Prepared in cooperation with the Hot Springs Village Property Owners Association, Arkansas Department of Environmental Quality, Arkansas Game and Fish Commission, U.S. Bureau of Land Management, Arkansas Natural Resources Commission, and U.S. Fish and Wildlife Service

Water Quality and Biological Characteristics of the Middle Fork of the Saline River, Arkansas, 2003-06

Scientific Investigations Report 2008-5018

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

Cover Photograph. Middle Fork of the Saline River below the confluence with Mill Creek. Photograph by Aaron L. Pugh, U.S. Geological Survey.

Water Quality and Biological Characteristics of the Middle Fork of the Saline River, Arkansas, 2003-06

By Joel M. Galloway, James C. Petersen, Erica L. Shelby, and Jim A. Wise

Prepared in cooperation with the Hot Springs Village Property Owners Association, Arkansas Department of Environmental Quality, Arkansas Game and Fish Commission, U.S. Bureau of Land Management, Arkansas Natural Resources Commission, and U.S. Fish and Wildlife Service

Scientific Investigations Report 2008-5018

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

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2008

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS--the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Galloway, J.M., Petersen, J.C., Shelby, E.L., and Wise, J.A., 2008, Water quality and biological characteristics of the Middle Fork of the Saline River, Arkansas, 2003-06: U.S. Geological Survey Scientific Investigations Report 2008-5018, 77 p.

Contents

Figures

Tables

Conversion Factors and Datums

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
centimeter per year (cm/yr)	0.3937	inch per year (in./yr)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)
cubic meter per day per square kilometer [(m^3/d)/km^2]	684.28	gallon per day per square mile [(gal/d)/mi^2]
	Mass	
kilogram per year (kg/yr)	2.205	pound per year (lb/yr)
kilogram per day (kg/d)	2.205	pound per day (lb/d)
kilogram per square kilometer (kg/km^2)	5.711	pound per square mile (lb/mi^2)
kilogram per year per square kilometer (kg/yr/km^2)	5.711	pound per year per square mile (lb/yr/mi^2)

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

$$°F = (1.8 \times °C) + 32$$

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.

Water year is defined as beginning October 1 and ending September 30.

Water Quality and Biological Characteristics of the Middle Fork of the Saline River, Arkansas, 2003-06

By Joel M. Galloway, James C. Petersen, Erica L. Shelby[1], and Jim A. Wise[1]

Abstract

The Middle Fork of the Saline River has many qualities that have been recognized by State and Federal agencies. The Middle Fork provides habitat for several rare aquatic species and is part of a larger stream system (the Upper Saline River) that is known for relatively high levels of species richness and relatively high numbers of species of concern.

Water-quality samples were collected and streamflow was measured by the U.S. Geological Survey at three sites in the Middle Fork Basin between October 2003 and October 2006. The Arkansas Department of Environmental Quality collected discrete synoptic water-quality samples from eight sites between January 2004 and October 2006. The Arkansas Department of Environmental Quality also sampled fish (September-October 2003) and benthic macroinvertebrate communities (September 2003-December 2005) at five sites.

Streamflow varied annually among the three streamflow sites from October 2003 to October 2006. The mean annual streamflow for Brushy Creek near Jessieville (MFS06) was 0.72 cubic meters per second for water years 2004-2006. The Middle Fork below Jessieville (MFS05) had a mean annual streamflow of 1.11 cubic meters per second for water years 2004-2006. The Middle Fork near Owensville (MFS02), the most downstream site, had a mean annual streamflow of 3.01 cubic meters per second. The greatest streamflows at the three sites generally occurred in the winter and spring and the least in the summer.

Nutrient dynamics in the Middle Fork are controlled by activities in the basin and processes that occur in the stream. Point sources and nonpoint sources of nutrients occur in the Middle Fork Basin that could affect the water-quality. Nitrogen and phosphorus concentrations generally were greatest in Mill Creek (MFS04E) and in the Middle Fork immediately downstream from the confluence with Mill Creek (MFS04) with decreasing concentrations at sites farther downstream in Middle Fork. The site in Mill Creek is located downstream from a wastewater-treatment plant discharge and concentrations at sites farther downstream probably had lesser concentrations because of dilution effects and from algal uptake. Nutrient concentrations generally were significantly greater during high-flow conditions compared to base-flow conditions.

Flow-weighted nutrient concentrations were computed for the three streamflow sites and were compared to 82 relatively undeveloped sites identified across the Nation, to the Alum Fork of the Saline River near Reform, Arkansas, and to the Illinois River south of Siloam Springs, Arkansas, a site influenced by numerous point and nonpoint sources of nutrients. Annual flow-weighted nutrient concentrations for MFS06, MFS05, and MFS02 were greater than relatively undeveloped sites, but were substantially less than the Illinois River south of Siloam Springs.

Fecal indicator bacteria concentrations were slightly greater at MFS06 and MFS05 compared to concentrations at MFS02 for October 2003 to October 2006. MFS05 had the greatest *E.coli* concentrations and MFS06 had the greatest fecal coliform concentrations. Overall, fecal indicator bacteria concentrations were significantly greater for samples collected during high-flow conditions compared to samples collected during low-flow conditions at all three sites.

Suspended-sediment concentrations did not vary significantly among MFS06, MFS05, and MFS02 for all the samples collected from October 2003 to October 2006. Suspended-sediment concentrations were significantly greater in samples collected during high-flow conditions compared to samples collected during base-flow conditions. Synoptic samples indicated varied total suspended-solids distributions from upstream to downstream in the Middle Fork between January 2004 and October 2006. Overall, total suspended-solids values were the greatest at site MFS02 and decreased at sites upstream and downstream.

Turbidity measured when water-quality samples were collected showed little variation between MFS06, MFS05, and MFS02. The State standard primary value (10 nephelometric turbidity units) was exceeded in 9 samples collected from MFS06, 11 samples at MFS05, and 12 samples from MFS02. The State standard stormflow value (18 nephelometric turbid-

---

[1] Arkansas Department of Environmental Quality

ity units) was exceeded in 5 samples collected from MFS06, 7 samples at MFS05, and 10 samples from MFS02. Turbidity data varied from upstream to downstream at the eight synoptic sites in the Middle Fork Basin from January 2004 to October 2006, similar to the patterns of the total suspended-solids data.

Dissolved-oxygen concentrations at MFS02 demonstrated seasonal changes from October 2003 to October 2006. Dissolved-oxygen concentrations generally were greater in the winter and spring compared to the summer and fall. The dissolved-oxygen concentrations at MFS02 were less than 6 milligrams per liter during 189 days from October 2003 to October 2006, mainly in the summer and fall.

Synoptic samples were analyzed for 19 different trace metals. Several of the metals generally had concentrations near or below the laboratory reporting level. Concentrations of boron, copper, and zinc had the greatest concentrations in Mill Creek, at the site below the wastewater-treatment discharge (site MFS04E), compared to the other sites in the Middle Fork from January 2004 to October 2006.

Continuously measured turbidity and streamflow data were compared to total phosphorus, fecal indicator bacteria, and suspended-sediment concentrations at site MFS02 to potentially provide continuous estimates of these constituents. Total phosphorus, fecal indicator bacteria, and suspended-sediment concentrations had relatively fair correlations with turbidity and streamflow at higher turbidity and streamflows, but were poorly correlated at lower turbidities and streamflow.

Biological samples (benthic macroinvertebrate and fish communities) were collected and habitat variables were measured at various times between September 2003 and October 2005 at five sites. Physical habitat variables were measured at each site to assess biological or ecological integrity.

Although there was some variation of total habitat scores among sites, and temporally, the habitats at all sites during all seasons uniformly were classified as suboptimal. Scores for sediment deposition, embeddedness, and velocity/depth regime variability (all of which could be affected by excess sediment) generally were lower than scores for other habitat variables.

Several biological metrics associated with Middle Fork Basin sites varied in a reasonably consistent manner. These metrics and the communities they represent could be affected by water quality or other habitat factors. Habitats (all of which were classified as suboptimal habitats as measured by total habitat scores) did not vary substantially among sites or in a way that suggests that physical habitat is the major factor causing the biological community differences among these sites; nonetheless, degraded habitats could be having a detrimental but similar effect on all sites. However, several biological metrics varied at Middle Fork Basin sites in a way that is similar to the variation in many of the water-quality variables—elevated or depressed at the Mill Creek site (relative to the site upstream from Mill Creek) and then returning to or approaching values associated with the site upstream from Mill Creek. Values for Middle Fork Basin sites for most metrics that were compared to values for least disturbed Ouachita Mountains streams were similar to the values for the least disturbed sites.

Implications for rural landowners, suburban landowners, government entities, and natural-resource managers include that water quality, habitat, and aquatic biological communities in the Middle Fork Basin are the result of the interaction of several factors. In addition, although data indicate that macroinvertebrate and fish communities are somewhat affected by water-quality degradation, these effects are greatest near the Mill Creek wastewater-treatment plant and communities farther downstream are similar to communities upstream from Mill Creek or to communities from relatively undisturbed sites.

Introduction

The Middle Fork of the Saline River (fig. 1) flows through parts of Garland and Saline Counties in south-central Arkansas and is a tributary of the Saline River. The Middle Fork of the Saline River (hereafter referred to as the “Middle Fork” in the text of this report) originates north of Jessieville in Garland County, flows southeastward through Hot Springs Village and into Saline County, before its confluence with the Alum Fork of the Saline River south of Crows, Arkansas.

The Middle Fork has many qualities that have been recognized by State and Federal agencies. The Middle Fork has been recognized by the Arkansas Department of Environmental Quality as an Extraordinary Water Resource under Regulation No. 2 (Arkansas Pollution Control and Ecology Commission, 2004) and listed under the U.S. Department of the Interior’s Nationwide Rivers Inventory (National Park Service, 2006). Several impoundments on tributaries to the Middle Fork along with four point-source discharges have prompted concern about potential changes in the quantity and quality of streamflow in the basin.

The Middle Fork provides habitat for several rare aquatic species and is part of a larger stream system (the Upper Saline River) that is known for relatively high levels of species richness and relatively high numbers of species of concern (Warren and Hlass, 1999; Harris, 1999; Warren and others, 1999; Crump and Warren, 1999; Warren and Tinkle, 1999). The stream provides important habitat for the federally threatened Arkansas fatmucket (*Lampsilis powellii*) (U.S. Fish and Wildlife Service, 2006). Two species listed as species of special concern by the Arkansas Natural Heritage Commission include the Ouachita madtom (*Noturus lachneri*) (Arkansas Natural Heritage Commission, 2005a) and the southern pocketbook mussel (*Lampsilis ornata*) (Arkansas Natural Heritage Commission, 2005b).

Because of activities in the basin that can affect the aquatic health of the Middle Fork and its importance as habitat for rare and threatened aquatic species, a study was conducted from October 2003 to October 2006 by the U.S. Geological Survey (USGS) in cooperation with the Hot Springs Village

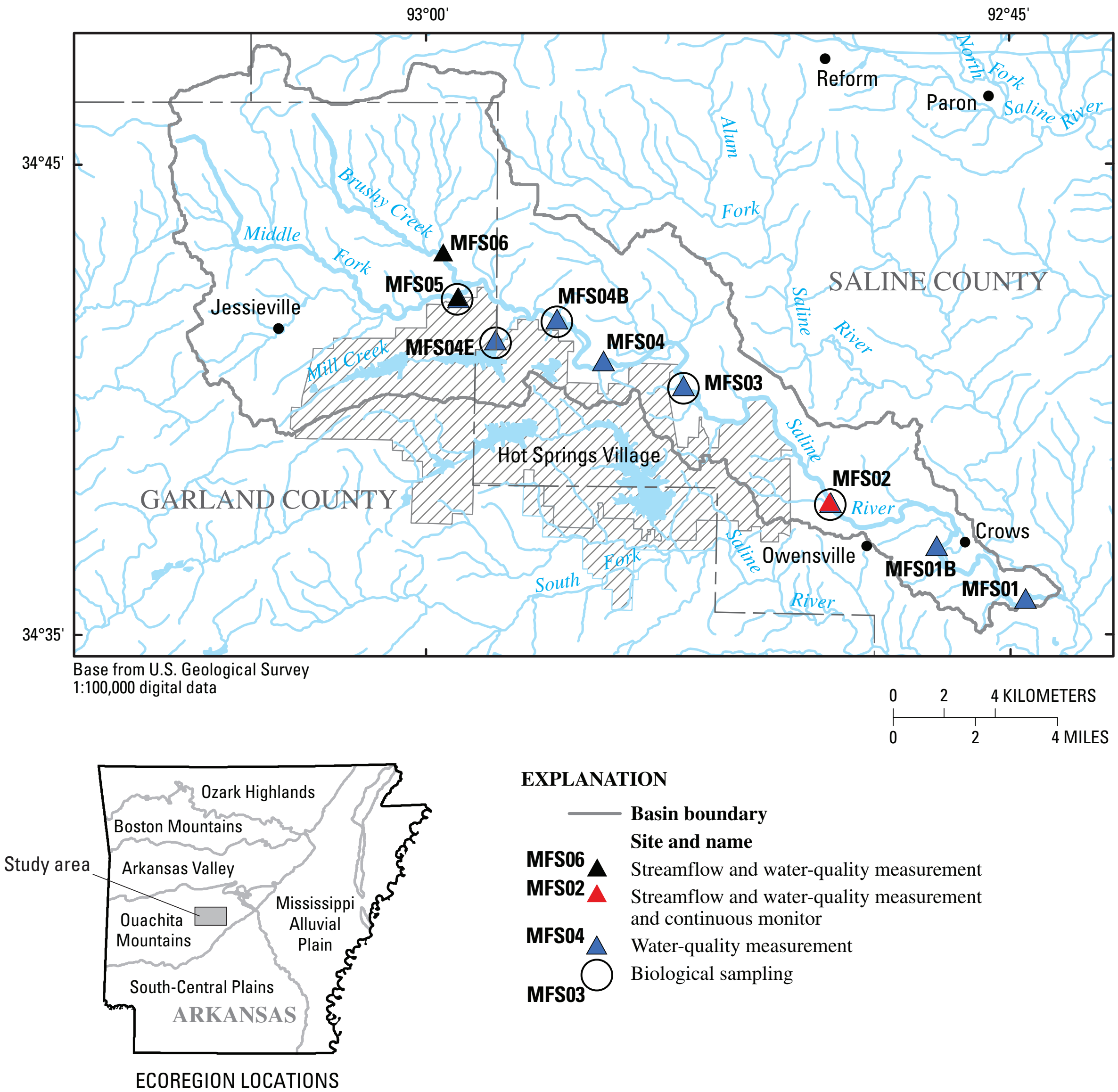

Figure 1. Middle Fork Basin, Arkansas.

Property Owners Association, Arkansas Department of Environmental Quality (ADEQ), Arkansas Game and Fish Commission, U.S. Bureau of Land Management, Arkansas Natural Resources Commission, and the U.S. Fish and Wildlife Service to examine the hydrology, water quality, and biological communities in the Middle Fork Basin. These data were used to compare the water quality and biological communities to factors that potentially affect the ecology of the stream.

Study Area Description

The study area is the Middle Fork Basin upstream from the Alum Fork confluence (fig. 1). The Middle Fork has a drainage area of approximately 277 km^2 at the confluence (Yanchosek and Hines, 1979). The Middle Fork and most of its larger tributaries are perennial streams; the 7-day, 10-year low flow for the Middle Fork near Crows previously has been estimated to be 0.04 cubic meters per second (m^3/s) upstream from the confluence (Hunrichs, 1983). Average annual precipitation near the center of the study area is about 137 cm/yr and average annual runoff is about 51 cm/yr (Freiwald, 1984).

The Middle Fork Basin lies in the Ouachita Mountains physiographic section (Fenneman, 1938). This physiographic section generally coincides with the Ouachita Mountains ecoregion (Omernik and Gallant, 1987). The Ouachita Mountains area is typified by open high hills to open low mountains vegetated by oak, hickory, and pine (Omernik and Gallant, 1987). The surface geology of the area is generally shale and sandstone (Haley, 1976).

Land use within the study area is primarily forest (fig. 2). The drainage basin above MFS05 (Middle Fork below

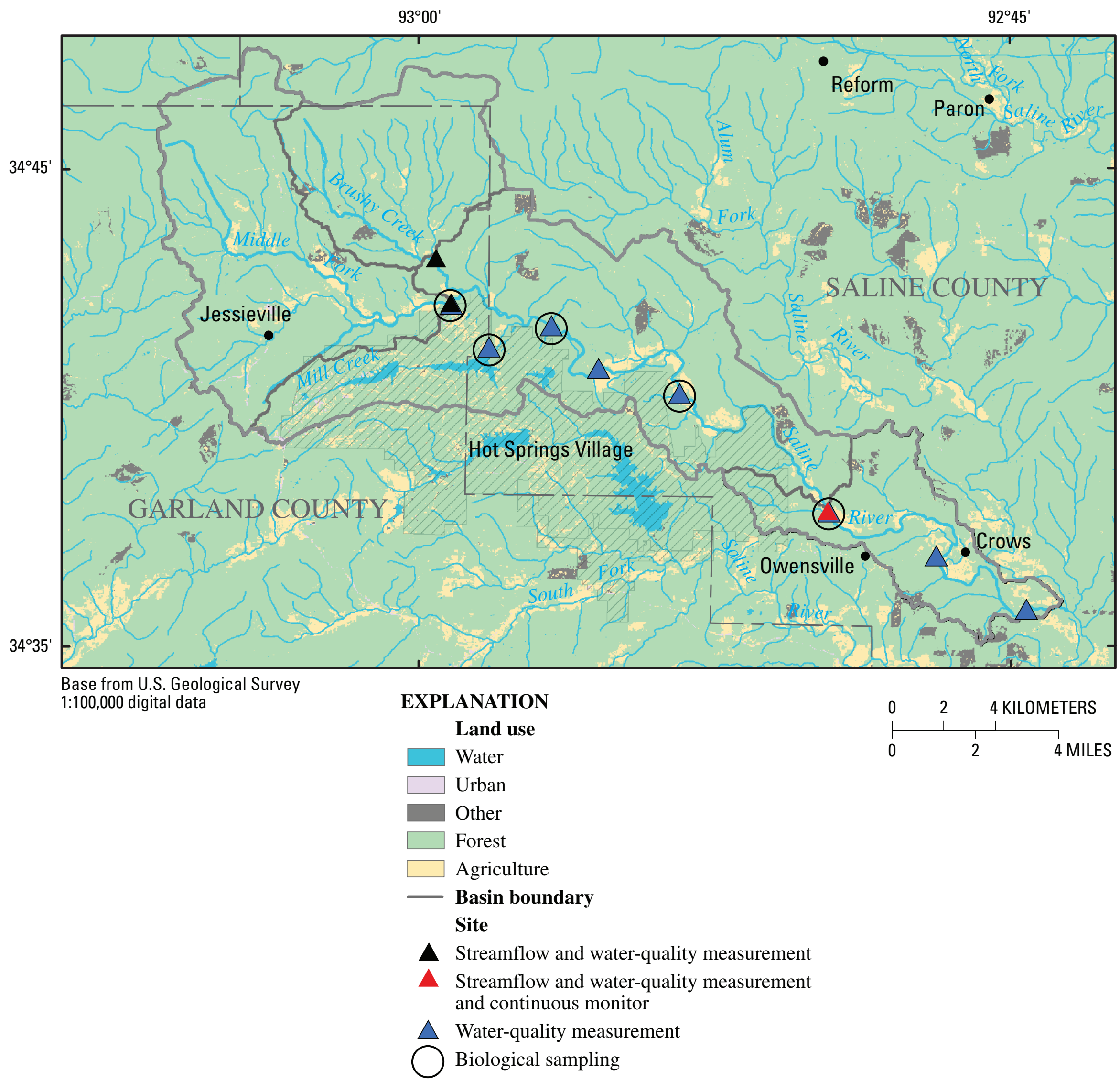

Figure 2. Land use in the Middle Fork Basin, Arkansas.

Jessieville, USGS station number 07362641) is approximately 94 percent forested, 5 percent agricultural land use, and less than 1 percent urban land use and encompasses about 78 km^2 (28 percent of the entire Middle Fork Basin). The drainage basin above MFS06 (Brushy Creek near Jessieville, USGS station number 07362656) is approximately 98 percent forested, 1 percent agricultural land use, and less than 1 percent urban and other land uses and encompasses about 46 km^2 (17 percent of entire basin). The land use in the drainage area above MFS02 (Middle Fork near Owensville, USGS station number 07362693) is composed of approximately 92 percent forested land, 5 percent agricultural land use, and 3 percent urban and other land use and encompasses about 243 km^2 (88 percent of entire basin). Much (about 36 percent) of the Middle Fork Basin lies within Hot Springs Village, a gated community with an area of about 98 km^2 (City-data.com, 2006) and a population of about 8,400 people (U.S. Census Bureau, 2006).

Purpose and Scope

The primary purpose of this report is to describe the water quality and biological characteristics (fish and benthic macroinvertebrate communities) of the Middle Fork (and selected tributaries) and to compare the water quality and biological communities to factors that potentially affect the ecology of the stream. A secondary purpose of this report is to examine relations between continuously measured data (specific conductance, turbidity, streamflow) and total dissolved solids, total phosphorus, fecal indicator bacteria, and suspended-sediment concentrations to evaluate the usefulness of using the continuous data as surrogates for total dissolved solids, nutrient, fecal indicator bacteria, and suspended-sediment concentrations.

Water-quality samples were collected and streamflow was measured by the USGS at three sites in the Middle Fork Basin (fig. 1, table 1) between October 2003 and October 2006. Samples were analyzed for nutrients, total organic carbon, suspended sediment concentration (SSC), total dissolved solids (TDS), turbidity, and pathogen indicator bacteria. Field measurements also were conducted including water temperature, specific conductance, turbidity, dissolved oxygen, and pH. Streamflow was recorded continuously from May 2002 to October 2006 at MFS02 (Middle Fork near Owensville) and from October 2003 to October 2006 at MFS06 (Brushy Creek near Jessieville) and at MFS05 (Middle Fork below Jessieville). Water temperature, specific conductance, turbidity, dissolved oxygen, and pH also were recorded continuously from October 2003 to October 2006 at MFS02.

The ADEQ collected discrete synoptic water-quality samples from eight sites (fig. 1, table 1) between January 2004 and October 2006. Samples were analyzed for nutrients, total dissolved solids, trace metals, TSS, and turbidity.

ADEQ also sampled fish and benthic macroinvertebrate communities at five sites. Fish were sampled once in September-October 2003 and benthic macroinvertebrates were sampled four times (September-October 2003, April-June 2004, April 2005, and December 2005).

Methods of Study

The following sections describe methods used for measurement of streamflow, collection and analysis of water-quality samples and other water-quality data, collection and analysis of biological samples, and data analysis. Data were collected by the USGS and ADEQ.

Streamflow Data Collection

Stream stage was measured continuously by the USGS at a site on Brushy Creek and two sites on the Middle Fork (fig. 1, table 1). Stage and instantaneous discharge were measured to compute the continuous streamflow from stage-discharge rating curves using methods described in Rantz and others (1982).

Water-Quality Data Collection

Water-quality samples were collected at three sites by the USGS and at eight sites by ADEQ (fig. 1, table 1). Collection methods, sampling frequency, and analytical methods varied between the two agencies.

Water-quality samples were collected monthly and during 14 supplemental high-flow events by USGS at three sites on the Middle Fork from October 2003 to October 2006. Samples were collected following equal-width increment methods using depth-integrated samplers and processed using protocols described in U.S. Geological Survey (variously dated). Samples were analyzed for nutrients (total ammonia plus organic nitrogen, dissolved nitrite plus nitrate, dissolved ammonia, total nitrogen, dissolved orthophosphorus, and total phosphorus), total organic carbon, fecal indicator bacteria (*Escherichia coli* and fecal coliform), suspended sediment concentration (SSC), turbidity, and total dissolved solids (TDS). Nutrient, total organic carbon, turbidity, and TDS analyses were conducted at the USGS National Water Quality Laboratory in Denver, Colorado, following procedures described in Fishman (1993). Samples were analyzed for fecal indicator bacteria in the field by USGS personnel following procedures described in Myers and Wilde (1999). SSC analyses were conducted at the USGS laboratory in Rolla, Missouri, following procedures described in Guy (1969). Field measurements, including water temperature, dissolved-oxygen concentration, pH, and specific conductance also were collected with each sample following protocols described in Wilde and Radke (1998). In addition, a multiparameter water-quality monitor was installed and operated at MFS02 (Middle Fork near Owensville; fig. 1, table 1) Water-quality measurements including water temperature, dissolved-oxygen concentration, pH, specific conductance, and turbidity were recorded continuously from October 2003 to October 2006. The operation of the water-quality monitor and data computations were conducted according to methods described in Wagner and others (2006).

To maintain proper quality assurance and control (QA/QC) of water-quality data, protocols for instrument calibration (Wilde and Radke, 1998) and equipment cleaning (Wilde and others, 1998) were followed. Associated blank and replicate water-quality samples also were collected by USGS personnel periodically. Forty-four blank samples and 58 replicate samples were collected at sites that were part of the USGS water-quality monitoring program in Arkansas from October 2003 to October 2006 including three replicate samples and two blank samples collected at the three Middle Fork sites. Results indicated that cleaning procedures were adequate in preventing cross-contamination of samples and that the laboratory results were reproducible. QA/QC sample data were stored in the USGS National Water Information System (NWIS) database (http://waterdata.usgs.gov/nwis).

Eight synoptic samples were collected by ADEQ at each of seven sites in the Middle Fork and one site in Mill Creek, a tributary to the Middle Fork, from January 2004 to October 2006. Samples were collected in the middle of the stream cross section at a single point just below the water surface in a riffle or run where the stream was well-mixed. Samples were analyzed for nutrients (total ammonia plus organic nitrogen, dissolved nitrite plus nitrate, dissolved ammonia, total nitrogen, dissolved orthophosphorus, and total phosphorus), total organic carbon, trace metals (aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, selenium, silver, thallium, vanadium, and zinc), TDS, and total suspended solids (TSS). Field measurements, including water temperature, dissolved-oxygen concentration, pH, specific conductance, and turbidity also were collected with each sample. All sample analyses were conducted by the ADEQ water-quality laboratory in

Table 1. Water quality, streamflow, and biological sites for the Middle Fork Basin, Arkansas.

Site name	U.S. Geological Survey station number	Stream	Latitude, in decimal degrees	Longitude, in decimal degrees	Data collected
MFS06 (Brushy Creek near Jessieville)[1]	07362656	Brushy Creek	34.7192	92.9928	Streamflow, water quality
MFS05 (Middle Fork below Jessieville)[1,2]	07362641	Middle Fork	34.7029	92.9862	Streamflow, water quality, macroinvertebrates, fish community
MFS04E[2]		Mill Creek	34.6879	92.9703	Water quality, macroinvertebrates, fish community
MFS04B[2]		Middle Fork	34.6953	92.9440	Water quality, macroinvertebrates, fish community
MFS04[2]		Middle Fork	34.6804	92.9240	Water quality
MFS03[2]		Middle Fork	34.6716	92.8898	Water quality, macroinvertebrates, fish community
MFS02 (Middle Fork near Owensville)[1,2]	07362693	Middle Fork	34.6303	92.8267	Streamflow, water quality, continuous water quality, macroinvertebrates, fish community
MFS01B[2]		Middle Fork	34.6149	92.7816	Water quality
MFS01[2]		Middle Fork	34.5962	92.7436	Water quality

[1] Data collected by the U.S. Geological Survey.

[2] Data collected by the Arkansas Department of Environmental Quality.

Little Rock, Arkansas, following methods described in American Public Health Association and others (1995).

Field quality-assurance samples were collected by ADEQ (duplicate samples) for approximately every tenth stream sample collected, for a total of 13 duplicate samples from January 2005 to October 2006. Matrix spikes and blank sample analyses also were conducted at the same frequency by the ADEQ laboratory from January 2005 to October 2006. Results generally indicated that cleaning procedures were adequate in preventing cross-contamination of samples and that the laboratory results were reproducible.

Biological Data Collection

Biological samples (benthic macroinvertebrates and fish communities) were collected and habitat variables were measured at various times between September 2003 and October 2005 at five sites (fig. 1, table 1). Macroinvertebrate community samples were collected during the fall (September 17 to September 19) of 2003, spring (May 11 to June 3) of 2004, spring (April 20-21) of 2005, and fall (December 6 to December 7) of 2005. Fish community samples were collected in the fall (September 23-October 14) of 2003. Habitat variables generally were measured within a few days of the macroinvertebrate sampling.

Aquatic Macroinvertebrates

Macroinvertebrate samples were collected from two riffles at each site. A D-frame dip net with a 500-micron mesh net was used to collect samples along diagonal transects through each riffle using a 5-minute traveling kick method (Montana Department of Environmental Quality, 2006). The net was placed with the opening facing upstream and moved along the transect while the substrate in front of the net was disturbed by kicking and allowing the current to carry organisms and debris into the net. The samples were cleaned of larger debris in the field and preserved in 70 percent ethanol.

In the ADEQ laboratory in Little Rock, Arkansas, each sample was individually subsampled (Davidson and Clem, 2003). The entire sample was placed in a dissecting pan. The pan was swirled to distribute the sample. A 10.2-cm diameter stainless steel ring was “randomly” dropped into the pan. Organisms were removed until the ring was depleted of organisms. If less than 95 organisms were encountered in the ring, the sample was swirled again and the ring was randomly replaced on the sample. The same procedure was followed until a minimum of 95 organisms was removed from the sample. All organisms were removed from the sample if the sample contained less than 95 organisms. Once processing in an area within the ring was begun, the entire ring was processed.

Taxa counts were used to calculate several metrics (table 2) for use in comparison of macroinvertebrate communities of sites in the Middle Fork Basin. These metrics include measures of community composition, function, and tolerance. Some of these metrics are expected to increase with perturbation, while others are expected to decrease with perturbation (table 2).

Fish

Fish communities were sampled using backpack and barge electrofishing units using pulsed direct current. The units were used in the shallow pools and runs while wading upstream and dipping the stunned fishes from the water with dip nets. The riffles were collected by placing a 6.1-m seine near the toe of the riffle and working the electrofishing unit in a downstream direction through the riffle while disrupting the bottom substrate; fish were herded into the seine or carried into the seine by the current. Fish individuals were collected from all available habitats within the sample area until a sample considered fully representative of the fish community in the area was obtained.

The larger identifiable specimens were field identified and released. Smaller specimens and specimens needing additional identification were preserved in a 10 percent formalin solution and returned to the ADEQ laboratory for identification.

Physical Habitat

Ten physical habitat variables were measured at each site using the U.S. Environmental Protection Agency (EPA) rapid bioassessment protocol (RBP) to provide data that could be used to assess biological or ecological integrity (Barbour and others, 1999). The measured variables (termed “habitat parameters” in the RBP) were epifaunal substrate/available cover, embeddedness, velocity/depth regime, sediment deposition, channel flow status, channel alteration, riffle frequency, bank stability, vegetative protection, and riparian vegetative zone width. Based on criteria from the RBP, each of the 10 variables was given a score ranging from 0 to 20 (poor, 0-5; marginal, 6-10; suboptimal, 11-15; or optimal, 16-20). Scores for individual variables were summed and the habitat at the site was characterized as poor (0-49), marginal (50-99), suboptimal (100-149), and optimal (150-200). Scores usually increase as habitat quality increases (Barbour and others, 1999).

Physical habitat characterization additionally included conducting a pebble count in each of two riffles from the habitat reach in September 2003. Pebble counts were conducted to determine bed material particle-size distribution in wadeable reaches. At the surveyed cross sections, a pebble-count transect was established, and the pebble count was conducted using the following method to select and measure approximately 100 particles per riffle:

(1) begin the count at each transect at bankfull elevation on the left bank and proceed to bankfull elevation on the right bank,
(2) proceed one step at a time, with each step constituting a sampling point,
(3) at each step, reach down to the tip of your boot with your finger extended, and pick up the first particle touched by the extended finger,
(4) to reduce sampling bias, look away from the channel bottom when taking steps or retrieving particles, and
(5) as you retrieve each particle, measure the intermediate axis. If the intermediate axis length cannot be determined easily, measure the long diameter and the short diameter of the particle, and calculate the average of the two numbers.
Particle sizes were aggregated by size class and the percentage of particles in each size class was calculated.

A two-person team conducted all habitat assessments. This method reduced bias and subjectivity between assessors. No physical habitat activities were conducted in the stream until all biological collections were completed. Any deviations from the previously mentioned methods were noted in the project field notebook. All information was recorded in the field on appropriate data forms. Photographs were taken at each site (upstream and downstream).

Data Analysis

Streamflow Data Analysis

Streamflow was separated using the Base Flow Index (BFI) hydrograph separation computer program to identify base-flow and surface-runoff components (Wahl and Wahl, 1995). The BFI program uses the Institute of Hydrology method of base-flow separation, which divides the annual hydrograph (water year) into increments and identifies the minimum flow for each increment. Each incremental minimum was compared to adjacent minimums to determine turning points on the base-flow hydrograph. If 90 percent of a given minimum was less than both adjacent minimums, then that minimum was a turning point. Straight lines were drawn between the turning points to define the base-flow hydrograph (Wahl and Wahl, 1995). The area beneath the hydrograph was the estimate of the volume of base flow for the period. The ratio of the base-flow volume to total-flow volume was the BFI.

Water-Quality Data Analysis

Water-quality samples collected from MFS06 (Brushy Creek near Jessieville), MFS05 (Middle Fork below Jessieville), and MFS02 (Middle Fork near Owensville) were separated into those collected during base-flow conditions and those collected during high-flow conditions. Base-flow water-quality samples were indentified for days when the estimated base flow was greater than or equal to 70 percent of

Table 2. Benthic macroinvertebrate metrics and expected response of metric to perturbation.

[modified from Barbour and others, 1999; EPT, Ephemeroptera plus Plecoptera plus Trichoptera; N/A, not applicable]

Metric	Description	Expected response to perturbation
Total taxa (taxa richness)	Measures the overall variety of the macroinvertebrate assemblage	decrease
Percent (relative abundance) EPT	Percent of organisms in the insect orders Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies)	decrease
Percent (relative abundance) *Cheumatopsyche*	Percent of a moderately tolerant Trichoptera genus	either
Percent (relative abundance) EPT minus percent (relative abundance) *Cheumatopsyche*	Calculated to determine percent of less tolerant EPT taxa	decrease
Percent (relative abundance) Isopoda	Percent of aquatic “sow bugs”	increase
Percent (relative abundance) Chironomidae	Percent of midge fly larvae; usually tolerant	increase
Percent (relative abundance) Diptera	Percent of aquatic “fly” larvae; usually tolerant	either
Percent (relative abundance) collector/gatherers	Percent of organisms that collect fine particulate organic matter from the substrate/streambed	either
Percent (relative abundance) scrapers	Percent of organisms that scrape food (algae) from substrate, plants	decrease
Percent (relative abundance) filterers	Percent of organisms that filter fine particulate organic matter from the water	increase
Percent (relative abundance) clingers	Percent of organisms able to remain stationery on bottom substrates in flowing waters	decrease
Percent (relative abundance) herpobenthos	Percent of burrowers plus sprawlers	increase
Percent (relative abundance) haptobenthos	Percent of clingers plus crawlers	decrease
Hilsenhoff Biotic Index	Tolerance value multiplied by number of organisms divided by total number of organisms	increase
Shannon-Weiner Diversity Index	An index that is maximized by increasing taxa richness and evenness of number of individuals across all taxa	decrease
Percent (relative abundance) tolerant	Percent of organisms with a tolerance value less than 7	increase
Percent (relative abundance) intolerant	Percent of organisms with a tolerance value greater than 3	decrease
Percent (relative abundance) facultative	Percent of organisms with a tolerance value between 3 and 7	either
Dominant taxa	Taxa which dominates the sample; highest percent	N/A
Percent (relative abundance) of dominant taxa	Percent of the dominant taxa	N/A
Codominant taxa	Taxa which codominates the sample; second highest percent	N/A
Percent (relative abundance) of codominant taxa	Percent of the codominant taxa	N/A

the total daily mean flow. High-flow samples were defined as water-quality samples collected on days when the estimated base-flow component was less than 70 percent of the total daily mean flow (surface-runoff component was greater than 30 percent of total daily mean flow).

The resulting streamflow and water-quality data were analyzed or summarized using several statistical and graphical techniques. Boxplots were used to compare concentrations of selected water-quality constituents. Concentrations reported as less than a laboratory reporting level were converted to one-half the laboratory reporting level for preparation of boxplots, calculation of total nitrogen concentrations (the sum of nitrite plus nitrate and ammonia plus organic nitrogen), and statistical analyses. The Wilcoxon rank sum test (Helsel and Hirsch, 1992) was used to test for differences in selected water-quality constituents among sites. The Wilcoxon rank sum test is a nonparametric test that determines the probability (p) that the mean of a dataset is similar to the mean of another dataset within a 95 percent confidence interval ($p<0.05$).

