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Evaluation of Four Structural Best Management Practices for Highway Runoff in Beaufort and Colleton Counties, South Carolina, 2005–2006

Scientific Investigations Report 2008–5150

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

Cover photograph. View of Factory Creek in Beaufort, South Carolina, from structural best management practice 1.

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch per hour (in/h)	0 .0254	meter per hour (m/h)
inch per year (in/yr)	25.4	meter per year (m/s)
feet per second (ft/s)	0.3048	meter per second (m/s)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)

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

Concentrations of chemical constituents in sediment are given in micrograms per gram (µg/g) or milligrams per kilogram (mg/kg).

Concentrations of bacteria in water are reported in colonies per 100 milliliters (col/100 mL).

Concentrations of bacteria in sediment are reported in colonies per 100 grams (col/100 g) of sediment.

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

$$°F = (1.8 \times °C) + 32$$

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

$$°C = (°F - 32)/1.8$$

Turbidity is reported in nephelometric turbidity units (NTU).

Acronyms and Abbreviations

A	Cross-sectional area of the wetted channel
ADT	Average daily traffic
ANOVA	Analysis of variance
ASTM	American Society for Testing and Materials
BMP	Best management practice
BOD_5	Biochemical oxygen demand
CCC	Criteria continuous concentration
CMC	Criteria maximum concentration
COD	Chemical oxygen demand
DQO	Data-quality objective
E. coli	*Escherichia coli*
ED	Event duration
EDF	Empirical distribution function
EMC	Event-mean concentration
EMQ	Event-mean flow
ER	Efficiency ratio
g/event	Grams per event
h	Hour
ISL	Individual storm load
kg/event	Kilograms per event
K-S test	Kolmogorov-Smirnov test
L_i	Event-mean load
LRL	Laboratory reporting level
LT-MDL	Long-term method detection level
MEP	Maximum extent practicable
MS4	Large municipal separate storm sewer system
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric turbidity units
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
PAH	Polycyclic aromatic hydrocarbon
p-values	Probability values
Q	Flow
QC	Quality control
RPD	Relative percentage difference
SCDOT	South Carolina Department of Transportation
SCDHEC	South Carolina Department of Health and Environmental Control
SSC	Suspended sediment concentration
TKN	Total Kjeldahl nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TSS	Total suspended solids
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
V	Average flow velocity

Evaluation of Four Structural Best Management Practices for Highway Runoff in Beaufort and Colleton Counties, South Carolina, 2005–2006

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Abstract

From 2005 to 2006, the U.S. Geological Survey worked cooperatively with the South Carolina Department of Transportation in Beaufort and Colleton Counties, South Carolina, to assess the performance of four different structural devices that served as best management practices (BMPs). These structural devices were installed to mitigate the effects of stormwater runoff on waterways near State roads. The South Carolina Department of Transportation is required to address the quality of stormwater runoff from State-maintained roadways as part of the National Pollutant Discharge Elimination System stormwater program mandated in the Clean Water Act.

The performance assessment of the four structural best management practices was based on stormflow measurements and chemical analyses of stormwater-quality samples collected during a 20-month period from March 2005 through October 2006, which represented a range of seasons and rainfall intensities. A total of 49 sample sets that included stormwater from the inlet and outlet of each of the four structural devices were collected as flow-weighted composites to provide event-mean concentrations of suspended sediment, nutrients, and trace metals. In addition, each set included grab samples that were collected to provide the first flush concentrations of oil and grease and fecal-indicator bacteria.

A tiered statistical approach was used in the data analysis. Performances of the four structural BMPs were assessed individually based on how well the BMPs were able to reduce the selected constituents. Descriptive statistics and nonparametric Wilcoxon signed rank tests were applied to event-mean concentrations and loads in the water entering the inlet and in the water leaving the outlet of each BMP for each constituent to identify if significant reductions occurred. If significant reductions occurred, the BMP was considered efficient at reducing the constituent. To quantify efficiency, a simplistic approach was applied to compute mean and geometric mean efficiency ratios for the significantly reduced constituents in each BMP. Each BMP performance was ranked based on its computed efficiency ratios, however, the computed efficiency ratios were not sufficient to determine if statistical differences occurred among the performances of the four BMPs. Consequently, a more complex approach was used to apply statistical comparison tests to reduction percentages computed for individual storms (a modified removal efficiency of individual storm-load approach) to determine if differences in event-mean concentrations, loads, and reduction percentages for significantly reduced constituents occurred among the four structural BMPs.

Overall, the four BMPs were efficient in reducing suspended-sediment event-mean concentrations and loads in the stormwater entering the inlets of the BMPs to significantly lower event-mean concentrations before discharging the stormwater from the outlets. The cumulative suspended-sediment event-mean load in stormwater entering the BMPs from the storms sampled during the data-collection period was 1,026 kilograms (1.13 tons). The BMPs removed a cumulative suspended-sediment load of 558 kilograms (0.62 ton). The BMPs tended to preferentially trap the sand-size fraction of the sediment, thereby releasing a greater percentage of fine-grained (silt and clay) sediment in the water discharging from the outlet. The preferential trapping of fine-grained sediment by the BMPs could explain, at least in part, why the BMPs were not successful at significantly reducing these constituents.

In general, the four BMPs were not successful at significantly reducing fecal bacteria, nutrients, and total organic carbon (including associated properties of biochemical oxygen demand and chemical oxygen demand). Three of the four BMPs significantly lowered oil and grease concentrations before the stormwater discharged from the outlet. Additionally, only one BMP was effective at reducing all total and particulate trace-metal event-mean concentrations and particulate trace-metal event-mean loads in stormwater entering the inlet. With respect to trace-metal event-mean concentrations, however, minimal or no improvement in outlet water quality was observed for the four BMPs, and the majority of the outlet concentrations were above the established acute and chronic aquatic-life criteria by the South Carolina Department of Health and Environmental Control.

No statistical differences among the removal-efficiency of the four BMPs were determined for suspended-sediment event-mean concentrations, total suspended solids event-mean concentrations, or oil and grease concentrations. These statistical findings indicated that differences among the mean

efficiency ratios were not significant among the BMPs for these properties. Additionally, one BMP generally had statistically greater removal efficiency for total and particulate cadmium, copper, lead, and zinc than one or more of the other three BMPs.

Statistical correlation tests were unable to identify a single major factor that would explain the high variability in inlet and outlet water concentrations and in removal efficiencies estimated by reduction percentage. Highly variable inlet and outlet concentrations for each BMP that produced highly variable reduction percentages were probably the result of multiple interacting factors, particularly rainfall intensity, the amount of rainfall between sampling events, traffic density, and the period of time since the last maintenance (clean out) of the BMP.

Introduction

As part of the National Pollutant Discharge Elimination System (NPDES) permit program mandated in the Clean Water Act, the South Carolina Department of Transportation (SCDOT) is required to address the quality of stormwater runoff from State-maintained roadways. Stormwater runoff from State roadways is considered to be discharge from large municipal separate storm-sewer systems (MS4) by the NPDES program of the South Carolina Department of Health and Environmental Control (SCDHEC) and, therefore, requires development of a stormwater-management program that meets the standard of "reducing pollutants to the maximum extent practicable (MEP)" (South Carolina Department of Health and Environmental Control, 2001). To mitigate the effects of runoff from State roadways to area waterbodies, the SCDOT has installed structural best management practices (BMPs) throughout South Carolina. Structural BMPs are constructed facilities or measures that have been determined to be the most effective, practical means of preventing or reducing pollution from non-point sources. Examples of SCDOT-installed BMPs include grassed waterways, detention ponds, and vendor-supplied structural systems. Many of the vendor-supplied structural systems incorporate some combination of filtration media, hydrodynamic sediment removal, oil and grease removal, or screening to remove pollutants from stormwater.

Previous research and engineering design studies have assessed the ability of stormwater-treatment BMPs to reduce pollutant concentrations and loadings in stormwater (Barbaro, 2001; Smith, 2002). However, the ability to relate findings from past research to SCDOT sites is limited because of noted inconsistencies in performance studies (Strecker and others, 2000; U.S. Environmental Protection Agency, 2002a, 2002b). One common problem with past research has been characterizing event-mean concentrations (EMCs) and evaluating whether a measured difference between BMPs is statistically significant. This problem exists because the studies did not compensate for differences in environmental factors among sites or for the high degree of variability in EMCs. Highly variable EMCs cannot be characterized using the generally low (usually 3) number of samples collected, thereby creating a BMP performance dataset that is not sufficient in determining a statistically significant difference in BMPs.

The U.S. Geological Survey (USGS), in cooperation with the SCDOT, conducted an investigation to evaluate the performance of three BMPs (BMP1, BMP2, and BMP3) in the Beaufort, S.C., area and one BMP (BMP4) at the I-95 rest area near Walterboro, Colleton County, S.C., that represent four different vendor-supplied systems (fig. 1): BMP1 by Stormceptor,[1] BMP2 by CDS Technologies, BMP3 by Vortechnics, and BMP4 by CrystalStream Technologies. These devices will be referred to as BMPs1–4 hereafter (table 1). Structural BMPs are designed to capture sediment, total suspended solids, trash, organic material, and floatable oil and grease from stormwater runoff before releasing the stormwater to waterways. In addition, other pollutants that adsorb to sediments and particulates also can be trapped by the structure. Although many types of

[1] Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Table 1. Description of four structural best management practice (BMP) sites in Beaufort and Colleton Counties, South Carolina.

[m², square meter; U/S, upstream; D/S, downstream]

Station identification number	Site description	Drainage area, m² (acres)	Number of samples collected
322518808039571	BMP1 inlet U/S side U.S. Hwy 21 near Beaufort, S.C.	9,060 (2.24)	13
322518808039572	BMP1 outlet U/S side U.S. Hwy 21 near Beaufort, S.C.		
322517008039551	BMP2 inlet D/S side U.S. Hwy 21 near Beaufort, S.C.	4,490 (1.11)	12
322517008039552	BMP2 outlet D/S side U.S. Hwy 21 near Beaufort, S.C.		
322525908038381	BMP3 inlet east corner S.C. Hwy 802 near Beaufort, S.C.	23,900 (5.90)	12
322525908038382	BMP3 outlet east corner S.C. Hwy 802 near Beaufort, S.C.		
324756508046271	BMP4 inlet I-95 Southbound Rest Area near Walterboro, S.C.	11,200 (2.77)	12
324756508046272	BMP4 outlet I-95 Southbound Rest Area near Walterboro, S.C.		

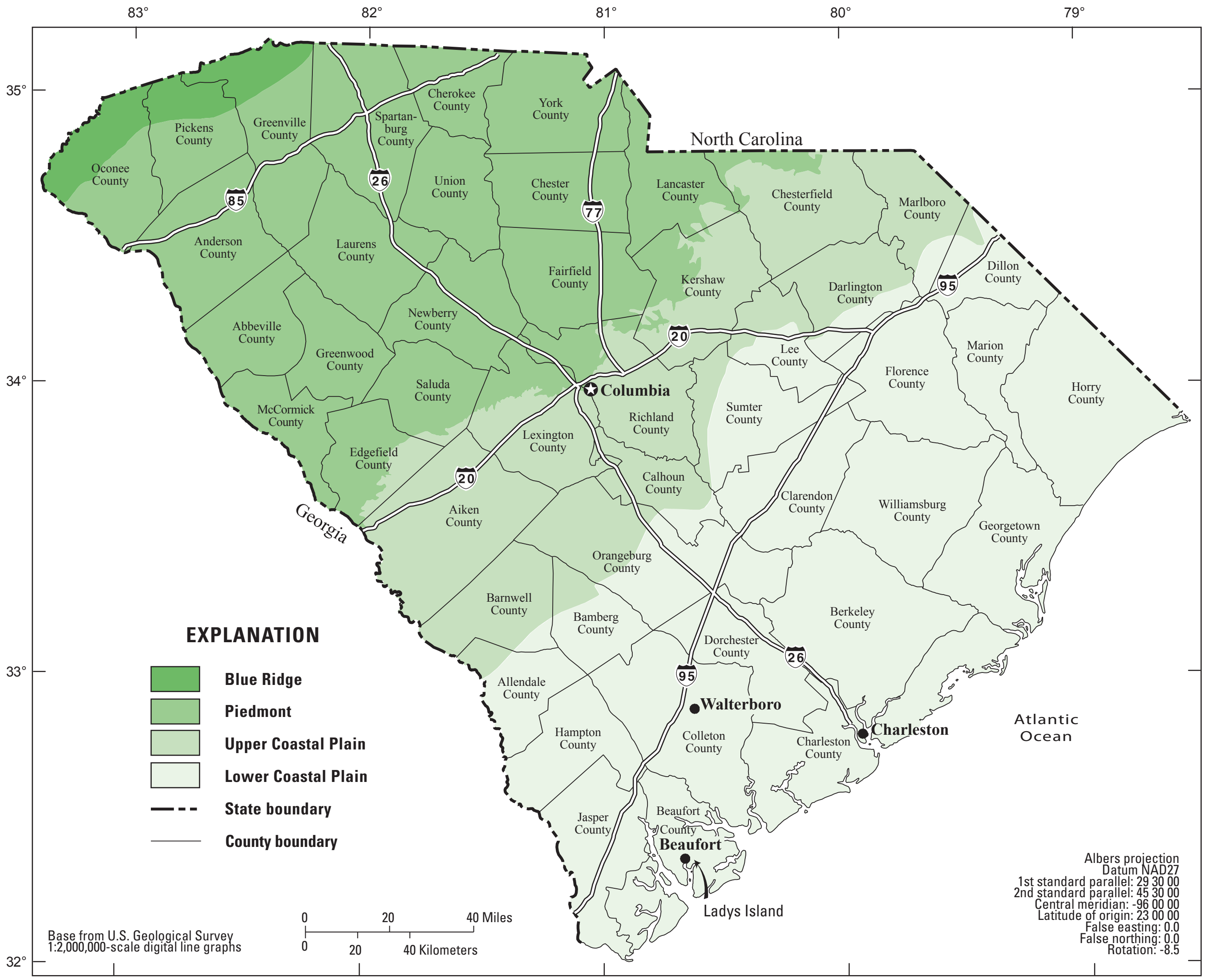

Figure 1. Study area in Beaufort and Colleton Counties, South Carolina.

hydrodynamic separation systems were available commercially, the four BMPs evaluated for this investigation were selected because (1) the SCDOT previously had installed these devices according to manufacturer's specifications, (2) the major types of available hydrodynamic separation systems were represented (U.S. Environmental Protection Agency, 1999), and (3) they were near each other.

A subset of data collected in this investigation also could be used by the SCDOT to characterize stormwater quality at these sites to meet the NPDES permit requirements. The results of this investigation could be applicable to sites throughout the Southeast where similar conditions exist.

Purpose and Scope

The purpose of this report is to document the effectiveness of the BMP devices in reducing suspended sediment, selected metals, nutrients, and organics concentrations by comparing estimated removal efficiencies. The results provide the SCDOT with quantitative data to evaluate the effectiveness of these BMPs at enhancing stormwater-runoff quality. This information can be used by the SCDOT and other State, local, and Federal agencies in the selection of appropriate BMPs for future installation.

The specific objectives of this report are to:

1. determine event-mean concentrations of constituents in water entering and leaving the BMPs,
2. compute event-mean loads of constituents in water entering and leaving the BMPs,
3. estimate the removal efficiency of the BMPs for selected constituents,
4. compare removal efficiencies of constituents among BMPs, and
5. evaluate the relation of water-quality constituents to average daily traffic (ADT) data through correlation analysis.

Description of Study Area

The study area is located in the lower Coastal Plain Physiographic Province in Beaufort and Colleton Counties near the Atlantic Coast of South Carolina (fig. 1). The Coastal Plain Province is characterized by gently sloping topography drained by low-gradient streams that are commonly tidally influenced near the coast.

