EFFECTS OF LAND-MANAGEMENT PRACTICES ON SEDIMENT YIELDS IN NORTHEASTERN GUILFORD COUNTY, NORTH CAROLINA

By Catherine L. Hill

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INTERNATIONAL SYSTEM UNITS

The following factors may be used to convert inch-pound units published in this report to metric (International System) units.

Multiply inch-pound unit	By	To obtain metric unit
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/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)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
ton (short, 2,000 pounds)	0.9072	megagram (Mg), or metric ton (t)
	Mass per unit area	
ton per acre	36.7144	kilogram per hectare

Temperature: In this report temperature is given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by the following equation:

$$°C = 5/9 \times (°F-32)$$

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-MANAGEMENT PRACTICES ON SEDIMENT YIELDS IN NORTHEASTERN GUILFORD COUNTY, NORTH CAROLINA

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ABSTRACT

Streamflow, precipitation, and suspended-sediment data were collected from two small agricultural basins in the Piedmont province of North Carolina. The data were used to determine the effects of land-management practices on sediment yield. One basin of 7.4 acres represents best land-management practices with strip cropping, crop rotation, contour farming, and grassed waterways. The other basin of 4.8 acres represents standard land-management practices with down-slope row orientation, unmaintained grassed waterways, and without crop rotation.

Data collected during the 1985-87 water years were used to develop regression equations to describe the relation between suspended-sediment discharge and water discharge. Data sets consisting of suspended-sediment concentrations and corresponding instantaneous water-discharge data were developed. There were two data sets from each basin, one representing data collected during the growing season, May through September, and the other representing data collected during the nongrowing season, October through April.

Four regression equations were developed, one for each data set, and were tested for goodness-of-fit by use of graphical analysis, influence diagnostics, significance tests, and residuals analysis. Following acceptance of the four equations, the slope of each individual line was tested to determine if season was a significant variable. Seasonally, the average sediment yields (2.7 tons per acre) from the basin having best land-management practices were only about one-seventh of those (20 tons per acre) from the basin having standard land-management practices.

Comparison of annual sediment yields in the agricultural basins against the yield from a nearby forested basin, which represents a nearly undisturbed basin, indicates a 10- to 100-fold increase in sediment yields from the study basins. The forested basin sediment yield was 0.1 ton per acre in the 1987 water year.

Sheet erosion, which represents soil moving from high areas to low areas in a basin but not necessarily reaching a stream, is also influenced by land-management practices. This type of erosion was estimated to be 3.6 tons per acre per year for the basin with best land-management practices and 45 tons per acre per year for the basin with standard land-management practices.

INTRODUCTION

Runoff and the resulting soil erosion from agricultural lands is a major source of nonpoint pollution nationwide. Of the 421 million acres of cropland in the United States, 118 million are considered highly erodible (Myers, 1988). Land is defined as highly erodible when the potential erosion is more than eight times the rate at which the soil can maintain continued productivity (U.S. Department of Agriculture, 1986). These 118 million acres are further broken down according to State, with 7 States having over 5 million acres, 19 States (including North Carolina) having 1 to 5 million acres, 8 States having 500,000 to 1 million acres, and the remainder having less than 500,000 acres of highly erodible land (fig. 1).

Accelerated erosion, erosion occurring at a rate greater than the natural formation of soil, is a result of two factors: (1) improper management of productive soils and (2) exploitation of marginal lands (Dregne, 1982). Such factors as row orientation up and down the slope or the effect of intense raindrops on unprotected, barren land will eventually cause any soil to erode. Accelerated erosion has been acknowledged as a serious problem in the United States since the 1930's. The concept of soil-loss tolerance, or the maximum average annual permissible soil loss that can occur without decreasing soil productivity, was applied to croplands as early as 1947 (Schmidt and others, 1982). However, soil erosion continues

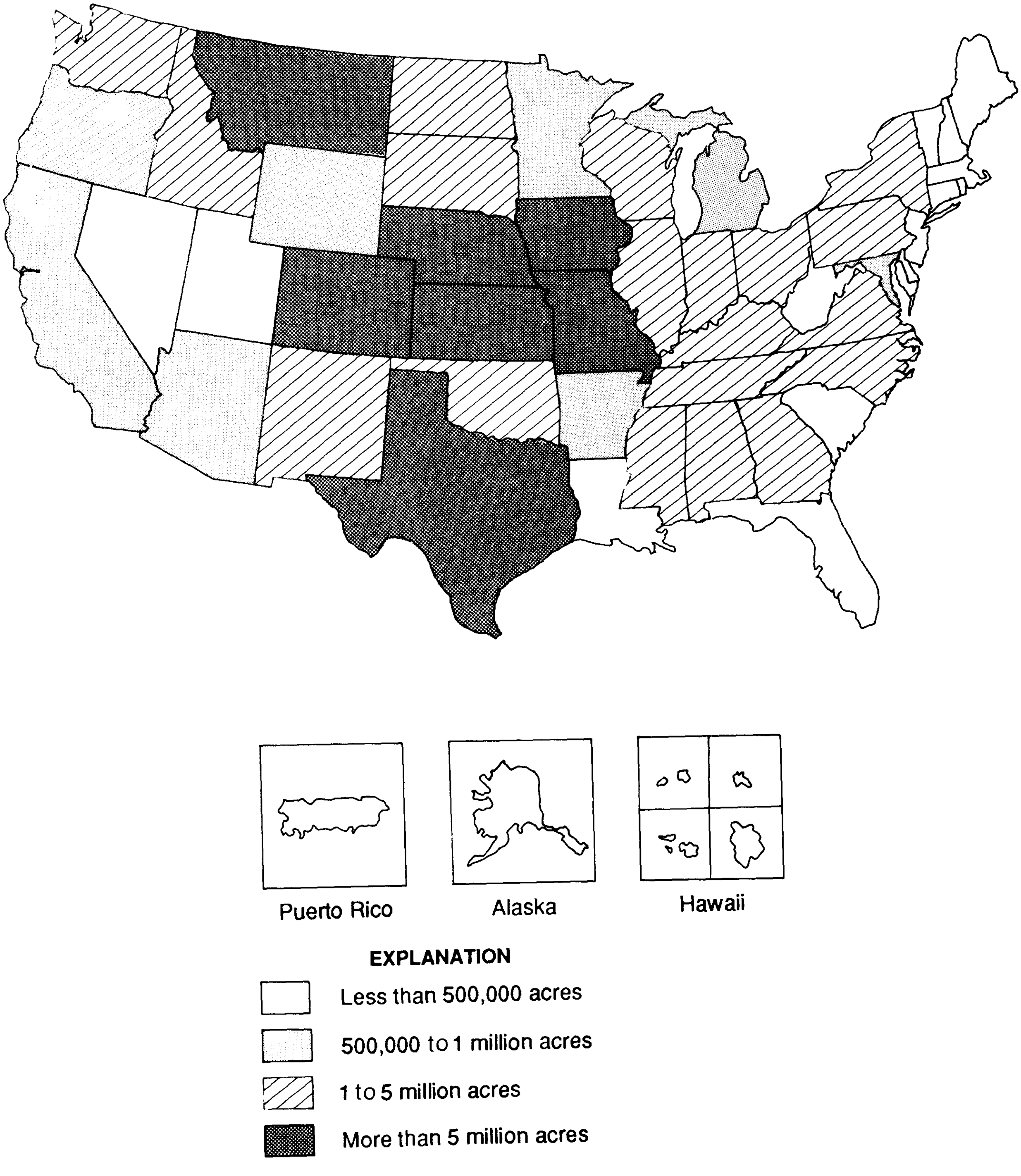


Figure 1.--Remaining acres of highly erodible land needing conservation treatment, by State.
(Reproduced with permission of Journal of Soil and Water Conservation; modified from Meyers, 1988.)

to be a relentless process more than 40 years later due, in part, to advances in technology masking erosion and misperceptions concerning the extent of the erosion.

Advances in technology have masked the effects of soil erosion on crop yield (Krauss and Allmaras, 1982). Soil erosion reduces crop yield, primarily through the loss of nutrients and available water in the soil (Langdale and Shrader, 1982). This loss of nutrients and available water can generally be compensated for, or masked, by increasing fertilizer applications and irrigation.

Land-owner perceptions of erosion severity have also affected the successful implementation of soil conservation policies. A recent survey of farmers showed misperceptions about the severity of erosion and the effectiveness of best land-management practices (BMP's). BMP's are defined by the Soil Conservation Service (SCS) as practices developed by a process that considers the effect on water quality as well as social, political, economic, and technical feasibility. In contrast, standard land-management practices (SMP's) are defined by characteristics such as ungrassed water ways and straight-row farming (North Carolina Agricultural Extension Service, 1982). The farmers' perceptions of highly erodible land represented only 28 percent of what the U.S. Department of Agriculture criteria define as highly erodible (Osterman and Hicks, 1988). This misconception might be one reason why voluntary erosion-control programs have had limited success.

Soil erosion has recently become a national priority in the United States and other developed countries. In the United States, the seriousness of the soil erosion problem was reaffirmed and addressed with the passage of the 1985 Farm Bill. This bill presents various ways to reduce soil erosion and the resulting nonpoint-source pollution. Nonpoint-source pollution, such as sediment, depends on the hydrologic cycle, or the resulting flow of water across the soil surface, to provide the transport process. In discussing the 1985 Farm Bill, Wilson Scaling, Chief of the SCS, described one of SCS's basic goals as achieving significant reductions in soil erosion without imposing unreasonable economic costs on producers or the taxpayers

(Scaling, 1988). The Conservation Compliance Provision of the Farm Bill requires farmers to use approved conservation systems on highly erodible croplands or lose eligibility for certain U.S. Department of Agriculture program benefits. These benefits include crop insurance, Farmers Home Administration loans, and price and income supports.

The Conservation Compliance Provision of the Farm Bill also discourages the production of crops on highly erodible cropland that is not protected from erosion. It requires farmers to develop conservation plans by January 1, 1990, and fully implement these plans by January 1, 1995. These plans will be developed by farmers in cooperation with the SCS and the local conservation district.

