metals in the sediments of this stream compared with other streams draining urban watersheds.

General Water-Quality Properties

Several water-quality properties--dissolved oxygen, stream temperature, pH, and specific conductance--from water samples collected monthly from February 1984 through January 1985 were analyzed. Summary statistics for these general water-quality measures did not indicate impaired water quality in any of the three streams (table 7). Specific information on these individual measures will be presented in the paragraphs that follow.

Dissolved oxygen concentrations in each of the streams at the time of sampling were never lower than 6.2 milligrams per liter (mg/L). This low value (71 percent saturation) was determined in a May 29 sample from Devil's Cradle Creek during high flow, but it is within North Carolina water-quality

Table 7.--*Summary statistics for general water-quality characteristics of stream water from the study watersheds*
[mg/L, milligrams per liter; °C, degrees Celcius; µS/cm, microsiemens per centimeter]

Constituent	Statistic	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
Dissolved oxygen (mg/L)	Mean	9.8	8.9	9.3
	Number of samples	12	12	11
	Standard deviation	1.7	1.6	1.6
	Minimum-maximum	7.7-13.2	6.2-11.8	6.8-12.0
Water temperature (°C)	Mean	14.1	14.9	15.6
	Number of samples	14	12	11
	Standard deviation	6.3	6.4	6.9
	Minimum-maximum	3-22.5	5-23	6-25
pH (pH units)	Median	6.5	6.3	6.5
	Number of samples	13	12	12
	25th-75th percentile	6.0-6.8	5.9-6.3	6.3-6.6
	Minimum-maximum	5.7-7.2	5.6-6.8	5.9-6.8
Specific conductance (µS/cm at 25 °C)	Mean	60	68	85
	Number of samples	14	12	12
	Standard deviation	18.0	7.6	24.6
	Minimum-maximum	40-85	50-78	37-119

standards (North Carolina Environmental Management Commission, 1986) and should not adversely affect aquatic life. It should be pointed out that dissolved oxygen concentrations are normally at their diel minimum just prior to daylight and that the sampling schedule for this study did not address diel variations for any of the constituents. Therefore, the reported values for dissolved oxygen are not necessarily representative of the most stressful oxygen concentrations. However, the values in table 7 represent samples collected from each of the three sites on the same day, and the data are useful for making comparisons of health conditions of the streams at the sampling sites. Dissolved oxygen in the stream draining the forested site, Smith Creek, had an average concentration of 9.8 mg/L and was higher (though not in a statistical sense) than the average concentration at either the agricultural site or the urban site.

Measured stream temperatures indicated no values that could adversely affect warm-water fish species native to Piedmont streams. The highest temperature measured during the study was 25 °C in Marsh Creek. This temperature was recorded on August 14, 1984, and is well below the maximum 32 °C prescribed by North Carolina's water-quality standards (North Carolina Environmental Management Commission, 1986). Mean stream-water temperature was lowest at the forested sampling site and highest at the urban sampling site, but the differences were not statistically significant.

Measured pH values were similar at all sites. Median values are used as a measure of central tendency for pH because the property is expressed as a logarithmic quantity and an arithmetic mean is not appropriate. Values of pH from the three sampling sites indicate that Devil's Cradle Creek had a median value of 6.3 units; Smith Creek and Marsh Creek each had a median pH of 6.5 units.

North Carolina water-quality standards specify that surface waters shall have pH values which are "...normal for the waters in the area, which generally shall range between 6.0 and 9.0..." (North Carolina Environmental Management Commission, 1986). All three sites in the study at times had pH values below the 6.0 units standard. Twenty-two percent of pH measurements made during the study were less than 6.0 pH units. The lowest pH, a value of 5.6 units, was measured at the agricultural site on May 29, 1984. This sample was collected during high streamflow and may indicate a depression of stream pH resulting from an influx of low pH rainwater. Other pH values less than 6.0 pH units also were from samples collected during times of high discharge. Rainfall in the region usually has a pH of about 4.5 units, so the lowest pH in streams would be expected to occur during storms.

Analyses of water samples collected at the three study sites indicate that the stream draining the forested watershed had the lowest mean specific conductance (60 microsiemens per centimeter (μS/cm)), and the stream draining the urban watershed had the highest (85 μS/cm). The differences among streams were statistically significant ($F = 6.27$, $p < 0.005$). For most Piedmont streams, specific conductance is inversely related to stream discharge, with the highest specific conductance values occurring at the lowest flow (Daniel and others, 1979; Eddins and Crawford, 1984).

Nutrients

Nutrients play an important role in stream quality because they are required for growth of phytoplankton, periphyton, and bacteria. Nutrients are especially important in streams that are tributaries to reservoirs because of the potential for nuisance algal growths in the quiescent, unshaded lake waters.

Nutrient concentrations vary widely for the three study streams. Mean concentrations of dissolved orthophosphate-phosphorus, total phosphorus, dissolved nitrite plus nitrate-nitrogen, dissolved ammonia-nitrogen, and total nitrogen were all higher in the stream draining the agricultural watershed, Devil's Cradle Creek, than in either of the streams draining the forested, Smith Creek, or urban, Marsh Creek, watersheds (tables 8 and 9). For these data, the log-probability regression method was used to estimate values for samples reported by the laboratory as being less than the detection limit (Gilliom and Helsel, 1986; Helsel and Gilliom, 1986). Concentrations of dissolved nitrite plus nitrate-nitrogen and dissolved ammonia-nitrogen were higher in the stream draining the urban watershed than in the stream draining the forested watershed. Dissolved orthophosphate-phosphorus and total phosphorus concentrations were approximately the same in the streams draining both the urban and the forested watersheds. However, total nitrogen concentrations averaged slightly higher in the forested watershed stream than in the urban watershed stream. The percentage of nitrogen in the form of available nitrogen (dissolved nitrite plus nitrate-nitrogen and dissolved ammonia nitrogen) was highest in the stream draining the agricultural watershed and lowest in the stream draining the forested watershed (table 8). Therefore, the stream draining the agricultural watershed contained the greatest total amount of nutrients available for biological uptake.

The general pattern of highest concentrations of nutrients in the agricultural watershed is to be expected because fertilization of crops adds nutrient loads far above naturally occurring levels. Elevated nutrient concentrations in urban watersheds have been found by other researchers who cited leaking sewer lines and lawn fertilization as contributing nutrients to streams (Pitt and Bozeman, 1980; Porter, 1980).