Beaufort County encompasses an area of 587 square miles (mi^2) and is bordered to the west by Jasper County and to the north by Hampton and Colleton Counties. The eastern side of Beaufort County borders the Atlantic Ocean for 30 miles. Three of the four BMP sites are located on Ladys Island, which is south of Beaufort, S.C. (fig. 2). Storm runoff in this portion of the study area flows to the Beaufort River, which is an estuarine system.

Colleton County encompasses an area of 1,056 mi^2 and is bordered to the east by Dorchester and Charleston Counties, to the north by Bamberg County, to the west by Hampton County, and to the south by Beaufort County and the Atlantic Ocean. One of the four BMP sites is located at the I-95 South rest area, south of Walterboro, S.C. (fig. 3). Storm runoff in this part of the study area flows to non-tidal, freshwater streams.

The climate of the study area is characterized by hot, humid summers and moderate winters. The monthly mean temperature ranges from about 50 degrees Fahrenheit (ºF) in January to about 83 ºF in July (National Oceanic and Atmospheric Administration, 2007). Precipitation in the study area averages about 52 inches per year (in/yr) (National Oceanic and Atmospheric Administration, 2007). During the 2005–2006 data-collection period, annual precipitation ranged from 22.8 to 50.5 inches (in.) in Beaufort, S.C., and from 24.4 to 26.6 in. in Walterboro, S.C. (National Oceanic and Atmospheric Administration, 2007).

Data-Collection Methods

The approach of this investigation included an initial data-collection period followed by the final data compilation and analysis. From March 2005 through October 2006, the USGS operated data-collection stations at four BMP structures in Beaufort and Colleton Counties, South Carolina (table 1). The data-collection effort included monitoring the quantity of rainfall and stormflow and collecting stormwater- and sediment-quality samples. Established guidelines and protocols were used to ensure the quality of the resulting data.

Rainfall and Stormflow Data

At each of the BMP sites, the USGS established a gaging station to continuously monitor flow and water level (stage). Calibrated electromagnetic flowmeters were installed in the inlet pipes upstream from the BMPs according to manufacturers' and USGS guidelines (Carter and Davidian, 1968; Kennedy, 1984; Marsh-McBirney, 2003). Average flow velocity (V) in feet per second (ft/s) and cross-sectional area of the wetted channel (A) in square feet (ft^2) obtained from the pipe dimensions and measured water level were used to calculate flow (Q) in cubic feet per second (ft^3/s). Average velocity is determined using the surface velocity (measured by the sensor) and empirical equations. Flow is calculated by using a continuity equation:

$$Q = V \times A, \tag{1}$$

where all variables are as previously defined.

Mean flow for each storm event (event-mean flow or EMQ) was computed and used in the data analysis. Water levels in the treatment chamber of each BMP were measured by a pressure transducer. Rainfall data were collected with tipping bucket raingages at BMP2 and BMP4. Data were collected at 5-minute intervals and stored in a datalogger onsite. Satellite telemetry was used to transmit data every 4 hours to the USGS South Carolina Water Science Center in Columbia, South Carolina. Procedures outlined in the USGS South Carolina Water Science Center Surface-Water Quality-Assurance Plan (Cooney, 2001) were used to ensure proper data handling, review, and approval procedures were followed. Surface-water data are stored in the USGS National Water Information System (NWIS) databases and quality-assured surface-water data are available for retrieval on the Internet at *http://waterdata.usgs.gov/sc/nwis/sw*.

Water-Quality Data

Water samples were collected during selected storm events over a 21-month period to capture a range of runoff conditions and seasons. The NPDES criteria for target storm events were rainfall amounts greater than 0.1 in. and less than 0.1 in. of rainfall during the 72 hours prior to the sampled event (South Carolina Department of Health and Environmental Control, 2001). In September 2005, the USGS and SCDOT decided to reduce the NPDES minimum 72-hour dry period between sample collections to a minimum 24-hour dry period between sample collections. By reducing the minimum dry period between samples, the number of events eligible for sampling increased and also provided a more realistic determination of the BMP efficiency over a range of storm events, not just NPDES-defined events.

Over the 21-month data collection period, 49 sample sets (a sample set includes an inlet and an outlet water sample) were collected from the 4 BMPs. Thirteen sample sets were collected at BMP1, and 12 sample sets were collected at BMP2, BMP3, and BMP4 (Appendix A). Of the 49 sample sets, 38 sample sets (78 percent) were collected following the criteria of 72 hours of dry (no runoff) conditions between sample collections. Water samples were collected over a range of seasons. For this investigation, seasons were based on the summer and winter solstice and vernal and autumnal equinox. All four BMP sites had at least three runoff events for the spring and summer seasons, at least two runoff events for fall, and at least one runoff event for the winter season.

Figure 2. Best management practice (BMP) sites BMP1, BMP2, and BMP3 along U.S. Route 21 and S.C. Route 802 near Beaufort, South Carolina.

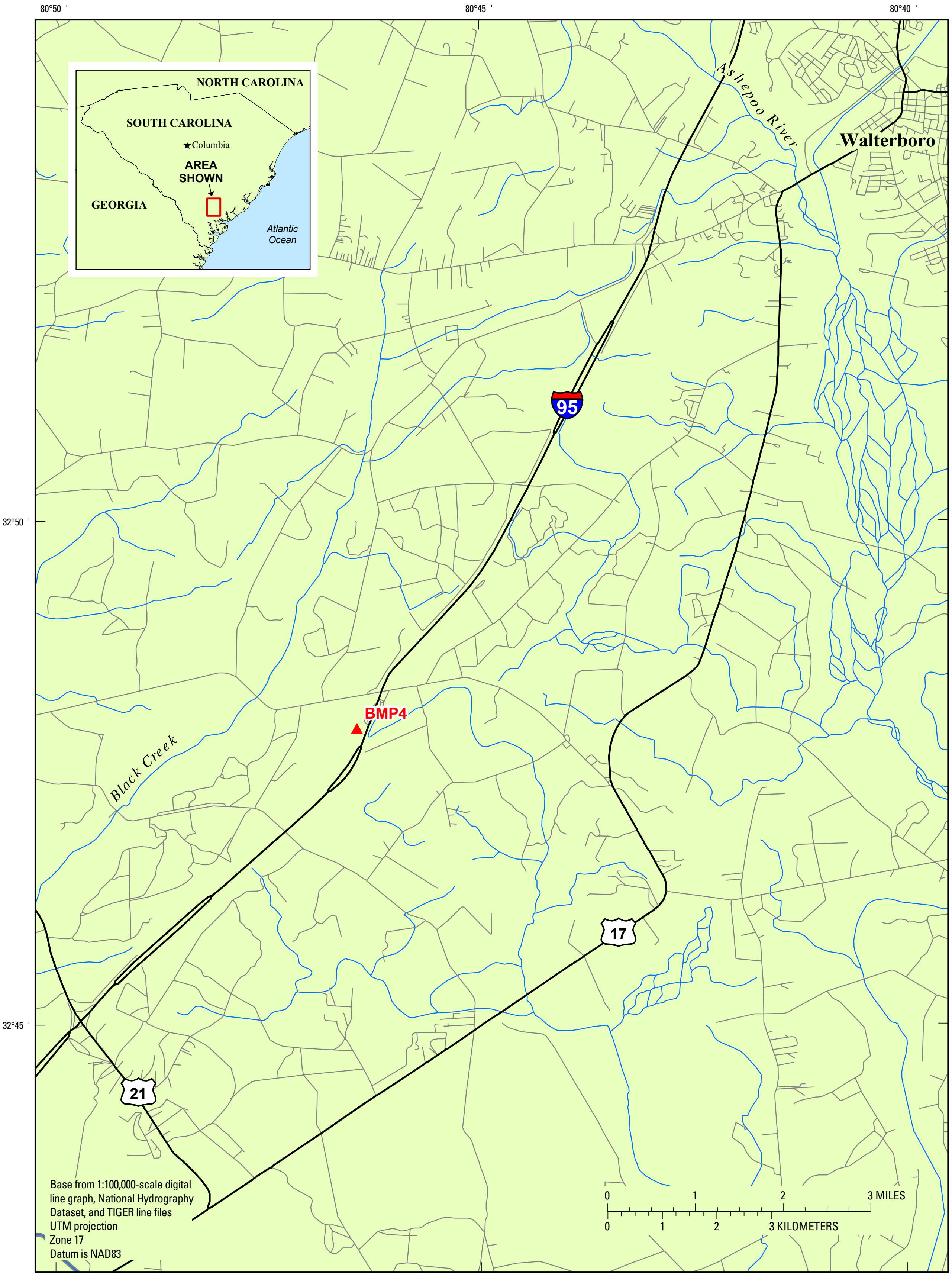

Figure 3. Best management practice (BMP) site BMP4 at I-95 southbound rest area in Colleton County, South Carolina.

Grab samples and flow-composite samples were collected for water-quality analysis using point sampling methods (U.S. Geological Survey, 2006). Sampling equipment was cleaned prior to use according to appropriate inorganic constituent procedures described in Wilde (2004). Samples for compositing were collected automatically using a programmed sampler with pre-cleaned tubing and sample bottles. Grab samples were collected in designated bottles using long-handled poles to reach the inlet and outlet streams during the first 15 to 30 minutes of a storm for the collection of initial stormwater runoff, which was considered to contain accumulations of specified constituents (table 2). These grab samples were collected in sterilized 250-milliliter (mL) glass bottles for analysis of biochemical oxygen demand (BOD), *Escherichia coli* (*E. coli*), enterococci, and total fecal-coliform concentrations (table 2; Myers and others, 2007; U.S. Geological Survey, 2006). A second grab sample was collected in 1-liter (L) pre-baked amber glass bottles for the analysis of oil and grease concentrations (U.S. Geological Survey, 2006). Eight samples from each BMP also were collected as grab samples and were analyzed for base/neutral extractable organic compound (polycyclic aromatic hydrocarbon) concentrations for comparison to the oil and grease concentrations.

During each runoff event, refrigerated automatic samplers were used to collect water samples of the BMP inlet and outlet waters at fixed time intervals. Samples were collected in pre-cleaned, acid-rinsed plastic bottles. Flow-weighted volumes of each sample were computed and placed in a compositing device to produce a flow-weighted composite sample. These samples were analyzed for nutrient, major-ion, trace-metal, chemical-oxygen-demand (COD), and suspended-sediment concentrations (table 2). The concentration measured in the composite sample represented the mean constituent concentration during a runoff event, called the event-mean concentration (EMC; Waschbusch, 1999). Samples were collected in accordance with Environmental Technology Verification Program protocols (U.S. Environmental Protection Agency, 2002a), which states that outlet samples will be taken at a point where the bypass water is combined with the effluent from the BMP. The only exception among the BMPs was BMP3 where the outlet sample was not taken at a point where the bypass stormwater would be combined with the stormwater from the BMP during high-flow events due to the configuration of BMP3.

The individual samples were processed in the field prior to shipment to the laboratory. Sample processing includes preparation (for example, compositing and filtering) and preservation (for example, acidification) of the final composite sample (Wilde and others, 2004). Procedures followed are specific to the constituent being analyzed and are described in Wilde and others (2004) and are listed in Appendix B. Pre-cleaned, acid-rinsed 8-L plastic churns were used as the compositing devices. For analysis of dissolved constituents, samples were filtered using 0.45-micron glass-fiber capsule filters that were conditioned with 1-L of deionized water.

Inlet and outlet samples were analyzed for nutrients, trace metals, oil and grease, turbidity, total suspended solids, and chemical oxygen demand by the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado (Appendix B). Total organic nitrogen and ammonia (total Kjeldahl nitrogen or TKN) and total phosphorus (TP) concentrations

Table 2. Constituents analyzed and sampling quantity for four structural best management practice (BMP) sites in Beaufort and Colleton Counties, South Carolina.

Constituents	Sample locations	Type of sample	Number of events sampled
pH, conductance	inlet/outlet	Sonde	12–13
Oil and grease	inlet/outlet	Grab	12–13
Turbidity	inlet/outlet	Flow-composited	12
Total suspended solids	inlet/outlet	Flow-composited	12
Chemical oxygen demand	inlet/outlet	Flow-composited	12
Nutrients (total phosphorus, total Kjeldahl nitrogen)	inlet/outlet	Flow-composited	12
Trace metal (lead, zinc, copper, nickel, and cadmium [total and dissolved])	inlet/outlet	Flow-composited	12
Base/neutral extractable organic compounds (polycyclic aromatic hydrocarbons)	inlet/outlet	Grab	8
Major ions (calcium, magnesium, hardness)	inlet/outlet	Flow-composited	12
Five-day biochemical oxygen demand	inlet/outlet	Grab	12
Suspended sediment	inlet/outlet	Flow-composited	12
Fecal coliform, enterococci, *Escherichia coli*	inlet/outlet	Grab	12
Bed-sediment inorganics	inlet/outlet	Grab	3

were determined by analyses described by Patton and Truitt (2000) and Patton and Truitt (1992), respectively. Dissolved and total trace-metal concentrations were determined by inductively coupled plasma-optical emission spectrometry and inductively coupled plasma-mass spectrometry (Fishman and Friedman, 1989; Faires, 1993; Hoffman and others, 1996; Garbarino and Struzeski, 1998). Oil and grease concentrations were determined according to U.S. Environmental Protection Agency (USEPA) method 1664A (U.S. Environmental Protection Agency, 1999). Whole-water samples were analyzed for turbidity and chemical oxygen demand according to standard method 2130 (American Public Health Association, 1998) and the HACH method (Fishman and Friedman, 1989), respectively.

Whole-water samples were analyzed for suspended-sediment concentrations and sand/fine fraction at the USGS Kentucky Sediment Laboratory, in Louisville, Kentucky, according to American Society for Testing and Materials (ASTM) method D3977-97 (American Society for Testing and Materials, 2002). Methods for analyzing suspended-sediment concentrations at the USGS Sediment Laboratory in Kentucky also are described in Knott and others (1993) and Shreve and Downs (2005).

Suspended sediment (SSC) and total suspended solids (TSS) concentrations are obtained from two different laboratory analytical methods used to quantify concentrations of suspended organic and inorganic particles in surface waters (Gray and others, 2000). The SSC analytical method is considered to produce more reliable results; however, the TSS method is often the method adopted for regulatory monitoring. Generally, a bias in relation to SSC and TSS is observed when sand-sized material is greater than 25 percent of the sediment dry weight, such that the SSC values tend to exceed their paired TSS values (Gray and others, 2000). Based on past research by Gray and others (2000), this bias indicated TSS was a poor measure of suspended particles in stormwater when the dominant fraction was sand-size or coarser.

Whole-water samples were analyzed by USGS South Carolina Water Science Center personnel for fecal indicator bacteria using the Colilert-18 and Enterolert methods developed by IDEXX. The Colilert-18 method has been approved by the USEPA for drinking water and ambient water and is proposed for use in the NPDES. The IDEXX microbiological methods are described in Standard Methods for Examination of Water and Wastewater, 20th edition (Cleseri and others, 1998) and USGS National Field Manual (Myers and others, 2007).

A SCDHEC-certified contract laboratory analyzed samples for 5-day biochemical oxygen demand (BOD_5). The USEPA method 405.1 (Standard Methods 5210B) was the method used to determine BOD_5 for the study.

Sediment-Quality Data

In March 2005, prior to the start of data collection, the bed sediment previously retained by the BMPs was removed. Following this removal of sediment, each BMP device was cleaned a total of three times at 6- to 8-month intervals. The bed-sediment retained by each device was quantified. BMP2 and BMP3 were not cleaned out at the completion of the study due to equipment failure, but sediment samples were collected at these sites. Prior to each cleaning, core samples were collected from the retained sediment and analyzed for trace metals, organic and inorganic carbon, and fecal bacteria. The collection and processing of bed-sediment samples followed protocols documented in the USGS National Water-Quality Field Manual (Radtke, 2005). The collection and processing of bacteria (enterococci, *Escherichia coli*, and total coliform) samples from bed-sediment samples followed protocols established by the USGS, which are documented in the USGS National Water-Quality Field Manual (Myers and others, 2007). USGS South Carolina Water Science Center personnel analyzed bacteria samples using the Colilert-18 and Enterolert methods developed by IDEXX.