Experience has indicated that control of nonpoint-source pollution is more appropriate when based on preventive land-management practices rather than direct compliance with water-quality standards (Harper, 1987). The Environmental Protection Agency's primary strategy for control of nonpoint-source pollution is through design and implementation of appropriate BMP's (U.S. Environmental Protection Agency, 1985). Although the implementation of BMP's can reduce nonpoint pollution, particularly sediment, few scientific studies specifically address water-quality questions relevant to agricultural practices in the clay-type soils prevalent in central North Carolina in the Piedmont province. In addition, as indicated by misperceptions of soil erodibility and the benefits of BMP's, there is a need for a statistical evaluation of data available to objectively quantify the effects that land-management practices have on erosion and sediment yield.

An area in the north-central part of the North Carolina Piedmont was chosen to document the effects of land-management practices on sediment losses (fig. 2). This area was chosen because of the susceptibility of soils to erosion and the ongoing agricultural activities. Results of this study may apply to similar agricultural lands in the Piedmont physiographic region of the southeastern United States.

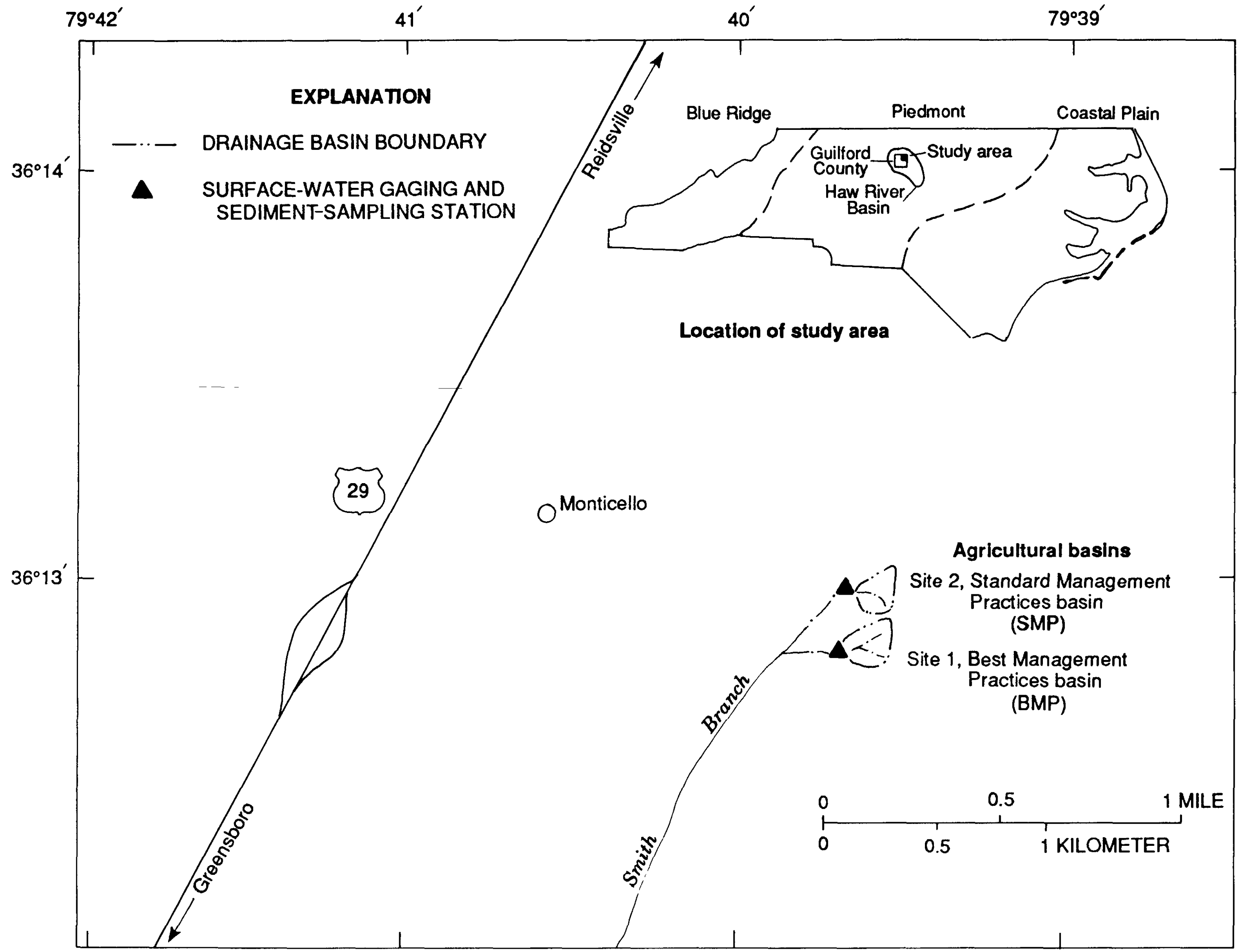


Figure 2.--Location of agricultural basins and study sites in the Piedmont of North Carolina.

Data used for this report were collected as part of a larger study. In late 1984, the U.S. Geological Survey (USGS) and the Guilford Soil and Water Conservation District, with assistance from SCS, began a cooperative study designed to document the effects of land-management practices on sediment yields, as well as nutrients and selected organic constituents in surface runoff and ground water. A monitoring network of surface- and ground-water stations was installed for this purpose.

Purpose and Scope

This report contains a statistical evaluation of the effects of land-management practices on sediment yields in Guilford County, North Carolina. Data available from two agricultural basins, one under BMP's (grassed waterways, strip cropping, contour farming, and crop rotation) and the other under SMP's (row orientation up and down the slope, unmaintained grassed waterways, and without crop rotation) were analyzed seasonally, annually, and for discrete runoff events to determine differences in sediment yields caused by selected land-management practices.

Suspended-sediment concentrations and the corresponding instantaneous water-discharge values collected during the period June 1985 through September 1987 were used to develop regression equations to predict suspended-sediment concentrations. These equations were evaluated for goodness-of-fit. Sediment yields were calculated by applying the predictive equations to unit-discharge data collected during the period October 1985 through September 1988. The resulting sediment yields were analyzed seasonally, annually, and for discrete precipitation events to evaluate the effects of land-management practices on sediment yield.

Acknowledgments

The author wishes to acknowledge the technical assistance of the Guilford Soil and Water Conservation District staff and the Soil Conservation Service, as well as the unfailing cooperation of the agricultural basin landowners, Messrs. Larry and T.R. Spencer.

DESCRIPTION OF THE STUDY AREA

The study area is in Guilford County in north-central North Carolina, about 7 miles northeast of Greensboro (fig. 2) and 1 mile southeast of Monticello in the headwaters of the Haw River basin. It is located upstream from a major public water-supply reservoir in a State-designated nutrient-sensitive watershed. The government provides increased cost-sharing and technical assistance for farmers to install BMP's where it is expected these improvements have the potential for reducing surface- and ground-water pollution.

Physiography

The study area is in the north-central part of the Piedmont province of North Carolina that is in the Piedmont physiographic region of the United States. This region extends in a southwesterly direction from New York to Alabama, encompassing the nonmountainous part of the older Appalachians. Typically, the landscape is a rolling surface of gentle slopes, cut or bounded by valleys of steeper slope and depth, often several hundred feet deep. Soil erosion is favored in the Piedmont region by the character of the clay soils derived from highly feldspathic rocks that are decayed to great depths (Fenneman, 1938). The southern Piedmont physiographic region (fig. 3) encompasses an area of 59,000 square miles extending from Virginia through North Carolina, South Carolina, Georgia, and into Alabama (Smith and others, 1978).

The Piedmont province of North Carolina occupies almost 45 percent of the State's area, between the Blue Ridge and the Coastal Plain provinces (Clay and others, 1975). The area is characterized by clayey soils, rolling topography, and abundant rainfall. These characteristics, combined with SMP's as defined by the SCS (North Carolina Agricultural Extension Service, 1982) such as ungrassed waterways and straight-row farming, contribute to the accelerated erosion of valuable cropland. Streams in the Piedmont province have the highest sediment yields in North Carolina (Simmons, 1988). Average annual soil loss from cropland in the Piedmont area of North

