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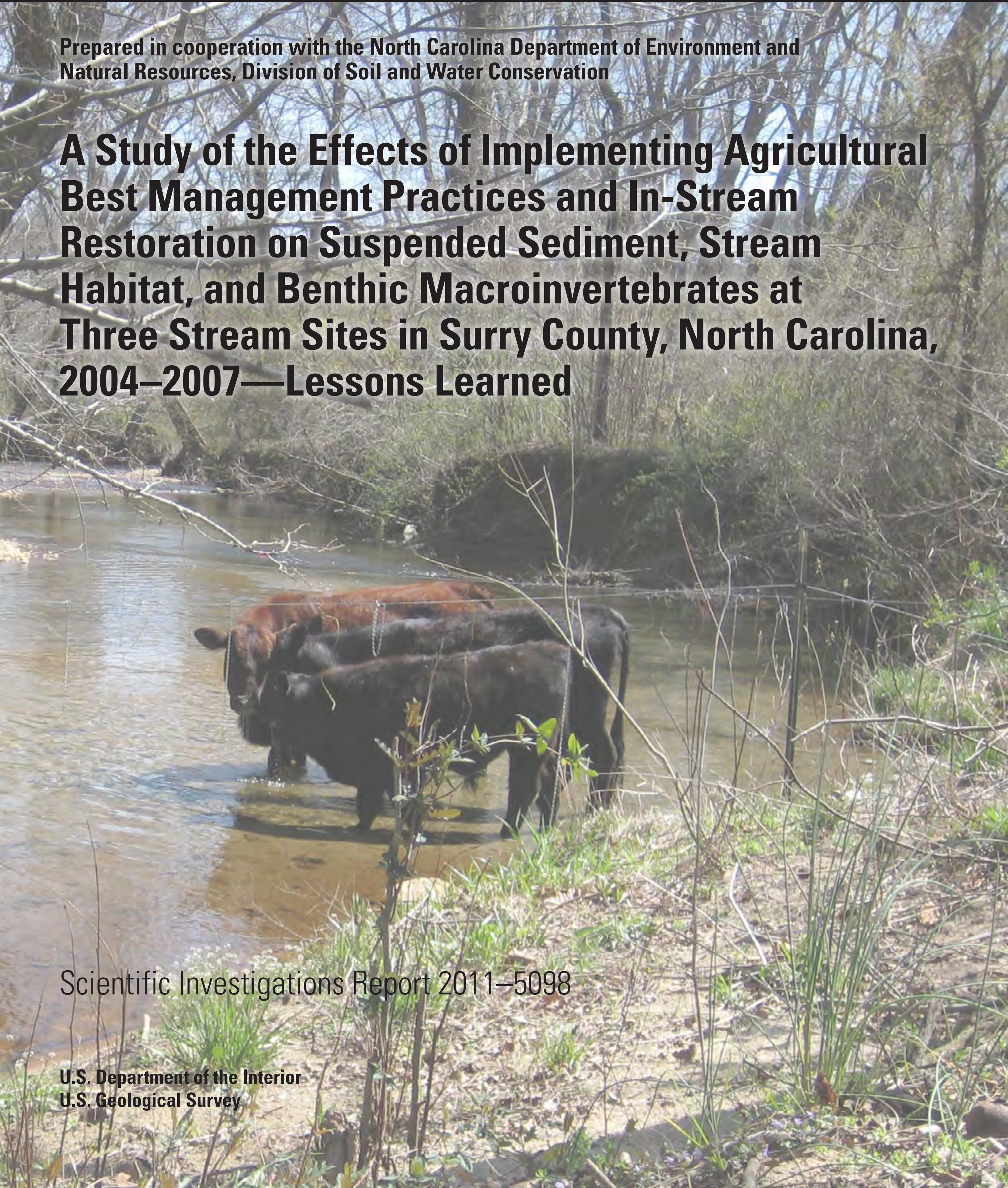

Prepared in cooperation with the North Carolina Department of Environment and Natural Resources, Division of Soil and Water Conservation

A Study of the Effects of Implementing Agricultural Best Management Practices and In-Stream Restoration on Suspended Sediment, Stream Habitat, and Benthic Macroinvertebrates at Three Stream Sites in Surry County, North Carolina, 2004–2007—Lessons Learned

Scientific Investigations Report 2011–5098

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph. Pauls Creek near Pine Ridge, North Carolina, April 2, 2008 *(G.M. Ferrell, U.S. Geological Survey)*.

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Conversion Factors, Datums, and Definitions

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Mass	
ton per day per square mile [(ton/d)/mi^2]	0.3503	megagram per day per square
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)
ton per year (ton/yr)	0.9072	metric ton per year
	Specific capacity	
gallon per minute per foot | [(gal/min)/ft)]	0.2070	liter per second per meter [(L/s)/m]

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
micron	0.00003937	inch (in.)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second per square kilometer [(m^3/s)/km^2]	91.49	cubic foot per second per square mile [(ft^3/s)/mi^2]
millimeter per year (mm/yr)	0.03937	inch per year (in/yr)
	Mass	
megagram per day per square kilometer [(Mg/d)/km^2]	2.8547	ton per day per square mile [(ton/d)/mi^2]
megagram per year (Mg/yr)	1.102	ton per year (ton/yr)
metric ton per year	1.102	ton per year (ton/yr)
	Specific capacity	
liter per second per meter [(L/s)/m]	4.831	gallon per minute per foot [(gal/min)/ft]

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

A Study of the Effects of Implementing Agricultural Best Management Practices and In-Stream Restoration on Suspended Sediment, Stream Habitat, and Benthic Macroinvertebrates at Three Stream Sites in Surry County, North Carolina, 2004–2007—Lessons Learned

By Douglas G. Smith, G.M. Ferrell, Douglas A. Harned, and Thomas F. Cuffney

Abstract

The effects of agricultural best management practices and in-stream restoration on suspended-sediment concentrations, stream habitat, and benthic macroinvertebrate assemblages were examined in a comparative study of three small, rural stream basins in the Piedmont and Blue Ridge Physiographic Provinces of North Carolina and Virginia between 2004 and 2007. The study was designed to assess changes in stream quality associated with stream-improvement efforts at two sites in comparison to a control site (Hogan Creek), for which no improvements were planned. In the drainage basin of one of the stream-improvement sites (Bull Creek), several agricultural best management practices, primarily designed to limit cattle access to streams, were implemented during this study. In the drainage basin of the second stream-improvement site (Pauls Creek), a 1,600-foot reach of the stream channel was restored and several agricultural best management practices were implemented. Streamflow conditions in the vicinity of the study area were similar to or less than the long-term annual mean streamflows during the study. Precipitation during the study period also was less than normal, and the geographic distribution of precipitation indicated drier conditions in the southern part of the study area than in the northern part. Dry conditions during much of the study limited opportunities for acquiring high-flow sediment samples and streamflow measurements.

Suspended-sediment yields for the three basins were compared to yield estimates for streams in the southeastern United States. Concentrations of suspended sediment and nutrients in samples from Bull Creek, the site where best management practices were implemented, were high compared to the other two sites. No statistically significant change in suspended-sediment concentrations occurred at the Bull Creek site following implementation of best management practices. However, data collected before and after channel stabilization at the Pauls Creek site indicated a statistically significant ($p<0.05$) decrease in suspended-sediment discharge following in-stream restoration.

Stream habitat characteristics were similar at the Bull Creek and Hogan Creek reaches. However, the Pauls Creek reach was distinguished from the other two sites by a lack of pools, greater bankfull widths, greater streamflow and velocity, and larger basin size. Historical changes in the stream channel in the vicinity of the Pauls Creek streamgage are evident in aerial photographs dating from 1936 to 2005 and could have contributed to stream-channel instability. The duration of this study likely was inadequate for detecting changes in stream habitat characteristics.

Benthic macroinvertebrate assemblages differed by site and changed during the course of the study. Bull Creek, the best management practices site, stood out as the site having the poorest overall conditions and the greatest improvement in benthic macroinvertebrate communities during the study period. Richness and diversity metrics indicated that benthic macroinvertebrate community conditions at the Hogan Creek and Pauls Creek sites declined during the study, although the status was excellent based on the North Carolina Index of Biotic Integrity.

Experiences encountered during this study exemplify the difficulties of attempting to assess the short-term effects of stream-improvement efforts on a watershed scale and, in particular, the difficulty of finding similar basins for a comparative study. Data interpretation was complicated by dry climatic conditions and unanticipated land disturbances that occurred during the study in each of the three study basins. For example, agricultural best management practices were implemented in the drainage basin of the control site prior to and during the study. An impoundment on Bull Creek upstream from the streamgaging station probably influenced water-quality conditions and streamflow. Road construction in the vicinity of the Pauls Creek site potentially masked changes

related to stream-improvement efforts. In addition, stream-improvement activities occurred in each of the three study basins over a period of several years prior to and during the study so that there were no discrete before and after periods available for meaningful comparisons. Historical and current land-use activities in each of the three study basins likely affected observed stream conditions. The duration of this study probably was insufficient to detect changes associated with agricultural best management practices and stream-channel restoration.

Introduction

High concentrations of suspended sediment originating from nonpoint sources are considered to be a major cause of stream impairment in rural areas of North Carolina (North Carolina Department of Environment and Natural Resources, 1998). Large amounts of sediment can contribute to stream impairment by (1) facilitating transport of contaminants, such as phosphorus, metals, and pesticides, into streams; (2) degrading stream habitat through siltation; (3) decreasing light penetration and primary productivity; (4) causing channel instability; and (5) degrading biotic communities and ecosystem health (Ryan, 1991; Waters, 1995; Newcombe and Jensen, 1996; U.S. Department of Agriculture, 1997). Benthic invertebrates are particularly sensitive indicators of adverse effects of high sediment concentrations (Lenat and others, 1979) and are considered to be indicators of both water-quality and habitat conditions (Plafkin and others, 1989).

Much effort has gone into modifying land-use activities to control erosion and reduce sediment input to streams. From 1987 to 1997, cropland erosion decreased from a nationwide average of 6.0 tons per acre per year [(tons/acre)/yr] to 4.6 (tons/acre)/yr as best management practices (BMPs) were implemented and marginal agricultural lands were removed from production (U.S. Department of Agriculture, 2007). Efforts to decrease the amount of sediment in streams also have focused on the stabilization of streambanks and channels through practices such as establishing riparian buffer zones and reconfiguring channels. However, in spite of decades of efforts designed to reduce erosion, high concentrations of suspended sediment remain a major cause of stream impairment in North Carolina.

Sediment in streams is regulated by the State of North Carolina through two divisions of the North Carolina Department of Environment and Natural Resources (NCDENR)—the Division of Land Resources (DLR) and the Division of Soil and Water Conservation (DSWC). The DLR Land Quality Section regulates sedimentation under the auspices of the North Carolina Sediment Pollution Control Act of 1973 (as amended through 1999), which primarily addresses construction sites and road maintenance. In contrast, regulation of sediment by the DSWC is largely through voluntary, nonregulatory programs, which offer incentives for erosion control on agricultural and forested lands. In addition to programs offered through the State, the U.S. Department of Agriculture (USDA) also provides financial and technical assistance for a variety of voluntary erosion-reduction and stream-improvement measures through programs such as the Environmental Quality Incentives Program (EQIP), the Conservation Security Program (CSP), and the Agricultural Water Enhancement Program (AWEP). In recent years, statewide efforts to decrease sediment loads in streams have expanded. From 1984 to 1997, more than 24,000 contracts were approved through the North Carolina Agriculture Cost Share Program administered by the DSWC to implement agricultural BMPs. An estimated average annual retention of about 1.5 million tons of soil during this period is attributed to the implementation of BMPs (North Carolina Department of Environment and Natural Resources, 2008). From 1999 to 2008, more than $1.4 million was invested in BMPs in Surry County, which is estimated to have resulted in an annual reduction in soil erosion of more than 31,600 tons/yr (table 1; North Carolina Department of Environment and Natural Resources, 2009).

Despite this large monetary investment, few studies have been conducted to evaluate either the short-term or, perhaps more importantly, the long-term effects of agricultural BMP implementation and in-stream restoration on suspended sediment, habitat, and biota in North Carolina streams. Research regarding the effects of agricultural BMPs in North Carolina

Table 1. Estimated annual reduction in runoff of soil, nitrogen, and phosphorus and cost of implementing agricultural best management practices in Surry County, North Carolina, 1998–2007.

[N, nitrogen; P, phosphorus; Source: North Carolina Department of Environment and Natural Resources, Division of Soil and Water Conservation, 2009]

Calendar year	Soil (tons)	N (pounds)	P (pounds)	Cost
2007	535	0	0	$140,762
2006	601	30,516	19,898	$220,293
2005	1,010	876	81	$144,833
2004	1,661	7,427	260	$182,466
2003	1,982	6,904	240	$210,513
2002	4,121	27,010	1,700	$197,093
2001	6,422	67,308	2,780	$121,696
2000	6,306	26,459	1,020	$88,023
1999	8,598	41,610	1,357	$81,458
1998	411	10,155	351	$93,819
Total	31,646	218,265	27,687	$1,480,956

has been conducted primarily in the Coastal Plain Physiographic Province, an area where erosion and sedimentation are less of a concern than nutrient delivery (for example, Gilliam and others, 1997; Lecce and others, 2006). Few studies have been conducted in the Piedmont Physiographic Province of North Carolina. An 8-year monitoring study in the Long Creek Basin in the western Piedmont of North Carolina was conducted to evaluate the effects of BMPs designed to exclude cattle from streams and manage animal wastes. Declines were observed in fecal bacteria levels and phosphorus concentrations; however, no changes in suspended-sediment and nitrate concentrations were observed (Line, 2002). Brannan and others (2000) evaluated the effects of animal waste BMPs on nutrients and sediment in the Owl Run watershed, a 4.45-square-mile (mi^2) basin in the Piedmont of Virginia, over a 10-year period and observed decreases in nitrogen loads throughout the basin. However, sediment and orthophosphorus loads in some of the subbasins increased.

Various factors, including basin size, number and type of BMP, proximity of BMPs to streams, and historic land-use characteristics, appear to affect the response of streams to implementation of BMPs. In a study evaluating the response of streams in Ontario, Canada, to the implementation of agricultural BMPs, Yates and others (2007) found that the likelihood of detecting improvement in stream-quality increased as the number of BMPs implemented increased and the size of the basin decreased. The response time to stream improvement efforts appears to differ with respect to the extent of the improvement activity and the aspect of stream quality being evaluated. Ranganath and others (2009) compared channel morphology and benthic invertebrate assemblages along paired stream reaches with and without livestock exclusion. Stream reaches from which livestock were excluded were deeper and had more coarse substrate material in riffles. Differences in benthic invertebrate assemblages were not evident, even when comparing sites where cattle had been excluded for 50 years. The lack of effects of livestock exclusion on benthic invertebrate communities was attributed to the relatively short lengths of the stream reaches from which livestock were excluded (Ranganath and others, 2009). Another investigation of Piedmont streams was conducted by Galeone and others (2006) in the Mill Creek watershed of Lancaster County, Pennsylvania, to determine the effects of livestock exclusion and the creation of riparian buffers on stream chemistry and benthic invertebrate communities. Four years after the BMPs were implemented, the researchers observed reductions in suspended-sediment concentrations and improvement in benthic invertebrate communities associated with livestock exclusion and decreases in nutrient concentrations associated with the creation of riparian buffers in addition to livestock exclusion (Galeone and others, 2006).

The relation between erosion rates and suspended-sediment discharge is complex, and extrapolation of the effects of erosion-control efforts to suspended-sediment loads may not be practical, especially over short time periods. Although upland soil erosion is likely the original source of much of the suspended sediment in streams, re-suspension of sediment in the stream channel and streambank erosion can contribute to high concentrations of suspended sediment even when rates of soil erosion are small (Slaymaker, 1982; Phillips, 1987). Study results from a wide range of settings indicate that only a small portion of eroded soil is discharged downstream (Trimble, 1983, Walling, 1983; Walling and others, 2006) and that decades may be required to detect sediment-discharge reductions that result from decreased rates of erosion (Trimble, 1983; Richter and Korfmacher, 1995). In a study evaluating sediment export in a piedmont stream basin in north-central Georgia, Jackson and others (2005) estimated that full removal of eroded soil stored in stream channels would require several thousands of years at the present (2005) export rates.

Unrestricted access of livestock, especially cattle, to streams can contribute to streambank erosion (Rickard and Cushing, 1982; Trimble and Mendel, 1995). Because streambank erosion can produce a major component of the suspended-sediment load in a stream (Grissinger and others, 1991; Simon and Darby, 1997), in-stream restoration is potentially more effective, at least in the short term, at decreasing stream-sediment loads than are agricultural BMPs designed to reduce upland erosion. There are a variety of in-stream restoration techniques that range from channel stabilization and reconfiguration to livestock exclusion and establishment of vegetation along streambanks and on flood plains. However, channel stabilization and reconfiguration, which generally involve the use of heavy equipment, are typically much more costly than BMP implementation. Thus, an evaluation is needed of the effects of individual and combined agricultural BMPs and in-stream restoration activities on streamwater quality, habitat, and biota. To meet this need, the U.S. Geological Survey (USGS) and the DSWC developed a cooperative study designed to assess changes produced by the implementation of agricultural BMPs and in-stream restoration activities at selected sites in Surry County North Carolina.

Purpose and Scope

The purpose of this report is to describe the results and lessons learned from a study to assess the effects of agricultural BMPs and in-stream restoration techniques on suspended-sediment concentrations, stream habitat, and benthic macroinvertebrate assemblages at three small stream sites in rural areas of North Carolina (fig. 1; table 2). The drainage basin of one of the sites lies primarily in Carroll County, Virginia.

Streamflow data were collected at the study sites from 2004 to 2007. Data collected to assess water-quality conditions at the sites from 2004 to 2007 included suspended-sediment and nutrient concentrations as well as physical characteristics. Stream-habitat assessments were made annually during 2004–2006. Benthic macroinvertebrate samples were obtained annually from 2004 to 2007. Study basins were characterized on the basis of physical characteristics, land use and cover, and stream-improvement measures.

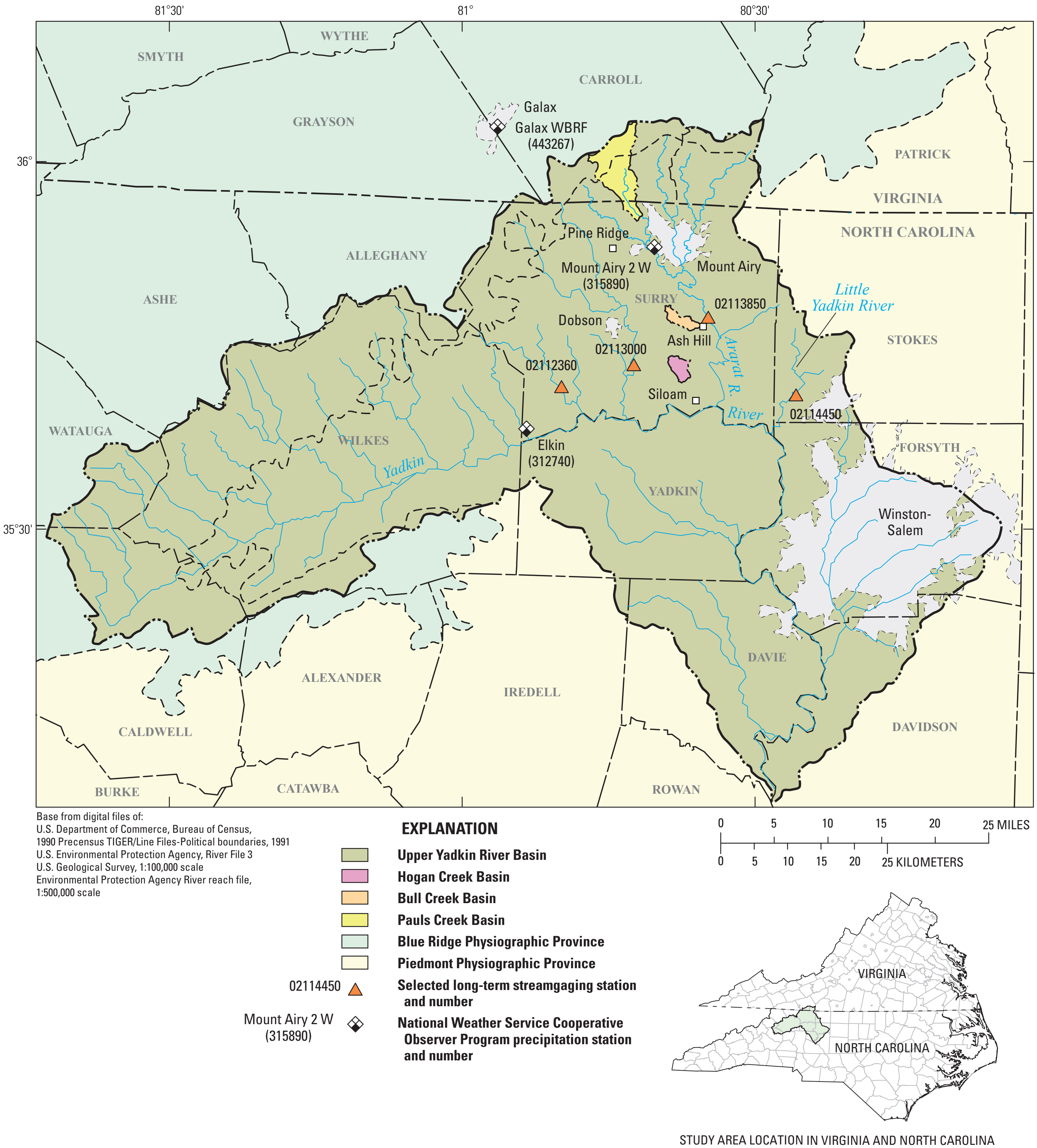

Figure 1. Locations of Hogan Creek, Bull Creek, and Pauls Creek study basins in Surry County, North Carolina, and Carroll County, Virginia, and selected monitoring sites in the Blue Ridge and Piedmont Physiographic Provinces of North Carolina and Virginia.

Table 2. Characteristics of the Hogan Creek, Bull Creek, and Pauls Creek study sites in Surry County, North Carolina.

[mi^2, square mile; BMP, best management practice; SR, secondary road; N.C., North Carolina]

Site name (locations shown in fig. 1)	Drainage area (mi^2)	Site identification number[a]	Site type	Period of streamflow record	Habitat assessment dates	Benthic macro-invertebrate collection dates	Nutrient sample collection dates
Hogan Creek at SR 2038 near Siloam, N.C.	3.32	0211351575	Control	08/11/2004 to 09/30/2007	08/26/2004 08/18/2005 08/21/2006	03/24/2004 02/16/2005 03/08/2006 03/20/2007	11/10/2004 03/30/2005 06/09/2005 08/18/2005 11/03/2005 01/26/2006 03/08/2006 08/21/2006 11/16/2006 03/20/2007 05/15/2007 09/25/2007
Bull Creek at Ash Hill, N.C.	3.30	0211397263	BMPs	06/01/2004 to 09/30/2007	08/26/2004 08/18/2005 08/22/2006	03/24/2004 02/16/2005 03/08/2006 03/21/2007	11/10/2004 03/30/2005 06/09/2005 08/18/2005 11/03/2005 01/26/2006 03/08/2006 08/22/2006 11/15/2006 03/21/2007 05/15/2007 09/26/2007
Pauls Creek above SR 1625 near Pine Ridge, N.C.	20.7	0211371675	In-stream restoration and BMPs	08/18/2004 to 09/30/2007	08/27/2004 08/19/2005 08/22/2006	03/24/2004 02/17/2005 03/09/2006 03/21/2007	11/09/2004 03/29/2005 06/10/2005 08/19/2005 11/04/2005 01/25/2006 03/09/2006 08/22/2006 11/15/2006 03/21/2007 05/16/2007 09/26/2007

[a]Site identification number corresponds to number used in the U.S. Geological Survey National Water Information System database.

Description of the Study Area

The three rural stream sites selected for this study are in Surry County, North Carolina, in the Upper Yadkin River Basin (fig. 1). The drainage basins of the study sites range in size from 3.3 to 20.7 mi^2 (table 2). The drainage basins of the two smaller sites, Hogan and Bull Creeks, (figs. 2, 3, respectively) are entirely within the Piedmont Physiographic Province (fig. 1; Fenneman and Johnson, 1948). The drainage basin of Pauls Creek (fig. 4), the largest of the study sites, lies primarily in the southern part of Carroll County, Virginia. About a third of the Pauls Creek drainage basin lies within the Blue Ridge Physiographic Province and the remaining two-thirds of the basin lies within the Piedmont Physiographic Province (Fenneman and Johnson, 1948; fig. 4). The northern part of the Piedmont Physiographic Province is gently rolling to hilly in contrast to the steep slopes along the southern edge of the Blue Ridge Physiographic Province.

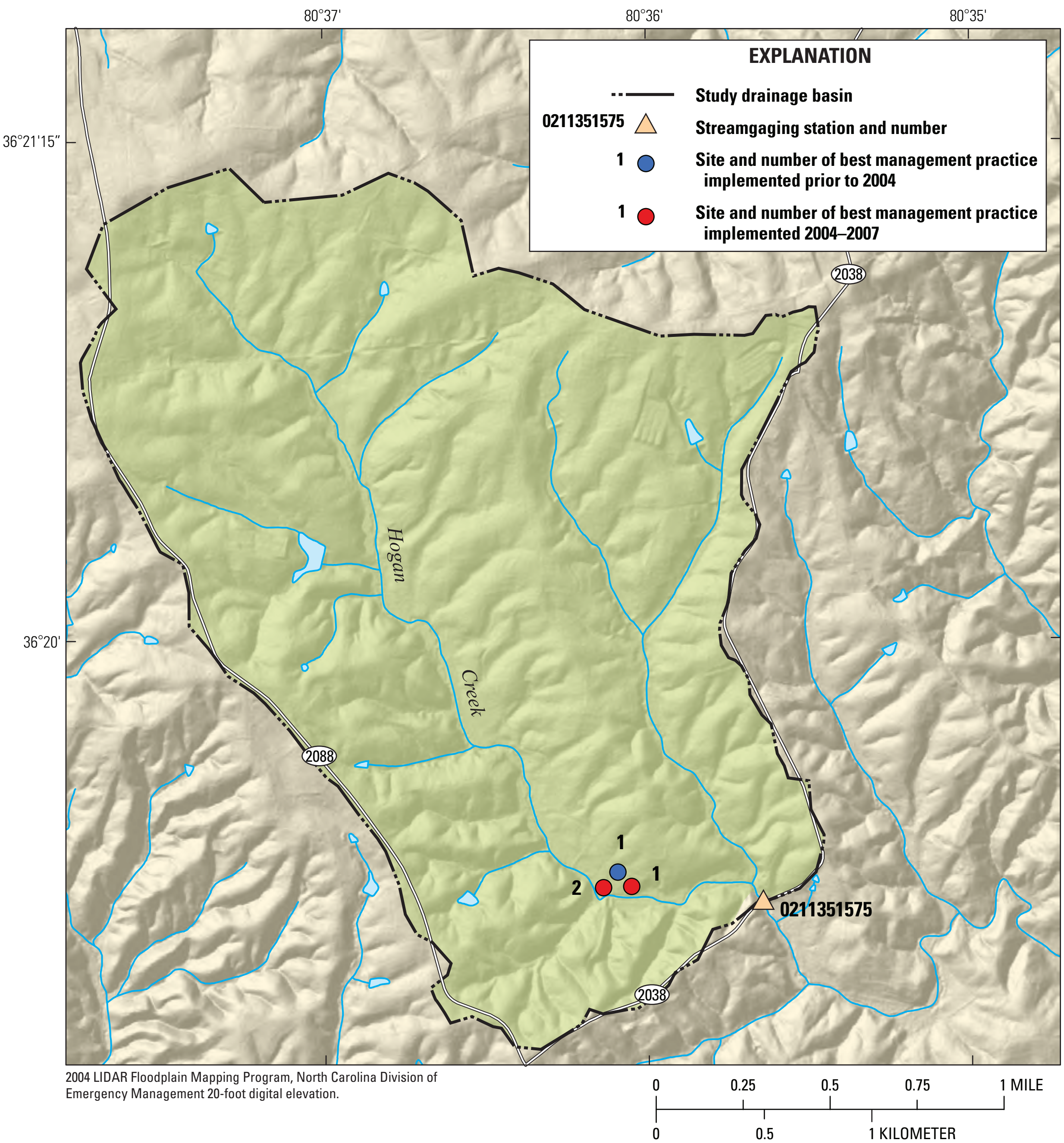

Figure 2. Drainage basin for Hogan Creek at SR 2038 near Siloam, North Carolina, and locations of streamgaging station and agricultural best management practice sites, 2001–2007. [Best management practice numbers correspond to table 4.]