Table 8.--*Summary statistics for nutrient concentrations in stream water from the study watersheds*

[<, less than; mg/L, milligrams per liter]

Constituent	Statistic	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
Dissolved orthophosphate phosphorus (mg/L as P)	Mean	<0.01	0.05	0.02
	Number of samples	13	12	12
	Standard deviation	.00	.06	.01
	Minimum-maximum	<0.01-<0.01	<0.01-0.20	<0.01-0.04
Total phosphorus (mg/L as P)	Mean	.09	.27	.10
	Number of samples	14	12	12
	Standard deviation	.14	.25	.06
	Minimum-maximum	<0.01-0.46	0.01-0.73	0.03-0.24
Dissolved nitrite plus nitrate-nitrogen (mg/L as N)	Mean	.08	.59	.41
	Number of samples	13	12	12
	Standard deviation	.07	.16	.19
	Minimum-maximum	<0.10-0.24	0.35-0.84	0.13-0.78
Dissolved ammonia-nitrogen (mg/L as N)	Mean	.05	.49	.11
	Number of samples	12	9	11
	Standard deviation	.05	.58	.10
	Minimum-maximum	<0.01-0.15	<0.01-1.30	<0.01-0.25
Total nitrogen (mg/L as N)	Mean	1.70	2.11	1.42
	Number of samples	5	12	12
	Standard deviation	1.29	.91	.62
	Minimum-maximum	0.50-3.80	0.90-3.90	0.70-2.80
Total nitrogen (percent in available form)		7.6	51.2	36.6

Table 9.--*Summary of results for mean nutrient concentrations in the study streams as related to watershed land use*

[>, greater than; ≥, greater than or equal to]

Nutrient	Relative concentrations among watersheds				
Dissolved orthophosphate-phosphorus	Agricultural	>	Urban	≥	Forested
Total phosphorus	Agricultural	>	Urban	≥	Forested
Dissolved nitrite plus nitrate-nitrogen	Agricultural	>	Urban	>	Forested
Dissolved ammonia-nitrogen	Agricultural	>	Urban	>	Forested
Total nitrogen	Agricultural	>	Forested	>	Urban

Trace Metals

Samples for both total and dissolved forms of the trace metals cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc were analyzed from the three study sites on an approximately monthly basis. For the purpose of calculating means, concentrations reported as less than the detection limit were estimated by using the log-probability regression method (Gilliom and Helsel, 1986; Helsel and Gilliom, 1986). Summary statistics for these constituents are presented in tables 10 and 11.

Concentrations of metals in the three streams were lower than those known to pose a threat to aquatic life. This point is illustrated by quantitative comparisons between total metal concentrations found during this study and North Carolina water-quality standards for all freshwaters (table 11). Water-quality standards based on total concentrations of the constituent have been established for all of the metals considered in this report, with the exception of manganese. Mean concentrations for total cadmium, total chromium, total copper, total lead, total nickel, and total zinc were all below existing water-quality standards. However, mean total iron concentrations exceeded the water-quality standard at all three sites. These high concentrations of iron, however, are not considered harmful to aquatic life or human health. The existing iron standard of 1,000 micrograms per liter (μg/L) was established for aesthetic purposes, to prevent staining of laundry and fixtures.

Although mean concentrations of metals were generally less than existing water-quality standards, concentrations in individual samples occasionally exceeded the standards. This was the case for total copper, total lead, and total zinc at all three sites and for total cadmium at the forested and agricultural sites. As a general rule, high metals concentrations in the streams occurred during periods of high stream discharge. Therefore, while the norm for these sites is a condition conducive to a healthy aquatic community, concentrations of metals that may threaten aquatic life were measured at times at all three sites. Even though water-quality standards for metals were exceeded, healthy biological communities existed in the streams draining the forested and agricultural watersheds. Therefore, the use of total metal concentrations for standards may not be a reliable indicator of the biologically available fraction.

Table 10.--*Summary statistics for dissolved metal concentrations in stream water from the study watersheds*

[μg/L, micrograms per liter; <, less than; --, no data]

Constituent	Statistic	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
Dissolved cadmium (μg/L)	Mean	0.59	0.64	0.54
	Number of samples	14	12	12
	Standard deviation	.52	.83	.56
	Minimum-maximum	<1-2	<1-3	<1-2
Dissolved chromium (μg/L)	Mean	<10	[1]<10	<10
	Number of samples	12	11	12
	Standard deviation	.0	--	.0
	Minimum-maximum	<10-10	--	<10-10
Dissolved copper (μg/L)	Mean	3.0	2.8	1.9
	Number of samples	11	9	12
	Standard deviation	2.9	4.7	1.3
	Minimum-maximum	<1-8	<1-15	<1-4
Dissolved iron (μg/L)	Mean	117	206	88
	Number of samples	14	12	12
	Standard deviation	138	260	148
	Minimum-maximum	16-490	30-1,000	14-550
Dissolved lead (μg/L)	Mean	2.0	1.8	1.9
	Number of samples	13	11	10
	Standard deviation	1.4	1.6	1.7
	Minimum-maximum	<1-5	<1-6	<1-6
Dissolved manganese (μg/L)	Mean	65	60	93
	Number of samples	11	12	12
	Standard deviation	70	20	39
	Minimum-maximum	16-230	23-90	21-190
Dissolved nickel (μg/L)	Mean	1.3	1.1	1.0
	Number of samples	14	12	12
	Standard deviation	1.2	.6	.0
	Minimum-maximum	<1-5	<1-2	<1-1
Dissolved zinc (μg/L)	Mean	9.5	8.9	10.6
	Number of samples	13	10	11
	Standard deviation	4.2	3.5	3.8
	Minimum-maximum	5-20	<3-14	3-17

[1] All samples were below the detection limit of 10 μg/L.

Table 11.--*Summary statistics for total metal concentrations in stream water from the study watersheds*

[µg/L, micrograms per liter; <, less than; --, no data]

Constituent	Statistic	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)	North Carolina water-quality standard for all freshwaters
Total cadmium (µg/L)	Mean	1.0	1.6	1.0	2
	Number of samples	14	12	12	
	Standard deviation	1.2	2.1	1.2	
	Minimum-maximum	<1-5	<1-8	<1-2	
Total chromium (µg/L)	Mean	4.0	3.8	6.0	50
	Number of samples	14	12	12	
	Standard deviation	4.1	3.8	5.6	
	Minimum-maximum	<1-13	<1-11	<1-17	
Total copper (µg/L)	Mean	7.9	5.0	12.5	[1]15
	Number of samples	14	12	12	
	Standard deviation	13.1	5.1	18.5	
	Minimum-maximum	<1-51	<1-18	<1-64	
Total iron (µg/L)	Mean	4,390	3,930	4,890	[1]1,000
	Number of samples	14	12	12	
	Standard deviation	6,010	5,760	6,550	
	Minimum-maximum	730-22,000	1,100-22,000	560-19,000	
Total lead (µg/L)	Mean	5.1	6.6	14.4	[2]25
	Number of samples	14	12	12	
	Standard deviation	7.2	10.8	17.6	
	Minimum-maximum	<1-27	1-40	<1-46	
Total manganese (µg/L)	Mean	221	113	178	--
	Number of samples	14	12	12	
	Standard deviation	338	55	74	
	Minimum-maximum	20-1,200	40-220	80-320	
Total nickel (µg/L)	Mean	3.3	2.9	3.5	[2]50
	Number of samples	14	12	12	
	Standard deviation	3.3	3.0	2.4	
	Minimum-maximum	<1-13	<1-9	<1-8	
Total zinc (µg/L)	Mean	31	23	39	[1]50
	Number of samples	14	12	12	
	Standard deviation	19	17	28	
	Minimum-maximum	<10-70	10-70	10-110	

[1] Action level above which discharge monitoring and pollutant reduction are required.