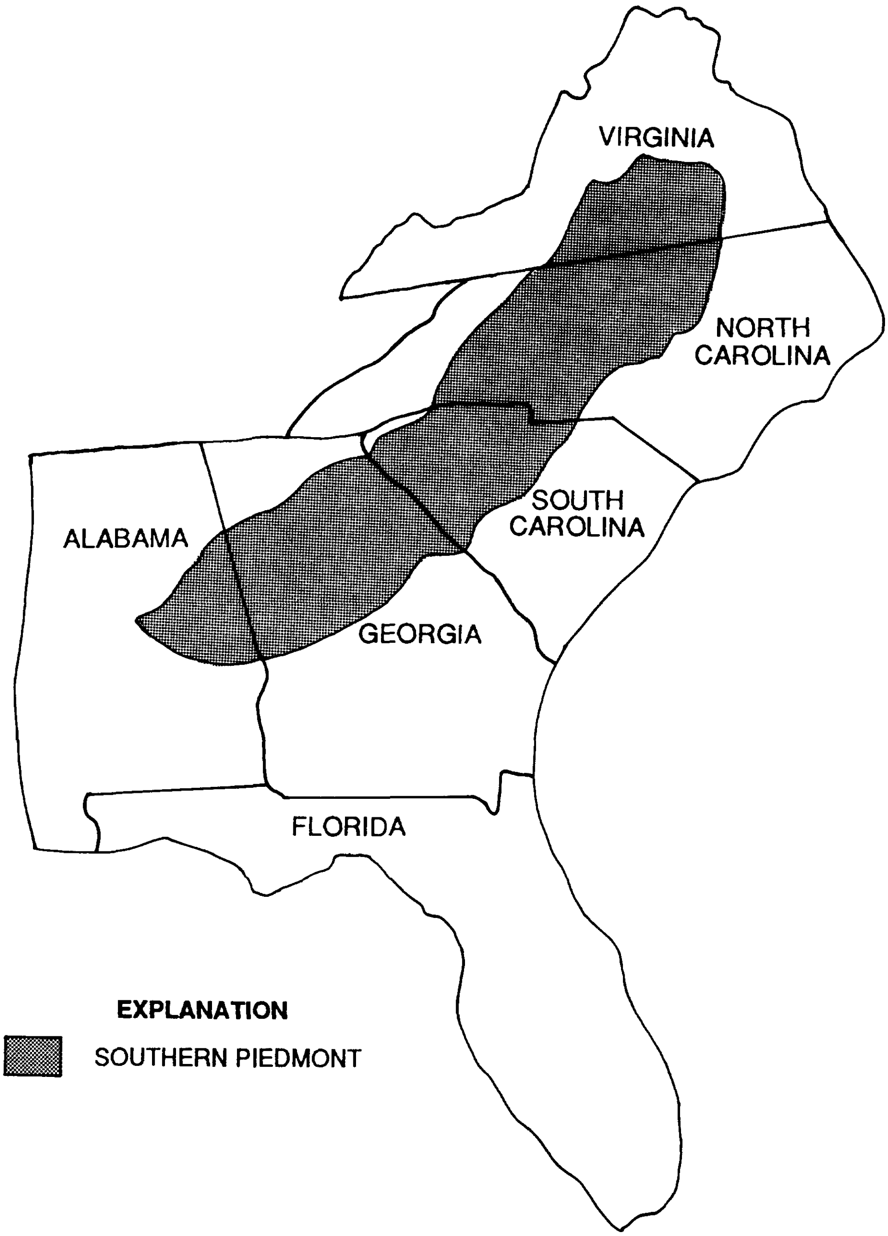


Figure 3.--Location of southern Piedmont physiographic region. (From Smith and others, 1978.)

Carolina is 18 tons per acre. This rate is about three times the State average and almost four times greater than the amount considered acceptable by the SCS (U.S. Department of Agriculture, 1982).

Climate

Climate in the Piedmont province is relatively mild, with average temperatures of 77 °F in July and 40 °F in January. There are frequent occasions of below-freezing temperatures in early mornings, but it rarely remains below freezing through the day (Hardy and others, 1967). Precipitation is relatively evenly distributed throughout the year, with an average annual accumulation of 42 inches (Eder and others, 1983). Most of the precipitation is in the form of rain, but some snow and sleet generally fall each year. Although North Carolina has no distinct wet or dry season, historically, the most precipitation occurs in July and August due to locally heavy thunderstorms or hurricanes. The least precipitation generally occurs in October and November. Average runoff is about 13 inches per year (Yonts, 1971).

Agricultural Basin Characteristics

Data were collected from two adjacent, completely cultivated basins located 1 mile southeast of Monticello. Both basins are cultivated by the same farmer, minimizing variations in land preparations and crop cultivation. Tobacco and wheat are the primary and secondary crops. The typical growing season, when tobacco is in the ground at the two study basins, is May through September. The nongrowing season, which occurs after the tobacco has been harvested, is generally October through April. A small-grain cover crop is planted in both basins during the nongrowing season, but growth is generally sparse. The basins are a paired watershed design, with one basin representing BMP's and the other representing SMP's. The basins were arbitrarily assigned BMP or SMP designation; the BMP-designated basin was farmed according to BMP standards and the other was not.

Smith Branch lower tributary near Monticello (fig. 2, site 1) represents BMP's with (1) grassed waterways, (2) field borders, (3) contour farming, (4) crop rotation, and (5) strip cropping. The strip cropping is a pattern of alternating two years of tobacco with two years of wheat seeded with fescue. During the first year of the study, 1984-1985, the drainage area was 5.9 acres. In the fall of 1985, the row orientation was modified to improve runoff conditions, increasing the basin to 7.4 acres. During the growing season, 3.7 acres are planted in tobacco. The remaining 3.7 acres are planted in fescue or wheat. The strips were rotated in the fall of 1987.

Smith Branch upper tributary near Monticello (fig. 2, site 2) represents SMP's with (1) row orientation up and down the slope, (2) poorly-maintained grassed waterways, and (3) continuous production of tobacco during the growing season (no crop rotation). This basin has a drainage area of 4.8 acres. During the third year of the study, 1987, the waterway began filling up with sediment, causing some runoff to pond before reaching the runoff gage. The waterway was reworked during the fall of 1987, improving runoff conditions.

Both basins are underlain by reddish clay soils of the Cecil-Madison Association, derived from felsic crystalline parent rock. The predominant soil series is Cecil sandy-clay loam, which is moderately eroded with erodibility factors of 0.28 to 0.37, well drained, and moderately permeable. Topsoil depths range from completely eroded to about 12 inches, with an average depth of 7 inches. The subsoil extends to a depth of approximately 62 inches. There are two small pockets of Helena sandy-loam soil, one in each basin near the runoff gages. This soil is moderately well drained with moderate to moderately slow permeability (Larry Sink, Soil Conservation Service, written commun., 1984). Soil textures were determined from soil borings taken from each basin. Analysis done by the North Carolina Department of Transportation, Soils Laboratory, classified the soil texture as approximately 25-percent sand, 31-percent silt, and 44-percent clay at depths up to 9 feet below land surface. Primary particle size distributions done on several suspended-sediment samples indicate an average suspended-sediment composition of 25-percent silt and 75-percent clay.

Guilford Soil and Water Conservation District conducted a topographic survey of the two basins to establish elevations at the stream gages and within the basins, as well as to determine the drainage areas. Land-surface elevations slope gradually from about 835 feet at the eastern edge of the basins to 810 feet near the stream gages at the western edge of the basins (fig. 4). Slopes on both basins range from 0 to 10 percent.

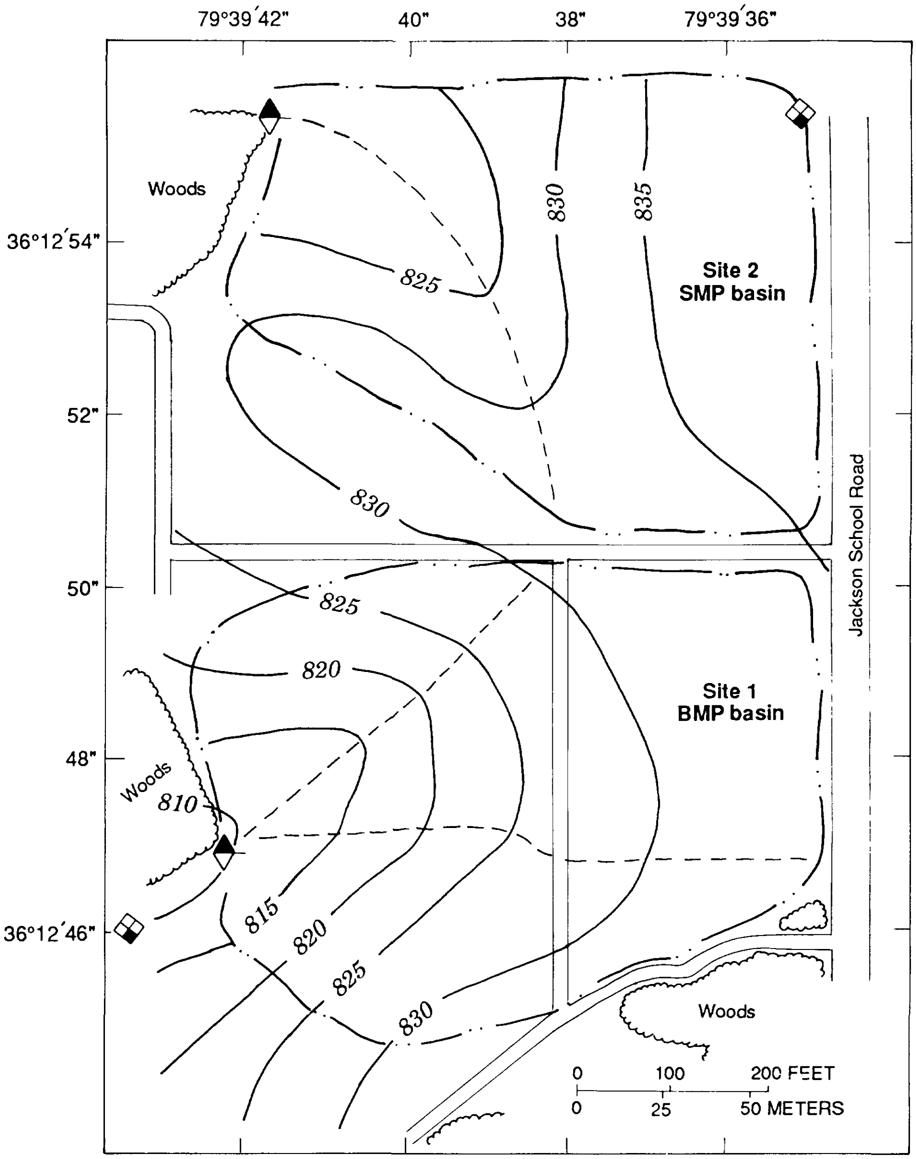
Although the major difference between the two basins is the type of conservation practice, it should be noted that the basins have other differences in physical characteristics that may affect runoff and sediment transport values. Surface slopes are somewhat greater in the BMP basin, where elevations range from about 830 to 810 feet compared with elevations of about 835 to 825 feet in the SMP basin. The average slope is 4 percent in the BMP basin and 3 percent in the SMP basin. In addition, the BMP basin is drained by two waterways, whereas the SMP basin is drained by one centrally located waterway.

DATA COLLECTION AND ANALYSIS

Data Collection

Hydrologic data collected at the two basins include precipitation quantity, gage height and discharge of the runoff, and suspended-sediment concentrations in the runoff. Each basin has a rain gage and stream gage, which record precipitation accumulation and gage height of runoff at 5-minute intervals. The rain gages are located approximately 0.25 mile apart at diagonal ends of the two basins.

The waterways draining the basins are intermittent stream courses, and runoff occurs only during and immediately following precipitation events. Located at the low point of each basin, the gages are equipped with standard 120-degree V-notch weirs and wingwalls. Gage design was based on calculated flow amounts, and wingwall alignment was based on row orientation. Discharge measurements were made volumetrically and with current meters over the full range of stage using standard USGS methods (Rantz and others, 1982). Discharge ratings for the two basins were developed using discharge measurements and theoretical ratings for the V-notch weirs.