Water-quality constituent loads and yields were calculated from constituent concentrations and streamflow measured at each site. Constituent load (L) is a function of the volumetric rate of water passing a point in the stream (Q) and the constituent concentration within the water (C). Regression methods used to estimate constituent loads use the natural logarithm (ln)-transformed relation between Q and C to estimate daily C (or L) for a particular constituent (Cohn and others, 1989; Cohn and others, 1992; Cohn, 1995). The regression method can account for non-normal data distributions, seasonal and long-term cycles, censored data, biases associated with using logarithmic transformations, and serial correlations of the residuals (Cohn, 1995). The regression method uses discrete water-quality samples often collected over several years and a daily streamflow hydrograph. A typical log-linear regression model for estimating load can be expressed as:

$$\ln(L) = \beta_0+\beta_1\ln(Q_d)+\beta_2 T+\beta_3\sin(2\pi T)+\beta_4\cos(2\pi T) \quad (1)$$

where

ln ( ) represents the natural logarithm function;
β_o, β_1, β_2, β_3, and β_4 are the coefficients of the model;
Q_d is the daily mean discharge; and
T is decimal time.

In this model, if a relation between discharge and load exists, then the β_1 coefficient will be significantly ($p<0.05$) different from zero. Temporal trends are identified by β_2, and seasonal influences are identified by β_3 and β_4.

Seasonality and time were not included in the regression analysis decribed in this report because the period of data collection was too short (3 years) to describe or identify seasonal or temporal trends in the data for the regression model. Therefore, only the relations between natural logarithmic-transformed L and Q were used:

$$\ln(L) = \beta_0+\beta_1\ln(Q_d) \quad (2)$$

Transforming the results of the model from logarithmic space to real space was accomplished using two methods: an adjusted maximum likelihood estimator (AMLE) and a least absolute deviation (LAD) (Cohn and others, 1992). The AMLE method was used if the constituent had censored values and the LAD method was used to transform the results if no censored values were included in the data or if outliers in the residuals were present. The S-LOADEST computer program (Runkel and others, 2004) was used to estimate annual and monthly constituent loads at MFS05, MFS06, and MFS02 for water years 2004 through 2006.

Annual yields (kilograms per square kilometer) also were calculated from estimated annual loads at each site. The yield was calculated by dividing the annual load (kilograms per year) by the drainage area (square kilometers) contributing flow at the location of the sampling site.

Flow-weighted concentrations also were calculated from the estimated annual loads. Flow-weighted concentrations were calculated by dividing the annual load by annual mean flow, and applying appropriate conversion factors for dimensional units:

$$C_{FW} = (L/Q_{Annual}) \times 1.12 \times 10^3 \quad (3)$$

where

C_{FW} represents the flow-weighted concentration, in milligrams per liter,
L represents the annual constituent load, in kilograms per year, and
Q_{Annual} represents the annual mean streamflow, in cubic meters per second.

The continuously recorded streamflow and water-quality measurement data (specific conductance, pH, water temperature, dissolved oxygen, and turbidity) and water-quality sample data for total dissolved solids, total phosphorus, total nitrogen, suspended-sediment concentrations, and fecal indicator bacteria densities at site MFS02 (Middle Fork near Owensville; fig. 1) were used to evaluate potential relations between the continuously measured data and the water-quality sample data using methods described in Christensen and others (2000) who used simple regression equations to develop relations. The concentrations of constituents often are strongly related to other water-quality measurements and factors such as hydrologic conditions, season, and location. The simplest regression equation can be expressed as:

$$y_i = mx_i + b + e_i \qquad i = 1, 2, \ldots, n \quad (4)$$

where

y_i is the i th observation of the dependent variable;
m is the slope;
x_i is the i th observation of the independent variable;
b is the intercept;
e_i is the random error for the i th observation; and
n is the sample size.

The terms *m* and *b* represent the parameters that need to be estimated from the data. The most common estimation method is least squares (Helsel and Hirsch, 1992). In least-squares estimation, the error term, e_i, is assumed to be normally distributed with a mean equal to zero and constant variance, σ^2.

To determine which independent variable or variables (x) to include in each regression equation, a stepwise procedure was used (Ott, 1993). Each independent variable was added to the model one at a time to determine if there was a significant ($p<0.05$) correlation. Independent variables that were evaluated included specific conductance, turbidity, streamflow, and time.

Several measures were used to evaluate the regression equations. These included the sum of square errors (SSE), the sum of squares of y about the mean (SS_y), and the coefficient of determination (R^2). The least-squares estimators in equation 4 (*m* and *b*) were obtained by minimizing the SSE, which is calculated as follows:

$$SSE = \Sigma[(y_i - E(y_i)]^2 \quad (5)$$

where

y_i represents the value of y at the i th data point, and

$E(y_i)$ is the estimated value of y at the i th data point.

SSE is a dimensional measure of fitting y on x and is a measure of the unexplained variability. The SS_y represents the total variability (explained and unexplained) about the mean in y values and is calculated as follows:

$$SS_y = \Sigma(y_1 - \overline{y})^2 \quad (6)$$

in which $\overline{y}$ is the mean of y.

Both SSE and SS_y are dimensional measures. Dimensionless measures often are required in practice for the purpose of comparing constituents with different dimensions (units of measure). A dimensionless measure of fitting y on x is the R^2, or the fraction of the variance explained by regression:

$$R^2 = 1.0 - (SSE/SS_y) \quad (7)$$

The larger the explained variability compared to the unexplained variability, the better the equation fits the data, and this should lead to a more precise prediction of y (Ott, 1993). The R^2 ranges from 0 to 1 and often is called the multiple coefficient of determination in multiple linear regression.

Another measure often used to explain variability in regression equations is mean square error (MSE). MSE is calculated as follows:

$$MSE=(SSE/n-2)^{0.5} \quad (8)$$

The MSE is presented for each equation to assess the variance between predicted and observed values.

Graphical plots were created to determine linearity and visually examine relations and grouping of the data. For certain equations, either the independent variable, dependent variable, or both were transformed to convert all equations to linear equations. Log transformations of variables can eliminate curvature in the data and simplify the analysis of the data (Ott, 1993). For example, by taking the natural log of an independent variable in a nonlinear regression equation, it is possible to achieve a linear equation.

Biological Data Analysis

Several community composition attributes (metrics) were calculated for each macroinvertebrate and fish sample. Values of several of these metrics were compared to metric values for least-disturbed, Ouachita Mountains ecoregion reference streams of similar watershed sizes.

The Shannon-Weiner diversity index, *H'* (Shannon and Weaver, 1949; Washington, 1984), which is a measure of taxa richness (the number of taxa in the community) and the evenness of the taxa distribution, was calculated using the equation:

$$H' = \sum_{i=1}^{s} (P_i)(\log P_i) \quad (9)$$

where

s is equal to the total number of taxa in the sample;

P_i equals the proportion of each taxon in the sample; and

$\log P_i$ is log base 10 of that proportion value for each taxon.

The Hilsenhoff biotic index (HBI) (Hilsenhoff, 1987), which is an indicator of organic pollution that uses tolerance values to weight taxa abundances, was calculated using the following equation:

$$HBI = \sum_{i=1}^{s} [(n_i)(a_i)/N] \quad (10)$$

where

s is equal to the total number of taxa in the sample,

n_i is the number of individuals of each taxon,

a_i is the tolerance value of each taxon, and

N is the total number of organisms in the sample.

The fish communities were evaluated by comparing eight community metrics (table 3) at each site to the metrics for fish communities of least-disturbed, Ouachita Mountains ecoregion reference streams of similar watershed sizes (Bennett and others, 1987). A fish community structure index (CSI) was calculated from these metrics based on scoring criteria derived from ecoregion reference stream data. The maximum scores were developed from average values for reference streams,

Table 3. Criteria used for scoring fish community structure index (CSI) metrics.

[Diversity index is Shannon-Weiner logarithmic, base 10; >, greater than; <, less than]

Score	4	2	0
Criteria	**Metric, as percent (except diversity index, dimensionless)**		
Cyprinidae	45 - 60	36 - 46 or 60 - 67	<36 or >67
Ictaluridae	>1[1]	<1 - 0.5[1]	<0.5[1] or >2 bullheads
Centrarchidae	8-26	3 - 8 or 26 - 33[2]	<3 or >33[2]
Percidae	>14	8-14	<8
Sensitive species	>24	16 - 24	<16
Primary trophic feeders	<48	48 - 58	>58
Key species	>23	10-23	<10
Diversity index	>2.63	2.63 - 2.11	<2.11

[1] No more than 2 percent bullheads.

[2] No more than 7 percent green sunfish.

and different score levels were based on one and two standard deviations from the average. In addition to the eight CSI metrics, species richness (number of species) and stoneroller relative abundance were used to assess the fish communities.

Hydrologic Characteristics

Streamflow varied annually among the three streamflow sites from October 2003 to October 2006 (water years 2004-2006) (Brossett and others, 2005, 2006; U.S. Geological Survey, 2007) (fig. 3, table 4). The mean annual streamflow for Brushy Creek near Jessieville (MFS06) was 0.72 m^3/s for water years 2004-2006, with the greatest annual mean streamflow in 2005 (0.92 m^3/s) and the least in 2006 (0.54 m^3/s). The Middle Fork below Jessieville (MFS05) had a mean annual streamflow of 1.11 m^3/s for water years 2004-2006 with the greatest annual mean streamflow in 2004 (1.26 m^3/s) and the least in 2006 (0.98 m^3/s). The Middle Fork near Owensville (MFS02), the most downstream site, had a mean annual streamflow of 3.01 m^3/s with the greatest annual mean in 2005 (3.64 m^3/s) and the least annual mean streamflow in 2006 (2.50 m^3/s).

Streamflow in the Middle Fork also varied seasonally from October 2003 to October 2006 (fig. 3, table 4). Daily mean streamflows at MFS06 ranged from 0 to 18.66 m^3/s and from 0.01 to 48.14 m^3/s at MFS05. MFS02 had daily mean streamflows ranging from 0.04 to 96.28 m^3/s. The greatest streamflows at the three sites generally occurred in the winter (December, January, and February) and spring (March, April, May) and the least in the summer (June, July, and August). The greatest mean monthly streamflow occurred in March at the three sites and the least mean monthly streamflow occurred in August (table 4).

The drainage basin upstream from the gaging station on Brushy Creek (MFS06) composes approximately 19 percent, and the drainage basin upstream from the gaging station on the Middle Fork below Jessieville (MFS05) composes approximately 32 percent of the drainage basin upstream from the gaging station on the Middle Fork near Owensville (MFS02). The mean annual streamflow at MFS06 composed approximately 24 percent and MFS05 composed approximately 37 percent of the streamflow at MFS02. On an annual basis, it appears that about 39 percent of the streamflow at MFS02 was added downstream from MFS06 and MFS05. The largest tributary downstream from MFS06 and MFS05 is Mill Creek. In late fall and spring, MFS06 contributed a greater proportion of the streamflow ranging from 21 to 33 percent of the streamflow at MFS02 and in late summer and fall contributed a lesser proportion when the streamflow was only about 6 to 15 percent of the streamflow at MFS02. MFS05 contributed from 34 to 49 percent of the streamflow at MFS02 in the spring to 23 percent in midsummer (July).

Much of the total streamflow for the three sites occurred on relatively few days from October 2003 to October 2006 (fig. 4). The upper 50 percent of the streamflow passed sites MFS06 and MFS05 in 57 days (5 percent of the entire period). The upper 50 percent of the total streamflow at MFS02 passed the site in 71 days (6 percent of the entire period). This suggests that during a typical year (365 days), the upper 50 percent of the streamflow passes MFS06 and MFS05 in about

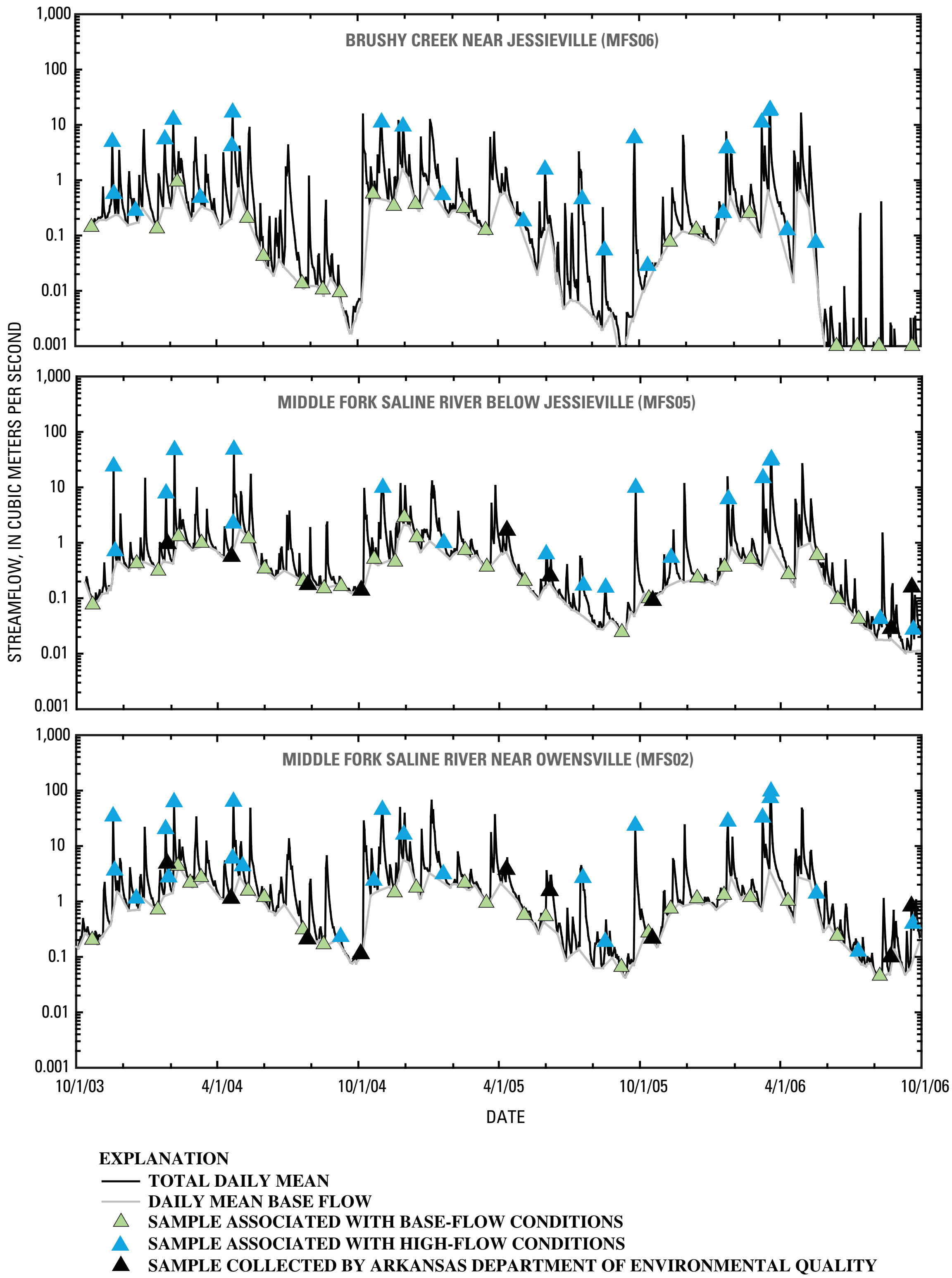

Figure 3. Daily base flow and total daily streamflow and water-quality sample times for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

Table 4. Annual and monthly streamflow statistics for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

[Values are mean streamflow in cubic meters per second]

Station	Water Year	October	November	December	January	February	March	April	May	June	July	August	September	Annual
Brushy Creek near Jessieville (MFS06)	2004	0.18	1.26	1.03	0.83	3.08	1.64	3.32	2.36	0.45	0.56	0.34	0.15	1.26
	2005	1.79	2.70	1.82	2.63	1.02	1.30	0.72	0.15	0.20	0.13	0.05	0.48	1.08
	2006	0.12	0.93	0.27	1.45	0.69	4.15	2.31	1.46	0.16	0.05	0.11	0.03	0.98
	Mean for 2004-2006	0.70	1.63	1.04	1.64	1.60	2.36	2.12	1.33	0.27	0.24	0.17	0.22	1.11
Middle Fork below Jessieville (MFS05)	2004	0.12	0.66	0.86	0.77	1.50	0.99	1.62	1.21	0.13	0.43	0.05	0.01	0.69
	2005	1.90	2.69	1.28	2.13	0.52	1.02	0.61	0.11	0.17	0.29	0.02	0.26	0.92
	2006	0.03	0.58	0.15	0.85	0.38	2.46	1.34	0.62	0.00	0.01	0.01	0.00	0.54
	Mean for 2004-2006	0.68	1.31	0.76	1.25	0.80	1.49	1.19	0.65	0.10	0.25	0.03	0.09	0.72
Middle Fork near Owensville (MFS02)	2004	0.24	2.76	2.44	2.60	6.79	5.20	5.51	4.83	1.14	2.23	0.86	0.14	2.88
	2005	5.70	9.90	5.09	9.86	2.79	4.36	2.28	0.51	0.92	0.78	0.15	1.31	3.64
	2006	0.31	2.49	1.24	3.48	1.70	11.49	5.35	2.83	0.42	0.12	0.18	0.27	2.50
	Mean for 2004-2006	2.08	5.05	2.92	5.31	3.76	7.02	4.38	2.72	0.83	1.04	0.40	0.57	3.01

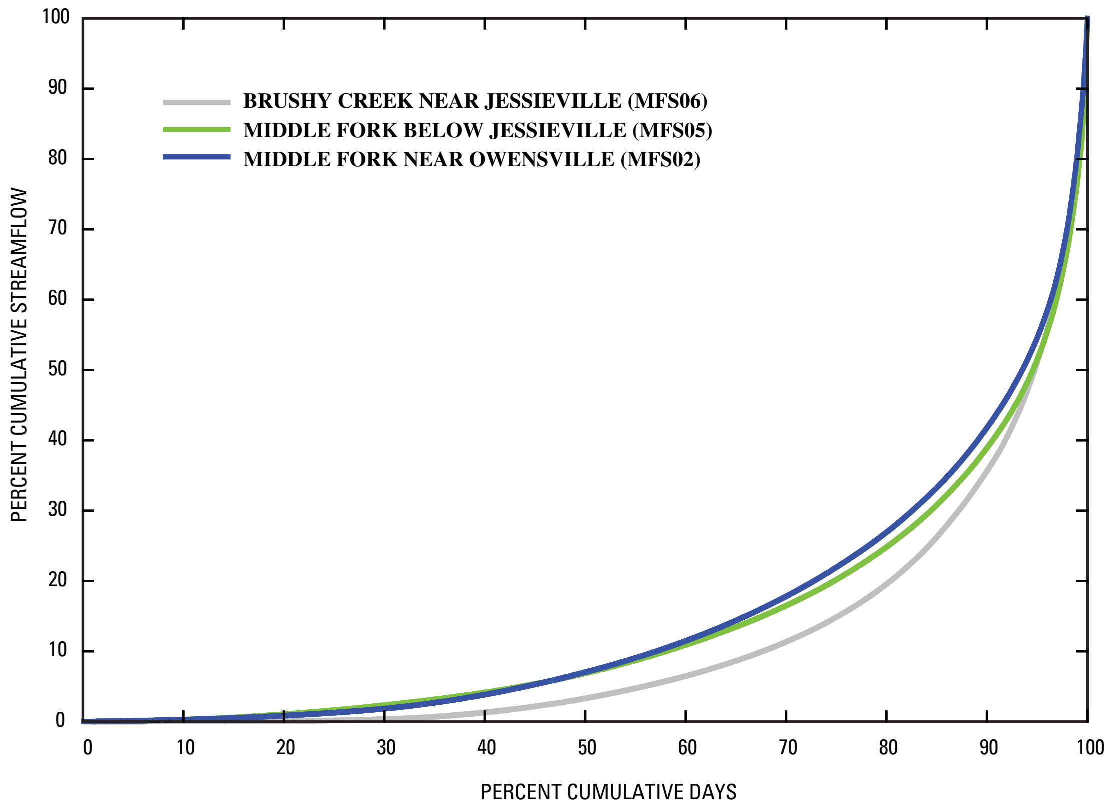

Figure 4. Flow accumulation curves for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

18 days and passes MFS02 in about 22 days. If concentrations of materials transported were constant, regardless of the magnitude of flow, season, and other variables, more than one-half of the material transported past the three sites in a given year would occur in about 3 weeks.

The streamflow for MFS05 and MFS02 had a greater component of base flow than MFS06 (fig. 3). MFS05 had the greatest percentage of base flow for October 2003 to October 2006 with approximately 33 percent of the total annual streamflow contributed by base flow. MFS02 had a slightly smaller component of base flow, with 32 percent of the total annual streamflow contributed by base flow. MFS06 had the least amount of base flow with approximately 23 percent of the total annual streamflow contributed by base flow. MFS06, MFS05, and MFS02 had the least amount of baseflow in 2006 than other years with percent contributions of 19 percent, 26 percent, and 30 percent, respectively. The greatest amount of base flow occurred in 2005 at MFS06 (26 percent of the total annual streamflow) and MFS05 (39 percent of the total annual streamflow). MFS02 had the greatest component of base flow in 2004 (33 percent of the total annual streamflow).

Water-Quality Characteristics

Water-quality data were collected by the USGS at two sites on the Middle Fork and one site on Brushy Creek, a tributary to the Middle Fork, to evaluate changes in water-quality conditions over time. ADEQ collected synoptic water-quality data at eight sites in the Middle Fork and in Mill Creek, a tributary to the Middle Fork, to evaluate spatial changes in water quality in the Middle Fork.

Nutrients and Organic Carbon

Nutrient dynamics in the Middle Fork are controlled by activities in the basin and processes that occur in the stream. Point sources and nonpoint sources of nutrients that could affect the water quality occur in the Middle Fork Basin. Wastewater-treatment plant discharge can be a major point source of nitrogen (mainly nitrate), phosphorus, and organic material. Septic systems can act as point sources as nutrients migrate through the ground-water system into the stream. The influence of point sources is usually more evident during base-flow conditions in a stream because concentrations are less affected by dilution. Nonpoint sources of nitrogen, phosphorus, and organic carbon are mainly delivered during runoff events as rainfall washes material off the landscape into the stream, resulting in greater concentrations during high-flow conditions. Some nonpoint sources of nutrients include runoff from agricultural areas, where fertilizers are applied or livestock production occurs; runoff from urban areas where fertilizers are applied to lawns, shrubs, and trees; and from atmospheric deposition of nitrogen. Natural sources of nitrogen and phosphorus include fixation of atmospheric nitrogen by plants and animals, dissolution of phosphorus-bearing rocks or minerals in the soil, and oxidation of organic matter, including soil organic matter and decaying plants and animals (Hem, 1989).

Instream processes also occur in the Middle Fork that can affect nutrient concentrations. Aquatic vegetation, particularly algae, depends on nitrogen and phosphorus for its food supply. Nitrate is the most stable ion of nitrogen over a wide range of conditions and is readily assimilated by algae. Orthophosphorus is the phosphorus species most readily available for use by aquatic plants. Total phosphorus concentrations include inorganic phosphorus (in solution, complexed with iron or other trace elements, or adsorbed to sediment particles) and organic phosphorus.

Sources of organic carbon in the water column can include those outside the aquatic system and within the aquatic system. Natural sources of organic carbon outside the aquatic system include soils and plants, and sources within the aquatic system include excretion from actively growing algae or the decomposition of dead algae and macrophytes. Anthropogenic (human influenced) sources of organic carbon include wastewater-treatment discharges, animal waste, and septic systems. Activities that cause land disturbance such as row-crop agriculture, animal grazing, timber harvesting, mining, road construction and maintenance, and urbanization also can result in increased stream concentrations of organic carbon.

Concentrations

Nitrogen concentrations were significantly greater ($p<0.05$) at MFS02 (Middle Fork near Owensville) compared to concentrations upstream at MFS06 (Brushy Creek near Jessieville) and MFS05 (Middle Fork below Jessieville) (fig. 1), for all of the samples collected from October 2003 to October 2006 (fig. 5). Median nitrite plus nitrate concentrations at MFS06 and MFS05 were 0.08 and 0.06 mg/L as nitrogen, respectively. MFS02 had a median nitrite plus nitrate concentration of 0.16 mg/L as nitrogen, about two times greater than the upstream sites. The median total ammonia plus organic nitrogen concentration at MFS02 was 0.24 mg/L as nitrogen; MFS06 and MFS05 both had median concentrations of 0.13 mg/L as nitrogen. The total nitrogen concentrations at MFS02 were significantly greater than the two upstream sites for all of the samples collected from October 2003 to October 2006 with a median concentration of 0.30 mg/L as nitrogen. The median concentrations at MFS06 and MFS05 were 0.20 and 0.16 mg/L as nitrogen, respectively.

Nitrogen concentrations in the Middle Fork Basin were significantly ($p<0.05$) greater in samples collected during high-flow conditions than in samples collected during base-flow conditions. Nitrite plus nitrate concentrations were significantly greater at the two upstream sites (MFS06 and MFS05) during high-flow conditions compared to base-flow conditions; however, concentrations collected at MFS02 did not vary significantly with flow conditions. Nitrite plus nitrate concentrations measured at MFS06, MFS05, and MFS02 during base-flow conditions had median concentrations of 0.06, 0.03, and 0.16 mg/L as nitrogen, respectively (fig. 5). During high-flow conditions, median concentrations for samples collected at the three sites were nearly three times greater than the median concentrations during base-flow conditions. Median total ammonia plus organic nitrogen concentrations measured during high-flow conditions also were nearly three times greater than concentrations measured during base-flow conditions at the three sites.

Synoptic data collected by ADEQ from January 2004 to October 2006 demonstrated that nitrogen concentrations generally were greatest in Mill Creek (site MFS04E) and in the Middle Fork immediately downstream from the confluence with Mill Creek (MFS04), with decreasing concentrations at sites farther downstream in the Middle Fork (figs. 6 and 7). The site in Mill Creek is located downstream from a wastewater-treatment plant discharge and had nitrite plus nitrate concentrations ranging from 10.3 mg/L as nitrogen in January 2004 to 27.6 mg/L in June 2005. Nitrite plus nitrate concentrations were substantially less at the site located in the Middle Fork immediately downstream from the confluence with Mill Creek (site MFS04B) ranging from 0.28 mg/L as nitrogen in January 2004 to 7.70 mg/L as nitrogen in September 2006 (fig. 6). Concentrations at sites farther downstream from the confluence probably had lesser concentrations because of dilution effects and from algal uptake. In January 2004, when high-flow conditions were present and little algal growth probably occurred, nitrite plus nitrate concentrations at sites located on the Middle Fork downstream from the confluence with Mill Creek were similar, ranging from 0.27 to 0.28 mg/L as nitrogen. Comparatively, in October 2005, when base-flow conditions were present and conditions were conducive for algal growth, concentrations decreased substantially in the Middle Fork from 3.61 mg/L as nitrogen at site MFS04B to 0.01 mg/L as nitrogen at site MFS01. Total ammonia plus organic nitrogen concentrations demonstrated different spatial patterns than the nitrite plus nitrate (fig. 7). Although the greatest concentrations generally were measured at site MFS04E in Mill Creek, sites located downstream in the Middle Fork did not vary substantially from those at MFS04E. Synoptic samples also were analyzed for dissolved ammonia, and most concentrations were below the laboratory reporting level of 0.03 mg/L as nitrogen, indicating that most of the total ammonia plus organic nitrogen was organic nitrogen. Organic nitrogen is not readily available for direct use by aquatic plants; therefore, the pattern of decreasing concentrations demonstrated by the nitrite plus nitrate, presumably by algal uptake, was not observed with the total ammonia plus organic nitrogen concentrations.

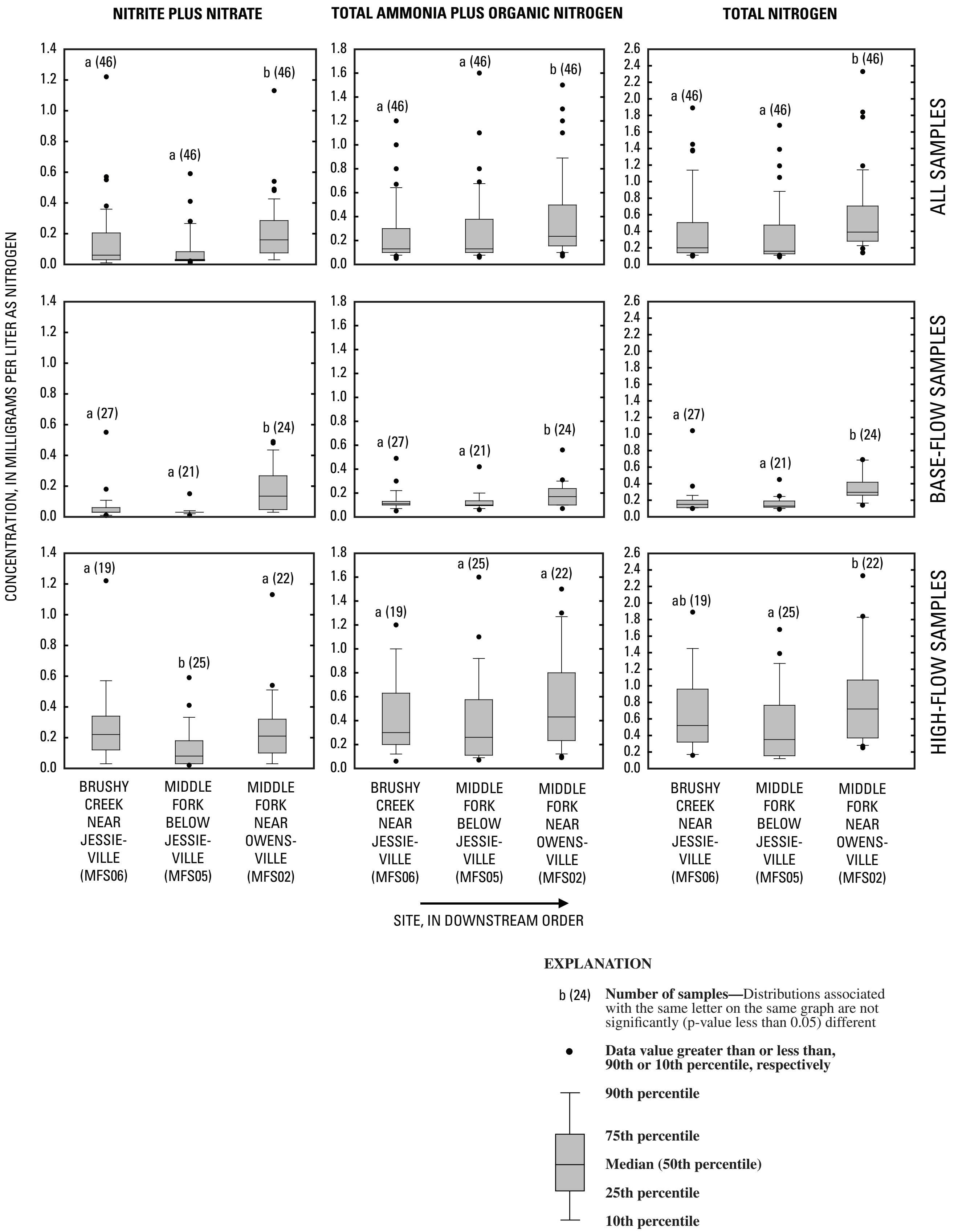

Figure 5. Distribution of nitrogen concentrations for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

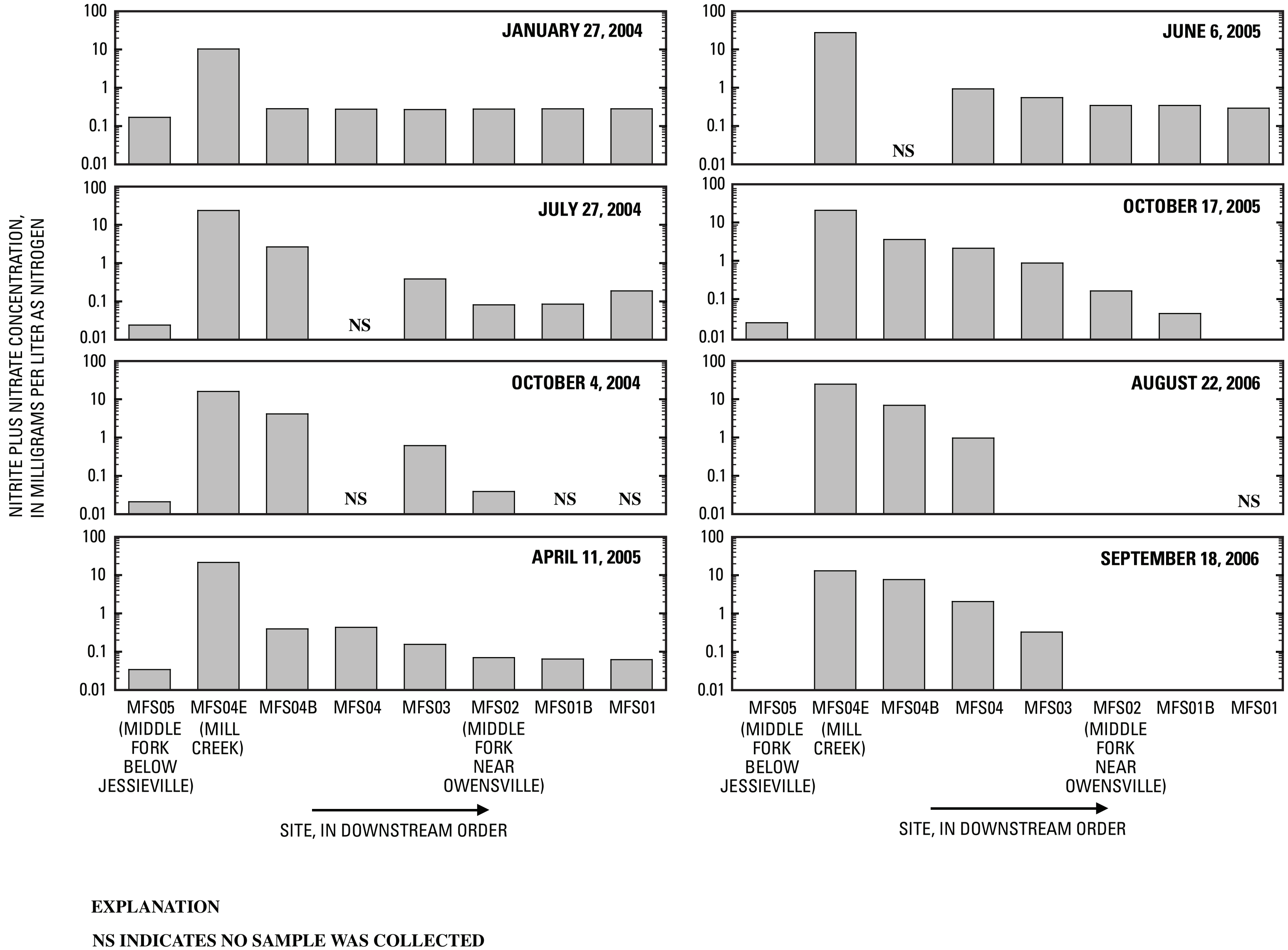

Figure 6. Spatial distribution of nitrite plus nitrate concentrations in the Middle Fork Basin, Arkansas, January 2004 to October 2006.

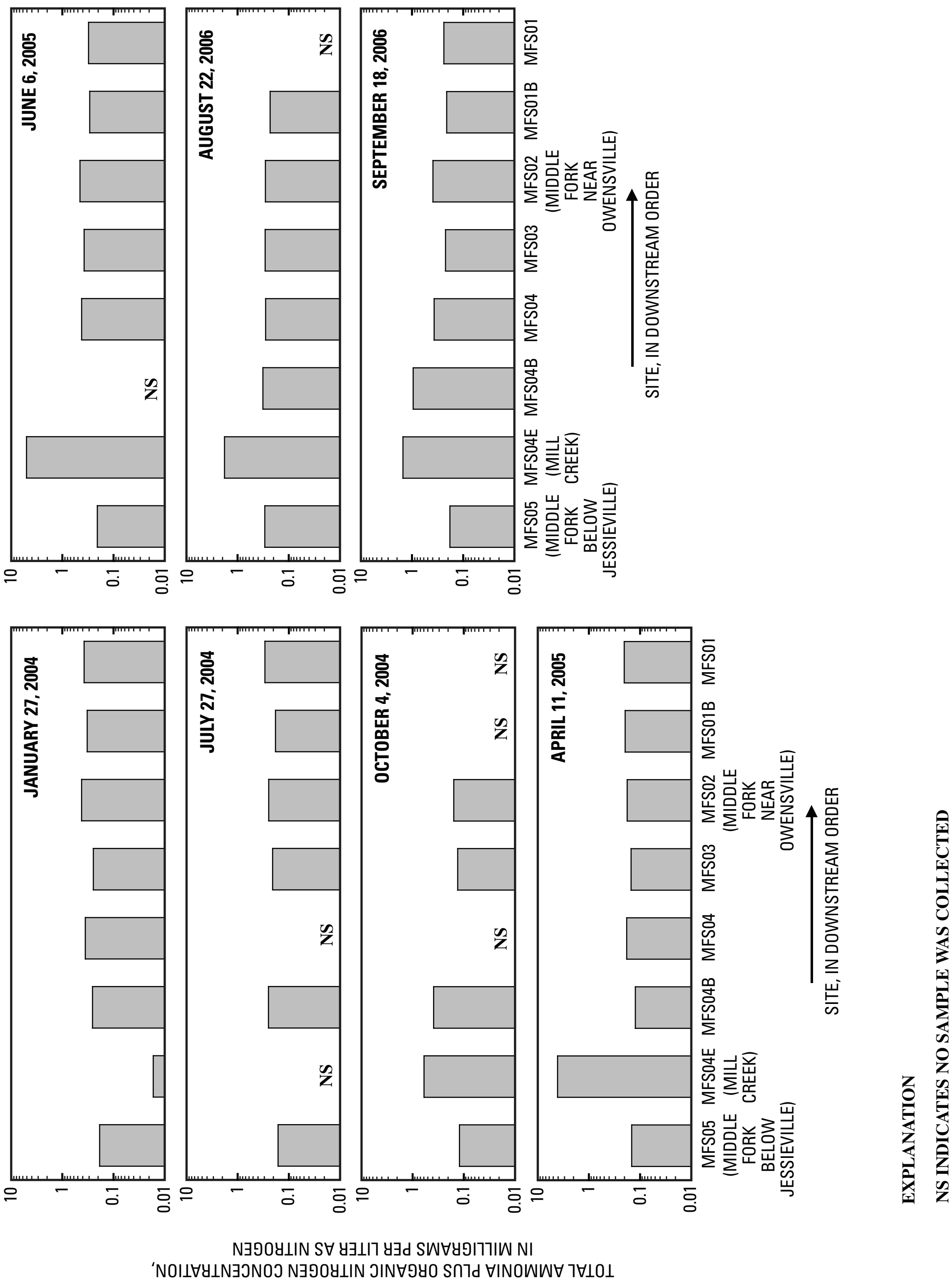

Figure 7. Spatial distribution of total ammonia plus organic nitrogen concentrations in the Middle Fork Basin, Arkansas, January 2004 to October 2006.