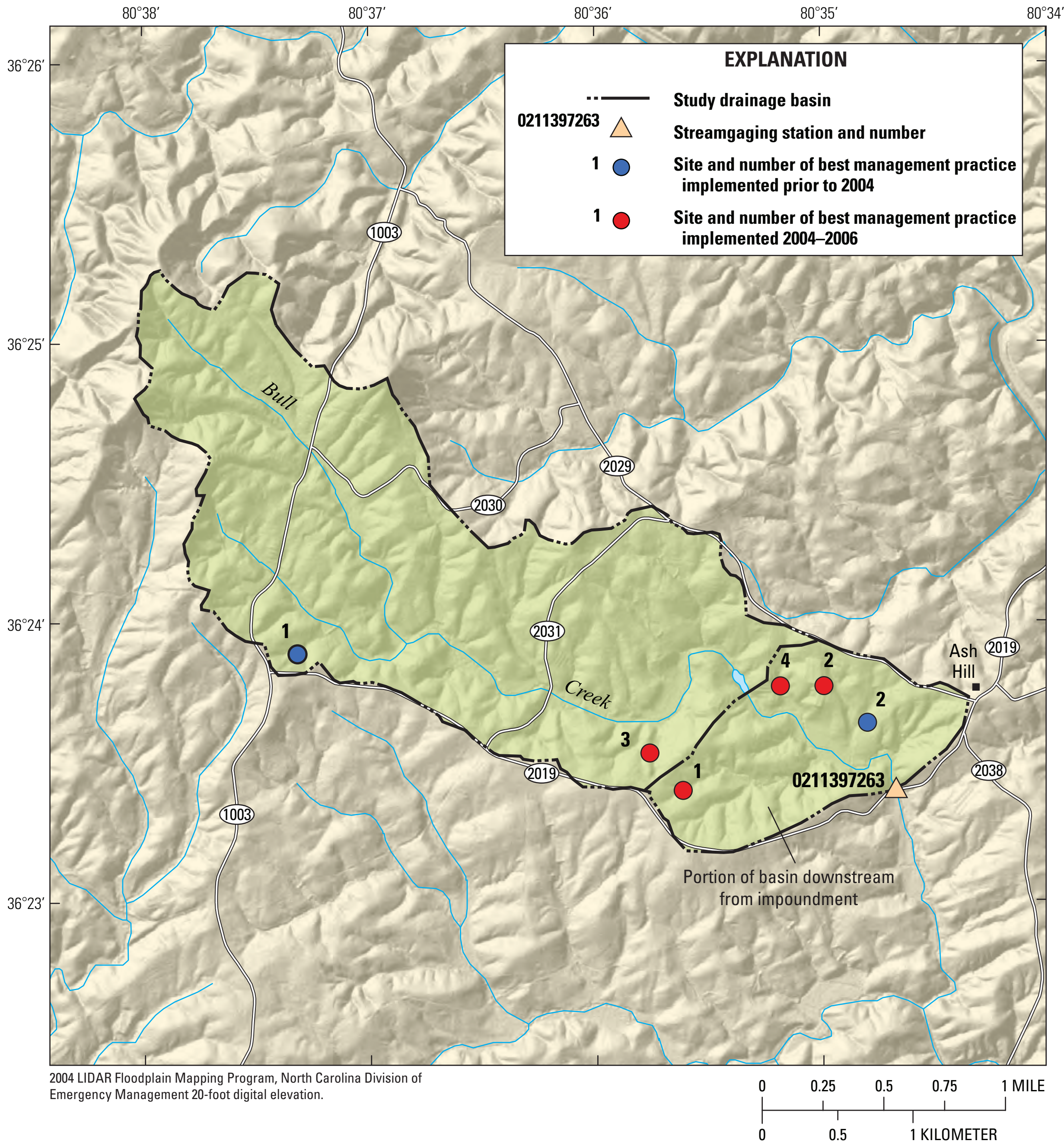

Figure 3. Drainage basin for Bull Creek at Ash Hill, North Carolina, delineating the portion of the basin downstream from the impoundment, and locations of the streamgaging station and agricultural best management practice sites, 1995–2006. [Best management practice numbers correspond to table 4.]

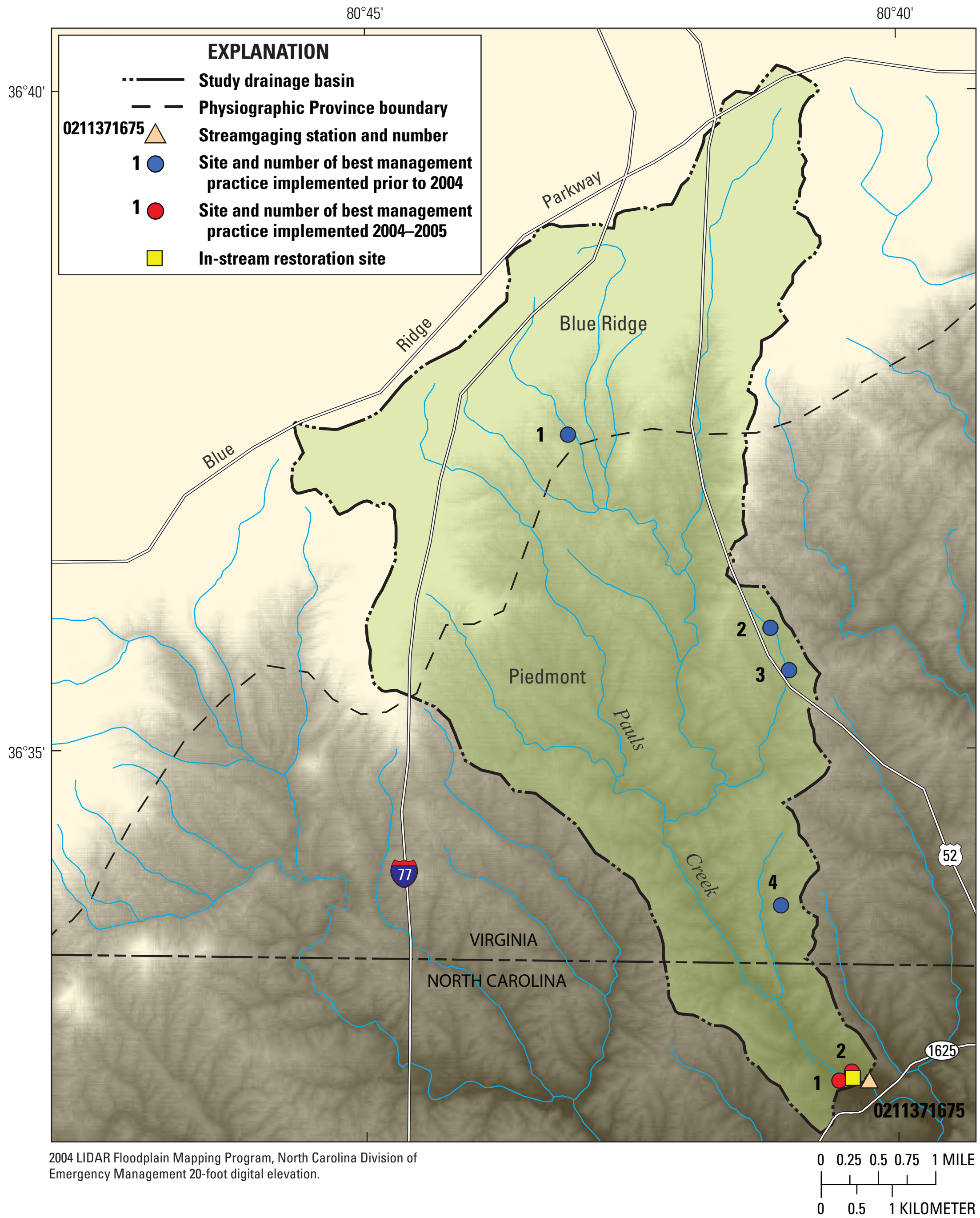

Figure 4. Drainage basin for Pauls Creek above SR 1625 near Pine Ridge, North Carolina, and locations of streamgaging station, agricultural best management practice sites, and in-stream restoration site, 1989–2005. [Best management practice numbers correspond to table 4.]

Land-use patterns in the drainage basins of the study sites correspond to the physiographic characteristics (table 3). In 2002, pasture and hay production were the dominant land uses in the two smaller basins and represented slightly more than one-half of the total land area in these basins (table 3). In contrast, forests covered more than 60 percent of the land area in the Pauls Creek drainage basin (U.S. Department of Agriculture, 2006a, b). Major crops in the study basins included winter wheat, soybeans, and corn. Urban and residential land uses accounted for about 20.2 and 20.1 percent of the Hogan and Bull Creek Basins, respectively, compared to 1.2 percent of the Pauls Creek Basin (U.S. Department Agriculture,

Table 3. Major land-use categories in 2002 in the Hogan Creek, Bull Creek, and Pauls Creek study basins in Surry County, North Carolina, and Carroll County, Virginia.

[BMP, best management practice; <, less than; Source: U.S. Department of Agriculture, 2006a, b]

Land-use category (shown as percentages of basin area)	Hogan Creek (control site)	Bull Creek (BMP site)	Pauls Creek (in-stream restoration and BMP site)
Crop	6.5	6.6	2.9
Fallow	0.8	0.4	0.2
Pasture, grassland, and hay	53.5	51.4	35.6
Forest	18.9	21.4	60.1
Urban/residential	20.2	20.1	1.2
Water	0.1	0.1	<0.1

2006a, b). Maps showing the drainage basins, including locations of stream-improvement measures, are provided in figures 2–4; diagrams of the timelines for sampling, streamgaging station installation, and stream-improvement measures are provided in figures 5–7, for the Hogan Creek, Bull Creek, and Pauls Creek sites, respectively.

The Hogan Creek site was used as a control site. Although implementation of agricultural BMPs in the Hogan Creek Basin was not planned during this study, two livestock-exclusion BMPs were completed in May and August 2007 (figs. 2, 5; table 4). In addition, one livestock-exclusion BMP was implemented in the Hogan Creek Basin prior to the study (fig. 2; table 4).

Four agricultural BMPs were implemented in the Bull Creek drainage basin during the study, and two were implemented prior to the study (figs. 3, 6; table 4). Three of the BMPs implemented during the study were designed to restrict access of livestock to streams. The fourth BMP involved the repair and improvement of a lined poultry composter, which is unlikely to have affected stream-sediment concentrations.

The Pauls Creek site was selected to assess the combined effects of in-stream channel restoration and agricultural BMPs on stream quality. Prior to restoration efforts, streambank erosion contributed to the loss of riparian vegetation and undercutting of streambanks (fig. 8). From late October through November 2005, a 1,600-foot (ft) reach of the Pauls Creek stream channel was stabilized by grading and installing a series of stone structures designed to minimize streambank erosion (fig. 9*A*–*C*). These

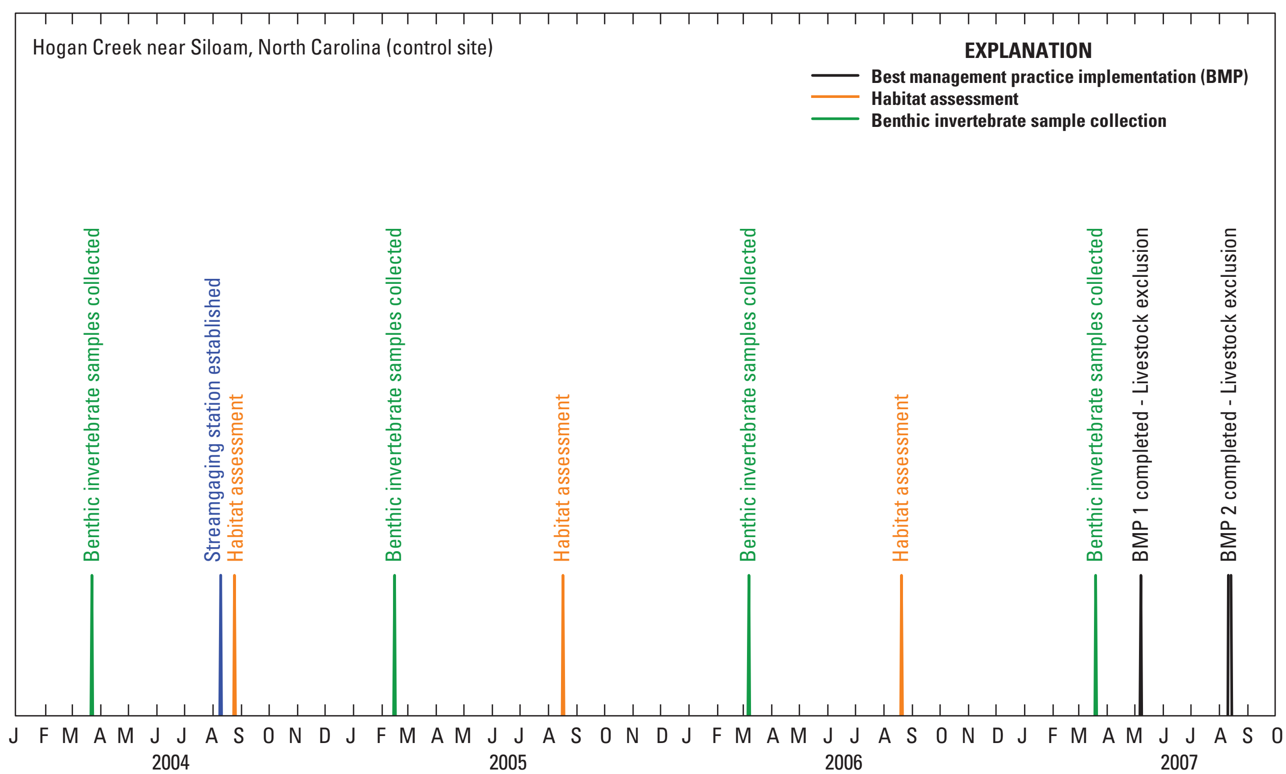

Figure 5. Timeline for streamgaging station installation, best management practice implementation, habitat assessment, and benthic invertebrate sampling at Hogan Creek near Siloam, North Carolina, 2004–2007. [Best management practice numbers correspond to table 4.]

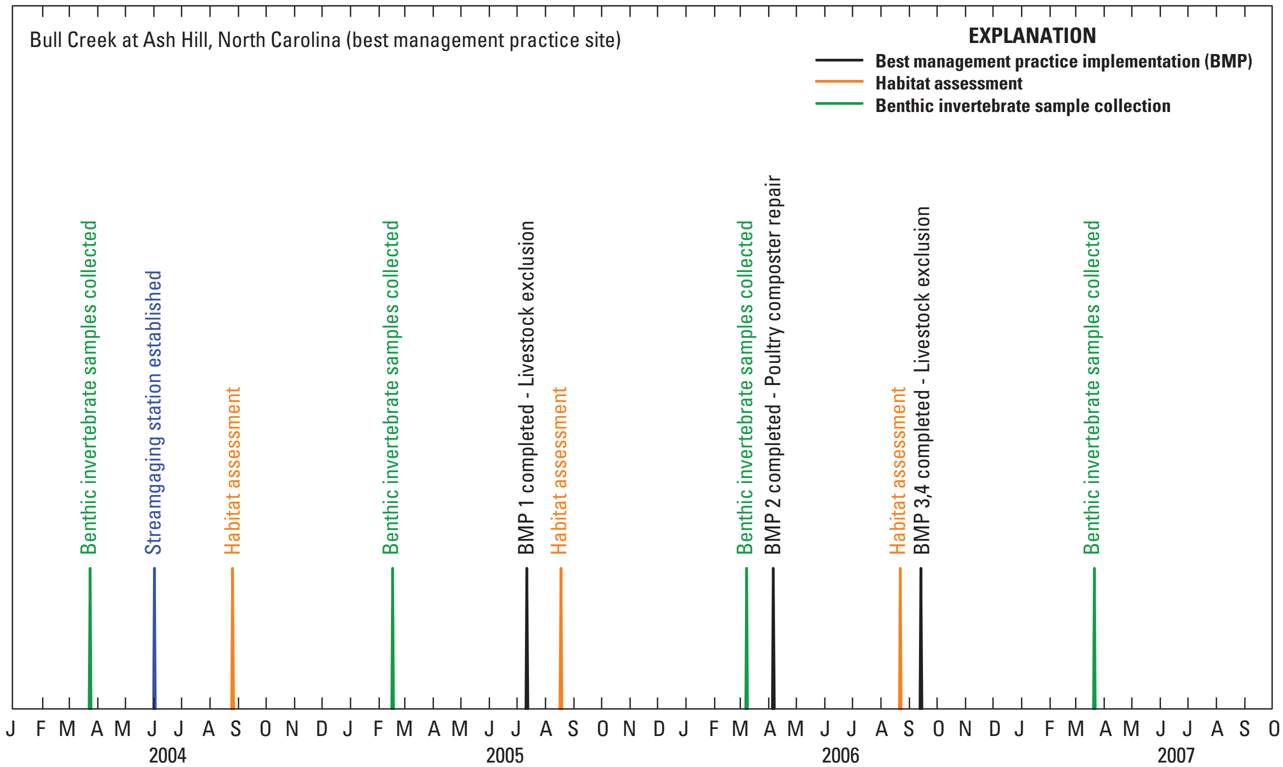

Figure 6. Timeline for streamgaging station installation, best management practice implementation, habitat assessment, and benthic invertebrate sampling at Bull Creek at Ash Hill, North Carolina, 2004–2007. [Best management practice numbers correspond to table 4.]

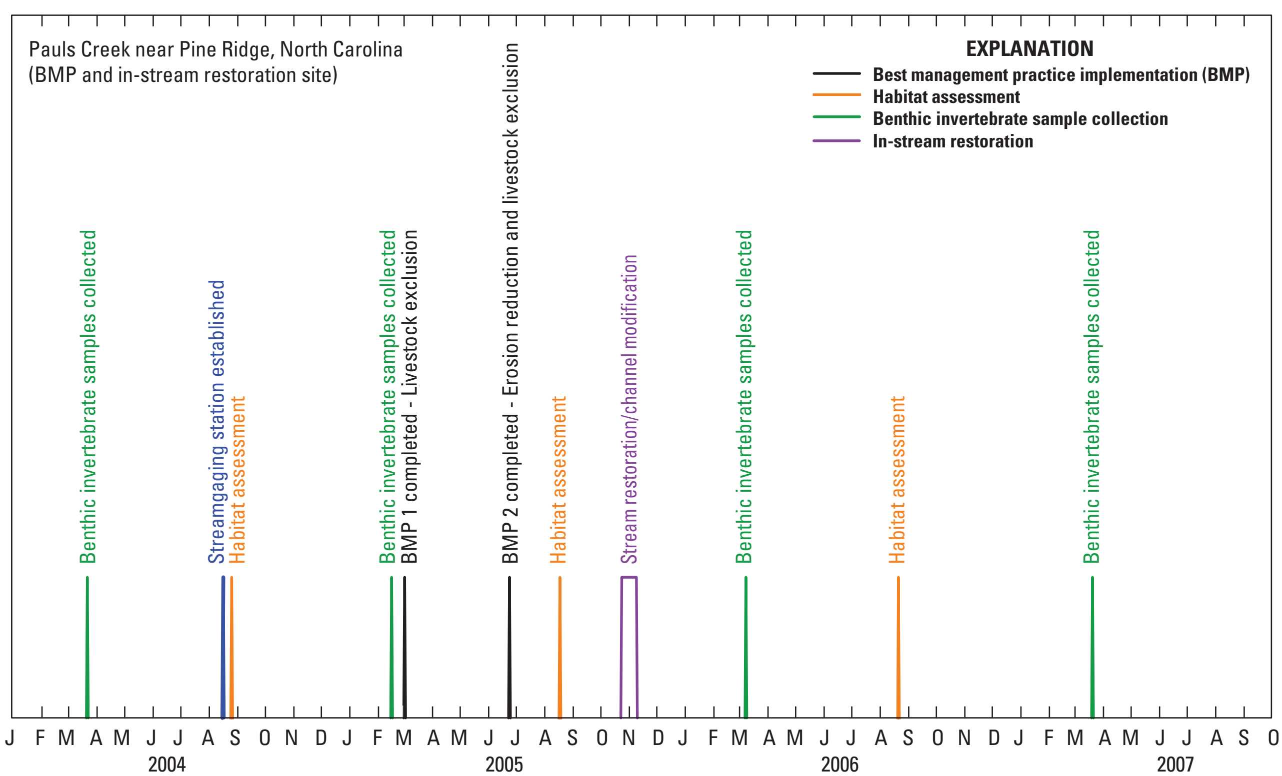

Figure 7. Timeline for streamgaging station installation, best management practice implementation, in-stream restoration, habitat assessment, and benthic invertebrate sampling at Pauls Creek near Pine Ridge, North Carolina, 2004–2007. [Best management practice numbers correspond to table 4.]

Table 4. Summary of agricultural best management practices implemented in drainage basins of the Hogan Creek, Bull Creek, and Pauls Creek study sites in Surry County, North Carolina, and Carroll County, Virginia, 1989–2007.

[Source: T. Davis, Surry County Soil and Water Conservation District, written commun., July 14, 2008, and T. Phipps, New River Soil and Water Conservation District, written commun., April 28, 2008]

Map number	Date implementation completed	Description
Figure 2	Hogan Creek near Siloam, North Carolina, drainage basin	
	pre-2004	
1	December 2001	Livestock exclusion
	post-2004	
1	May 2007	Livestock exclusion
2	August 2007	Livestock exclusion
Figure 3	Bull Creek at Ash Hill, North Carolina, drainage basin	
	pre-2004	
1	November 1995	Erosion control
2	December 2003	Livestock exclusion
	post-2004	
1	July 2005	Livestock exclusion
2	April 2006	Poultry composter repair
3	September 2006	Livestock exclusion
4	September 2006	Livestock exclusion
Figure 4	Pauls Creek near Pine Ridge, North Carolina, drainage basin	
	pre-2004	
1	June 1989	Pasture to forest conversion
2	May 1992	Pasture to forest conversion
3	March 2002	Livestock exclusion
4	September 2003	Livestock exclusion
	post-2004	
1	March 2005	Livestock exclusion
2	June 2005	Livestock exclusion and erosion reduction

Figure 8. Eroded streambank prior to in-stream restoration upstream from the streamgaging station at Pauls Creek near Pine Ridge, North Carolina, November 5, 2005.

Figure 9. The restored reach upstream from the streamgaging station at Pauls Creek near Pine Ridge, North Carolina, showing (*A*) typical rock vane structure installed in the stream channel upstream from the streamgaging station, (*B*) channel-stabilization work in progress on November 4, 2005, and (*C*) typical bank-stabilizing structure installed in the stream channel upstream from the streamgaging station.

structures were primarily cross vanes that were constructed with large boulders positioned in the stream to direct flow toward the center of the channel. The restored reach was entirely upstream from the Pauls Creek streamgaging station with channel modifications ending about 200 ft upstream from the gage. Two agricultural BMPs, one designed to exclude livestock from the stream and the other designed to exclude livestock and decrease streambank erosion, were implemented in the vicinity of the streamgaging station at Pauls Creek (table 4; figs. 4, 7, 8). In addition, two BMPs primarily designed to decrease erosion through conversion of erodible cropland to forests and two BMPs designed to exclude livestock from streams were implemented prior to this study upstream from the streamgaging station in the Virginia part of the basin from 1989 to 2003 (table 4).

Methods of Investigation

A before-after control impact paired (BACIP) study design (Osenberg and others, 1994) was used to assess the effects of agricultural BMPs and in-stream restoration on stream quality. To accomplish this, two impacted sites were selected, one where BMPs were implemented and a second where channel stabilization, a type of in-stream restoration, was performed in addition to BMP implementation. A third site where neither BMP implementation nor in-stream restoration was planned was selected as a control site. Continuous streamflow data were obtained from 2004 to 2007. Water-quality and suspended-sediment samples were collected before and after BMP implementation and in-stream restoration. Most of the suspended-sediment samples were obtained concurrently to allow for analysis as paired samples. Stream habitat conditions at each site were assessed annually from 2004 to 2006. Benthic macroinvertebrate samples were collected annually at each site from 2004 to 2007. Methods of data collection and analysis are described in the following sections.

Site Selection

Selection of the study sites was a joint effort by the USGS and DSWC to target agricultural basins on the State's 303d list (N.C. Department of Environment and Natural Resources, 1998). In order to differentiate between the response of streams to implementation of agricultural BMPs and in-stream restoration efforts, sites were identified where agricultural BMPs were planned and where in-stream restoration was planned. Sites where no BMP implementation nor in-stream restoration measures were planned also were identified for use as potential control sites. An effort also was made to identify sites with primarily rural characteristics. Other factors involved in the site-selection process included accessibility and channel characteristics that were suitable for sample collection and streamflow measurements.

Ultimately, three sites were selected for the collection of streamflow, water-quality, habitat, and benthic macroinvertebrate data from 2004 to 2007. During the course of the study, several agricultural BMPs were implemented in one stream basin (Bull Creek); channel stabilization and agricultural BMPs were implemented in a second stream basin (Pauls Creek); and a third stream basin (Hogan Creek), where two agricultural BMPs were implemented during the last part of the study, was used as a control site.

Streamflow Data Collection

Streamgaging stations were constructed at each of the study sites. A stage-streamflow relation, or rating, was developed for each site. The relation between stage and streamflow at low to mid ranges of flow was defined by multiple streamflow measurements made at each site using established guidelines and procedures (Rantz and others, 1982). The relation between stage and flow at mid to high ranges was based on results of a one-dimensional step-backwater hydraulic model developed for each site using the Hydrologic Engineering Centers River Analysis System (HEC-RAS) software (Brunner, 2002). To develop the models, multiple channel cross sections were surveyed at each site. Cross-section data and channel-roughness coefficients were entered into an unsteady flow model, which then was used to predict streamflows from water-surface profiles and stage data recorded at each site. Flow values predicted by the model and field measurements of streamflow were combined to develop a final rating for each site from which streamflow data were subsequently calculated.

Climatic conditions in the study basins were evaluated with respect to streamflow at nearby long-term USGS streamgaging stations and precipitation records collected at National Weather Service (NWS) Cooperative Observer Program stations in Surry County, North Carolina, and at the WBRF (formerly WBOB) radio station in Galax, Virginia, during the study period. Departures from normal monthly precipitation and annual precipitation totals measured at the Mount Airy 2 W and Elkin weather stations were obtained from the State Climate Office of North Carolina NC CRONOS database (Corey Davis, State Climate Office of North Carolina, written commun., January 13, 2010). Monthly and annual rainfall totals measured at the WBRF radio station in Galax, Virginia, were obtained from the Southeast Regional Climate Center (2009) at The University of North Carolina, Chapel Hill.

Water-Quality Data

Methods used for collection and analysis of water-quality data, including physical characteristics, nutrients, and suspended-sediment concentrations, are described in the following sections.

Collection and Analysis of Water-Quality Samples

Water samples for analysis of suspended-sediment and nutrient concentrations were collected near the streamgaging station at each study site. Samples for analysis of suspended-sediment concentration were collected at 2-week intervals by Surry County Soil and Water Conservation District (SWCD) personnel. Additional samples for analysis of suspended-sediment concentration were collected by USGS personnel on a quarterly basis and during storm events. Beginning in early 2006, collection of suspended-sediment samples during periods of runoff was emphasized in order to obtain data over a greater range of streamflow to facilitate calculation of loads. Suspended-sediment samples were collected with a depth-integrating sampler, either a DH-48 or DH-59 sampler, at multiple points across each stream according to techniques described by Edwards and Glysson (1988). The suspended-sediment samples were analyzed by the USGS Kentucky Water Science Center Sediment Laboratory in Louisville, Kentucky, according to methods described by Guy (1969).

Water-quality samples were collected by USGS personnel on a quarterly basis to characterize general water chemistry and nutrient concentrations at the three study sites. Water-quality samples were composited from samples collected at multiple points across each stream and processed in accordance with procedures and guidelines in the USGS national field manual (U.S. Geological Survey, variously dated). The nutrients analyzed included total phosphorus, dissolved orthophosphate, dissolved nitrite plus nitrate, dissolved ammonia, and total ammonia plus organic nitrogen. Nutrient samples were analyzed by the USGS National Water Quality Laboratory in Denver, Colorado. Nitrogen constituents and dissolved orthophosphate were analyzed according to methods described in Fishman (1993), and total phosphorus was analyzed according to methods described in Patton and Truitt (1992). Physical characteristics of stream water including dissolved-oxygen concentration, pH, temperature, and specific conductance were measured on site in conjunction with the collection of nutrient samples. A total of 11 quality-assurance samples, consisting of replicates and blanks, were obtained during this study and analyzed for nutrients and suspended-sediment concentration.

Calculation of Suspended-Sediment Loads

Annual in-stream load estimates for suspended sediment for water years[1] 2005–2007 were calculated by using the USGS program S-LOADEST (David L. Lorenz, U.S. Geological Survey, written commun., 2004). Documentation for S-LOADEST and S-PLUS for Windows—Release 2.1 (Slack and others, 2003) is available to the public at the USGS software library at *http://water.usgs.gov/software/library.html*.

[1]Water year is the period October 1 through September 30 and is identified by the year in which the period ends. For example, the 2005 water year began on October 1, 2004, and ended on September 30, 2005.

The load estimates were obtained by using a five-variable log-linear regression model (Cohn and others, 1989; Gilroy and others, 1990; Cohn and others, 1992).

$$ln\mathrm{L} = a_0 + a_1 ln\mathrm{Q} + a_2 t + a_3 \sin(2\pi t) + a_4 \cos(2\pi t) + e \quad (1)$$

where

ln = natural logarithm function;

L = load (Q * c);

c = concentration, in milligrams per liter;

Q = instantaneous discharge at time of concentration sampling, in cubic feet per second;

t = time, in decimal years;

sin = sine function;

cos = cosine function;

π = 3.14169;

a_0, a_1, a_2, a_3, a_4 = coefficients of the regression model; and

e = model error term.