EXPLANATION

—*810*— LAND-SURFACE CONTOUR--Shows elevation of land surface. Contour interval 5 feet. Datum is sea level

—·· — DRAINAGE BOUNDARY

- - - - - - WATERWAY

▲ STREAMFLOW GAGING STATION

▽ SEDIMENT-SAMPLING SITE

◈ PRECIPITATION STATION

SMP STANDARD LAND-MANAGEMENT PRACTICES

BMP BEST LAND-MANAGEMENT PRACTICES

Figure 4.--Land-surface elevations, drainage areas, waterways, and gages in agricultural basins.

Automatic water-pumping samplers obtained instream samples of suspended sediment at 5-minute intervals during selected storms. The samplers were set to activate at a certain gage height and continue to collect samples while the gage height is higher than a reference level.

Suspended-sediment concentrations were analyzed using methodology documented by Guy (1969). All data collected for this study are in the computerized national data files of the USGS, National Water Data Storage and Retrieval System (Hutchinson, 1975). Data collected from 1985 through 1988 have been published (Hill, 1989).

Information on preparation and cultivation of the tobacco and wheat crops, including field preparation, disking, and plowing, was collected by the Guilford Soil and Water Conservation District. This information assisted in analyzing sediment yields resulting from discrete precipitation events.

Data Analysis

Suspended Sediment

Suspended-sediment samples were collected manually and with automated sampling equipment. Samples collected using an automated sampler at a fixed point may not be representative of actual suspended-sediment concentrations averaged over a stream cross section. However, manual sampling produces a sample that is both depth- and width-integrated. For this reason, some authors (Crawford, 1989, for example) have suggested using an adjustment factor to eliminate possible bias in the automated sample concentrations. This factor would adjust the automated sample concentrations to the concurrently collected manual sample concentration, presumably eliminating any potential bias. The relation between samples collected manually and those collected with an automatic sampling device is shown in figure 5.

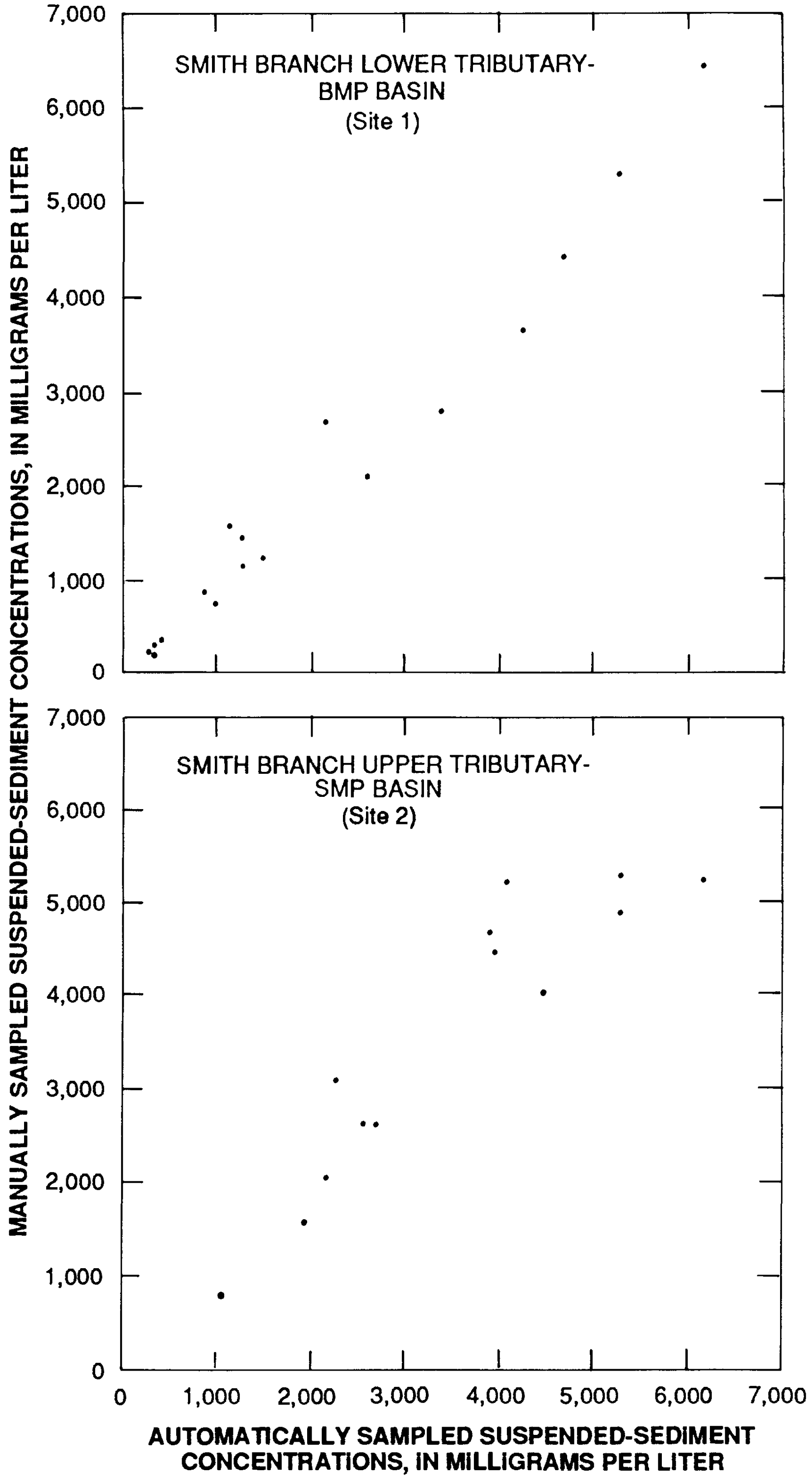


Figure 5.--Relation between manually sampled and automatically sampled suspended-sediment concentrations in the study basins.

An adjustment model was developed based on the relation between concentrations of suspended sediment in samples collected automatically and those in samples collected manually. The model is:

$$Ca = Bo + (B1)(Cm) + e, \qquad (1)$$

where: Ca is the automated sample concentration;
Cm is the manual sample concentration;
Bo is a constant;
$B1$ is the coefficient; and
e is the error term.

A hypothesis test, equivalent to testing for $Bo = 0$ and $B1 = 1.0$, was conducted to determine whether an adjustment was warranted. For the two sites, the computed F-statistics with 2 and (n-2) degrees of freedom, where n is equal to the number of samples, were 0.57 and 0.36, with corresponding P values of 0.579 and 0.709, for the BMP and SMP basins, respectively. This indicates that adjustments to concentrations collected by the automated sampler are not warranted; therefore, only unadjusted concentrations from automated samples are used in this report. It should be noted that the suspended-sediment concentrations in manually collected samples do not cover the full range of concentrations in samples collected by the automated sampler. The median suspended-sediment concentrations of manually collected samples were about half the median concentrations in samples collected by the automated sampler. This is true for samples from both basins.

The method used to collect sediment samples does not account for all the sediment flux at each sampling station. The unmeasured part consists primarily of bed-material discharge, which represents the larger sizes of sediment that roll or skip along the streambed (Simmons, 1976). According to a study by Chang and others (1965), who used an empirical equation to calculate bed-material discharge, computed values of this unmeasured part of total sediment discharge ranged from 1 to 4 percent of the total suspended-sediment discharge.

Precipitation

Precipitation was below normal during the entire study period (fig. 6). Annual precipitation was 31 percent, 10 percent, and 21 percent below normal, during the 1986, 1987, and 1988 water years, respectively. Rainfall during the growing season was 26 percent, 33 percent, and 12 percent below normal for the respective 1986, 1987, and 1988 seasons. During the nongrowing season, precipitation was 35 percent below normal, 9 percent above normal, and 28 percent below normal for the 1986, 1987, and 1988 seasons. The precipitation deficiency implies any sediment yield calculated would also be below normal seasonally and annually. It is assumed that comparisons of sediment yields between the two basins are not affected.

Precipitation data from the National Oceanic and Atmospheric Administration centers located in Greensboro, 15 miles southwest of the study area, and in Reidsville, about 10 miles northeast of the study area, were used for long-term comparison purposes (National Oceanic and Atmospheric Administration, 1980). Precipitation totals at the study area, which represent mean values from the two gages, were within 5 percent of precipitation totals recorded at the Greensboro and Reidsville National Oceanic and Atmospheric Administration stations.

Runoff

Runoff occurred more readily in the BMP basin during the nongrowing season and in the SMP basin during the growing season (fig. 7). Seasonal comparisons of runoff totals in the two basins for water years 1986-88 indicate runoff is 11- to 42-percent greater in the BMP basin during the nongrowing season and 88- to 140-percent greater in the SMP basin during the growing season. In the nongrowing season, 3.7 acres (50 percent of the basin) are plowed in the BMP basin and 4.8 acres (100 percent of the basin) are plowed in the SMP basin. The larger plowed area in the SMP basin allows more rainfall to be trapped in the rough soil surface, decreasing runoff potential.