Phosphorus concentrations were significantly greater ($p<0.05$) at MFS02 (Middle Fork near Owensville) compared to concentrations at MFS06 (Brushy Creek near Jessieville) and MFS05 Middle Fork below Jessieville) for all samples collected from October 2003 to October 2006 (fig. 8). Although orthophosphorus concentrations were similar between MFS06 and MFS05 and significantly greater ($p<0.05$) at MFS02, the median concentrations for all three sites were 0.01 mg/L as phosphorus, which is the laboratory reporting level. Median total phosphorus concentrations for MFS06 and MFS05 were 0.02 mg/L as phosphorus and the median concentration for MFS02 was 0.05 mg/L as phosphorus.

Total phosphorus concentrations were significantly greater ($p<0.05$) in samples collected during high-flow conditions compared to samples collected during base-flow conditions at the three sites although orthophosphorus concentrations did not vary significantly with flow conditions at MFS06 and MFS02. Median total phosphorus concentrations for the samples collected at base-flow conditions for MFS06, MFS05, and MFS02 were 0.020, 0.020, and 0.035 mg/L as phosphorus, respectively (fig. 8). For samples collected during high-flow conditions, the median concentrations were 0.030, 0.020, and 0.070 mg/L as phosphorus, respectively.

Synoptic data collected by ADEQ demonstrated that phosphorus concentrations were generally greatest in Mill Creek (site MFS04E) and in the Middle Fork immediately downstream from the confluence with Mill Creek (MFS04) with decreasing concentrations at sites farther downstream in the Middle Fork (figs. 9 and 10). Site MFS04E had orthophosphorus concentrations ranging from 1.7 mg/L as phosphorus in January 2004 to 3.73 mg/L as phosphorus in June 2005. Total phosphorus concentrations ranged from 0.07 mg/L as phosphorus in April 2005 to 4.21 mg/L as phosphorus in June 2005. Similar to nitrogen, concentrations at sites farther downstream had lesser concentrations probably because of dilution effects and from algal uptake. In January 2004, when high-flow conditions were present and little algal growth probably occurred, orthophosphorus concentrations at sites located on the Middle Fork downstream from the confluence with Mill Creek were similar, ranging from 0.02 to 0.03 mg/L as phosphorus (fig. 9). Comparatively, in October 2005, when base-flow conditions were present and conditions were conducive for algal growth, concentrations decreased substantially in the Middle Fork from 0.45 mg/L as phosphorus at site MFS04B to 0.01 mg/L as phosphorus at site MFS01. Similar patterns were observed with total phosphorus concentrations (fig. 10).

Total organic carbon concentrations measured at MFS06 and MFS05 were similar to concentrations measured downstream at MFS02 from October 2003 to October 2006 (fig. 11). Median concentrations at MFS06 and MFS05 were 2.5 and 2.6 mg/L as carbon, respectively. The median concentration at MFS02 was 2.90 mg/L as carbon. Concentrations ranged from less than 1.0 to 25.1 mg/L as carbon at MFS06 and from less than 1.0 to 27.2 mg/L as carbon at MFS05. MFS02 had total organic carbon concentrations ranging from 1.3 to 24.0 mg/L as carbon.

Total organic carbon concentrations were significantly greater in samples collected during high-flow conditions compared to samples collected during base-flow conditions at all three sites. Median total organic carbon concentrations for samples collected during base-flow conditions for MFS06, MFS05, and MFS02 were 1.80, 2.00, and 2.45 mg/L as carbon, respectively (fig. 11). Median concentrations for samples collected during high-flow conditions were 6.30, 4.90, and 6.95 mg/L as carbon, respectively.

Synoptic samples indicated little variation in total organic carbon among sites along the Middle Fork (fig.12). The site in Mill Creek (site MFS04E) had the greatest concentrations, ranging from 4.34 to 6.11 mg/L as carbon. Sites downstream from Mill Creek had concentrations ranging from 0.82 to 4.70 mg/L as carbon.

Loads

Annual and monthly nutrient and organic carbon loads were estimated for MFS06 (Brushy Creek near Jessieville), MFS05 (Middle Fork below Jessieville), and MFS02 (Middle Fork near Owensville) for water years 2004-2006 (October 2003 to October 2006). Water-quality constituent concentrations and measured streamflow data were used to estimate loads.

MFS02 had the greatest annual nitrogen loads among the three sites for water years 2004-2006 (fig.13, table 5). The nitrogen loads at the MFS02 were greatest mainly because the estimated loads are related to the annual streamflow, and MFS02 had the greatest annual streamflow among the three sites, in addition to having the greatest concentrations. The mean annual nitrite plus nitrate load for the 3-year period for MFS02 was 30,300 kg/yr as nitrogen compared to MFS06 and MFS05 with mean annual loads of 8,030 and 6,280 kg/yr as nitrogen, respectively. The mean annual nitrite plus nitrate load at MFS02 was approximately 52 percent greater than the loads at MFS06 and MFS05 combined, indicating other substantial sources of nitrogen between the two upstream sites and MFS02. The mean annual total ammonia plus organic nitrogen loads were 6,910 kg/yr as nitrogen (MFS06), 12,100 kg/yr as nitrogen (MFS05), and 40,600 kg/yr as nitrogen (MFS02) and the total nitrogen loads were 16,700 kg/yr as nitrogen (MFS06), 21,800 kg/yr as nitrogen (MFS05), and 68,400 kg/yr as nitrogen (MFS02). The mean annual load of total ammonia plus organic nitrogen and total nitrogen at MFS02 were approximately 52 and 42 percent greater, respectively, than the loads estimated for MFS06 and MFS05 combined. MFS06 and MFS02 generally had the greatest estimated annual nitrogen loads in 2005 and MFS05 had the greatest loads in 2004 (fig. 13, table 5). Annual total nitrogen loads for MFS06 ranged from 14,200 (2006) to 21,600 kg/yr as nitrogen (2005) and from 14,700 (2005) to 29,400 kg/yr as nitrogen (2004) at MFS05. Annual total nitrogen loads for MFS02 ranged from 59,200 (2006) to 83,700 kg/yr as nitrogen (2005). The variation in annual loads is mainly because of the variation in streamflow. MFS06 and MFS02 had the greatest annual mean streamflow in 2005 and the least in 2006, while MFS05 had the greatest annual mean streamflow in 2004 and the least in 2006.

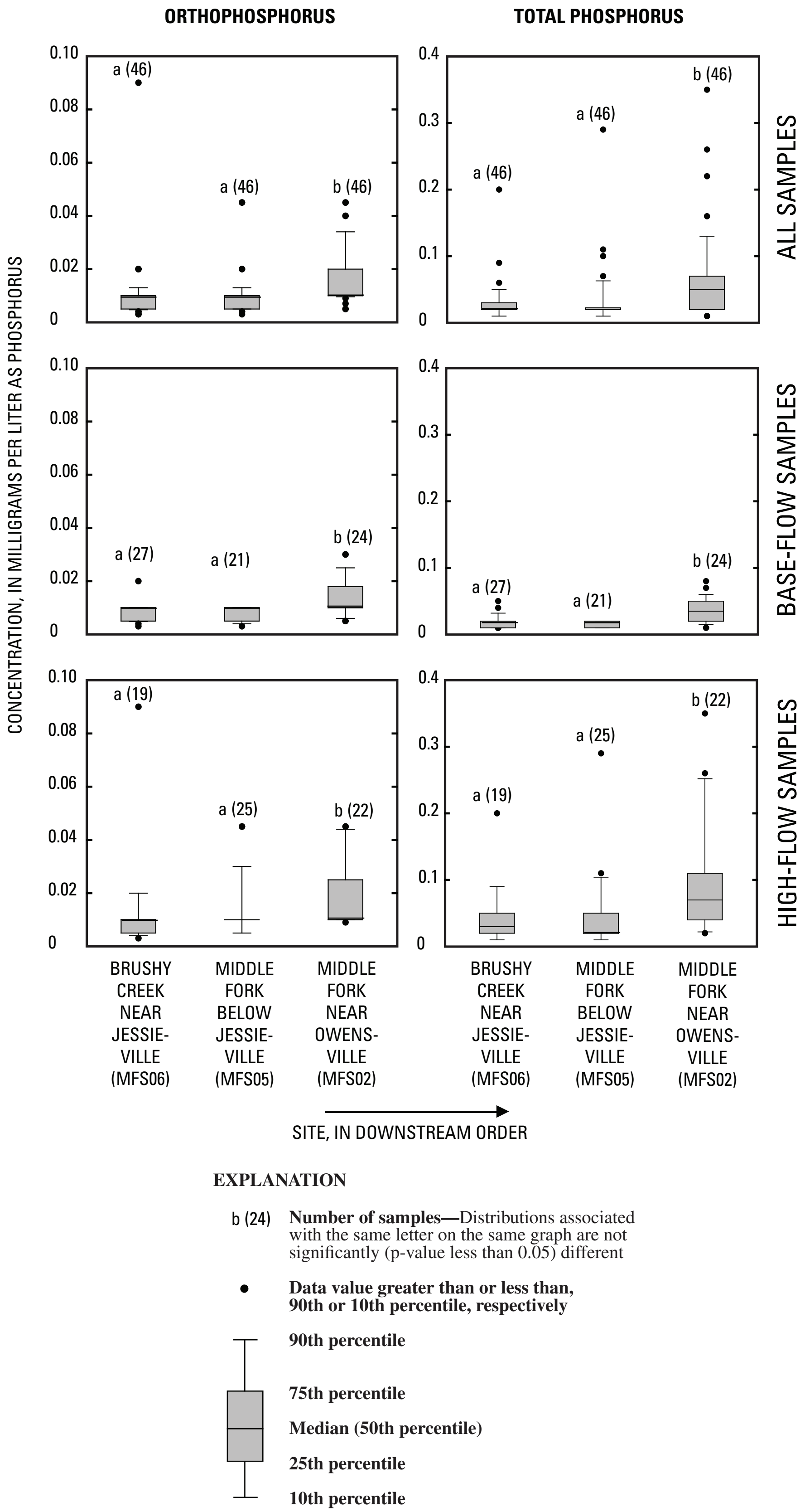

Figure 8. Distribution of phosphorus concentrations for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

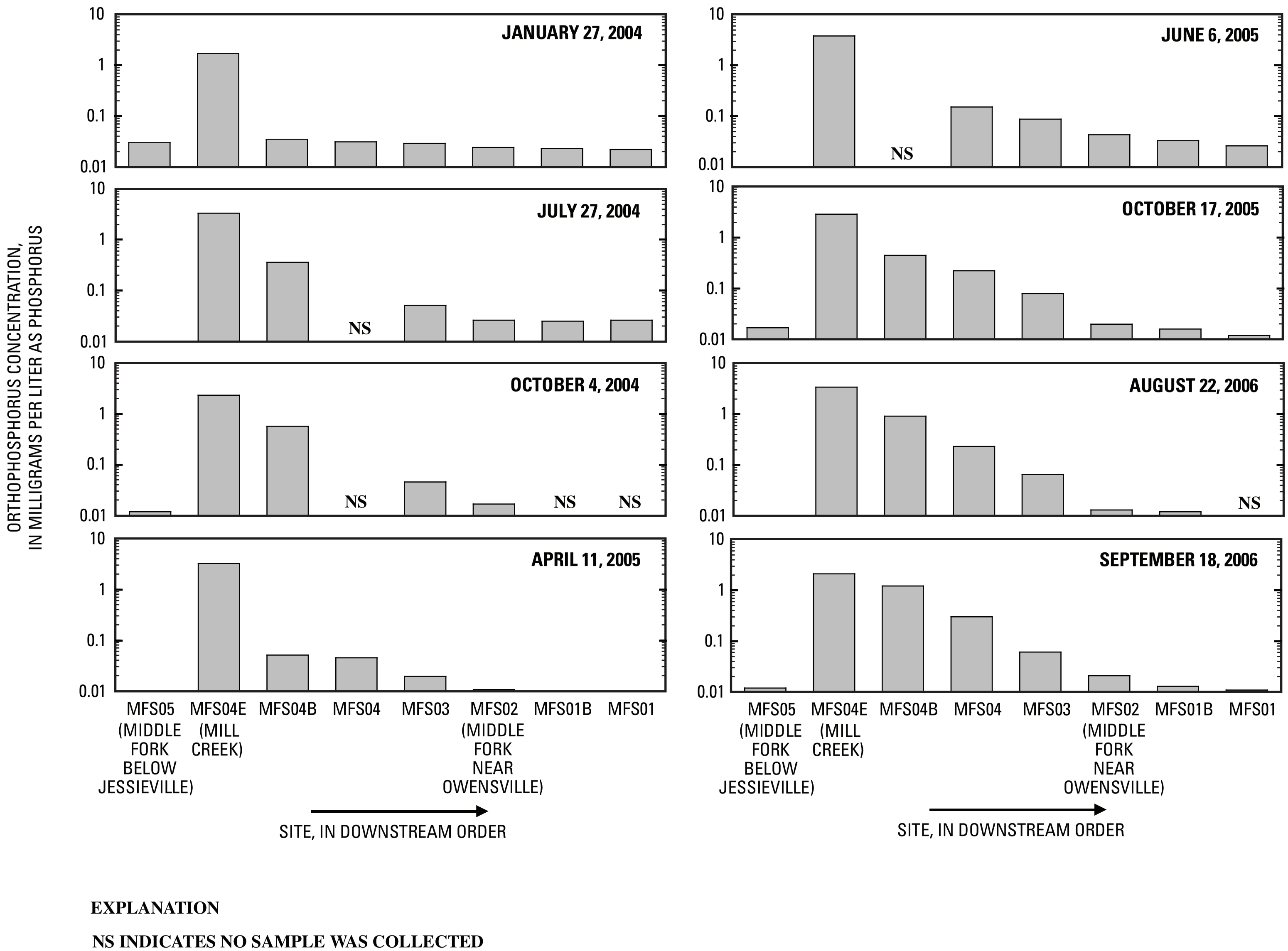

Figure 9. Spatial distribution of orthophosphorus concentrations in the Middle Fork Basin, Arkansas, January 2004 to October 2006.

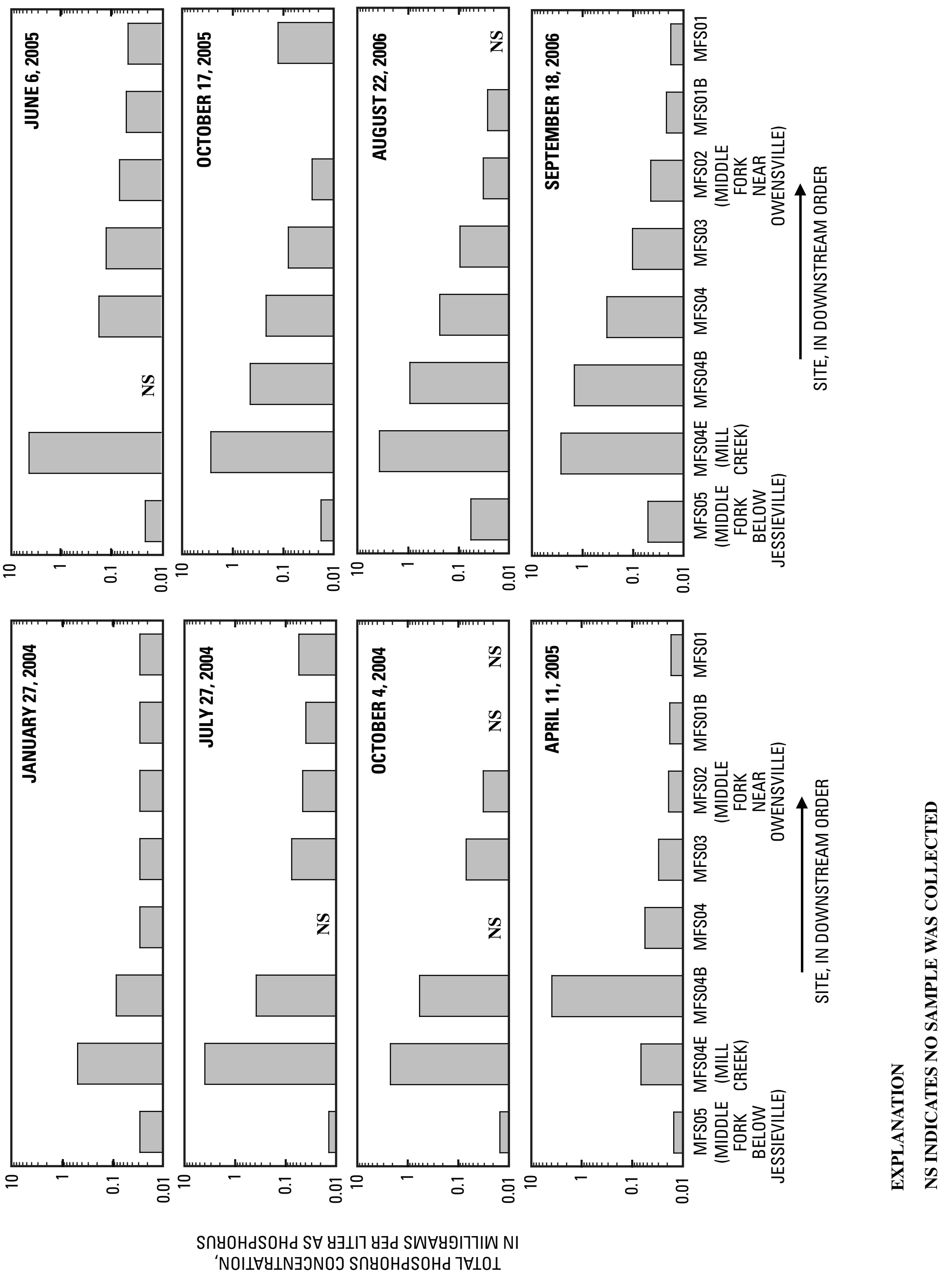

Figure 10. Spatial distribution of total phosphorus concentrations in the Middle Fork Basin, Arkansas, January 2004 to October 2006.

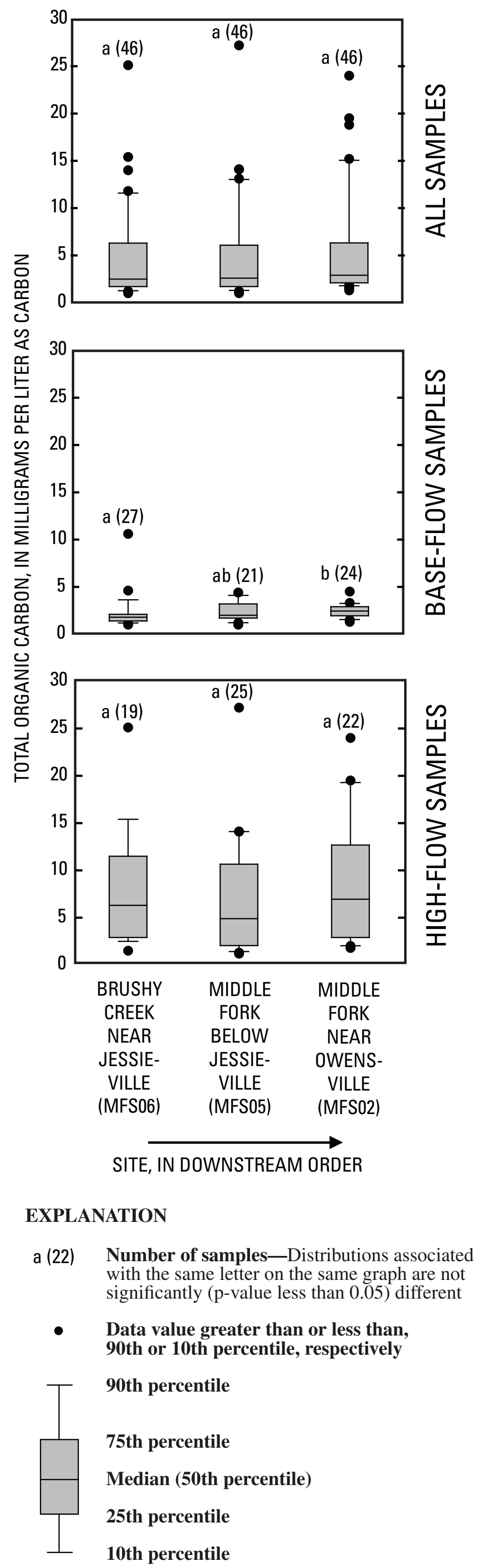

Figure 11. Distribution of total organic carbon concentrations for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

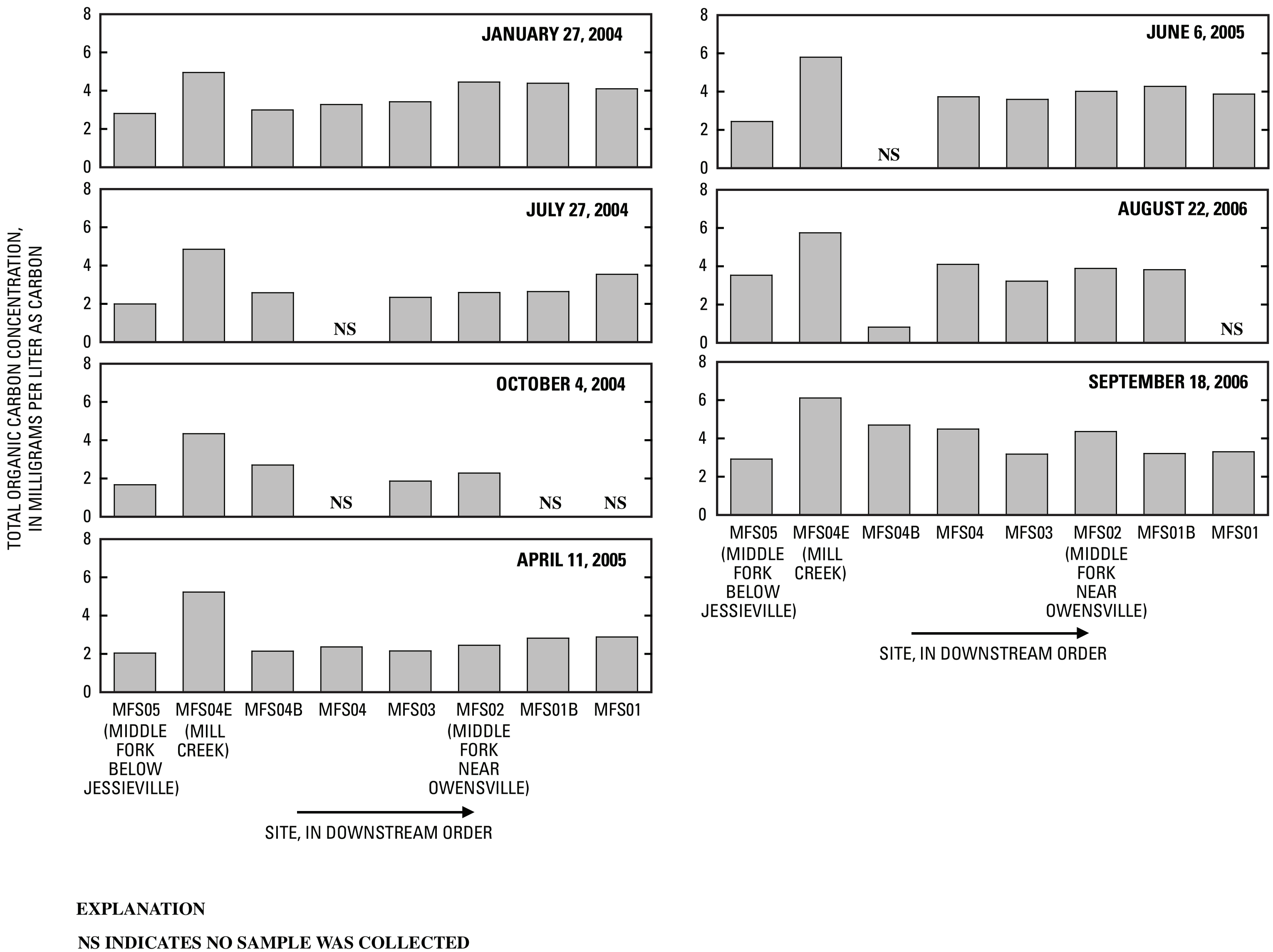

Figure 12. Spatial distribution of total organic carbon concentrations in the Middle Fork Basin, Arkansas, January 2004 to October 2006.

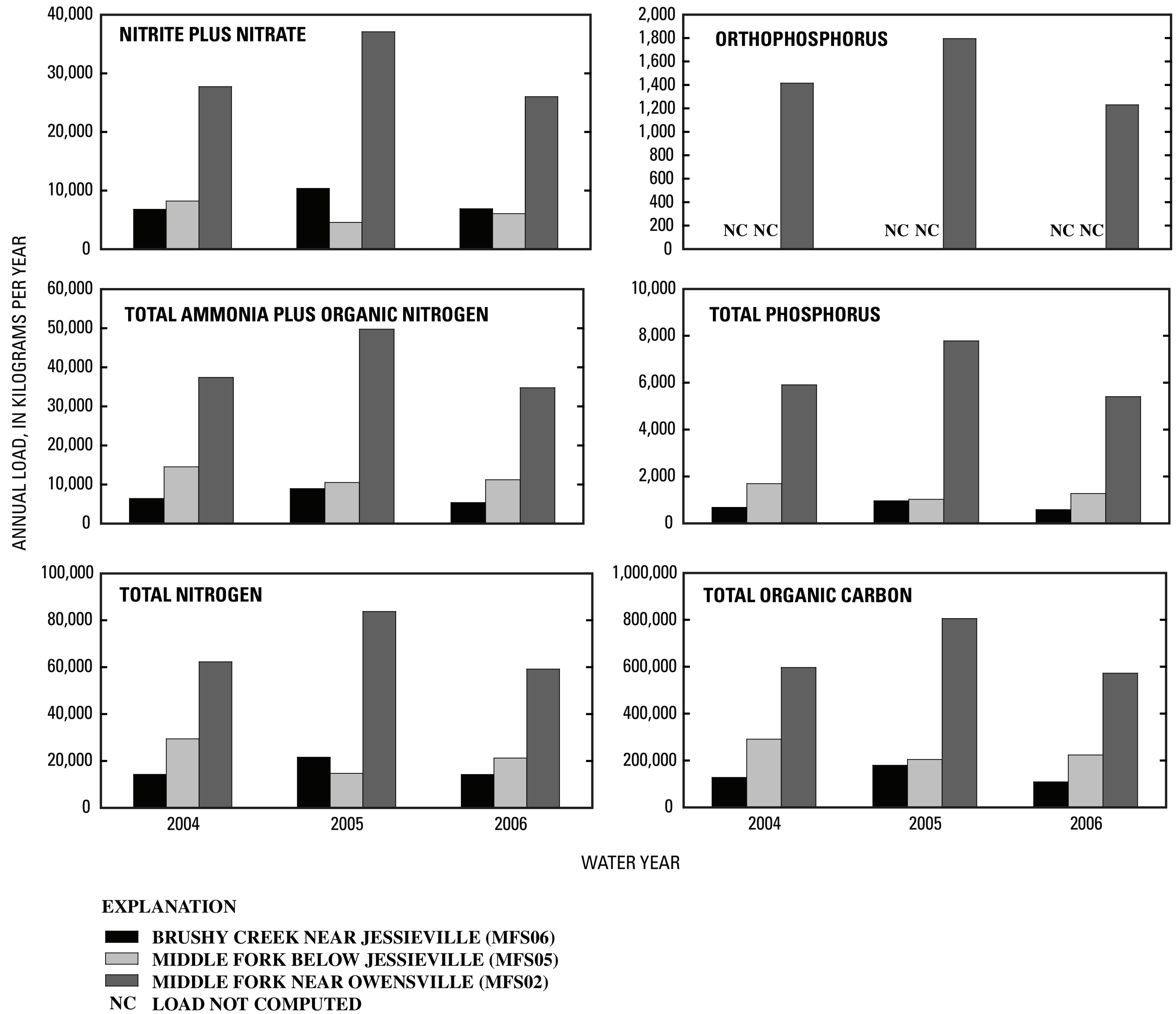

Figure 13. Annual loads of nutrients and total organic carbon for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

Table 5. Annual nitrogen, phosphorus, organic carbon, and suspended-sediment loads and yields for Brushy Creek near Jessieville, Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

[N, nitrogen, P, phosphorus; C, carbon; kg/yr, kilograms per year; kg/yr/km², kilograms per year per square kilometer; --, not calculated]

Site identification number	Site name	Water year	Nitrite plus nitrate as N		Total ammonia plus organic nitrogen as N		Total nitrogen as N		Orthophosphorus as P	
			Load, in kg/yr	Yield, in kg/yr/km²	Load, in kg/yr	Yield, in kg/yr/km²	Load, in kg/yr	Yield, in kg/yr/km²	Load, in kg/yr	Yield, in kg/yr/km²
07362656	Brushy Creek near Jessieville (MFS06)	2004	6,800	148	6,420	139	14,300	309	--	--
		2005	10,400	225	8,940	194	21,600	468	--	--
		2006	6,880	149	5,360	116	14,200	308	--	--
		Mean	8,030	174	6,910	150	16,700	362	--	--
		Median	6,880	149	6,420	139	14,300	309	--	--
07362641	Middle Fork below Jessieville (MFS05)	2004	8,220	105	14,500	185	29,400	376	--	--
		2005	4,560	58	10,500	135	14,700	188	--	--
		2006	6,060	78	11,200	143	21,200	272	--	--
		Mean	6,280	80	12,100	154	21,800	279	--	--
		Median	6,060	78	11,200	143	21,200	272	--	--
07362693	Middle Fork near Owensville (MFS02)	2004	27,700	114	37,400	154	62,300	256	1,420	6
		2005	37,100	152	49,700	205	83,700	344	1,800	7
		2006	26,000	107	34,800	143	59,200	243	1,230	5
		Mean	30,300	124	40,600	167	68,400	281	1,480	6
		Median	27,700	114	37,400	154	62,300	256	1,420	6

Table 5. Annual nitrogen, phosphorus, organic carbon, and suspended-sediment loads and yields for Brushy Creek near Jessieville, Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.—Continued

[N, nitrogen, P, phosphorus; C, carbon; kg/yr, kilograms per year; kg/yr/km^2, kilograms per year per square kilometer; --, not calculated]

Site identi-fication number	Site name	Water year	Total phosphorus as P		Total organic carbon as C		Suspended sediment		Total dissolved solids	
			Load, in kg/yr	Yield, in kg/yr/km^2	Load, in kg/yr	Yield, in kg/yr/km^2	Load, in kg/yr	Yield, in kg/yr/km^2	Load, in kg/yr	Yield, in kg/yr/km^2
07362656	Brushy Creek near Jessieville (MFS06)	2004	679	15	127,000	2,760	560,000	12,200	1,070,000	23,300
		2005	963	21	180,000	3,900	801,000	17,400	1,400,000	30,400
		2006	586	13	109,000	2,360	491,000	10,700	817,000	17,700
		Mean	743	16	139,000	3,010	617,000	13,400	1,100,000	23,800
		Median	679	15	127,000	2,760	560,000	12,200	1,070,000	23,300
07362641	Middle Fork below Jessieville (MFS05)	2004	1,690	22	291,000	3,720	2,250,000	28,800	2,760,000	35,300
		2005	1,030	13	204,000	2,610	1,480,000	19,000	2,520,000	32,300
		2006	1,270	16	224,000	2,860	1,720,000	22,000	2,150,000	27,500
		Mean	1,330	17	240,000	3,060	1,820,000	23,300	2,480,000	31,700
		Median	1,270	16	224,000	2,860	1,720,000	22,000	2,520,000	32,300
07362693	Middle Fork near Owensville (MFS02)	2004	5,910	24	597,000	2,450	5,080,000	20,900	6,370,000	26,200
		2005	7,780	32	806,000	3,310	7,060,000	29,000	7,780,000	32,000
		2006	5,400	22	573,000	2,350	5,300,000	21,800	5,380,000	22,100
		Mean	6,360	26	659,000	2,700	5,810,000	23,900	6,510,000	26,800
		Median	5,910	24	597,000	2,450	5,300,000	21,800	6,370,000	26,200

Estimated annual phosphorus loads were greatest at MFS02 compared to sites MFS06 and MFS05 (fig. 13). The mean annual total phosphorus loads at MFS02 was 6,360 kg/yr as phosphorus, almost 67 percent greater than the mean annual loads at MFS06 (743 kg/yr as phosphorus) and MFS05 (1,330 kg/yr as phosphorus) combined, indicating that most of the mass of total phosphorus transported past MFS02 is added downstream from sites MFS06 and MFS05. Orthophosphorus loads were not computed for MFS06 and MFS05 because more than 85 percent of the measured concentrations at the two sites were less than the laboratory reporting level. The mean annual orthophosphorus load at MFS02 was 1,480 kg/yr as phosphorus. Annual total phosphorus loads for MFS06 ranged from 586 (2006) to 963 kg/yr as phosphorus (2005) and from 1,030 (2005) to 1,690 kg/yr as phosphorus (2004) at MFS05. MFS02 had annual total phosphorus loads ranging from 5,400 (2006) to 7,780 kg/yr as phosphorus (2005).

Monthly nutrient loads indicated that most of the mass of nutrients that was transported past the three sites occurred in the spring (March, April, and May) and winter (December, January, and February) and the least amount of mass was transported in the summer (June, July, and August) (fig. 14, table 6). The mean daily total nitrogen loads ranged from 14 kg/d as nitrogen in August to 503 kg/d as nitrogen in March at MFS02. Mean daily total phosphorus loads ranged from 2 kg/d as phosphorus in August to 45 kg/d as phosphorus in March.

MFS02 had the greatest annual total organic carbon loads compared to the two upstream sites for water years 2004-2006 (fig. 13, table 5). The mean annual total organic carbon load for MFS02 was 659,000 kg/yr as carbon and the loads for MFS06 and MFS05 were 139,000 and 240,000 kg/yr as carbon, respectively.

The total organic carbon loads varied temporally for water years 2004-2006 (fig. 13). MFS02 and MFS06 had the greatest loads in 2005 and the least loads in 2006 and MFS05 had the greatest loads in 2004 and the least in 2005. Similar to the nutrient loads, the monthly total organic carbon loads demonstrated the greatest loads in the spring and winter and least loads in the summer (fig. 14, table 6).

Yields

Although MFS02 had the greatest nutrient loads among the three sites, MFS06 had the greatest annual nitrite plus nitrate and total nitrogen yields (fig. 15, table 5). The mean annual nitrite plus nitrate yield for water years 2004-2006 for MFS06 was 174 kg/yr/km^2 as nitrogen, while MFS05 and MFS02 had yields of 80 and 124 kg/yr/km^2 as nitrogen, respectively. The mean annual total nitrogen yield for MFS06 was 362 kg/yr/km^2, while MFS05 and MFS02 had yields of 279 and 281 kg/yr/km^2 as nitrogen, respectively. Similar to the annual loads, MFS02 had the greatest total ammonia plus organic nitrogen and total phosphorus yields compared to the two upstream sites.

MFS05 had the greatest mean annual total organic carbon yield and MFS02 had the least mean annual yield of total organic carbon for water years 2004-2006 (fig. 15, table 5). The mean annual total organic carbon yield at MFS06 was 3,010 kg/yr/km^2 as carbon. MFS05 and MFS02 had mean annual total organic carbon yields of 3,060 and 2,700 kg/yr/km^2 as carbon, respectively.

Flow-Weighted Concentrations

Flow-weighted concentrations were computed for the three sites to compare the water-quality conditions to other stream basins. Flow-weighted concentrations were compared to 82 relatively undeveloped sites identified across the Nation, including a site in Arkansas, the Cossatot River near Vandervoort (Clark and others, 2000). Flow-weighted concentrations also were compared to the Alum Fork of the Saline River near Reform, Arkansas, a site within the same river system as the Middle Fork that has a drainage basin composed of approximately 99 percent forested land (Galloway and Green, 2004), and to the Illinois River south of Siloam Springs, Arkansas, a site that is influenced by numerous point source discharges, and urban and agricultural land use.