The discharge term ($a_1 \, ln \, Q$) in the model addresses variability in concentration resulting from variability in discharge or streamflow. The time term (a_2t) adjusts for variability resulting from a linear time trend in concentration, and the sine and cosine terms adjust for seasonal variability in concentration. Bias generated in the estimated load when the load is transformed from log to linear units was corrected by using the minimum variance unbiased estimator correction (MVUE; Bradu and Mundlak, 1970). Censored data were adjusted statistically by using the adjusted maximum likelihood estimator described by Cohn (1988).

Statistical Analysis of Suspended-Sediment Data

Streamflow and suspended-sediment data were analyzed using non-parametric techniques to determine if stream-improvement measures (BMP implementation at the Bull Creek site, and in-stream restoration plus BMP implementation at the Pauls Creek site) affected suspended-sediment concentration and suspended-sediment discharge. Statistical analysis followed the BACIP (before-after control-impact paired sites) study design (Ellis and Schneider, 1997; Glasby, 1997). The Hogan Creek site was used as the control site for evaluation of the impacted sites. Graphical comparisons were made for values of suspended-sediment concentration, instantaneous suspended-sediment discharge, and the instantaneous streamflow obtained at the time of suspended-sediment sample collection. Values from the control site were paired with values from both impacted sites. Comparisons were made after these paired values were divided into groups representing conditions before and after stream-improvement measures.

An unbalanced two-way analysis of variance (ANOVA) for ranked values of suspended-sediment concentration and instantaneous suspended-sediment discharge was performed to evaluate the effect of stream-improvement measures on suspended-sediment concentration and suspended-sediment discharge (Helsel and Hirsch, 1992). The analysis was considered to be unbalanced because the number of samples collected before and after the time of stream improvement were unequal. Suspended-sediment concentrations and instantaneous suspended-sediment discharge were ranked for each site. The ANOVA model included differences between sites (stream-improvement site and the control site) and differences in time period (before and after stream improvement, either implementation of BMPs at Bull Creek or in-stream restoration plus implementation of BMPs at Pauls Creek), and the interaction between sites and time period. Samples that could not be paired with a sample from the control site (Hogan Creek) were excluded from analysis as were samples collected during in-stream restoration at Pauls Creek. Samples were considered to be paired if they were collected on the same day or, if streamflow was stable (no recent precipitation), within a 2-day period. Because of the correlation of suspended-sediment concentration with streamflow, the streamflow at the time of collection of each suspended-sediment sample also was ranked and evaluated by ANOVA.

The ANOVA model corresponds to

$$X_{ijk} = \mu + A_i + B_j + (AB)_{ij} + e_{ijk} \quad (2)$$

where

i = 1, 2 (control site and stream-improvement site)

j = 1, 2 (before and after date of stream-improvement effort)

k = 1, 2,…n (number of measurements)

X_{ijk} = dependent variable response (suspended-sediment concentration, suspended-sediment discharge, or streamflow at the time of sediment sample collection)

μ = mean value of either suspended-sediment concentration rank, suspended-sediment discharge rank, or streamflow rank

A_i = effect of the ith level of site type (control site or stream-improvement site)

B_j = effect of the jth level of time period (before or after stream-improvement activity)

$(AB)_{ij}$ = interaction effect of ith level of A and jth level of B

e_{ijk} = random error component associated with the response variable X_{ijk}.

The null (H_0) and alternative (H_a) hypotheses tested included

H_0: A_1=A_2 and H_a: $A_1 \neq A_2$

H_0: B_1=B_2 and H_a: $B_1 \neq B_2$

H_0: $(AB)_{11}$=$(AB)_{12}$=$(AB)_{21}$=$(AB)_{22}$=0 and

H_a: $(AB)_{ij} \neq 0$

Results of the ANOVA were evaluated on the basis of Type III sums of squares to account for the unbalanced design (Shaw and Mitchell-Olds, 1993).

Suspended-sediment data also were analyzed using Student's *t*-test for paired samples with unequal variances on ranked values (Zimmerman and Zumbo, 1993; Ruxton and Sheldon, 2006). This statistical test is also referred to as the *t*-test with the Welch correction or the Welch *t*-test (Welch, 1947). Values for suspended-sediment concentration, instantaneous suspended-sediment discharge, and instantaneous streamflow were paired as for the previously described ANOVA procedure to ensure similarity of hydrologic conditions at the control and stream-improvement site. Suspended-sediment concentration, instantaneous suspended-sediment discharge, and instantaneous streamflow at the time of suspended-sediment sample collection were ranked by site. Paired sets of ranked values were analyzed where each pair consisted of data for the control site (Hogan Creek) and for a stream-improvement site (either Bull Creek or Pauls Creek). The ranked values for each set were split into before and after groups with the before group representing the period prior to stream improvement and the after group representing the period following the stream-improvement activity. As for the ANOVA, data obtained during the time of stream restoration at Pauls Creek were excluded. To test for the effects of stream improvement, the differences between the control site and the stream-improvement site were compared for the before and after periods.

H_0: $\mu_{c-}=0$
H_A: $\mu_{c-t}\neq 0$

where μ_{c-t} is the mean of the difference between the variable for the control site and for the stream-improvement site. In addition, between-site differences were analyzed for ranked values using the *t*-test for unequal variances and unequal sample size. The differences in ranks of paired values (control site and stream-improvement site) were compared for periods before and after stream improvement.

H_0: $\mu_{(c-t)b}=\mu_{(c-t)a}$
H_A: $\mu_{(c-t)b}\neq \mu_{(c-t)a}$

where $\mu_{(c-t)b}$ is the mean of the difference between the control site and stream-improvement site before treatment, and $\mu_{(c-t)a}$ is the mean of the difference between the control site and stream-improvement site following treatment.

Stream Habitat Assessment and Data Analysis

Stream habitat conditions at each of the study sites were assessed annually from 2004 to 2006 at transect and reach scales by USGS personnel. Current and historical basin characteristics potentially contributing to habitat conditions at the study sites also were assessed. Transect- and reach-scale habitat conditions were assessed along a 150-meter (m) stream reach at each of the three study sites, and selected channel, bank, and riparian characteristics were measured or observed. These annual assessments were made during the month of August at each of the study sites. Methods of habitat evaluation correspond to those of the USGS National Water-Quality Assessment Program (NAWQA; Fitzpatrick and others, 1998). Data were verified and entered into the USGS NAWQA Biological Transactional Database (BioTDB). The Habitat Data Analysis System (HDAS), a subsystem of BioTDB, was used to calculate the summary statistics and descriptive variables used for characterization of stream habitat. Basin characteristics were determined from USGS 7.5-minute topographic maps of the study area as described in Fitzpatrick and others (1998).

Land-Use Analysis

Various current and historical land-use activities within each study basin were characterized to aid in interpretation of data obtained during this study. Land-use information for the drainage basins of the study sites (table 3) was obtained from Cropland Data Layers of the USDA's National Agricultural Statistical Survey based on imagery for 2002 (U.S. Department of Agriculture, 2006a, b). Information about past types and locations of agricultural BMPs was obtained from the records of the Surry County Soil and Water District in Dobson, North Carolina, and the New River Soil and Water Conservation District, in Galax, Virginia. To further assess recent land-use changes other than implementation of BMPs and in-stream restoration, an inspection of each stream basin was conducted following the completion of the data-collection effort. As part of the inspection, the area where each BMP had been implemented during the study was visited, and other recent land-use changes within the study basins were documented.

Because long-term and historical changes in land use can have a large effect on stream characteristics, an effort was made to evaluate historical conditions in the drainage basins of the study sites. General land-use characteristics of the drainage basins and physical characteristics of the stream channel in the vicinity of the study sites were evaluated by using historical aerial photographs taken by the USDA Agricultural Stabilization and Conservation Service from 1936 to 1994, and comparing the historical photographs with recent aerial photographs from various sources. The historical photographs were obtained from the files of the Surry County Soil and Water Conservation Agricultural Extension Service in Dobson, North Carolina, and were scanned and georeferenced to USGS 7.5-minute topographic maps using a minimum of 20 points per photograph. On the scanned image of each aerial photograph, these points were manually selected and matched with corresponding points on the appropriate topographic map to minimize distortion associated with camera lens, angle, and terrain.

Benthic Macroinvertebrate Data

Methods pertaining to collection and analysis of benthic macroinvertebrate samples and the processing and statistical analysis of data are described in the following sections.

Sample Collection and Analysis

Benthic macroinvertebrates were collected from the 150-m stream reaches established at the study sites for characterizing stream habitat. Sampling protocols from the USGS NAWQA Program (Moulton and others, 2002) were used to collect five quantitative benthic macroinvertebrate samples from riffles with cobble and (or) gravel substrates. Riffles are presumed to contain the richest assemblage of macroinvertebrates in a sampling reach and constitute the richest targeted habitat (RTH) sample (Moulton and others 2002). Samples were collected by using a Slack sampler equipped with a 500-micron mesh net to remove invertebrates from a 0.25-square-meter (m^2, 0.5-m x 0.5-m) area of riffle. Each of the five riffle samples was processed separately to produce five replicate samples for each site and sampling date.

Invertebrate samples were processed by using methods described in Moulton and others (2000) for 300-organism subsamples. The samples collected in 2004 were picked by biology students from The University of North Carolina at Chapel Hill and identified by David R. Lenat (retired, North Carolina Division of Environmental Quality). Subsequent samples were picked and identified by Michael Bilger while affiliated with the USGS Pennsylvania Water Science Center (2005) and subsequently with EcoAnalysts, Inc. (2006 and 2007) in Selinsgrove, Pennsylvania.

Data Processing and Statistical Analysis

Prior to statistical analysis, datasets were examined for errors and corrected for taxonomic ambiguities. Taxonomic ambiguities arise when organisms from a particular sample or group of samples are not identified to the same taxonomic level. Ambiguities in the invertebrate data were resolved by using the Invertebrate Data Analysis System (IDAS) software (v. 4.2; Cuffney, 2003). The benthic macroinvertebrate data were expressed as number of organism per sample (no./0.25 m^2) for each taxon. That is,

$$N_i = C_i / (L * F) \tag{3}$$

where

N_i = number of organisms of taxon "i" in the sample,

C_i = number of organisms of taxon "i" counted in the laboratory,

L = portion of the sample processed by the laboratory (laboratory subsample), and

F = proportion of the field sample submitted to the laboratory (field subsample).

The IDAS software was used to process invertebrate samples, calculate metrics, and prepare data for ordination (Cuffney and others, 1993). Terrestrial invertebrates and pupae were excluded from the analyses. Life stages (larvae and adults) were combined. Ambiguous taxa (Cuffney and others, 2007) were resolved separately for each sample by distributing the abundance of ambiguous parents among their children. The invertebrate attributes file was optimized based on data for the southeastern United States (Barbour and others, 1999; North Carolina Department of Environment and Natural Resources, 2006).

Ordination analyses (nonmetric multidimensional scaling, NMDS) were conducted using Primer 6 (Clarke and Gorley, 2006). Invertebrate abundances were fourth-root transformed, and Bray-Curtis similarity was used for the NMDS (Bray and Curtis, 1957). The effects of station and year were tested by using two-way crossed analysis of similarity (ANOSIM). Diversity measures also were calculated using Primer 6 (Clarke and Gorley, 2006).

Results and Discussion

Streamflow characteristics at the study sites and the results of water-quality, stream-habitat, and benthic-invertebrate sampling are presented in the following sections. The data obtained from the sampling efforts during this study were evaluated to determine if there were differences between sites. The data also were evaluated over time to determine if there were changes in response to the implementation of agricultural BMPs and stream-restoration measures. Suspended-sediment concentrations also were evaluated in the context of streamflow and annual yields. Data interpretation was complicated by the numerous stream improvements and other unplanned land-use changes that occurred in the study basins.

Streamflow

Streamflow influences sediment transport and habitat characteristics (Poff and others, 2006), which in turn affects biota (Allan, 2004). Most sediment transport, streambank erosion, and channel alteration occur under high streamflow conditions (Jacobson and others, 2001). Streamflow is influenced by a variety of climatological and physical factors, especially precipitation. Continuous records of streamflow were collected at all three study sites to characterize the amount and variability of streamflow during the study. The period of record for the Bull Creek streamgaging station was June 2004 through September 2007, and the period of record for the Hogan Creek and Pauls Creek streamgaging stations was early August 2004 through September 2007. Daily mean streamflow values and summary statistics for Hogan, Bull, and Pauls Creeks are provided in Appendixes 1A–C, respectively.

The Hogan and Bull Creek drainage basins are nearly identical in size and land-use characteristics (tables 2, 3), and streamflow at these sites was correspondingly similar. During the period of study, instantaneous streamflow at the Hogan Creek site ranged from 0.29 to 1,060 cubic feet per second (ft^3/s); the highest streamflow occurred after a rainfall event in September 2004, and the lowest streamflow occurred during several days in August 2007. The annual mean streamflow for the period of study at the Hogan Creek site was 3.26 ft^3/s. Annual mean runoff calculated from streamflow records at the Hogan Creek site was 0.98 cubic foot per square mile (ft^3/mi^2), or 13.32 inches per year (in/yr).

During the study period, instantaneous streamflow values recorded at the Bull Creek site ranged from 0.24 to 609 ft^3/s; the highest streamflow occurred after a rainfall event in October 2005, and the lowest streamflow occurred during several days in August 2007. The annual mean streamflow at the Bull Creek site was 3.44 ft^3/s. Annual mean runoff calculated from streamflow records at the Bull Creek site was 1.04 ft^3/mi^2, or 14.14 in/yr.

The drainage basin for the Pauls Creek site is about seven times larger than the basins of the Hogan Creek and Bull Creek sites (table 2), and streamflow at the Pauls Creek site was correspondingly greater. During the study period, instantaneous streamflow values recorded at the Pauls Creek site ranged from 8.6 to 1,880 ft^3/s; the highest streamflow occurred after a storm event in June 2006, and the lowest streamflow occurred during August 19–21, 2007. The annual mean streamflow at the Pauls Creek site was 35.2 ft^3/s, an order of magnitude higher than the annual mean streamflow at the other two study sites. Annual mean runoff derived from streamflow records at the Pauls Creek site was calculated at 1.70 $(ft^3/s)/mi^2$, or 23.11 in/yr.

The USGS operates several long-term streamgaging stations in the upper Yadkin River Basin for purposes unrelated to this study (fig. 1). Streamflow records from four of these nearby gaging stations indicate that streamflow conditions in the study area were near or less than long-term annual mean streamflow during the study (table 5). Although some parts of Surry County were undergoing a prolonged drought, comparison of current and historical streamflow records for the streamgaging stations at the Ararat River at Ararat (station number 02113850), Fisher River near Copeland (station number 02113000), and Mitchell River near State Road (station number 02112360) indicate that annual mean streamflows during 2004 and 2005 were near or slightly greater than the long-term mean streamflows (table 5). Annual mean streamflows at these sites were less than the long-term means in 2006 and 2007 (table 5). In contrast, streamflow records from the streamgaging station on the Little Yadkin River near Dalton (station number 02114450) indicate that the annual mean streamflow in 2004 was slightly greater than the long-term mean but less than the long-term mean during 2005–2007 (table 5).

Climatological conditions in the study basins affected observed streamflow conditions. Departures of annual precipitation amounts from normal for 2004–2007 and the 30-year normal precipitation for 1971–2000 from records at three nearby National Weather Service Cooperative Observer weather stations are listed in table 6. Cumulative precipitation totals for the period 2004–2007 were less than normal at all three nearby weather stations, and the departures from normal increased from north to south. Total precipitation amounts were 3.57, 4.05, and 24.74 inches less than normal at the Galax, Mount Airy 2 W, and Elkin weather stations, respectively. Total precipitation was less than normal at all three weather stations in 2005 and 2007 (table 6). At the Galax weather station, total precipitation amounts were greater than normal only in 2004. At the Mount Airy 2 W station, total precipitation amounts were greater than normal in 2004

Table 5. Annual mean streamflow at long-term USGS streamgaging stations in the vicinity of the Hogan Creek, Bull Creek, and Pauls Creek study sites in Surry County, North Carolina, 2004–2007.

[mi^2, square mile; ft^3/s, cubic foot per second; N.C., North Carolina]

Streamgaging station (site identification number)[a]	Drainage area (mi^2)	Annual mean streamflow (ft^3/s) Water year 2004	2005	2006	2007	Long-term annual mean streamflow[b] (ft^3/s)	Period of record
Ararat River at Ararat, N.C. (02113850)	231	352	336	261	303	307	1964–2008
Fisher River near Copeland, N.C. (02113000)	128	205	195	141	165	180	1932–2008
Mitchell River near State Road, N.C. (02112360)	78.8	135	141	91.1	99.4	124	1964–2008
Little Yadkin River near Dalton, N.C. (02114450)	42.8	46.8	39.6	35.9	38.9	45.3	1960–2008

[a]Site identification number corresponds to number used in the U.S. Geological Survey National Water Information System database.

[b]Long-term annual mean streamflow for the period of record.

Table 6. Departures of annual precipitation from normal at National Weather Service Cooperative Observer Program stations in the vicinity of the study site drainage basins in Surry County, North Carolina, and Carroll County, Virginia, 2004–2007.

[SR, secondary road; N.C., North Carolina]

National Weather Service Cooperative Observer Program station (number)[a]	Annual precipitation, departure from normal, in inches				Cumulative departure from normal for 2004–2007, in inches	1971–2000 Normal annual precipitation, in inches	Descriptions of the locations of the National Weather Service Cooperative Observer Program station relative to the study sites[b]
	Calendar year						
	2004	2005	2006	2007			
Galax radio WBRF (443267)	7.33	–0.77	-2.40	–7.73	–3.57	43.9	Station is about 17 miles northwest of the Pauls Creek above SR 1625 near Pine Ridge, N.C., streamgaging station
Mount Airy 2 W (315890)	0.56	–3.80	1.25	–2.06	–4.05	46.90	Station is about 3 miles south-southeast of the Pauls Creek above SR 1625 near Pine Ridge, N.C., streamgaging station and about 8 miles north-northwest of the Bull Creek at Ash Hill, N.C., streamgaging station
Elkin (312740)	–3.25	–5.60	–4.04	–11.85	–24.74	48.7	Station is about 16 miles southwest of the Hogan Creek at SR 2038 near Siloam, N.C., streamgaging station

[a]Precipitation data are from the State Climate Office of North Carolina (2010).

[b]Locations of the National Weather Service Cooperative Observer Program stations are shown in figure 1.

and 2006. At the Elkin station, total precipitation amounts were less than normal every year from 2004 to 2007. Thus, precipitation amounts were variable with respect to time and location during the study. This geographic variability in the distribution of precipitation likely produced different climatic conditions at each of the study sites, which affected streamflow and sediment transport. Because of these differences, the applicability of the study design is questionable, especially the comparisons of Pauls Creek with Hogan Creek, because these two sites appear to have had the largest difference in climatic conditions during the study period.

Relation of Suspended Sediment to Streamflow

The highest concentrations of suspended sediment at the study sites generally occurred in conjunction with increased streamflow following periods of runoff, as shown in figures 10–12. As a result of dry conditions during the study, suspended-sediment samples were collected only under low to medium streamflow conditions. During 2004–2005, suspended-sediment samples were collected at each site on a biweekly basis primarily under low-flow conditions. A series of suspended-sediment samples were collected at each site over medium ranges of streamflow following a rainfall event on November 16, 2006. In 2006 and 2007, emphasis was placed on collecting suspended-sediment samples in conjunction with rainfall events. During this time, Surry County SWCD personnel continued to collect samples at each site on a biweekly basis but also collected suspended-sediment samples following several rainfall events. Suspended-sediment concentrations in many of these samples were elevated even though streamflow was relatively low (figs. 10–12). Because of dry conditions and travel distance to the study sites, no suspended-sediment samples or streamflow measurements were collected under high-flow conditions either before or after completion of stream-improvement measures at the Bull Creek and Pauls Creek sites. Thus, insufficient data are available for before and after stream-improvement comparisons of suspended-sediment concentrations during high-flow conditions at the BMP and in-stream restoration sites.

Water Quality

Water-quality data collected at the study sites include physical properties, nutrient concentrations, and suspended-sediment concentrations. Complete water-quality results are provided in Appendixes 2A–C. Basin comparisons of sample concentration distributions for the study period are shown in figures 13–17.

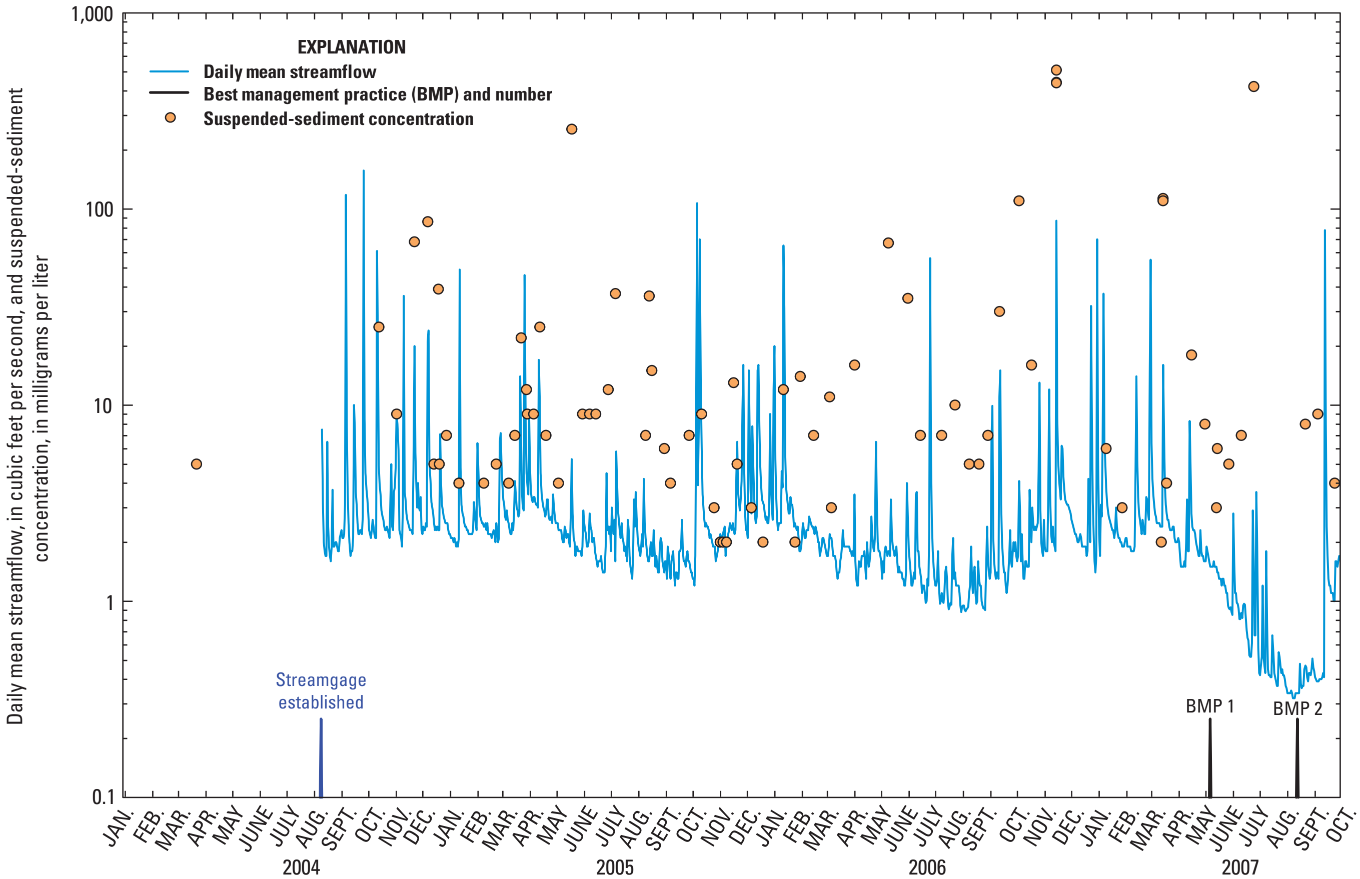

Figure 10. Daily mean streamflow, suspended-sediment concentration, and a timeline of best management practice (BMP) implementation at the Hogan Creek site, Surry County, North Carolina, 2004–2007. [Best management practice numbers correspond to table 4.]

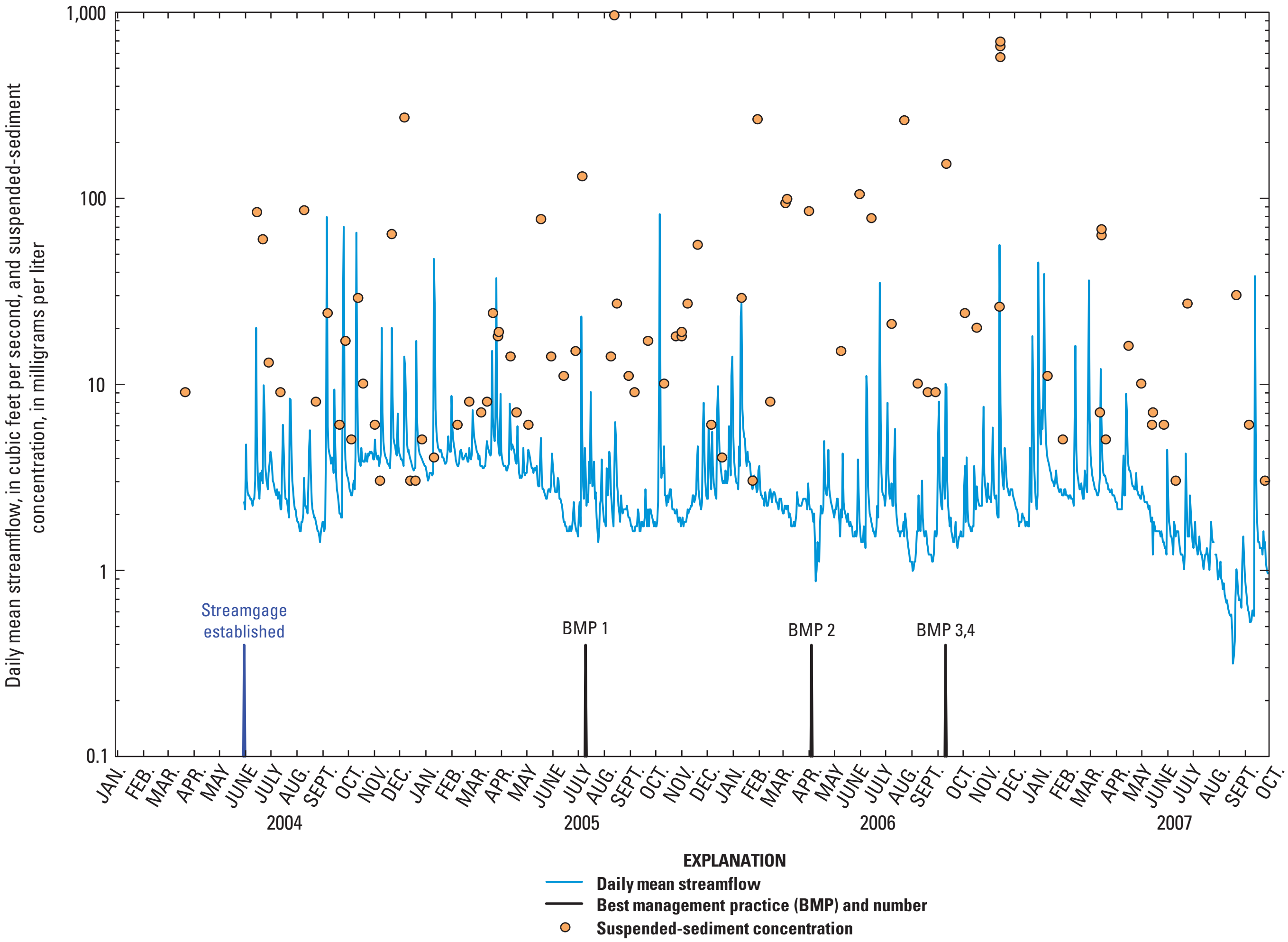

Figure 11. Daily mean streamflow, suspended-sediment concentration, and a timeline of best management practice (BMP) implementation at the Bull Creek site, Surry County, North Carolina, 2004–2007. [Best management practice numbers correspond to table 4.]