[2] If more stringent, 0.01 of the 96-hour LC50 (American Public Health Association, 1976) is the standard.

For both dissolved and total forms of these metals, concentrations were similar in all three streams. One-way analyses of variance using a completely randomized design (Steel and Torrie, 1980) for each of the metals considered indicated no statistically significant difference (at the 0.05 level of probability) among sampling sites for any of the eight metals, for either dissolved or total forms (table 12). This finding is somewhat surprising because higher concentrations of metals would be expected in the stream draining the urban watershed (Wilber and Hunter, 1979; Duda and others, 1982; Kelly and Hite, 1984). A possible explanation is the largely residential nature of the urban watershed selected for this study and the lack of heavy industry or manufacturing in the urban watershed.

Table 12.--*Results of completely randomized one-way analyses of variance for tests of differences between concentrations of metals in the study streams*

Constituent	Results of analysis of variance Value of F	 Degrees of freedom	 Probability of greater value of F
Dissolved:			
Cadmium	0.21	2,35	0.81
Chromium[1]	--	--	--
Copper	.46	2,29	.64
Iron	1.29	2,35	.29
Lead	.04	2,31	.96
Manganese	1.75	2,32	.19
Nickel	1.60	2,35	.23
Zinc	.53	2,31	.59
Total:			
Cadmium	.86	2,35	.43
Chromium	.87	2,35	.43
Copper	.97	2,35	.39
Iron	.07	2,35	.93
Lead	2.08	2,35	.14
Manganese	.85	2,35	.43
Nickel	.10	2,35	.91
Zinc	1.77	2,35	.18

[1] All samples of chromium were below the detection limit of 10 micrograms per liter.

Despite the lack of statistically significant differences among sites, it may be instructive to compare metal concentrations among the forested, agricultural, and urban watersheds. For the eight metals considered, mean concentrations of dissolved cadmium, chromium, copper, lead, nickel, and zinc differed little among the three sites. Mean concentrations of dissolved iron were highest at the agricultural site; whereas dissolved manganese was highest at the urban site. However, the stream draining the urban watershed had the highest mean total metal concentration for chromium, copper, iron, lead, nickel, and zinc.

Interstitial Water

Interstitial water is that water existing in spaces in the bottom material, between the sediment particles. This water is particularly important for benthic macroinvertebrates that burrow in the sediments. Results from the only interstitial water sampling, October 1985, show that orthophosphate-phosphorus was less than the detection limit of 0.01 mg/L at all depths sampled in all three streams (table 13). Ammonia-nitrogen concentrations were higher at the forested site than at either the agricultural site or the urban site. The elevated ammonia concentrations at the forested site may be attributable to inputs of ammonia from decaying leaves in the water at the time of sampling. Not enough samples were analyzed for nitrite plus nitrate-nitrogen to establish a pattern. On the basis of these limited data, there is no apparent reason that biological communities would be either beneficially or adversely affected at either of the three study sites.

Table 13.--*Results of nutrient analyses of interstitial water and near-bottom water from the study watersheds*
[mg/L, milligrams per liter; --, no data]

Sample depth (vertical distance from sediment-water interface, in inches)	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
Ammonia-nitrogen (mg/L)			
+2.0	0.18	--	6.0
+ .4	.24	0.02	.07
- .4	.05	--	.01
-1.2	.76	.01	.01
-2	.71	--	.01
-4	.36	.31	.12
Nitrite plus nitrate-nitrogen (mg/L)			
+2.0	--	--	2.3
+ .4	--	--	1.8
- .4	--	--	2.1
-1.2	--	--	2
-2	--	--	2.2
-4	--	--	--
Orthophosphate-phosphorus (mg/L)			
+2.0	<0.01	--	<0.01
+ .4	<.01	<.01	<.01
- .4	<.01	--	<.01
-1.2	<.01	<.01	<.01
-2	<.01	--	<.01
-4	<.01	<.01	<.01

AQUATIC INVERTEBRATES

Benthic macroinvertebrate data from the three streams have been summarized both for individual taxa and for 12 major taxonomic groups. Discussions of taxa richness and abundance focus on the data summarized for these groups (primarily families of aquatic insects). The discussions draw on concepts of classical stream ecology claiming that certain groups of stream organisms, especially the insects belonging to the orders Ephemeroptera, Plecoptera, and Trichoptera, are more sensitive to stress from pollution and other disturbances than other aquatic invertebrate groups (Richardson, 1925; Patrick, 1949; Gaufin, 1958; Hynes, 1960). These concepts have been refined since the pioneering work of the early researchers and a good update and review has been published by Wiederholm (1984).

Taxa Richness

Mean taxa richness values (table 14) generally showed the same between-station patterns for both kick-net and standardized qualitative collections. However, more species were collected with standardized qualitative samples, and between-site changes could be more easily detected.

Analysis of variance is the appropriate parametric statistical test for comparing mean numbers of taxa found at the three sampling sites. Like other parametric tests, analyses of variance require that the samples are independent, come from a normally distributed population, and have equal variances. For the macroinvertebrate data, samples within each of the 12 invertebrate groups, for each of the three stations, and for each of the two sampling techniques, were tested to see if all three of these assumptions were met. In all, there were 72 subsamples to be tested. Twenty-two of the 72 subsamples (31 percent) failed to meet at least one of the assumptions. Nonetheless, the consequences of violating the assumptions are relatively small when sample sizes are similar (Norusis, 1983). Therefore, the traditional parametric tests were applied. Where an analysis of variance indicated a statistically significant difference among means, Duncan's multiple-range test (Steel and Torrie, 1980) was used to identify the specific means that were statistically different.

Table 14.--*Mean taxa richness for invertebrate collections from the study watersheds*
[Results in mean numbers of species]

Invertebrate group	Mean taxa richness					
	Kick net collections			Standard qualitative collections		
	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)	Smith Creek (forested watershed)	Devei's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
Annelids						
Oligochaeta	2.0	[1]5.0	[1] [2]7.0	2.3	3.8	5.3
Insects						
Ephemeroptera	9.8	[1]5.3	[1] [2]2.8	14.0	[1]6.8	[1] [2]3.3
Plecoptera	4.5	2	[1] .5	5.3	2.8	[1]0
Trichoptera	7.5	[1]4	[1]2	9.8	[1]4.5	[1] [2]2
Subtotal (EPT)[3]	21.8	[1]11.3	[1]5.3	29	[1]14	[1] [2]4.5
Coleoptera	6.3	3.5	[1] .5	9.3	7.5	[1] [2]1.3
Odonata	6.3	4	[1]2.3	9	7	[1] [2]4.5
Megaloptera	1.8	[1] .5	[1] [2] .3	2.8	2	[1] [2]0
Diptera: Miscellaneous	5.5	4.3	[1] [2]2.3	7.3	5.3	[1]1.8
Diptera: Chironomids	18.5	23.8	[2]10.8	23.3	22.8	[1] [2]13.8
Crustaceans						
Crustacea	2	2.5	1	2	3.3	1.5
Mollusks						
Mollusca	1.3	3.3	2.3	1.5	[1]4.5	[2]2.8
Other	2.5	2	1.5	2.5	2	1.8
Total	67.8	60	[1] [2]32.8	88.8	73	[1] [2]37

[1] Statistically different from the forested watershed at the 0.05 level of confidence.
[2] Statistically different from the agricultural watershed at the 0.05 level of confidence.
[3] EPT represents the sum of Ephemeroptera, Plecoptera, and Trichoptera.