Annual flow-weighted nutrient concentrations for MFS06, MFS05, and MFS02 were greater than relatively undeveloped sites, but were substantially less than the Illinois River south of Siloam Springs, Arkansas, a site influenced by numerous point and nonpoint sources of nutrients (fig. 16). The mean annual flow-weighted nitrite plus nitrate concentrations for MFS06 (0.36 mg/L as nitrogen) and MFS02 (0.32 mg/L as nitrogen) were more than two times greater than relatively undeveloped sites across the Nation, and the mean concentration for MFS05 (0.18 mg/L as nitrogen) was similar. The flow-weighted nitrite plus nitrate concentration for the Illinois River south of Siloam Springs was more than six times greater than the concentration for MFS06 and MFS02 and more than 12 times greater than the flow-weighted concentration for MFS05. The mean flow-weighted total nitrogen concentrations for each of the three sites were nearly two times greater than relatively undeveloped sites across the Nation. The flow-weighted concentration for the Illinois River south of Siloam Springs was approximately four times greater than concentrations at the three sites. Flow-weighted orthophosphorus concentrations were not calculated for MFS06 and MFS05 because most of the measured concentrations were less than the laboratory reporting level (0.01 mg/L as phosphorus). The mean flow-weighted concentration for MFS02 (0.016 mg/L as phosphorus) was similar to relatively undeveloped sites across the Nation and was more than an order of magnitude less than the flow-weighted orthophosphorus concentration for the Illinois River south of Siloam Springs. For total phosphorus, the mean flow-weighted concentrations for MFS06 (0.033 mg/L as phosphorus) and MFS05 (0.038 mg/L as phosphorus) were similar to concentrations for relatively undeveloped sites across the Nation (0.035 mg/L as phosphorus). MFS02 had a mean flow-weighted total phosphorus concentration that was

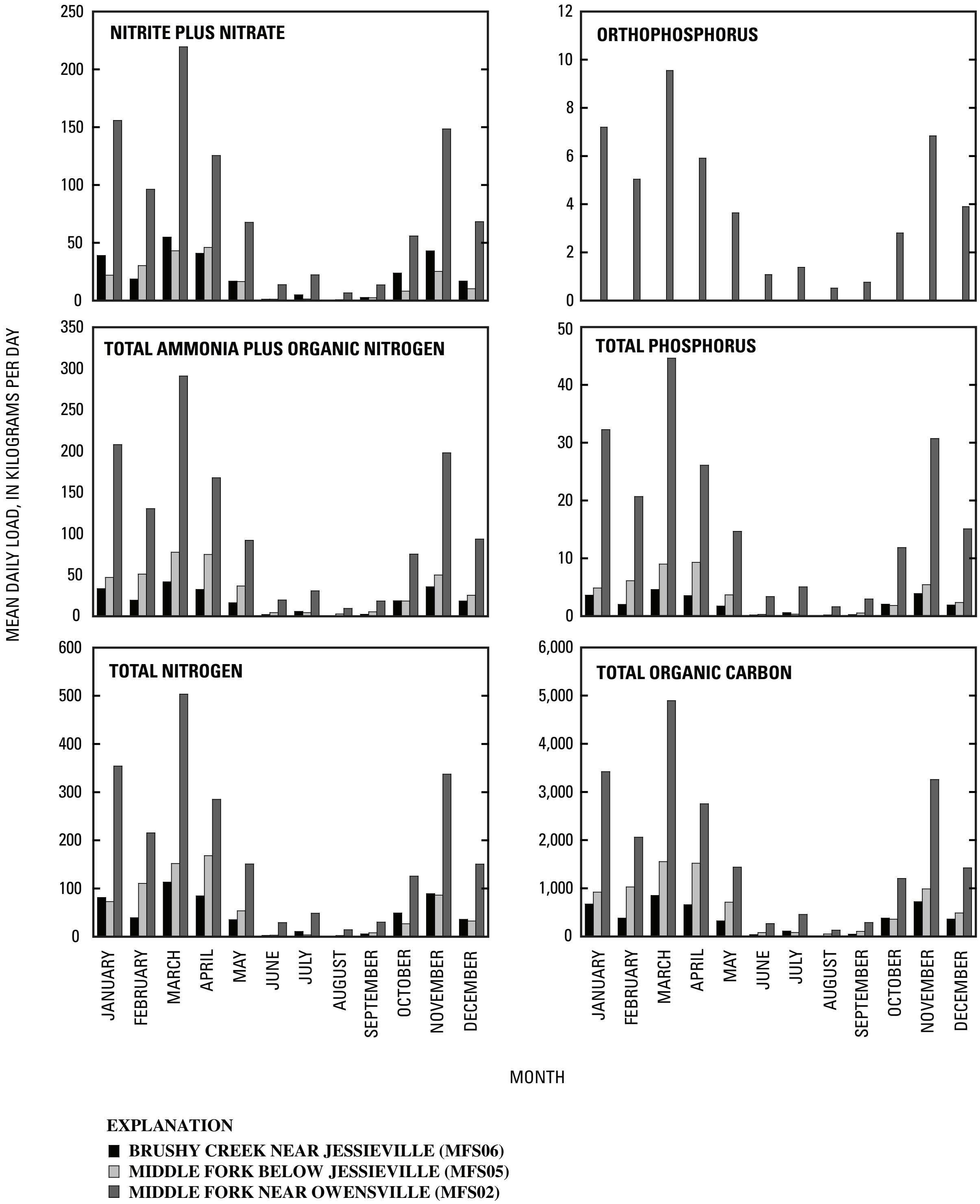

Figure 14. Monthly loads of nutrients and total organic carbon for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

Table 6. Monthly nitrogen, phosphorus, organic carbon, and supended-sediment loads for Brushy Creek near Jessieville, Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

[N, nitrogen; P, phosphorus; C, carbon; <, less than; --, not calculated]

Site identification number	Site name	Month	Mean daily load, in kilograms per day							
			Nitrite plus nitrate as N	Total ammonia plus organic nitrogen as N	Total nitrogen as N	Orthophosphorus as P	Total phosphorus as P	Total organic carbon as C	Suspended sediment	Total dissolved solids
07362656	Brushy Creek near Jessieville (MFS06)	October	24	19	49	--	2	381	1,720	2,820
		November	43	36	89	--	4	722	3,240	5,440
		December	17	18	36	--	2	360	1,550	3,290
		January	39	33	81	--	4	672	3,000	5,200
		February	19	19	39	--	2	379	1,640	3,450
		March	55	42	113	--	5	850	3,860	6,110
		April	41	32	85	--	4	658	2,960	4,930
		May	17	16	35	--	2	323	1,420	2,750
		June	1	2	3	--	<1	37	149	463
		July	5	6	11	--	1	112	480	1,071
		August	<1	<1	<1	--	<1	7	28	126
		September	3	2	6	--	<1	47	210	367
07362641	Middle Fork below Jessieville (MFS05)	October	8	18	27	--	2	358	2,620	4,560
		November	25	50	86	--	5	987	7,480	9,660
		December	10	25	32	--	2	489	3,480	6,990
		January	22	47	73	--	5	921	6,840	9,990
		February	30	51	110	--	6	1,030	8,030	9,600
		March	43	78	152	--	9	1,550	12,000	13,400
		April	46	75	168	--	9	1,520	12,000	11,700
		May	16	37	54	--	4	713	5,240	8,290
		June	1	4	3	--	<1	80	504	2,320
		July	1	4	4	--	<1	82	539	1,990
		August	1	3	2	--	<1	51	331	1,420
		September	2	5	8	--	1	106	772	1,620
07362693	Middle Fork near Owensville (MFS02)	October	56	75	126	3	12	1,200	10,200	12,500
		November	148	198	337	7	31	3,260	29,500	28,700
		December	68	94	151	4	15	1,420	10,700	18,500
		January	156	208	354	7	32	3,420	31,100	30,300
		February	96	130	215	5	21	2,060	17,200	22,900
		March	219	291	503	10	45	4,900	47,200	38,900
		April	125	168	285	6	26	2,750	25,100	25,400
		May	68	92	151	4	15	1,440	11,700	16,857
		June	14	20	29	1	3	269	1,530	6,120
		July	22	31	49	1	5	458	3,230	6,940
		August	7	10	14	1	2	132	798	3,010

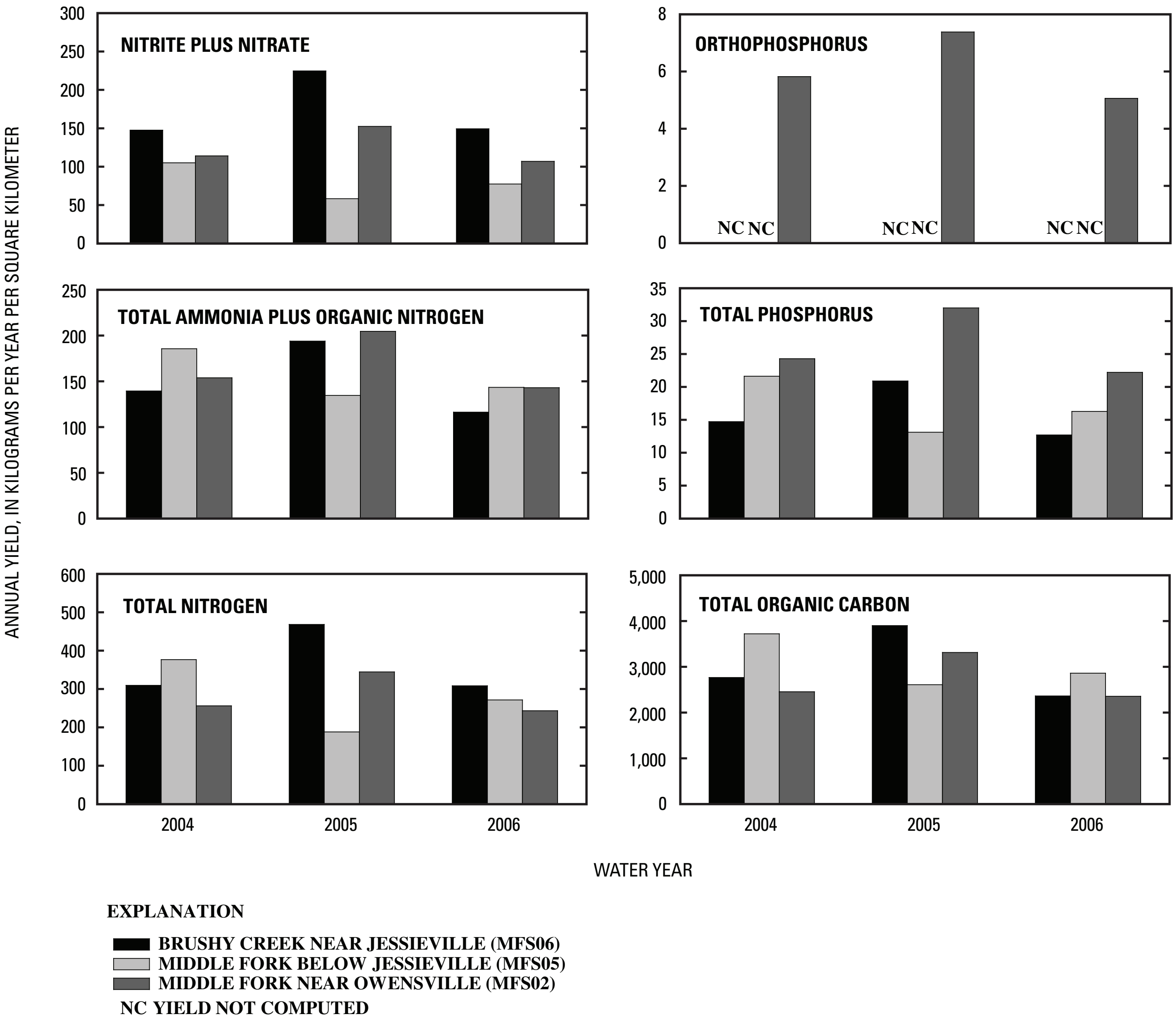

Figure 15. Annual yields of nutrients and total organic carbon for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

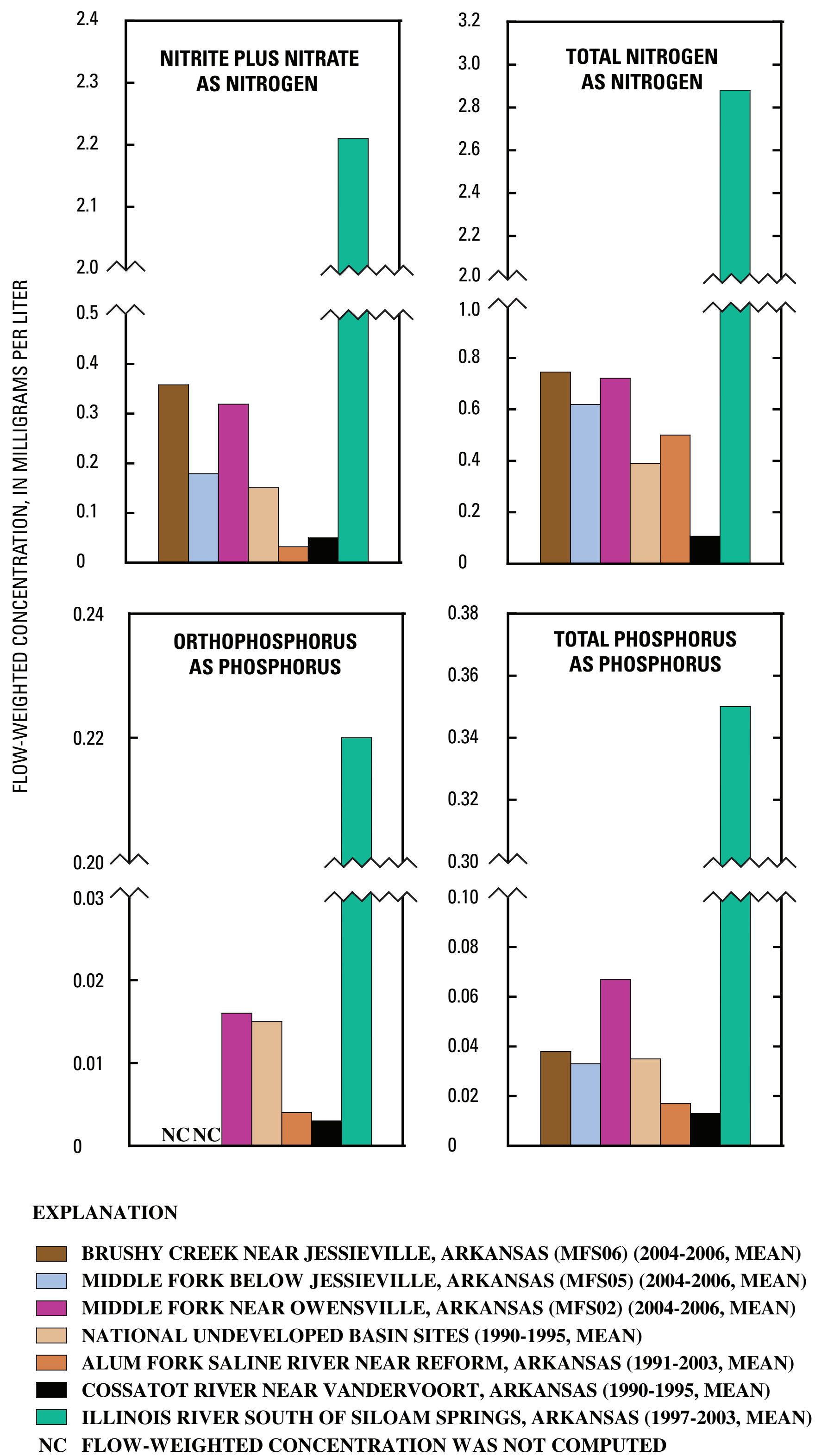

Figure 16. Mean annual flow-weighted concentrations of nutrients and total organic carbon for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

almost two times greater than concentrations for the other two sites in the Middle Fork Basin and relatively undeveloped sites across the Nation. The mean flow-weighted total phosphorus concentration for the Illinois River south of Siloam Springs was about 10 times greater than the concentrations at MFS06 and MFS05 and about five times greater than the concentrations at MFS02.

Fecal Indicator Bacteria

Fecal indicator bacteria are measures of the sanitary quality of water. Indicator bacteria are not typically disease-causing but are correlated to the presence of water-borne pathogens. Sources of fecal indicator bacteria include undisinfected wastewater-treatment discharges; combined-sewer overflows; septic systems; animal wastes from feedlots, barnyards, and pastures; manure application areas; and stormwater. The indicator bacteria measured at three Middle Fork sites (MFS06, MFS05, and MFS02) included fecal coliforms and *Escherichia coli* (*E. coli*), which are restricted to the intestinal tracts of warm-blooded animals. *E. coli* is strictly an inhabitant of the gastrointestinal tract of warm-blooded animals and its presence in water is direct evidence of fecal contamination from warm-blooded animals and the possible presence of pathogens (Durfour, 1977). The fecal coliform indicator bacteria test is not as specific for fecal coliform bacteria and can test positive for soil bacteria as well.

Overall, *E. coli* concentrations were slightly greater at MFS05 (Middle Fork below Jessieville) compared to concentrations at MFS06 and MFS02 (Brushy Creek and the Middle Fork near Owensville) for October 2003 to October 2006 (fig. 17). MFS05 had a maximum *E. coli* concentration of 21,000 colonies per 100 milliliters (col/100 mL) and a median concentration of 150 col/100 mL. In comparison, MFS06 had maximum and median *E. coli* concentrations of 9,300 and 130 col/100 mL, respectively, and MFS02 had maximum and median concentrations of 14,000 and 60 col/100 mL, respectively.

E. coli concentrations were significantly greater ($p<0.05$) for samples collected during high-flow conditions compared to samples collected during base-flow conditions at all three sites, although the highest concentrations at the two upstream sites were measured during base-flow condition. For MFS06, *E. coli* concentrations measured during base-flow conditions ranged from 5 col/100 mL to 9,300 col/100 mL with a median of 27 col/100 mL (fig. 17). In samples collected during high-flow conditions, *E. coli* ranged from 8 to 4,300 col/100 mL with a median of 220 col/100 mL. MFS05 had *E. coli* concentrations ranging from 10 to 21,000 col/100 mL with a median of 56 col/100 mL during base-flow conditions, and concentrations ranging from 8 to 7,200 col/100 mL with a median of 360 col/100 mL during high-flow conditions. *E. coli* concentrations measured at MFS02 ranged from 8 to 180 col/100 mL with a median of 42 col/100 mL in samples collected during base-flow conditions and ranged from 20 and 14,000 col/100 mL with a median concentration of 1,040 col/100 mL in samples collected during high-flow conditions.

Generally, MFS06 (Brushy Creek) had the greatest fecal coliform concentrations compared to concentrations at MFS05 and MFS02 (Middle Fork below Jessieville and the Middle Fork near Owensville) for October 2003 to October 2006 (fig. 17). MFS06 had a maximum fecal coliform concentration of 30,000 col/100 mL and a median concentration of 106 col/100 mL. MFS05 had maximum and median concentrations of 16,000 and 100 col/100 mL, respectively, and MFS02 had maximum and median concentrations of 6,600 and 56 col/100 mL, respectively.

Fecal coliform bacteria followed similar patterns as *E. coli* bacteria with significantly ($p<0.05$) greater concentrations in samples collected during high-flow conditions compared to concentrations in samples collected during base-flow conditions. Median fecal coliform concentrations for MFS06, MFS05 and MFS02 were 58, 62, and 45 col/100 mL, respectively, in samples collected during base-flow conditions and had median concentrations of 330, 190, and 390 col/100 mL, respectively, during high-flow conditions (fig. 17). The maximum concentrations for MFS06 and MFS05 were 30,000 and 16,000 col/100 mL, respectively, for samples collected during base-flow conditions and 5,100 and 7,900 col/100 mL, respectively, for samples collected during high-flow conditions. MFS02 had maximum fecal coliform concentrations of 270 col/100 mL in samples collected during base-flow conditions and 6,600 col/100 mL in samples collected during high-flow conditions.

The differences in fecal indicator bacteria among the three sites probably were related to activities that occur upstream from the three sites. The drainage basin upstream from MFS05, which had the greatest fecal indicator bacteria concentrations, contains a greater percentage of agricultural land use, mainly pasture located adjacent to the stream channel, than the drainage that contributes streamflow to Brushy Creek (MFS06). Although the drainage basin contributing streamflow to MFS02 had the same percentage of agricultural land use as the drainage basin upstream from MFS05 and more urban land use, it had the lowest concentrations among the three sites. The lower concentrations may be because most of the pasture land is located farther upstream from the site, with no substantial occurrence immediately adjacent to the stream near the site. Also, livestock may have less access to the stream near MFS02 compared to MFS06.

Suspended Sediment and Total Suspended Solids

Suspended sediment in water is the particulate matter that consists of soil and rock particles eroded from the landscape. Sediment can be transported in the water column or can settle to the streambed. The movement of suspended sediment in streams is important in the fate and transport of chemicals in the environment because the particles can sorb nutrients, trace

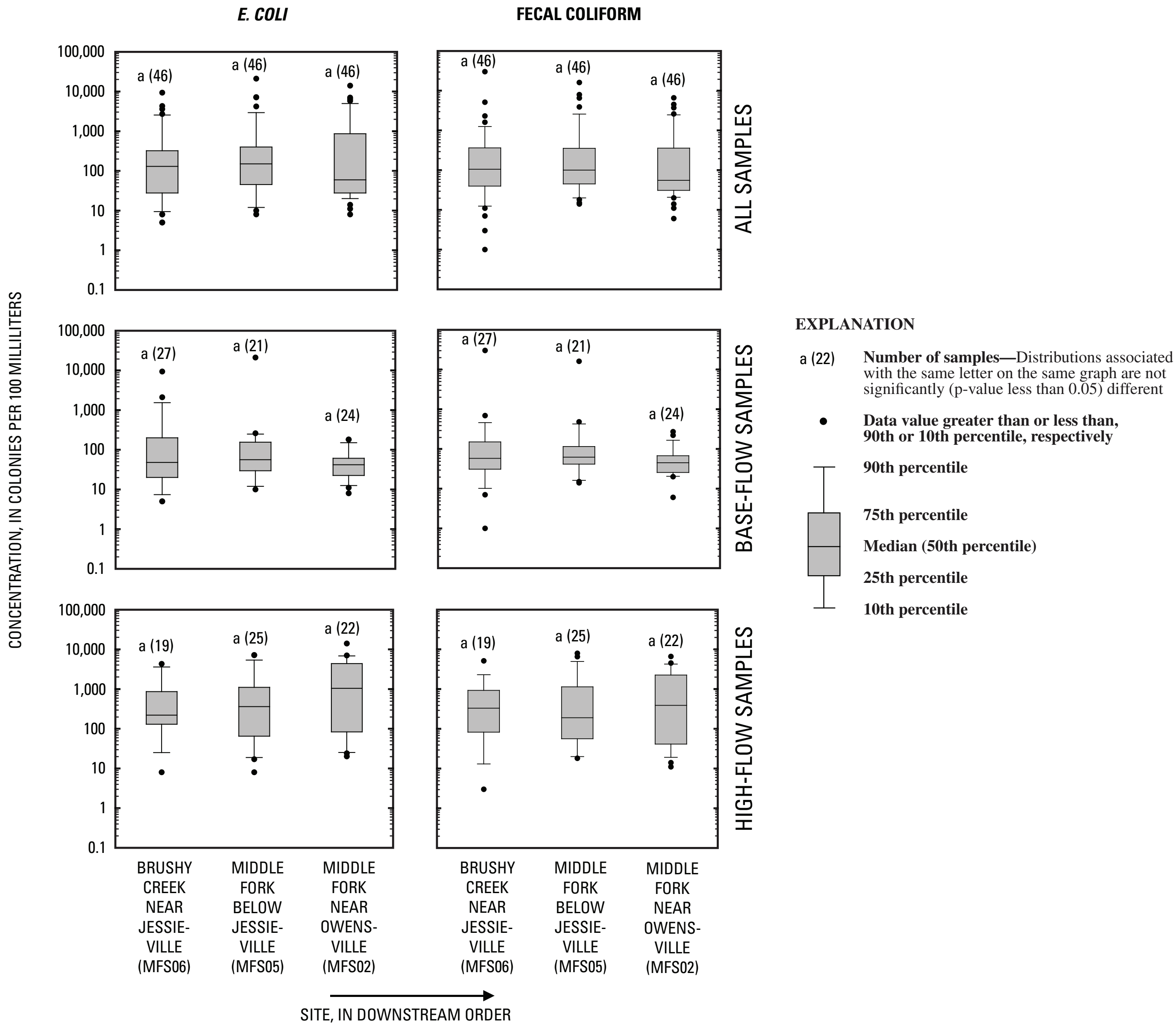

Figure 17. Distribution of fecal indicator bacteria for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

elements, and organic compounds. Fecal bacteria also can be associated with suspended sediment (Schillinger and Gannon, 1985). Large concentrations of suspended sediment often are associated with storm-runoff events that increase streamflow, erosion, and resuspension of bed material. Activities such as row-crop agriculture, animal grazing, timber harvesting, mining, road construction and maintenance, and urbanization can cause increased SSC in streams.

Synoptic samples collected by ADEQ were not analyzed for SSC, but were analyzed for TSS. Although TSS concentrations are not always directly comparable to SSC because of analytical differences (Gray and others, 2000), the data commonly follow similar patterns.

Concentrations

SSC did not vary significantly among MFS06 (Brushy Creek near Jessieville), MFS05 (Middle fork below Jessieville), and MFS02 (Middle Fork near Owensville) for all the samples collected from October 2003 to October 2006 (fig. 18). Median SSCs were 13, 20, and 20 mg/L for MFS06, MFS05, and MFS02, respectively. Maximum SSCs were 191, 355, and 309 mg/L for MFS06, MFS05, and MFS02, respectively.

SSCs were significantly greater ($p<0.05$) in samples collected during high-flow conditions compared to samples collected during base-flow conditions. Samples collected at base-flow conditions at MFS06, MFS05, and MFS02 had median concentrations of 11, 18, and 16 mg/L, respectively (fig. 18). The median concentrations at MFS06, MFS05, and MFS02 for samples collected during high-flow conditions were 17, 23, and 34 mg/L, respectively.

Synoptic samples indicated TSS distributions varied from upstream to downstream in the Middle Fork between January 2004 and October 2006 (fig. 19). In October 2004 and April 2005, TSS values did not vary more than 2.0 mg/L among the eight sites, although some of the sites did not have data in October 2004 (sites MFS04, MFS01B, and MFS01). In January 2004, TSS was the least at sites MFS05 and MFS04B with steadily increasing values at sites downstream. The greatest TSS values were observed in June 2005 during relatively high-flow conditions. TSS values were the greatest at MFS02 and decreased at sites upstream and downstream. Site MFS01, the most downstream site, had the greatest TSS in July 2004 compared to the other sites. MFS01 also had the greatest TSS in October 2005 (11.5 mg/L) compared to the other sites, which had TSS values less than 2.5 mg/L. In August 2006, the greatest TSS was measured at site MFS04B (5.0 mg/L) compared to TSS values less than 1.0 mg/L at the other sites. MFS02 had the greatest TSS values in September 2006. The varied distributions in the Middle Fork may be explained by the different flow conditions that occurred at the time the samples were collected and by activities immediately upstream from the various sites that showed greater TSS values. For example, road construction, or other activity that disturbs the land surface immediately upstream from a site could cause an

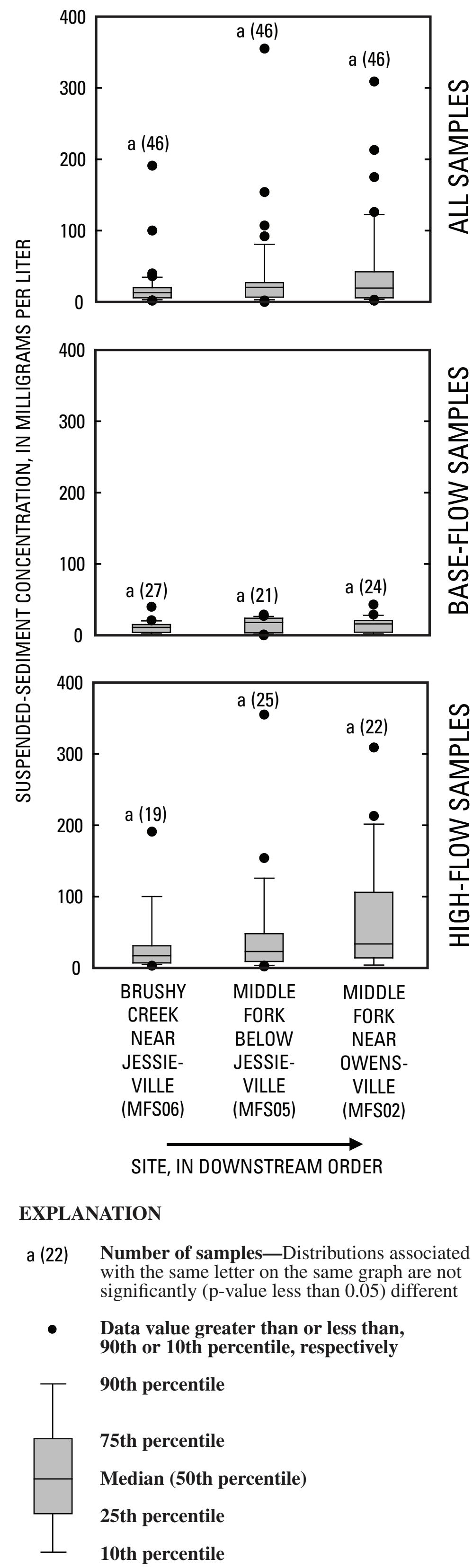

Figure 18. Distribution of suspended sediment for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

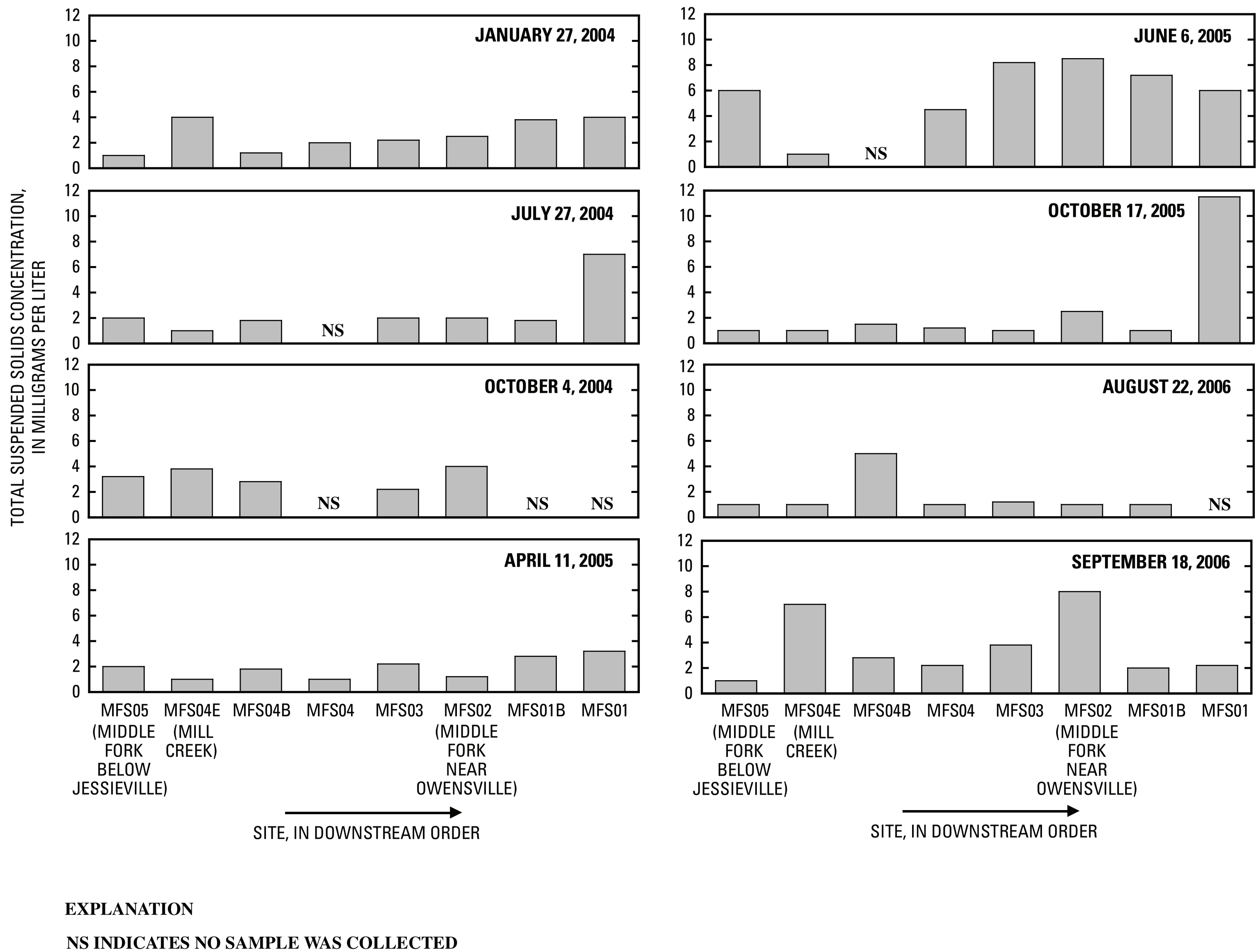

Figure 19. Spatial distribution of total suspended solids in the Middle Fork Basin, Arkansas, January 2004 to October 2006.

increase in TSS in the stream following a runoff event. Also, resuspension of sediment from activities in the stream, such as livestock crossing the stream, could cause greater TSS values at sites immediately downstream. Different flow conditions could cause varying TSS because of different velocity distributions. As velocities increase at some sites, resuspension of sediment into the water column could occur, and at other sites decreased velocities could occur causing the transported sediment to settle out of the water column onto the streambed. Another explanation is that TSS is composed of both inorganic and organic material, and if an increased amount of algal growth and mortality were to occur at a site, the TSS values could be greater than at sites that did not have as much algal growth and mortality, which would probably be more evident in samples collected at base-flow conditions. In addition, variability in TSS data could also be attributed to the sampling method. TSS data were collected by ADEQ at a single point in the stream. If the stream was not well mixed, the TSS concentrations could vary depending on where in the stream cross section the sample was collected and may not represent the water-quality conditions of the entire cross section of the stream.

Loads

MFS02 had the greatest annual suspended-sediment loads and MFS06 had the least suspended-sediment loads, mainly because the annual mean streamflow was greatest at MFS02 and the least at MFS06 (fig. 20, table 5). The mean estimated annual suspended-sediment load was 5,810,000 kg/yr for MFS02 and 617,000 and 1,820,000 kg/yr for MFS06 and MFS05, respectively. The greatest loads occurred in 2005 at MFS06 and MFS02 and in 2004 at MFS05. The least loads occurred in 2006 at MFS06, in 2005 at MFS05, and in 2004 at MFS02.

Monthly loads showed that the greatest transport occurred in the spring and winter and the least in the summer months (fig. 20, table 6). MFS05 had monthly suspended-sediment loads ranging from 331 kg/d in August to 12,000 kg/d in March and April. Monthly loads ranged from 28 kg/d in August to 3,860 kg/d in March at MFS06, and from 798 kg/d in August to 47,200 kg/d in March for MFS02.

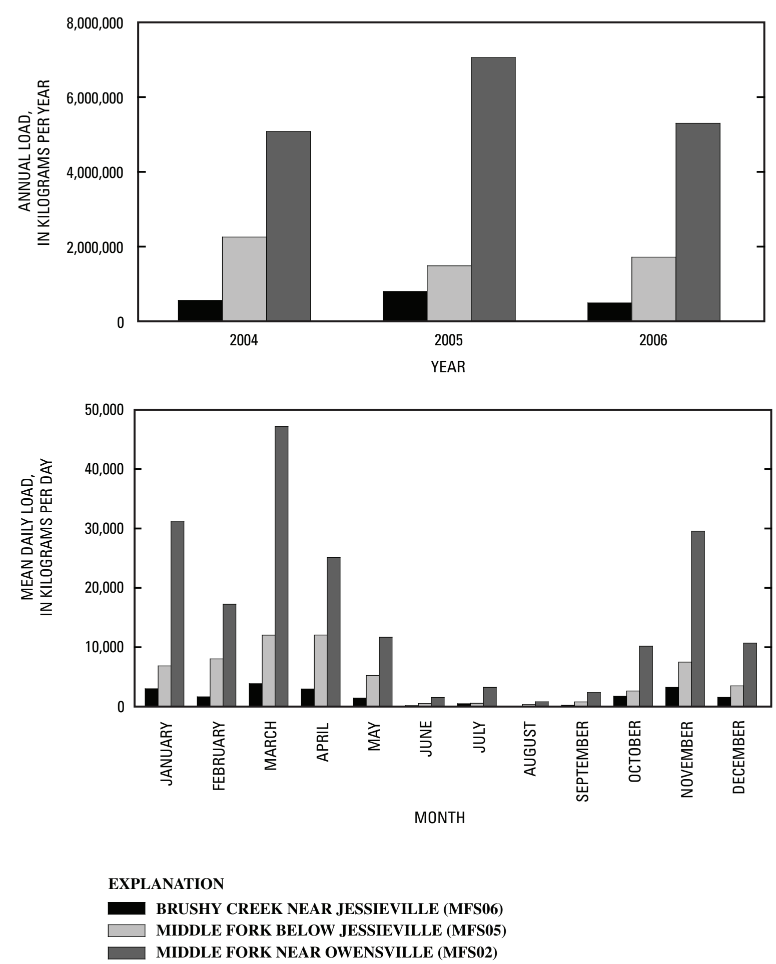

Figure 20. Annual and monthly loads of suspended sediment for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

Yields

The mean annual suspended-sediment yield was the greatest at MFS02 among the three sites for water years 2004-2006, although MFS05 had the greatest annual yields in 2004 and 2006 (fig. 21, table 5). The mean annual yield for MFS02 was 23,900 kg/yr/km^2. MFS06 and MFS05 had mean annual suspended-sediment yields of 13,400 and 23,300 kg/yr/km^2, respectively. The annual yields for MFS05 ranged from 19,000 kg/yr/km^2 in 2005 to 28,800 kg/yr/km^2 in 2004. The annual yields for MFS02 ranged from 20,900 kg/yr/km^2 in 2004 to 29,000 kg/yr/km^2 in 2005.