Average Daily Traffic Data

During the investigation, the SCDOT conducted vehicle traffic counts during 7-day periods in the summer (August 2–14, 2006) and fall (October 16–23, 2006) at each of the four BMP sites. A Peek ADR 200 counter with pneumatic road tubes was used to count and classify vehicles passing the BMP site each hour. The axle spacing of each vehicle was used to assign each vehicle to 1 of 14 classifications: motorcycle, car with 1-axle trailer, car with 2-axle trailer, pick-up truck or van, bus, commercial truck (which has 8 subclasses: 2-axle single unit, single trailer with 4 or fewer axles, 5-axle single trailer, 6-axle single trailer, 5-axle multi-trailer, 6-axle multi-trailer, any 7-axle multi-trailer, any 8-axle multi-trailer), and other (vehicle not matching one of the above).

Total traffic counts between the summer and fall seasons for BMP1, BMP2 and BMP3 showed little to no difference among the three sites. For BMP4, the summer season had more than twice the amount of traffic as the fall season. At all four sites, cars were the most frequent vehicle, at more than 50 percent, followed by pick-up truck or van at BMP1, BMP2, and BMP3, and commercial trucks at BMP4.

Quality Control and Quality Assurance

Water-quality data from each sampled event were reviewed for completeness, precision, bias, and transcription errors when received from the laboratory as part of the quality-assurance procedures. After review, the data were approved and made available through the USGS NWIS. Collection and analysis of quality-control (QC) samples were part of this study. The goal of QC sampling was to identify, quantify, and document bias and variability in data that resulted from the collection, processing, shipping, and handling of samples. The bias and variability associated with environmental data must be known for the data to be interpreted properly and scientifically defensible (U.S. Geological Survey, 2006). Ten percent of all samples analyzed were QC samples. Field and equipment blanks were analyzed to ensure that the sampler, intake lines, churns, and bottles did not contaminate samples; split samples (replicates) were analyzed to document reproducibility of laboratory results.

Field blanks were used to evaluate the level of contamination from the sampling equipment and sample processing methods to the environmental sample concentrations. No detections of TKN, TP, magnesium, turbidity, TSS, total organic carbon (TOC), COD, dissolved and total cadmium, dissolved and total copper, and dissolved lead, were reported for the blanks, indicating negligible contamination. Total lead was detected in one blank at an estimated concentration of 0.05 microgram per liter (µg/L), which is about 1 percent of the amount of total lead detected in the environmental samples. The highest levels detected in the field blanks were total zinc and nickel (2 and 0.08 µg/L, respectively). Corresponding concentrations of 1.4 and 0.07 µg/L of dissolved zinc and nickel, respectively, indicated the contamination was predominately in the dissolved phase. However, these levels were less than 5 percent of the levels detected in the environmental samples, so environmental samples likely were not contaminated by sampling equipment or processing.

Replicate samples collected along with storm samples were analyzed to evaluate the inherent bias and accuracy of the field collection, processing, and laboratory analysis procedures. The data-quality objectives (DQOs) required that detections of constituents in replicate samples be within 20 percent of those detected in actual storm samples. The relative percentage difference (RPD) was computed for the sample set (storm and replicate sample); the RPD is the constituent concentration in the storm sample minus the concentration in the replicate sample divided by the average of the storm sample and replicate sample constituent concentrations multiplied by 100. A statistical summary of the results is provided in table 3. Absolute values of the RPD were used in the calculation of these statistics.

The computed RPDs were within the required DQO with the exception of six constituents in one replicate: total suspended solids (34.7 percent), suspended sediment (24.6 percent), dissolved cadmium (33.3 percent), total cadmium (20.0 percent), dissolved zinc (23.7 percent), and total nickel (20.0 percent). Low concentrations in the storm samples could have contributed to the elevated RPDs in the other trace-metal replicate samples. Review of the replicate sample set for dissolved cadmium indicated that one time exceedence was negligible because both concentrations were estimated at concentrations below the laboratory reporting level (LRL) and differed by only 0.01 µg/L (storm sample = E 0.02 µg/L, replicate sample = E 0.03 µg/L, where E indicates an estimated value). The higher RPDs were computed for replicate sample sets with low-level concentrations of dissolved lead (–0.24 and 0.13 µg/L), total nickel (–0.87 µg/L), and dissolved zinc (2.2 µg/L). The one-time high RPDs for total suspended solids and suspended sediment were computed for the first replicate sample sets—subsequent replicate sample sets met the DQO of 20 percent.

Table 3. Statistical summary of the relative percent differences between storm and replicate samples from selected structural best management practice (BMP) sites in Beaufort and Colleton Counties, South Carolina, 2005–2006.

Constituents	Relative percent difference			
	Mean	Median	Maximum	Minimum
Turbidity	11.4	5.6	39.8	4.0
Lab pH	2.1	2.6	4.3	0
Lab specific conductivity	0.1	0	0.3	0
Hardness	1.7	0.8	5.3	0
Calcium	1.8	2.1	3.5	0.6
Magnesium	2.1	2.4	3.3	1.8
Total suspended solids	12.0	2.9	34.7	0
Total Kjeldahl nitrogen	6.2	6.5	14.3	0
Total phosphorus	3.3	0	14.3	0
Total organic carbon	2.6	3.0	5.3	0.4
Suspended sediment finer than 63 microns	9.2	9.4	16.7	6.3
Suspended sediment	6.7	0.9	24.6	0
Dissolved cadmium	11.3	7.1	33.3	0
Total cadmium	7.0	5.9	20.0	0
Dissolved copper	2.0	0.7	6.3	0
Total copper	3.4	0.8	17.6	0
Dissolved lead	14.8	12.8	35.8	1.7
Total lead	3.9	1.9	15.5	0
Dissolved nickel	4.7	5.5	7.7	1.7
Total nickel	3.6	0.2	20.0	0
Dissolved zinc	9.5	7.3	23.7	1.4
Total zinc	4.2	1.8	19.2	0

Data Analysis and Performance Assessment

Statistical data analysis formed the foundation of the performance assessment in this investigation. For objectives one and two (see Purpose and Scope section), basic descriptive statistics were applied to the constituent EMC and load data for each BMP performance assessment, and results are summarized in this report. Event-mean concentrations for suspended sediment, total suspended solids, oil and grease, nutrients, bacteria, and metals were summarized statistically and described in tabular and graphical formats. Loads for suspended sediment, total suspended solids, oil and grease, nutrients, bacteria, and metals also were computed for each individual storm and summarized statistically for each BMP. To assess the removal efficiency of the individual BMPs and to compare the removal efficiencies among BMPs during the period of study, a tiered statistical approach was applied based on USGS (Waschbusch, 1999) and USEPA (U.S. Environmental Protection Agency, 2002b) methodologies. The tiers are analogous to two historical or traditional approaches described and reviewed by the USEPA and the American Society of Civil Engineers: the removal efficiency of individual storm loads (ISL) and the efficiency ratio (ER; U.S. Environmental Protection Agency, 2002b). These approaches were made more robust by the use of statistical tests for comparison of data within and among BMPs.

The first step was to assess the performance of each individual BMP's reduction of selected constituents in stormwater. This assessment was done by statistically determining if significant reductions in constituent EMCs and loads existed between stormwater entering the inlet of the BMP and stormwater leaving the outlet of the BMP. In other words, the EMC or load of the inlet water was assumed to represent the average stormwater concentration or load for each constituent, and the EMC or load of the outlet water was assumed to represent the average "treated water" concentration or load after the BMP removed or reduced the constituent for each individual storm. If significant reductions existed, the BMP was considered efficient at reducing that constituent. Only those constituents that were found to be significantly reduced by individual BMPs were included in the comparison among BMPs. To quantify removal efficiencies for the individual BMPs, geometric mean and mean percentage reductions for the significantly reduced constituents in each BMP were computed by the ER method. The simplistic ER method was the recommended approach to quantify removal efficiency of a BMP (U.S. Environmental Protection Agency, 2002b).

Computed percentage reductions by the ER method were not sufficiently diagnostic to determine if statistical differences existed among the performances of the four BMPs. Consequently, a more complex approach also applied statistical comparison tests to percentage reductions computed for individual storms (a modified removal efficiency of the ISL approach) to determine if differences in event-mean concentrations, loads, and percentage reductions in significantly reduced constituents existed among the four structural BMPs (U.S. Environmental Protection Agency, 2002b).

Selection of an appropriate method for treating censored data is necessary when laboratories report quantitative, estimated, and censored results, as was the case in this study for oil and grease concentrations and a few trace-metal concentrations. The NWQL used this type of reporting where (1) results above a "quantitation limit" (equivalent to the NWQL's LRL) are reported as quantitative, (2) results between the "quantitation limit" and the "detection limit" (equivalent to the NWQL's long-term method detection level, or LT-MDL) are reported as estimated, and (3) results below the detection limit are reported as censored. In an effort to minimize the probability of reporting false negatives, the NWQL reported censored results (non-detections) as "< LRL" rather than "< LT-MDL" (Childress and others, 1999; Appendix B). Prior to statistical analysis of the data, all censored values for a constituent were set to half of its LT-MDL, while all estimated results were retained (Appendix B).

Limitations of the dataset were that the data analysis treated all estimated (semi-quantitative) values as quantitative values (Helsel, 2005). In other words, for reported values above the LRL, there is a 99.9-percent confidence that the reported concentration is equal to the actual concentration in the sample. For example, if the LRL for a constituent is 7 mg/L, then there is relatively high confidence that a reported concentration of 12 mg/L is exactly greater than a reported concentration of 10 mg/L by 2 mg/L. At the same LRL of 7 mg/L, however, there is less confidence that an estimated value of 5 mg/L is exactly 2 mg/L greater than an estimated value of 3 mg/L. The comparative statistical analysis in this report assumed that an estimated value of 5 mg/L had an unknown actual value, but the unknown actual value had a higher likelihood of being greater than (rather than equal to or less than) an estimated value of 3 mg/L. Therefore, in nonparametric statistical analyses (which were used in this report) an estimated value of 5 mg/L had a higher likelihood of being ranked above (rather than equal to or below) an estimated value of 3 mg/L because these analyses are based on the ranks of the data and not on the actual values.

Exceptions to this approach were for *E. coli* and enterococci concentrations that were above the maximum quantification level of the methods used. For most samples, a 1:10 dilution was used. This dilution translates to a maximum reporting level of 25,000 colonies per 100 milliliters (col/100 mL), and the results would be censored as > 25,000 col/100 mL. For data analysis, the censored value of 25,000 col/100 mL was taken as the actual value, producing a negative bias to the data analysis, such that reported median and mean concentrations potentially are skewed lower than the actual concentrations.

Load Computation

Event load is the quantity of material transported by a stream or pipe during a storm. This quantity represents the amount of a particular material contributed to the stream or pipe from the surrounding drainage area in stormwater runoff. The event is a function of the stormwater concentration and the flow rate (Rasmussen, 1998). For the BMP sites, the event-mean load (L_i) in kilograms per event (kg/event) resulting from stormwater runoff for an individual storm event is calculated by multiplying the event-mean concentration (EMC_i) in milligrams per liter by the mean stormflow (Q_i) in cubic feet per second of water passing the sampling site during the storm event ($_i$) by the event duration (ED_i) in minutes:

$$L_i = a \, EMC_i \, Q_i ED_i, \qquad (2)$$

where

a = 0.0017, a constant that converts the input variables to units of kilograms per event.

Units of measurement did vary by constituent. Most constituent loads were expressed as kilograms per event. The exception was metal constituents because of their lower concentrations. Metal loads were expressed as grams per event (g/event).

Removal Efficiency Estimation

One objective of the investigation was to evaluate how efficiently each BMP removed or reduced constituents in the stormwater. The EMC of the inlet water was assumed to represent the average stormwater concentration for each constituent, and the EMC of the outlet water was assumed to represent the average “treated water” concentration after the BMP removed or reduced the constituents for each individual storm. Removal efficiency for individual storms was estimated by computing the percentage of reduction in EMC between inlet and outlet samples for each BMP based on the equation below:

$$\text{Percent reduction} = [(EMC_i - EMC_o)/EMC_i] \times 100, \qquad (3)$$

where

EMC_i is the EMC of the inlet water, in milligrams or micrograms per liter, and

EMC_o is the event-mean concentration of the outlet water, in milligrams or micrograms per liter.

The same approach and the same equation were applied to event-mean loads computed for each BMP. These computed values were used as input into statistical tests to determine if a significant difference existed among the BMPs.

An average of removal efficiencies computed for individual storm loads (ISL approach; U.S. Environmental Protection Agency, 2002b) did not take into account storage of contaminants, especially for those BMPs with permanent pool volumes (for example, retention ponds) and provided equal weight to all storm-event efficiencies. A second approach was applied for comparison purposes. Efficiency ratios were computed to quantify the average removal efficiency of each BMP and to weight all storms equally, regardless of magnitude using the ER approach (U.S. Environmental Protection Agency, 2002b). The following two equations were used to calculate average removal efficiency:

$$ER = (\text{mean } EMC_i - \text{mean } EMC_o)/\text{mean } EMC_i, \qquad (4)$$

and

$$ER = (\text{geometric mean } EMC_i - \text{geometric mean } EMC_o)/\text{geometric mean } EMC_i, \qquad (5)$$

where

ER is the efficiency ratio (dimensionless) and other variables are as previously defined.

Computations based on the geometric mean are considered to be a better estimate of the actual performance because they are less affected by outliers (U.S. Environmental Protection Agency, 2002b). The ER method of summarizing the efficiency of BMP performance was supplemented by appropriate non-parametric statistical tests to determine if the differences between the mean and geometric mean EMCs of the inlet and outlet waters are significant.

Statistical Analysis

Several statistical tests were performed on the data for exploratory, descriptive, and interpretative analyses. Initially, a test for normality was made using the Anderson-Darling Test (Anderson and Darling, 1952; Stephens, 1974). The Anderson-Darling test is an empirical distribution function (EDF) test that is used on datasets with small sample sizes ($n < 25$) to determine if a sample of data came from a population with a specific distribution. It is a modification of the Kolmogorov-Smirnov (K-S) test and gives more weight to the tails than does the K-S test (Stephens, 1974). The majority of the water-quality data did not have a normal distribution, so non-parametric approaches were selected for data analysis.

Descriptive statistics including mean, maximum, minimum, and median values were computed and graphically represented in box plots. Median values were used for comparison because they diminish the effects of outliers on the data (Helsel and Hirsch, 1992). Boxplots serve as graphical summaries of the data and are based on percentiles of the data distribution. For example, a 75^{th} percentile represents the concentration whereby 75 percent of all concentrations measured were below that 75^{th} percentile concentration. The 50^{th} percentile, or median, represents the “middle” concentration, such that 50 percent of the data are above that concentration and 50 percent are below. The entire box on the plot represents the median 50 percent of the data (from the 75^{th}

to the 25th percentile) (Helsel and Hirsch, 1992). The vertical lines above and below the box display the data range from the 90th and 10th percentiles, such that 80 percent of the data are within the range outlined by the upper and lower lines. Outliers represent data that are outside of the range.