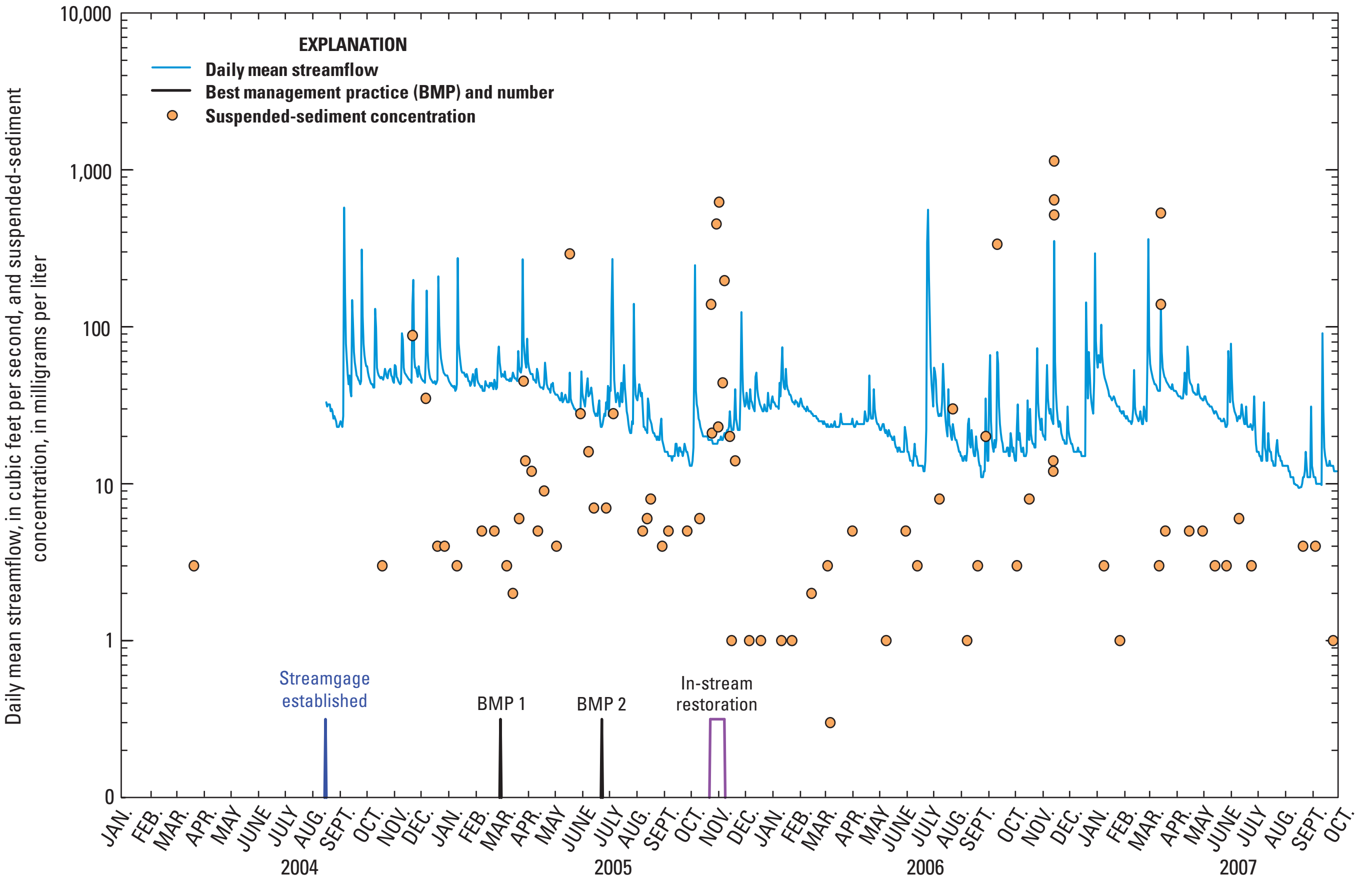

Figure 12. Daily mean streamflow, suspended-sediment concentration, and a timeline of best management practice implementation and in-stream channel restoration at the Pauls Creek site, Surry County, North Carolina, 2004–2007. [Best management practice numbers correspond to table 4.]

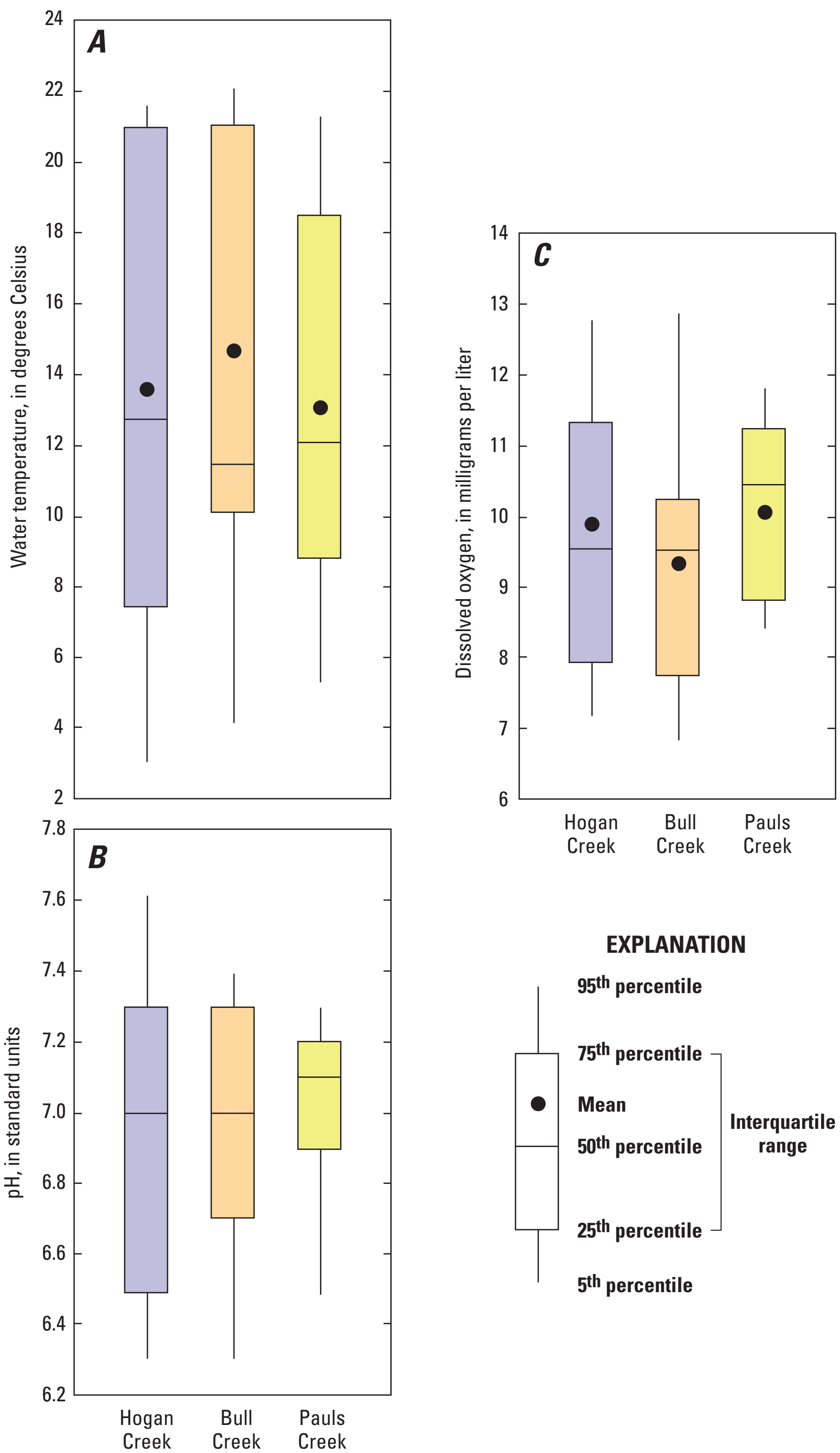

Figure 13. Distributions of (*A*) water temperature, (*B*) pH, and (*C*) dissolved-oxygen concentrations in surface-water samples collected at the study sites in Surry County, North Carolina, 2004–2007.

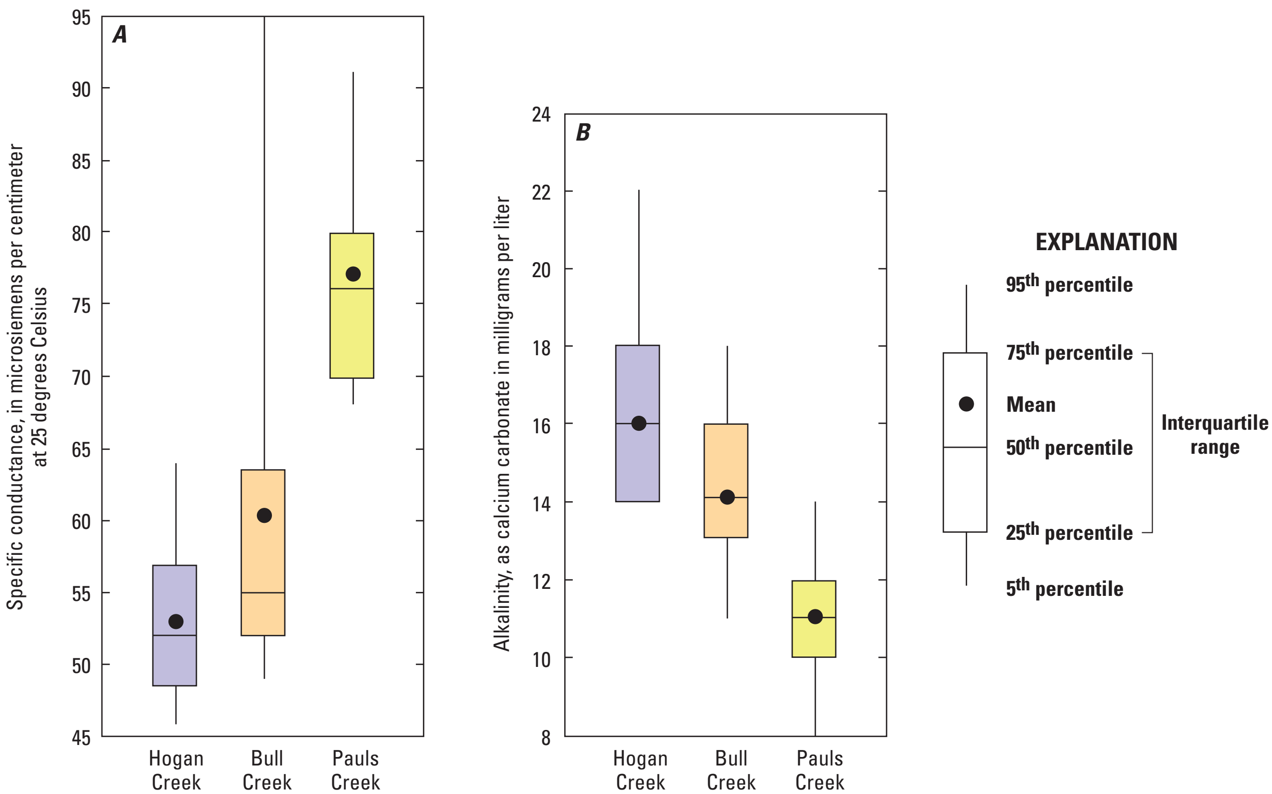

Figure 14. Distributions of (*A*) specific conductance and (*B*) alkalinity in surface-water samples collected at the study sites in Surry County, North Carolina, 2004–2007.

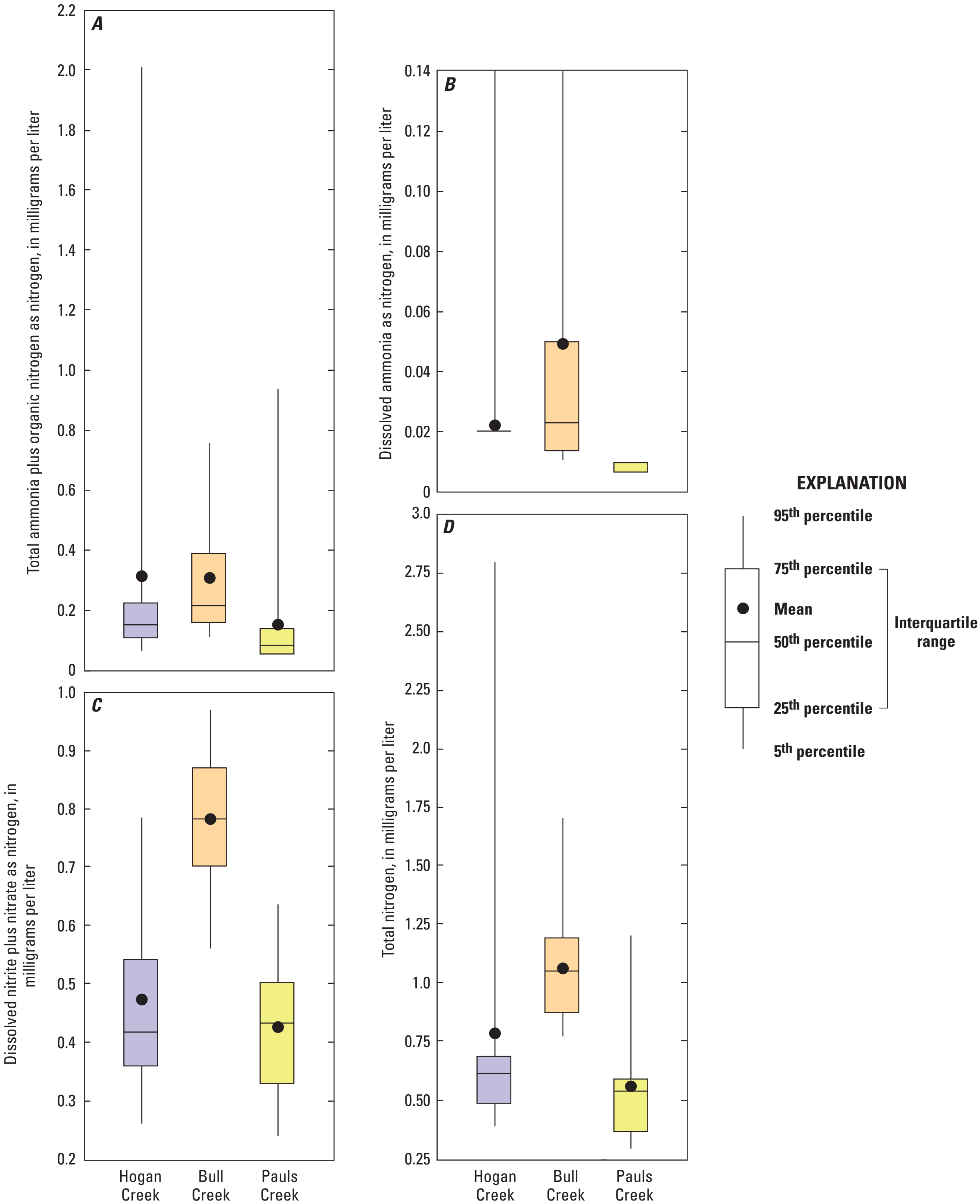

Figure 15. Distributions of (*A*) total ammonia plus organic nitrogen, (*B*) dissolved ammonia nitrogen, (*C*) dissolved nitrite plus nitrate, and (*D*) total nitrogen in surface-water samples collected at the study sites in Surry County, North Carolina, 2004–2007.

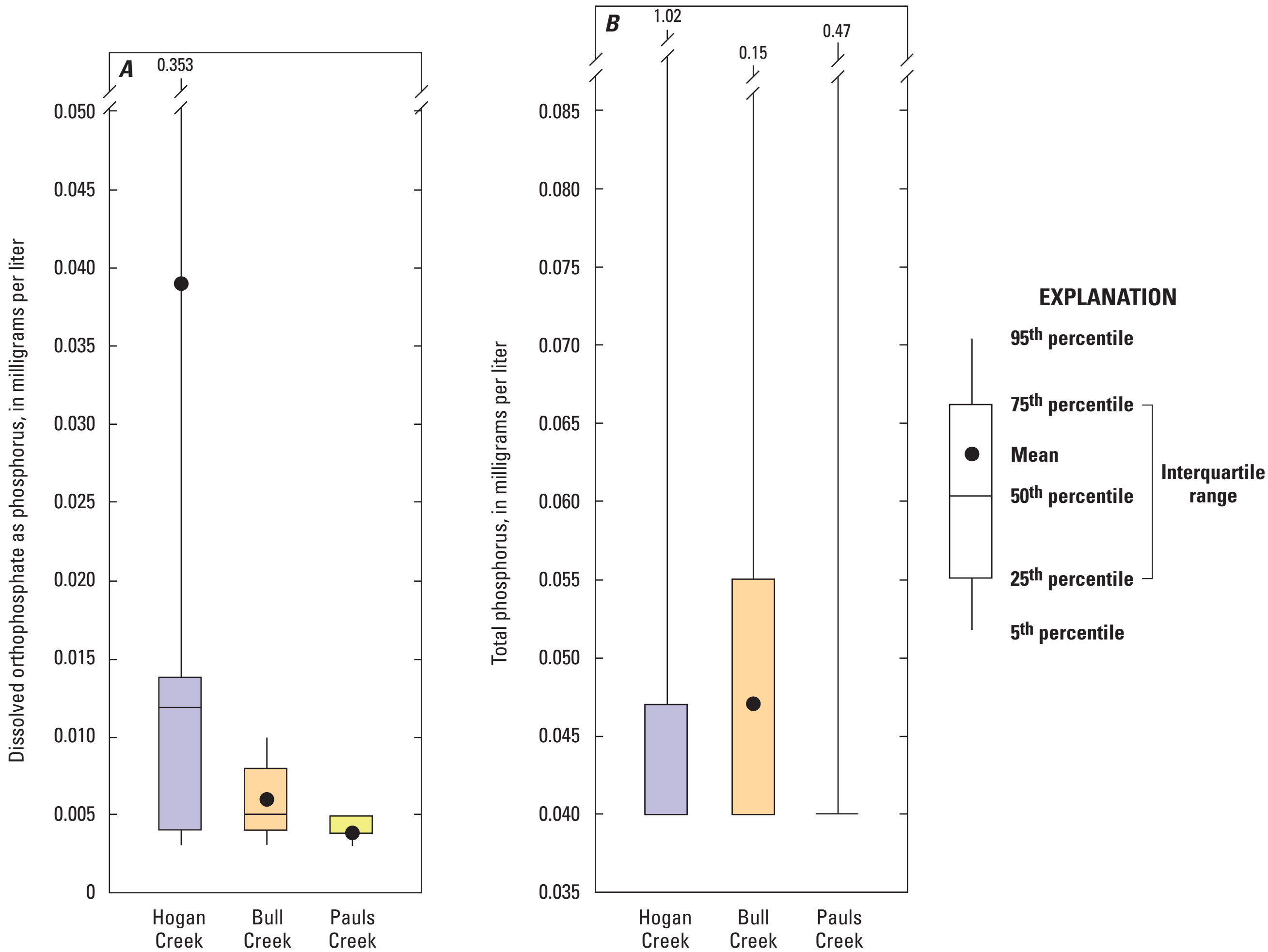

Figure 16. Distributions of (*A*) dissolved orthophosphate and (*B*) total phosphorus in surface-water samples collected at the study sites in Surry County, North Carolina, 2004–2007.

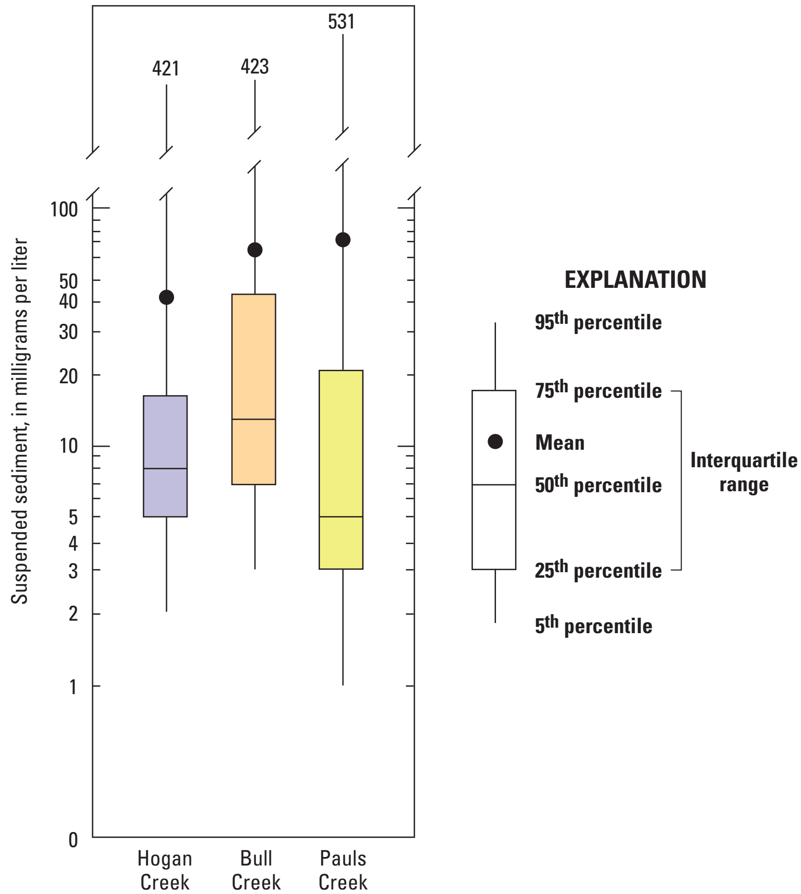

Figure 17. Distributions of suspended-sediment concentration in surface-water samples collected at the study sites in Surry County, North Carolina, 2004–2007.

Physical Properties and Nutrients

One assumption of the paired-basin study design is that the compared basins are geochemically similar before any stream improvements are implemented. Water samples were collected quarterly from 2004 to 2007 at the three study sites to characterize general water chemistry and nutrient concentrations (table 7). The frequency of sampling was insufficient to allow a detailed characterization of the basins or statistical testing of the effects of BMPs or in-stream restoration. However, the data allow a general basin comparison to determine if the paired-basin study design assumption of like basins was reasonable for the study sites. The Kruskal-Wallis one-way ANOVA test (Helsel and Hirsch, 1992) was used to determine if there were differences between basins with respect to water quality. Paired-basin differences were tested using Tukey's Studentized range on the ranked data (Helsel and Hirsch, 1992).

The physical properties of the water samples collected from Hogan Creek (control site), Bull Creek (BMP site), and Pauls Creek (in-stream restoration and BMP site) had generally similar data distributions of water temperature, dissolved-oxygen concentration, and pH (fig. 13; table 7). Differences in these properties among the sites were not statistically significant. Pauls Creek had statistically significantly higher specific conductance and lower alkalinity (fig. 14) than the other sites. Specific conductance is influenced by mineralogy and residence time. Alkalinity and acid-neutralizing capacity (ANC) are measures of the capacity of water to neutralize acids. Alkalinity and ANC differ in that alkalinity refers to the acid-neutralizing capacity of filtered water, whereas ANC refers to unfiltered water. For the purposes of this report, both are referred to as alkalinity. Differences between the specific conductance and alkalinity in samples from the study sites are likely a function of the different geologic setting and larger drainage area of the Pauls Creek Basin in comparison to the Hogan and Bull Creek Basins.

Bull Creek had statistically significantly higher concentrations of total ammonia plus organic nitrogen, dissolved ammonia, dissolved nitrite plus nitrate, and total nitrogen than the other sites (fig. 15). Total nitrogen was computed as the sum of total ammonia plus organic nitrogen, dissolved ammonia, and dissolved nitrite plus nitrate. Simmons and Heath (1982) reported mean concentrations of nitrogen in high-flow water samples collected from 15 streams in forested and rural

Table 7. Summary of water-quality data for the Hogan Creek, Bull Creek, and Pauls Creek study sites in Surry County, North Carolina, 2004–2007.

[SR, secondary road; mg/L, milligram per liter; —, not calculated; µS/cm, microsiemen per centimeter; °C, degrees Celsius; $CaCO_3$, calcium carbonate; N, nitrogen; <, less than; P, phosphorus; BMP, best management practice]

Constituent or physical property	Units	Number of measurements	Maximum	Minimum	Mean	Median
Hogan Creek at SR 2038 near Siloam, N.C. (control site)						
dissolved oxygen	mg/L	12	12.8	7.2	9.9	9.6
pH	standard units	12	7.6	6.3	—	7.0
specific conductance	µS/cm at 25 °C	12	64	46	53	52
water temperature	°C	12	21.4	3.0	13.6	12.8
alkalinity[a]	mg/L as $CaCO_3$	11	23	13	16	16
total ammonia plus organic nitrogen, as N	mg/L	12	2.0	0.07	0.31	0.16
dissolved ammonia, as N	mg/L	12	0.14	<0.010	0.022[b]	<0.020
dissolved nitrite plus nitrate, as N	mg/L	12	0.79	0.26	0.46	0.41
dissolved nitrite, as N	mg/L	12	0.006	<0.002	0.002[b]	0.001
total nitrogen, as N	mg/L	12	2.8	0.39	0.77	0.62
dissolved orthophosphate, as P	mg/L	12	0.353	<0.006	0.039[b]	0.012
total phosphorus, as P	mg/L	12	1.02	<0.04	0.12[b]	0.04
suspended sediment	mg/L	79	510	2	42	8
Bull Creek at Ash Hill, N.C. (BMP site)						
dissolved oxygen	mg/L	11	12.9	6.8	9.4	9.6
pH	standard units	11	7.4	6.3	—	7.0
specific conductance	µS/cm at 25 °C	11	95	49	61	55
water temperature	°C	11	22.0	4.1	14.7	11.3
alkalinity[a]	mg/L as $CaCO_3$	11	19	10	14	14
total ammonia plus organic nitrogen, as N	mg/L	12	0.75	0.12	0.30	0.22
dissolved ammonia, as N	mg/L	12	0.14	<0.020	0.05[b]	0.02
dissolved nitrite plus nitrate, as N	mg/L	12	0.97	0.56	0.78	0.78
dissolved nitrite, as N	mg/L	12	0.020	0.001	0.006	0.005
total nitrogen, as N	mg/L	12	1.7	0.77	1.1	1.0
dissolved orthophosphate, as P	mg/L	12	0.010	<0.006	0.006[b]	0.005[b]
total phosphorus, as P	mg/L	12	0.15	<0.04	0.05[b]	0.04[b]
suspended sediment	mg/L	89	967	3	65	14
Pauls Creek above SR 1625 near Pine Ridge, N.C. (in-stream restoration and BMP site)						
dissolved oxygen	mg/L	12	11.8	8.4	10.1	10.4
pH	standard units	12	7.3	6.5	—	7.1
specific conductance	µS/cm at 25 °C	12	91	68	77	76
water temperature	°C	12	21.3	5.5	13.1	12.1
alkalinity[a]	mg/L as $CaCO_3$	11	14	8	11	11
total ammonia plus organic nitrogen, as N	mg/L	12	0.93	<0.10	0.16[b]	0.08[b]
dissolved ammonia, as N	mg/L	12	0.011	<0.010	<0.010	<0.010
dissolved nitrite plus nitrate, as N	mg/L	12	0.64	0.24	0.42	0.43
dissolved nitrite, as N	mg/L	12	0.002	<0.002	0.001[b]	0.001
total nitrogen, as N	mg/L	12	1.2	<0.47	0.56[b]	0.53
dissolved orthophosphate, as P	mg/L	12	0.005	<0.006	0.004[b]	0.004
total phosphorus, as P	mg/L	12	0.47	<0.04	<0.04	<0.04
suspended sediment	mg/L	79	1,140	0.3	72	5

[a]Includes measurements of acid neutralizing capacity in addition to alkalinity.

[b]Value estimated by using a log-probability regression to predict the values of data less than the detection limit.

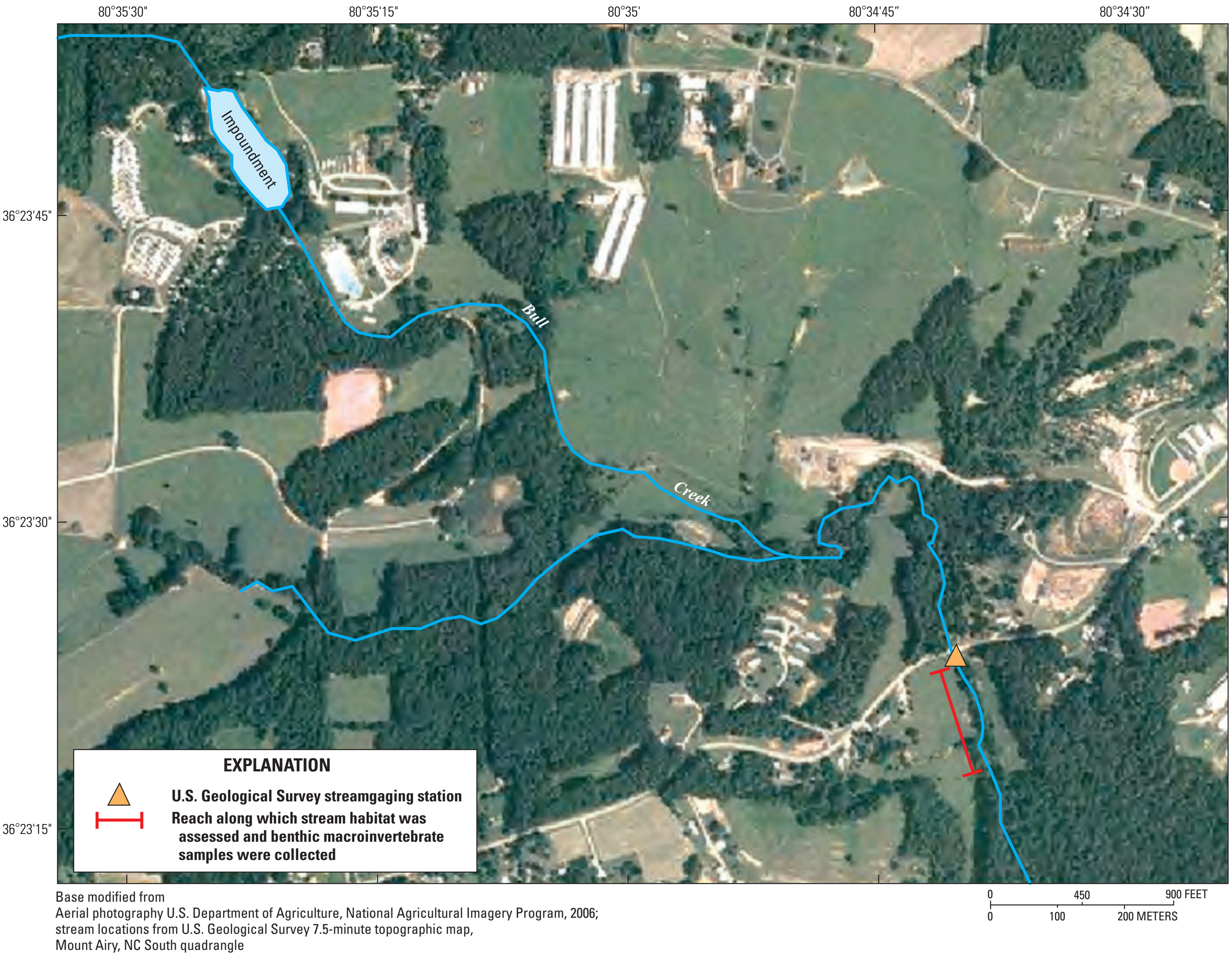

Figure 18. Enhanced aerial photograph showing land cover upstream from Bull Creek at Ash Hill, North Carolina, and locations of the streamgaging station, upstream impoundment, and the reach used for stream-habitat assessment and sampling for benthic macroinvertebrates during 2004–2007.

basins in the North Carolina Piedmont and Blue Ridge Physiographic Provinces as nitrate nitrogen, 0.17 milligram per liter (mg/L); ammonia nitrogen, 0.01 mg/L; organic nitrogen, 0.13 mg/L; and total nitrogen, 0.30 mg/L. Mean values for base flow, which is predominantly groundwater, were reported as nitrate nitrogen, 0.08 mg/L; ammonia nitrogen, 0.00 mg/L; organic nitrogen, 0.11 mg/L; and total nitrogen, 0.19 mg/L. Nitrogen constituent values for all sites were high compared to the values reported for forested and rural basins. Forested riparian buffers, which are effective in decreasing both point and nonpoint sources of nitrogen (Lowrance and others, 1984; Sweeney and others, 2004), are absent or minimal along much of the main stem of Bull Creek in the vicinity of the study site (fig. 18). In contrast, riparian zones are largely forested in the vicinity of the Hogan Creek (fig. 19) and Pauls Creek (fig. 20) study sites.