The analyses of variance were conducted combining data from all sampling dates but keeping the two sampling techniques separate. Results indicate that, relative to the stream draining the forested watershed, the stream draining the agricultural watershed had significantly lower mean taxa-richness values for two of the most intolerant groups: Ephemeroptera and Trichoptera (Keup and others, 1966). Lower mean taxa richness also was usually observed for Odonata, Megaloptera, and Coleoptera, although these differences were not always statistically significant. Declines in mean taxa richness of these groups in the stream draining the agricultural watershed were partially offset by increases in Mollusca and Oligochaeta.

Much greater declines in mean taxa richness were observed in the stream draining the urban watershed, relative to both the stream draining the forested watershed and the stream draining the agricultural watershed. These declines were statistically significant for all of the eight insect groups plus the mollusks. Only the Oligochaetes, a group very tolerant to environmental change (Keup and others, 1966), increased in diversity in the stream draining the urban watershed (table 14).

When total taxa richness summed over all sampling dates is considered (table 15), the pattern is largely unchanged. The invertebrate groups most intolerant of stressful conditions still show a progressive drop in taxa richness in comparing streams draining the forested, agricultural, and urban watersheds. However, the larger data set suggests less difference between the stream draining the forested watershed and the stream draining the agricultural watershed for Coleoptera, Odonata, and Megaloptera, but a greater difference for miscellaneous Diptera.

Whether average taxa richness per sample or total taxa richness over all dates sampled is used for the analysis, there is little effect on the percent reduction in either total taxa richness or Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa richness (table 16). EPT taxa richness offers a combined measure of three groups that are sensitive to stress from pollution (Patrick, 1975). If the size of the data set is increased by combining data from both kick-net samples and standardized qualitative samples, a similar pattern is observed (table 16).

The primary effect of added sediment in streams is a reduction in the amount of rubble-type habitat. In an area of mixed rubble and sand habitat,

Table 15.--*Total taxa richness for invertebrate collections from the study watersheds*

[Results in numbers of species; --, no data]

Invertebrate group	Total taxa richness								
	Kick net collections			Standardized qualitative collections			Both collection techniques combined		
	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
Annelids									
Oligochaeta	3	11	12	7	8	9	8	11	12
Insects									
Ephemeroptera	20	10	6	25	14	6	27	14	6
Plecoptera	11	8	2	13	9	0	14	10	2
Trichoptera	16	7	4	18	7	3	22	9	4
Subtotal (EPT)[1]	47	25	12	56	30	9	63	33	12
Coleoptera	13	10	2	15	16	4	17	17	5
Odonata	10	9	5	12	11	7	13	11	7
Megaloptera	2	1	1	3	3	--	3	3	1
Diptera: Miscellaneous	10	8	6	17	12	6	18	13	8
Diptera: Chironomids	43	52	26	55	44	34	66	59	42
Crustaceans									
Crustacea	3	4	2	3	5	2	3	5	3
Mollusks									
Mollusca	4	8	5	5	9	5	6	10	6
Other	3	4	3	5	4	5	5	7	5
Total	138	132	74	178	142	80	202	169	101

[1] EPT represents the sum of Ephemeroptera, Plecoptera, and Trichoptera.

most of the invertebrates will occupy the rubble substrate. If sedimentation causes a decrease in rubble-type habitat, a reduction in taxa richness will be observed due to the relation between species richness and area (Gleason, 1922). In an area affected by sedimentation, if the area sampled is increased, there is a good probability of including more rubble-type habitat. Taxa-richness values from sediment-affected areas will then approach those from nonsediment-affected areas. The net result is that sedimentation decreases the numbers of individual organisms but not the number of taxa. In this study, combining samples is, in effect, the same as increasing the area sampled. Similar reductions in taxa richness were observed for all sample sizes; therefore, it is likely that effects other than sedimentation are affecting the benthic fauna (Lenat and others, 1981). Otherwise, as sample size is increased, taxa richness values would also increase.

Table 16.--*Reduction in taxa richness for streams draining agricultural and urban watersheds, compared to the stream draining the forested watershed*

Measure of taxa richness	Percent reduction in taxa richness Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
Kick net samples:		
Mean taxa richness	12	52
Mean EPT[1] taxa richness	48	76
Total taxa richness	4	46
Total EPT taxa richness	47	74
Kick net samples and standardized qualitative samples combined:		
Total taxa richness	16	50
Total EPT taxa richness	48	81

[1] EPT indicates the sum of Ephemeroptera, Plecoptera, and Trichoptera.

The observed reductions in taxa richness indicate moderate stress in the stream draining the agricultural watershed and severe stress in the stream draining the urban watershed (North Carolina Division of Environmental Management, 1983). When data from both sampling techniques and from all sampling dates are combined, total taxa richness relative to the stream draining the forested watershed was reduced by 16 percent in the stream draining the agricultural watershed and by 50 percent in the stream draining the urban watershed (table 16).

Abundance

Density (abundance) values often mirrored the patterns observed for taxa-richness values, but several important differences were seen, especially in the stream draining the Devil's Cradle Creek watershed. The abundance of all insect groups was very low in the stream draining the Marsh Creek watershed. Note that quantitative estimates of density were generated only from kick-net samples.

As expected, the densities of Ephemeroptera and Plecoptera were lower in the agricultural watershed than in the forested watershed. However, in contrast with species richness values, no decline in Trichoptera density was observed in the agricultural watershed compared to the forested watershed. This pattern indicates that some trichopteran species are tolerant of agricultural runoff and other changes associated with agricultural land uses, such as reduced shading, increased sediment, and higher stream temperatures. The opposite trend was observed for Coleoptera in this stream. The stream draining the agricultural watershed had many species but few individuals of Coleoptera, especially in the Dytiscidae and Hydrophilidae. Elmid beetles, a sensitive coleopteran family (Gaufin, 1973), were abundant in the stream draining the forested watershed but were considerably less abundant in the stream draining the agricultural watershed.

Several groups were found to be in greater abundance in the streams draining the Devel's Cradle Creek and Marsh Creek watersheds than in the stream draining the Smith Creek watershed. Chironomidae were very abundant in the agricultural watershed stream, averaging almost 3,000 per sample versus 200 to 500 per sample in the other two streams. Oligochaeta were abundant in both streams draining the agricultural and urban watersheds, but maximum density was recorded in the urban watershed stream. The invertebrates making up the "Other" category were most abundant in the stream draining the agricultural watershed but also were abundant in the urban watershed stream. This increased density was due primarily to the appearance in November of the tolerant nemertean, Prostoma graecens.