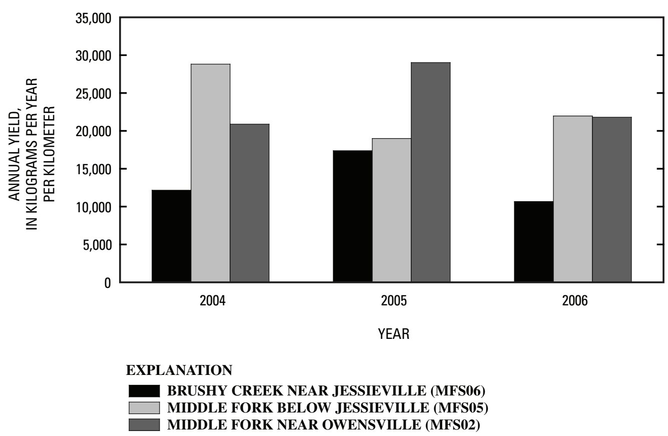

Figure 21. Annual yields of suspended sediment for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

Flow-Weighted Concentrations

Flow-weighted concentrations were computed for the three sites and compared to water-quality conditions of other stream basins. Flow-weighted concentrations were compared to the Alum Fork of the Saline River near Reform, Arkansas, a site within the same river system as the Middle Fork that has a drainage basin composed of approximately 99 percent forested land (Galloway and Green, 2004), and the Illinois River south of Siloam Springs, Arkansas, a site that is influenced by numerous point-source discharges, and urban and agricultural land use. Flow-weighted SSCs were not available for relatively undeveloped sites identified across the Nation (Clark and others, 2000), that were used for comparison of flow-weighted nutrient concentrations.

Mean flow-weighted SSCs for MFS06, MFS05, and MFS02 were greater than the mean flow-weighted concentration for the Alum Fork near Reform and substantially less than the flow-weighted concentration for the Illinois River south of Siloam Springs (fig. 22). The mean flow-weighted SSCs for MFS05 (52 mg/L) and MFS02 (61 mg/L) were approximately two times greater than the flow-weighted concentration for MFS06 (27 mg/L) and more than three times greater than the flow-weighted concentration for the Alum Fork near Reform (17 mg/L). The Illinois River south of Siloam Springs had a mean flow-weighted SSC that was approximately four times the flow-weighted concentrations for MFS05 and MFS02 and more than eight times the mean flow-weighted concentration for MFS06.

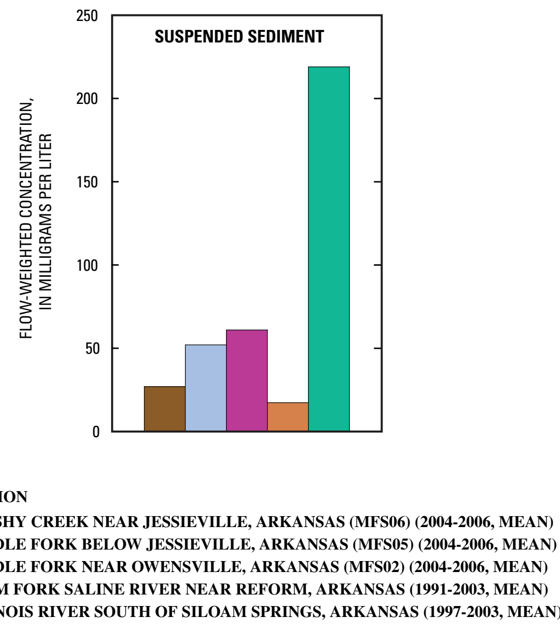

Figure 22. Mean annual flow-weighted concentrations of suspended sediment for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

Turbidity

Turbidity is an expression of the optical properties of a sample that cause light rays to be scattered and absorbed (Gray and Glysson, 2003). Turbidity of water is caused by the presence of suspended and dissolved inorganic matter such as clay and silt; suspended and dissolved organic matter such plankton, microscopic organisms, small terrestrial organic material, and organic acids; and water color. In the Middle Fork Basin, turbidity was measured when water-quality samples were collected by the USGS and ADEQ and was measured continuously at MFS02 (Middle Fork near Owensville) from October 2003 to October 2006. Because turbidity is an optical property, instruments with different optical sensors may not yield the same results. Different instruments were used to measure turbidity in samples collected by the USGS (in nephelometric turbidity ratio units) compared to measurements in samples collected by ADEQ (in nephelometric turbidity units) and the continuously recorded turbidity data at site MFS02 (in formazine nephelometric turbidity units). Therefore, each type of data is described separately in the following section.

Turbidity measured when water-quality samples were collected showed little variation between MFS06, MFS05, and MFS02 (fig. 23). MFS06 had turbidity values ranging from 1 to 120 nephelometric turbidity ratio units (NTRU) with a median value of 3 NTRU. Turbidity measured at MFS05 ranged from less than 1 to 250 NTRU with a median value of 2 NTRU. Turbidity at MFS02 ranged from less than 1 to 170 NTRU with a median of 3 NTRU. The current (2007) standard for turbidity in Ouachita Mountains Ecoregion streams is 10 NTU for the primary value not to be exceeded by any instream activity or waste discharge and 18 NTU for storm-runoff flow (value that cannot be exceeded in 20 percent of monthly samples collected in at least 24 months; Arkansas Pollution Control and Ecology Commission, 2004). The primary value (10 NTU) was exceeded in 9 samples from MFS06, 11 samples collected at MFS05, and 12 samples from MFS02. The stormflow value (18 NTU) was exceeded in 5 samples from MFS06, 7 samples collected at MFS05, and 10 samples from MFS02.

Turbidity data varied from upstream to downstream at the eight synoptic sites in the Middle Fork Basin from January 2004 to October 2006 (fig. 24), similar to the patterns of the TSS data (fig. 19). The greatest turbidity was observed in January 2004, ranging from 5.9 NTU (site MFS04E) to 15.3 NTU (MSF01), increasing from upstream to downstream. Site MFS02 had the greatest turbidity among the sites in June 2005 and September 2006 and site MFS01 had the greatest turbidity among the sites in January 2004, July 2004, and October 2005. In October 2004 and April 2005, turbidity did not vary more than 2.0 NTU among the eight sites, although some of the sites did not have data in October 2004 (sites MFS04, MFS01B, and MFS01). The varied distributions in turbidity in the Middle Fork may be explained by the different flow conditions that occurred at the time the samples were collected and by activities immediately upstream from the various sites that affect the inorganic and organic material in the stream. For example, road construction, or other activity that disturbs the land surface immediately upstream from a site, excessive algal growth, and resuspension of sediment from activities in the stream, such as livestock crossing the stream may affect the turbidity in the stream. In addition, variability in turbidity data could also be attributed to the sampling method. Turbidity data were collected by ADEQ in conjunction with water-quality samples at a single point in the stream and could vary depending on where in the stream cross section the sample was collected if the stream was not well mixed.

Continuously measured turbidity at MFS02 demonstrated a wide range of variability from October 2003 to October 2006 (fig. 25). High turbidity values generally were associated with high-flow events, when organic and inorganic material is flushed into the system from the landscape. The mean turbidity for the period of October 2003 to October 2006 for MFS02 was 8 formazine nephelometric turbidity units (FNTU) with a maximum value of 151 FNTU (table 7). The mean daily turbidity for water year 2004 was the greatest of the 3-year period with a value of 12 FNTU. Water years 2005 and 2006

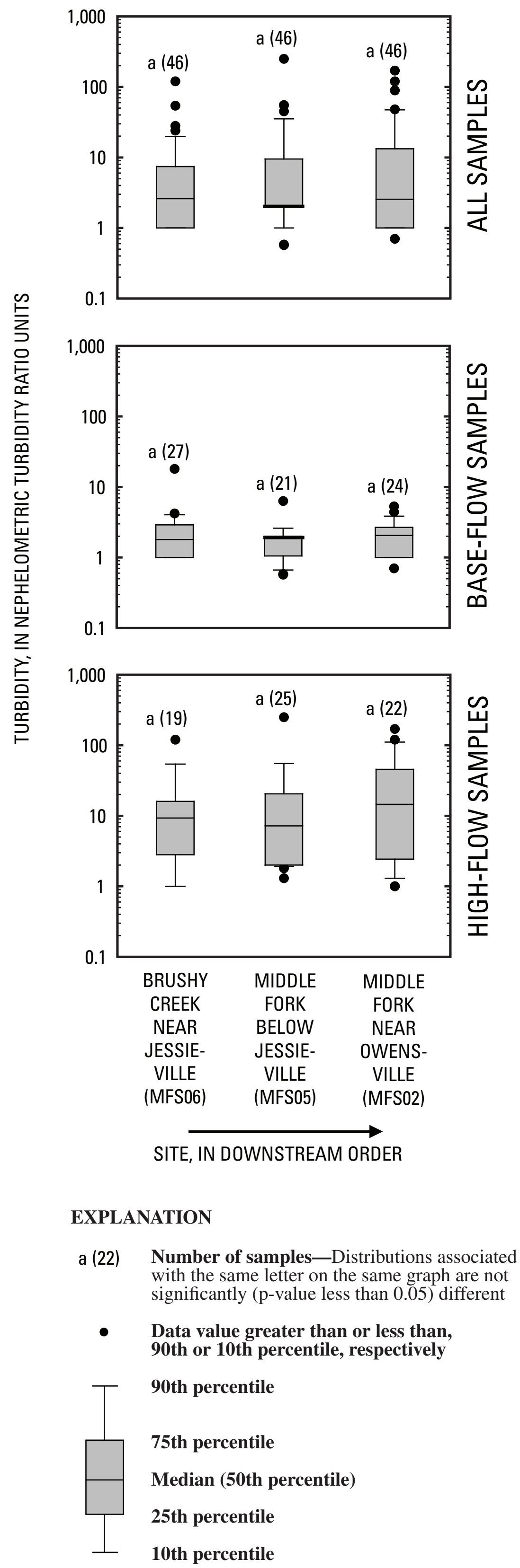

Figure 23. Distribution of turbidity for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

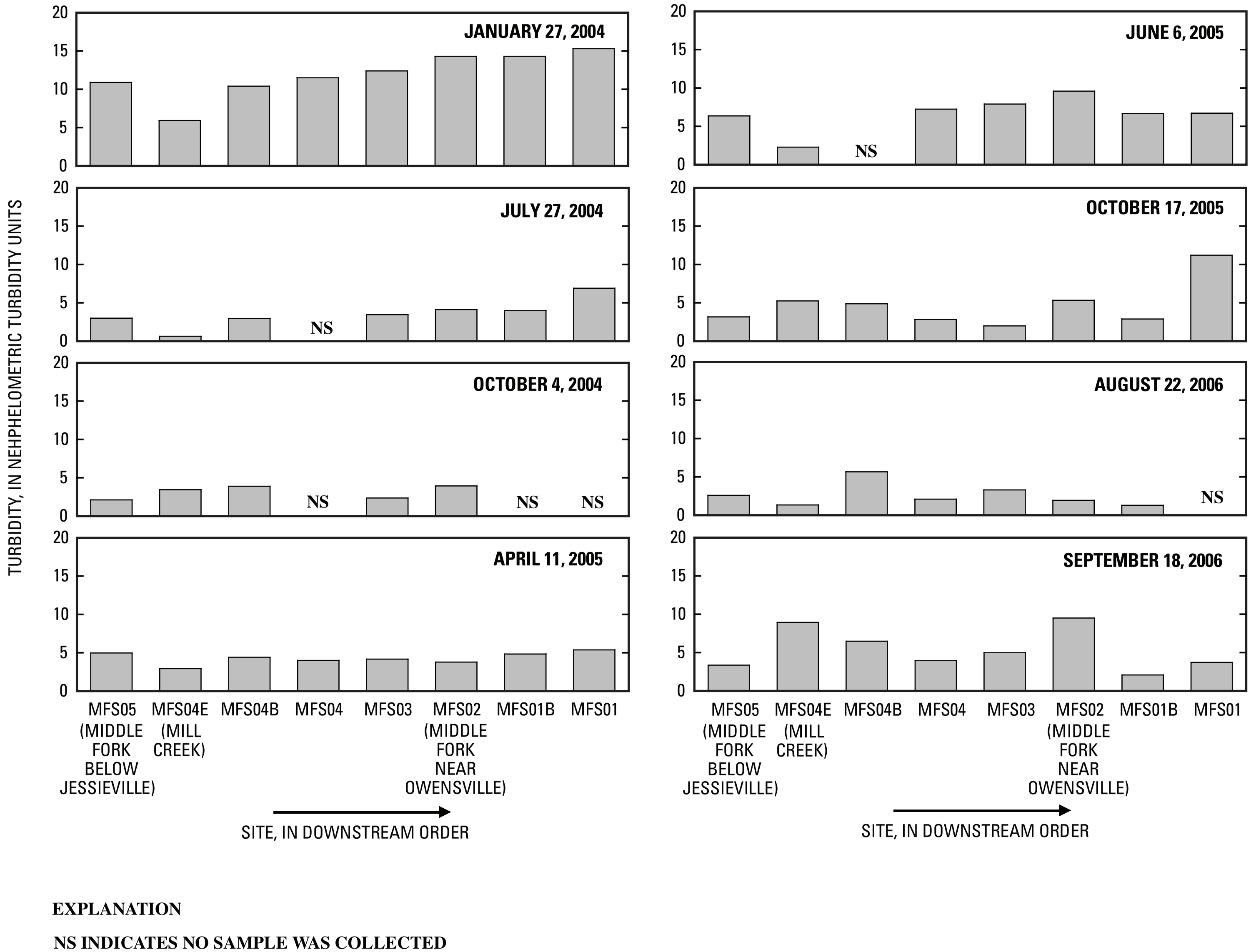

Figure 24. Spatial distribution of turbidity in the Middle Fork Basin, Arkansas, January 2004 to October 2006.

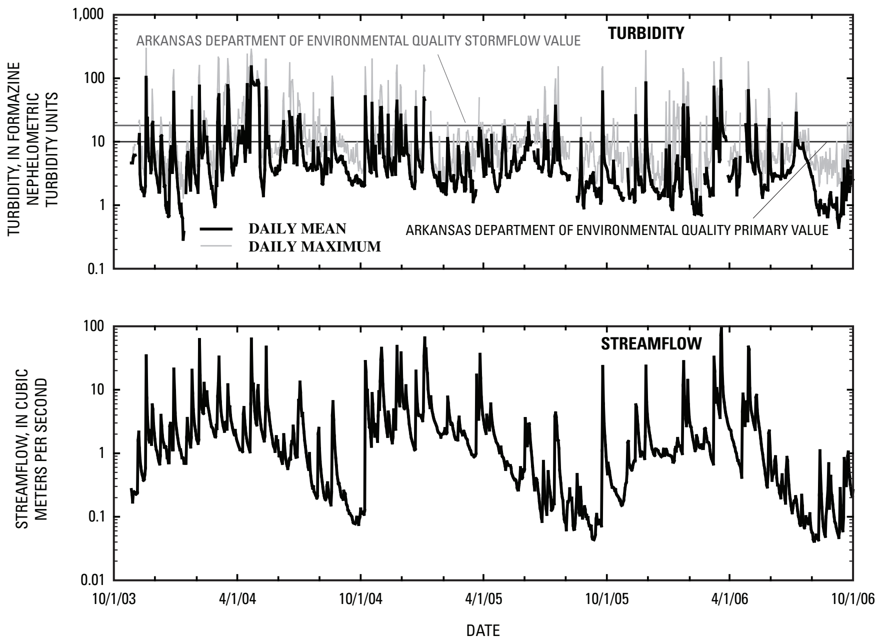

Figure 25. Daily mean and maximum turbidity and daily mean streamflow for the Middle Fork near Owensville (site MFS02), Arkansas, October 2003 to October 2006.

Table 7. Annual turbidity, water temperature, specific conductance, dissolved oxygen, and pH statistics for the Middle Fork near Owensville (site MFS02), Arkansas, October 2003 to October 2006.

[FNTU, formazin nephelometric turbidity units; °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than]

Water year	Statistic	Turbidity (FNTUs)	Temperature, (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	pH (standard units)
2004	Mean	12	16.9	131	9.6	7.6
	Maximum	151	28.6	249	14.0	8.3
	Minimum	<1	4.6	59	5.9	7.0
	Instantaneous maximum	293	30.2	252	15.7	8.9
	Instantaneous minimum	<1	3.8	44	4.9	6.7
2005	Mean	6	17.9	139	9.4	7.6
	Maximum	61	29.6	204	14.0	8.5
	Minimum	1	2.5	43	4.9	6.9
	Instantaneous maximum	200	30.7	205	16.1	9.2
	Instantaneous minimum	<1	1.7	39	3.8	6.7
2006	Mean	5	17.4	156	9.0	7.7
	Maximum	90	29.6	209	15.0	8.5
	Minimum	<1	3.1	38	5.1	6.6
	Instantaneous maximum	270	31.2	211	17.4	9.3
	Instantaneous minimum	<1	2.0	31	3.0	6.4
Entire period	Mean	8	17.4	142	9.3	7.6
	Maximum	151	29.6	249	15.0	8.5
	Minimum	<1	2.5	38	4.9	6.6
	Instantaneous maximum	293	31.2	252	17.4	9.3
	Instantaneous minimum	<1	1.7	31	3.0	6.4

had mean daily turbidities of 6 and 5 FNTU, respectively. During days when the base flow composed 70 percent or more of the total daily streamflow (base-flow conditions), the mean daily turbidity was 4 FNTU. During high-flow conditions, the mean daily turbidity was 12 FNTU. Mean daily turbidity at MFS02 exceeded ADEQ's primary value (Arkansas Pollution Control and Ecology Commission, 2004) for 155 days and the stormflow value for 81 days during water years 2005-2006.

Continuously measured turbidity and streamflow data collected from October 2003 to October 2006 were compared to total phosphorus, fecal indicator bacteria, and SSC at site MFS02 (Middle Fork near Owensville) to potentially provide continuous estimates for the different constituents (fig. 26). Total phosphorus did not seem to have a good relation with turbidity except at turbidities greater than about 20 FNTU (fig. 26). Total phosphorus also did not show a strong relation with streamflow. Generally, at streamflows greater than about 5.7 m^3/s, total phosphorus showed a better relation compared to lesser streamflows. Similarly, fecal indicator bacteria (*E. coli* and fecal coliform) did not show a good relation with turbidity and streamflow at turbidities less than about 20 FNTU and streamflows less than about 5.7 m^3/s, but had better relations at greater values of turbidity and streamflow. SSC also demonstrated a relatively good relation with both turbidity and streamflow at higher turbidity and streamflows. Generally, at turbidities greater than 10 FNTU and streamflows greater than about 2.8 m^3/s, SSC had a better relation with both turbidity and streamflow than at lesser turbidities and streamflow.

Total phosphorus had a relatively poor correlation with turbidity and streamflow. A multiple regression equation was developed to describe the relation between total phosphorus and logarithmic-transformed turbidity and streamflow (table 8). Regression statistics showed a poor relation with an R^2 of 0.52 and an MSE of 0.0008. Estimated total phosphorus concentrations were fairly similar to measured concentrations with the exception of several outliers at higher concentrations (fig. 27). Total phosphorus may not have had a strong relation with turbidity and streamflow because of other processes that control concentrations in the stream including biological activity, especially during base-flow conditions.

Fecal indicator bacteria demonstrated a relatively fair relation with turbidity and streamflow (fig. 26). A logarithmic-transformed regression equation used to estimate *E. coli* and fecal coliform concentrations from logarithmic-transformed turbidity and streamflow showed a relatively fair correlation with an R^2 of 0.77 and an MSE of 0.182 for *E. coli* and an R^2 of 0.68 and MSE of 0.209 for fecal coliform (table 8). Estimated *E. coli* and fecal coliform concentrations were mostly less than measured concentrations, especially at measured concentrations greater than 2,000 col/100 mL (fig. 27). Other predictive variables that control bacteria concentrations may need to be identified and implemented into the regression equation to reduce the error in the estimated concentrations as a longer period of data collection is accumulated.

Overall, SSC demonstrated a relatively fair relation with turbidity and streamflow (fig. 26). A regression equation was developed to describe the relation of logarithmic-transformed SSC with logarithmic-transformed turbidity and streamflow (table 8). The regression equation demonstrated a fair relation with an R^2 of 0.65 and an MSE of 0.118 (table 8). Estimated SSC were similar to measured concentrations except for three outliers with concentrations greater than 150 mg/L, which were considerably less than the measured concentrations (fig. 27). The error of the estimated SSC may be reduced as more data are collected at higher SSC concentrations, likely to occur during high-flow conditions, to improve the relation with turbidity and streamflow.

Total Dissolved Solids and Specific Conductance

TDS concentrations were the least at MFS06 and the greatest at MFS05 from October 2003 to October 2006 (fig. 28). The median TDS concentration for MFS06 was 54 mg/L compared to median concentrations of 102 mg/L at MFS05 and 87 mg/L at MFS02. Concentrations ranged from 31 to 122 mg/L at MFS06 and from 41 to 148 mg/L at MFS05. The low concentrations at MFS06 compared to the other two sites may be because the streamflow was less affected by ground water, which generally has greater TDS concentrations because of more interaction with the geologic formations in the basin. As discussed earlier in this report, the base flow at MFS06 was considerably less than the other two sites, indicating that the streamflow is more influenced by rainfall-runoff events, resulting in lower concentrations of TDS. Likewise, MFS02 had lower TDS concentrations than MFS05 possibly because runoff from rainfall, which generally has low TDS concentrations, may have more influence on the water chemistry than the interaction with the ground water upstream from MFS02.

TDS concentrations did not vary significantly in samples collected at different flow conditions at MFS06 and MFS05, but were significantly less in samples collected during high-flow conditions compared to base-flow conditions at MFS02. The median TDS concentration in samples collected during base-flow conditions for MFS02 was 95 mg/L compared to the median concentration of 73 mg/L in samples collected during high-flow conditions (fig. 28). TDS concentrations at MFS02 may be significantly less at high-flow conditions compared to base-flow conditions because the wastewater-treatment plant upstream from synoptic site MFS04E, which had high TDS concentrations, may influence concentrations during base-flow conditions; during rainfall-runoff events, the concentrations were diluted by the increased streamflow from rainfall.

Mill Creek (site MFS04E) had the greatest TDS concentrations in the synoptic samples collected from January 2004 to October 2006 with considerably less concentrations at sites on the Middle Fork (fig. 29). Concentrations ranged from 221 mg/L (April 2005) to 339 mg/L (June 2005) at site MFS04E in Mill Creek. Concentrations showed an incremental decrease in sites located in the Middle Fork downstream from the

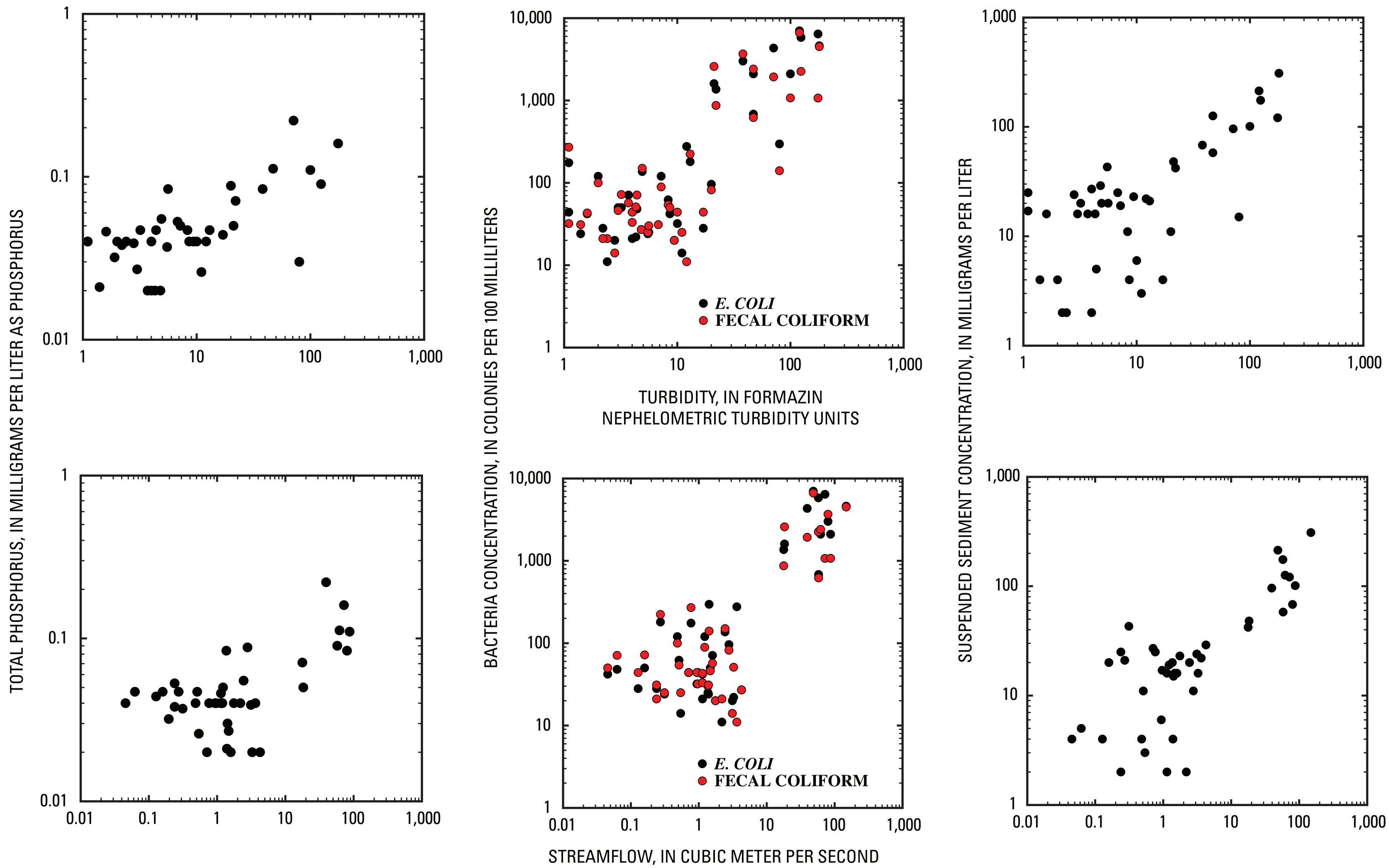

Figure 26. Comparison of total phosphorus, fecal indicator bacteria, and suspended-sediment concentrations with turbidity and streamflow for the Middle Fork near Owensville (site MFS02), Arkansas, October 2003 to October 2006.

Table 8. Regression equations for estimates of total dissolved solids, total phosphorus, *E. coli,* fecal coliform, and suspended-sediment concentrations for the Middle Fork near Owensville (site MFS02), Arkansas, October 2003 to October 2006.

[SSE, sum of squares of errors; MSE, mean square error; R^2, coefficient of determination; N, number of data points used in regression; *turb*, turbidity; *Q*, streamflow; *SC*, specific conductance]

Constituent	Equation	SSE	MSE	R^2	N
Total phosphorus (*TP*)	$TP = 0.031\log_{10}(turb) + 0.015\log_{10}(Q) + 0.0000891$	0.030	0.0008	0.52	40
E. coli (*EC*)	$\log_{10}(EC) = 0.684\log_{10}(turb) + 0.428\log_{10}(Q) + 0.635$	6.91	0.182	0.77	41
Fecal coliform (*FC*)	$\log_{10}(FC) = 0.554\log_{10}(turb) + 0.389\log_{10}(Q) + 0.788$	8.15	0.209	0.68	42
Suspended sediment (*SSC*)	$\log_{10}(SSC) = 0.260\log_{10}(turb) + 0.343\log_{10}(Q) + 0.378$	4.73	0.118	0.65	43
Total dissolved solids (*TDS*)	$TDS = 0.415(SC) + 27.4$	1,900	65.6	0.86	31

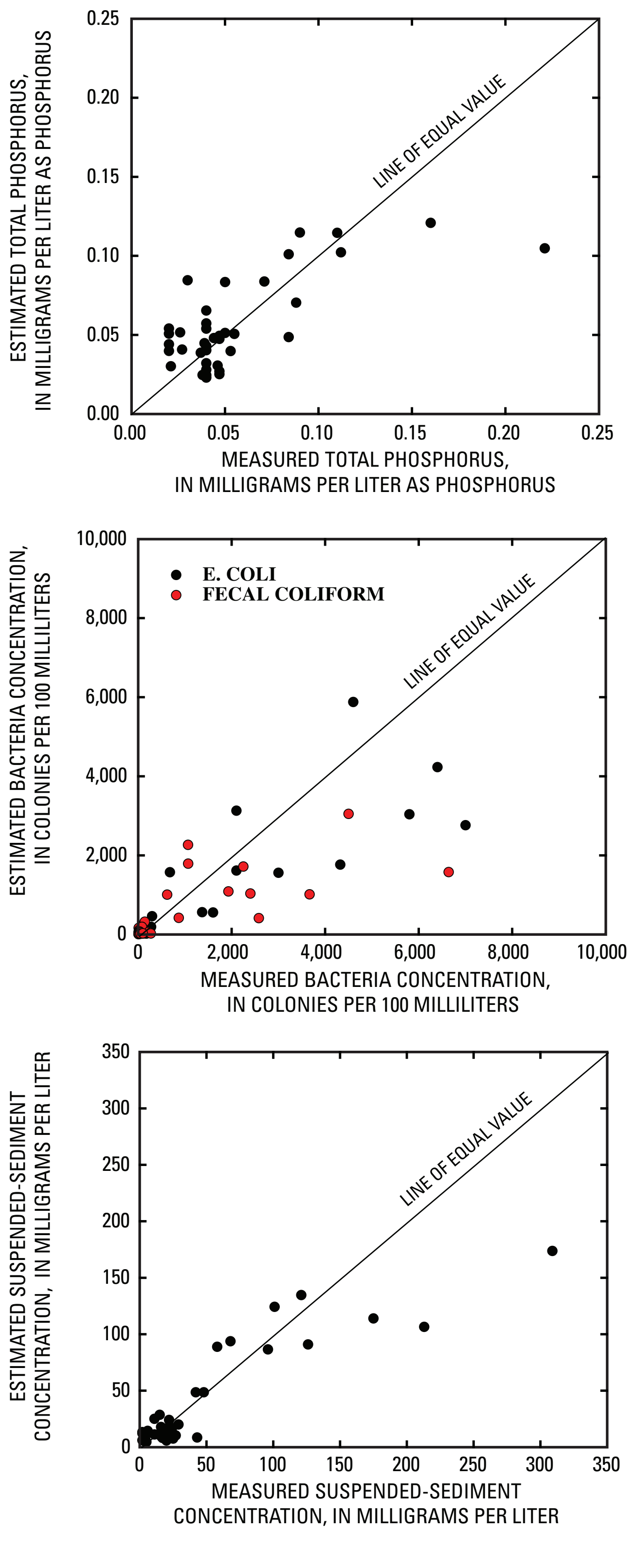

Figure 27. Comparison of measured and estimated total phosphorus, fecal indicator bacteria, and suspended-sediment concentrations for the Middle Fork near Owensville (site MFS02), Arkansas, October 2003 to October 2006.

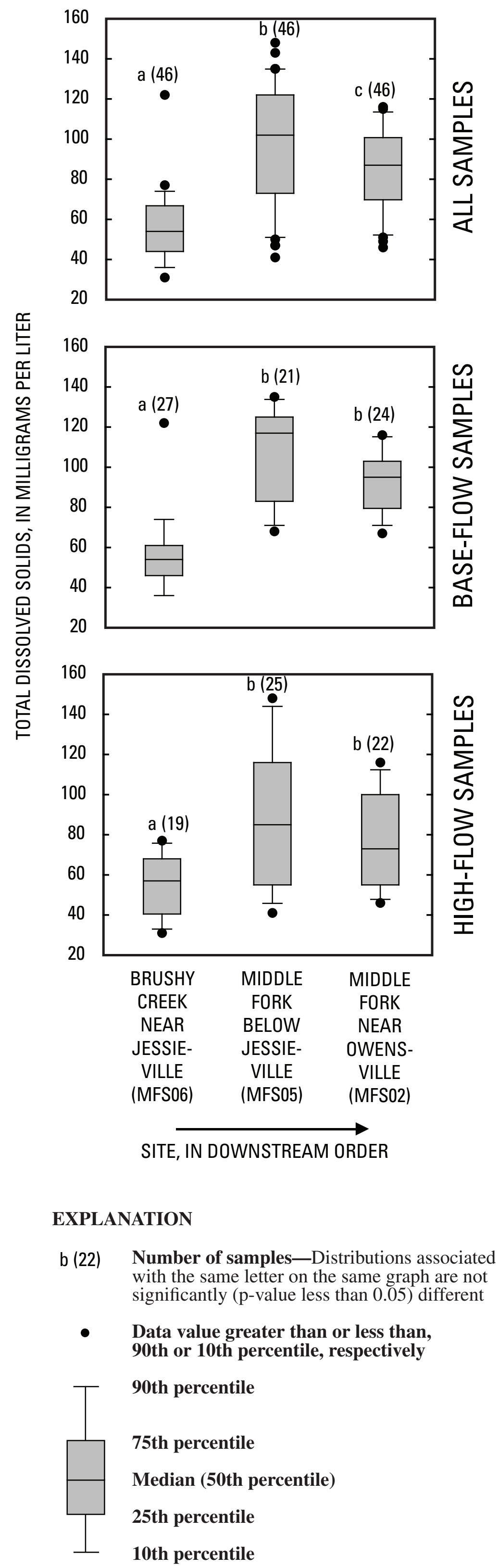

Figure 28. Distribution of total dissolved solids for Brushy Creek near Jessieville, the Middle Fork below Jessieville, and the Middle Fork near Owensville, Arkansas, October 2003 to October 2006.

confluence of Mill Creek. The median TDS concentrations decreased from 147 mg/L at site MFS04B, located just downstream from the confluence with Mill Creek, to 84 mg/L at site MFS01, the furthest downstream site in the Middle Fork. Dilution is probably the main factor controlling the TDS concentrations at the synoptic sites because TDS concentrations generally decreased as streamflow increased downstream.

Electrical conductivity is a measure of the capacity of water to conduct an electrical current and is a function of the types and quantities of dissolved substances in water (Hem, 1989). As concentrations of dissolved ions increase, conductivity of the water increases. Specific conductance is the conductivity expressed in units of microsiemens per centimeter (µS/cm) at 25 degrees Celsius. Specific conductance was measured continuously at MFS02 (Middle Fork near Owensville) from October 2003 to October 2006.