The removal efficiency performance of each BMP was assessed by statistical comparison of EMCs and loads. These statistical results provided the ability to discuss performance efficiencies of individual BMPs by evaluating if a significant difference existed in EMCs and loads between the water entering the inlet of the BMP and water leaving the outlet of the BMP (Helsel and Hirsch, 1992; U.S. Environmental Protection Agency, 2002b). A non-parametric test to compare inlet and outlet EMCs and loads was chosen because of the general non-normal distribution of the data. If an EMC or load in water exiting the outlet of a BMP was statistically less than the EMC or load entering the BMP, the BMP was considered successful at removing some amount of the storm-contributed EMC or load. If no statistical difference was identified, then poor removal by the BMP was indicated. For constituents with inlet and outlet EMCs and loads that were significantly different, further comparison was made among the BMPs to determine if one or more BMP had greater ability in removing those particular constituents than others.

The Wilcoxon signed rank test was applied to the inlet and outlet data to determine if a statistical difference exists between the paired measurements of inlet and outlet EMCs and loads for each storm event (Helsel and Hirsch, 1992). The Wilcoxon signed rank test ranks pairs of measurements from a dataset that show higher differences than other pairs of measurements from the same dataset. The hypothesis being tested was whether the input and output EMCs and loads were the same, or if they were greater in the input than in the output. An alpha level of 0.05 translates to a 95-percent confidence that the statistical finding was correct; this level was used to determine statistically significant differences, such that statistical tests that had probability values (p-values) below the alpha level of 0.05 were considered statistically significant and that the alternative hypothesis was true. Because most of the datasets were not normally distributed, the test was performed on ranks of the data. The exact distribution of the test statistic V was used to compute the p-value when no correlations in the data existed. If correlations existed, a Z-score was used to compute the p-value.

A different non-parametric statistical approach was used for comparison of the efficiencies of the BMPs. The multiple comparison analysis was used to determine if percentage reductions of concentrations of selected constituents in individual storms were statistically different among the four BMPs (Helsel and Hirsch, 1992). The selected constituents were those identified as significantly reduced by the BMPs in the first statistical analysis. Specifically, the analysis was performed in two steps (Helsel and Hirsch, 1992). First, an analysis of variance (ANOVA) on ranked data (also called the Kruskal-Wallis test) was applied to the data to determine if a statistical difference existed among at least one of the medians of the groups of data. The Kruskal-Wallis test is a robust test that determines only if a difference existed among the BMPs; the test did not identify which BMPs were different from the others. A second test was conducted to identify the actual differences. If the more robust Kruskal-Wallis test indicated that a difference existed, then a multiple comparison test called the Tukey's honestly significantly different (HSD) test (for similar sample sizes) was applied to the groups of data only to identify which group or groups were different from the others. A significant difference was determined at an alpha level of 0.05, which means that if the p-value of the ANOVA test was less than 0.05, a significant difference existed among the analyzed data group with a 95-percent confidence that the statistical finding was correct.

Spearman's rho correlation analysis also was applied to water-quality data from the different BMPs to evaluate the strength of association among selected water-quality and other related constituents (for example, rainfall, mean flow, and ADT; Helsel and Hirsch, 1992). An alpha level of 0.05 (95-percent confidence) for significant correlations was selected for the analysis. Spearman correlation measures the observed co-variation and the strength of the monotonic relation between two variables—where change is in one direction only (either strictly increasing or strictly decreasing, but not reversing direction). Correlation is quantified with a coefficient. The coefficient for this analysis is rho. A rho ranges from 0 to 1; the closer rho is to 1, the stronger the correlation. A p-value is computed during the analysis. A correlation resulting in a p-value below the alpha level of 0.05 (p-value < 0.05) is considered significant in this report. Caution should be used when interpreting correlation analysis results because a significant correlation proves only co-variation, not cause and effect.

Hydrologic Conditions

Rainfall intensity varied among seasons and sites. Among all four sites, rainfall intensity ranged from 0.04 to 0.81 inch per hour (in/h) with an average value of 0.26 in/h (Appendix A). The highest intensity occurred in the summer and the lowest in the spring. Rainfall duration of a runoff event is the time between the start of the rainfall and the end of sampling the inlet and outlet waters. Of the 49 sample sets that were collected, rainfall duration ranged from 0.42 to 3.75 hours (h) with an average of 2.02 h.

All of the BMPs were not sampled during every storm event. Because the strength of a storm and amount of rainfall produced influence concentrations in the inlet waters of the BMP, statistical comparisons of total rainfall and rainfall intensity among the storm samples at each BMP were conducted to determine if the four BMP datasets represented similar storm conditions during the same storm event. The statistical test determined that the sampled precipitation amounts and intensities were not different among the four BMPs in Beaufort and Colleton Counties (table 4), indicating that datasets from each

Table 4. Summary of the statistical results comparing precipitation, mean stormflow, and precipitation intensity at four structural best management practice (BMP) sites in Beaufort and Colleton Counties, South Carolina, 2005–2006.

Constituent	Kruskal-Wallis test statistics				Comparison among BMP inlet and outlet waters—Tukey HSD test results				
	Chi-squared	Degrees of freedom	R-squared	Probability value		BMP1	BMP2	BMP3	BMP4
Precipitation for storm event	1.3205	3	0.04425	0.7243	Group	A	A	A	A
					N	12	12	12	12
Mean stormflow	8.7126	3	0.29689	0.0334	Group	B	B	B	B
					N	13	12	12	12
Precipitation intensity	0.3038	3	0.01636	0.9593	Group	A	A	A	A
					N	13	12	12	12

BMP represented samples from similar storm conditions. However, BMP3 had higher mean stormflow than the other three BMPs; this is probably related to the much larger size of the watershed that drains to BMP3. BMP3 drains from 2.1 to 5.3 times more area than the other BMPs.

BMP1 Performance Assessment

BMP1 is located along the northbound lane of U.S. Route 21 near the Woods Memorial Bridge in Beaufort, S.C. (fig. 2). The drainage area for this BMP is 2.24 acres (table 1), and the area is almost entirely composed of impervious area. A curb-and-gutter system is used to intercept highway runoff. During normal operating conditions, stormwater flows into the upper chamber and is diverted by a u-shaped weir into the separation/holding chamber. Right-angle outlets direct flow around the circular walls of the chamber. Fine and coarse sediments settle to the floor of the chamber, while lighter-than-water constituents, such as petroleum products, rise and become trapped. During high-flow events, peak stormwater flows pass over the diverting weir and are discharged from the device into the Beaufort River (Stormceptor, 2008).

Samples were collected from the BMPs in accordance with Environmental Technology Verification Program protocols (U.S. Environmental Protection Agency, 2002a). Inlet samples were collected before the stormwater was diverted into the BMP's chamber. Outlet samples were collected at the outfall of the BMP at a point where the bypass stormwater would be combined with the stormwater from the BMP during high-flow events.

The event-mean concentrations and loads of the following water-quality constituents are summarized for BMP1: (1) suspended sediment and total suspended solids (TSS); (2) oil and grease concentrations; (3) bacteria; (4) nutrients (TKN and TP); and (5) metals. BMP1 is designed for the removal of suspended sediments and oil and grease; however, the removal of particulate and dissolved forms of other water-quality constituents also were considered in the assessment.

Suspended Sediment, Total Suspended Solids, and Sediment

Analytical methods to determine SSC and TSS were used to quantify concentrations of suspended organic and inorganic particles in surface waters. A significant monotonic correlation exists between TSS and SSC in the inlet and outlet waters at BMP1 (inlet and outlet: rho = 0.90639, p-value < 0.0001) (fig. 4), but not a one-to-one correlation as would be expected for measurements of the same substance (suspended particles). Comparison of the SSC and TSS concentrations from the BMP1 sampling events demonstrated a negative bias for TSS concentrations, especially greater than 100 mg/L. The greatest difference was observed at the inlet SSC concentration of 2,390 mg/L that had a corresponding TSS concentration of only 204 mg/L. Further evaluation of grain size indicated the bias between SSC and TSS concentrations tended to increase as the percentage of the sediment finer than 63 microns (finer than sand) decreased below 50 percent.

This bias between SSC and TSS is noteworthy because different statistical findings were identified between SSC and TSS when comparisons were made among other properties and between inlet and outlet waters. Because the SSC analytical method better captures large particles (sand), thereby producing more representative results (Gray and others, 2000), statistical findings based on SSC results are considered more indicative of the BMP performance. However, because the TSS method is often the method adopted for regulatory monitoring, BMP comparisons based on TSS results also are discussed in this report.

Event-mean concentrations of SSC in the inlet water of BMP1 ranged from 10 to 2,036 mg/L, with a median value of 92.0 mg/L (fig. 5, table 5). The SSC EMCs in the outlet water were lower and less variable than the inlet water, with a median of 45 mg/L (fig. 5). Suspended sediment EMCs were reduced significantly in the outlet water as compared to the inlet water by BMP1 during the period of study (V-statistic = 78; p-value = 0.0002; table 5). This statistical finding indicated that BMP1 performed efficiently at reducing SSC in

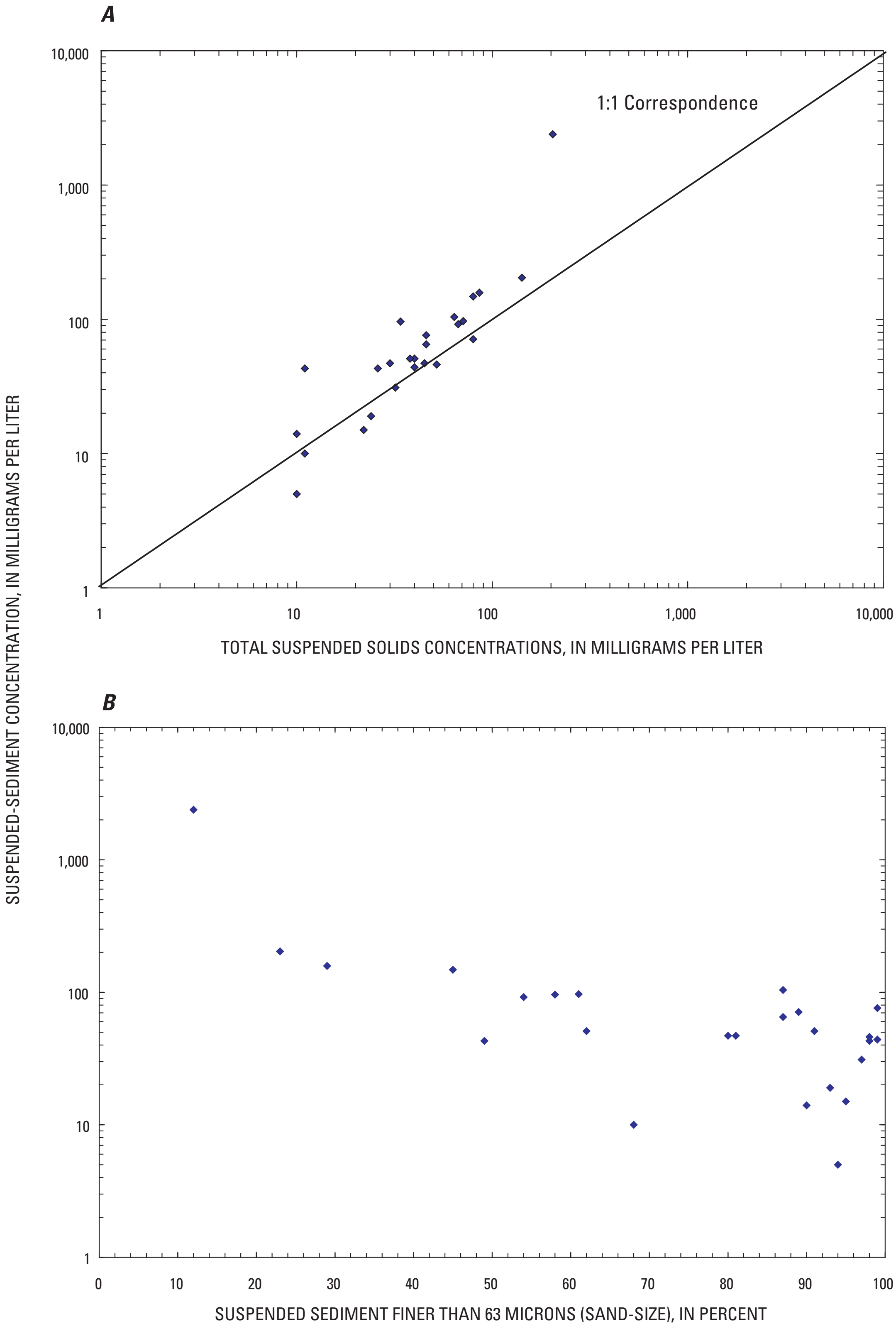

Figure 4. Relation between *(A)* suspended-sediment and total suspended solids concentrations and between *(B)* suspended-sediment concentrations and percentage of sediment finer than sand measured at best management practice 1 at U.S. Route 21 near Beaufort County, S.C., 2005–2006.

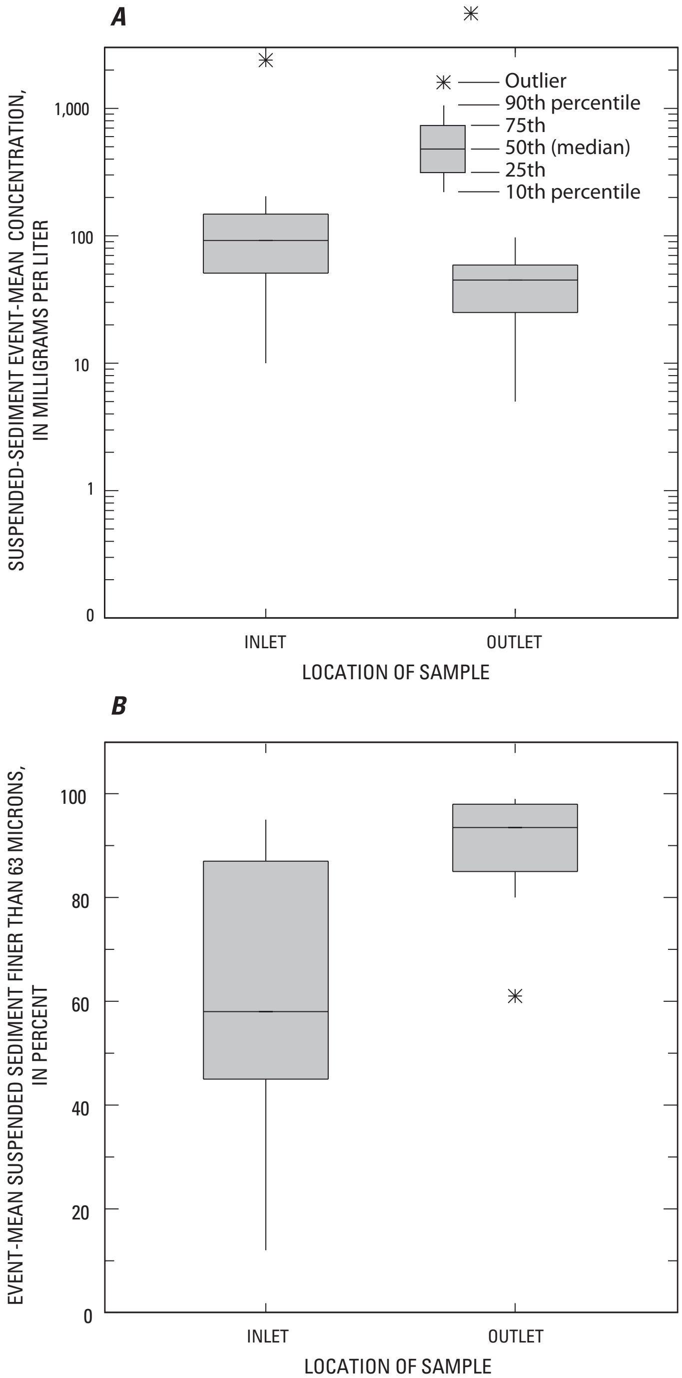

Figure 5. Event-mean *(A)* concentrations of suspended sediment, in milligrams per liter, and *(B)* percentages of suspended sediment finer than 63 microns, at best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

stormwater. Median EMCs of TSS of 46 and 32 mg/L for inlet and outlet water, respectively, were about half and three-quarters, respectively, of the median SSC concentrations for BMP1 (fig. 6). Lower median EMCs for TSS, when compared to median SSC EMCs, could be explained by the underestimation of suspended sediment discussed previously (fig. 4). The less variable TSS EMCs were significantly different between inlet and outlet waters (Z-score = 2.1744, p-value = 0.0148; table 5).