Dissolved orthophosphate and total phosphorus concentrations for the study basins were generally low (fig. 16; table 7). Statistically significantly higher concentrations of dissolved orthophosphate were detected at Hogan Creek than at the other sites. Simmons and Heath (1982) reported mean concentrations of 0.01 mg/L total phosphorus in both surface water during stormflow and in base flow from 15 streams in forested and rural basins in the North Carolina Piedmont and Blue Ridge Physiographic Provinces. Caldwell (1992) reported total phosphorus concentrations of less than (<) 0.01–0.24 mg/L in stormflow and <0.01–0.08 mg/L in low-flow samples from three streams in forested and rural basins of the Piedmont and Blue Ridge Provinces. Total phosphorus concentrations in water samples from the study sites were generally within the ranges reported for forested Piedmont basins, with the exception of

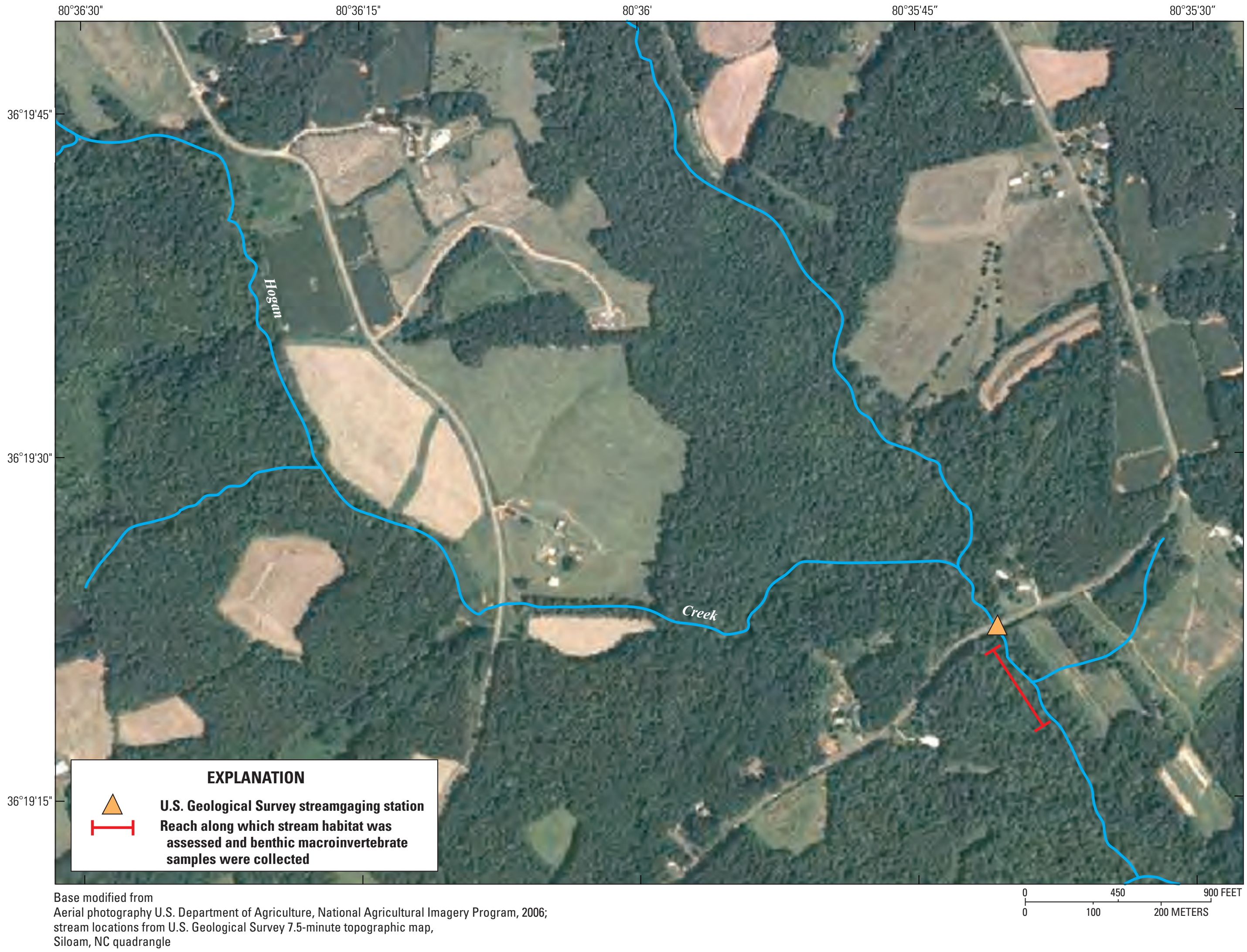

Figure 19. Enhanced aerial photograph showing land cover upstream from Hogan Creek near Siloam, North Carolina, and locations of the streamgaging station and the reach used for stream-habitat assessment and sampling for benthic macroinvertebrates during 2004–2007.

one relatively high concentration (1.02 mg/L) determined for a sample from Hogan Creek (fig. 16).

Suspended-sediment samples were collected at a greater frequency than samples for other analytes, to allow for statistical testing of the effects of best management practices and in-stream restoration efforts at the Bull Creek and Pauls Creek sites (see suspended-sediment section). Bull Creek had statistically significantly higher concentrations of suspended sediment than the other sites when comparing results for the entire study (fig. 17; table 7).

The assumption of the paired-basin study design that the compared basins were geochemically similar before any treatment effects were implemented could not be tested because of limited pretreatment data. In addition, the Kruskal-Wallis test comparisons for specific conductance and alkalinity, which are constituents that vary largely as a function of geologic setting and basin size, indicate that the assumption of geochemical similarity of the study basins was not met.

Suspended-Sediment Yields

The suspended-sediment yields estimated for the three study basins allow a comparison among the basins and provide a framework for comparisons with loads estimated for other streams in North Carolina and the southeastern United States. Suspended-sediment load, or the total mass of suspended sediment transported by a stream, is a function of the interaction of physical characteristics of the stream basin, including topographic and physiographic factors, geology, soil characteristics, precipitation, land use, land cover, and land-management

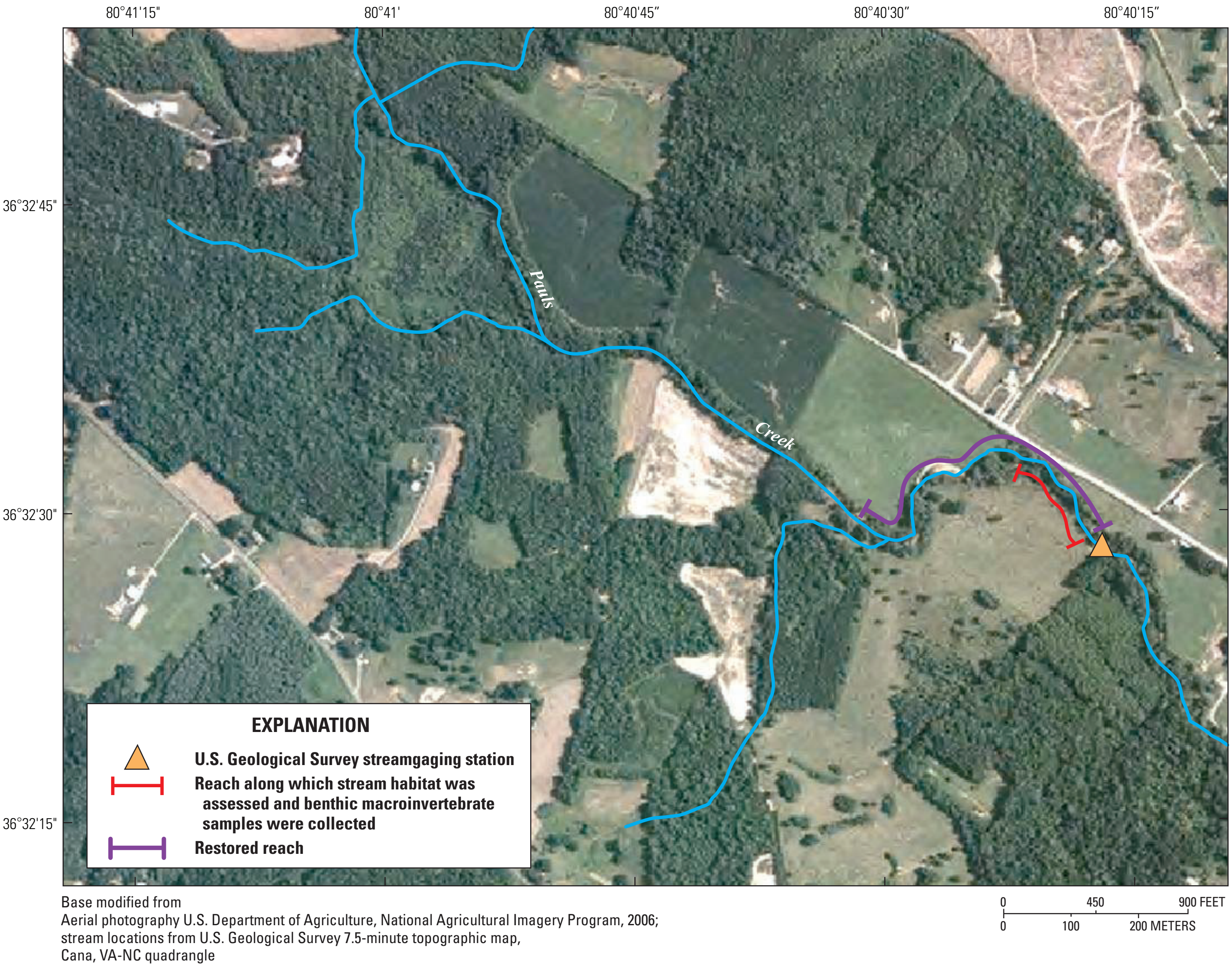

Figure 20. Enhanced aerial photograph showing land cover upstream from Pauls Creek near Pine Ridge, North Carolina, and locations of the streamgaging station, the restored reach, and the reach used for stream-habitat assessment and sampling for benthic macroinvertebrates during 2004–2007.

practices. Estimation of a suspended-sediment yield, expressed as load (in tons) divided by drainage area (in square mile), allows basin comparisons of sediment delivery and can be used to assess the effectiveness of management actions. Sediment yield is strongly correlated with streamflow, so the greatest yields for any period generally are associated with the highest flows. Thus, dry climatic conditions, such as those that occurred during this study, can affect comparisons of sediment delivery among basins.

The r^2 values and review of the residuals indicated a reasonable fit of the regression models to the data (table 8). The range of daily mean streamflows used in prediction fell within the range of streamflows used in model calibration. Suspended-sediment data collected during in-stream restoration activities at the Pauls Creek site were excluded from the model calibration data.

The time term produced by the model gives an indication of whether the load has changed with time. This term was not statistically significant at the 0.05 probability level for any of the sites, which indicates that no significant time trend was detected during the study period. This lack of significance of a time term, based on the datasets available for the model, indicates that no linear change was observed in the relation of suspended-sediment concentration to streamflow over time; hence, the effects of in-stream restoration and BMP implementation were not evident over the course of this study. One or both of the seasonal terms in the regression model were significant for each of the three sites, indicating a

Table 8. Regression model coefficients and r^2 values for the suspended-sediment load models developed for the study sites in Surry County, North Carolina, 2004–2007.

[BMP, best management practice; *, denotes statistical significance at the 0.05 probability level; ln, natural logarithm; Q_i, instantaneous streamflow; t, time in decimal years; sin, trigonometric sine function; cos, trigonometric cosine function; π, pi, approximately = 3.14159; r^2, coefficient of determination]

Model terms[a]	Hogan Creek (control site)	Bull Creek (BMP site)	Pauls Creek (in-stream restoration and BMP site)
intercept (a_0)	0.380*	1.726*	0.160
ln Q_i (cubic feet per second)	2.115*	3.059*	2.037*
t (decimal years)	0.172	–0.005	0.103
sin ($2\pi t$) seasonal term	–0.193	–0.512*	–0.108
cos ($2\pi t$) seasonal term	–0.653*	–0.969*	–0.816*
r^2	0.76	0.89	0.85

[a]Model terms correspond to equation 1.

Table 9. Annual range of daily mean streamflow and suspended-sediment yields for the study sites in Surry County, North Carolina, for water years 2005–2007.

[ft^3/s, cubic foot per second; BMP, best management practice; $tons/mi^2$, tons per square mile]

Water year[a]	Range of daily mean streamflow (ft^3/s)			Suspended-sediment yield ($tons/mi^2$)		
	Hogan Creek (control site)	Bull Creek (BMP site)	Pauls Creek (in-stream restoration and BMP site)	Hogan Creek (control site)	Bull Creek (BMP site)	Pauls Creek (in-stream restoration and BMP site)
2005	1.2 – 61	1.4 – 65	13 – 274	50	102	131
2006	0.88 – 107	0.86 – 82	11 – 557	139	127	589
2007	0.32 – 87	0.86 – 56	9.4 – 362	111	104	76

[a]The 12-month period October 1 for any given year through September 30 of the following year. A water year is designated by the calendar year in which the period ends and includes 9 of the 12 months.

strong seasonal variation in suspended-sediment load for all sites. The applicability of the regression model is adversely affected by the paucity of suspended-sediment data at higher streamflows. Model results also were affected by the relatively short duration of data collection both before and after stream-improvement efforts.

The annual suspended-sediment yields for the three sites (table 9) show considerable basin-to-basin and year-to-year variation. Three complete years (2005, 2006, and 2007) of flow data were used in the prediction to generate load and yield estimates for water years 2005–2007. The estimated loads and yields reflected the varying total streamflow from each basin for the 3 years. The highest loads and yields for all sites occurred during water year 2006 (table 9).

Comparison of sediment yields for the study basins indicates that Hogan Creek, the control site, had the smallest mean annual suspended-sediment yield in 2005 and the lowest mean yield over the 3-year study period; Pauls Creek had the largest mean yield during the first 2 years of the study and the lowest during 2007 (table 9). The high mean yield at Pauls Creek was largely due to the high sediment yield in 2006, the year during which in-stream restoration occurred. In 2007, after completion of in-stream restoration, the sediment yield at Pauls Creek was the least of the three sites. The suspended-sediment yield for Hogan Creek (control site) was higher in 2007 than in 2005. Because the time component of the model was not statistically significant, annual differences in sediment yield are due to differences in streamflow and cannot be attributed to stream-improvement measures.

The yields estimated for the three study sites are high in comparison to suspended-sediment yields estimated for other basins in the southeastern United States (1973–2005; Staub and others, 2010). Suspended-sediment yields for 20 basins across the Southeast ranged from 7.12 to 1,489 $tons/mi^2$

(Staub and others, 2010). All three study sites fall within the range of the 60th to 90th percentiles of suspended-sediment yields across the Southeast. Annual suspended-sediment yields for the period 1970–79 reported by Simmons (1993) for predominately rural basins in the upper Yadkin–Pee Dee River basin of North Carolina, an area encompassing the three study basins, averaged 300 tons/mi^2 with a range of 160–440 tons/mi^2. Only the yield of 589 tons/mi^2 estimated for the Pauls Creek site in 2006 (table 9) exceeded the average reported by Simmons (1993). The sample-collection strategy during the last 2 years of this study, which emphasized sample collection during and after periods of runoff, may have contributed to overestimation of sediment yields.

Paired-Basin Analysis of Suspended-Sediment Concentrations

Suspended-sediment concentration and instantaneous sediment discharge for time periods before and after stream improvements were compared by using graphical and statistical nonparametric techniques. Suspended-sediment data for the control site (Hogan Creek) were compared with suspended-sediment data from the stream-improvement sites (Bull Creek and Pauls Creek). Selection of the before- and after-improvement periods was complicated by the multiple stream-improvement efforts that took place in each of the study basins (fig. 21). Data for the Bull Creek and Pauls Creek sites were divided into before and after periods based on the time of the most significant stream improvement in each of the respective basins. The livestock-exclusion BMP, completed in July 2005 (table 4), was selected as the most significant stream improvement in the Bull Creek Basin. This BMP was selected for use as the dividing point between before and after periods because it occurred about midway through the study, and it was likely to have an effect on water quality. Although three other BMPs were implemented in the Bull Creek Basin after July 2005, one focused entirely on the repair of a poultry composter and was unlikely to have an effect on surface-water quality. The two remaining BMPs were completed in September 2006, and selecting either of them as the dividing point for the evaluation of data before and after improvements would have resulted in only 1 year of post-improvement data and excluded more than a year of data from analysis. The completion of the in-stream restoration in early November 2005 was selected as the dividing point for evaluation of data before and after improvements were made at the Pauls Creek site. Data collected during in-stream restoration at the Pauls Creek site were excluded from analysis.

Distributions of suspended-sediment concentration, instantaneous sediment discharge, and instantaneous streamflow for the before and after stream-improvement periods are shown in figure 22 for Hogan Creek and Bull Creek and in figure 23 for Hogan Creek and Pauls Creek. In general, the range of values, especially suspended-sediment concentrations, was greater for samples collected after

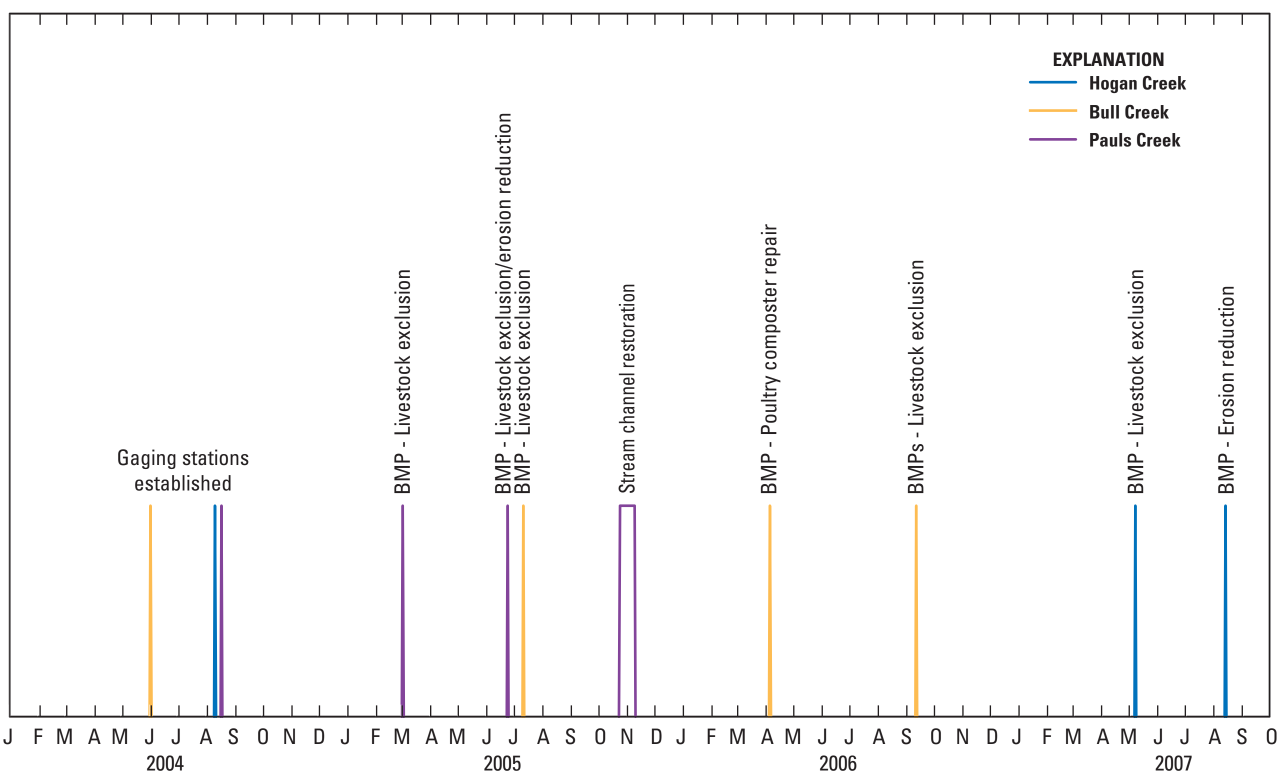

Figure 21. Combined timeline for stream-improvement efforts in the study basins in Surry County, North Carolina, and Carroll County, Virginia, 2004–2007. [BMP, best management practice]

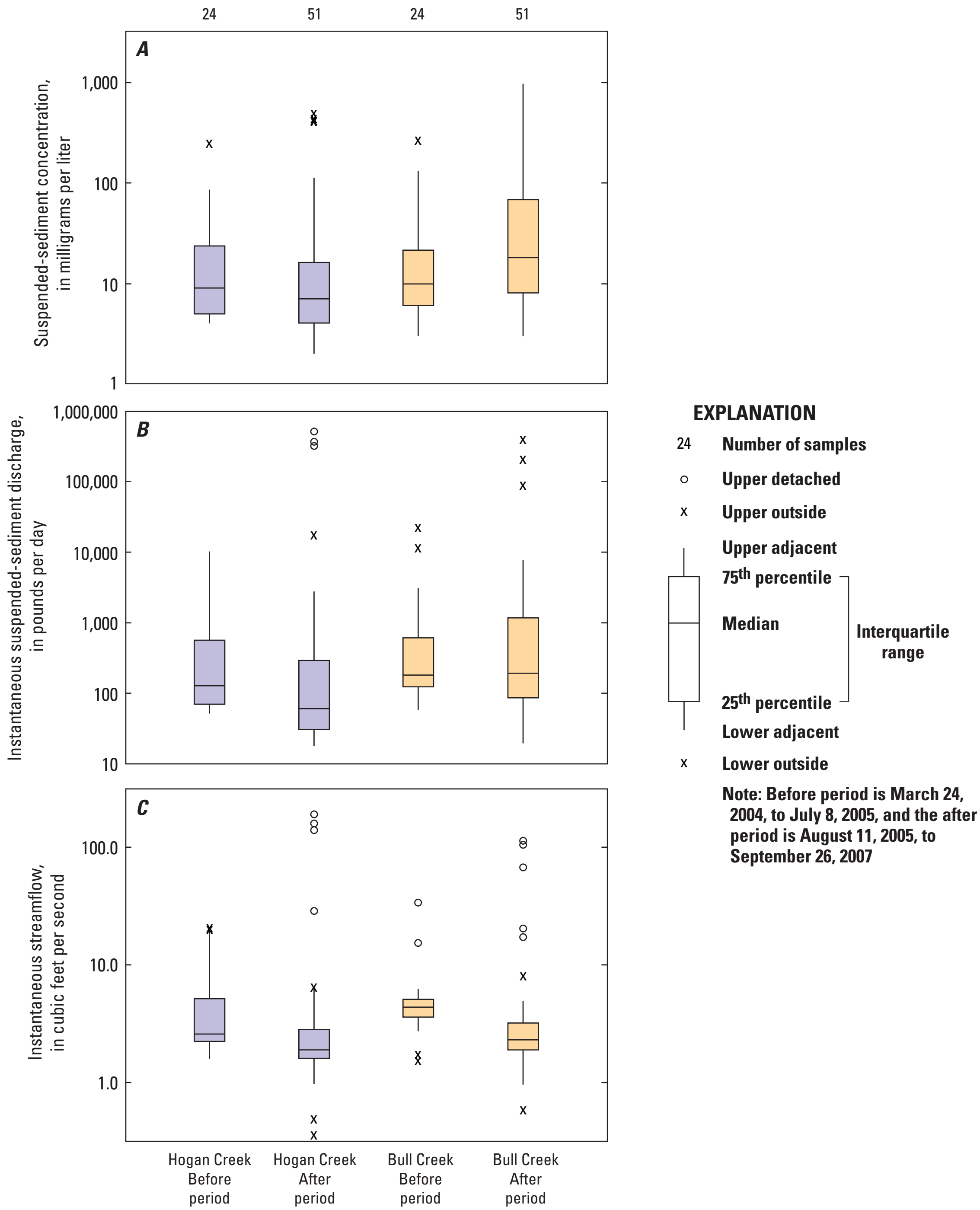

Figure 22. Distributions of (*A*) suspended-sediment concentration, (*B*) instantaneous suspended-sediment discharge, and (*C*) instantaneous streamflow at time of suspended-sediment sampling at Hogan Creek near Siloam and at Bull Creek at Ash Hill before and after implementation of best management practices in the Bull Creek Basin, Surry County, North Carolina, 2004–2007.

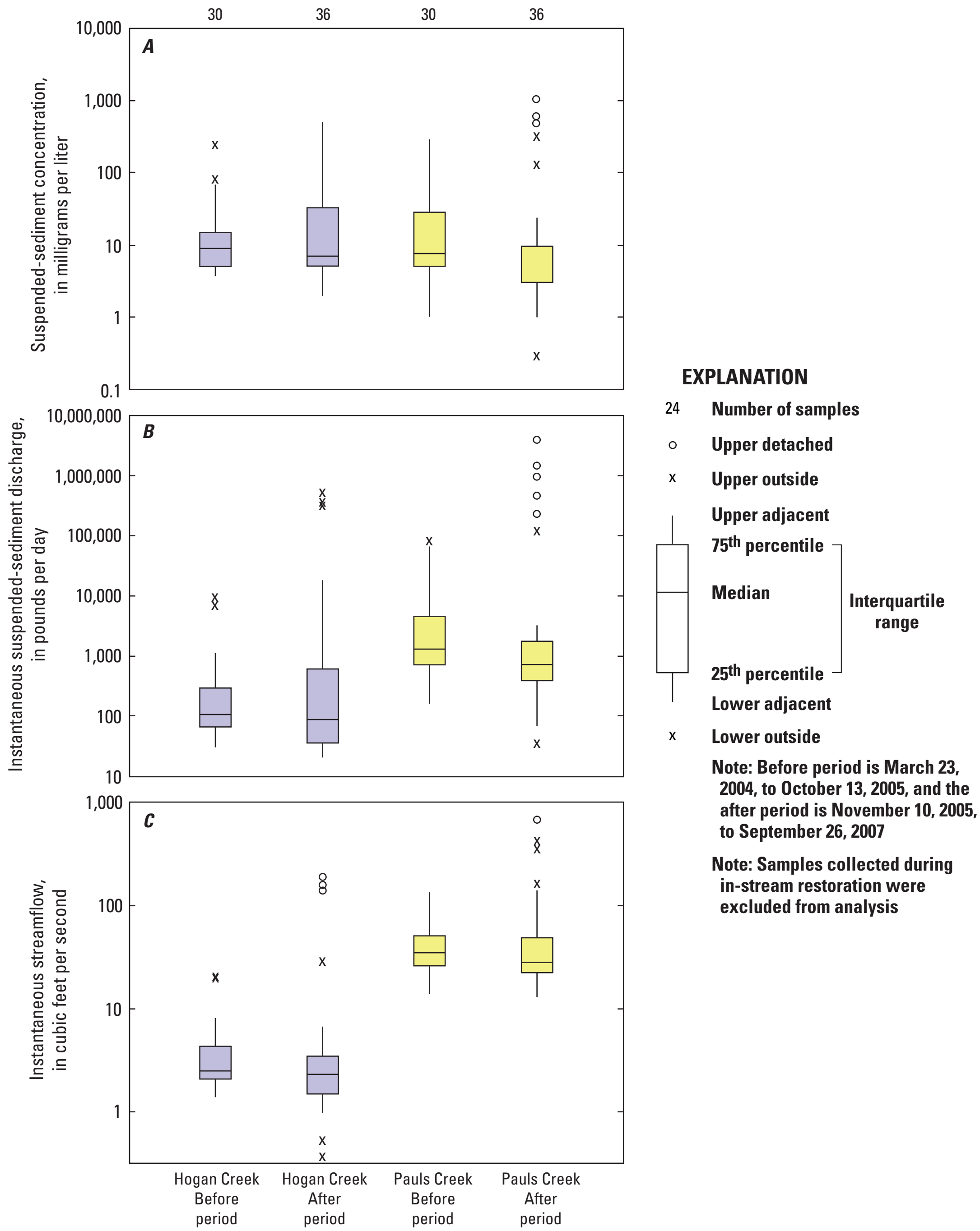

Figure 23. Distributions of (*A*) suspended-sediment concentration, (*B*) instantaneous suspended-sediment discharge, and (*C*) instantaneous streamflow at time of suspended-sediment sampling at Hogan Creek near Siloam and at Pauls Creek near Pine Ridge before and after in-stream restoration and implementation of best management practices in the Pauls Creek Basin, Surry County, North Carolina, 2004–2007.

stream improvement than before stream improvement. The increased range of values of suspended-sediment concentrations may have been partially affected by the sampling strategy employed in 2006 and 2007 that emphasized sample collection during or following rainfall events. The median suspended-sediment concentration and median instantaneous sediment discharge at Bull Creek after stream improvement were slightly higher than the median values before stream improvement (fig. 22*A*, *B*). Similar differences in suspended-sediment concentration and instantaneous sediment discharge were not observed in the Hogan Creek data (fig. 22*A*, *B*). The median instantaneous streamflow during suspended-sediment sampling was lower after stream improvement than before stream improvement for both Hogan and Bull Creeks (fig. 22*C*), which probably is related to the extended period of precipitation deficits, especially in 2007 (table 6). The increased emphasis in 2006 on collecting samples in conjunction with precipitation events could have contributed to the observed increases in suspended-sediment concentrations and instantaneous suspended-sediment discharge following stream improvement at the Bull Creek site.