Specific conductance at MFS02 generally varied with streamflow from October 2003 to October 2006 (fig. 30). The mean daily specific conductance for the period was 142 µS/cm with greatest annual mean in water year 2006 (156 µS/cm) and the least annual mean in water year 2004 (131 µS/cm) (table 7). The daily maximum was 249 µS/cm with an instantaneous maximum of 252 µS/cm and a daily minimum of 38 µS/cm with an instantaneous minimum of 31 µS/cm for the entire period. Similar to TDS, the specific conductance generally decreased with increasing streamflow, mainly because during base-flow conditions the wastewater-treatment discharge upstream from synoptic site MFS04E, which had high TDS concentrations, may influence the specific conductance, and during rainfall-runoff events the concentrations were diluted by the increased streamflow from rainfall, which generally has low specific conductance. In the winter and spring, when

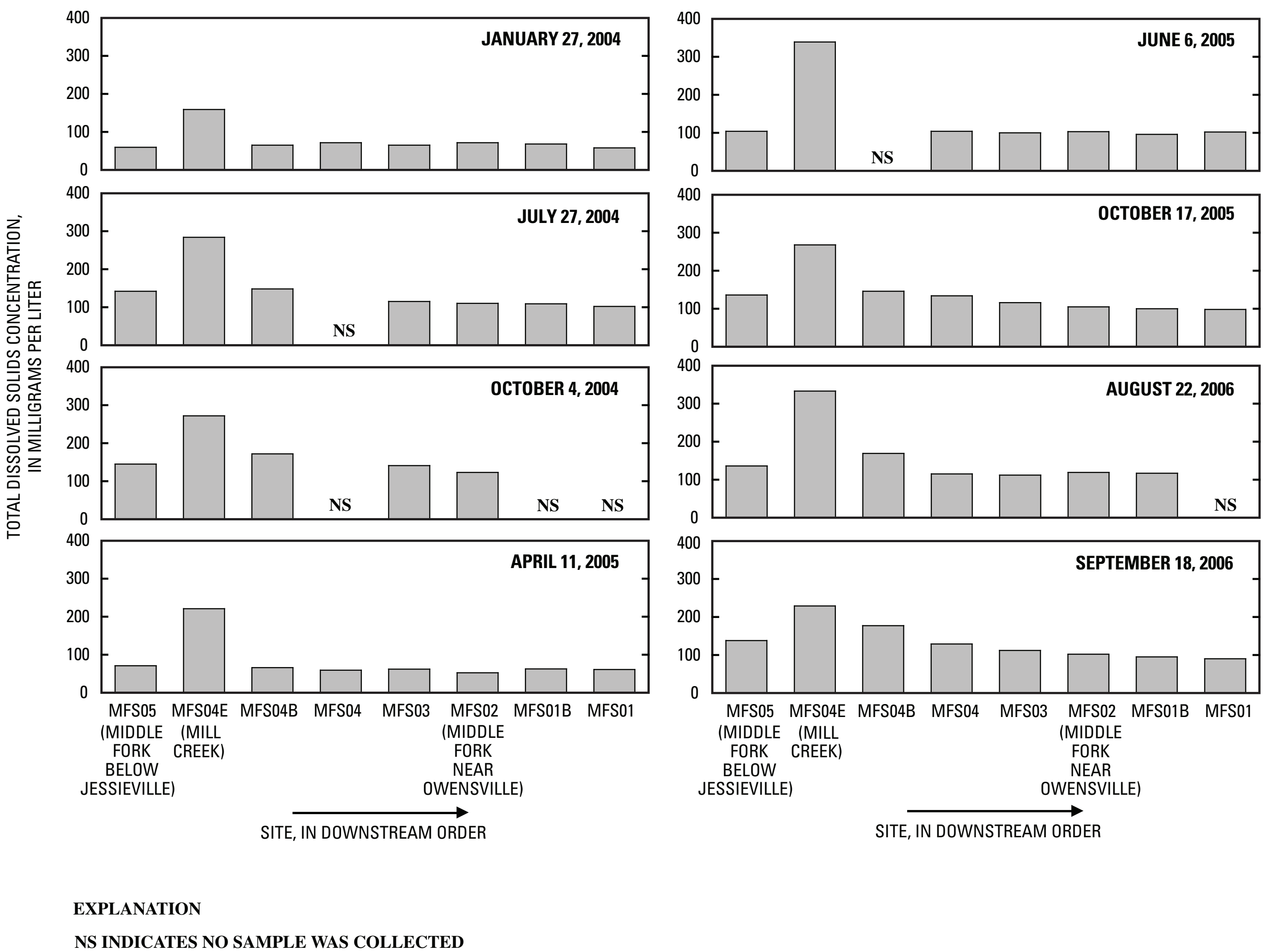

Figure 29. Spatial distribution of total dissolved solids in the Middle Fork Basin, Arkansas, January 2004 to October 2006.

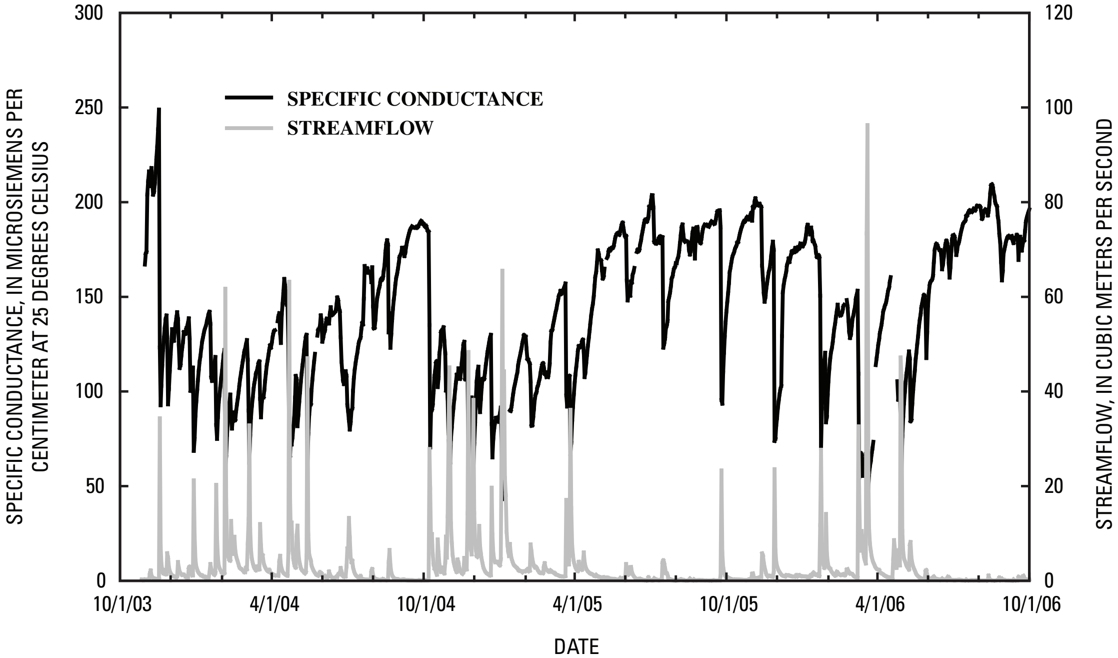

Figure 30. Daily mean specific conductance and streamflow for the Middle Fork near Owensville (site MFS02), Arkansas, October 2003 to October 2006.

the greatest streamflow occurred, the mean monthly specific conductance ranged from 107 µS/cm (March) to 134 µS/cm (May) and in the summer and fall, the mean monthly specific conductance ranged from 145 µS/cm (November) to 179 µS/cm (September).

Specific conductance at site MFS02 was correlated to TDS using a linear regression analysis (table 8). There was a relatively good correlation between TDS and specific conductance with an R^2 of 0.86 and an MSE of 65.6. Estimated TDS was similar to measured TDS through most of the range of concentrations (fig. 31). Because only 31 data values were used to develop the regression of TDS and specific conductance, the error of the estimated TDS may be reduced as more data are collected to improve the relation between the two datasets.

Dissolved Oxygen and pH

Dissolved oxygen is important in chemical reactions in water and in the life cycles of aquatic organisms. Sources of dissolved oxygen in surface waters are primarily atmospheric reaeration and photosynthetic activity of aquatic plants. Dissolved oxygen is consumed by the respiration of aquatic plants, ammonia nitrification, and the decomposition of organic matter in a stream. The solubility of dissolved oxygen is affected by water temperature and atmospheric pressure. Dissolved-oxygen solubility increases with colder water, while warmer water holds less amounts of dissolved oxygen, and solubility increases with increasing atmospheric pressure and decreases with decreasing atmospheric pressure.

Dissolved-oxygen concentrations at MFS02 varied seasonally from October 2003 to October 2006 (fig. 32). Dissolved-oxygen concentrations generally were greater in the winter and spring when temperatures were lower and streamflow was greater compared to the summer and fall when higher water temperatures and less streamflow occurred. From December through May (winter and spring), the mean daily temperature and dissolved-oxygen concentration were 12.3 °C and 11.1 mg/L, respectively. In comparison, from June through November (summer and fall), the mean daily temperature and dissolved-oxygen concentration were 22.6 °C and 7.6 mg/L, respectively. In the winter and spring, daily mean dissolved-oxygen concentrations ranged from 6.0 to 15.0 mg/L compared to the summer and fall when concentrations ranged from 3.0 mg/L to 17.4 mg/L. The mean dissolved-oxygen concentration for the entire period (October 2003 to October 2006) was 9.3 mg/L (table 7). The current (2007) standard for dissolved-oxygen concentration in streams in the Ouachita Mountains Ecoregion that have a drainage area of greater than 16 km^2 is 6.0 mg/L (Arkansas Pollution Control and Ecology Commission, 2004). The dissolved-oxygen concentrations at MFS02 were less than 6.0 mg/L during 189 days from October 2003 to October 2006, mainly in the summer and fall.

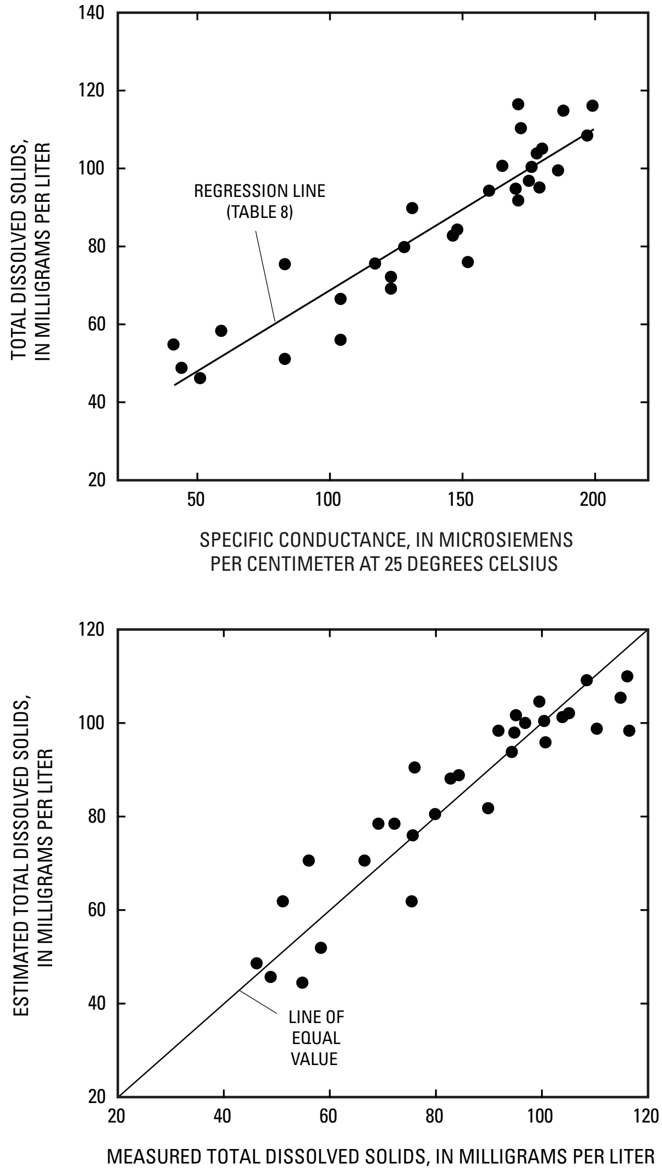

Figure 31. Comparison of specific conductance and total dissolved-solids data and estimated and measured total dissolved solids for the Middle Fork near Owensville (site MFS02), Arkansas, October 2003 to October 2006.

Dissolved-oxygen concentrations also demonstrated the effects of biological activity and other processes that affect oxygen solubility. Diurnal fluctuations in dissolved-oxygen concentrations were noticeable, particularly during base-flow conditions in late summer and fall. The diurnal fluctations reflect algal processes in a stream because during the day, when solar radiation is the greatest, aquatic plants use photosynthesis during growth, which produces oxygen and consumes carbon dioxide (CO_2). During the night aquatic plants undergo respiration, which produces CO_2 and consumes oxygen (Allen, 1995). During extended base-flow conditions in the summer and fall when water temperatures are greater than other periods of the year and stream velocities are less, algal growth can occur more readily. Diurnal fluctuations were the most varied in August 2006 when streamflow was the least for the period of October 2003 to October 2006 (fig. 33). Dissolved-oxygen concentrations generally were the least from about 4:00 a.m. to 8:00 a.m., and the greatest from about 2:00 p.m. to 4:00 p.m. Some days had greater fluctuation in dissolved oxygen than others in August 2006. The days with greater fluctuations (August 17-22, 2006) were probably associated with clear skies, providing more solar radiation to the water surface for more photosynthetic activity compared to days with considerably less fluctuation in dissolved oxygen (August 13-15, 23-31, 2006), which were probably associated with cloudy days when relatively less solar radiation is transmitted to the water surface, reducing the photosynthetic activity.

The pH of an aqueous solution is controlled by interrelated chemical reactions that produce or consume hydrogen ions (Hem, 1989). Many reactions that occur in natural water among solutes (solid or gaseous) or other liquid species involve hydrogen ions, and, therefore, effect the pH. For example, the reaction of CO_2 with water is one of the most important in controlling the pH in natural water systems (Hem, 1989).

MFS02 had pH values that changed seasonally from October 2003 to October 2006 (fig. 32). For the entire period, the mean pH was 7.6 standard units and ranged from 6.4 to 9.3 standard units (table 7). pH generally was greater in the winter and spring when temperatures were lower and streamflow was greater compared to the summer and fall when higher water temperatures and less streamflow occurred. From December through May (winter and spring), the mean monthly pH ranged from 7.5 (May) to 7.9 standard units (February). In comparison, from June through November (summer and fall), the mean monthly pH ranged from 7.4 (October) to 7.6 standard units (July and August). The current (2007) standard for pH in streams in the Ouachita Mountains is that pH should not be below 6.0 or above 9.0 standard units and should not fluctuate more than 1.0 standard unit in a 24-hour period (Arkansas Pollution Control and Ecology Commission, 2004). The pH at MFS02 exceeded 9.0 standard units during 5 days in February 2005 and August 2006, but did not fall below 6.0 standard units at any time during the entire period (October 2003 to October 2006).

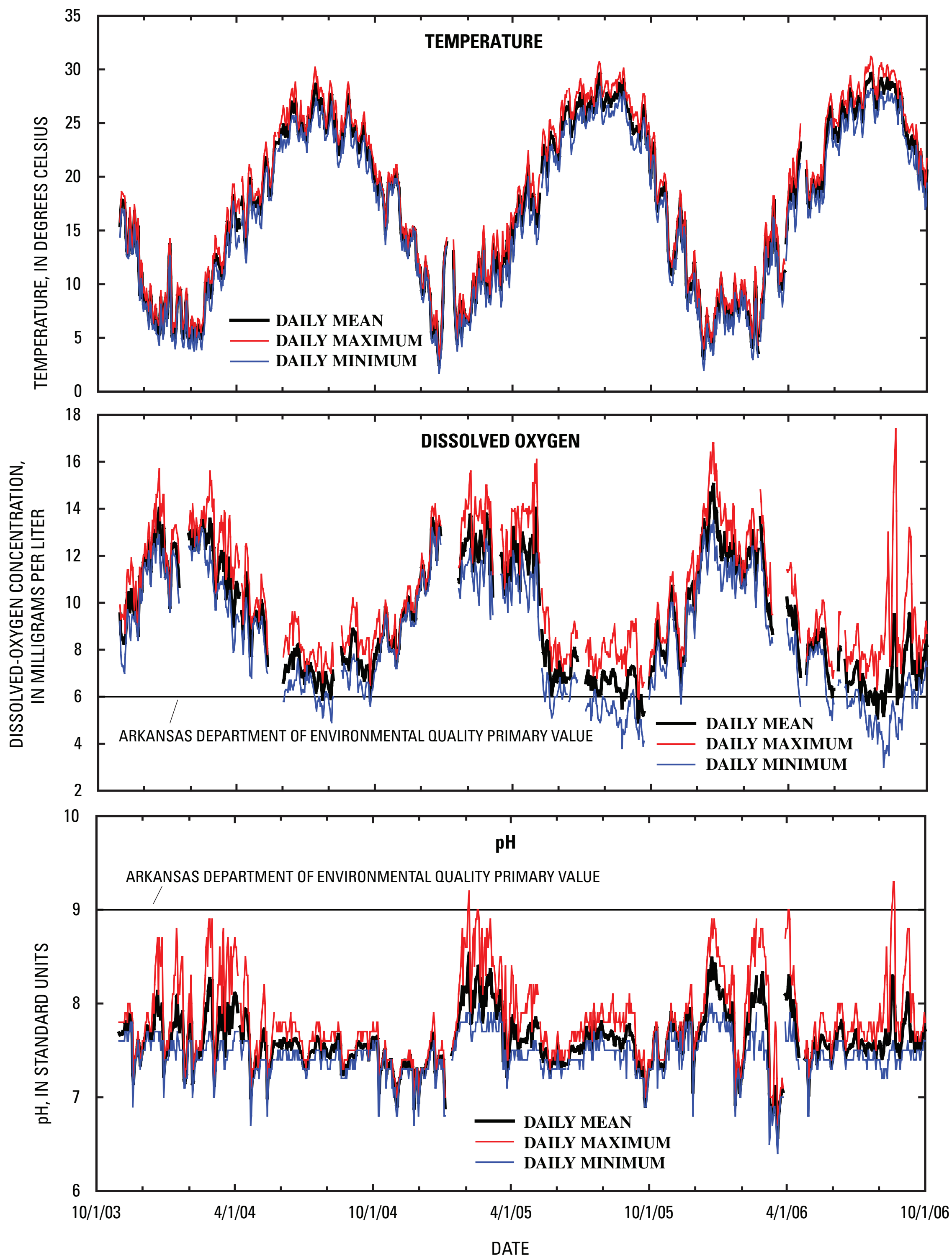

Figure 32. Daily mean water temperature, dissolved-oxygen concentration, and pH for the Middle Fork near Owensville (site MFS02), Arkansas, October 2003 to October 2006.

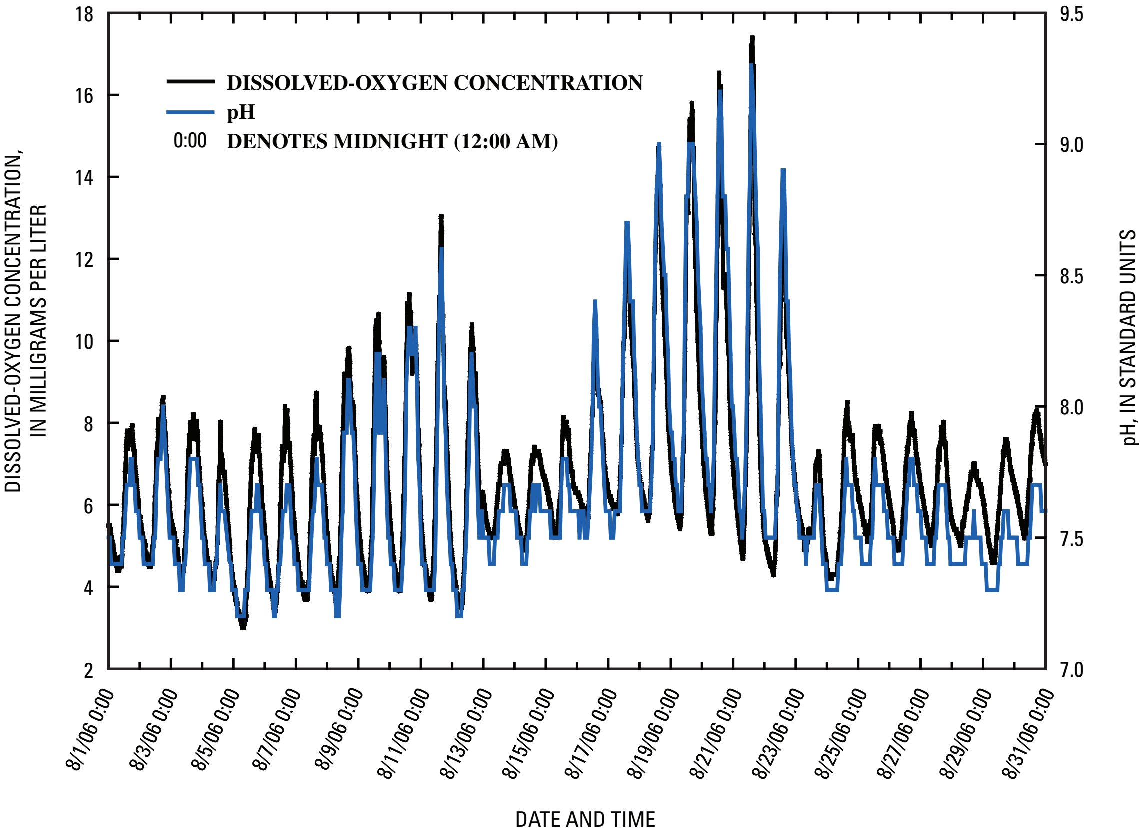

Figure 33. Hourly dissolved-oxygen concentrations and pH for the Middle Fork near Owensville (site MFS02), Arkansas, August 2006.

Similar to dissolved oxygen, pH fluctuated diurnally, with higher pH during the day, and lower pH at night (fig. 33). The fluctuations are the result of the same processes that produce the diurnal changes in dissolved oxygen during base-flow conditions. As aquatic plants produce CO_2 during respiration at night, pH decreases, and when CO_2 is consumed during the day from photosynthesis, pH increases (Allen, 1995). For example, diurnal fluctuations were the most varied in August 2006, when streamflow was the least for the period of October 2003 to October 2006 (fig. 33). pH generally was the least from about 2:00 a.m. to 9:00 a.m., and the greatest from about 2:00 p.m. to 4:00 p.m., ranging from 7.3 to 9.3 standard units. Diurnal fluctuations also occurred in the late winter and early spring, when temperatures were relatively lower and dissolved oxygen and streamflow were relatively greater.

Trace Metals

Synoptic samples collected by ADEQ were analyzed for 19 different trace metals. Several of the metals generally had concentrations near or below the laboratory reporting level, including aluminum, antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, nickel, selenium, silver, thallium, and vanadium. Several other metals such as barium, boron, copper, iron, manganese, and zinc had measurable concentrations.

Concentrations of boron, copper, and zinc had the greatest concentrations in Mill Creek, at the site below the wastewater-treatment discharge (site MFS04E) compared to the other sites in the Middle Fork from January 2004 to October 2006 (fig. 34). The median boron concentration in Mill Creek was 179 µg/L compared to the other sites with median concentrations ranging from 5.73 (site MFS05) to 37.7 µg/L (site MFS04B), decreasing in concentration at sites downstream from Mill Creek. It appears that concentrations are less in the Middle Fork downstream from the confluence probably because of dilution. Copper concentrations showed similar patterns with a median concentration of 9.13 µg/L in Mill Creek compared to the Middle Fork sites with median concentrations ranging from 0.57 (site MFS05) to 1.84 µg/L (site MFS04B). Similarly, zinc concentrations were greatest in Mill Creek, with decreasing concentrations in sites in the Middle Fork downstream from the confluence with Mill Creek. Zinc had a wider range of concentrations at MFS02 compared to the other sites downstream from Mill Creek, mainly because more samples were collected over a wider range of flow conditions at that site. The current (2007) standards for copper for the Ouachita Mountains Ecoregion are 5.6 µg/L for acute effects and 4.2 µg/L for chronic effects (Arkansas Pollution Control and Ecology Commission, 2004). All samples collected at site MFS04E exceeded the standard for acute effects (5.6 µg/L) and one sample collected at site MFS04B exceeded the standard for acute effects. No samples collected from the other sites exceeded the standards for copper. None of the samples collected at any of the sites from January 2004 to October 2006 exceeded the standards for zinc, and no standards exist for boron.

Barium, iron, and manganese concentrations were the greatest at the most upstream site in the Middle Fork (site MFS05) and were the least at the site in Mill Creek (site MFS04E) compared to the other sites in the Middle Fork (fig. 34). The median barium concentration at site MFS05 was 23.90 µg/L and the median concentration at MFS04E in Mill Creek was 4.87 µg/L. Barium concentrations in the Middle Fork increased farther downstream from the confluence with Mill Creek with median concentrations ranging from 17.65 to 21.35 µg/L. Median iron concentrations at sites MFS05 and MFS04E were 82.30 and 25.00 µg/L, respectively, with median concentrations downstream from Mill Creek ranging from 52.80 to 82.95 µg/L. Manganese concentrations followed similar patterns with the greatest concentrations at site MFS05 and the least at site MFS04E. Barium, iron, and magnesium concentrations had wider ranges of concentrations at site MFS02 compared to the other sites downstream from Mill Creek, mainly because more samples were collected over a wider range of flow conditions at that site.

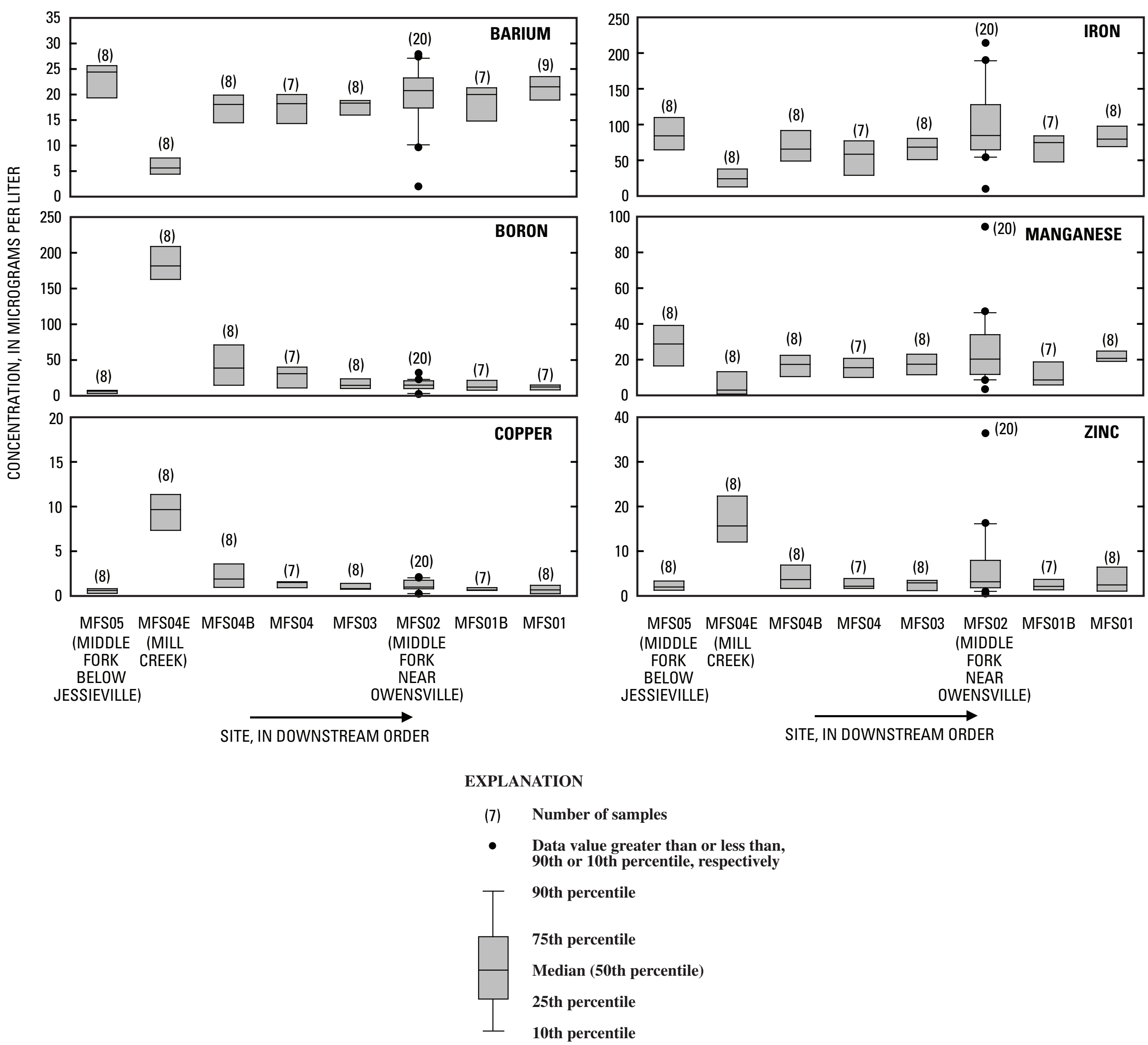

Figure 34. Spatial distribution of selected trace metals in the Middle Fork Basin, Arkansas, January 2004 to October 2006.

Biological Characteristics

Several biological characteristics appear to be affected by water-quality conditions in Mill Creek and the Middle Fork. In general, nutrient and trace metal concentrations in Mill Creek are substantially different from concentrations in the Middle Fork. Concentrations of nutrients and some trace metals are substantially higher at Mill Creek and near the confluence of Mill Creek and Middle Fork than at sites farther downstream from the confluence. Other differences between habitat variables associated with sites are less apparent. Selected habitat, macroinvertebrate, and fish variables are described below.

Physical Habitat

Although there was some variation of total habitat scores among sites and temporally (table 9), the habitats at all sites during all seasons uniformly were classified as suboptimal. Scores ranged from 105 (MFS03 in fall 2003) to 146 (MFS05 in spring 2005). During all of the four sampling periods the highest total habitat scores occurred at MFS05; typically the lowest scores occurred at MFS03. Marginal or poor scores for individual habitat variables were most often associated with substrate embeddedness, bank stability, and riparian vegetative zone width. Scores for sediment deposition, embeddedness, and velocity/depth regime variability (all of which could be affected by excess sediment) generally were lower than scores for other habitat variables. Optimal scores for individual habitat variables were most often associated with riparian vegetative zone width and a lack of channel alteration. Total scores at individual sites generally were higher in the spring than in the fall.

Distribution of substrate particle size, as indicated by pebble count data associated with riffles, was relatively similar at all sampling sites (table 10) and the median particle size at all sites was coarse or very coarse gravel. However, bedrock was present only at the two most downstream sites (MFS03 and MFS02), sand was substantially more common at MFS05 and MFS03 than at other sites, and cobble was substantially more common at MFS04E than at other sites.

Benthic Macroinvertebrate Community

More than 80 taxa were collected in samples from the five sites during the four sampling periods. Relative abundance values (in percent) are reported for each taxa in table 11. Metrics were compared to metrics for least-disturbed streams in the Ouachita Mountains ecoregion (table 12).

Richness

Taxa richness varied among sites and temporally (fig. 35, table 13). The minimum taxa richness (10) occurred at MFS04E in spring 2004 and the maximum (34) occurred at MFS02 in fall 2005. During two of the four sampling periods the lowest taxa richness occurred at MFS04E, but during the other two sampling periods taxa richness was lower at either MFS05 or MFS02. Taxa richness was not consistently higher in the fall or the spring.

During all of the sampling periods taxa richness values at most sites were similar to or greater than values for least-disturbed streams in the Ouachita Mountains (fig. 35) indicating that conditions in the basin were not having a detrimental effect on macroinvertebrate taxa richness. Taxa richness generally was lower in samples collected in spring 2004. During other sampling periods taxa richness at all sites (including MFS04E) almost always was similar to values for least-disturbed streams.

Composition

Shannon-Weiner diversity index values varied among sites and temporally (table 13). Values ranged from 2.44 (MFS04E in spring 2005) to 4.15 (MFS05 in spring 2005). During four sampling periods the lowest Shannon-Weiner diversity index values occurred at MFS04E; generally the highest values occurred at MFS05. Lowest values for sites on the mainstem of the Middle Fork generally occurred at the site immediately downstream from the confluence with Mill Creek and at MFS02. However, in the fall of 2005 the lowest value for mainstem sites occurred at MFS04E and the highest value occurred at MFS02.

EPT relative abundance varied among sites and seasonally (fig. 35, table 13). The minimum EPT relative abundance (35.2 percent) occurred at MFS04E in spring 2005 and the maximum (73.2 percent) occurred at MFS03 in fall 2005. During two of the four sampling periods the lowest EPT relative abundance occurred at MFS04E and during the other two sampling periods EPT relative abundance was lowest at MFS05. Highest EPT relative abundance during a sampling period occurred at MFS02 and MFS03. EPT relative abundance generally was higher in the fall than in the spring.

EPT relative abundance values for Middle Fork Basin sites generally were similar to values for least-disturbed streams in the Ouachita Mountains ecoregion (fig. 35). This indicates that conditions in the basin were not having a detrimental effect on macroinvertebrate communities.

Several taxa were dominant or codominant taxa in one or more samples (table 13). *Cheumatopsyche* and *Stenonema* were the most common dominant or codominant taxa; others were *Stenelmis, Isonychia,* Chironomidae, *Lirceus, Rithrogena,* and *Caenis*. Dominant taxa often composed more than 20 percent of the individuals in a sample and codominant taxa often composed more than 15 percent of the individuals in a sample. *Cheumatopsyche* and *Lirceus* were often the dominant or codominant taxa at MFS04E. Both taxa are indicative of perturbations. Some Isopoda (including Asellidae, such as *Lirceus*) are indicators of organic pollution, and may be more abundant within the recovery zones in streams with nutrient

Table 9. Rapid bioassessment protocol habitat scores for the Middle Fork Basin, Arkansas, September 2003 to December 2005.

[ES, epifaunal substrate and available cover; EM, embeddedness; VE, velocity and depth regime; SD, sediment deposition; CF, channel flow status; CA, channel alteration; RF, riffle frequency; BS, bank stability; VP, vegetative protection; RV, riparian vegetative zone width; BS, VP, and RV are combined scores from the left and right banks of the stream]

Site	Season	ES	EM	VE	SD	CF	CA	RF	BS	VP	RV	Total score	Habitat characterization
MFS05 (Middle Fork below Jessieville)	Fall 2003	12	13	10	13	10	18	11	12	17	18	133	Suboptimal
MFS04E (Mill Creek)		13	12	10	11	13	18	13	13	14	15	130	Suboptimal
MFS04B		12	13	11	12	11	18	14	11	13	14	128	Suboptimal
MFS03		6	5	10	6	15	16	16	13	11	8	105	Suboptimal
MFS02 (Middle Fork near Owensville)		13	14	12	11	11	16	13	13	14	13	129	Suboptimal
MFS05 (Middle Fork below Jessieville)	Spring 2004	15	13	14	12	11	17	13	14	16	16	141	Suboptimal
MFS04E (Mill Creek)		12	12	10	11	16	18	15	14	15	16	139	Suboptimal
MFS04B		12	12	10	11	12	17	13	12	15	16	129	Suboptimal
MFS03		13	13	12	12	16	18	13	14	11	10	130	Suboptimal
MFS02 (Middle Fork near Owensville)		12	13	12	11	13	18	13	14	12	12	128	Suboptimal
MFS05 (Middle Fork below Jessieville)	Spring 2005	15	15	15	13	12	18	10	16	16	18	146	Suboptimal
MFS04E (Mill Creek)		11	10	10	12	16	18	15	16	15	15	136	Suboptimal
MFS04B		14	13	16	11	10	18	12	14	14	15	136	Suboptimal
MFS03		12	11	10	10	13	16	15	14	9	9	119	Suboptimal
MFS02 (Middle Fork near Owensville)		13	13	13	10	10	15	13	15	13	12	125	Suboptimal
MFS05 (Middle Fork below Jessieville)	Fall 2005	14	12	17	13	6	17	14	11	18	18	138	Suboptimal
MFS04E (Mill Creek)		13	10	13	7	17	15	18	14	12	13	131	Suboptimal
MFS04B		12	11	11	15	17	17	16	9	13	14	133	Suboptimal
MFS03		14	11	13	11	16	17	16	12	9	8	125	Suboptimal
MFS02 (Middle Fork near Owensville)		14	14	14	13	13	16	13	13	10	12	131	Suboptimal

Table 10. Pebble-count size distribution data from two riffles at sites in the Middle Fork Basin, Arkansas, September 2003.

[mm, millimeters]

Size class	Size description	Intermediate diameter size range (mm)	Mean percent in size class: MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)
Sand	very fine	0.062-0.125	0.0	0.0	0.0	0.0	0.0
	fine	0.125-0.25	0.0	0.0	0.0	0.0	0.0
	medium	0.25-0.50	0.9	0.0	0.0	0.9	0.5
	coarse	0.50-1.0	3.3	1.8	2.0	8.6	0.9
	very coarse	1.0-2.0	9.4	1.9	5.1	6.4	4.0
Gravel	very fine	2.0-4.0	5.3	1.5	4.3	2.8	4.0
	fine	4-5.7	0.5	1.4	0.9	1.9	1.8
	fine	5.7-8	3.4	4.2	2.0	2.0	2.6
	medium	8-11.3	0.9	2.7	1.9	0.4	1.3
	medium	11.3-16	9.1	3.8	4.5	7.0	8.1
	coarse	16-22.6	10.1	3.7	7.1	5.1	5.4
	coarse	22.6-32	13.4	10.0	13.5	12.0	15.6
	very coarse	32-45	10.2	9.6	17.6	8.5	19.8
	very coarse	45-64	8.5	10.1	14.4	13.6	13.8
Cobble	small	64-90	9.1	20.9	11.7	10.9	13.4
	small	90-128	8.6	13.5	10.6	9.2	2.2
	large	128-180	5.8	9.7	4.1	2.4	0.5
	large	180-256	1.0	3.9	0.0	0.5	0.0
Boulder	small	256-362	0.5	0.9	0.0	0.0	0.0
	small	362-512	0.0	0.0	0.0	1.4	0.0
	medium	512-1,024	0.0	0.0	0.4	0.0	0.0
	large	1,024-2,048	0.0	0.0	0.0	0.0	0.0
Bedrock	bedrock		0.0	0.0	0.0	6.4	6.1
	Total		100.0	100.0	100.0	100.0	100.0

Table 11. Benthic macroinvertebrate tolerance values, functional groups, and relative abundance for sites in the Middle Fork Basin, Arkansas, September 2003 to December 2005.