A different seasonal pattern was noted in the density of insect groups in the stream draining the agricultural watershed, relative to streams in both the forested and urban watersheds. For the agricultural site, a sharp maximum was recorded for the summer (June) samples, whereas the stream draining the urban watershed had a moderate increase in density in June, but maximum density was recorded in the autumn (November). This pattern indicates that allochthonous energy sources (that is, leaf-fall in autumn) were of primary importance at the urban site, while summertime autochthonous production was most important at the agricultural site. Another investigation (Schlosser and Karr, 1981) also has suggested that autochthonous productivity is an important energy source in streams draining agricultural watersheds.

When density values of individual groups of invertebrates are expressed as a percentage of total abundance (table 17), it is apparent that the benthic community structure in the stream draining the forested watershed is similar to that observed at several other Piedmont streams in forested watersheds in North Carolina: Olin Creek, Iredell County; Huffines Mill Creek, Rockingham County; Four-Mile Creek, Davidson County (North Carolina Division of Environmental Management, 1982). All these sites are dominated by Ephemeroptera (38 to 46 percent), Diptera (25 to 29 percent), and Trichoptera (10 to 16 percent). At the agricultural site, dominance switches from intolerant Ephemeroptera to tolerant Diptera (63 percent). Similar results have been observed at agricultural sites in Rockingham County (North Carolina Division of Environmental Management, 1982). In the stream draining the urban watershed, the community is dominated by the most tolerant group, Oligochaeta. Together, Diptera and Oligochaeta comprise over 75 percent of the invertebrate fauna in the stream draining the urban watershed. Streams in urban areas are typically dominated by these two groups, which are both tolerant of poor water quality (Lenat and others, 1981).

Number of Unique Taxa

The number of unique taxa is defined here as the number of taxa (excluding grossly tolerant species) occurring in only one of the three streams. This type of analysis is important because unpolluted streams often have many intolerant species (species that cannot live in polluted environments) which occur at low abundances. The most intolerant species may occur only in the cleanest streams and, therefore, may be important indicators of water-quality changes, which can not be adequately evaluated

Table 17.--*Percentage of invertebrate communities from Piedmont streams contributed by various groups of organisms*

[Due to rounding, totals do not add up to 100 percent; --, no data]

Invertebrate group	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)	Other forested watersheds in Piedmont[1]		
				Olin Creek	Huffine's Mill Creek	Four-Mile Creek
Annelids						
Oligochaeta	0.7	5.4	54.6	0	3	0
Insects						
Ephemeroptera	41.4	8.3	4	42	46	38
Plecoptera	7.1	2.4	.2	10	2	14
Trichoptera	16.2	13.1	5.6	16	15	10
Coleoptera	5.5	.7	.1	4	1	9
Odonata	1.1	1	.8	--	--	--
Megaloptera	1.5	.2	0	--	--	--
Diptera: Miscellaneous	12.4	12.1	5.9	--	--	--
Chironomids	12.4	51.3	17.7	--	--	--
Total	24.8	63.4	23.6	25	29	27
Crustaceans						
Crustacea	.4	2.2	.5	--	--	--
Mollusks						
Mollusca	.3	.7	2.3	--	--	--
Other	.4	2.5	8	1	2	2

[1] Data from North Carolina Division of Environmental Management, 1982.

by quantitative analysis. Such taxa will be recorded as "unique" species. This type of analysis has been used by several investigators to identify water-quality differences between streams (Winner and others, 1980; Lenat, 1984).

The greatest number of unique taxa, 75, occurred in the stream draining the forested watershed, with 42 unique taxa in the stream draining the agricultural watershed, and only 9 unique taxa in the stream draining the urban watershed (table 18). For most groups of aquatic insects, the number of unique species was greatest in the stream draining the forested watershed; however, the numbers of unique taxa for noninsect groups was always greatest in the stream draining the agricultural watershed. Unique species in the stream draining the urban watershed were limited to the most pollution-tolerant groups (Chironomidae, Oligochaeta, "Other"). This analysis indicates that the stream draining the forested watershed had conditions most supportive of invertebrate groups that are sensitive to pollution and, therefore, independently supports earlier analyses of between-stream differences in water quality.

Table 18.--*Numbers of unique taxa in invertebrate collections from the study watersheds*

Invertebrate group	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
Annelids			
Oligochaeta	1	2	2
Insects			
Ephemeroptera	14	2	0
Plecoptera	5	1	0
Trichoptera	14	1	0
Coleoptera	5	8	0
Odonata	4	2	0
Diptera: Miscellaneous	6	3	0
Diptera: Chironomids	26	15	5
Crustaceans			
Crustacea	0	2	0
Mollusks			
Mollusca	0	3	0
Other	0	3	2
Total	75	42	9

Species Level Data

Invertebrate data presented thus far in this report have focused on summaries of observations: taxa richness, density, and the number of unique species. Additional information can be gained by examining data at the species (or taxon) level in order to reach conclusions about abundance or dominance of species in the selected stream settings. The large size of this data set (274 taxa), however, precludes an examination of all taxa. Therefore, a quantitative method of classifying rare, common, and abundant species was implemented. Only common and abundant species will be analyzed because rare species may be anomalous and not indicative of the water quality of the stream.

Because the two sampling techniques used in this study produced different numbers of individual organisms, different methods were used for evaluating whether a species was rare, common, or abundant. For kick-net samples, a species was classified as rare if less than 20 individual organisms were found in the sample. For the standardized qualitative collections, species were classified as rare if fewer than 3 individuals were found in the sample, common if 3 to 9 individuals were found, and abundant if 10 or more individuals were found. Assigned abundance values were: 1 for rare species, 3 for common species, and 10 for abundant species. A qualitative score was developed for each species by summing the abundance values over all four sampling dates. A qualitative score of 5 or greater from any of the three sites was defined as an arbitrary cut-off for including a species in the analysis. Thus, species with 20 or more individuals in a kick-net sample or having a qualitative score of 5 or more from the standardized qualitative sampling were selected for analysis. Of the total 274 species, 132 were identified as nonrare.

Of these 132 commonly found taxa, 47 were most abundant in the stream draining the forested watershed, and 27 of those were found only in the stream draining the forested watershed. Eighty-five taxa were found in the streams draining the agricultural and urban watersheds in numbers greater than or equal to the abundance in the stream draining the forested watershed. Seventy-three of these were found in the stream draining the agricultural watershed, 26 in the stream draining the urban watershed, and 14 in both the stream draining the agricultural watershed and the stream draining the urban watershed.

There is little overlap between the common and abundant species in the three streams (table 19). Although the watersheds were similar in size and had similar soil types, each stream developed a highly characteristic community. Land use, possibly as it affects substrate characteristics, appears to be a major factor in influencing the development of the aquatic macroinvertebrate communities.

Table 19.--*Comparisons of common and abundant species of macroinvertebrates from the study watersheds*

Sites compared	Total combined abundant taxa	Number of abundant taxa found at both sites
Forested versus agricultural	46	8
Agricultural versus urban	36	6
Forested versus urban	39	3

For each stream, a list was compiled of the 10 most abundant species collected in the kick-net samples. The list was supplemented by any species with a qualitative score ≥ 15 (table 20).