Suspended-sediment concentration, instantaneous suspended-sediment discharge, and instantaneous streamflow also showed greater variability in the samples collected after stream improvement than in the samples collected before stream improvement at the Hogan Creek and Pauls Creek sites (fig. 23). Median values of suspended-sediment concentration, instantaneous suspended-sediment discharge, and instantaneous streamflow at Hogan Creek were similar with regard to time period. Likewise, median values of suspended-sediment concentration and median instantaneous suspended-sediment discharge at the Pauls Creek site were similar for both time periods but slightly lower after stream improvement (fig. 23*A*, *B*).

Statistical procedures used to evaluate suspended-sediment data included ANOVA and the Student's *t*-test. Results of the ANOVA using ranked values for paired samples are summarized in table 10. Comparison of Bull Creek, the site affected by implementation of BMPs, with Hogan Creek, the control site, indicated statistically significant differences ($p<0.05$) in only one variable—streamflow. Sampled streamflow at these sites was statistically lower after BMP implementation at $p<0.0001$ (fig. 22*C*). Dry climatic conditions, especially during the latter part of this study and in the southern part of the study area (table 6), are likely the cause of the lower streamflows associated with suspended-sediment sample collection following BMP implementation in the Bull Creek Basin. A weak ($p<0.10$) significance also was found for the interaction term (Site*Time Period) at these sites (table 10). Comparison of the Pauls Creek site, which was affected by in-stream restoration and BMP implementation, with the Hogan Creek site, the control site, indicated only a weakly significant ($p=0.07$) difference in instantaneous sediment discharge between the before and after stream-improvement periods.

Results for Student's *t*-test on ranked values of suspended-sediment concentration, instantaneous suspended-sediment discharge, and instantaneous streamflow for paired samples following the BACIP design are summarized in table 11. Analyses indicated that ranked means of instantaneous streamflow at the time of suspended-sediment sample collection were lower at both Bull Creek and Hogan Creek

Table 10. Summary of two-factor analysis of variance for pairs of ranked suspended-sediment concentration, instantaneous suspended-sediment discharge, and instantaneous streamflow values at Surry County study sites before and after stream-improvement efforts, 2004–2007.

[Time period pertains to period before or after stream-improvement efforts; bold type denotes statistical significance at p<0.05; underlined type denotes statistical significance at p<0.10; F, test statistic; p, probability level; BMP, best management practice]

Comparison	Factors	Suspended-sediment concentration		Instantaneous suspended-sediment discharge rank		Instantaneous streamflow rank	
		F	p	F	p	F	p
Effects of BMP implementation							
Bull Creek : Hogan Creek (control) before and after BMP implementation[a]	Time period	0.38	0.537	2.52	0.115	**22.91**	**<0.0001**
	Site	0.37	0.543	0.24	0.625	0.07	0.795
	Interaction	<u>2.87</u>	<u>0.0926</u>	1.85	0.176	0.52	0.471
Effects of in-stream restoration and BMP implementation							
Pauls Creek : Hogan Creek (control) before and after in-stream restoration and BMP implementation[b]	Time period	1.55	0.22	<u>3.42</u>	<u>0.07</u>	1.76	0.19
	Site	0.02	0.88	0.01	0.90	0.00	1.00
	Interaction	2.03	0.16	0.98	0.33	0.03	0.86

[a]The before period was from 03/24/2004 to 07/08/2005, and the after period was from 08/11/2005 to 09/26/2007.

[b]The before period was from 03/23/2004 to 10/13/2005, and the after period was from 11/10/2005 to 09/26/2007. Samples collected during in-stream restoration were excluded from analysis.

Table 11. Statistical summary of Student's t-test for before and after stream-improvement effort periods for ranked values and differences between ranked values of suspended-sediment concentration, instantaneous suspended-sediment discharge, and instantaneous streamflow at study sites in Surry County, North Carolina, 2004–2007.

[p, probability level based on two-tailed test; BMP, best management practice; bold type denotes statistical significance at p<0.05; underlined type denotes statistical significance at p<0.10]

Site pairs	Time period	Number of samples	Suspended-sediment concentration rank		Instantaneous suspended-sediment discharge rank		Instantaneous streamflow rank	
			mean	p	mean	p	mean	p
Effects of BMP implementation[a]								
Bull Creek (BMP)	Before	24	32.0	0.105	38.6	0.878	**51.3**	**0.003**
	After	51	40.8		37.7		**31.7**	
Hogan Creek (control)	Before	24	40.8	0.452	**45.5**	**0.0415**	**47.8**	**0.007**
	After	51	36.7		**34.5**		**33.4**	
Difference between Bull Creek and Hogan Creek for before and after periods	Before	24	**–8.73**	**0.0003**	**–7.0**	**0.001**	3.5	0.123
	After	51	**4.11**		**–4.0**		–1.6	
Effects of in-stream restoration and BMP implementation[b]								
Pauls Creek (in-stream restoration and BMP)	Before	31	38.9	0.062	**39.2**	**0.048**	36.2	0.419
	After	36	30.0		**29.7**		32.2	
Hogan Creek (control)	Before	31	33.7	0.550	33.5	0.905	36.7	0.290
	After	36	34.3		32.7		31.7	
Difference between Pauls Creek and Hogan Creek for before and after periods	Before	31	4.22	0.128	2.55	0.313	–1.08	0.684
	After	36	–3.42		–2.07		0.8	

[a]For Bull Creek–Hogan Creek comparisons, the before period was from 03/24/2004 to 07/08/2005, and the after period was from 08/11/2005 to 09/26/2007.

[b]For Pauls Creek–Hogan Creek comparisons, the before period was from 03/23/2004 to 10/13/2005, and the after period was from 11/10/2005 to 09/26/2007. Samples collected during in-stream restoration were excluded from analysis.

following stream improvement, with p values of 0.003 and 0.007, respectively (table 11). No statistically significant differences between the before and after periods were detected for ranked values of suspended-sediment concentration or instantaneous suspended-sediment discharge at Bull Creek. At Hogan Creek, instantaneous suspended-sediment discharge was statistically lower (p=0.04) after stream improvement than before stream improvement. The decrease in instantaneous suspended-sediment discharge at Hogan Creek likely is related to the corresponding decrease observed in streamflow (table 11). Comparisons of the differences in ranked values for suspended-sediment concentration and instantaneous suspended-sediment discharge indicates that suspended-sediment concentration (p=0.003) and instantaneous suspended-sediment discharge (p=0.001) were higher at Bull Creek relative to Hogan Creek for the period after stream improvement than for the period before stream improvement (table 11). These increases may be due, in part, to the emphasis placed on the collection of suspended-sediment samples during and following runoff events from 2006 to 2007 and to differences in land use and other characteristics of these basins.

Analysis of the data for Pauls Creek (the in-stream restoration site) showed a statistically significant (p<0.048) decrease in ranked values of instantaneous suspended-sediment discharge and a weakly significant decrease (p=0.062) in suspended-sediment concentration after stream improvement (table 11). No statistically significant differences were observed between the before and after periods for Hogan Creek (the control site). The observed decrease in suspended-sediment concentration and instantaneous suspended-sediment discharge from the before to after periods suggests that stream improvement efforts at Pauls Creek were successful in reducing stream sediment. The proximity of the restored reach and BMPs to the sampling site increases the likelihood of detecting changes in sediment concentration at the Pauls Creek site over short time periods. In contrast, the distance from the locations of BMPs implemented in the Bull Creek Basin to the sampling site is much greater and likely would require a longer time period for detecting changes in suspended-sediment concentrations.

Stream Habitat Assessment

Physical aspects of stream habitat influence the distribution and composition of benthic invertebrates (Maddock, 1999) and should be addressed as part of stream restoration activities (Smiley and Dibble, 2005). Habitat characteristics interact at multiple scales to influence stream biota (Keller, 1978). For example, changes in channel characteristics affect in-stream characteristics, which in turn affect the structure of stream communities (Huryn and Wallace, 1987). The habitat-assessment data collected during this study provide a means of evaluating differences between sites and identifying changes that occurred from 2004 to 2006 at a given site. These data, however, describe local conditions at the selected reach and are not necessarily representative of the entire stream, which can be highly variable in agricultural watersheds. Habitat data are summarized by selected basin-level and reach-level characteristics in tables 12 and 13, respectively. Aerial photographs showing approximate locations of the habitat assessment reaches and land cover in the vicinity of the reaches are provided in figures 18–20. Graphical evaluations of selected reach characteristics are provided in figures 24–26 and 29–33. Algorithms used for calculating habitat-assessment data are provided in Appendix 3, and reach- and transect-level data collected during the assessments are provided in Appendix 4.

Basin-level characteristics of the study sites are based primarily on the altitude and shape of the basins and provide information about the hydrologic similarity of the basins. In comparison to the Hogan Creek Basin (fig. 2), the shapes of the Bull Creek (fig. 3) and Pauls Creek (fig. 4) Basins are elongated. Although similar in area (table 2), the Bull Creek Basin is about 45 percent longer than the Hogan Creek Basin (table 12). In comparing drainage basins of similar size, Gregory and Walling (1973) found that runoff in an elongated basin resulted in smaller peak flows and longer flow duration than in a round basin. The drainage basin shape factor, also referred to as the form factor, is expressed as a dimensionless ratio of drainage area divided by the square of basin length. Differences in the shape factor of the study sites reflect the elongated shape of the Bull Creek and Pauls Creek Basins (table 12). The relative similarity of the shapes of the Bull Creek and Pauls Creek Basins is indicated by relatively similar drainage basin shape factors, 0.156 and 0.171, respectively. In contrast, the shape factor for the Hogan Creek Basin in 0.328 (table 12). Likewise, compaction coefficients, which indicate how round a basin is (a circular basin would have a compaction coefficient of 1.0), differ for the Bull Creek and Pauls Creek Basins (1.64 and 1.68, respectively) from the compaction coefficient for the Hogan Creek Basin (1.30, table 12).

Relief also differs considerably in the three study basins. Relief in the Pauls Creek Basin is 2,095 ft. In contrast, relief in the Bull Creek and Hogan Creek Basins, is 570 ft and 240 ft, respectively (table 12). These differences in relief also are

Table 12. Selected geomorphic characteristics of study site drainage basins in Surry County, North Carolina, and Carroll County, Virginia.

[ft, foot; N.C., North Carolina]

Site	Length[a] (ft)	Maximum elevation (ft)	Minimum elevation (ft)	Perimeter (ft)	Drainage basin shape factor[b]	Compactness coefficient[c]	Basin relief[d] (ft)	Relative relief ratio[e]	Entire stream gradient[f]	Relief ratio[g]
Hogan Creek near Siloam, N.C.	16,800	1,210	970	44,300	0.328	1.30	240	0.005	0.010	0.014
Bull Creek at Ash Hill, N.C.	24,300	1,550	980	55,900	0.156	1.64	570	0.010	0.018	0.023
Pauls Creek near Pine Ridge, N.C.	58,200	3,220	1,120	143,000	0.171	1.68	2,095	0.015	0.034	0.036

[a]Length of the line, parallel to the main drainage line, from headwater divide to gaging station (Schumm, 1956).

[b]Ratio of drainage area to the square of the basin length (Horton, 1932).

[c]Ratio of the basin perimeter to the perimeter of the circle that has the same area as the catchment area (Gravelius, 1914).

[d]Highest elevation on the headwater divide minus the elevation at the gaging station (Schumm, 1956).

[e]Ratio of the difference between elevation at 85 and 10 percent of stream length and stream length between these two points (Craig and Rankl, 1978).

[f]Ratio of basin relief to the perimeter (Sherman, 1932).

[g]Ratio of basin relief and basin length (Schumm, 1956).

Table 13. Selected habitat characteristics of stream reaches at the study sites in Surry County, North Carolina, 2004–2006.

[N.C., North Carolina; BMP, best management practice; %, percent; Cv, coefficient of variation]

Habitat characteristic	Hogan Creek near Siloam, N.C. (control site)			Bull Creek at Ash Hill, N.C. (BMP site)			Pauls Creek near Pine Ridge, N.C. (in-stream restoration and BMP site)		
	2004	2005	2006	2004	2005	2006	2004	2005	2006
Riffle (%)	37.5	32.7	44.4	45.3	40.1	36.7	43.7	50	28
Run (%)	26.7	67.3	44.5	43.4	55.1	56.4	56.3	50	72
Pool (%)	35.8	0	11.1	11.34	4.8	6.97	0	0	0
Pool/Riffle (dimensionless ratio)	0.96	0	0.25	0.25	0.12	0.19	0	0	0
Depth of water (foot)									
Minimum	0.16	0.10	0.10	0.20	0.07	0.13	0.20	0.16	0.26
Maximum	1.41	2.03	1.94	1.74	2.99	1.44	2.76	2.79	2.53
Mean	0.56	0.75	0.62	0.52	0.52	0.52	0.98	1.05	1.15
Cv (%)	55.0	62.0	67.1	66.1	106	61.5	53.6	52.8	50.6
Bank vegetative cover (%)									
Minimum	10	10	0	10	0	10	20	0	10
Maximum	70	80	80	100	100	100	100	100	100
Mean	27	30	32	49	58	75	63	74	72
Median	25	30	30	45	60	95	60	80	90
Froude number (dimensionless)	0.12	0.10	0.11	0.17	0.21	0.13	0.20	0.24	0.15
Bank erosion (% of transects where present)	45.5	45.5	45.5	27.3	40.9	40.9	27.3	40.9	13.6
Silt cover (% of points on transects where present)	100	100	100	100	100	100	100	98.2	27.6
Bankfull channel depth (foot)									
Minimum	2.0	4.1	4.8	4.4	4.2	4.5	3.9	4.4	5.3
Maximum	8.4	8.0	8.3	8.3	7.7	7.8	10.3	14.2	12.7
Mean	6.1	6.1	6.4	6.0	5.9	6.3	7.6	7.5	7.5
Median	6.4	5.9	6.4	5.8	5.9	6.4	7.5	7.3	7.1
Bankfull channel width (foot)									
Minimum	24.6	24.3	22.0	20.3	23.0	24.0	37.7	32.8	48.0
Maximum	47.6	49.2	46.0	34.1	37.1	35.0	61.0	70.5	74.0
Mean	34.2	34.9	33.9	27.0	28.5	30.3	49.9	56.1	64.1
Median	34.1	32.8	31.0	26.6	28.2	32.0	50.5	62.3	65.0
Woody debris (% of points on transects where present)	21.8	23.6	20.0	12.7	9.1	18.2	16.4	30.9	5.4
Undercut banks	13.7	13.7	18.2	9.1	18.2	7.3	9.1	13.6	13.6
Canopy closure (%)									
Minimum	35.3	47.1	64.7	11.8	11.8	11.8	0	5.9	0
Maximum	100	100	100	100	100	100	100	100	100
Mean	93.3	96.1	96.9	90.6	89.8	87.2	68.4	65.0	70.1

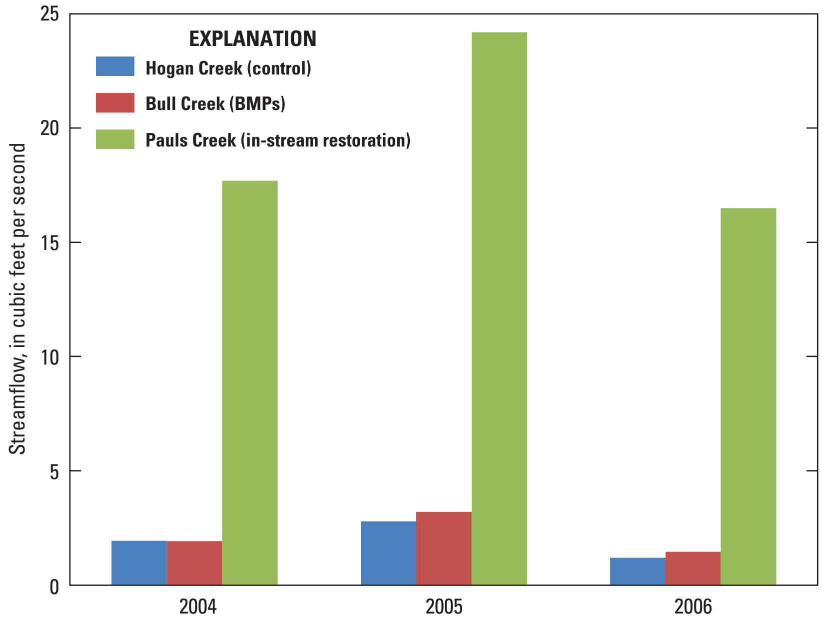

Figure 24. Instantaneous streamflow at time of habitat assessments at study sites in Surry County, North Carolina, August 2004–2006. [BMP, best management practice]

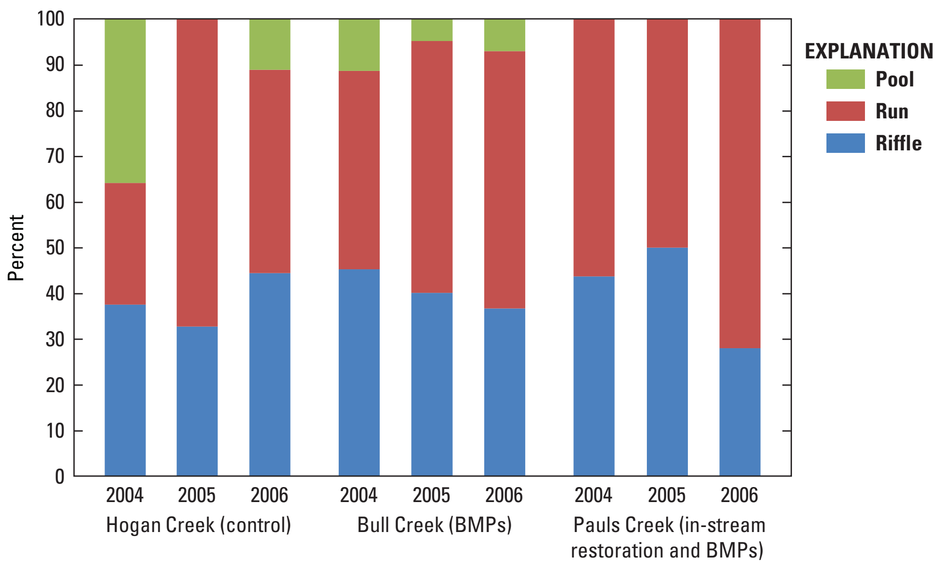

Figure 25. Distribution of geomorphological units along stream reaches used for habitat assessments at study sites in Surry County, North Carolina, August 2004–2006. [BMP, best management practice]

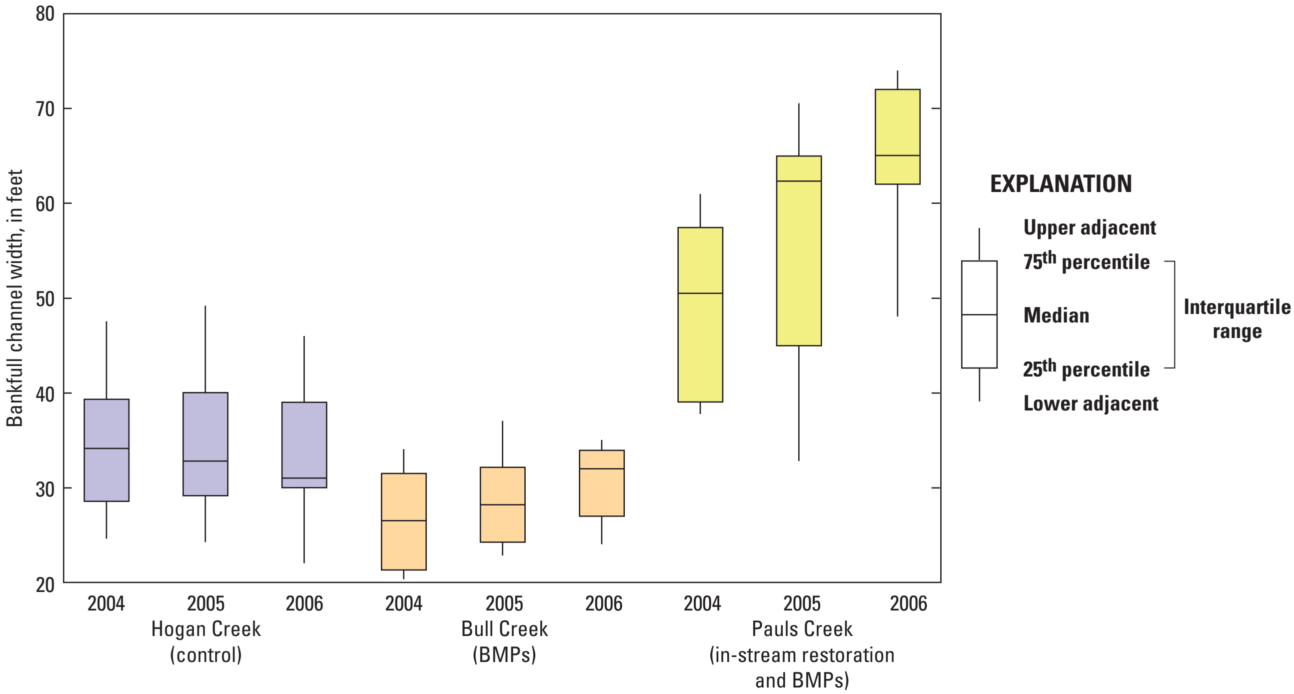

Figure 26. Distributions of bankfull channel widths at stream reaches used for habitat assessments at study sites in Surry County, North Carolina, August 2004–2006. [Each boxplot is based on 11 observations; BMP, best management practice]

apparent in the stream gradient and relief ratio of the study basins (table 12). Although the Hogan Creek and Bull Creek Basins are similar in size, they differ with regard to shape and relief. Whereas, the Bull Creek and Pauls Creek Basins differ in size but are similar with respect to shape. The Bull Creek Basin is intermediate to the Pauls Creek and Hogan Creek Basins with respect to stream gradient and relief ratio. Basin characteristics are related to channel and streamflow characteristics, which ultimately influence biota (Keller, 1978). The basin-scale differences observed between the Hogan Creek Basin and the other two basins suggest that the Hogan Creek site may not be suitable for use as a control site.

Reach-level characteristics showed various differences and similarities between the study sites with minor differences observed over time. Streamflow measured at the time of the habitat assessments generally was similar for a given site (fig. 24). However, streamflow measured at the time of habitat assessment at the Pauls Creek site was nearly 10 times greater than the streamflow measured at the Hogan Creek and Bull Creek sites and corresponds to the nearly tenfold greater size of the Pauls Creek drainage basin relative to the drainage basins of the other sites. Streamflow at the three sites was slightly greater during the 2005 assessment period than during the 2004 and 2006 assessments (fig. 24).

Habitat characteristics within the stream reaches at the Hogan and Bull Creek sites were more similar than those at the Pauls Creek site. The relative geomorphological composition (pool, run, and riffle) of the stream reaches, as illustrated in figure 25, shows that none of the Pauls Creek reach was classified as a pool. The relative percentages of geomorphologic units for the Bull Creek site showed less variation over time than did the Hogan and Pauls Creek sites (fig. 25; table 13). At Pauls Creek, the percentage classified as a run increased and the percentage classified as a riffle decreased in the 2006 habitat assessment (fig. 25; table 13), which was made following completion of the in-stream restoration in the reach.

Stream channels are affected by adjacent and upstream land-use activities. Increased peak flows associated with increased amounts of impervious surfaces or loss of vegetative cover increase channel erosion (Booth and Jackson, 1997; Hession and others, 2003). The median bankfull channel widths for the Hogan Creek and Bull Creek reaches were less than median bankfull channel width determined for the Pauls Creek reach (fig. 26; table 13) and reflect the smaller sizes of these basins in comparison to the Pauls Creek Basin. The increase in median bankfull channel width for the Pauls Creek reach from 2004 to 2006 (fig. 26) is likely the result of modifications in the channel resulting from the in-stream restoration in the reach. The mean bankfull channel width for the Hogan Creek reach was slightly greater than for the Bull Creek reach (fig. 26; table 13). Channel width is a function of streamflow conditions and can be altered by land use and riparian vegetation. Channel widths have been shown to increase downstream from bridges (Gregory and Brookes, 1983). Sweeny and others (2004) linked stream-channel narrowing to loss of riparian forests. The wider channel at Hogan Creek in comparison to

Figure 27. The Hogan Creek study site at SR 2038 near Siloam, North Carolina, showing the stream channel (*A*) looking upstream toward the SR 2038 bridge, and (*B*) looking downstream from near the streamgaging station.

Figure 28. Impoundment upstream from the streamgaging station on Bull Creek at Ash Hill, North Carolina.

Bull Creek could be a response, in part, to the bridge at the upper end of the Hogan Creek reach (fig. 27*A*, *B*) and the presence of more riparian forests in the vicinity of the Hogan Creek reach (fig. 19) than along the Bull Creek reach (fig. 18). Lower peak flows associated with the elongated shape of the Bull Creek Basin relative to the Hogan Creek Basin also could contribute to the observed channel-width differences (Gregory and Walling, 1973). The impoundment upstream from the gage on Bull Creek also may influence channel characteristics by decreasing peak streamflow (figs. 18, 28).

Stream velocities were greater at Bull Creek than at Hogan Creek, in part because of the narrower channel and greater stream gradient of the Bull Creek reach (fig. 29). The stream velocities of all three sites increased slightly from 2004 to 2005 and decreased from 2005 to 2006. These observed patterns in stream velocities were likely affected by changes in climatic conditions.

The duration of this study likely was inadequate for observing changes in channel morphology in response to BMP implementation. Several studies evaluating the response of stream channels to livestock exclusion indicate that a period greater than 1 to 2 years is required to detect changes (Baker, 1977; Kondolf, 1993). Magilligan and McDowell (1997) found that a recovery period of more than 14 years following implementation of livestock exclusion BMPs was needed to obtain measurable changes in Oregon stream channels. Median bankfull depths and bankfull width-to-depth ratios showed little difference from year to year at the Hogan Creek and Bull Creek reaches (figs. 30, 31; table 13). However, median bankfull width-to-depth ratios in the Pauls Creek reach increased each year from 2004 to 2006 (fig. 31).

Although the duration of this study was insufficient to differentiate between normal stream-channel characteristics and the effects of BMPs and in-stream restoration, an evaluation of stream habitat in eastern Wisconsin by Wang and others (2006) found that response to in-stream restoration and BMPs implemented along streams was more readily detected than the response to BMPs implemented in upland areas.

Vegetative cover on streambanks, which affects streambank stability and resistance to erosion, was greater in the Bull Creek and Pauls Creek reaches than in the Hogan Creek reach (fig. 32; table 13). However, differences in the dominant type of vegetation growing on streambanks, the lateral extent of riparian buffer zones, and land use along the reaches may also influence resistance to erosion. The Hogan Creek reach is primarily forested (fig. 19) in contrast to the Bull Creek (fig. 18) and Pauls Creek (fig. 20) reaches, which are primarily pasture.

Availability of in-stream cover, which indicates potential habitat for benthic macroinvertebrates, generally was greatest for the Bull Creek reach (fig. 33). Silt was present at all measured points in the Hogan Creek and Bull Creek reaches (table 13) from 2004 to 2006, but the presence of silt in the Pauls Creek reach decreased from 100 percent to 27.6 percent of the surveyed points during 2004–2006 (table 13). Silt adversely affects benthic invertebrates by filling voids in the substrate that provide habitat (Ryan, 1991). Habitat characteristics at the Pauls Creek reach had the greatest variability over time, primarily because in-stream restoration occurred in the reach used for habitat characterization (figs. 24–26 and 29–33; table 13).