Turbidity has been used as a surrogate measure of the suspended sediment or particulates in water. For BMP1, however, turbidity values were not correlated to TSS (rho = 0.2010; p-value = 0.5100) or SSC (rho = 0.34370; p-value = 0.2472) for the period of study. For BMP1, the median event-mean turbidities in the inlet and outlet waters were similar (21 and 22 nephelometric turbidity units [NTU], respectively) (fig. 6). As observed with TSS, no significant difference in turbidity was identified between inlet and outlet water, indicating that BMP1 was not efficient at reducing TSS EMCs and turbidity in stormwater.

Amounts and particle sizes of the SSC were different in the inlet water compared with the amounts and sizes in the outlet water (fig. 5). The percentage of the suspended sediment finer than sand (particle sizes less than 63 microns, such as silt and clay) was highly variable in the inlet water of BMP1, with a median of 58.0 percent which indicates about 42 percent of the sediment was sand-sized particles or larger (fig. 5; table 5). The predominant size fraction of suspended sediment in outlet water was finer than sand (median of 93.5 percent) and significantly finer than in the inlet waters (Z-score = 2.9440, p-value = 0.0016). The change in the character of the SSC indicated that BMP1 was more efficient at capturing the sand-sized fractions of the suspended sediment than the silt- and clay-sized fractions. This preferential retention of coarser grained sediment also could influence the lack of retention of certain nutrients (such as phosphorus), bacteria, and trace metals (such as lead and zinc) because of their tendency to adsorb preferentially to finer grained sediment.

Examination of the grain sizes of the accumulated sediment within BMP1 in May 2006 further verified this preferential retention of the coarser grained fractions. Only about 1 percent of the sediment that accumulated in BMP1 was smaller than 63 microns (clay and silt) (fig. 7), even though the average suspended sediment from the inlet waters was composed of 58 percent fine-grained sediment (table 5; fig. 5). Additionally, in May 2005, October 2005, May 2006, and October 2006, trace-metal concentrations were measured in the retained coarser grained sediment. Concentrations in order from greatest to least concentration, in micrograms per

Table 5. Summary statistics describing the comparison among event-mean concentrations in inlet and outlet waters of best management practice 1 (BMP1), Beaufort County, South Carolina, 2005–2006.

[>, greater than; µg/L, micrograms per liter; mg/L, milligrams per liter; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters]

Constituent	Units	Location	Median	Mean	Standard deviation	Comparison among event-mean concentrations in inlet and outlet waters of BMP1		Wilcoxon signed-rank test		
						Number	[1]Inlet > outlet	V-statistic	Z-score	Probability value
Dissolved cadmium	µg/L	Inlet	0.07	0.09	0.05	13	No	19		0.971
	µg/L	Outlet	0.03	0.04	0.02	13				
Total cadmium	µg/L	Inlet	0.32	0.28	0.12	13	Yes		2.805	0.003
	µg/L	Outlet	0.17	0.21	0.11	13				
Particulate cadmium	µg/L	Inlet	0.18	0.19	0.10	13	No		0.909	0.182
	µg/L	Outlet	0.15	0.17	0.12	13				
Dissolved copper	µg/L	Inlet	9.80	10.8	7.57	13	Yes	87		0.001
	µg/L	Outlet	6.00	6.50	3.87	13				
Total copper	µg/L	Inlet	19.8	19.3	8.00	13	Yes		2.587	0.005
	µg/L	Outlet	13.5	16.0	7.68	13				
Particulate copper	µg/L	Inlet	7.30	8.46	5.60	13	No		–0.385	0.650
	µg/L	Outlet	9.00	9.75	7.53	13				
Dissolved lead	µg/L	Inlet	0.43	0.52	0.46	13	No		0.700	0.758
	µg/L	Outlet	0.44	0.65	0.65	13				
Total lead	µg/L	Inlet	14.3	15.8	10.8	13	Yes	85		0.002
	µg/L	Outlet	11.0	10.8	5.70	13				
Particulate lead	µg/L	Inlet	13.7	15.3	10.7	13	Yes	87		0.001
	µg/L	Outlet	10.8	10.2	5.90	13				
Dissolved nickel	µg/L	Inlet	3.23	3.71	2.20	13	No	50		0.393
	µg/L	Outlet	3.13	3.56	2.31	13				
Total nickel	µg/L	Inlet	6.17	6.20	2.96	13	Yes		1.713	0.043
	µg/L	Outlet	4.00	5.17	2.80	13				
Particulate nickel	µg/L	Inlet	2.32	2.51	1.89	13	No	26		0.916
	µg/L	Outlet	1.73	1.64	0.97	13				
Dissolved zinc	µg/L	Inlet	32.6	50.3	35.6	13	Yes	74		0.024
	µg/L	Outlet	28.1	36.6	18.8	13				
Total zinc	µg/L	Inlet	128	116	53.5	13	Yes		2.418	0.008
	µg/L	Outlet	77.0	95.3	48.8	13				
Particulate Zinc	µg/L	Inlet	60.0	65.9	40.3	13	No	56		0.249
	µg/L	Outlet	52.9	58.7	46.0	13				
Total Kjeldahl nitrogen	mg/L	Inlet	1.70	2.31	1.54	13	No		1.644	0.511
	mg/L	Outlet	1.30	2.00	1.46	13				
Total phosphorus	mg/L	Inlet	0.28	0.29	0.14	13	Yes		1.993	0.023
	mg/L	Outlet	0.19	0.22	0.11	13				
Turbidity	NTU	Inlet	21.0	24.9	15.6	13	No		1.328	0.092
	NTU	Outlet	22.0	21.8	12.2	13				
Total organic carbon	mg/L	Inlet	38.0	30.3	16.1	13	No		0.839	0.201
	mg/L	Outlet	17.7	24.7	14.8	13				
Total suspended solids as residue	mg/L	Inlet	46.0	65.0	55.0	13	Yes		2.174	0.015
	mg/L	Outlet	32.0	37.5	21.3	13				
Biochemical oxygen demand	mg/L	Inlet	15.2	25.8	25.1	13	No	15		0.987
	mg/L	Outlet	20.5	33.0	27.4	13				
Chemical oxygen demand	mg/L	Inlet	120	108	53.0	13	No		1.307	0.096
	mg/L	Outlet	80.0	100	52.0	13				
Enterococci	col/100 mL	Inlet	1,190	3,930	4,630	12	No	30		0.765
	col/100 mL	Outlet	3,550	6,780	8,440	12				
Escherichia coli	col/100 mL	Inlet	820	2,710	5,830	11	No	12		0.973
	col/100 mL	Outlet	1,100	5,210	9,570	11				
Suspended sediment finer than sand	percent	Inlet	58.0	58.5	26.9	13	[2]Yes		2.944	0.002
	percent	Outlet	93.5	89.9	11.2	13				
Suspended sediment	mg/L	Inlet	92.0	264	641	13	Yes	78		0.000
	mg/L	Outlet	45.0	45.0	26.6	13				
Oil and grease	mg/L	Inlet	8.00	7.69	4.02	13	Yes	2.370		0.009
	mg/L	Outlet	4.00	4.42	2.76	13				

[1] Probability that the input and output concentrations are the same versus the probability that the concentration is greater in the input than in the output.

[2] One-sided test to see if the percentage of suspended sediment finer than 63 microns is greater in the output than in the input.

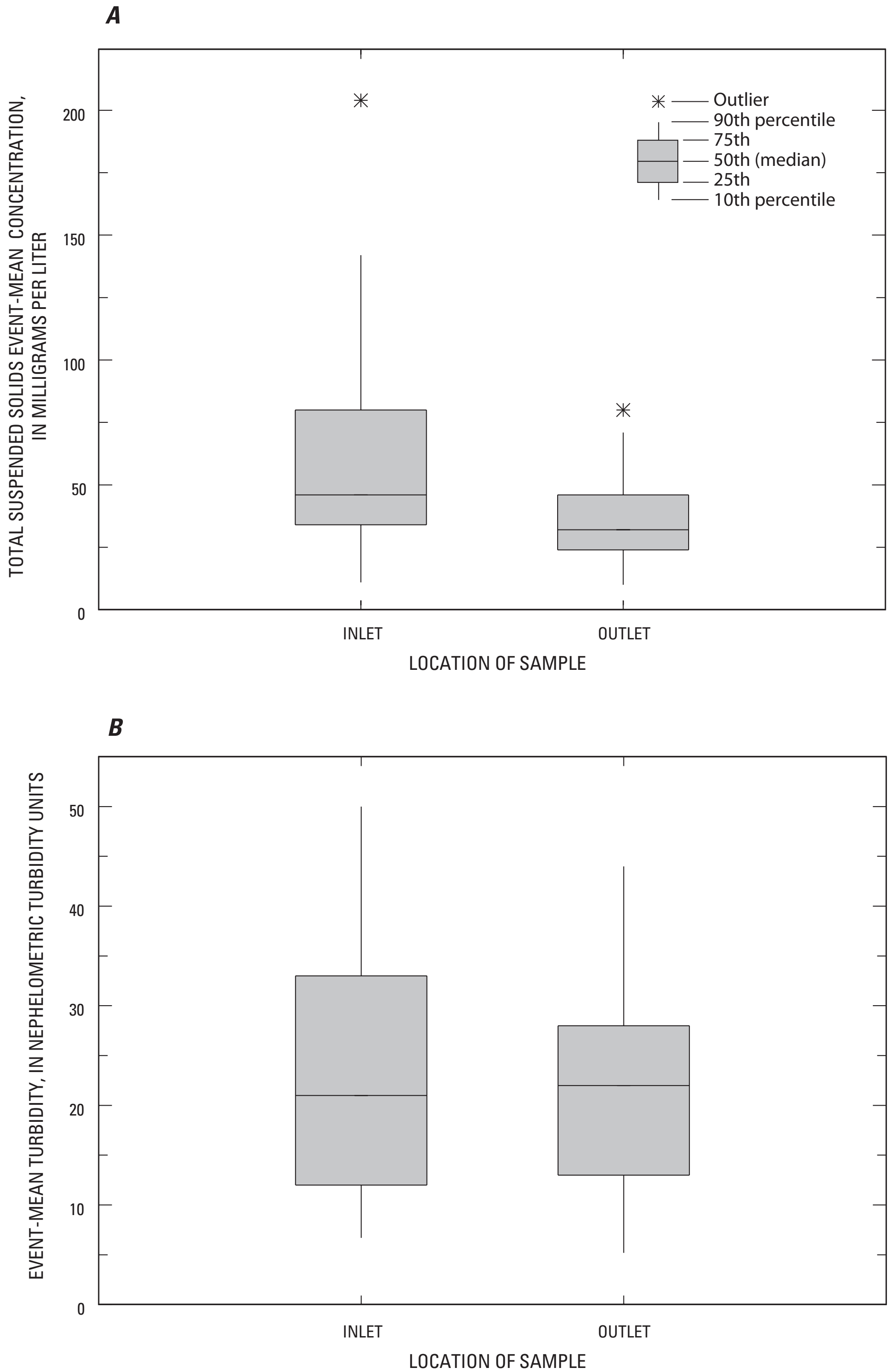

Figure 6. Event means of *(A)* total suspended solids concentrations and *(B)* turbidity for best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

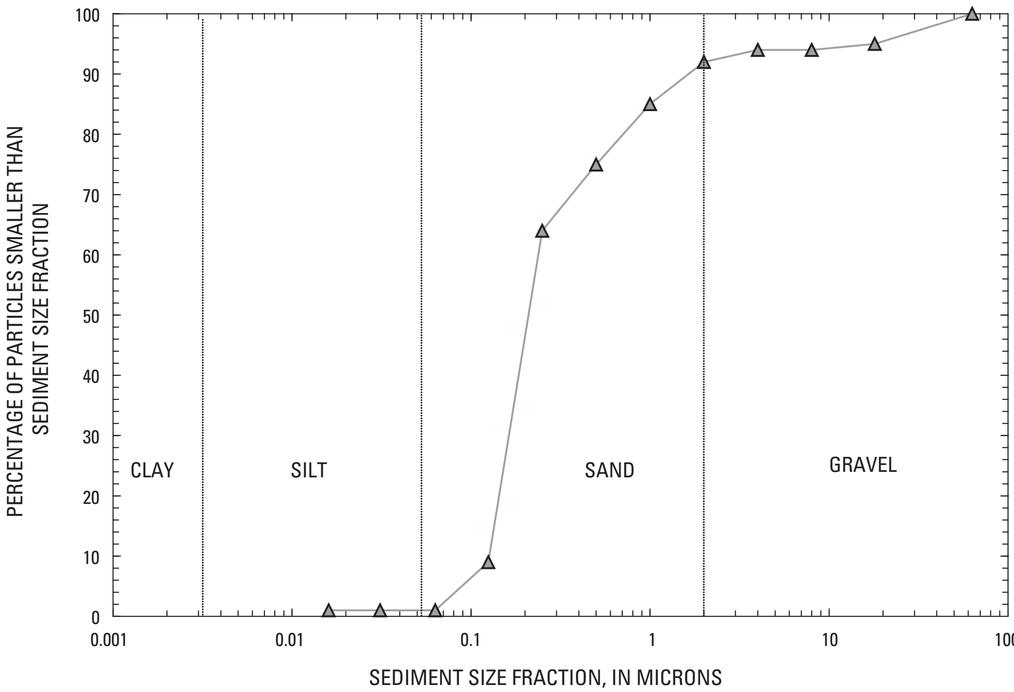

Figure 7. Particle-size distribution of sediment collected from within structural best management practice 1 at U.S. Highway 21 near Beaufort County, S.C., May 2006.

gram, were lead, zinc, copper, nickel, and cadmium (fig. 8). The retention and mobility characteristics of these metals in fine-grained sediment are well known (Ellis and Revitt, 1982; McBride, 1989; Stumm and Morgan, 1996; Burton and others, 2005; Morrison and Benoit, 2005; Knox and others, 2006). Preferential adsorption by the metals to amorphous oxides and organic carbon instead of adsorption to clays may explain their persistence in the coarser grained sediment retained by BMP1.

Event-mean loads for individual storm events were computed for inlet and outlet waters. Stormwater reaching the inlet of BMP1 had SSC loads that ranged several orders of magnitude from 0.57 to 137 kg/event (median of 6.58 kg/event) (fig. 9; table 6). Stormwater leaving the outlet of BMP1 had SSC loads ranging from 0.42 to 6.99 kg/event (median of 3.18 kg/event).

The SSC loads were statistically different between inlet and outlet waters (V-statistic, 55; p-value = 0.0010; table 6), and some reduction in SSC was observed for individual storm events. Computation of that reduction indicated that BMP1, on average for the sampled storm events, reduced SSC loads from stormwater by 17.5 +/- 12.8 kg/event, or an average of 50.7 +/- 7.09 percent (fig. 10; Appendix D-1). Cumulatively, BMP1 received more than 209 kilograms (kg) of suspended sediment during the sampled storm events from 2005 to 2006. Of that 209 kg, BMP1 was able to remove 175 kg (Appendix D-2).

SSC was not correlated significantly with hydrologic variables, such as rainfall, rainfall intensity, or stormflow. Particulate forms of the trace metals were correlated with SSC, however, indicating that particulate metals had similar transport as suspended sediment through the structural BMP.