Table 20.--*Dominant species of macroinvertebrates in the study watersheds*

[spp., more than one unidentified species in the genus; sp., one unidentified species in the genus; --, no data; gr., group; cf., compare]

			Abundance					
			Smith Creek (forested watershed)		Devil's Cradle Creek (agricultural watershed)		Marsh Creek (urban watershed)	
Taxon	Invertebrate group	Feeding type	Number of individuals (kick net collections)	Qualitative score (standardized qualitative collections)	Number of individuals (kick net collections)	Qualitative score (standardized qualitative collections)	Number of individuals (kick net collections)	Qualitative score (standardized qualitative collections)
			Kick net samples					
Stenonema modestum	Ephemeroptera	Collector-gatherer	2,646	40	260	33	--	--
Cheumatopsyche spp.	Trichoptera	Filter-feeder	2,525	40	3,916	33	148	21
Isonychia sp.	Ephemeroptera	Filter-feeder	1,595	31	--	--	--	--
Chimarra sp.	Trichoptera	Filter-feeder	1,064	33	--	--	--	--
Prosimulium mixtum	Diptera	Filter-feeder	793	13	--	--	--	--
Optioservus sp.	Coleoptera	Scraper/collector-gatherer	610	21	--	--	--	--
Rheotanytarsus spp.	Diptera	Filter-feeder	476	7	1,664	13	--	--
Microtendipes sp.	Diptera	Filter-feeder	414	26	3,972	40	--	--
Pseudocloeon spp.	Ephemeroptera	Scraper	375	13	772	20	--	--
Taeniopteryx metequi	Plecoptera	Shredder	364	13	--	--	--	--
Cricotopus bicinctus	Diptera	Scraper	--	--	1,204	21	153	31
Simulium venustum	Diptera	Filter-feeder	--	--	800	23	--	--
Conchapelopia gr.	Diptera	Predator	--	--	696	17	--	--
Polypedilum convictum	Diptera	Collector-gatherer	160	16	644	11	--	--
Polypedilum scalaenum	Diptera	Collector-gatherer	--	--	548	16	--	--
Empididae	Diptera	Predator	--	--	456	2	--	--
Limnodrilus hoffmeisteri	Oligochaeta	Collector-gatherer	--	--	--	--	604	10
Nais spp.	Oligochaeta	Collector-gatherer	--	--	--	--	588	14
Prostoma graecens	Oligochaeta	Predator	--	--	--	--	388	3
Polypedilum illinoense	Diptera	Collector-gatherer	--	--	--	--	152	10
Lumbriculidae	Oligochaeta	Collector-gatherer	--	--	--	--	98	26
Baetis flavistriga	Ephemeroptera	Scraper	--	--	--	--	96	11
Limnodrilus cervix	Oligachaeta	Collector-gatherer	--	--	--	--	88	6
Cricotopus infuscatus gr.	Diptera	Scraper	--	--	--	--	76	40

Table 20.--*Dominant species of macroinvertebrates in the study watersheds*--Continued

[spp., more than one unidentified species in the genus; sp., one unidentified species in the genus; --, no data; gr., group; cf., compare]

			Abundance					
			Smith Creek (forested watershed)		Devil's Cradle Creek (agricultural watershed)		Marsh Creek (urban watershed)	
Taxon	Invertebrate group	Feeding type	Number of individuals (kick net collections)	Qualitative score (standardized qualitative collections)	Number of individuals (kick net collections)	Qualitative score (standardized qualitative collections)	Number of individuals (kick net collections)	Qualitative score (standardized qualitative collections)
Standardized qualitative samples (qualitative score equal to or greater than 15)								
Nigronia serricornis	Megaloptera	Predator	168	33	--	--	--	--
Boyeria vinosa	Odonata	Predator	46	33	--	--	--	--
Ophiogomphus sp.	Odonata	Predator	19	26	--	--	--	--
Hydropsyche betteni	Trichoptera	Filter-feeder	265	24	302	40	45	15
Eurylophella bicolor	Ephemeroptera	Collector-gatherer	154	24	--	--	--	--
Baetisca carolina	Ephemeroptera	Collector-gatherer	50	23	--	--	--	--
Macromia sp.	Odonata	Predator	12	19	--	--	--	--
Cordulegaster sp.	Odonata	Predator	4	19	--	--	--	--
Psephenus herricki	Coleoptera	Scraper	64	19	--	--	--	--
Parametriocnemus lundbecki	Diptera	Collector-gatherer	62	19	--	--	--	--
Thienemaniella spp.	Diptera	Collector-gatherer	12	17	376	31	--	--
Tipula abdominalis	Diptera	Shredder	10	17	--	--	--	--
Dubiraphia vittata	Coleoptera	Collector-gatherer	108	17	--	--	--	--
~~Caenis~~ sp.	Ephemeroptera	Collector-gatherer	120	16	--	--	6	20
Tanytarsus spp.	Diptera	Collector-gatherer	100	16	--	--	--	--
Macronychus glabratus	Coleoptera	Collector-gatherer	42	15	--	--	--	--
Progomphus obscurus	Odonata	Predator	--	--	47	24	--	--
Cryptochironomus fulvus	Diptera	Predator	--	--	224	23	--	--
Tribelos sp.	Diptera	Collector-gatherer	--	--	52	23	--	--
Dicrotendipes neomodestus	Diptera	Filter-feeder	--	--	104	21	--	--
Orthocladius cf. obumbratus	Diptera	Scraper	--	--	124	20	--	--
Orthocladius cf. robacki	Diptera	Scraper	--	--	236	20	--	--
Argia spp.	Odonata	Predator	--	--	16	19	3	23
Enallagma sp.	Odonata	Predator	--	--	4	17	2	21
Campeloma decisum	Mollusca	Scraper	--	--	17	17	--	--
Chironomus sp.	Diptera	Collector-gatherer	--	--	21	16	--	--
Cambarus sp.	Crustacea	Scavenger	--	--	18	16	14	24
Gyrinus/Dineutes	Coleoptera	Predator	--	--	8	16	--	--
Antocha sp.	Diptera	Collector-gatherer	--	--	16	15	--	--
Hydroptila sp.	Trichoptera	Piercer	--	--	288	15	--	--

Many of the most abundant species in the stream draining the forested watershed were absent or reduced in abundance in the stream draining the agricultural watershed. However, only a small reduction in total species richness was observed, as many new species were present in the stream draining the agricultural watershed. This pattern did not occur in the stream draining the urban watershed, where taxa richness was much reduced relative to both the stream draining the forested watershed and the stream draining the agricultural watershed.

Feeding Type

Invertebrates collected during the study were also categorized according to feeding types (Merritt and Cummins, 1978; North Carolina Division of Environmental Management, 1987). Analysis of feeding types suggested that land use also affects the food web in aquatic systems. The percentages assigned to each feeding type were computed using data from both the kick-net collections and the standardized collections. Each data set was given equal weight in this computation.