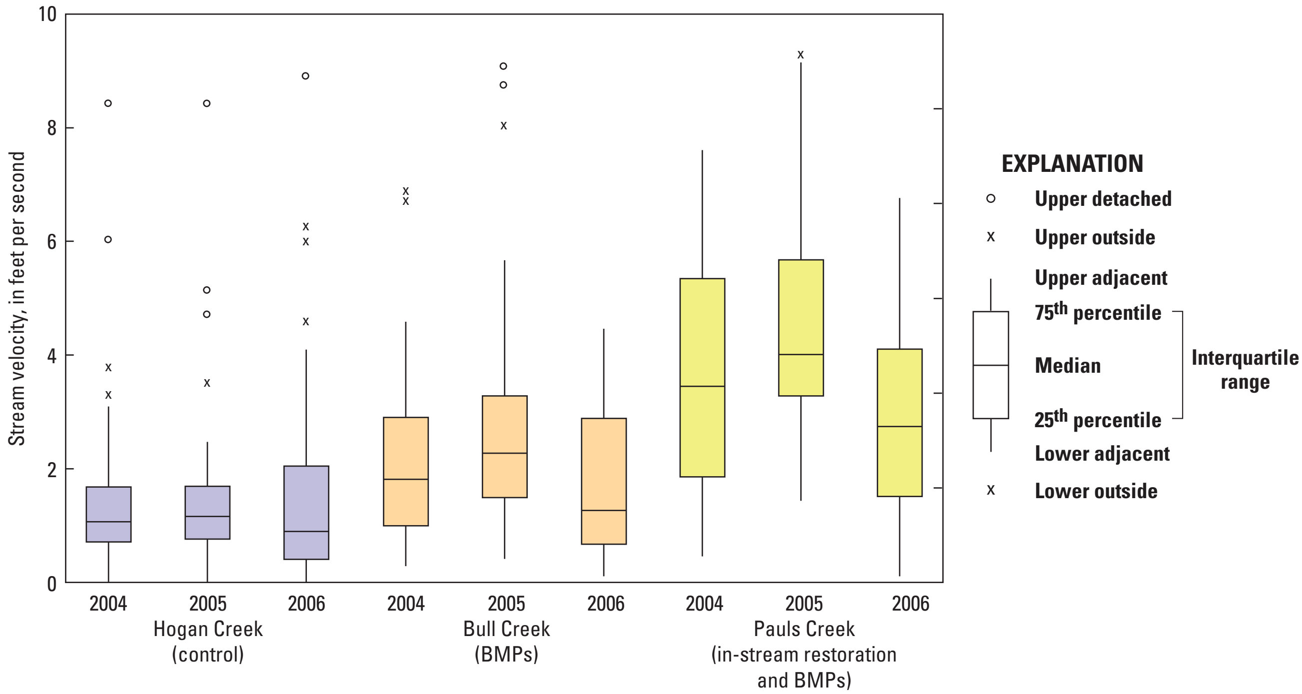

Figure 29. Distributions of stream velocities in stream reaches used for habitat assessments at study sites in Surry County, North Carolina, August 2004–2006. [Each boxplot is based on 33 observations; BMP, best management practice]

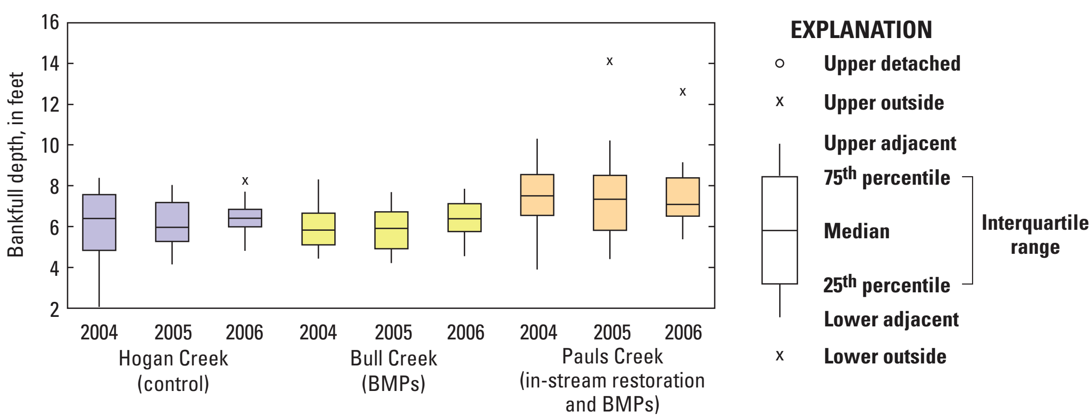

Figure 30. Distributions of bankfull depths in stream reaches used for habitat assessments at study sites in Surry County, North Carolina, August 2004–2006. [Each boxplot is based on 22 observations; BMP, best management practice]

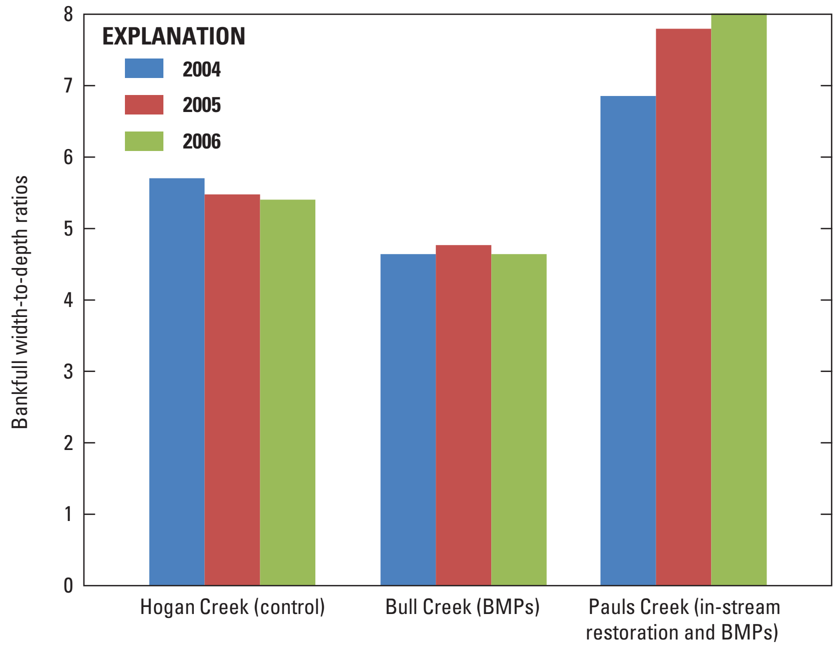

Figure 31. Median bankfull width-to-depth ratios for stream reaches used for habitat assessments at study sites in Surry County, North Carolina, August 2004–2006. [BMP, best management practice]

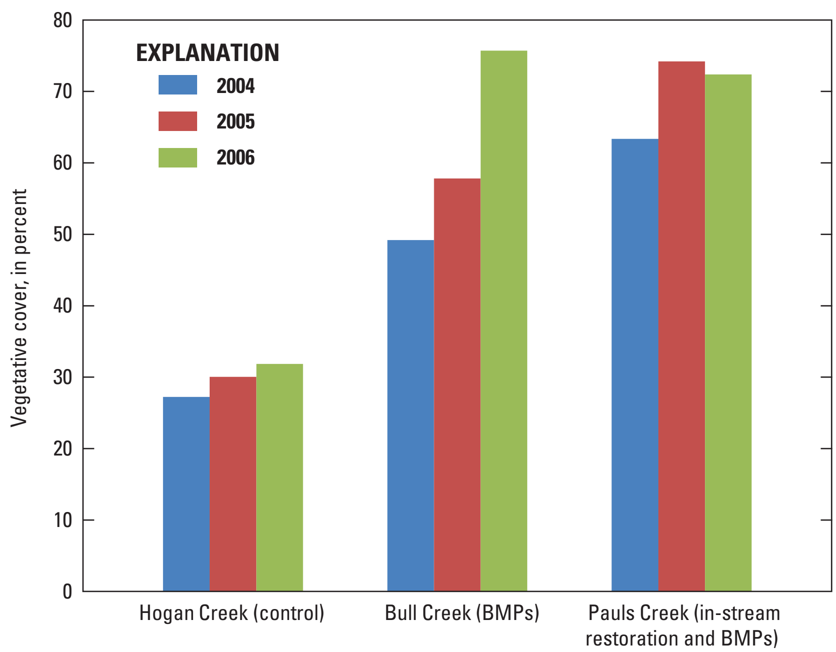

Figure 32. Streambank vegetative cover along stream reaches used for habitat assessments at study sites in Surry County, North Carolina, August 2004–2006. [BMP, best management practice]

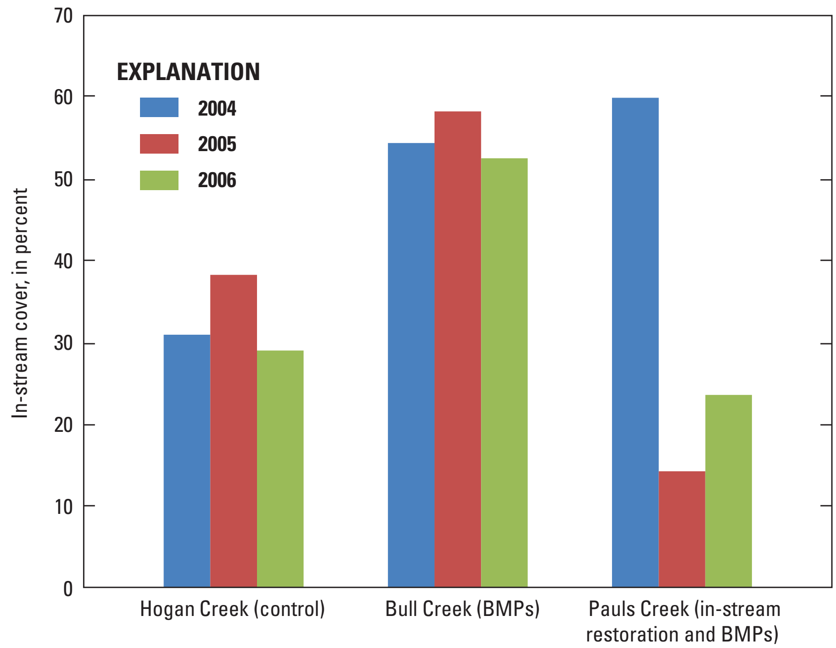

Figure 33. In-stream cover at stream reaches used for habitat assessments at study sites in Surry County, North Carolina, August 2004–2006. [BMP, best management practice]

Land-Use Characterization and Assessment

Historic and recent land use, and changes in land use that occurred in the study basins including BMP implementation and in-stream restoration, are described in this section. Land-use activities, historic and recent, can affect present-day water-quality conditions and benthic invertebrate populations. The significance of historic land use was demonstrated by Harding and others (1998), who found that 1950s land use within a catchment was a better predictor of invertebrate diversity than either 1990s land use or current riparian land use. They attributed loss of species to the influence of historic widespread changes in land use. Historic and recent aerial photographs were examined to determine if changes in land use and channel geometry were apparent in the vicinity of the study sites.

Recent land-use activities were evaluated on the basis of observations made during and immediately following this study. In addition to BMP implementation and in-stream restoration, numerous other land-use changes were observed during this study and are described for the Hogan Creek, Bull Creek, and Pauls Creek sites in the following sections.

Hogan Creek

Although originally intended to serve as the control site, agricultural BMPs were implemented in the Hogan Creek Basin before and during the period of study (figs. 2, 5; table 4). Suspended-sediment samples collected during this study may reflect changes caused by these BMPs. The implementation of one BMP prior to this study in 2001 and two additional BMPs implemented in 2007 may have affected the suitability of this site for use as a control site.

No major changes in the stream channel were evident in historical and recent aerial photographs of the area near the Hogan Creek streamgaging station. After completion of the study, evidence of logging was observed in the southwestern part of the Hogan Creek Basin upstream from the streamgaging station. Subsequent information gathered about this activity indicated that approximately 49 acres had been cleared for agricultural use, and logging of that area began in April 2007 and ended sometime during the summer (B. Elam, North Carolina Forest Service, written commun., 2010). This cleared area was converted to cropland in the fall of 2007. Since this logging activity took place before the end of sample collection, it is possible that increased rates of erosion from the area being logged resulted in higher suspended-sediment concentrations in this stream. However, water samples collected during low flow at the Hogan Creek site in 2007 do not appear to have increased suspended-sediment concentrations (fig. 10).

Bull Creek

Various land-use changes and other activities in the Bull Creek Basin may have affected water-quality conditions during this study. Historical and recent aerial photographs of the vicinity of the streamgaging station did not show evidence of major changes in the stream channel. However, two agricultural BMPs were implemented in the Bull Creek Basin prior to this study (figs. 3, 6; table 4).

Several land-use activities capable of affecting water-quality conditions in the Bull Creek Basin were observed during the study. For example, less than 1 mile (mi) upstream from the streamgaging station, land clearing and other disturbances in a large area of private property likely contributed to increased suspended-sediment concentrations in Bull Creek during the study. In addition, work on a dam on Bull Creek about 0.9 mi upstream from the streamgaging station likely affected streamflow and suspended-sediment concentrations in Bull Creek (figs. 18, 28). Furthermore, a campground with year-round trailer camping, a swimming pool, and other facilities were in operation upstream from the site and may have influenced streamflow patterns and water-quality conditions at the Bull Creek site. Because the timeframe for these disturbances could not be determined, however, the samples affected by these activities in the Bull Creek Basin could not be identified. Moreover, these activities could have masked reductions in suspended-sediment concentrations attributable to the implementation of BMPs.

The impoundment created by the dam upstream from the Bull Creek streamgaging station also affects water-quality conditions in Bull Creek by trapping suspended sediment above the dam (Grimshaw and Lewin, 1980; Simmons, 1993). Two of the six BMPs implemented in the Bull Creek Basin—one implemented during this study and one implemented prior to this study—are upstream from the impoundment (fig. 3) and are expected to have minimal effect on suspended-sediment concentrations at the study site.

Pauls Creek

Various land-use activities in the Pauls Creek Basin may have affected water-quality conditions during this study. Multiple agricultural BMPs were implemented in the Pauls Creek Basin before and during the period of study (figs. 4, 7; table 4). Prior to this study, four BMPs were implemented from 1989 to 2003 in the Pauls Creek Basin in Virginia, and two additional BMPs were implemented at the site during this study.

Other land-use activities that could have affected stream conditions at the Pauls Creek site include stream-channel changes that are evident in aerial photographs dating from 1936 to 2005 (fig. 34). The channel upstream from the Pauls Creek streamgaging station, as shown in figure 34*A*, splits into two separate channels that rejoin about 1,000 ft downstream. Diverging channels such as these are referred to as anabranches (Nanson and Knighton, 1996). One of the branches typically conveys water only during high streamflow conditions. Divergent stream channels are evident at the Pauls Creek site in the aerial photographs taken from 1936 to 1992 (fig. 34*B*–*F*). The smaller southern branch of the stream and adjacent woody vegetation, as can be seen in previous photographs, are absent in the 1998 aerial photograph (fig. 34*G*). Thus, it appears that the southern branch of the stream was filled in between 1992 and 1998. The forested area northeast of the streamgaging station also appears to have been cleared between 1992 and 1998 (fig. 34*G*, *H*).

In addition to the implementation of BMPs, in-stream restoration, and channel changes, other land-use activities occurred in the Pauls Creek Basin during the study. About 1 mi of unpaved road that parallels the stream near the streamgaging station was widened and resurfaced during the study. Between June and November 2006, extensive grading of the road embankment occurred, and a large volume of soil was removed from the road embankment to decrease the slope of the hillside above the road (C. Riggins, North Carolina Department of Transportation, oral commun., February 2, 2010). Although multiple sediment-control measures were in place to reduce the effects, this road-construction activity resulted in exposure of soil to precipitation and runoff. Suspended-sediment samples collected from Pauls Creek, especially those collected during medium flow on November 16, 2006, likely were affected by these road-construction activities.

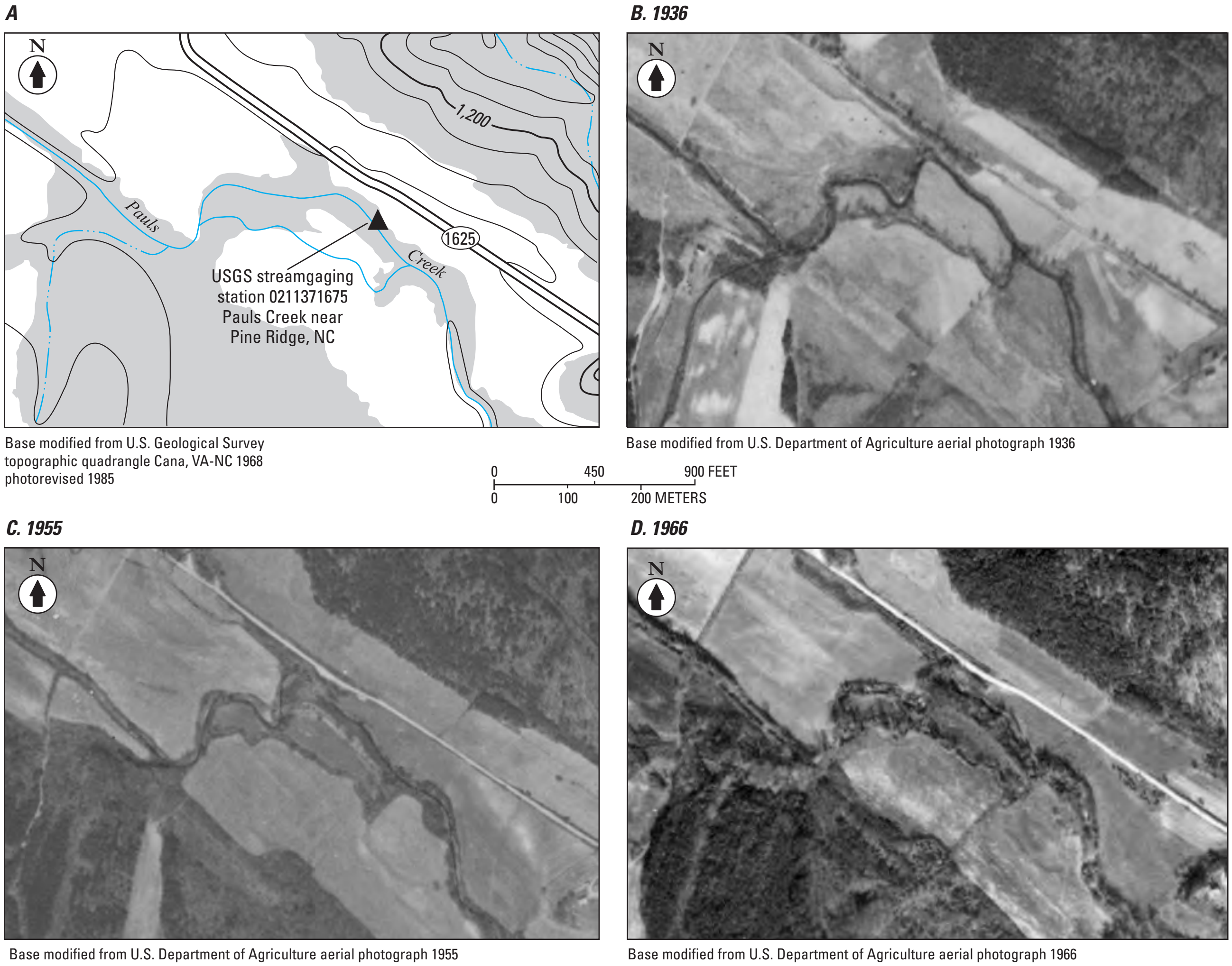

Figure 34. Map and aerial photographs of stream channel and adjacent land use near the study site on Pauls Creek above SR 1625 near Pine Ridge, North Carolina, 1936–2005.

Benthic Invertebrate Assemblages

Data for the benthic invertebrate samples collected during this investigation are provided in appendixes 4A–I. From 2004 to 2007, a total of 164 invertebrate taxa were collected from the Hogan Creek, Bull Creek, and Pauls Creek sites (Appendix 4A–C). The benthic invertebrate assemblages in these streams are typical of those expected for streams in the Blue Ridge and Piedmont Physiographic Provinces of North Carolina. Mean taxa richness ranged from 24.6 to 39.0 (table 14), and mean density ranged from about 1,180 to 2,500 individuals per square meter (table 15). Taxa richness is the number of taxa present in a sample, and large numbers of taxa generally indicate a healthy community. Insects were the most abundant group of invertebrates in all streams on all sampling dates, both in terms of richness and abundance, with midge (Chironomidae) larvae constituting the majority of the insects. Midges generally are considered to be the family of insects most tolerant of pollution.

The benthic invertebrate assemblages from the Pauls Creek site differed from those from the Hogan Creek and Bull Creek sites by generally having a higher percentage of EPT [Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)] taxa, a lower percentage of midge taxa, and a higher percentage of insect taxa (table 14). The Pauls Creek site also tended to have a higher density of EPT organisms and lower density of midge larvae than the other two sites (table 15). Unlike the midges, EPT taxa generally are considered sensitive to pollution. The two metrics used to summarize the tolerance of the organisms in the streams—Ave. Tol. (average tolerance of the taxa) and NCIBI (North Carolina Index of Biotic Integrity), average tolerance of the taxa weighted by their density—indicated significant differences among the streams. The NCIBI (density-weighted tolerance) is particularly noteworthy, as this measure directly relates to the biological condition of the streams as defined by the North Carolina Department of Environment and Natural Resources (2006; fig. 35). Based on

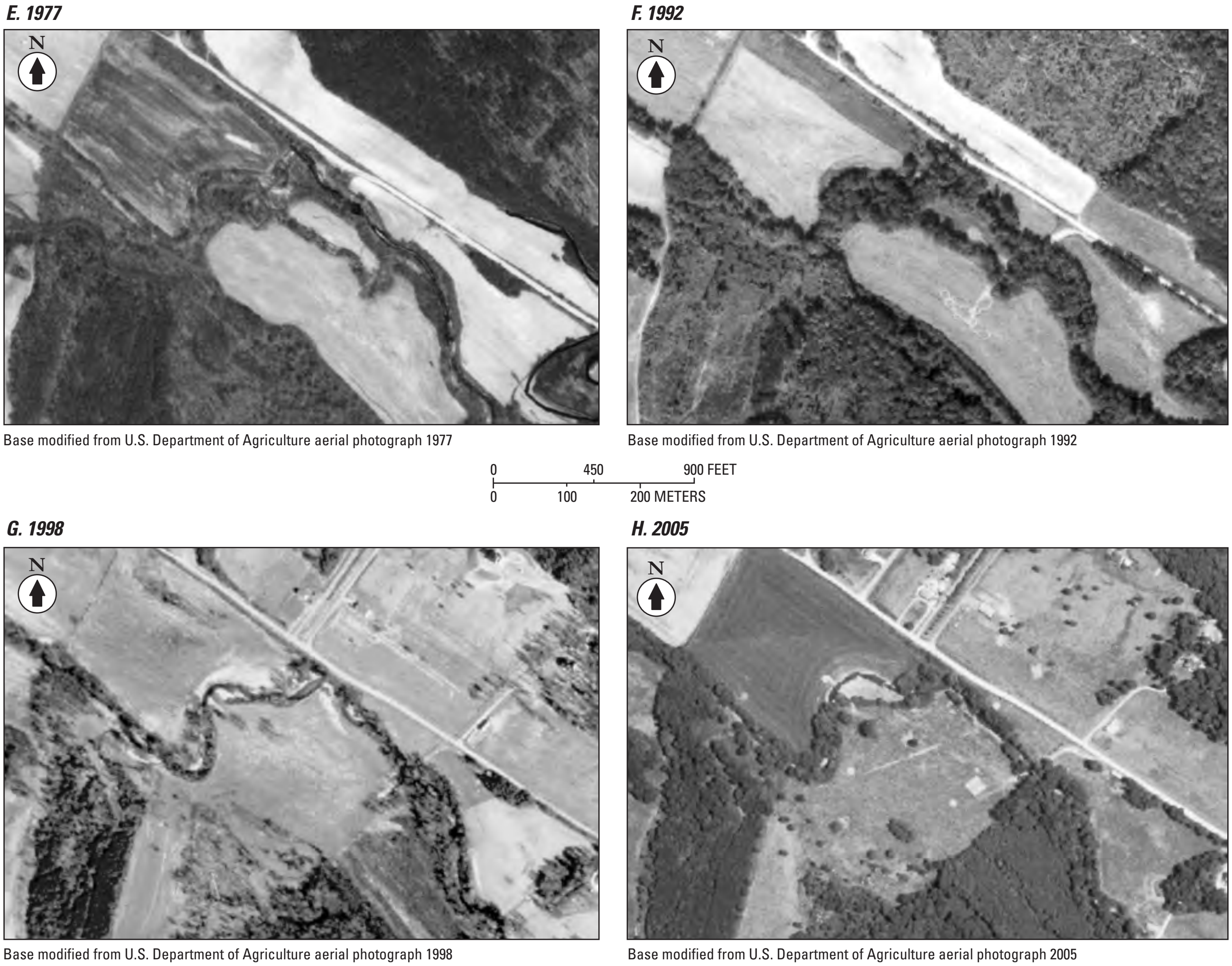

Figure 34. Map and aerial photographs of stream channel and adjacent land use near the study site on Pauls Creek above SR 1625 near Pine Ridge, North Carolina, 1936–2005.—Continued

the NCIBI, conditions in Hogan Creek, Bull Creek, and Pauls Creek were rated excellent in all years of the study. Higher suspended-sediment concentrations could be a contributing factor to the lower ranking for the Bull Creek site relative to the Hogan Creek and Pauls Creek sites, which typically had lower median suspended-sediment concentrations than Bull Creek (table 7). The habitat assessments, however, indicated the presence of silt on the substrate at nearly all of the points surveyed along the reaches of all three streams (table 13). The only exception was at Pauls Creek in 2006 when silt was observed at about 28 percent of the points. Thus, the association of poorer conditions at Bull Creek with sediment is uncertain. The between-stream differences in the NCIBI were consistent across years, which indicates that the effects of stream-improvement efforts (BMP and in-stream restoration) could not be detected using these methods. Tolerance indices also indicated no definitive patterns in the benthic invertebrate assemblages collected at the study sites (fig. 36). However, the highest tolerance indices, which indicate the poorest stream conditions, were for the Bull Creek site; the lowest tolerance indices, which indicate the best stream conditions, were for the Pauls Creek site (fig. 36).

A two-dimensional ordination (nonmetric multidimensional scaling) was used to summarize the complexity of the invertebrate assemblages (fig. 37). The ordination derives scores for each site along each axis such that sites with similar assemblages are located close to one another in the ordination diagram, and sites with dissimilar assemblages are located far apart. Ordination analysis summarizes assemblage structure more completely than assemblage metrics, which emphasize only a small proportion of the assemblage (for example, EPT summarizes only the mayflies, stoneflies, and caddisflies). The ordination diagram for the invertebrate samples (fig. 37) shows that samples from the three sites (Hogan Creek, Bull Creek, and Pauls Creek) tend to be grouped together with relatively little overlap on each collection date. The ordination

Table 14. Richness metrics and average tolerance of selected benthic macroinvertebrate assemblages in samples collected at the study sites in Surry County, North Carolina, 2004–2007.

[EPT, assemblage composed of mayflies, stoneflies, and caddisflies; %, percent; BMP, best management practice]

Site	Year	Taxa richness (mean ± standard error)				Average tolerance
		Number of taxa	Insects (%)	Midges (%)	EPT (%)	
Hogan Creek (control site)	2004	30.8 ± 2.1	92.3 ± 2.62	37.4 ± 7.26	34.9 ± 5.52	3.7 ± 5.5
	2005	32.8 ± 2.0	94.7 ± 1.68	31.2 ± 2.73	41.8 ± 3.91	3.3 ± 3.9
	2006	28.2 ± 1.8	91.7 ± 1.61	29.8 ± 1.83	43.9 ± 2.15	3.5 ± 2.1
	2007	27.6 ± 2.3	92.1 ± 1.68	34.0 ± 1.08	37.8 ± 0.98	3.3 ± 1.0
Bull Creek (BMP site)	2004	27.2 ± 1.9	91.9 ± 1.34	39.9 ± 2.12	30.5 ± 2.36	4.6 ± 2.4
	2005	39.0 ±1.6	86.3 ± 2.29	39.8 ± 3.84	23.8 ± 1.94	4.7 ± 1.9
	2006	29.6 ± 1.6	92.8 ± 2.42	39.4 ± 5.48	30.7 ± 2.82	4.4 ± 2.8
	2007	36.2 ± 1.3	90.2 ± 2.00	42.2 ± 3.41	25.7 ± 4.85	4.5 ± 4.9
Pauls Creek (in-stream restoration and BMP site)	2004	30.4 ± 1.6	93.2 ± 0.68	23.5 ± 4.80	50.9 ± 5.37	2.8 ± 5.4
	2005	28.6 ± 2.9	96.6 ± 0.12	27.9 ± 3.93	53.2 ± 2.34	2.5 ± 2.3
	2006	29.8 ± 0.9	95.0 ± 0.98	25.3 ± 3.12	54.6 ± 2.00	2.5 ± 2.0
	2007	24.6 ± 2.4	93.3 ± 2.89	26.6 ± 4.60	50.9 ± 2.37	2.5 ± 2.4

Table 15. Benthic macroinvertebrate density, abundance percentages of selected assemblages, and average tolerance metrics for samples collected from stream reaches at the study sites in Surry County, North Carolina, 2004–2007.