[Tolerance values range from 0 (least tolerant) to 10 (most tolerant); cg, collector-gatherer; sc, scraper, pr, predator; cf, filterer; sh, shredder; mp, macrophyte piercer]

					Relative abundance, in percent																			
					Fall 2003					Spring 2004					Spring 2005					Fall 2005				
Class or order	Family or subfamily	Genus and species	Tolerance value[1]	Functional group	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)
Amphipoda		*Hyalella azteca*	8	cg	0.0	0.0	0.0	0.0	0.0	0.0	7.7	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.8	0.7	0.8
Amphipoda		*Gammarus*	6	cg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.8	0.0	0.4
Coleoptera	Elmidae	*Stenelmis*	5	sc	14.4	7.7	18.1	17.9	12.5	13.5	0.0	19.8	3.7	15.7	5.7	12.8	12.8	8.5	9.0	6.8	5.5	6.3	5.8	5.9
Coleoptera	Elmidae	*Ancyronyx*	6	sc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Coleoptera	Elmidae	*Microcylloepus*	3	sc	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Coleoptera	Elmidae	*Dubiraphia*	5	sc	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	1.7	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.8	0.7	0.4
Coleoptera	Elmidae	*Optioservus*	5	sc	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coleoptera	Psephenidae	*Psephenus/Ectopria*	4	sc	10.3	3.8	11.8	6.0	1.5	3.2	0.0	3.0	1.2	0.0	0.0	0.3	2.6	3.0	2.5	2.3	3.5	3.9	2.2	1.2
Coleoptera	Gyrinidae	*Dineutus*	6	pr	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0
Coleoptera	Staphylinidae		5	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coleoptera	Scirtidae		5	sc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Coleoptera	Dryopidae	*Helichus*	5	sc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Coleoptera	Hydrophilidae		8	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
Collembola			5	cg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 11. Benthic macroinvertebrate tolerance values, functional groups, and relative abundance for sites in the Middle Fork Basin, Arkansas, September 2003 to December 2005.—Continued

[Tolerance values range from 0 (least tolerant) to 10 (most tolerant); cg, collector-gatherer; sc, scraper, pr, predator; cf, filterer; sh, shredder; mp, macrophyte piercer]

					Relative abundance, in percent																			
					Fall 2003					Spring 2004					Spring 2005					Fall 2005				
Class or order	Family or subfamily	Genus and species	Tolerance value[1]	Functional group	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)
Decapoda	Cambarinae		6	cg	1.1	1.0	1.6	0.0	1.5	3.2	0.0	3.0	0.6	0.6	0.6	0.3	0.9	0.0	0.0	0.0	0.4	0.0	0.0	0.4
Diptera	Chironomidae		7	cg	1.7	1.9	3.1	1.8	1.5	13.5	3.8	2.0	15.5	6.2		4.0	18.8	20.7	15.6	2.8	1.2	2.4	0.7	8.7
Diptera	Simulidae		6	cf	0.0	0.0	0.0	0.6	0.7	7.1	0.0	0.0	0.0	0.0	1.9	1.0	0.9	1.2	4.1	0.0	0.0	0.0	0.7	4.3
Diptera	Tabanidae	*Tabanus*	9	pr	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
Diptera	Tipulidae	*Haxatoma/Tipula*	5	sh	0.6	0.0	0.0	0.6	0.0	0.0	11.5	0.0	0.0	0.6	1.3	0.3	0.0	0.0	0.0	0.0	1.2	0.0	0.7	1.2
Diptera	Dixidae	*Dixella*	3	cg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diptera	Empididae		6	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Diptera	Ceratopogoniidae		7	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
Diptera	Stratiomyidae		10	cg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ephemeroptera	Baetidae	*Baetis*	3	cg	5.7	2.9	3.9	10.1	1.5	0.0	0.0	5.0	7.5	0.0	7.5	0.3	6.8	11.0	13.9	0.0	0.0	0.0	5.1	0.4
Ephemeroptera	Caenidae	*Caenis*	7	cg	7.5	0.0	3.9	4.2	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.2	0.0	0.0	0.0	0.8	0.7	11.1
Ephemeroptera	Heptagenidae	*Leurocuta*	2	sc	2.9	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ephemeroptera	Heptageniidae	*Stenacron*	4	cg	0.6	1.9	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	1.1	0.0	0.0	0.0	0.0
Ephemeroptera	Heptageniidae	*Stenonema*	4	sc	19.0	28.8	26.8	17.3	24.3	7.1	19.2	13.9	15.5	13.5	8.2	9.4	8.5	2.4	2.5	16.5	43.3	11.8	8.7	7.1
Ephemeroptera	Heptageniidae	Unknown	3	sc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 11. Benthic macroinvertebrate tolerance values, functional groups, and relative abundance for sites in the Middle Fork Basin, Arkansas, September 2003 to December 2005.—Continued

[Tolerance values range from 0 (least tolerant) to 10 (most tolerant); cg, collector-gatherer; sc, scraper, pr, predator; cf, filterer; sh, shredder; mp, macrophyte piercer]

					Relative abundance, in percent																			
					Fall 2003					Spring 2004					Spring 2005					Fall 2005				
Class or order	Family or subfamily	Genus and species	Tolerance value[1]	Functional group	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)
Ephemeroptera	Isonychidae	*Isonychia*	3	cf	5.2	0.0	6.3	8.3	25.7	1.3	0.0	1.0	1.9	2.2	3.1	0.0	1.3	0.6	2.5	18.8	0.0	7.9	17.4	7.1
Ephemeroptera	Trichorythodidae	*Trichorythodes*	5	cg	1.1	0.0	0.8	2.4	0.0	0.0	0.0	0.0	0.6	0.0	1.3	0.7	1.7	6.7	0.0	0.0	1.6	1.6	8.0	6.7
Ephemeroptera	Leptophlebiidae	*Choroterpes*	3	cg	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ephemeroptera	Ephemerellidae	*Ephemerella*	2	cg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0
Ephemeroptera	Heptageniidae	*Rithrogenia*	1	cg	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	8.8	0.0	2.6	1.2	4.1	0.0	0.0	0.0	0.0	0.0
Ephemeroptera	Neoephemeridae	*Neoephemera*	2	cg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ephemeroptera	Potomanthidae	*Anthropotomus*	2	cg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Gastropoda	Pleuroceridae		6	sc	6.3	0.0	0.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gastropoda	Physidae		7	sc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Gastropoda	Planorbidae		7	sc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.4
Gastropoda	Viviparidae		6	sc	0.0	0.0	0.0	0.0	7.4	7.7	0.0	0.0	0.6	12.4	3.8	0.3	0.4	0.0	2.5	11.4	3.5	4.7	3.6	4.7
Gastropoda	Hydrobiidae		7	sc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
Isopoda	Asellidae	*Lirceus*	8	cg	0.6	21.2	3.9	1.2	0.0	0.0	15.4	13.9	6.2	0.0	1.3	44.0	14.1	16.5	3.3	0.0	20.9	17.3	1.4	0.4
Lepidoptera	Pyralidae	*Petrophila*	5	sh	0.6	1.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.8	2.2	0.0
Lepidoptera	Unknown		5	sh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0

Table 11. Benthic macroinvertebrate tolerance values, functional groups, and relative abundance for sites in the Middle Fork Basin, Arkansas, September 2003 to December 2005.—Continued

[Tolerance values range from 0 (least tolerant) to 10 (most tolerant); cg, collector-gatherer; sc, scraper, pr, predator; cf, filterer; sh, shredder; mp, macrophyte piercer]

					Relative abundance, in percent																			
					Fall 2003				Spring 2004					Spring 2005					Fall 2005					
Class or order	Family or subfamily	Genus and species	Tolerance value[1]	Functional group	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)
Lepidoptera	Tortricidae	*Archips*	5	sh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Megaloptera	Chorydalidae	*Chorydalus*	5	pr	7.5	0.0	4.7	9.5	4.4	9.0	0.0	2.0	2.5	1.1	3.8	0.0	1.3	0.6	2.5	1.1	0.0	0.0	0.0	1.2
Odonata	Coenagrionidae	*Argia*	8	pr	1.7	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.4
Odonata	Coenagrionidae	Unknown	9	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	2.4	0.0	0.0
Odonata	Coenagrionidae	*Ischnura*	10	pr	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Odonata	Coenagrionidae	*Enallagma*	9	pr	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Odonata	Gomphidae	*Stylogomphus*	4	pr	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0
Odonata	Gomphidae	Unknown	3	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0
Odonata	Gomphidae	*Gomphus*	6	pr	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Odonata	Gomphidae	*Hagenius*	4	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Odonata	Caleopterygidae	*Aeterina*	8	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Odonata	Caleopterygidae	*Caleopteryx*	8	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
Odonata	Caleopterygidae	*Hetaerina*	6	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Odonata	Lestidae	*Lestes*	9	pr	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oligochaeta			5	cg	2.3	0.0	3.9	1.8	3.7	0.0	0.0	3.0	1.9	2.8	5.0	0.3	3.0	0.6	2.5	2.8	0.8	0.8	5.1	3.2

Table 11. Benthic macroinvertebrate tolerance values, functional groups, and relative abundance for sites in the Middle Fork Basin, Arkansas, September 2003 to December 2005.—Continued

[Tolerance values range from 0 (least tolerant) to 10 (most tolerant); cg, collector-gatherer; sc, scraper, pr, predator; cf, filterer; sh, shredder; mp, macrophyte piercer]

					Relative abundance, in percent																			
					Fall 2003					Spring 2004					Spring 2005					Fall 2005				
Class or order	Family or subfamily	Genus and species	Tolerance value[1]	Functional group	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)
Bivalvia	Corbiculidae	*Corbicula*	6	cf	1.1	1.9	0.0	5.4	2.2	3.8	0.0	0.0	1.2	2.2	1.3	0.3	0.4	0.0	0.8	1.1	1.2	0.8	1.4	1.6
Bivalvia	Sphaeriidae		6	cf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	3.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
Plecoptera	Perlidae	*Neoperla*	1	pr	4.6	0.0	0.8	0.6	0.7	4.5	0.0	10.9	12.4	0.0	0.6	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Plecoptera	Perlidae		1	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
Plecoptera	Perlidae	*Eccoptura*	3	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Plecoptera	Perlidae	*Acroneuria*	2	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0
Plecoptera	Perlidae	*Agnetia*	0	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Plecoptera	Unknown	Unknown	2	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Plecoptera	Perlodidae		2	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Plecoptera	Perlodidae	*Isoperla*	2	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0
Plecoptera	Chloroperlidae	*Alloperla*	1	pr	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	5.7	0.7	3.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Plecoptera	Capniidae		1	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Plecoptera	Pteronarcyidae		1	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Plecoptera	Leuctridae		0.5	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.4	0.0	0.8	1.4	2.4
Plecoptera	Taeniopterygidae		5	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.3	0.4	18.9	28.3	19.4

Table 11. Benthic macroinvertebrate tolerance values, functional groups, and relative abundance for sites in the Middle Fork Basin, Arkansas, September 2003 to December 2005.—Continued

[Tolerance values range from 0 (least tolerant) to 10 (most tolerant); cg, collector-gatherer; sc, scraper, pr, predator; cf, filterer; sh, shredder; mp, macrophyte piercer]

					Relative abundance, in percent																			
					Fall 2003					Spring 2004					Spring 2005					Fall 2005				
Class or order	Family or subfamily	Genus and species	Tolerance value[1]	Functional group	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)
Plecoptera	Perlidae	*Perlesta*	5	pr	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	1.9	1.0	2.1	2.4	2.5	0.0	0.0	0.0	0.0	0.0
Trichoptera	Hydropsychidae	*Cheumatopsyche*	6	cf	0.6	19.2	3.1	2.4	1.5	23.7	26.9	17.8	23.0	25.3	3.8	22.5	9.8	10.4	32.0	2.8	10.6	10.2	2.9	2.0
Trichoptera	Hydropsychidae	*Macrostemum*	3	cf	0.6	0.0	0.0	0.6	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Trichoptera	Rhyacophilidae		1	pr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0
Trichoptera	Brachycentridae	*Micrasema*	1	sh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
Trichoptera	Limnephilidae		4	sh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0
Trichoptera	Hydroptilidae		6	mp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	2.1	1.2	0.0	0.0	0.4	0.0	0.0	0.0
Trichoptera	Philopotomidae	*Chimarra*	3	cf	2.3	4.8	5.5	6.0	2.9	1.9	3.8	0.0	3.7	0.0	1.3	0.7	4.3	0.0	0.0	2.3	0.4	2.4	0.7	4.0
Trichoptera	Helicopsychidae		5	sc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Trichoptera	Polycentropodidae	*Polycentropus*	4	pr	0.6	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0
Trichoptera	Psychomiidae	*Psychomia*	3	cg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

[1] From Barbour and others (1999) and Mandaville (2002).

Table 12. Benthic macroinvertebrate metric data for least-disturbed Ouachita Mountains ecoregion streams.

[Data are from Arkansas Department of Environmental Quality files, Little Rock, Arkansas, for 9 (fall) or 11 (spring) sites collected in 2002; streams are Little Missouri River, Caddo River, South Fork Saline River, Black Fork Fourche LaFave River, Cossatot River, and South Fork Ouachita River. HBI, Hilsenhoff biotic index; EPT, Ephemeroptera plus Plecoptera plus Trichoptera]

	Metric value				
Metric	**Minimum**	**25th percentile**	**Mean**	**75th percentile**	**Maximum**
		Spring			
HBI	3.35	3.71	3.92	4.24	4.54
Number of taxa (taxa richness)	16	19.5	21.5	23.0	28
Number of EPT taxa	10	11.0	12.3	14.0	14
Number of Diptera taxa	1	2.0	2.8	3.5	5
Number of intolerant taxa	5	5.0	7.4	8.5	12
EPT (relative abundance, in percent)	47.8	55.7	61.7	67.2	85.1
Diptera (relative abundance, in percent)	3.7	12.6	18.9	26.9	28.8
Chironomidae (relative abundance, in percent)	3.4	5.2	14.0	20.7	26.1
Isopoda (relative abundance, in percent)	0.0	0.0	0.7	0.9	2.8
Tolerant taxa (relative abundance, in percent)	0.0	0.9	2.9	3.7	7.5
Shredders (relative abundance, in percent)	0.0	0.7	3.3	4.7	8.8
Collectors (relative abundance, in percent)	31.3	37.9	48.7	57.7	70.6
Filterers (relative abundance, in percent)	0.9	2.0	6.5	6.0	25.0
Scrapers (relative abundance, in percent)	11.0	25.2	31.0	37.2	49.5
Predators (relative abundance, in percent)	2.9	7.3	10.3	13.3	18.7
		Fall			
HBI	3.73	4.27	4.36	4.54	4.81
Number of taxa (taxa richness)	15	16	20	22	26
Number of EPT taxa	7	8	9	9	11
Number of Diptera taxa	1	2	2	3	4
Number of intolerant taxa	3	4	5	5	6
EPT (relative abundance, in percent)	32.2	57.5	61.6	73.0	74.0
Diptera (relative abundance, in percent)	2.0	5.8	7.0	8.2	10.2
Chironomidae (relative abundance, in percent)	2.0	3.1	4.9	7.0	7.9
Isopoda (relative abundance, in percent)	0.0	0.0	0.0	0.0	0.0
Tolerant taxa (relative abundance, in percent)	3.0	3.9	11.4	19.4	27.1
Shredders (relative abundance, in percent)	0.0	0.0	0.3	0.0	1.2
Collectors (relative abundance, in percent)	26.7	29.4	38.8	48.0	50.4
Filterers (relative abundance, in percent)	4.1	4.7	10.1	13.3	23.6
Scrapers (relative abundance, in percent)	26.8	34.0	41.7	49.0	53.7
Predators (relative abundance, in percent)	3.1	6.3	9.1	12.6	18.6

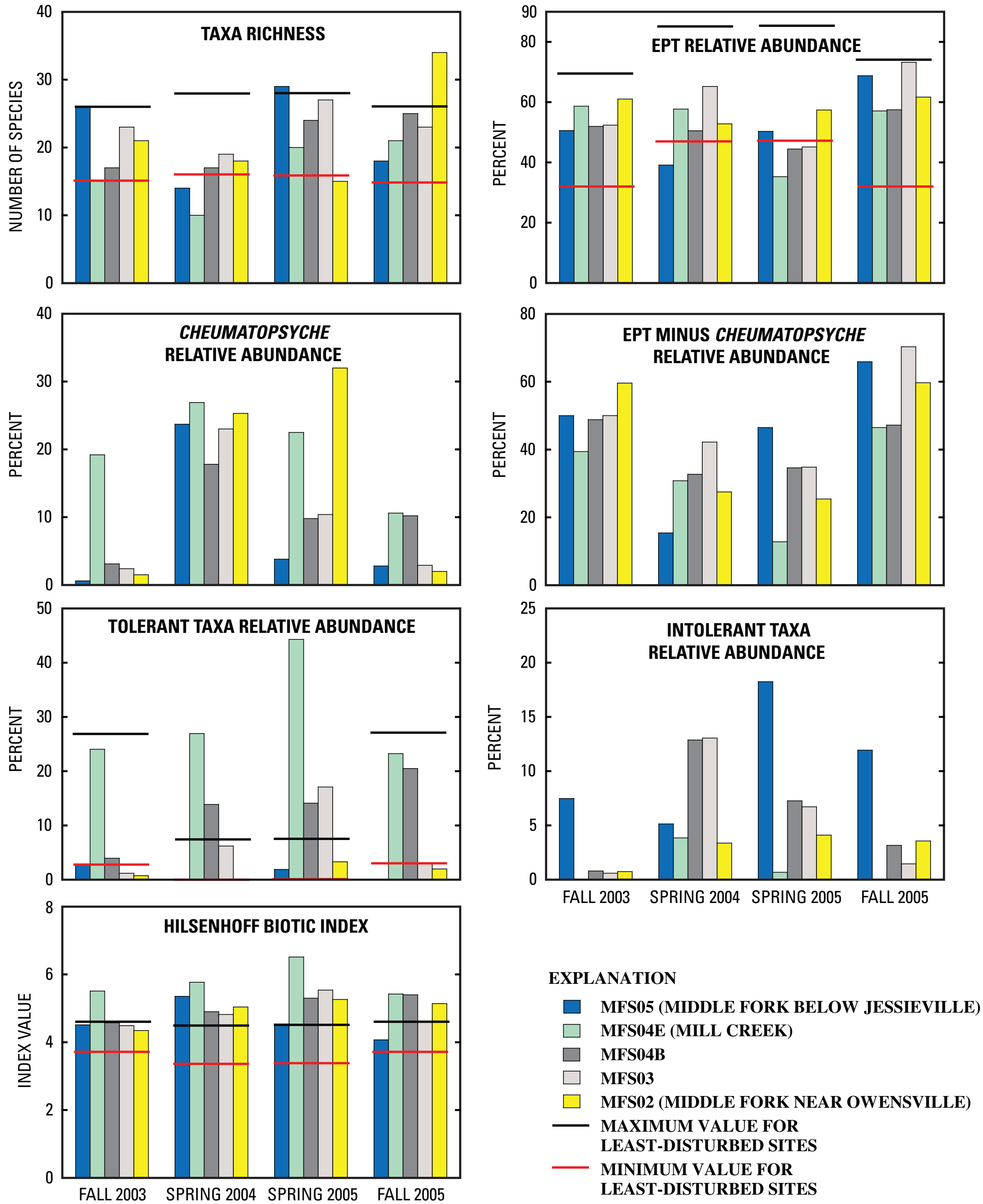

Figure 35. Selected benthic macroinvertebrate community metric values for sites in the Middle Fork Basin, Arkansas, and for least-disturbed Ouachita Mountains ecoregion sites.

Table 13. Bethic macroinvertebrate community metric values for sites in the Middle Fork Basin, Arkansas, September 2003 to December 2005.

[EPT, Ephemeroptera plus Plecoptera plus Trichoptera; Diversity Index, Shannon-Weiner logarithmic, base 10]

			Relative abundance, in percent					
Site	**Season**	**Taxa richness**	**EPT**	***Cheumatopsyche***	**EPT minus *Cheumatopsyche***	**Isopoda[1]**	**Chironomidae**	**Diptera**
MFS05 (Middle Fork below Jessieville)	Fall 2003	26	50.6	0.6	50.0	0.6	1.7	2.9
MFS04E (Mill Creek)		15	58.7	19.2	39.4	21.2	1.9	1.9
MFS04B		17	52.0	3.1	48.8	3.9	3.1	3.1
MFS03		23	52.4	2.4	50.0	1.2	1.8	3.0
MFS02 (Middle Fork near Owensville)		21	61.0	1.5	59.6	0.0	1.5	2.2
MFS05 (Middle Fork below Jessieville)	Spring 2004	14	39.1	23.7	15.4	0.0	13.5	20.5
MFS04E (Mill Creek)		10	57.7	26.9	30.8	15.4	3.8	15.4
MFS04B		17	50.5	17.8	32.7	13.9	2.0	2.0
MFS03		19	65.2	23.0	42.2	6.2	15.5	16.1
MFS02 (Middle Fork near Owensville)		18	52.8	25.3	27.5	0.0	6.2	9.0
MFS05 (Middle Fork below Jessieville)	Spring 2005	29	50.3	3.8	46.5	1.3	21.4	25.2
MFS04E (Mill Creek)		20	35.2	22.5	12.8	44.0	4.0	5.4
MFS04B		24	44.4	9.8	34.6	14.1	18.8	19.7
MFS03		27	45.1	10.4	34.8	16.5	20.7	22.0
MFS02 (Middle Fork near Owensville)		15	57.4	32.0	25.4	3.3	15.6	19.7
MFS05 (Middle Fork below Jessieville)	Fall 2005	18	68.8	2.8	65.9	0.0	2.8	3.4
MFS04E (Mill Creek)		21	57.1	10.6	46.5	20.9	1.2	2.4
MFS04B		25	57.5	10.2	47.2	17.3	2.4	2.4
MFS03		23	73.2	2.9	70.3	1.4	0.7	2.9
MFS02 (Middle Fork near Owensville)		34	61.7	2.0	59.7	0.4	8.7	14.2

Table 13. Benthic macroinvertebrate community metric values for sites in the Middle Fork Basin, Arkansas, September 2003 to December 2005.—Continued

[EPT, Ephemeroptera plus Plecoptera plus Trichoptera; Diversity Index, Shannon-Weiner logarithmic, base 10]

		Relative abundance, in percent					
Site	Season	Tolerant	Intolerant	Facultative	HBI	HBI class	Diversity Index
MFS05 (Middle Fork below Jessieville)	Fall 2003	2.9	7.5	87.4	4.51	good	3.87
MFS04E (Mill Creek)		24.0	0.0	71.2	5.51	fair	2.97
MFS04B		3.9	0.8	89.8	4.57	good	3.37
MFS03		1.2	0.6	92.3	4.49	good	3.71
MFS02 (Middle Fork near Owensville)		0.7	0.7	95.6	4.35	very good	3.32
MFS05 (Middle Fork below Jessieville)	Spring 2004	0.0	5.1	92.9	5.35	good	3.34
MFS04E (Mill Creek)		26.9	3.8	65.4	5.77	fair	2.93
MFS04B		13.9	12.9	73.3	4.90	good	3.33
MFS03		6.2	13.0	77.0	4.82	good	3.35
MFS02 (Middle Fork near Owensville)		0.0	3.4	96.6	5.04	good	3.29
MFS05 (Middle Fork below Jessieville)	Spring 2005	1.9	18.2	78.6	4.54	good	4.15
MFS04E (Mill Creek)		44.3	0.7	54.4	6.51	fairly poor	2.44
MFS04B		14.1	7.3	74.4	5.30	good	3.74
MFS03		17.1	6.7	76.2	5.54	fair	3.75
MFS02 (Middle Fork near Owensville)		3.3	4.1	92.6	5.26	good	3.17
MFS05 (Middle Fork below Jessieville)	Fall 2005	0.0	11.9	85.8	4.07	very good	3.41
MFS04E (Mill Creek)		23.2	0.0	76.4	5.42	good	2.74
MFS04B		20.5	3.1	74.0	5.40	good	3.72
MFS03		2.9	1.4	94.9	4.59	good	3.51
MFS02 (Middle Fork near Owensville)		2.0	3.6	90.5	5.14	good	4.10

Table 13. Benthic macroinvertebrate community metric values for sites in the Middle Fork Basin, Arkansas, September 2003 to December 2005.—Continued

[EPT, Ephemeroptera plus Plecoptera plus Trichoptera; Diversity Index, Shannon-Weiner logarithmic, base 10]

Site	Season	Relative abundance, in percent					
		Scrapers	Filterers	Collector/gatherers	Clingers	Herpobenthos	Haptobenthos
MFS05 (Middle Fork below Jessieville)	Fall 2003	52.9	9.8	20.7	69.0	16.1	82.8
MFS04E (Mill Creek)		40.4	26.0	28.8	74.0	25.0	74.0
MFS04B		57.5	15.0	22.0	77.2	15.7	82.7
MFS03		42.9	23.2	22.0	71.4	17.9	82.1
MFS02 (Middle Fork near Owensville)		47.8	33.8	11.8	73.5	11.0	79.4
MFS05 (Middle Fork below Jessieville)	Spring 2004	31.4	37.8	17.3	58.3	17.3	71.8
MFS04E (Mill Creek)		19.2	30.8	26.9	53.8	30.8	69.2
MFS04B		38.6	18.8	26.7	62.4	19.8	76.2
MFS03		21.1	29.8	32.9	56.5	25.5	72.7
MFS02 (Middle Fork near Owensville)		43.3	30.3	20.8	67.4	12.4	74.2
MFS05 (Middle Fork below Jessieville)	Spring 2005	20.8	14.5	47.2	44.0	34.6	61.0
MFS04E (Mill Creek)		23.2	24.8	50.0	47.3	50.0	49.3
MFS04B		24.8	16.7	48.3	50.0	38.5	60.3
MFS03		15.9	12.2	62.2	42.1	47.0	53.0
MFS02 (Middle Fork near Owensville)		16.4	39.3	39.3	70.5	22.1	75.4
MFS05 (Middle Fork below Jessieville)	Fall 2005	36.9	25.0	6.8	50.6	8.5	79.0
MFS04E (Mill Creek)		55.9	12.2	26.8	64.6	26.8	68.9
MFS04B		28.3	21.3	24.4	44.9	24.4	70.9
MFS03		21.7	23.2	21.7	46.4	19.6	76.8
MFS02 (Middle Fork near Owensville)		21.3	19.8	32.0	35.2	34.8	60.1

Table 13. Benthic macroinvertebrate community metric values for sites in the Middle Fork Basin, Arkansas, September 2003 to December 2003.—Continued

[EPT, Ephemeroptera plus Plecoptera plus Trichoptera; Diversity Index, Shannon-Weiner logarithmic, base 10]

Site	Season	Dominant taxa	Percent dominant taxa	Codominant taxa	Percent codominant taxa
MFS05 (Middle Fork below Jessieville)	Fall 2003	*Stenonema*	19.0	*Stenelmis*	14.4
MFS04E (Mill Creek)		*Stenonema*	28.9	*Lirceus*	21.2
MFS04B		*Stenonema*	26.8	*Stenelmis*	18.1
MFS03		*Stenelmis*	17.9	*Stenonema*	17.3
MFS02 (Middle Fork near Owensville)		*Isonychia*	25.7	*Stenonema*	24.3
MFS05 (Middle Fork below Jessieville)	Spring 2004	*Cheumatopsyche*	23.7	*Stenelmis* and Chironomidae	13.5
MFS04E (Mill Creek)		*Cheumatopsyche*	26.9	*Stenonema*	19.2
MFS04B		*Stenelmis*	19.8	*Cheumatopsyche*	17.8
MFS03		*Cheumatopsyche*	23.0	*Stenonema* and Chironomidae	15.5
MFS02 (Middle Fork near Owensville)		*Cheumatopsyche*	25.3	*Stenelmis*	15.7
MFS05 (Middle Fork below Jessieville)	Spring 2005	Chironomidae	21.4	*Rithrogena*	8.8
MFS04E (Mill Creek)		*Lirceus*	44.0	*Cheumatopsyche*	22.5
MFS04B		Chironomidae	18.8	*Lirceus*	16.5
MFS03		Chironomidae	20.7	*Lirceus*	16.5
MFS02 (Middle Fork near Owensville)		*Cheumatopsyche*	32.0	Chironomidae	15.6
MFS05 (Middle Fork below Jessieville)	Fall 2005	*Isonychia*	18.8	*Stenonema*	16.5
MFS04E (Mill Creek)		*Stenonema*	43.3	*Lirceus*	20.9
MFS04B		*Cheumatopsyche*	18.9	*Lirceus*	17.3
MFS03		*Cheumatopsyche*	28.3	*Isonychia*	17.4
MFS02 (Middle Fork near Owensville)		*Cheumatopsyche*	19.4	*Caenis*	11.1

[1] All Isopoda in these samples were *Lirceus*.

enrichment (Smith, 2001). The dominance or codominance of *Cheumatopsyche*, Chironomidae, *Lirceus, Rithrogena*, and *Caenis* in many of the samples at all of the other sites indicates some disturbance from nutrients or sedimentation throughout the basin.

Tolerance Measures

Tolerant taxa relative abundance varied among sites and temporally (fig. 35, table 13). The minimum tolerant taxa relative abundance (0.0 percent) occurred at MFS05 in spring 2004 and fall 2005 and at MFS02 in spring 2004. The maximum (44.3 percent) occurred at MFS04E in spring 2005. During each of the four sampling periods, the highest tolerant taxa relative abundance occurred at MFS04E; generally the second highest tolerant taxa relative abundance occurred at MFS04B and the relative abundance of tolerant taxa decreased as the distance downstream from Mill Creek increased. Lowest tolerant taxa relative abundance during a sampling period occurred at MFS02 or MFS05.

Tolerant taxa relative abundances at MFS04E in the spring 2004 and spring 2005 samples were greater than values for least-disturbed streams in the Ouachita Mountains ecoregion (fig. 35); values at the two closest sites downstream from Mill Creek were substantially higher than expected in the spring 2005 samples. This indicates that the wastewater-treatment plant effluents may be having an adverse effect on macroinvertebrate communities near the discharge point. However, in the two fall periods, comparison of Middle Fork tolerant taxa relative abundance values to those for the least-disturbed sites indicated that communities at all Middle Fork Basin sites were not adversely affected.

Intolerant taxa relative abundances showed a similar but opposite response to that shown by tolerant taxa. The highest relative abundances of intolerant taxa typically occurred at MFS05. The lowest relative abundances typically occurred at MFS04E and intermediate relative abundances occurred downstream from Mill Creek.

Lirceus is a relatively common tolerant taxon at sampled sites. *Lirceus* were present in all but four samples collected during this study (table 13). The maximum *Lirceus* relative abundance (44.0 percent) occurred at MFS04E in spring 2005. During each of the four sampling periods the highest relative abundance (ranging from approximately 15 to 44 percent) occurred at MFS04E. The second highest *Lirceus* relative abundance generally occurred downstream from MFS04E at MFS04B and relative abundances decreased to values similar to those upstream from Mill Creek at MFS03 and MFS02.

Cheumatopsyche (a genus of caddisflies sometimes considered relatively tolerant of organic enrichment) relative abundance varied among sites and seasonally (fig. 35, table 13). *Cheumatopsyche* taxa generally have a tolerance value of 5 to 7, depending upon region (Barbour and others, 1999; Mandaville, 2002), which is dramatically higher than most other Trichoptera (caddisflies), and, therefore, often are excluded from EPT metrics. Some *Cheumatopsyche* become very abundant in streams subjected to moderate levels of pollution from nutrients (Hauer and Stanford, 1982). The minimum *Cheumatopsyche* relative abundance (0.6 percent) occurred at MFS05 in fall 2003 and the maximum (32.0 percent) occurred at MFS02 in spring 2005. During three of the four sampling periods the highest *Cheumatopsyche* relative abundance occurred at MFS04E. Lowest *Cheumatopsyche* relative abundance occurred at MFS05 during two of the sampling periods. *Cheumatopsyche* relative abundance generally was lower in the fall than in the spring.

EPT minus *Cheumatopsyche* (EPT-C) relative abundance varied among sites and seasonally (fig. 35, table 13). The minimum EPT-C relative abundance (12.8 percent) occurred at MFS04E in spring 2005 and the maximum (70.3 percent) occurred at MFS03 in fall 2005. During three of the four sampling periods the lowest EPT-C relative abundance occurred at MFS04E and during the other sampling period EPT-C relative abundance was lowest at MFS05. Highest EPT-C relative abundance during a sampling period occurred at MFS02, MFS03, and MFS05. EPT-C relative abundance generally was higher in the fall than in the spring.

Hilsenhoff biotic index (HBI) values ranged from 4.07 (very good and indicative of less perturbation, MFS05 in fall 2005) to 6.51 (fairly poor, at MFS04E in spring 2005). Typically, HBI values were categorized as good to very good at mainstem sites and fair at MFS03 and MFS04E (fig. 35, table 13). Values typically were higher (indicative of more perturbation) in the spring and lower (indicative of less perturbation) in the fall.

HBI values for sites downstream from the wastewater-treatment plant effluent discharge point usually were greater than values for least-disturbed streams in the Ouachita Mountains ecoregion (fig. 35) indicating that conditions in the basin were having a detrimental effect on macroinvertebrate communities. HBI values generally were most different from values for least-disturbed streams in samples collected in spring 2004. During all sampling periods, samples from MFS04E varied the greatest from values for the least-disturbed sites.

Trophic Measures

Scraper relative abundance (which is expected to decrease with environmental perturbation) varied among sites and seasonally (table 13). The minimum scraper relative abundance (15.9 percent) occurred at MFS03 in spring 2005 and the maximum (57.5 percent) occurred at MFS04B in fall 2003. During two of the four sampling periods the lowest scraper relative abundance occurred at MFS04E. During the other sampling periods scraper relative abundance was lowest at MFS03 or MFS02. Highest scraper relative abundance during a sampling period occurred at MFS04E, MFS04B, and MFS02. Scraper relative abundance generally was higher in the fall than in the spring.

Filterer relative abundance (which is expected to increase with environmental perturbation) varied substantially; however, there was little consistent pattern among sites or seasonally (table 13). The minimum filterer relative abundance (9.8 percent) occurred at MFS05 in fall 2003 and the maximum (39.3 percent) occurred at MFS02 in spring 2005. During two of the four sampling periods, the highest filterer relative abundance occurred at MFS05 and during the other sampling periods filterer relative abundance was highest at MFS04E or MFS02.

Fish Community

Streams in the Ouachita Mountains typically have a rich and diverse fish fauna; 75 native species occur in streams in the area of the Ouachita Mountains containing the upper section of the Saline River (Warren and Hlass, 1999). More than 30 species were collected from most of the sampled sites (table 14). The number of species collected increased as drainage area increased and ranged from 21 (MFS04E) to 42 (MFS02). Shannon-Weiner diversity (a measure of richness and numeric evenness) also increased with increases in drainage area. The least diversity occurred at MFS04E downstream from the Mill Creek wastewater-treatment plant.

At all sites most individuals were minnows (Cyprinidae) and sunfish (Centrarchidae); more than 70 percent of individuals were minnows or sunfish at all sites (table 15). More than 50 percent of all individuals were minnows at all but one site (MFS05). The highest relative abundance of minnows occurred at MFS04E (72.6 percent), and 48.4 percent of all fish collected at this site were central stonerollers (table 15). Central stonerollers are an algae-eating fish (a primary trophic-level species). The relative abundance of central stonerollers previously has been observed to be relatively high at sites in upland areas of northern Arkansas with elevated nutrient inputs and other disturbances (Arkansas Department of Environmental Quality, 1997; Petersen, 1998; Petersen, 2004).

The relative abundance of sensitive species ranged from 9.7 (MFS04E) to 37.5 percent (MFS04B) (table 15). The relative abundance of sensitive species at MFS04E was substantially lower than relative abundances at other sites (ranging from 26.4 to 37.5 percent).

The relative abundance of key individuals (individuals of fish species that normally are dominant species within the important groups such as fish families or trophic feeding levels) also was lowest at MFS04E (12.7 percent) (table 15). The relative abundance of key individuals ranged from 27.7 to 68.5 percent at other sites.

CSI scores for the five sites in the Middle Fork Basin (table 16) indicated that fish communities at the sites were fairly similar to highly similar to communities of least-disturbed sites in the Ouachita Mountains ecoregion (tables 15 and 16; fig. 36). Scores ranged from 14 at MFS04E to 32 at MFS03.

The fish community at MFS04E was fairly similar to communities of least-disturbed streams in the Ouachita Mountains ecoregion (table 16). This site had an overabundance of minnows, and a distinct lack of darters and sensitive species (table 15). The community was dominated by two minnow species (central stonerollers and striped shiners; table 14), which reduced the scores of all of the other metrics. The large stoneroller percentage also caused a reduction in the primary feeder metric score. This stream receives effluent from a wastewater-treatment facility which, occasionally, is 100 percent of the streamflow. In addition, the natural flow regime has been altered because of dams. It is likely that these two influences on the stream have caused the shift in the fish community in Mill Creek.