Oil and Grease

BMP1 was designed to remove floatable substances, such as oil and grease, including petroleum compounds commonly deposited on parking lots and road surfaces by vehicles. Because oil and grease tend to float on top of water, sampling for oil and grease required collection at the water surface of the inlet and outlet waters. The sampling port of the automated sampler was not set near the water surface, so the automated sampler was unable to perform this type of sampling. To ensure a representative sample, oil and grease samples were collected as grab samples (rather than composites) from the inlet and outlet waters on the rising limb of the stormflow hydrograph. Therefore, the oil and grease concentrations discussed in this report are not representative of an EMC, but are representative of “first flush” concentrations.

Oil and grease concentrations in the stormwater entering and leaving BMP1 were frequently below the LRL of 7 mg/L and were reported as estimated, or < 7 mg/L. A greater uncertainty in the results of the statistical analysis of oil and grease concentrations existed because of the semiquantitative nature of the estimated values that were retained as actual values for this study. Additionally, censored values were reported as 1.5 mg/L for the statistical analysis to represent half of the LT-MDL of 3 mg/L (Appendix B).

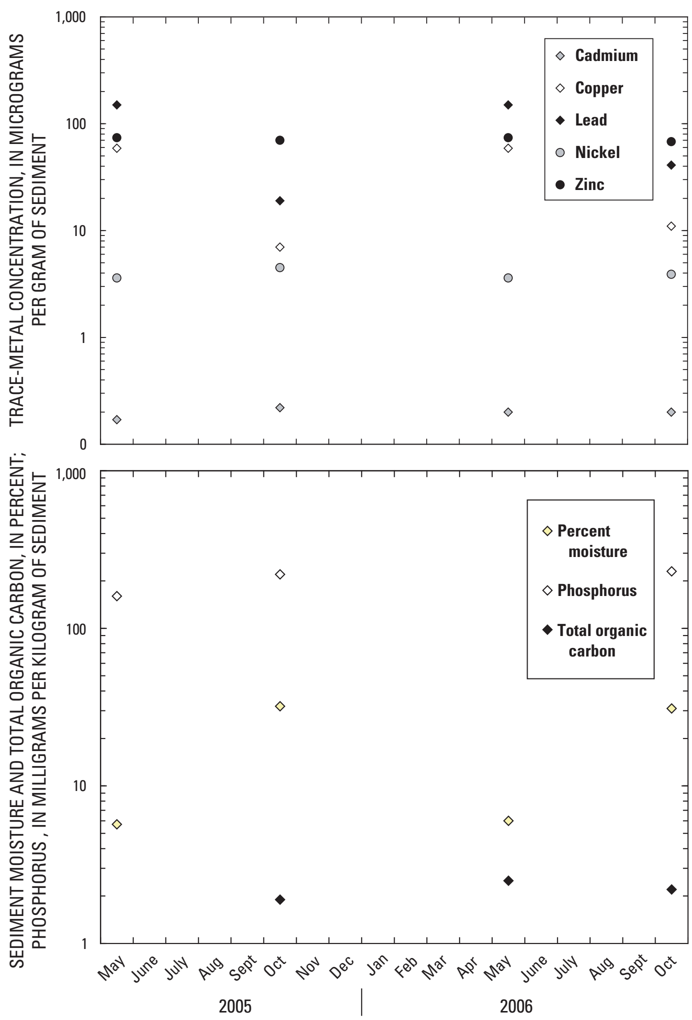

Figure 8. Sediment chemistry determined from samples collected from within best management practice 1 at U.S. Highway 21 near Beaufort County, S.C., May 2005, October 2005, May 2006, and October 2006.

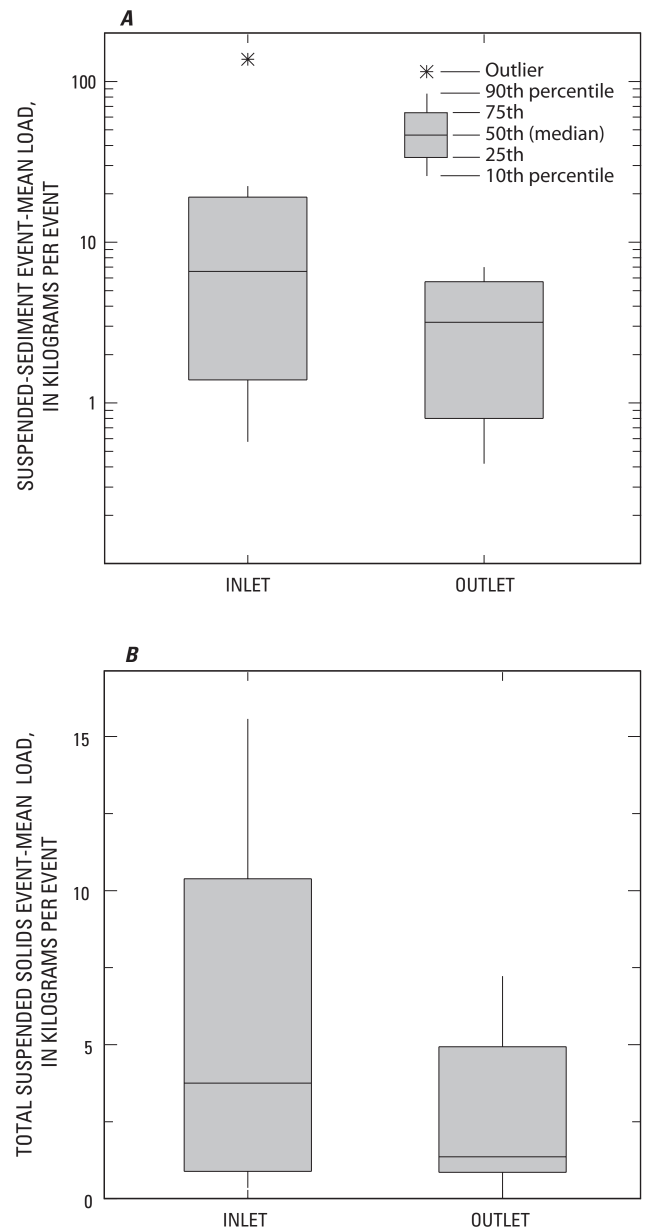

Figure 9. Event-mean loads of *(A)* suspended sediment and *(B)* total suspended solids, in kilograms per event, at best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

Table 6. Summary statistics describing the comparison among event-mean loads in inlet and outlet waters of best management practice 1 (BMP1), Beaufort County, South Carolina, 2005–2006.

[>, greater than; g/event; grams per event; kg/event, kilograms per event]

Constituent	Units	Location	Median	Mean	Standard deviation	Comparison among event-mean loads in inlet and outlet waters of BMP1		Wilcoxon signed-rank test		
						Number	[1]Inlet > outlet	V-statistic	Z-score	Probability value
Dissolved cadmium	g/event	Inlet	0.003	0.004	0.002	10	Yes		1.796	0.036
	g/event	Outlet	0.002	0.003	0.003	10				
Total cadmium	g/event	Inlet	0.01	0.02	0.01	10	Yes		1.786	0.037
	g/event	Outlet	0.01	0.01	0.01	10				
Particulate cadmium	g/event	Inlet	0.01	0.01	0.01	10	No	38		0.161
	g/event	Outlet	0.01	0.01	0.01	10				
Dissolved copper	g/event	Inlet	0.36	0.49	0.35	10	Yes	50		0.010
	g/event	Outlet	0.29	0.39	0.32	10				
Total copper	g/event	Inlet	1.09	1.09	0.62	10	No	40		0.116
	g/event	Outlet	0.91	0.98	0.61	10				
Particulate copper	g/event	Inlet	0.63	0.6	0.49	10	No	27		0.539
	g/event	Outlet	0.49	0.59	0.38	10				
Dissolved lead	g/event	Inlet	0.02	0.02	0.01	10	No	0		1.000
	g/event	Outlet	0.02	0.02	0.02	10				
Total lead	g/event	Inlet	0.92	1.04	0.83	10	Yes	46		0.032
	g/event	Outlet	0.61	0.75	0.57	10				
Particulate lead	g/event	Inlet	0.90	1.02	0.82	10	Yes	46		0.032
	g/event	Outlet	0.59	0.72	0.57	10				
Dissolved nickel	g/event	Inlet	0.17	0.16	0.09	10	No	22		0.722
	g/event	Outlet	0.16	0.17	0.1	10				
Total nickel	g/event	Inlet	0.34	0.33	0.19	10	No		0.868	0.193
	g/event	Outlet	0.29	0.28	0.15	10				
Particulate nickel	g/event	Inlet	0.12	0.17	0.16	10	Yes		1.684	0.046
	g/event	Outlet	0.1	0.12	0.11	10				
Dissolved zinc	g/event	Inlet	2.14	2.18	1.37	10	No	26		0.577
	g/event	Outlet	1.73	2.13	1.58	10				
Total zinc	g/event	Inlet	6.21	6.77	4.5	10	Yes	55		0.001
	g/event	Outlet	4.20	5.89	4.13	10				
Particulate zinc	g/event	Inlet	4.43	4.59	3.68	10	No	36		0.216
	g/event	Outlet	2.74	3.77	3.08	10				
Total ammonia plus organic nitrogen	kg/event	Inlet	0.11	0.12	0.08	10	No		1.258	0.101
	kg/event	Outlet	0.09	0.1	0.06	10				
Total phosphorus	kg/event	Inlet	0.01	0.02	0.01	10	Yes	46		0.032
	kg/event	Outlet	0.01	0.01	0.01	10				
Total organic carbon	kg/event	Inlet	1.22	1.58	1.38	10	No	24		0.652
	kg/event	Outlet	1.22	1.22	0.64	10				
Total suspended solids as residue	kg/event	Inlet	3.76	5.58	5.61	10	No		1.582	0.057
	kg/event	Outlet	1.36	2.85	2.59	10				
Biochemical oxygen demand	kg/event	Inlet	0.74	1.34	1.33	10	No	11		0.958
	kg/event	Outlet	1.23	2.03	1.75	10				
Chemical oxygen demand	kg/event	Inlet	5.32	5.16	2.5	10	No		0.667	0.252
	kg/event	Outlet	4.97	5.47	3.22	10				
Suspended sediment	kg/event	Inlet	6.58	20.9	41.7	10	Yes	55		0.001
	kg/event	Outlet	3.18	3.37	2.77	10				
Oil and grease	kg/event	Inlet	0.51	0.58	0.49	10	Yes		1.786	0.037
	kg/event	Outlet	0.15	0.22	0.19	10				

[1] Probability that the hypothesis that the input and output concentrations are the same versus the alternative one-sided hypothesis that the concentration is greater in the input than the output.

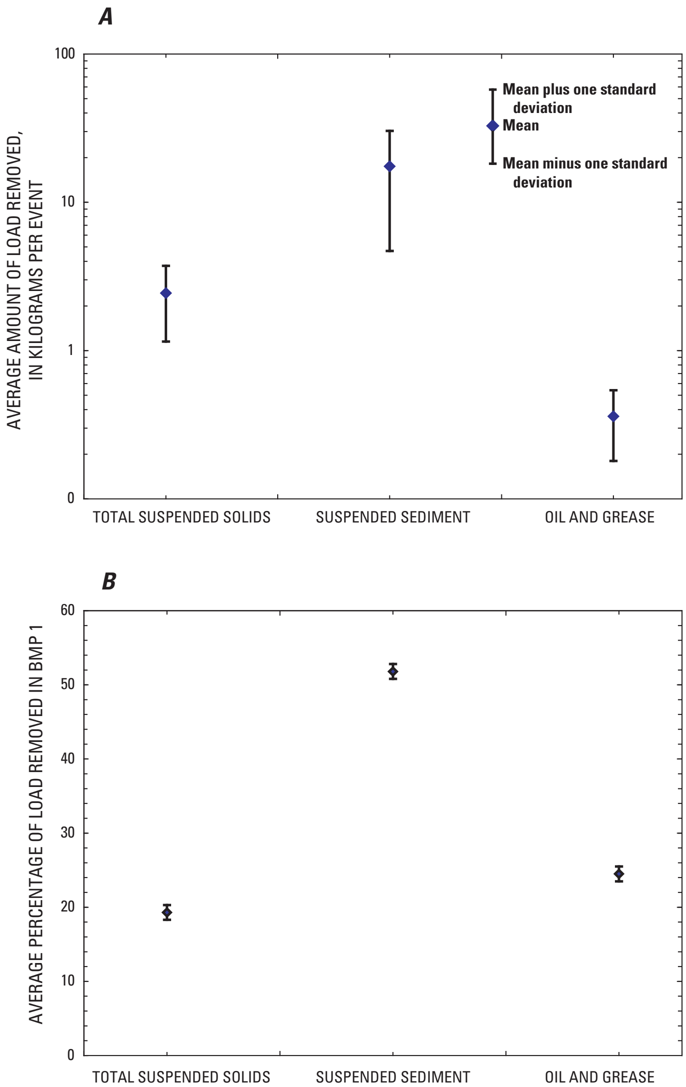

Figure 10. Total loads removed and average percentages of loads removed for total suspended solids, suspended sediment, and oil and grease at best management practice (BMP) 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

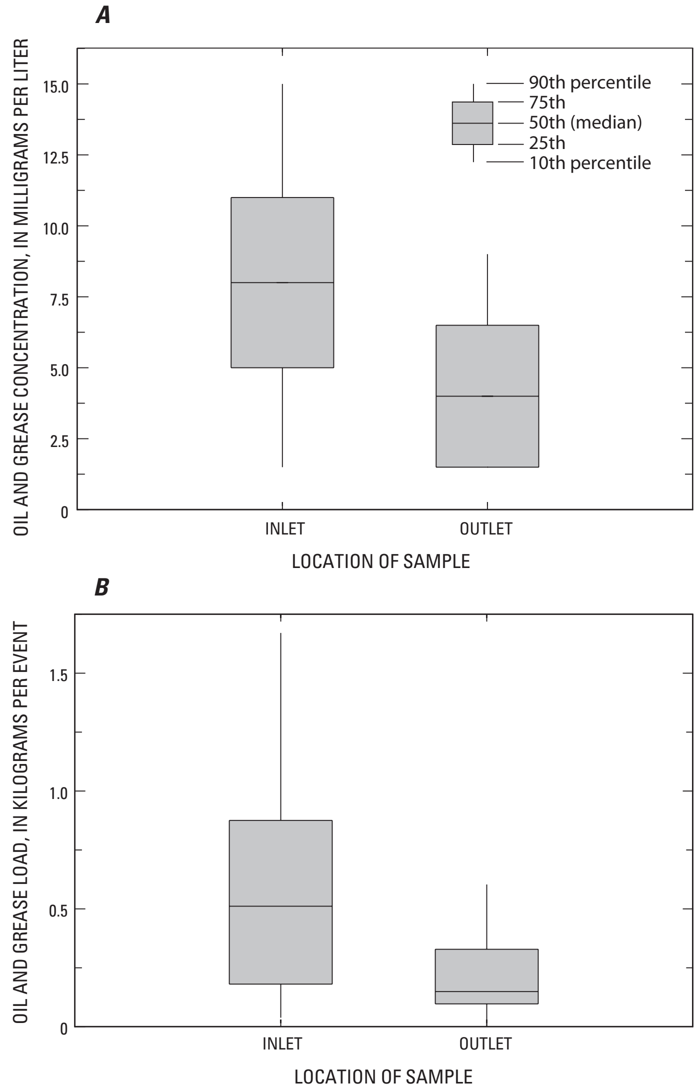

Figure 11. Oil and grease *(A)* concentrations in grab samples and *(B)* loads at best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

For the period of study, stormwater in the inlet of BMP1 had a median oil and grease concentration of 8.00 mg/L and a concentration range of < 7 to 15 mg/L (fig. 11; table 5). Oil and grease concentrations in the stormwater in the outlet of BMP1 were reduced significantly (Z-score = 2.3696, p-value = 0.0089) from the inlet, such that more than 75 percent of the oil and grease concentrations were less than the LRL of 7 mg/L (fig. 11). Consequently, outlet water had a median oil and grease concentration of < 7 mg/L. These results indicated that BMP1 was efficient at reducing oil and grease concentrations from greater than quantifiable levels to less than the LRL.