[no. organisms/m^2, number of organisms per square meter; %, percent; EPT, assemblage composed of mayflies, stoneflies, and caddisflies; BMP, best management practice]

Site	Year	Density (mean ± standard error) (no. organisms/m^2)	Relative abundance (mean ± standard error)		
			Insects (%)	Midges (%)	EPT (%)
Hogan Creek (control site)	2004	1,210 ± 112	98.4 ± 0.5	30.4 ± 10.3	60.0 ± 10.6
	2005	1,540 ± 287	98.5 ± 0.8	21.5 ± 4.7	68.7 ± 3.5
	2006	1,470 ± 250	98.1 ± 0.3	34.8 ± 7.5	56.8 ± 6.5
	2007	2,360 ± 621	98.1 ± 0.4	16.2 ± 3.9	74.7 ± 4.5
Bull Creek (BMP site)	2004	2,010 ± 487	94.5 ± 2.7	45.2 ± 8.7	38.2 ± 6.0
	2005	2,040 ± 482	89.8 ± 3.9	46.1 ± 5.9	28.2 ± 3.0
	2006	2,410 ± 783	91.1 ± 3.5	43.2 ± 5.8	33.3 ± 3.6
	2007	2,480 ± 624	93.4 ± 2.4	49.4 ± 4.3	30.1 ± 3.6
Pauls Creek (in-stream restoration and BMP site)	2004	1,180 ± 403	97.4 ± 1.9	15.7 ± 6.1	70.9 ± 8.7
	2005	1,440 ± 367	97.2 ± 2.4	15.3 ± 5.2	77.1 ± 6.1
	2006	1,660 ± 374	97.9 ± 1.4	12.9 ± 2.9	75.7 ± 3.8
	2007	2,500 ± 1,460	97.6 ± 1.0	11.2 ± 3.8	79.8 ± 4.2

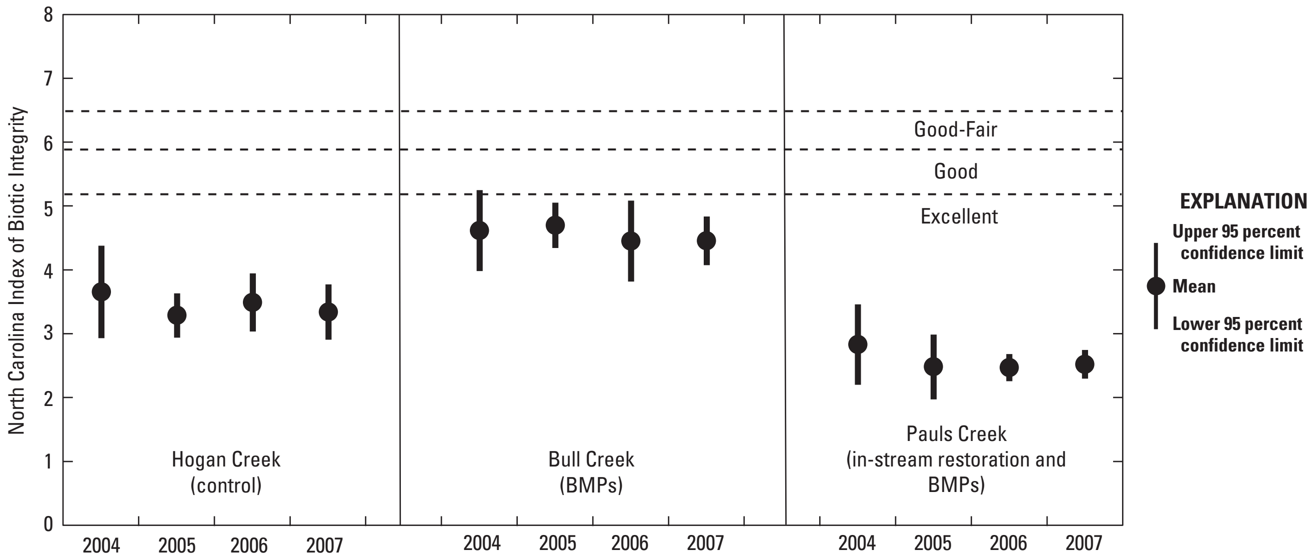

Figure 35. Distribution of North Carolina Indices of Biotic Integrity (NCIBI) for benthic macroinvertebrate samples collected annually at study sites in Surry County, North Carolina, 2004–2007. [BMP, best management practice]

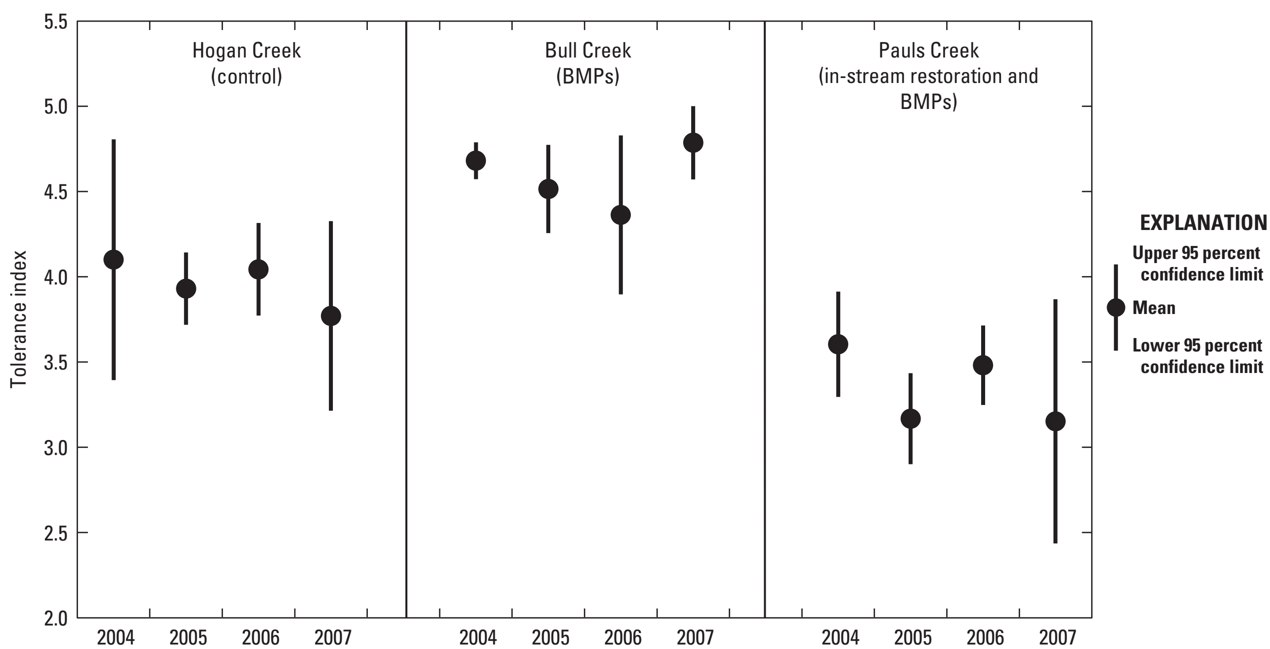

Figure 36. Tolerance indices based on species richness for benthic macroinvertebrate samples collected annually at study sites in Surry County, North Carolina, 2004–2007. [BMP, best management practice]

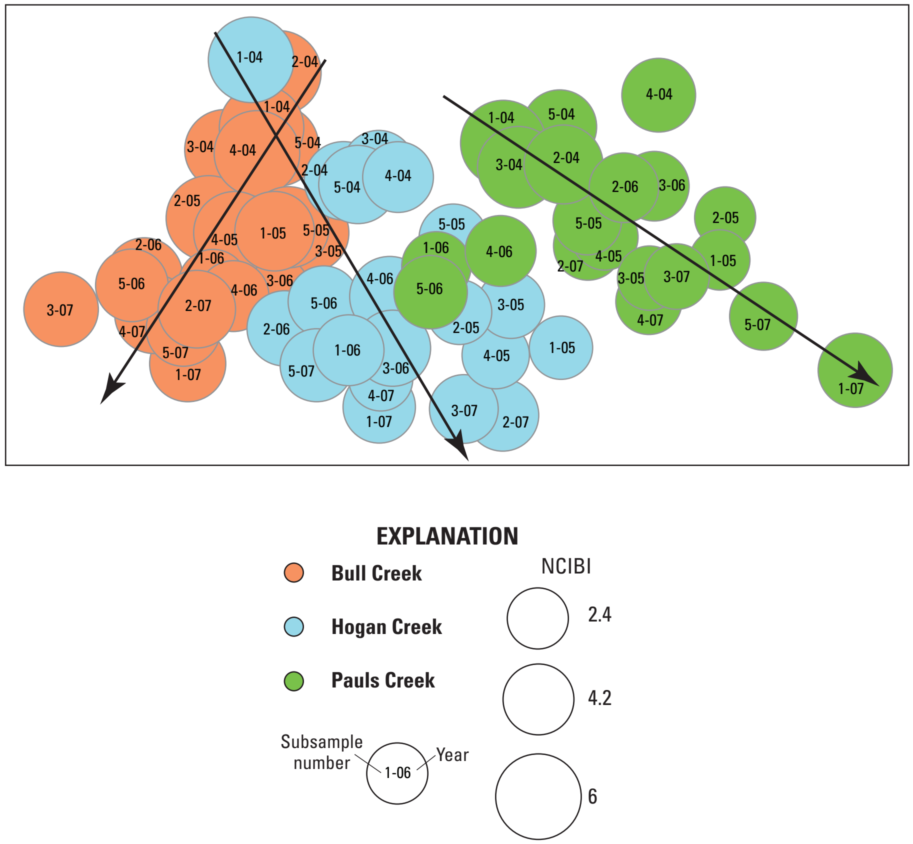

Figure 37. Ordination diagram for benthic macroinvertebrate assemblages in samples from study sites in Surry County, North Carolina, 2004–2007, showing North Carolina Indices of Biotic Integrity (NCIBI) and trajectories over time.

diagram also shows that the year in which the sample was collected has a strong influence on the position of the sample in the diagram. This indicates that year-to-year changes had a major effect on the structure of the assemblages. The arrows in this diagram provide a visual summarization of the trend in the change in assemblages over time for each of the streams. The trend lines for Hogan Creek and Pauls Creek are somewhat parallel, indicating similar changes over time. In contrast, the trajectory of changes for Bull Creek differs from the trajectories of the other two streams. This difference may indicate that the implementation of BMPs in the Bull Creek Basin or other changes in land use upstream from the study site affected the response of the macroinvertebrate assemblages to variations in stream conditions over time. The size of the bubbles representing the sites in the ordination diagram shows the relative condition of the invertebrate assemblages in the stream over time; the poorer the conditions at the site, the larger the size of the bubble. Figure 37 also shows that relatively little change in the condition of these three sites occurred over time during the study period. Analysis of similarity (ANOSIM, Clarke and Gorley, 2006) was used to test the effects of site and time. Both site and time (year) were found to have a highly significant effect ($p<0.001$) on assemblages. Given that this effect was observed for all sites, it is probably unrelated to BMP implementation or in-stream restoration. However, the difference in trajectories over time may be influenced by stream-improvement efforts or land-use changes that occurred upstream from sample-collection points.

The total taxa richness calculated for samples from each site provides a measure of benthic macroinvertebrate biodiversity. A decline in biodiversity can indicate that some aspect of a stream has changed, such as altered streamflow, a decrease in water-quality conditions, or habitat loss. Only minor changes in stream habitat characteristics at the study sites were observed from 2004 to 2006 (table 13; figs. 24–26, 29–33). Taxa richness, when expressed as the percentage of change from 2004 for the three study sites (fig. 38*A*), shows greater variation in total invertebrate taxa richness and an increase in taxa richness for Bull Creek, the BMP site. This increase in taxa richness may indicate a positive effect associated with the BMPs implemented in the Bull Creek Basin. However, taxa richness at both Hogan Creek (control site) and Pauls Creek (in-stream restoration and BMP site) declined from 2004 levels (fig. 38). Climatic conditions could have contributed to the decline in taxa richness, as streamflow conditions were affected by less-than-normal amounts of precipitation during the study (table 6). Disturbances, whether caused by drought or land-use changes, have been shown to have adverse effects

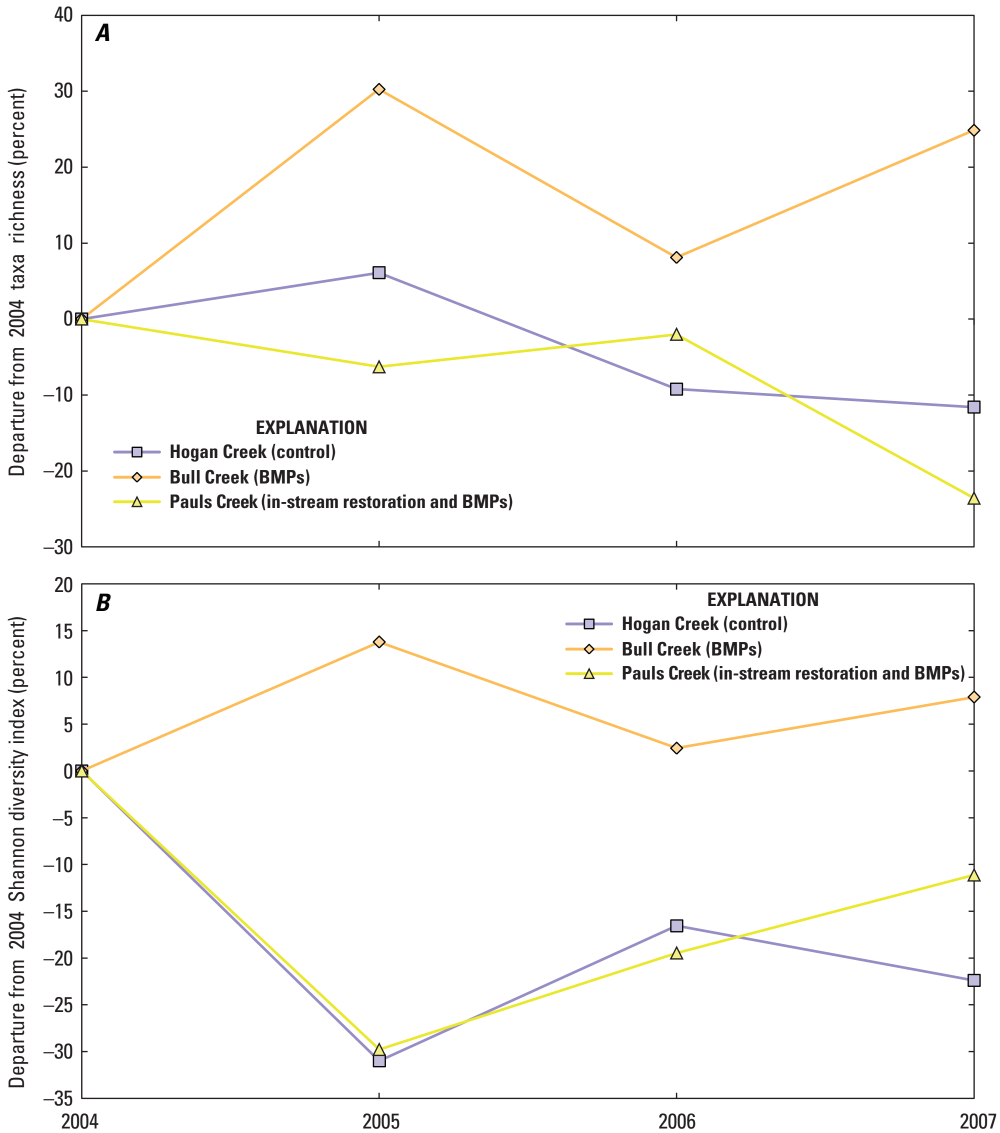

Figure 38. Departures of benthic macroinvertebrate samples from the 2004 (*A*) taxa richness and (*B*) Shannon diversity index for the study sites in Surry County, North Carolina, 2004–2007. [BMP, best management practice]

on benthic invertebrate populations (Sousa, 1984; Resh and others 1988). It is interesting to note that the disturbance associated with the in-stream restoration activities in the fall of 2006 at Pauls Creek had only a minor effect on benthic macroinvertebrate assemblages.

The Shannon diversity index (Krebs, 1989) combines the number of macroinvertebrate species (species richness) with the total number of species in a sample (abundance) to characterize species diversity in the invertebrate community. Higher values of this index indicate increased diversity. Changes in the Shannon diversity index for the three sites (fig. 38*B*) show a similar pattern to the changes observed in total taxa richness (fig. 38*A*). Shannon diversity indices show a decline relative to 2004 over time at both Hogan Creek (control site) and Pauls Creek (in-stream restoration plus BMP site) albeit with an increase after the major decline in 2005. An increase in the Shannon diversity index was indicated for Bull Creek, the BMP site. The change at Bull Creek is suggestive of a positive effect resulting from the BMPs implemented in Bull Creek during the study. However, the length of the study was insufficient to determine if the changes observed at Bull Creek are related to implementation of BMPs, to changes in climatic conditions and land-use activities during the study, or to normal variability in benthic invertebrate populations.

Conclusions

Detecting the effects of BMP implementation and in-stream restoration on water quality, stream habitat, and benthic macroinvertebrates was complicated by climatic conditions and various land-use changes that occurred during and prior to the study. Precipitation amounts varied across the study area, and dry climatic conditions produced corresponding declines in streamflow that contributed to trends in water quality observed for the study sites. In addition, interpretation of data was complicated by the length of time over which BMPs were implemented in the Bull and Pauls Creek Basins. Data interpretation was further complicated by unplanned land-use changes that occurred during the study, including road construction in the Pauls Creek Basin, land disturbance in the Bull Creek Basin, and logging activities and BMP implementation in the Hogan Creek Basin, the control site. Activities that occurred prior to the study, including implementation of BMPs in all basins, stream-channel modifications in the Pauls Creek Basin, and the presence of an impoundment upstream from the Bull Creek study site, also affected interpretation of the data.

In spite of the numerous complications, however, some important findings were obtained from this study. A key assumption of the paired-basin study design is that the basins being compared are similar in important respects except for the variables of interest. Land-use data indicate that the Bull Creek and Hogan Creek sites were similar (table 3). However, land use, physiographic setting, and drainage-basin size for the Pauls Creek site differ considerably from these same features for the other sites, and the Hogan Creek site may not be an appropriate control site for the Pauls Creek site.

Streamflow conditions in the vicinity of the study area were similar to or less than long-term annual means during the study period. Precipitation during the study also was less than long-term annual means, and less precipitation occurred in the southern part of the study area. This geographic variability in the distribution of precipitation likely produced different climatic conditions at each of the study sites, which affected streamflow and sediment transport. Because of these differences, the validity of comparisons among the sites may be questionable.

Physical characteristics of water samples collected on a quarterly basis suggested that the basins generally were comparable. Differences in water temperature, dissolved-oxygen concentration, and pH among the sites were not statistically significant. Pauls Creek had statistically significantly higher specific conductance and lower alkalinity (fig. 14) than the other sites. Differences between the specific conductance and alkalinity of samples from the study sites are likely a function of the different geologic setting and larger drainage area of the Pauls Creek Basin in comparison to the Hogan Creek and Bull Creek Basins.

Total ammonia plus organic nitrogen, dissolved ammonia, dissolved nitrite plus nitrate, and total nitrogen all showed statistically significantly higher concentrations at Bull Creek than at the other two sites (fig. 15). This finding may be due to fewer riparian buffers along Bull Creek in comparison to the other sites or to the proximity of livestock operations in the vicinity of the site. Nitrogen concentrations in samples from the Bull Creek site generally were higher than those reported in earlier studies for forested and rural basins. Dissolved orthophosphate and total phosphorus concentrations for the study basins generally were low (fig. 16; table 7). Concentrations of dissolved orthophosphate were statistically significantly higher at Hogan Creek than at the other sites.

Sediment yield is strongly correlated with streamflow; the greatest yields for any period generally are associated with the highest flows. Thus, dry climatic conditions, such as those that occurred during this study, can affect comparisons of sediment delivery among basins. The suspended-sediment yields estimated for the three study sites were high in comparison to yield estimates for other streams in the southeastern United States. Concentrations of suspended sediment in samples from Bull Creek, the site in which BMPs were implemented, were high in comparison to the other two sites (fig. 17). Suspended-sediment concentrations at the Bull Creek site did not show a statistically significant change following implementation of BMPs. Data collected before and after in-stream restoration at the Pauls Creek site indicated a statistically significant ($p<0.05$) decrease in instantaneous suspended-sediment discharge following in-stream restoration (table 11). The sampling strategy during the last 2 years of this study, which emphasized suspended-sediment sample collection during and after periods of runoff, may have contributed to an overestimation of sediment yields at the three study sites.

Bull and Hogan Creeks had similar habitat characteristics. The Bull Creek reach exhibited little change in habitat characteristics during the study period. Habitat characteristics at the Pauls Creek reach exhibited the greatest variability over time, primarily because in-stream restoration occurred within the reach used for habitat characterization (figs. 24–26, 29–33). The duration of this study may have been inadequate to detect appreciable differences in habitat characteristics, and changes that were observed during the study could not be effectively associated with stream improvements. However, the habitat measurements made during this study may prove useful in future reassessments of the study sites.

Benthic macroinvertebrate assemblages differed by site and changed over the course of the study. Bull Creek, the BMP site, stood out as the site having the poorest overall conditions and the greatest improvement in benthic macroinvertebrate communities during the study period and an assemblage change trajectory that differed from the trajectories for Hogan and Pauls Creek (fig. 37). These differences suggest that the BMPs affected Bull Creek more than the in-stream restoration and BMPs affected Pauls Creek. Changes in Pauls Creek tend to mirror those of the control stream (Hogan Creek), which indicates that the in-stream restoration and BMP implementation in Pauls Creek have not resulted in significant change. Richness and diversity metrics indicated that, although the status was excellent based on the North Carolina Index of Biotic Integrity, macroinvertebrate community conditions at the Hogan Creek and Pauls Creek sites declined during the study. However, attributing changes in macroinvertebrate communities to stream improvements was difficult given the relatively short timeframe for improvement, the effects of dry climatic conditions during the period of study, the relatively small area of the basins modified by BMPS and in-stream restoration, and other uncontrolled disturbances that occurred in each of the study basins.

Lessons Learned

Several lessons were learned from this study regarding the assessment of the effectiveness of agricultural BMPs and in-stream restoration on small streams. First and foremost was the recognition that experimental study designs are difficult to implement for basin-level studies. Unplanned and unanticipated changes occurred in each of the basins during the study, and previously unknown information was discovered during the course of the study that affected the results. To minimize the complexity of analysis and improve results, similar studies could benefit by carefully considering site selection, historical land use, previous stream improvements, the characteristics and locations of planned stream improvements, the establishment of data-collection sites both upstream and downstream from planned stream-improvement areas, and the collection of sufficient data for statistical analysis.

Site selection is an important component of water-quality studies. The BACIP design requires that compared sites are similar in all aspects except for the change or impact being tested, which in this study was either BMP implementation or in-stream restoration. Paired-basin analysis is considered to be applicable to small basins that are similar in size, slope, location, soils, and land cover (Clausen and Spooner, 1993). Minimal changes in the control basin and close proximity of the basins are also necessary (Clausen and Spooner, 1993). An investigation by King and others (2008) in the Big Walnut Creek watershed of central Ohio demonstrated successful use of paired-basin analysis in detecting the effects of agricultural stream-improvement measures on streamflow, water quality, and fish communities. However, the basins studied in the Big Walnut Creek watershed, which ranged in size from 1.5 to almost 1.8 mi^2, were smaller than the three basins compared in this study.

In addition to the selection of impacted sites, the BACIP design requires selection of appropriate control sites that are also comparable to the site being impacted by planned stream-improvement measures. The ideal control site will be of similar size, in a similar physical setting, and have similar past and present land-use characteristics as the impacted study sites. In this study, based on drainage-basin characteristics and land use, the Hogan Creek site appears to be a suitable control site for comparison with the Bull Creek site; however, it does not appear to be suitable for comparison with the Pauls Creek site. An ideal control site will not have stream-improvement efforts or other land-use changes occur within the drainage basin before or during an assessment, as occurred during this study with the Hogan Creek site. Identifying similar sites is challenging, however, and a great deal of effort is needed to identify potential study sites, especially sites that are suitable as control sites.

Detailed characterization of stream basins considered for study is essential. The physical setting and land-use activities within each drainage basin must be carefully evaluated. Physical attributes, including basin size, topography, and geologic setting, must be determined. Geomorphic characteristics of the basins, such as relief and shape, also can provide useful information regarding the similarity of sites. Land-use characteristics can be evaluated by using geographic information system (GIS) applications, aerial photographs, and information available from local, State, and Federal governmental agencies. Locations of features, such as livestock feeding operations and stream impoundments that can directly affect water-quality conditions, can be identified with aerial photographs. Additional spatial information related to land-use characteristics, such as population, land cover, agriculture, and forested areas, is important to consider and is available from various sources. In addition, it is important to conduct a field reconnaissance prior to final site selection to verify the accuracy of maps and aerial photographs and to confirm that the sites selected for study will satisfy the requirements of the study design.

To evaluate the effects of stream-improvement efforts, current and historical characteristics of the entire drainage basin must be considered. A decrease in suspended sediment resulting from the implementation of agricultural BMPs may not be immediately evident because of trapping of eroded soil prior to reaching the stream and storage of sediment in the stream channel. Likewise, changes in land use that are not associated with BMPs can affect the amount of sediment delivered to a stream and, correspondingly, the ability to detect changes in water quality associated with BMP implementation. As a result, short-term monitoring efforts may not accurately detect changes in water quality related to the implementation of agricultural BMPs.

Historical land-use changes were evident at some sites sampled during this study, and the results of the study may have been influenced by them. Historical land-use activities have been found to affect present-day stream conditions. For example, Harding and others (1998) found that catchment land use during the 1950s was a far better predictor of stream invertebrate diversity in the 1990s than was current land use. Aerial photographs taken by the U.S. Department of Agriculture covering much of the United States since the 1930s are useful for documenting historical land use. Historical maps, including topographic maps, also can provide information about past land use, such as the presence of stream impoundments at old mill sites. Historical land-use changes upstream from sample-collection points need to be identified and the long-term effects those changes can have on water-quality conditions carefully evaluated when selecting potential sites for study.

Prior to this study, agricultural BMPs had been implemented in each of the three basins studied. The period of time required for stream improvements to produce detectable changes in water-quality conditions and the duration of the effects of stream-improvement implementation are not well known. It is likely that stream-improvement measures implemented before the period of this study affected the results. Because stream improvements may influence stream conditions for many years, future studies may benefit if basins selected for study have had no prior stream improvements.

During this study, multiple agricultural BMPs were implemented in each of the three basins studied. Multiple improvements performed over a period of several years made evaluations of before- and after-improvement periods difficult, which resulted in much of the study falling into the "during-improvement" category. Future studies may be more successful at determining the effects of stream improvements if the improvements are implemented within a shorter time span and the number of improvements being studied is reduced.

The results of this study also were likely affected by the characteristics and locations of the stream improvements made during the period of study. Some agricultural BMPs implemented during this study may not significantly affect stream quality, such as the BMP implemented in the Bull Creek Basin that focused entirely on controlling groundwater infiltration at a poultry composter. The location of stream improvements relative to the stream channel also may have affected observed stream conditions. Stream improvements performed near a stream channel and near the sample-collection point are more likely to produce detectable changes in stream conditions in the short term. In contrast, stream improvements made farther away from the channel and farther upstream from the sampling point may take much longer to produce detectable changes. In addition, the magnitude of changes produced by improvements in more upland areas likely would be relatively smaller. Thus, the planning of similar studies in the future could benefit from careful consideration of the duration of the study, the locations of sampling points, and their proximity to planned stream improvements.

Efforts to determine the effectiveness of stream improvements implemented during this study were further complicated by unplanned activities that occurred in each of the basins studied. These activities included land clearing, road construction, and logging. The effects of these activities may have masked or dampened improvements in stream quality produced by the implementation of agricultural BMPs or in-stream restoration. Determining the effects of these unplanned activities on stream quality and differentiating these effects from the effects of the planned stream improvements was not possible given the limited scope of this study. Perhaps future studies using the BACIP design to assess stream improvements would produce better results if conducted in smaller stream basins or in basins where land-use activities are less diverse and more regulated, such as public lands.

The BACIP design is advantageous because it allows assessment of stream improvements with few sampling sites, requiring basically an impacted (improved) site and a control site. However, other study designs for evaluating effects of stream improvements, such as comparison of locations upstream and downstream from the improved areas, could be considered if land-use activities within the study drainage basins cannot be controlled or a suitable control site cannot be found. Sampling upstream and downstream from stream-improvement areas could lessen the effects of unplanned land-use activities as well as climatic variability and eliminate the need for control sites. However, comparison of upstream and downstream effects is best suited for areas where the stream-improvement efforts cover a small portion of the drainage basin or are near the stream.

Ideally, data collection would occur over a long enough period to show the effects of the stream improvements and to encompass variations associated with different climatic conditions. The length of time over which data would be collected and the frequency of data collection vary with the type of data. For example, it is likely that suspended-sediment and nutrient concentrations would change more rapidly in response to livestock exclusion than would habitat or invertebrate assemblages. Several years may be needed for changes in habitat characteristics to occur following livestock exclusion to allow time for vegetation to be established and streambanks to become stabilized. Normal seasonal variations in water quality and interannual variations in benthic invertebrate community structure may mask response to stream-improvement efforts if data are not collected over a long enough period to accommodate this variability. In theory, the BACIP design would eliminate the variability associated with climatic conditions provided that the sites are in climatically similar locations and observations are made over a long enough period to allow for response to the BMPs and climatic variation.

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Appendixes

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