The fish community at MFS05 was generally similar to communities at least-disturbed Ouachita Mountains ecoregion streams (table 16). The low relative abundance of minnows and darters and the high relative abundance of sunfishes caused this site to be listed as only generally similar. However, almost 90 percent of the habitat available at this site was pool habitat and less than 4 percent of the habitat was riffle. This could explain the shift in the community at this site.

The fish communities at the other three sites (MFS04B, MFS03, and MFS02) were highly similar to communities at least-disturbed Ouachita Mountains ecoregion streams (table 16). These sites had CSI scores of 30 to 32, at or near the maximum possible CSI score. All are downstream from Mill Creek, indicating that Mill Creek has little effect on the composition of fish communities of the Middle Fork. Other potential stresses on the lower reaches of the Middle Fork appear to be having little effect on the composition of the fish communities.

Implications

This report describes the results of one of several studies of the Middle Fork currently (2007) being conducted by various entities; the results of one other study are described in Pugh and others (2007). The other studies may yield results that could help place the water-quality, streamflow, and biological results described in this report in a broader context. For example, many stream reaches are wider and shallower than expected, possibly as a result of changes in sediment delivery or streamflow (Pugh and others, 2007). The wider, shallower stream geometry could affect biological communities.

Water-quality dynamics in the Middle Fork are controlled by both activities in the basin and processes that occur in the stream. Point sources (such as wastewater-treatment plants) and nonpoint sources of nutrients that could affect water quality occur in the Middle Fork Basin. Water-quality data indicate that nutrient concentrations generally were higher in downstream sections of the Middle Fork (downstream from the wastewater-treatment plant that discharges into Mill Creek) and that concentrations decreased downstream with increasing distance from Mill Creek. Nutrient concentrations also generally are higher during periods of high streamflow than at other

Table 14. Relative abundance of fish collected at sites in the Middle Fork Basin, Arkansas, September to October 2003.

[Relative abundance is the number of individuals divided by the number of total individuals in the sample, as a percent; <, less than]

Scientific name	Common name	Relative abundance, in percent: MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)
Ichthyomyzon spp.	Lamprey ammocoetes[1]	<0.1	0.0	<0.1	<0.1	0.2
Lepisosteus osseus	Longnose gar	0.0	0.0	0.0	0.0	<0.1
Dorosoma cepedianum	Gizzard shad[1]	0.0	0.0	<0.1	0.3	1.2
Esox americanus	Redfin pickerel	<0.1	0.0	<0.1	<0.1	0.1
Campostoma anomalum	Central stoneroller[1]	4.0	48.4	23.8	31.1	20.5
Cyprinella whipplei	Steelcolor shiner[2]	0.0	0.0	0.0	0.0	0.1
Luxilus chrysocephalus	Striped shiner	1.4	20.3	6.4	9.2	6.1
Lythrurus umbratilis	Redfin shiner	0.2	0.0	0.0	0.0	0.1
Notropis boops	Bigeye shiner[2,3]	23.9	3.5	24.9	8.3	14.9
Pimephales notatus	Bluntnose minnow[1]	6.4	0.4	3.0	5.0	10.1
Erimyzon oblongus	Creek chubsucker	0.3	0.0	<0.1	0.0	0.5
Hypentelium nigricans	Northern hog sucker[2,3]	1.2	0.6	1.1	1.6	1.7
Minytrema melanops	Spotted sucker	0.0	0.0	0.0	<0.1	0.8
Moxostoma carinatum	River redhorse[2]	0.0	0.0	0.0	0.2	0.3
Moxostoma duquesnei	Black redhorse[2]	2.1	0.9	2.5	2.3	3.6
Moxostoma erythrurum	Golden redhorse	0.9	0.1	3.2	0.4	2.7
Ameiurus melas	Black bullhead	0.0	0.0	0.0	<0.1	0.0
Ameiurus natalis	Yellow bullhead	1.3	0.5	0.4	0.3	0.1
Noturus lachneri	Ouachita madtom[2]	0.7	2.4	0.6	0.2	0.0
Noturus miurus	Brindled madtom	0.2	0.0	0.0	0.0	0.1
Noturus nocturnus	Freckled madtom[3]	0.0	0.8	0.7	1.5	1.3
Aphredoderus sayanus	Pirate perch	0.7	0.3	0.4	0.1	0.1
Fundulus catenatus	Northern studfish[2]	0.8	0.1	0.4	0.1	0.1
Fundulus olivaceus	Blackspotted topminnow	1.2	0.1	0.7	0.1	0.6
Gambusia affinis	Western mosquitofish	0.0	0.0	<0.1	0.2	<0.1
Labidesthes sicculus	Brook silverside	1.4	0.0	0.6	0.4	1.8
Ambloplites ariommus	Shadow bass[2]	0.3	0.0	0.1	0.4	0.1
Lepomis cyanellus	Green sunfish	3.8	5.3	1.9	3.4	1.6
Lepomis gulosus	Warmouth	0.0	0.0	0.0	0.0	0.1
Lepomis macrochirus	Bluegill	0.8	3.4	0.9	0.2	1.3
Lepomis megalotis	Longear sunfish[3]	41.7	7.4	18.5	16.1	19.4
Lepomis microlophus	Redear sunfish	0.0	1.0	0.0	0.0	0.1
Lepomis miniatus	Redspotted sunfish	0.3	0.0	0.2	0.1	0.2
Micropterus dolomieu	Smallmouth bass[2,3]	1.5	0.4	0.4	0.2	0.2
Micropterus punctulatus	Spotted bass	0.2	0.0	0.2	0.7	0.5
Micropterus salmoides	Largemouth bass	0.1	0.0	0.3	0.2	0.5

Table 14. Relative abundance of fish collected at sites in the Middle Fork Basin, Arkansas, September to October 2003.—Continued

[Relative abundance is the number of individuals divided by the number of total individuals in the sample, as a percent; <, less than]

Scientific name	Common name	Relative abundance, in percent				
		MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)
Etheostoma blennioides	Greenside darter[2]	1.2	1.5	4.8	8.4	3.8
Etheostoma collettei	Creole darter	1.7	2.4	1.0	4.1	1.0
Etheostoma gracile	Slough darter[2]	0.0	0.0	0.0	0.0	<0.1
Etheostoma nigrum	Johnny darter[2]	0.1	0.0	0.0	0.0	0.2
Etheostoma stigmaeum	Speckled darter[2]	0.0	0.0	0.0	0.2	<0.1
Etheostoma whipplei	Redfin darter[2]	1.1	0.3	1.5	2.1	2.5
Etheostoma zonale	Banded darter[2]	0.4	0.0	1.2	2.3	1.1
Percina caprodes	Logperch	0.0	0.0	<0.1	0.2	<0.1
Sander vitreus	Walleye[2]	0.0	0.0	0.0	<0.1	0.0
	Number of species	**31**	**21**	**32**	**36**	**42**
	Total specimens	**1,849**	**795**	**3,064**	**1,815**	**2,728**
	Level of effort (seconds)	**4,526**	**3,058**	**3,073**	**2,796**	**2,989**

[1] Primary trophic feeder.

[2] Sensitive species.

[3] Key species.

Table 15. Fish community metric values for sites in the Middle Fork Basin, Arkansas, September to October 2003.

[All values are relative abundance (percent) except species richness, community structure index (CSI), and diversity index; diversity index is Shannon-Weiner logarithmic base 10]

Metric	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)
Species richness	31	21	32	36	42
CSI score	20	14	30	32	30
Cyprinidae (minnows)	35.9	72.6	58.1	53.6	51.9
Ictaluridae (catfish, including madtoms)	2.2	3.7	1.7	2.1	1.5
Centrarchidae (sunfish, including black bass	48.7	17.5	22.6	21.2	24.1
Percidae (darters)	4.6	4.2	8.5	17.3	8.6
Sensitive species	33.3	9.7	37.5	26.4	28.7
Primary trophic feeders	10.5	48.8	26.9	36.4	32.0
Key species	68.5	12.7	45.6	27.7	37.6
Diversity index	2.97	2.57	3.25	3.39	3.67
Central stonerollers	4.0	48.4	23.8	31.1	20.5

Table 16. Fish community structure index (CSI) scores for sites in the Middle Fork Basin, Arkansas, September to October 2003.

[Degree of similarity categories are relative to least-disturbed streams in the Ouachita Mountains ecoregion; FS, fairly similar, scores of 9-16; GS, generally similar, scores of 17-24; HS, highly similar, scores of 25-32]

Characteristic	CSI scores				
	MFS05 (Middle Fork below Jessieville)	MFS04E (Mill Creek)	MFS04B	MFS03	MFS02 (Middle Fork near Owensville)
Cyprinidae	0	0	4	4	4
Ictaluridae	4	4	4	4	4
Centrarchidae	0	4	4	4	4
Percidae	0	0	2	4	2
Sensitive species	4	0	4	4	4
Primary trophic feeders	4	2	4	4	4
Key species	4	2	4	4	4
Diversity index	4	2	4	4	4
Total score	20	14	30	32	30
Degree of similarity	GS	FS	HS	HS	HS

times. Consequently, nutrient loads (mass) transported in the Middle Fork are higher during the winter and spring months because of the higher streamflow and higher concentrations during these months. Data for suspended sediment, TSS, and turbidity (which are related, but not equivalent measures) indicate spatial and hydrologic patterns of values that are similar to those for nutrients. Mean flow-weighted concentrations of nutrients and suspended sediment at sites in the Middle Fork Basin were intermediate to relatively undeveloped sites across the Nation and in Arkansas and to the Illinois River in northwestern Arkansas.

E. coli bacteria concentrations indicate that agricultural land use may have an effect on the water quality of the Middle Fork. Concentrations tend to be substantially higher in samples collected during periods of high streamflow. This indicates that runoff from agricultural land may also affect nutrient concentrations in the Middle Fork (in addition to the effect of discharge from the wastewater-treatment plant).

Concentrations of some trace metals (boron, copper, and zinc) were highest in Mill Creek. Concentrations of these metals were somewhat elevated in samples from sites downstream from Mill Creek.

Several biological metrics associated with Middle Fork Basin sites vary in a reasonably consistent manner. These metrics and the communities that they represent could be affected by water quality or other habitat factors. Habitats (all of which were classified as suboptimal habitats as measured by RBP total habitat scores) did not vary substantially among sites or in a way that suggests that physical habitat is the major factor causing the biological community differences among these sites; nonetheless, degraded habitats could be having a detrimental but similar effect on all sites. However, several biological metrics vary at Middle Fork Basin sites in a way that is similar to the variation in many of the water-quality variables—elevated or depressed at the Mill Creek site (relative to the site upstream from Mill Creek) and returning to or approaching values associated with the site upstream from Mill Creek. For example, the relative abundance of macroinvertebrates considered intolerant of environmental disturbance and the relative abundance of sensitive fish species typically were substantially lower at the Mill Creek site than at other sites in the basin. Values for most metrics that were compared to values for least-disturbed Ouachita Mountains streams were similar to the least-disturbed values.

Overall, these water-quality, streamflow, and biological data indicate several conclusions:

- water quality is being affected by point and nonpoint sources;
- water quality is somewhat poorer than in least-disturbed streams regionally and nationally, but substantially better than water quality in a stream in northwestern Arkansas (the Illinois River south of Siloam Springs) that is affected by a number of point and nonpoint sources of nutrients, sediment, and other potential contaminants;
- aquatic habitat quality is suboptimal and is most often detrimentally affected by factors related to sedimentation, bank stability, or riparian vegetative zone width;

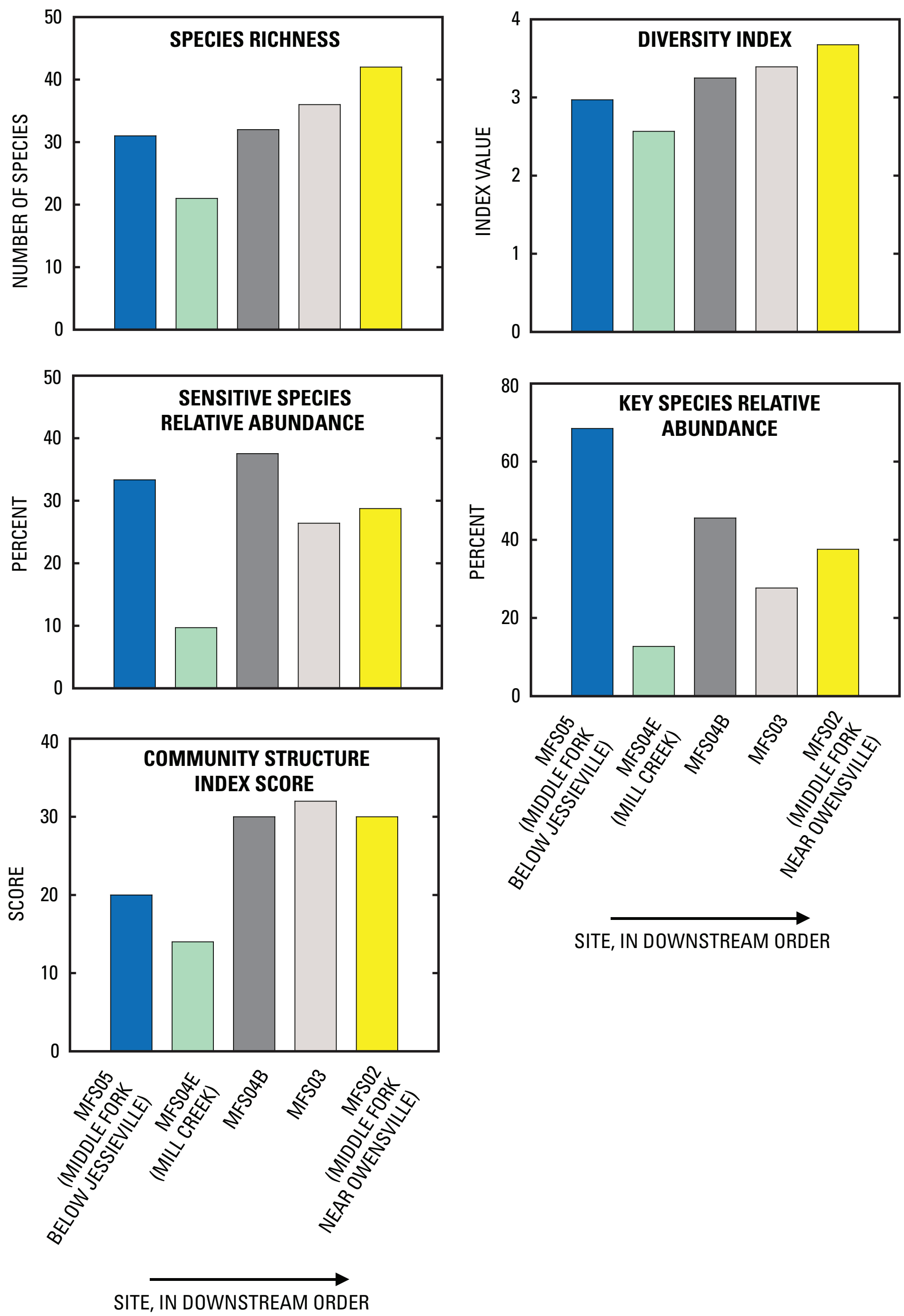

Figure 36. Selected fish community metric values for sites in the Middle Fork Basin, Arkansas, September to October 2003.

• several aquatic biological metrics at more than one site are affected by the effluent from the Mill Creek wastewater-treatment plant;

• biological metric values often were similar to values for least-disturbed Ouachita Mountains ecoregion streams; and

• biological communities also could be affected by other sources of contaminants or by habitat degradation.

Implications for rural landowners, suburban landowners, government entities, and natural-resource managers include that water quality, habitat, and aquatic biological communities in the Middle Fork Basin are the result of the interaction of several factors. Included in a list of potential factors are wastewater-treatment plant effluent, land use and land-use practices, construction activities, and unpaved roads. In addition, although data indicate that macroinvertebrate and fish communities are somewhat affected by water-quality degradation, these effects are greatest near the Mill Creek wastewater-treatment plant, and communities farther downstream are similar to communities upstream from Mill Creek or to communities from least-disturbed sites. For example, fish CSI scores at all three sites downstream from Mill Creek are highly similar to scores for least-disturbed streams in the Ouachita Mountains ecoregion; macroinvertebrate metric scores are more variable, but many were typical of scores for communities of least-disturbed Ouachita Mountains ecoregion streams. Habitat scores (total and individual variables) indicate that habitat factors related to riparian corridors and sedimentation are in less than optimal condition.

Summary

The primary purpose of this report is to describe the water quality and biological characteristics (fish and benthic macroinvertebrate communities) of the Middle Fork (and selected tributaries) and to compare the water quality and biological communities to factors that potentially affect the ecology of the stream. A secondary purpose of this report is to examine relations between continuously measured data (specific conductance, turbidity, streamflow) and total dissolved solids (TDS), total phosphorus, fecal indicator bacteria, and suspended-sediment concentrations (SSC) to evaluate the usefulness of using the continuous data as surrogates for total dissolved solids, nutrient, fecal indicator bacteria, and SSC.

Water-quality samples were collected and streamflow was measured by the U.S. Geological Survey (USGS) at three sites in the Middle Fork Basin between October 2003 and October 2006. Arkansas Department of Environmental Quality (ADEQ) collected discrete synoptic water-quality samples from eight sites between January 2004 and October 2006. ADEQ also sampled fish and benthic macroinvertebrate communities at five sites.

Streamflow varied annually among the three streamflow sites from October 2003 to October 2006. The mean annual streamflow for Brushy Creek near Jessieville (MFS06) was 0.72 m^3/s for water years 2004-2006. The Middle Fork below Jessieville (MFS05) had a mean annual streamflow of 1.11 m^3/s for water years 2004-2006. The Middle Fork near Ownesville (MFS02), the most downstream site, had a mean annual streamflow of 3.01 m^3/s. The greatest streamflows at the three sites generally occurred in the winter and spring and the least in the summer.

Nutrient dynamics in the Middle Fork are controlled by activities in the basin and processes that occur in the stream. Point sources and nonpoint sources of nutrients occur in the Middle Fork Basin that could affect the water quality. Nitrogen and phosphorus concentrations were significantly greater ($p<0.05$) at MFS02 compared to concentrations at MFS06 and MFS05 located upstream for all of the samples collected from October 2003 to October 2006. Nutrient concentrations generally were significantly greater during high-flow conditions compared to base-flow conditions. Synoptic data collected from January 2004 to October 2006 demonstrated that nitrogen and phosphorus concentrations were generally greatest in Mill Creek (site MFS04E) and in the Middle Fork immediately downstream from the confluence with Mill Creek (MFS04) with decreasing concentrations at sites farther downstream in the Middle Fork. The site in Mill Creek is located downstream from a wastewater-treatment plant discharge and concentrations at sites farther downstream probably had lesser concentrations because of dilution effects and from algal uptake.

MFS02 had the greatest annual nutrient, total organic carbon, and suspended-sediment loads among the three sites for water years 2004-2006. The loads at MFS02 were greatest mainly because MFS02 had the greatest annual streamflow among the three sites. Monthly nutrient loads indicated that most of the mass of nutrients that were transported past the three sites occurred in the spring and winter and the least amount of mass was transported in the summer.

Flow-weighted nutrient concentrations were computed for the three sites and were compared to 82 relatively undeveloped sites identified across the Nation, to the Alum Fork of the Saline River near Reform, Arkansas, and the Illinois River south of Siloam Springs, Arkansas. Annual flow-weighted nutrient concentrations for MFS06, MFS05, and MFS02 were greater than relatively undeveloped sites, but were substantially less than the Illinois River south of Siloam Springs, Arkansas, a site influenced by numerous point and nonpoint sources of nutrients.

Overall, *E. coli* bacteria concentrations were greater at MFS05 than at MFS06 and MFS02, and fecal coliform bacteria concentrations were greatest at MFS06 for October 2003 to October 2006. Fecal indicator bacteria concentrations were significantly greater for samples collected during high-flow conditions compared to samples collected during base-flow conditions at all three sites.

SSCs did not vary significantly among MFS06, MFS05, and MFS02 for all the samples collected from October 2003 to October 2006. SSCs were significantly greater in samples

collected during high-flow conditions compared to samples collected during base-flow conditions. Synoptic samples indicated TSS distributions varied from upstream to downstream in the Middle Fork between January 2004 and October 2006. Overall, TSS values were the greatest at MFS02 and decreased at sites upstream and downstream.

MFS02 had the greatest annual suspended-sediment loads and MFS06 had the least suspended-sediment loads, mainly because the annual mean streamflow was greatest at MFS02 and the least at MFS06. Monthly loads showed the greatest loads transported past the three sites occurred in the spring and winter and the least in the summer months. Mean flow-weighted SSCs for MFS06, MFS05, and MFS02 were greater than the mean flow-weighted concentration for the Alum Fork near Reform and substantially less than the flow-weighted concentration for the Illinois River south of Siloam Springs.

Turbidity measured when water-quality samples were collected showed little variation between MFS06, MFS05, and MFS02. The State standard primary value (10 NTU) was exceeded in 9 samples from MFS06, 11 samples collected at MFS05, and 12 samples from MFS02. The State standard stormflow value (18 NTU) was exceeded in 5 samples from MFS06, 7 samples collected at MFS05, and 10 samples from MFS02. Turbidity data varied from upstream to downstream at the eight synoptic sites in the Middle Fork Basin from January 2004 to October 2006, similar to the patterns of the TSS data.

Continuously measured turbidity and streamflow data were compared to total phosphorus, fecal indicator bacteria, and suspended-sediment concentrations at site MFS02 (Middle Fork near Owensville) to potentially provide continuous estimates of total phosphorus, fecal indicator bacteria, and suspended-sediment concentrations. Total phosphorus and fecal indicator bacteria did not show a good relation with turbidity and streamflow except at turbidities greater than 20 FTNU and streamflows greater than 5.7 m^3/s. SSC demonstrated a relatively good relation with turbidity and streamflow, especially at higher turbidity and streamflow.

Dissolved-oxygen concentrations at MFS02 varied seasonally from October 2003 to October 2006. Dissolved-oxygen concentrations generally were greater in the winter and spring when temperatures were lower and streamflow was greater compared to the summer and fall when higher water temperatures and less streamflow occurred. The dissolved-oxygen concentrations at MFS02 were less than 6 mg/L during 189 days from October 2003 to October 2006, mainly in the summer and fall. Diurnal fluctuations in dissolved-oxygen concentrations were noticeable, particularly during base-flow conditions in late summer and fall. Similar to dissolved oxygen, pH demonstrated diurnal fluctuations, with higher pH during the day, and lower pH at night. The fluctuations are the result of the same processes that produce the diurnal changes in dissolved oxygen during base-flow conditions.

Synoptic samples were analyzed for 19 different trace metals. Several of the metals generally had concentrations near or below the laboratory reporting level, including aluminum, antimony, arsenic, beryllium, cadmium, chromium, cobalt, lead, nickel, selenium, silver, thallium, and vanadium. Concentrations of boron, copper, and zinc had the greatest concentrations in Mill Creek, at the site below the wastewater-treatment discharge (site MFS04E), compared to the other sites in the Middle Fork from January 2004 to October 2006.

Biological samples (benthic macroinvertebrate and fish communities) were collected and habitat variables were measured at various times between September 2003 and October 2005 at five sites. Physical habitat variables were measured at each site using the USEPA rapid bioassessment protocol (RBP) to provide data that could be used to assess biological or ecological integrity, and pebble counts were conducted to determine bed material particle-size distribution in wadeable reaches.

Although there was some variation of total habitat scores among sites and temporally, the habitats at all sites during all seasons uniformly were classified as suboptimal. Marginal or poor scores for individual habitat variables most often were associated with substrate embeddedness, bank stability, and riparian vegetative zone width. Scores for sediment deposition, embeddedness, and velocity/depth regime variability (all of which could be affected by excess sediment) generally were lower than scores for other habitat variables.

Several biological metrics associated with Middle Fork Basin sites varied in a reasonably consistent manner. These metrics and the communities that they represent could be affected by water quality or other habitat factors. Habitats (all of which were classified as suboptimal habitats as measured by RBP total habitat scores) did not vary substantially among sites or in a way that suggests that physical habitat is the major factor causing the biological community differences among these sites; nonetheless, degraded habitats could be having a detrimental but similar effect on all sites. However, several biological metrics varied at Middle Fork Basin sites in a way that is similar to the variation in many of the water-quality variables—elevated or depressed at the Mill Creek site (relative to the site upstream from Mill Creek) and then returning to or approaching values associated with the site upstream from Mill Creek. For example, the relative abundance of macroinvertebrates considered intolerant of environmental disturbance and the relative abundance of sensitive fish species typically were substantially lower at the Mill Creek site than at other sites in the basin. Values for Middle Fork Basin sites for most metrics that were compared to values for least-disturbed Ouachita Mountains ecoregion streams were similar to the values for the least-disturbed sites.

Implications for rural landowners, suburban landowners, government entities, and natural-resource managers include that water quality, habitat, and aquatic biological communities in the Middle Fork Basin are the result of the interaction of several factors. Among the list of potential factors are wastewater-treatment plant effluents, land use and land-use practices, construction activities, and unpaved roads. In addition, although data indicate that macroinvertebrate and fish communities are somewhat affected by water-quality degradation, these effects are greatest near the Mill Creek wastewater-treatment plant and communities farther downstream are similar to communities upstream from Mill Creek or to communities from least-disturbed sites. For example, fish community structure index (CSI) scores at all three sites downstream from Mill Creek are highly similar to scores for least disturbed streams in the Ouachita Mountains ecoregion; macroinvertebrate metric scores are more variable, but many were typical of scores for communities of least-disturbed Ouachita Mountains ecoregion streams. Habitat scores (total and individual variables) indicate that habitat factors related to riparian corridors and sedimentation are in less than optimal condition.

References Cited

Allen, J.D., 1995, Stream ecology, structure and function of running waters: London, Great Britain, Chapman and Hall, 388 p.

American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1995, Standard Methods for the examination of water and wastewater (19th ed.): Washington D.C., American Public Health Association, variously paginated.

Arkansas Department of Environmental Quality, 1997, Illinois River Water Quality, Macroinvertebrate and Fish Community Survey, Benton and Washington Counties, Arkansas: Arkansas Department of Environmental Quality Report WQ97-03-01, variously paginated.

Arkansas Natural Heritage Commission, 2005a, Fishes of special concern, accessed November 27, 2006 at URL www.naturalheritage.com/pdf/ANIMALS-Fishes-2005.pdf.

Arkansas Natural Heritage Commission, 2005b, Invertebrates of special concern, accessed November 27, 2006 at URL www.naturalheritage.com/pdf/ANIMALS-Inverts-2005.pdf

Arkansas Pollution Control and Ecology Commission, 2004, Regulation Number 2, Regulation establishing water quality standards for surface waters of the State of Arkansas: Arkansas Pollution Control and Ecology Commission MDocket No. 03-003-R, 107 p.

Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B., 1999, Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish (2nd Ed.): Washington, D.C., U.S. Environmental Protection Agency, Office of Water, EPA 841-B-99-002, variously paginated.

Bennett, C., Giese, J., Keith, W., McDaniel, R., Maner, M., O'Shaughnessy, N., and Singleton, R., 1987, Physical, chemical, and biological characteristics of least-disturbed reference streams in Arkansas' ecoregions, volume I: Data compilation: Arkansas Department of Pollution Control and Ecology, 685 p.

Brossett, T.H., Schrader, T.P., and Evans, D.A., 2005, Water resources data, Arkansas, water year 2004: U.S. Geological Survey AR 04-1, 460 p.

Brossett, T.H., Schrader, T.P., and Evans, D.A., 2006, Water resources data, Arkansas, water year 2005: U.S. Geological Survey AR 05-1, 437 p.

Christensen, V.G., Jian, Xiaodong, and Ziegler, A.C., 2000, Regression analysis and real-time water-quality monitoring to estimate constituent concentrations, loads, and yields in the Little Arkansas River, south-central Kansas, 1995-99: U.S. Geological Survey Water-Resources Investigations Report 00-4126, 36 p.

City-data.com, 2006, Hot Springs Village, Arkansas accessed November 27, 2006 at URL www.city-data.com/city/Hot-Springs-Village-Arkansas.html

Clark, G.M., Mueller, D.K., and Mast, M.A., 2000, Nutrient concentrations and yields in undeveloped stream basins of the United States: Journal of American Water Resources Association, v. 4, no. 36, p. 844-867.

Cohn, T.A., 1995, Recent advances in statistical methods for the estimation of sediment and nutrient transport in rivers, U.S. National Report to the International Union Geodesy and Geophysics, 1991-1994: Reviews of Geophysics, Supplement 33, p. 1117-1123.

Cohn, T.A., Cauldes, D.L., Gilroy, E.J., Zynjuk, L.D., and Summers, R.M., 1992, The validity of a simple long-linear model for estimating fluvial constituent loads entering Chesapeake Bay: Water Resources Research, v. 28, no. 9, p. 2353-2363.

Cohn, T.A., DeLong, L.L., Gilroy, E.J., Hirsch, R.M., and Wells, D.K., 1989, Estimating constituent loads: Water Resources Research, v. 25, no. 5, p. 237-942.

Crump, B.G, and Warren, M.L., Jr., 1999, Diversity of aquatic insects, in Ozark-Ouachita Highlands Assessment, aquatic conditions, report 3 of 5: U.S. Department of Agriculture Forest Service, General Technical Report SRS-33, 317 p.

Davidson, C. L. and Clem, S.A., 2003, Comparison of 100-organism vs. 300-organism subsampling for use with ADEQ's aquatic macroinvertebrate sampling methodology: Arkansas Department of Environmental Quality Report WQ03-02-01, 14 p.

Dufour, A.P., 1977, Escherichia coli – The fecal coliform, in Hoadley, A.W., and Dutka, B.J., eds., Bacterial indicators/health hazards associated with water, 1977: American Society for Testing and Materials, ASTM STP 635, p. 48-58.

Fenneman, N.M., 1938, Physiography of eastern United States: New York, McGraw-Hill Book Co., Inc., 714 p.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, 217 p.

Freiwald, D.A., 1984, Average annual precipitation and runoff for Arkansas, 1951-80: U.S. Geological Survey Water-Resources Investigations Report 84-4363, 1 sheet.

Galloway, J.M. and Green, W.R., 2004, Water-quality assessment of Lakes Maumelle and Winona, Arkansas, 1991 through 2003: U.S. Geological Survey Scientific Investigations Report 2004-5182, 46 p.

Gray, J.R. and Glysson, G.D., eds., 2003, Proceedings of the Federal interagency workshop on turbidity and other sediment surrogates, April 30-May 2, 2002, Reno, Nevada: U.S. Geological Survey Circular 1250, 56 p.

Gray, J.R., Glysson, G.D., Turcios, L.M., and Schwarz, G.E., 2000, Comparability of suspended-sediment concentration and total suspended solids data: U.S. Geological Water-Resources Investigations Report 00-4191, 14 p.

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of Water-Resources Investigations Reports, book 5, chap. C1, 58 p.

Haley, B.R, 1976, Geologic map of Arkansas: U.S. Geological Survey, 1 sheet

Harris, J.L., 1999, Diversity of mussels, in Ozark-Ouachita Highlands Assessment, aquatic conditions, report 3 of 5: U.S. Department of Agriculture Forest Service, General Technical Report SRS-33, 317 p.

Hauer, F. R. and Stanford. J.A., 1982, Ecology and life histories of three net-spinning caddisfly species (Hydropsychidae: Hydropsyche) in the Flathead River, Montana: Freshwater Invertebrate Biology, v. l, no. 4, p. l8-29

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Amsterdam, Netherlands, Elsevier, 522 p.

Hem, J.D., 1989, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

Hilsenhoff, W.L, 1987, An improved index of organic stream pollution: Great Lakes Entomologist, v. 20, p. 31-39.

Hunrichs, R.A., 1983, Identification and classification of perennial streams of Arkansas: U.S. Geological Survey Water-Resources Investigations Report 83-4063, 1 sheet.

Mandaville, S.M., 2002, Benthic macroinvertebrates in freshwaters--taxa tolerance values, metrics, and protocols: Soil & Water Conservation Society of Metro Halifax, variously paginated.

Montana Department of Environmental Quality, 2006, Sample collection, sorting, and taxonomic identification of benthic macroinvertebrates: Montana Department of Environmental Quality, WQPBWQM-009 (Rev# 02), variously paginated.

Myers, D.N., and Wilde, F.D., 1999, Biological indicators: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A7, variously paginated.

National Park Service, 2006, National rivers inventory, accessed November 29, 2006 at URL www.nps.gov/ncrc/programs/rtca/nri

Omernik, J.M. and Gallant, A.L., 1987, Ecoregions of the south central states: U.S. Environmental Protection Agency, 1 sheet.

Ott, R.L., 1993, An introduction to statistical methods and data analysis: Belmont, California, Duxbury Press, 1051 p.

Petersen, J.C., 1998, Water-quality assessment of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma—fish communities in streams and their relations to selected environmental factors: U.S. Geological Survey Water-Resources Investigations Report 98-4155, 34 p.

Petersen, J.C., 2004, Fish communities of the Buffalo River Basin and nearby basins of Arkansas and their relation to selected environmental factors, 2001-2002: U.S. Geological Survey Scientific Investigations Report 2004-5119, 93 p.

Pugh, A. L, Garday, T. J., and Redman, R., 2007, Geomorphic characterization of the Middle Fork Saline River: Garland, Perry, and Saline Counties, Arkansas: U.S. Geological Survey Scientific Investigations Report 2007-5152, 65 p.

Rantz, S.E, and others, 1982, Measurement and computation of streamflow: Volume 1. Measurement of stage and discharge and Volume 2. Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, 631 p.

Runkel, R.L., Crawford, C.G., and Cohn, T.A., 2004, Load estimator (LOADEST): A FORTRAN program for estimating constituent loads in streams and rivers: U.S. Geological Survey Techniques and Methods, book 4, chap. A5, 69 p.

Schillinger, J.E., and Gannon, J.J., 1985, Bacterial adsorption and suspended particles in urban stormwater: Journal of Water Pollution Control Federation, v. 57, no. 5, p. 384-389.

Shannon, C.E. and Weaver, W., 1949, The mathematical theory of communication: Urbana, Ill., The University of Illinois Press, p. 19-27, 82-83, 104-107.

Smith, D. G. 2001, Pennak's freshwater invertebrates of the United States (4th ed.): New York, John Wiley, 638 p.

U.S. Census Bureau, 2006, U.S. Census Bureau fact finder, accessed November 28, 2006 at URL http://factfinder.census.gov/

U.S. Fish and Wildlife Service, 2006, Arkansas fatmucket, accessed November 29, 2006 at URL www.fws.gov/endangered/i/f/saf13.html

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9, available online at http://pubs.water.usgs.gov/twri9A.

U.S. Geological Survey, 2007, Water Resources of the United States – 2006 annual data report: U.S. Geological Survey Water-Data Report WDR-US-2006 accessed April 20, 2007 at URL http://web10capp.er.usgs.gov/adr06_lookup/search.jsp

Wagner, R.J., Boulger, R.W., Oblinger, C.J., Smith, B.A., 2006, Guidelines and standard procedures for continuous water-quality monitors: station operation, record computation, and data reporting: U.S. Geological Survey Techniques and Methods 1-D3, 51 p. and 8 attachments, accessed May 5, 2007, at URL http://pubs.water.usgs.gov/tm1d3

Wahl, K.L., and Wahl, T.L., 1995, Determining the flow of Comal Springs at New Braunsfel, Texas: Conference of Water Resources Engineering, August 16-17, 1995, San Antonio, Texas: American Society of Civil Engineers, p. 77-86.

Warren, M.L, Jr., and Hlass, Lisa, 1999, Diversity of fishes, in Ozark-Ouachita Highlands Assessment, aquatic conditions, report 3 of 5: U.S. Department of Agriculture Forest Service, General Technical Report SRS-33, 317 p.

Warren, M.L., Jr., Robison, H.W., and Tinkle, Karen, 1999, Diversity of crayfishes, in Ozark-Ouachita Highlands Assessment, aquatic conditions, report 3 of 5: U.S. Department of Agriculture Forest Service, General Technical Report SRS-33, 317 p.

Warren, M.L., Jr. and Tinkle, Karen, 1999, Endangered, threatened, and other aquatic species of special concern, in Ozark-Ouachita Highlands Assessment, aquatic conditions, report 3 of 5: U.S. Department of Agriculture Forest Service, General Technical Report SRS-33, 317 p.

Washington, H.G., 1984, Diversity, biotic and similarity indices, a review with special relevance to aquatic ecosystems: Water Resources, v. 18, no. 6, p.. 653-694.

Wilde, F.D., and Radke, D.B., 1998, Field measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, variously paginated.

Wilde, F.D., Radke, D.B., Gibs, J., Iwatsubo, R.T., 1998, Cleaning of equipment for water sampling: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A3, variously paginated.

Yanchosek, J.J. and Hines, M.S., 1979, Drainage area of streams in Arkansas—Ouachita River Basin: U.S. Geological Survey Open-File Report 80-334, 87 p.

Publishing support provided by
Lafayette Publishing Service Center

For more information concerning the research described in the report:

U.S. Geological Survey
Arkansas Water Science Center
401 Hardin Road
Little Rock, AR 72211-3528
(501) 228-3600

http://ar.water.usgs.gov

USGS

Galloway and others—**Water Quality and Biological Characteristics of the Middle Fork of the Saline River, Arkansas**—Scientific Investigations Report 2008-5018

Printed on recycled paper