Grab samples also were collected periodically for analysis for polycylic aromatic hydrocarbons (PAHs). The PAH concentrations represent a group of organic compounds derived from the combustion of fuels and leaching of asphalt. The oil and grease concentrations include the PAHs as a component of all compounds derived from oil and grease. The concentration of all uncensored individual PAH concentrations were summed to provide the total PAH concentration for the inlet and outlet water at BMP1 (table 7; Appendix C). The total PAH concentration in stormwater entering the inlet of BMP1 ranged from 0.06 to 1.78 µg/L; the amount leaving the outlet ranged from 0 to 1.07 µg/L. The maximum total PAH concentration in the inlet water and the high oil and grease concentration of 8 mg/L occurred during the same storm event.

Table 7. Comparison of oil and grease concentrations and total polycyclic aromatic hydrocarbon concentrations in the water from selected storms at best management practice 1, Beaufort County, South Carolina, 2006.

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

Date of sample	Oil and grease (inlet [mg/L])	Oil and grease (outlet [mg/L])	Total PAH (inlet [µg/L])	Total PAH (outlet [µg/L])
February 2, 2006	8	—	1.78	1.07
July 6, 2006	1.5	1.5	0.75	0.00
August 31, 2006	4	1.5	0.06	0.16

Oil and grease loads in the stormwater entering the inlet of BMP1 had a median value of 0.51 kg/event and a range of 0.04 to 1.67 kg/event for the study period. The stormwater leaving the outlet of BMP1 had oil and grease loads that were about half those of the inlet water (median of 0.15 kg/event; range of 0 to 0.60 kg/event; fig. 11). BMP1 was effective at significantly reducing the oil and grease loads that entered the BMP (Z-score = 1.7861, p-value = 0.0370). BMP1 reduced the oil and grease loads in stormwater by an average of 0.36 +/- 0.18 kg/event or 22.9 +/- 27.9 percent (fig. 10; Appendix D-1). For the sampled storm events, the cumulative load of oil and grease entering BMP1 was 5.79 kg, of which 3.58 kg were removed (Appendix D-2). These results indicated that BMP1 was efficient at reducing oil and grease loads in the stormwater entering the BMP.

Nutrients

The amount of biologically available nutrients, mainly nitrogen and phosphorus compounds, that enters nearby water bodies by way of stormwater can accelerate the process of eutrophication. Eutrophication from nutrient enrichment related to long-term contributions of nutrients to water bodies during storm events can result in high biochemical oxygen demand; depletion of dissolved oxygen; unpleasant taste and odors; and nuisance, or even toxic, algal blooms in the receiving water bodies.

For the purpose of this study, removal efficiency of nutrients by the BMPs was evaluated based on the TKN and TP concentrations of the inlet and outlet water for each BMP. The TKN form of nitrogen represents the particulate and dissolved forms of organically bound nitrogen and ammonia. The TP form of phosphorus is the total amount of phosphate in water, which also includes the particulate and dissolved forms. Additionally, only a few associated nutrient enrichment constituents, that including TOC, BOD_5, and COD, were analyzed because of their similar behavior to TKN. The organically bound nitrogen fraction of TKN is a part of the TOC measured in water. The BOD_5 represents the amount of oxygen that is consumed in 5 days by biological organisms that are actively degrading organically bound nitrogen and TOC in a body of water. However, BOD_5 does not include the oxidation of ammonia in the TKN to nitrate or nitrite, which is a process that also consumes oxygen. The COD represents the amount of oxygen consumed by all processes (biological and chemical) that consume oxygen, including decay of organic matter and oxidation of ammonia.

Stormwater entering the inlet of BMP1 had nutrient EMCs similar to the stormwater leaving the outlet of BMP1 (fig. 12). Inlet water had a median TKN concentration of 1.70 mg/L and a median TP concentration of 0.28 mg/L (fig. 12; table 5). Outlet water had median TKN and TP concentrations of 1.30 and 0.19 mg/L, respectively, that were reduced only slightly from the inlet water. Not only were median values similar; ranges in the TKN and TP concentrations in the inlet and outlet waters also had considerable overlap. The differences in TKN concentrations in the inlet and outlet waters at BMP1 were not statistically significant (Z-score = 1.6438, p-value = 0.5107). The differences in TP concentrations in the inlet and outlet waters at BMP1 were statistically significant (Z-score = 1.9930, p-value = 0.0231). This finding indicated that BMP1 was not efficient at reducing TKN concentrations, but was able to reduce TP concentrations in stormwater.

Median EMCs for TOC, BOD_5, and COD in the stormwater entering the inlet in BMP1 were 38.0, 15.2, and 120 mg/L, respectively (table 5). The much higher COD in comparison to BOD_5 indicates that organic decay processes were playing less of a role in oxygen consumption than other biological and chemical processes. Median EMCs for TOC, BOD_5, and COD in the stormwater leaving the outlet of BMP1 were 17.7, 20.5, and 80.0 mg/L, respectively. Although there appeared to be a reduction in median EMCs for TOC and COD and a small increase in EMCs for BOD_5 between inlet and outlet waters of BMP1, no statistical change in concentrations were determined (for TOC, Z-score = 0.8389 and p-value = 0.2008; for BOD_5, V-statistic = 15 and p-value = 0.9867; for COD, Z-score = 1.3065 and p-value= 0.0957). This finding indicates that BMP1 was not reducing EMCs for TOC, BOD_5, and COD in stormwater.

A great amount of overlap also was observed for the TKN loads entering and leaving BMP1; the inlet and outlet water had similar median TKN loads of 0.11 and 0.09 kg/event, respectively (fig. 13). Median TP loads for the inlet and outlet

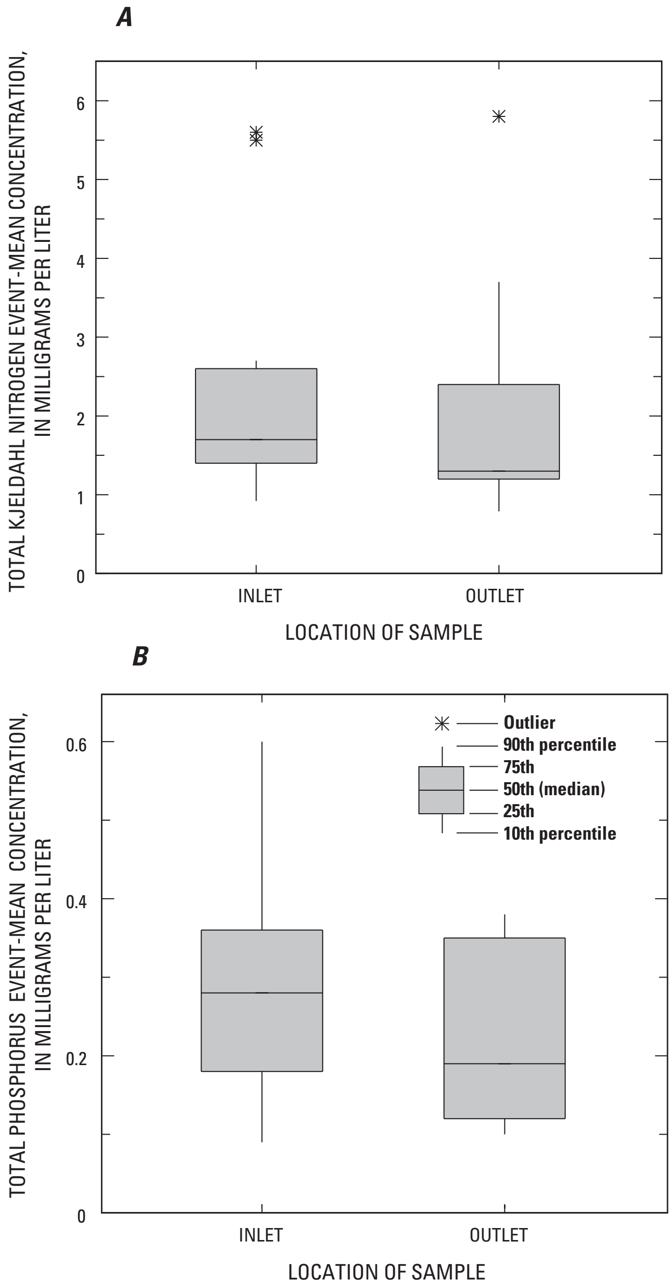

Figure 12. Event-mean concentrations of *(A)* total Kjeldahl nitrogen and *(B)* total phosphorus at best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

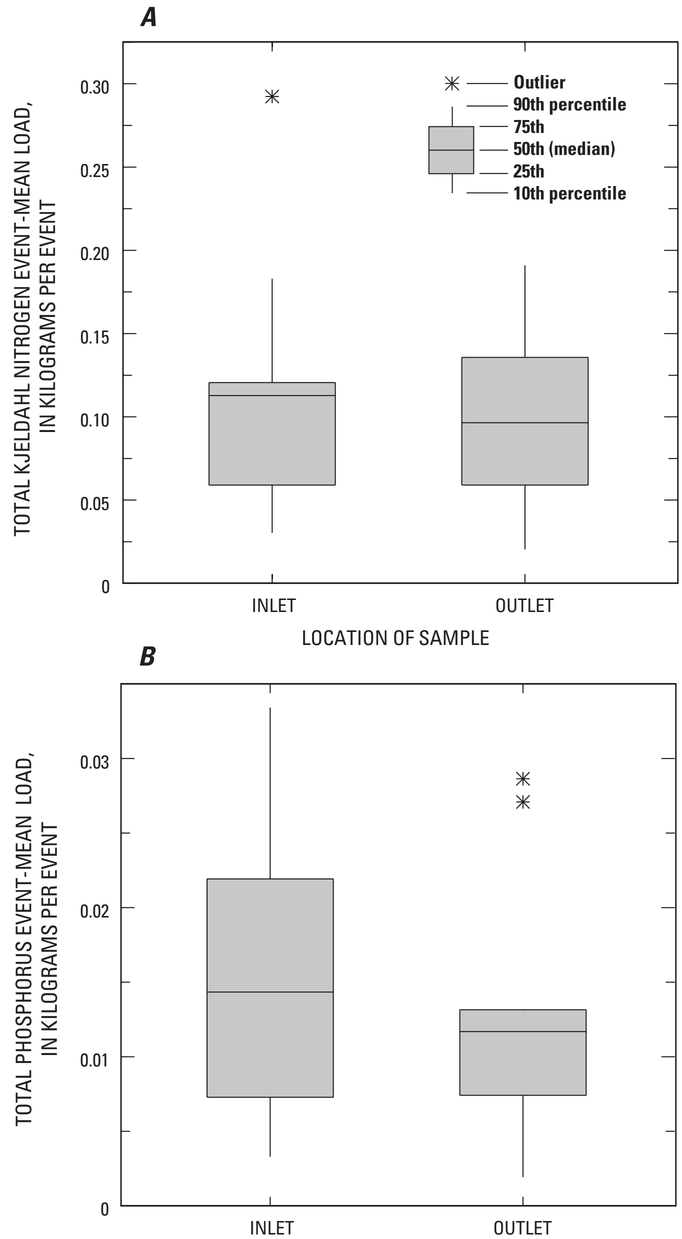

Figure 13. Event-mean loads of *(A)* total Kjeldahl nitrogen and *(B)* total phosphorus at best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

water were identical (0.01 kg/event); however, the range in TP loads for the outlet water appeared slightly reduced when compared to the inlet water. The TKN loads for BMP1 were not statistically different between inlet and outlet water for this study (table 6; Z-score = 1.2578; p-value = 0.1010). The TP loads were statistically different between inlet and outlet for this study (V-statistic = 46; p-value = 0.0322). This finding indicated that BMP1 was not efficient at reducing TKN loads, but was efficient in reducing TP loads in stormwater.

Median TOC, BOD_5, and COD loads in the stormwater entering the inlet in BMP1 were 1.22, 0.74, and 5.32 kg/event, respectively (table 6). Median TOC, BOD_5, and COD loads in the stormwater leaving the outlet of BMP1 were 1.22, 1.23, and 4.97 kg/event, respectively. No statistical difference in TOC, BOD_5, and COD loads between inlet and outlet waters for BMP1 were identified (for TOC, V-statistic = 24, p-value = 0.6523; for BOD_5, V-statistic = 11, p-value = 0.9580; and for COD, Z-score = 0.6669, p-value = 0.2524). This indicated that BMP1 was not reducing TOC, BOD_5, and COD loads in stormwater.

For the sampled storm events during 2005 and 2006, the average amount of TKN load that was reduced by BMP1 was 0.01 +/- 0.01 kg/event, or about 8.6 +/- 6 percent (fig. 14; Appendix D-1). The TP loads were reduced an average of 0.001 kg/event, or about 12.3 percent. Cumulatively for the sampled storm events, BMP1 received 1.17 kg of TKN load and removed only 0.15 kg, which further indicated poor performance of BMP1 for reducing nutrient loads in stormwater (Appendix D-2). BMP1 had cumulative TP loads entering its inlet of 0.16 kg and was able to remove only 0.03 kg of that load.

In relation to environmental and chemical factors, EMCs for TKN and TP entering and leaving BMP1 were correlated significantly with hydrologic variables of rainfall intensity and mean stormflow. EMCs for TOC, COD, and BOD_5 are commonly associated with each other, and TOC and COD were correlated with EMCs for TKN in the stormwater entering the inlet and leaving outlet of BMP1. However, EMCs for TP were correlated only with COD in the inlet waters but correlated significantly with TOC, COD, and BOD_5 in the outlet water. Additionally, most dissolved and total forms of the trace metals were correlated with TKN and TP, suggesting nutrients had similar transport as organic carbon and other oxygen-consuming compounds and trace metals through the structural BMP.