Streams in both agricultural and urban watersheds had a greater proportion of scrapers (species feeding on attached periphyton) than the stream draining the forested watershed (table 21). Shredders (feeding on coarse particulate organic matter) were found (in small numbers) only in the stream draining the forested watershed. Conversely, piercers and scavengers were found only in the streams draining the agricultural and urban water-

Table 21.--*Percentage composition by feeding type of invertebrate communities in the study watersheds*
[--, no data]

Feeding type	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
Filter-feeder	46	47	10
Collector-gatherer	34	19	46
Scraper	4	16	21
Predator	12	15	16
Shredder	4	--	--
Piercers and scavengers	--	3	7

sheds. Filter feeders were abundant in both the stream draining the forested watershed and the stream draining the agricultural watershed (46 and 47 percent, respectively), but were much less abundant (10 percent) in the stream draining the urban watershed. Collector-gatherers were important in all streams but comprised the greatest proportion of the fauna in the stream draining the urban watershed. Predators made up a relatively constant proportion of the fauna in all streams (12 to 16 percent).

FISH

Fish collections were made in September 1984 (rotenone) and February 1986 (shocking and seining) (table 22). Low flow during the September sampling may have affected the diversity of the fish community, especially the low species richness in the stream draining the forested watershed. This was the only sample with significant numbers of green sunfish. Lemly (1985) has suggested that green sunfish (an introduced species) may eliminate native species in small (first-order) Piedmont streams. Low flow during September 1984 may have caused Smith Creek, normally a second-order stream, to take on first-order characteristics with respect to streamflow. February sampling may also produce some atypical characteristics. Specifically, some larger game fish may retreat to deeper water during cold weather. Looking at the combined data (both collections) gives a broad approach to the analysis.

Table 22.--*Summary of combined fish collections from the study watersheds*

Community measure	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
Species richness	19	19	9
Darter species	2	1	1
Sucker species	2	2	0
Game fish species	6	6	3
Intolerant species	3	2	0
Number of individuals	305	755	79
Percent omnivores	70	54	66
Percent insectivorous cyprinids	8	0	1
Percent gamefish	19	20	13
Biomass (g)	3,766	8,494	503
Index of biotic integrity	50	48	34

Relative to stressed sites, unpolluted streams generally have higher total species richness, greater numbers of darter and sucker species, a higher proportion of insectivores, and a lower proportion of omnivores. Also, unpolluted streams have more rare and (or) intolerant species and more game fish, especially Centrarchidae (Karr, 1981; Fausch and others, 1984).

Application of these concepts to analysis of the fish data indicates good water quality in both the stream draining the forested watershed and the stream draining the agricultural watershed. Both streams had high species richness (19), substantial numbers of game fish, and either 3 or 4 darter-sucker combined species. Slightly better water quality was indicated in the stream draining the forested watershed by the presence of insectivorous Cyprinidae and two rare species: Umbra pygmaea and Etheostoma collis. Also, game fish species, especially redbreast sunfish, generally attained larger size in the stream draining the forested watershed (tables 23 and 24).

Table 23.--*Maximum length for selected fish species collected from the study watersheds*

[Results in inches; --, no data]

Fish species	September 1984 sample			February 1986 sample		
	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
Non-game fish						
Bluehead chub	4.88	6.30	1.42	6.22	6.30	6.10
White shiner	5.28	5.63	2.20	4.57	4.13	--
Swallotail shiner	2.60	2.91	2.56	2.36	--	2.32
Tesselated darter	2.05	2.87	--	2.32	3.31	2.83
Game fish						
Redfin pickerel	5.67	10.75	--	4.80	8.98	--
Redbreast sunfish	7.56	6.97	--	6.89	4.13	--
Bluegill	5.08	4.84	--	--	--	3.03
Largemouth bass	5.16	3.98	--	--	--	--

The stream draining the agricultural watershed had very large minnow populations in September, especially bluehead chub, golden shiner, and white shiner. Also, many nongame species (especially minnows) were larger in the stream draining the agricultural watershed than in the other two streams (tables 23 and 24). These fish probably benefited from the greater amounts of food (invertebrates, periphyton) available in the nutrient-rich stream draining the agricultural watershed. Similar results were observed at

Georgia streams draining agricultural watersheds by Cook and others (1983) and Georgia Department of Natural Resources (1983). However, these results cannot be applied to all Piedmont streams. For example, statewide fisheries surveys in North Carolina (1960-1965) linked agricultural land use with impaired fish communities (Bayless and Smith, 1964; Messer and others, 1965).

Table 24.--*Mean weight for selected fish species collected from the study watersheds*

[Units in ounces; --, no data]

	September 1984 sample			February 1986 sample		
Fish species	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
Non-game fish						
Bluehead chub	0.18	0.56	0.05	0.46	0.84	0.32
White shiner	.36	.37	.08	.56	.13	--
Swallowtail shiner	.10	.16	.07	.09	--	.05
Tesselated darter	.04	.10	--	.05	.08	.10
Game fish						
Redfin pickerel	.24	4.04	--	.42	1.92	--
Redbreast sunfish	2.80	.83	--	3.87	.42	--
Bluegill	1.90	.64	--	--	--	.21
Largemouth bass	1.48	.40	--	--	--	--

The fish community in the stream draining the urban watershed was clearly impaired relative to the streams draining the forested and the agricultural watersheds. This stream was characterized by low species richness, low biomass, and the absence of any intolerant species (table 22).

For both the stream draining the forested watershed and the stream draining the urban watershed, the conclusion reached is the same whether the macroinvertebrate community data or the fish community data are used. That is, both communities indicated impairment in the stream draining the urban watershed and a healthy condition in the stream draining the forested watershed. However, analysis of fish and macroinvertebrate collections lead to very different conclusions for the stream draining the agricultural watershed. The benthic macroinvertebrate community of the stream draining the agricultural watershed indicated the existence of stressed conditions, but the fish community indicated only minor stress. This may be due to either differences in sensitivity or differences in habitat.

EFFECTS OF LAND USE ON WATER QUALITY AND BIOTA

So far, this report has examined chemical and physical characteristics and the biota of streams in different land-use areas. In this section, a brief synopsis of the important findings will be presented simply to refresh the reader with the differences in stream characteristics that may be attributed to differences in land use.

A qualitative summary of the major findings of the study is presented in table 25. The stream draining the forested watershed was found to have the best water quality based on a number of different measures. This stream had the lowest suspended-sediment yield and the lowest stream-water nutrient concentrations. Analyses of invertebrate biota consistently reflected biological communities with high invertebrate taxa richness, a high number of intolerant groups, a high number of sensitive species, and a high number of unique species. Analyses of fish data from the stream draining the forested watershed also reflected a healthy system with high fish taxa richness, many gamefish species, and a high number of intolerant fish species.