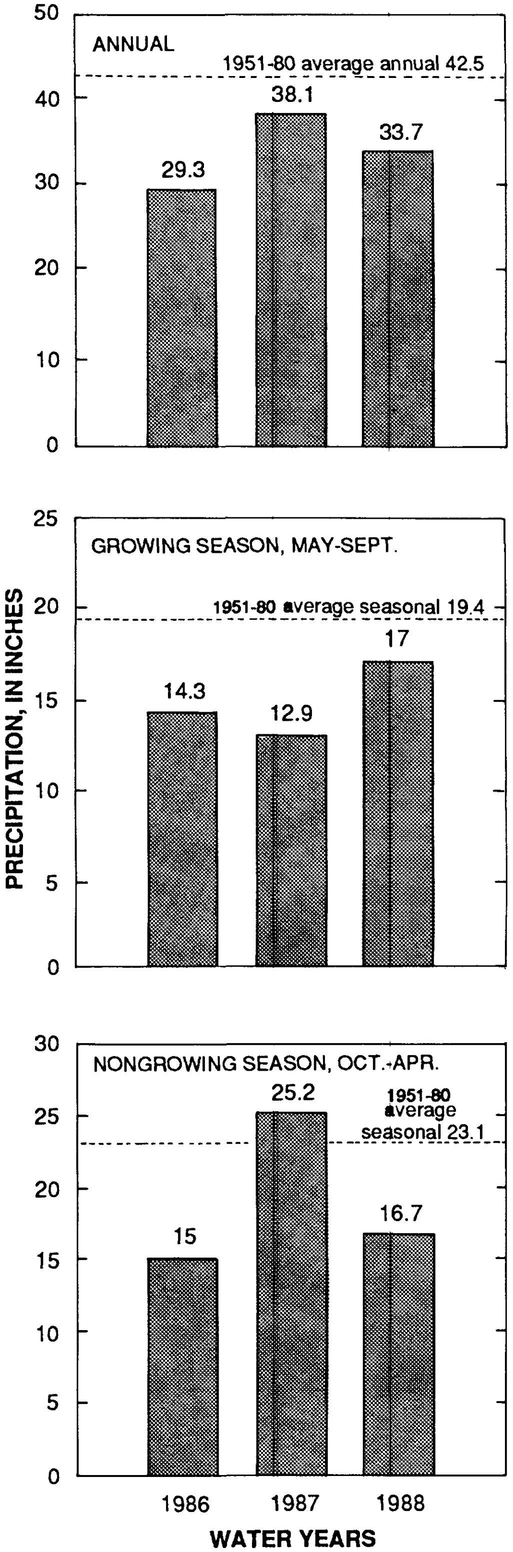


Figure 6.--Annual and seasonal precipitation compared with long-term average, 1951-80. (Modified from National Oceanic Atmospheric Administration, 1980.)

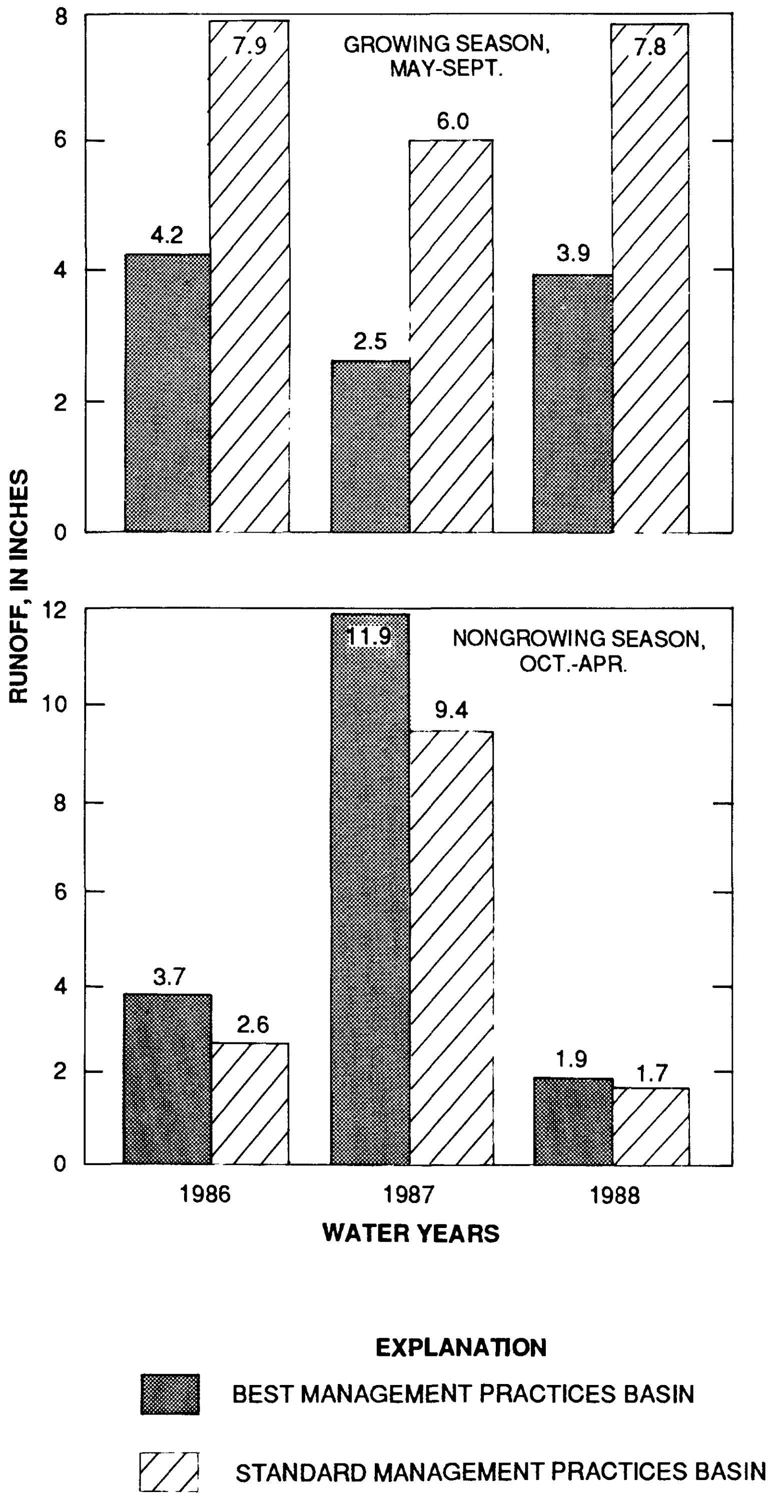


Figure 7.--Seasonal runoff at the two study basins, water years 1986-88.

During the growing season, 3.7 acres are planted in tobacco in the BMP basin and almost 4.8 acres are planted in tobacco in the SMP basin. The additional planted acre in the SMP basin creates additional bare soil, which hardens during the growing season and contributes to increased runoff in that basin. The contoured tobacco furrows in the BMP basin, which are only in place during the growing season, aid in reducing runoff by providing more area capable of storing water. Additionally, the wheat and grass strips in the BMP basin reduce runoff by decreasing the velocity, allowing more water to infiltrate the soil.

FACTORS AFFECTING EROSION AND SEDIMENT-YIELD POTENTIAL

Erosion and sediment-transport potential are affected by slope, soil characteristics, precipitation, and land management. The steepness and range of a slope, the soil composition and texture, the intensity of rainfall, and the extent of vegetative cover on the soil are all interrelated factors that affect the erosion and sediment yield potential of an agricultural basin.

Slope

The steepness and extent of a slope generally determine the amount of erosion that can occur. In the Piedmont province of North Carolina, slope gradients usually range from 10 to 20 feet per mile but are as extreme as 300 feet per mile (Simmons, 1988). Gradients in the study area range from 100 to 200 feet per mile.

Soils

Soils in the North Carolina Piedmont province are derived from the weathering of the underlying rock and can be categorized as (1) felsic crystalline rock, (2) mafic crystalline rock, (3) a mixture of felsic and mafic crystalline rock, and (4) sandstone, siltstone, and shale of the Triassic rocks (U.S. Department of Agriculture, 1982). The Cecil soils in the study area are derived from felsic crystalline rock. These are well drained soils with a loamy surface layer and a clayey subsoil.

The erodibility of soils varies depending on the soil composition. Erosion factors are used to predict the amount of potential erosion, the highest factors being most erodible. This factor, K, ranges from 0.24 to 0.49 in the Piedmont and from 0.28 to 0.37 for the sandy-clay-loam soil in the study sites (U.S. Department of Agriculture, 1977).

Soil texture also affects runoff; a rough, cloddy soil surface will promote infiltration and reduce runoff. Plowing the soil produces a rough surface that helps prevent runoff. Irregularities in the soil surface create pockets where rainfall can accumulate and stand until it can infiltrate the soil. Eventually, the impact of rain on bare soil will cause a crust to form on the soil, reducing the infiltration capacity (Thompson and Troeh, 1957). Typically, a field is plowed after the crop is harvested. Initially, the rough soil allows very little rainfall to run off. As winter progresses, the soil forms a crust, allowing less rain to infiltrate the soil and more to run off.

Precipitation and Runoff

Rainfall striking bare soil is generally recognized as the principle means of detachment of soil particles. Rain splash, the ability of raindrops to move soil particles, begins the erosion process. When precipitation exceeds the infiltration capacity of the soil, or when it falls too fast to infiltrate the soil, sheet erosion occurs. Sheet erosion is a thin sheet of soil transported downslope by water. This is one of the most widespread and detrimental forms of soil erosion. It causes the largest amount of soil loss, yet is the least noticeable. Sheet erosion sorts the soil particles, leaving behind the larger sand particles and carrying away fine silt and clay. These fine particles are the ones associated with most of the soil fertility (Thompson and Troeh, 1957). Intense rainfall produces greater sheet erosion and surface runoff. Surface runoff transports the sediment particles dislodged by sheet erosion, creating suspended sediment.

Land Management

Land-management practices, such as the use of a vegetative cover or mulch on the soil surface, prevents raindrops from striking the soil and causing detachment of the soil particles. When raindrops strike soil that is bare but recently plowed, some soil-particle detachment may occur, but transport is prevented due to trapped water in soil depressions. Vegetative cover also minimizes erosion through rainfall interception. Strip cropping, which is generally in place year round, assists in reducing runoff potential. The close-growing vegetation in the strips causes water velocity and turbulence to decrease, allowing more runoff to infiltrate the soil. Additionally, as the runoff velocity decreases in the wheat and grass strips, suspended sediment that accumulated in the water as it passed over the tobacco (or other crop) strip is redeposited, decreasing the sediment load. Contour farming (crop rows following land contours) also reduces runoff by decreasing velocity and providing more area capable of storing water.

Lack of vegetative cover creates splash erosion. Erosion generally increases with an increase in the amount of bare soil in a basin. This was verified in a study that defined sediment characteristics in North Carolina streams during the period 1970 to 1979 (Simmons, 1988). The study indicated that mean suspended-sediment yields from rural agricultural basins were 6 times greater than yields from forested basins.

STATISTICAL ANALYSIS OF DISCHARGE AND SUSPENDED-SEDIMENT DATA

Analyses of the data began in 1985 with the collection of suspended-sediment samples and water-discharge measurements. Data collected through 1987 were used for the model development and optimization. Simple regression models, with Y as a function of X, are in log form of a simple linear equation as follows:

$$\log Y = \log a + b \log X + \log v, \tag{2}$$

where: Y is a value of the response variable, suspended-sediment discharge;

X is a value of the explanatory variable, water discharge;

a is the intercept constant;

b is the slope coefficient; and

v is the random error term.

Each model was evaluated for goodness-of-fit to ensure that it adequately described the functional relation between the response variable, suspended-sediment discharge (flow-weighted suspended-sediment concentrations), and the explanatory variable, water discharge. Statistical tests used in the evaluation include graphical analyses, such as bivariate plots, central-tendency statistics, influence diagnostics, and residuals analysis.

The validity of the classical linear regression model and the statistical tests associated with it requires some assumptions concerning aspects of the statistical model. The first assumption is that the explanatory variable, X, is measured without error. The remaining assumptions concern the error term, v: the errors are assumed to be independent, normally distributed with a mean value of zero, and have a constant variance.

Data-Base Development

Erosion potential is determined by geology, soils, topography, land use, climate (Simmons, 1976), and other factors. Because the two study basins are adjacent and because geology, soils, topography, and climate are known to be similar, it seems reasonable to ascribe any differences in erosion rates to land-use or conservation practices. To identify the effects of management practices, two data sets were developed: one for the basin with BMP's and the other for the basin with SMP's. Each data set contains suspended-sediment samples and their respective instantaneous water discharge collected during the study period, 1985 through 1987. The data were log-transformed (base 10) to meet the assumptions of the linear model. To address the possibility of seasonal land use affecting the relation between suspended-sediment discharge and water discharge, each of the two original log-transformed data sets was further subdivided into growing-season and nongrowing-season data sets.

The four data sets were analyzed graphically for linearity and possible outliers, or data points that do not conform to the distribution or pattern in the bulk of the data. Outliers may arise where samples are contaminated or have an incorrect discharge applied, therefore warranting closer examination. Following refinement of the data sets through graphical analyses, influence diagnostics (SAS Institute, Inc.,[1] 1985) were calculated for each data point. These diagnostics are a useful tool for screening the data points, measuring the influence a data point has on the regression line. An example of the graphical relation between suspended-sediment discharge and water discharge, log-transformed, for the data set from the BMP basin is shown in figure 8.

Statistical Analysis

As discussed previously, one might expect land-management practices and seasonal changes to have a significant effect on erosion. Although no distinct difference or pattern was seen between seasonal data points from the SMP basin, regression equations were developed for each of the seasonal data sets to determine if there was a significant difference between suspended-sediment discharge and water discharge on a seasonal basis.

Descriptive statistics for water discharge and suspended-sediment concentrations for the four data sets are summarized in tables 1 and 2. Recognizing that water-quality data tend to be skewed and do not always follow the normal probability model, robust statistics are presented (Reckhow and Chapra, 1983). Robust statistics perform reasonably well even when assumptions, such as normality, are mildly violated. For example, the median is a measure of central tendency that is less influenced by extreme values than is the mean.

The median discharge is a measure of the amount of water leaving the basin by runoff, that is, not utilized by the crops or soil. The two basins have the same median discharge, even though the drainage area of the basin with BMP's is 55 percent greater than the drainage area of the SMP basin.

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[1] The use of firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

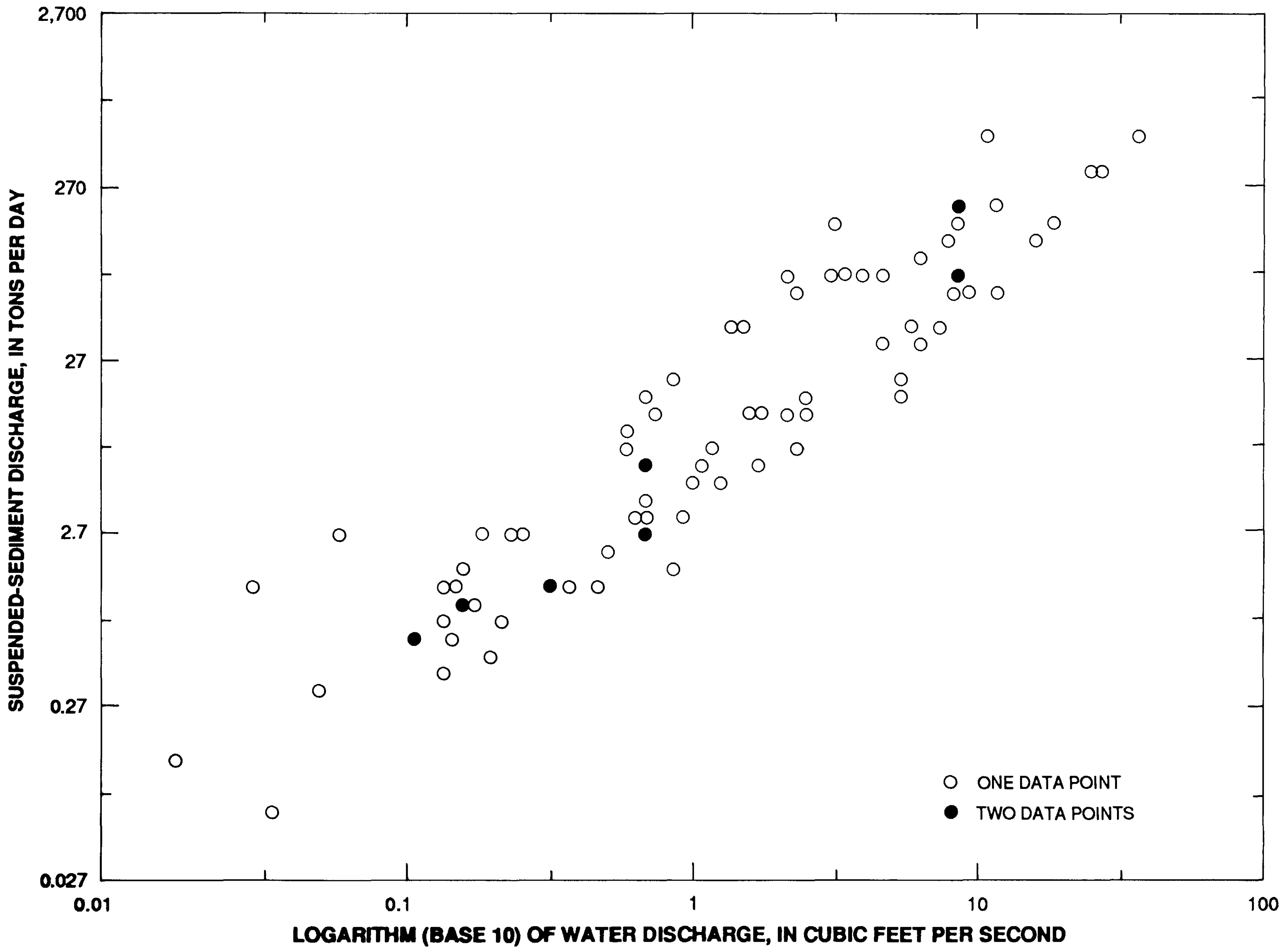

Figure 8.--Relation between suspended-sediment discharge and water discharge from Smith Branch lower tributary (BMP basin) during the growing season, 1985-87, log-transformed final data set.

Table 1.--*Descriptive summary statistics for water-discharge data, 1985-87*

[These data are for the data set used in the regression development and are not a summary of all the water-discharge data collected]

Station name	Land-management practice	Drainage area (acres)	Season	Number of samples	Water discharge (cubic feet per second) Maximum	Minimum	Median
Smith Branch lower tributary (site 1)	Best land management	7.4	All data	121	55	0.03	0.94
			Growing[1]	73	27	.03	.88
			Nongrowing[2]	48	55	.10	.94
Smith Branch upper tributary (site 2)	Standard land management	4.8	All data	110	24	.05	.94
			Growing[1]	84	24	.05	1.22
			Nongrowing[2]	26	13	.13	.44

[1]May through September.
[2]October through April.

Table 2.--*Descriptive summary statistics for suspended-sediment concentration data, 1985-87*

[These data are for the data set used in the regression development and are not a summary of all the suspended-sediment concentration data collected]

Station name	Land-management practice	Drainage area (acres)	Season	Number of samples	Suspended sediment (milligrams per liter) Maximum	Minimum	Median
Smith Branch lower tributary (site 1)	Best land management	7.4	All data	121	11,000	110	2,260
			Growing[1]	73	10,600	740	2,430
			Nongrowing[2]	48	11,000	110	1,080
Smith Branch upper tributary (site 2)	Standard land management	4.8	All data	110	57,200	840	7,590
			Growing[1]	84	57,200	840	7,070
			Nongrowing[2]	26	38,800	1,090	9,400

[1]May through September.
[2]October through April.

This indicates that more water is infiltrating the soil in the BMP basin and, therefore, that more water is potentially available for crop growth or ground-water replenishment.

Model Analysis

Following refinement of the four data sets through graphical analyses and the use of influence diagnostics, a regression procedure was used to calculate least squares estimates for the coefficients in the linear regression models. This procedure was also used to calculate supporting model statistics, such as the coefficient of determination, standard error of the coefficients, and the residuals. The results of each regression analysis were evaluated using standard criteria, including overall goodness-of-fit of the model and residuals analysis (Gujarati, 1988).

One would expect the slope of the line defining the relation between suspended-sediment discharge and water discharge to be positive, because the primary process is erosion with suspended sediment transported to the streams in overland runoff. In all four equations, the slopes were positive (table 3) in accordance with expectations.

Table 3.--*Equations for defining relations between suspended-sediment discharge and water discharge in the study basins, 1985-87*

[SSQ, suspended-sediment discharge, in tons per day; Q, water discharge, in cubic feet per second]

Seasonal data set	Equation	Number of samples	Standard error of estimate, in percent	Coefficient of determination, R-square
		Best land-management practices basin		
Growing[1]	$SSQ= 2{,}780Q^{1.147}$	73	73.9	0.89
Nongrowing[2]	$SSQ= 955Q^{1.683}$	48	74.5	.95
		Standard land-management practices basin		
Growing[1]	$SSQ= 6{,}950Q^{1.258}$	84	104	.86
Nongrowing[2]	$SSQ=11{,}700Q^{1.647}$	26	100	.84

[1]May through September.
[2]October through April.