Table 25.--*Summary of findings on relative quality of stream water, sediments, and biota for the study watersheds*

Stream characteristic	Smith Creek (forested watershed)	Devil's Cradle Creek (agricultural watershed)	Marsh Creek (urban watershed)
<u>Biota</u>			
Invertebrate taxa richness			
Total taxa richness	high	high	low
Intolerant groups	high	medium	low
Invertebrate abundance			
Sensitive invertebrate species	high	medium	low
Tolerant invertebrate species	low	medium	high
Number of "unique" invertebrate taxa	high	medium	low
Fish taxa richness	high	high	low
Game fish species	high	high	low
Intolerant fish species	high	medium	low
<u>Sediments</u>			
Suspended sediment yield	low	medium	high
Concentration of metals in sand-sized bottom material	high	low	medium
Concentration of metals in silt-clay-sized bottom material	high	low	medium
Percentage of sand-sized bottom material	low	high	medium
Percentage of silt-clay-sized bottom material	low	high	medium
<u>Stream water</u>			
Nutrient concentrations	low	high	medium
Total metal concentrations	medium	low	high
Dissolved metal concentrations	medium	medium	medium

The stream draining the agricultural watershed had intermediate water quality. Suspended-sediment yield was greater than in the stream draining the forested watershed but less than that in the stream draining the urban watershed. Total metal concentrations in bottom sediments and stream water were low, but nutrients in stream water were higher than at either of the other two streams. Biological data revealed some characteristics of a healthy community, such as high invertebrate and fish taxa richness and a large number of gamefish species. However, some of the sensitive invertebrate species and intolerant fish species found in the stream draining the forested watershed were not found in the stream draining the agricultural watershed.

By almost all the measures examined, the stream draining the urban watershed exhibited the most impaired water quality. Suspended-sediment yield was the highest of any of the three streams. Stream-water nutrient concentrations were intermediate, but total metal concentrations were greatest, though not statistically significant, in this stream. The stream draining the urban watershed consistently had biological assemblages with the lowest invertebrate taxa richness, the lowest number of representatives from intolerant invertebrate groups and sensitive species, and the lowest number of unique taxa. The lowest fish taxa richness, the lowest number of gamefish species, and the lowest number of intolerant fish species all were found in the stream draining the urban watershed.

The observed differences in stream water quality and biota in the three streams can be attributed to differences in land use because the three streams were selected so that factors other than land use were similar among watersheds. As might be expected, undisturbed, forested land-use practices had the least effect on stream water quality and urban land use had the greatest effect.

SUMMARY

Three streams in the Piedmont province of North Carolina with similar watershed characteristics but having different land uses were studied to compare the effects of land use on water-quality characteristics and aquatic biota. The three streams, Smith Creek, Devil's Cradle Creek, and Marsh Creek, were dominated by forested land, agricultural land, and urban land, respectively. Sediment chemistry and quantity, water chemistry, and biota were studied in each stream during the period from February 1984 through January 1985.

Investigations of sediment characteristics revealed that suspended-sediment yield was highest in the stream draining the urban watershed with an annual yield of 0.59 tons per acre during the year of the study. This was more than four times the 0.13 tons per acre yielded from the stream draining the forested watershed and almost twice the 0.31 tons per acre yielded from the stream draining the agricultural watershed.

Concentrations of metals associated with bottom material from all three streams were generally higher in the silt-clay fraction than in the sand fraction. Comparisons of total metal concentrations in bottom material among streams showed some inconsistencies. For the silt-clay sized fraction, chromium, iron, nickel, and zinc concentrations were highest in the stream draining the forested watershed, whereas cadmium and manganese concentrations were highest in the stream draining the urban watershed. For the sand fraction, chromium, copper, and manganese were highest in the stream draining the forested watershed, but iron was highest in the stream draining the urban watershed. These results are unexpected because previous research has found high concentrations of metals in water and sediment from streams in urban areas. Perhaps the dominance of residential land use and the lack of heavy industry and manufacturing in the selected urban watershed can explain this finding.

Particle-size distributions for bottom material showed that the stream draining the agricultural watershed had a higher percentage of sand-size and silt-clay size particles than either the stream draining the forested watershed or the stream draining the urban watershed. However, the bottom material of all three streams was dominated by the sand fraction.

Water-quality investigations revealed no excessively low dissolved oxygen, high water temperature, or extreme pH values at any of the three streams that would pose stressful conditions for aquatic life. Mean nutrient concentrations were highest in the stream draining the agricultural watershed. Concentrations of the metals cadmium, chromium, copper, iron, lead, nickel, and zinc were usually low enough that toxic conditions were not encountered. However, individual samples of total copper, iron, and lead from all three sites exceeded North Carolina water-quality standards for all fresh waters, and samples of total zinc from both the stream draining the forested watershed and the stream draining the urban watershed exceeded the State standard. The existence of healthy biological communities in streams where water-quality standards are exceeded may reflect the use of total concentrations of metals for the standards rather than available dissolved concentrations. Therefore, the use of total concentrations of metals for standards may not be a reliable indicator of the biologically available fraction. This also points out the need for multiple measures of stream quality and punctuates the value of biological sampling for evaluating stream health.

Benthic macroinvertebrate data (especially taxa richness) indicated the least impaired water quality at the forested site, intermediate water quality at the agricultural site, and the most impaired water quality at the urban site. Both agricultural and urban land-use sites showed water-quality changes that affected stream biota, but biota in the stream draining the urban watershed were clearly the most severely affected. The urban site was characterized by low taxa richness and low density of most invertebrate groups, indicating that sedimentation and water-quality may be affecting the invertebrate fauna.

The stream draining the agricultural watershed had low taxa richness values for intolerant groups but high taxa richness for some tolerant/facultative groups. This site also had the highest density of benthic macroinvertebrates, reflecting some nutrient enrichment. Seasonal changes in the biota indicated that benthic macroinvertebrates of this stream rely more heavily on periphyton production rather than leaf detritus.

Community structure of the macroinvertebrates is also useful for assessing stream quality. Because all three of the streams were of similar size and were located in geologically similar areas, we would expect the dominant species to be the same in each stream. However, lists of dominant species at each site produced little overlap. Because land use is the major feature that changes among the watersheds, this suggests that land use is of overriding importance in controlling the composition of stream benthic communities.

Both fish and macroinvertebrate community data indicated a healthy environment in the forested stream and an impaired environment in the urban stream. However, fish data from the agricultural stream indicated a healthy environment, with increased numbers of individuals and increased biomass compared to the forested and urban streams. On the other hand, macroinvertebrate data for the agricultural stream suggested a moderately impaired environment.

Differences in the dominant land use among the three watersheds are probably responsible for the observed differences in water quality and biota in the streams because these three streams were selected so that other physical factors would be similar. As might be expected, the largely undeveloped forested lands in the Smith Creek watershed have had little effect on stream water quality and biota. Agricultural land use in the Devil's Cradle Creek watershed appears to have contributed to the slightly elevated sediment yield of the stream, the relatively high nutrient concentrations in the stream, and the loss of some of the less tolerant species of biota. Urban land use in the Marsh Creek watershed appears to have had a pronounced effect on the water quality and on the biological community in that stream. Urban land use is believed to have contributed to the relatively high suspended-sediment yield of the stream, somewhat elevated concentrations of nutrients and total metals, and the loss of many species of invertebrates and fish from the stream. The impacts of these land-use practices on water quality and biota were not unexpected and may be typical of the effects of these land-use practices on other streams in the area.

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