Overall goodness-of-fit of the regression models is indicated by plots of the residuals against an indicated variable that show if there is a dependency between the residuals and the variable. These plots were checked graphically to determine the adequacy of the regression models. Each plot of the four data sets showed approximately constant variance of the residuals across the reference line, indicating that the assumption of constant variance of the error terms was not violated. In addition, no trends or patterns were seen among the residuals, indicating that the selected model form was appropriate. All four regressions meet the overall goodness-of-fit criteria, ensuring the validity of the statistics associated with the models, as typified by the residuals plot against suspended-sediment discharge for the BMP basin during the growing season (fig. 9).

Prior to applying the four models to unit-discharge values to determine sediment yields, slopes of individual lines in each basin were tested using t-tests in a manner identical to linear regression (Steel and Torrie, 1980). This was done to determine statistically if season was a significant variable. The hypothesis tested is that the slopes of the two regressions are equal, or Ho: b1 = b2. The alternative hypothesis is that the slopes are not equal, or Ha: b1 does not equal b2. Both computed t-statistics indicate that the slopes of the two regression lines for the basins were not equal. Therefore, in both instances, the null hypothesis was rejected; season does affect the slope of the regression line, and there is a need for two regression equations for each basin.

Statistics supporting the defined relations between suspended-sediment discharge and water discharge on a seasonal basis (table 3) are based on the exponential equations in the form:

$$\log Y = \log a + b \log X \tag{3}$$

where: Y is suspended-sediment discharge;
a is the intercept constant;
X is water discharge; and
b is the slope coefficient.

This allows the retransformed response variable to be expressed in common units rather than logarithmic units. Residuals for the exponential form of the log model are approximately log-normally distributed, or skewed; therefore, the exponential form estimates the median value but gives biased (low) estimates of the mean value of the retransformed response variable (Martin and Crawford, 1987).

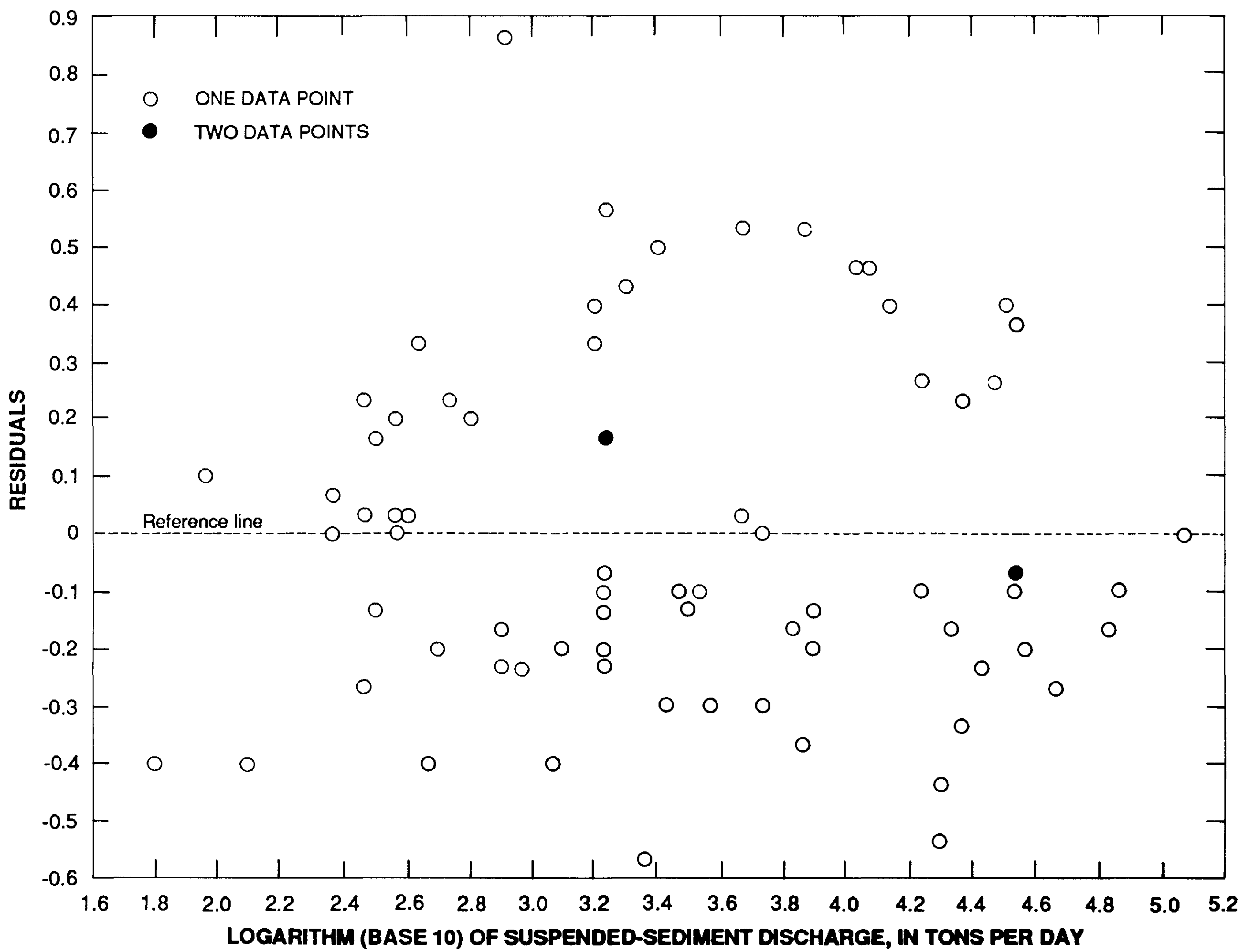

Figure 9.--Residuals from regression of suspended-sediment discharge and water-discharge data compared to log-transformed suspended-sediment discharge data from Smith Branch lower tributary (BMP basin) during the growing season, 1985-87.

EFFECTS OF LAND-MANAGEMENT PRACTICES ON SEDIMENT YIELD

Sediment yield is the suspended-sediment load divided by the basin drainage area and allows comparisons of sediment discharge on a unit-area per time basis. Values of seasonal sediment discharge for the two basins during the 1986, 1987, and 1988 water years were developed using the four regression equations (table 3) and unit-discharge data from the corresponding basin and season. For example, the regression equation developed using samples collected from the basin with BMP's during the growing season was applied to unit-discharge data collected during the period May 1 through September 30 from the same basin. The suspended-sediment unit-discharge data were summed to obtain daily values and then divided by the number of time increments per day for that growing season. To convert suspended-sediment discharge to sediment yield, each daily value of suspended-sediment discharge was multiplied by the standard conversion factor of 0.0027 to convert the value to tons and then divided by the number of acres in the basin to give daily values of sediment yield in tons per acre for the season.

Sediment yields, in tons per acre, from the two basins seasonally and annually for the 1986, 1987, and 1988 water years are given in figure 10 and table 4. Also presented in table 4 are seasonal and annual precipitation accumulations and runoff values. Runoff is expressed as inches of water averaged over the entire basin and can be compared directly, regardless of drainage area size.

On the average seasonal basis, the sediment yield from the study basin having BMP's was about one-seventh of that from the SMP basin (table 4). This is true for both growing and nongrowing seasons, indicating that although there is more runoff from the BMP basin during the nongrowing season, the effect of BMP's in reducing sediment losses is significant enough to compensate for the additional runoff. The data indicate that this comparison is relatively consistent regardless of season because the yield on an annual basis from the BMP basin is also about one-seventh of that from the SMP basin, with sediment yields averaging 2.7 and 20 tons per acre, respectively.

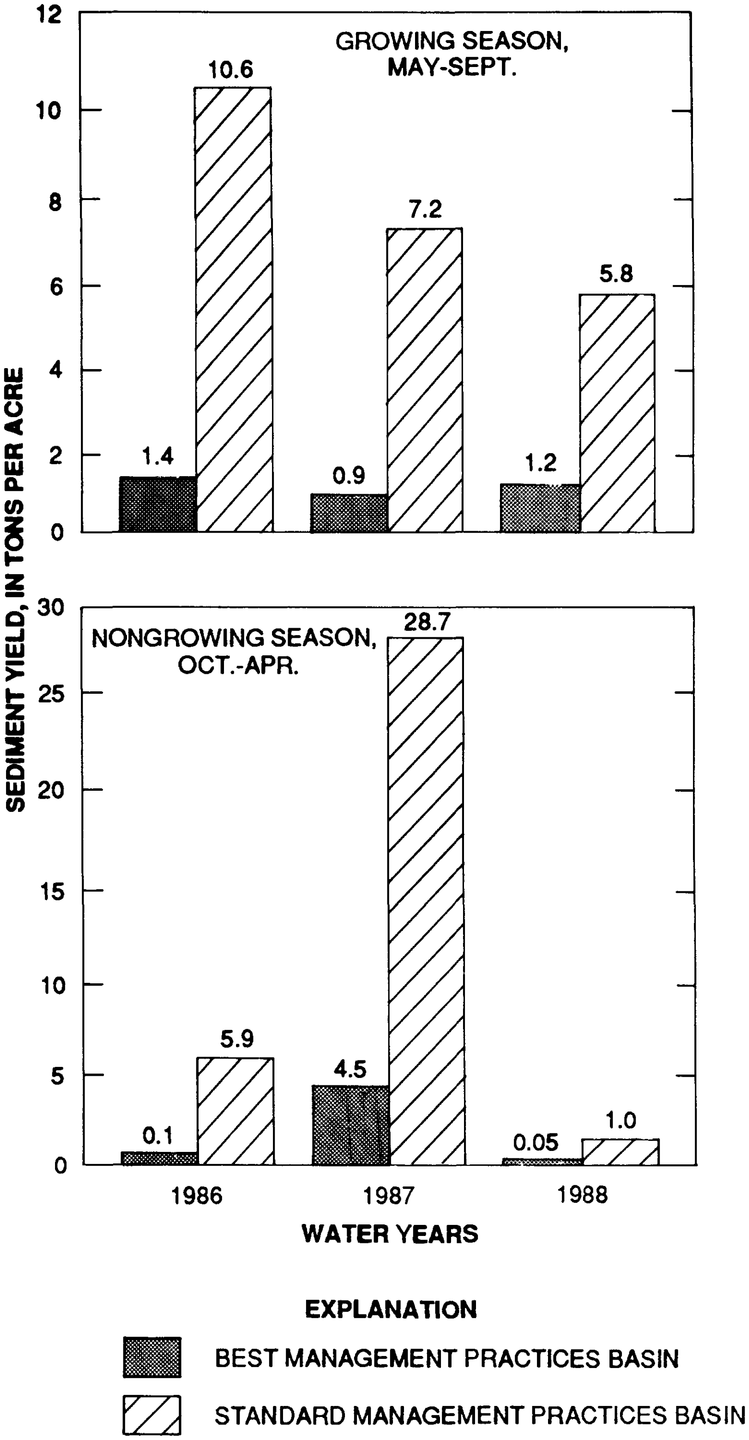

Figure 10.--Seasonal sediment yield at the two study basins, water years 1986-88.

Table 4.--*Seasonal and annual precipitation, runoff, and sediment yield for the study basins during 1986-88 water years*

Station name	Land-management practice	Drainage area (acres)	Season	Precipitation (inches)			Runoff (inches)			Sediment yield (tons per acre)			Average
				1986	1987	1988	1986	1987	1988	1986	1987	1988	
Smith Branch lower tributary (site 1)	Best land management	7.4	Annual	29.3	38.1	33.7	7.9	14.4	5.8	1.5	5.4	1.3	2.7
			Growing[1]	14.3	12.9	17	4.2	2.5	3.9	1.4	.9	1.2	1.2
			Nongrowing[2]	15	25.2	16.7	3.7	11.9	1.9	.1	4.5	.05	1.6
Smith Branch upper tributary (site 2)	Standard land management	4.8	Annual	29.3	38.1	33.7	10.5	15.4	9.5	16.5	35.9	6.8	20
			Growing[1]	14.3	12.9	17	7.9	6	7.8	10.6	7.2	5.8	7.9
			Nongrowing[2]	15	25.2	16.7	2.6	9.4	1.7	5.9	28.7	1	11.9

[1]May through September.
[2]October through April.

The annual sediment yields in the two study basins can be compared with sediment yields from a nearby forested basin. This forested basin, with a drainage area of 44 acres, is approximately 4 miles from the agricultural sites and represents background runoff and water-quality conditions for the area (Hill, 1989). During the 1986 water year, the sediment yield from the forested basin was calculated to be approximately 0.1 ton per acre. This is less than one-tenth the annual sediment yield from the BMP basin and less than one-hundredth that from the SMP basin.

The effects of land-management practices on sediment yield were analyzed for selected discrete runoff events with respect to soil or crop conditions that occurred in the 1987 water year. Four events (runoff and the resulting sediment yield) from each season were chosen for further analyses using the regression equations and unit-discharge values. During the nongrowing season, these events were analyzed (1) after the tobacco had been harvested but before the ground had been plowed, (2) immediately after the ground had been plowed, (3) at the end of the season after the plowed ground had hardened, and (4) after or when the ground became saturated. During the growing season, events were analyzed (1) immediately after the crop had been planted, (2) mid-season when the ground was dry, (3) near the end of the season when the tobacco crop was partially harvested, and (4) when the ground was saturated. Precipitation amounts and intensities, as well as the resulting sediment yields, are shown in table 5 for these events.

Table 5.--*Sediment yield and precipitation data for selected discrete precipitation events and agricultural conditions during the 1987 water year*

[BMP, best land-management practices; SMP, standard land-management practices]

Date	Number of days since last precipitation	Total precipitation (inches)	Duration (minutes)	Maximum precipitation in 5 minutes (inches)	Sediment yield (tons per acre) BMP basin	Sediment yield (tons per acre) SMP basin	Percent reduction of sediment yield, from SMP to BMP basin
Nongrowing season (October through April)							
[1]Oct. 14, 1986	1	0.80	720	0.10	0.003	0.447	0.09
[2]Oct. 25, 1986	3	.90	780	.04	.001	.001	0
[3]Apr. 15, 1987	12	3.22	1,140	.28	3.46	18.3	81
[4]Apr. 16, 1987	1	.70	1,120	.08	.223	2.10	89
Growing season (May through September)							
[5]May 26, 1987	2	.52	135	.13	.002	.014	86
[6]Aug. 4, 1987	12	.70	35	.17	.015	.617	98
[7]Sept. 7, 1987	1	1.69	1,440	.30	.336	2.24	85
[8]Sept. 8, 1987	1	1.33	355	.20	.235	1.39	83

[1]Tobacco completely harvested, fields not plowed yet.
[2]Fields plowed Oct. 20, 1986.
[3]Crust has formed on plowed fields.
[4]Ground saturated.
[5]Tobacco crop just planted.
[6]Mid-growing season, ground dry.
[7]End of growing season, tobacco partially harvested.
[8]Ground saturated.

The greatest difference in sediment yields from the two basins occurred during the nongrowing season before the ground was plowed; the yield from the BMP basin was less than one percent of that from the other basin. After the ground was plowed, effects of land-management practices appeared to be negligible. Toward the end of the nongrowing season when the plowed ground hardened, yields from the BMP basin generally were less than one-fifth of those from the SMP basin.

These results indicate that the application of BMP's tends to reduce sediment yields, with the greater reductions occurring in the middle of the growing season following a dry period. The findings are in accordance with theory because there is more bare soil in the SMP basin than in the BMP basin during the growing season, and as the season progresses, this soil hardens, reducing infiltration. Also, the wheat and grass strips in the BMP basin reduce runoff and allow sediment to become redeposited. Furthermore, the row contours in the BMP basin allow precipitation to become trapped, thereby reducing runoff and sediment losses.

The differences in sediment yield are relatively consistent, regardless of rainfall intensity. However, rainfall intensity does contribute to the amount of sediment yield, as seen by the April 15, 1987, storm. This storm, which produced maximum runoff at the two study basins for the current period of record (1985 to 1988), had a recurrence interval or long-term average number of years between occurrences of approximately 25 years. More than 3 inches of rain fell in less than one day. Runoff from this storm accounted for 65 to 75 percent of the total nongrowing-season sediment yields from the SMP and BMP basins during the 1987 water year.

Sheet erosion is also influenced by land-management practices. Guilford Soil and Water Conservation District calculated sheet erosion using the Universal Soil Loss Equation, which uses factors of soil erodibility, slope length and steepness, rainfall, crop management, and land conservation practices. Sheet erosion, which represents soil moving anywhere on the field but not necessarily reaching runoff, was estimated to be 3.6 tons per acre per year for the basin with BMP's and 45 tons per acre per year for the basin with SMP's.

SUMMARY AND CONCLUSIONS

Streamflow, precipitation, and suspended-sediment data were collected from two adjacent, agricultural basins in the Piedmont province of North Carolina. The data were used to determine the effects of land-management practices on sediment yield. One basin of 7.4 acres represents best land-management practices with strip cropping, crop rotation, contour farming, and grassed waterways. The other basin, 4.8 acres, represents standard land-management practices with down-slope row orientation, unmaintained grassed waterways, and without crop rotation.

The reddish Cecil soils underlying the study basins are derived from felsic crystalline rocks and are well drained with a loamy surface layer and a clayey subsoil extending to a depth of about 60 inches. Land slope ranges from 100 to 200 feet per mile at elevations of about 810 to 835 feet above sea level.

Automatic stage recorders and automatic water-pumping samplers were used to collect the data supplemented by routine manual observations. The stage recorders collected data at 5-minute intervals. The water samplers also operated on a 5-minute interval, but were active only during a storm when the instrument was switched on at a pre-set gage height. Two precipitation recorders automatically totalled rainfall at 5-minute intervals.

Data collected during the 1985-87 water years were used to develop regression equations to describe the relation between suspended-sediment discharge and water discharge. Data sets consisting of suspended-sediment concentrations and corresponding instantaneous water-discharge data were developed. There were two data sets from each basin, one representing data collected during the growing season, May through September, and the other representing data collected during the nongrowing season, October through April.

Four regression equations were developed, one for each data set, and were tested for goodness-of-fit using graphical analysis, influence diagnostics, significance tests, and residuals analysis. Following acceptance of the four models, the slope of each individual line was tested to determine if season was a significant variable, which would, therefore, warrant the use of all four models. In all instances, the computed t-statistic was greater than the critical t-value, indicating rejection of the hypothesis that season was insignificant.

Unit-discharge values from the 1986-88 water years were applied to the appropriate model, resulting in seasonal sediment yields for each basin. Seasonally, the average sediment yields (2.7 tons per acre) from the BMP basin were only about one-seventh of those (20 tons per acre) from the SMP basin. This difference in yields was relatively consistent regardless of season; therefore, it follows that the use of BMP's might reduce sediment yields from similar small acreage plots by 80 to 90 percent annually.

Comparison of annual sediment yield in the agricultural basins against the yield from a nearby forested basin, which represents a nearly undisturbed basin, indicates a 10- to 100-fold increase in sediment yield from the study basins. The forested basin sediment yield was 0.1 ton per acre in the 1987 water year.

Although rainfall intensity does not appear to affect the relative differences in sediment yields caused by implementation of BMP's, it does contribute to the amount of sediment yield occurring during one event. The storm of April 15, 1987, was the most intense storm during the study period, producing more than 3 inches of rain in less than one day. Runoff from this storm accounted for 65 and 75 percent of the total nongrowing season sediment yield from the SMP and BMP basins, respectively, during the 1987 water year; this indicates that a disproportionately large percentage of sediment yield occurs during the most intense storms.

Sheet erosion, which represents soil moving downslope in a basin but not necessarily reaching a stream, is also influenced by land-management practices. This type of erosion was estimated to be 3.6 tons per acre per year for the BMP basin and 45 tons per acre per year for the SMP basin.

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