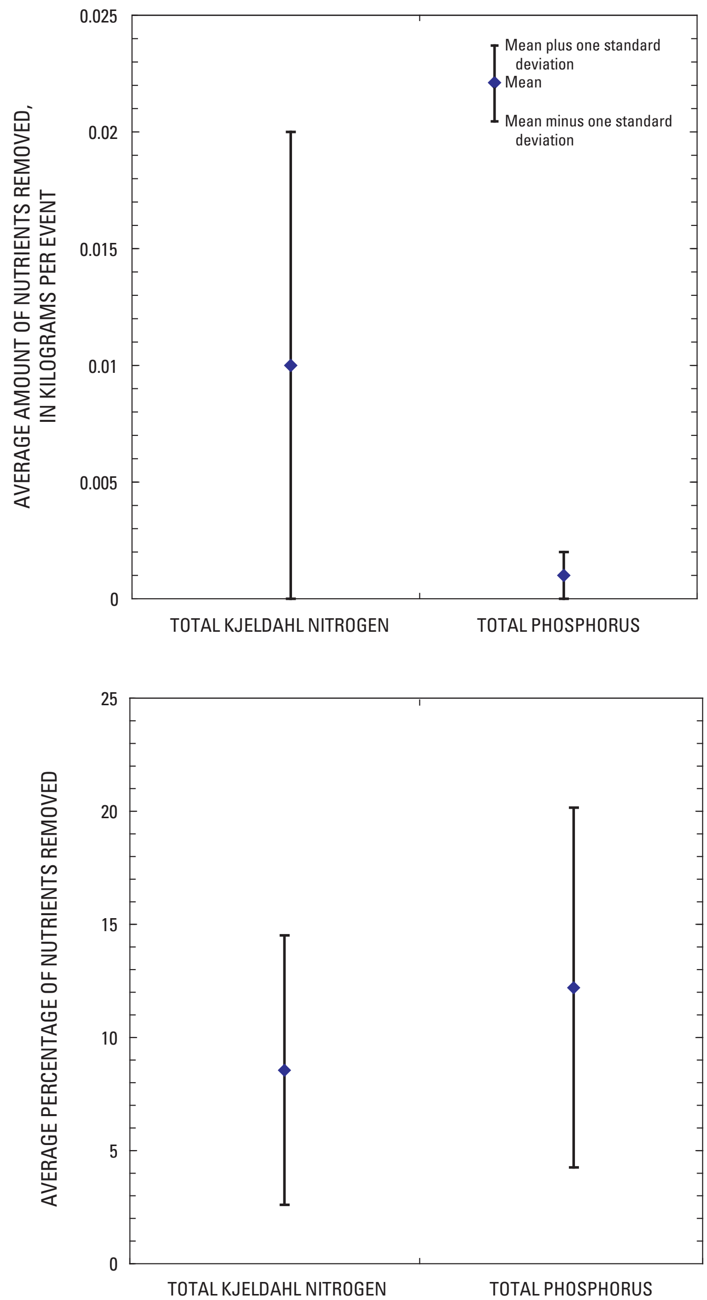

Figure 14. Average amounts and percentages of total Kjeldahl nitrogen and total phosphorus removed by best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

Indicator Bacteria

Indicator bacteria are types of bacteria not normally found in high numbers in oceans, rivers, or creeks, but always found in guts of warm-blooded animals, including humans. The presence of indicator bacteria signifies that other disease-causing or pathogenic organisms also may be present. Prior to 1986, the USEPA recommended bacteria criteria based on fecal coliforms to protect human health. In 1986, the USEPA recommended the use of criteria based on *E. coli* levels for freshwaters and enterococci levels for fresh and marine waters rather than the use of criteria based on fecal coliform (U.S. Environmental Protection Agency, 1986). The USEPA recommended this change in the use of bacteria indicator organisms because the USEPA studies demonstrated that *E. coli* and enterococci are better predictors of the presence of gastrointestinal illness-causing pathogens than fecal and total coliforms and hence provide a better means of protecting human health (Dufour, 1984; U.S. Environmental Protection Agency, 1986). For evaluation of water quality, the SCDHEC uses fecal coliform as freshwater indicator bacteria, with an exceedence criterion of 400 col/100 mL in 10 percent of samples (South Carolina Department of Health and Environmental Control, 2004). The SCDHEC uses enterococci as saltwater indicator bacteria, with a single-sample maximum criterion of 104 col/100 mL. The recommended criterion established by the USEPA for *E. coli* is 235 col/100 mL. For the purpose of this report, only enterococci and *E. coli* concentrations are discussed.

The ability of each BMP to reduce fecal indictor bacteria in stormwater was analyzed during this study. The potential for reduction exists because most fecal indicator bacteria are sessile or are attached to surfaces, including sediment surfaces, within the environment (Desmarais and others, 2002); if the BMP reduced the suspended sediment load, then bacteria concentrations would also be reduced. However, the study was limited by the fact that the grab samples collected for bacterial analysis were not representative of the entire storm hydrograph, but only of the first flush response.

BMPs potentially serve as repositories for fecal indicator bacteria. Research has indicated that *E. coli* and enterococci can survive for several days in aquatic sediment in situ suggesting that fecal indicator bacteria in water may not always indicate recent fecal contamination of that water but rather re-suspension of viable sediment-bound bacteria (LaLiberte and Grimes, 1982; Byappanahalli and others, 2003; Francy and others, 2003; Ferguson and others, 2004; Cinotto, 2005). Environmental conditions present in tidally influenced sediments, such as are present at the Beaufort County BMP sites, have been reported to help support elevated levels of enteric bacteria (Desmarais and others, 2002). One study reported that fecal indicator bacteria can survive in bed sediments of streams and lakes for up to 6 weeks and that re-suspension occurred primarily during the "first flush" or rising limb of the storm (Jamieson and others, 2005). A USGS study identified impervious surfaces as influencing bacterial contamination, primarily in sediments at or near storm-sewer outfalls (although elevated bacterial concentrations were not present in the storm sewer itself) (Cinotto, 2005).

The *E. coli* and enterococci concentrations in samples collected from stormwater entering and leaving BMP1 were not correlated in the inlet and outlet waters for the period of study (inlet: rho = –0.16364, p-value = 0.6515; outlet: rho = –0.21885, p-value = 0.5430). However, both fecal indicator bacteria ranged more than 4 orders of magnitude in concentrations during the study period. Median concentrations of 820 and 1,190 col/100 mL for *E. coli* and enterococci, respectively, for inlet water and 1,100 and 3,550 col/100 mL, respectively, for outlet water indicated an overall increase in fecal indicator bacterial concentrations (table 5; fig. 15). However, statistical tests of the *E. coli* and enterococci concentrations between inlet and outlet water indicated no significant change in these concentrations (p-values = 0.9731 and 0.7651, respectively; table 5).

Significant negative relations between *E. coli* and peak stormwater discharge and rainfall intensity (rho = –0.71667, p-value = 0.0298 and rho = –0.64545, p-value = 0.0320, respectively) were determined for the stormwater entering BMP1, indicating decreasing bacterial concentrations at higher flows (dilution effect). Enterococci concentrations had no significant correlation with hydrologic variables, but did have a correlation with BOD (rho = 0.67133, p-value = 0.0168). Therefore, the potential for the accumulated sediment and organic matter in the bottom of the BMP devices to serve as an additional source (in addition to the stormwater represented in the inlet water) of bacteria during storm events existed. That survival or growth, and then the re-suspension process, of enterococci and *E. coli* bacteria could have explained outlet water concentrations that were equal to or higher than inlet water concentrations.

Sediment samples removed from BMP1 during clean-out periods were analyzed for viable colonies of enterococci and *E. coli* in May 2006 (*E. coli* only) and in October 2005 and 2006. Enterococci concentrations were highly variable at 14,100 and 250 colonies per 100 grams of sediment in October 2005 and 2006, respectively (fig. 16). Although the sediment data were limited, no strong pattern between sediment and water concentrations was observed for enterococci, such that higher concentrations in sediment did not reflect higher concentrations in water. The *E. coli* concentrations were slightly less variable than enterococci concentrations, ranging from 98 to 3,900 colonies per 100 milligrams of sediment (fig. 17).

Enterococci concentrations in all but one inlet water sample were above the SCDHEC single sample maximum criterion of 104 col/100 mL (fig. 16). Similarly, all but three inlet water samples were above the USEPA recommended single sample criterion of 235 col/100 mL for *E. coli* (fig. 17).

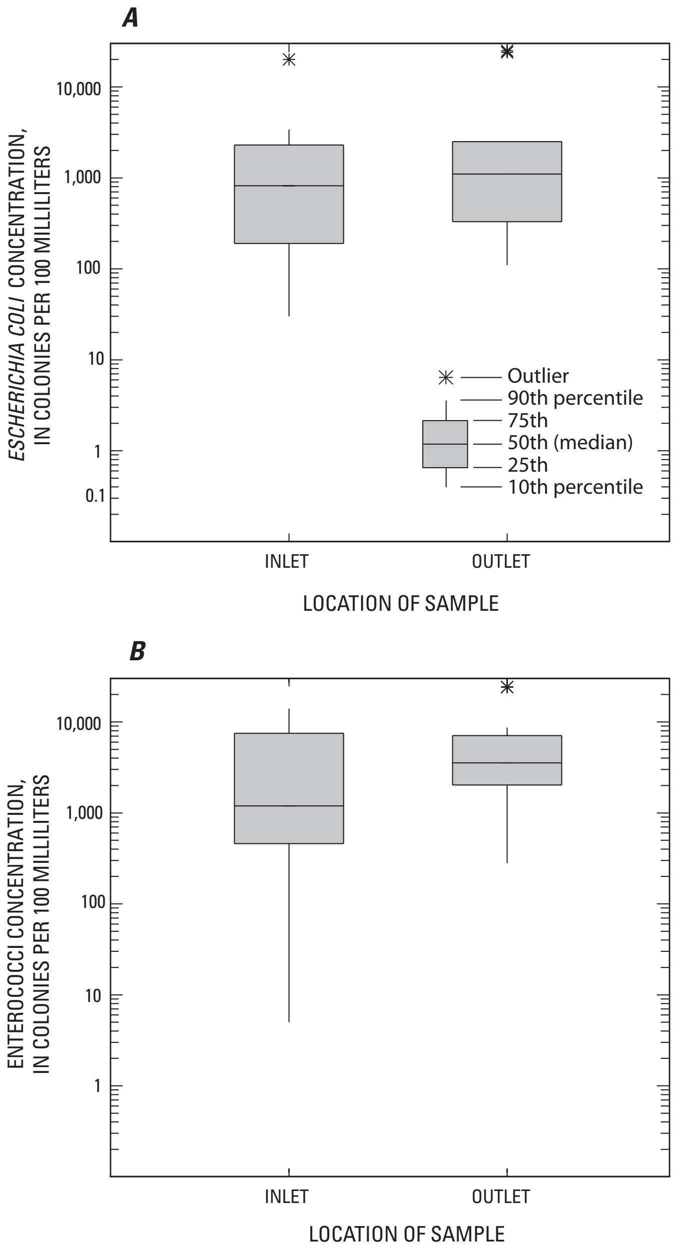

Figure 15. Concentrations of *(A) Escherichia coli* and *(B)* enterococci in grab samples collected from best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

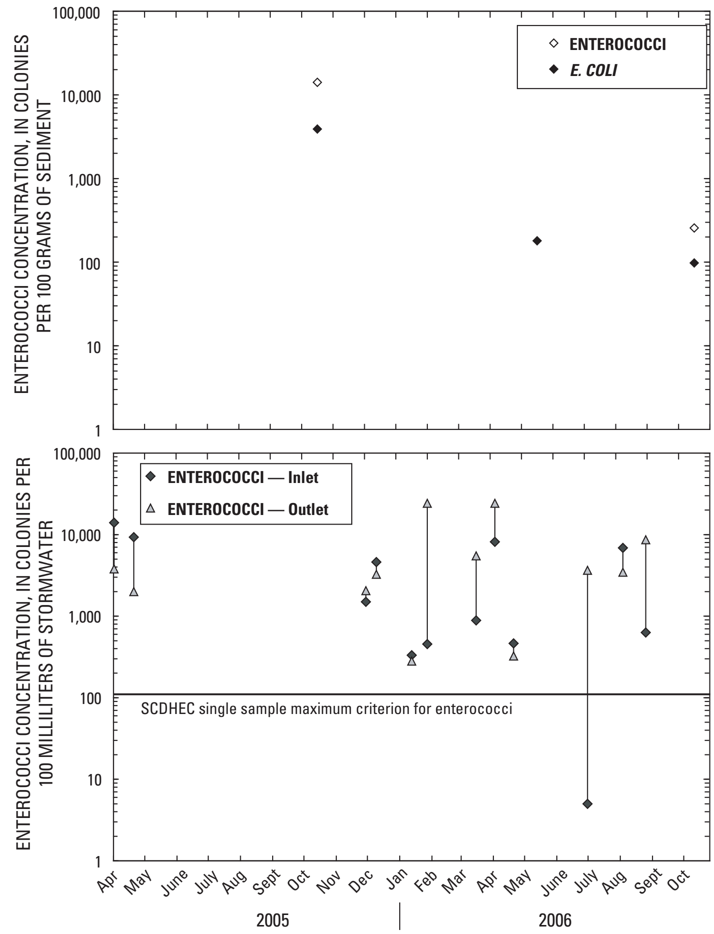

Figure 16. Time-series plots of enterococci concentrations in sediment and stormwater at best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control]

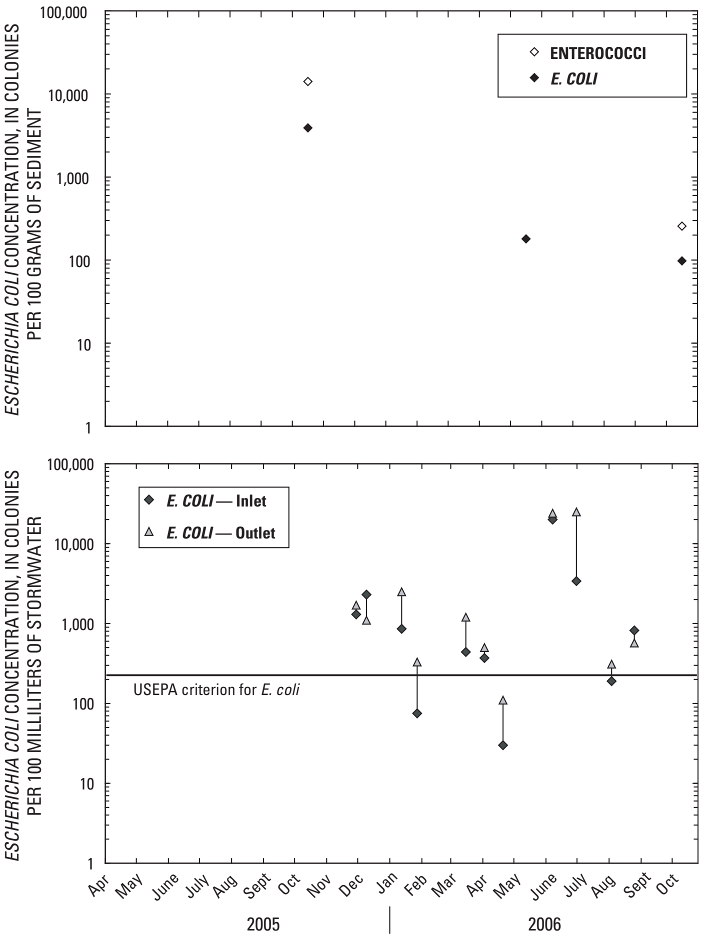

Figure 17. Time-series plots of *Escherichia coli* (*E. coli*) concentrations in sediment and stormwater for best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006. [USEPA, U.S. Environmental Protection Agency]

Metals

Inlet and outlet water samples were analyzed for total and dissolved metal concentrations. Concentrations of particulate forms of the metals were computed by subtracting dissolved metal concentrations from the total concentrations. It should be noted that traditional analytical methods used to determine dissolved metal concentrations used 0.45-micron filters to separate dissolved and particulate phases. Based on this operational definition, dissolved metal concentrations reported in this study included colloidal-sized particles. Colloids are generally defined as particles with diameters between 0.001 to 10 microns (Stumm and Morgan, 1996). Therefore, the dissolved metals concentrations include metals in solution and any metals attached to colloidal-sized particles less than 0.45 micron. The particulate metal concentration represents the remaining fraction and does not distinguish between the fraction of metals adsorbed to a mineral particle surface and the fraction that is part of an actual mineral structure.

The total metal concentrations in the inlet and outlet waters were compared to existing criteria to provide a relative screening tool. Acute and chronic aquatic-life criteria have been established for metal concentrations by the USEPA and adopted by the SCDHEC for receiving waters (South Carolina Department of Health and Environmental Control, 2004; U.S. Environmental Protection Agency, 2006). Criteria established by the USEPA and adopted by the SCDHEC for certain metals, including cadmium, copper, lead, nickel, and zinc, were based on empirical relations of toxicity to water hardness. That is, a relation was established linking the criteria concentrations with water hardness. These hardness-dependent criteria represented combined effects of different water-quality variables such as pH and alkalinity that tend to be correlated with hardness. Two criterion levels exist for metals: criteria maximum concentration (CMC) and criteria continuous concentration (CCC; table 8). Both levels of criteria are different for freshwater and saltwater. The median hardness for

Table 8. Freshwater and saltwater aquatic-life criteria.

[All values are in micrograms per liter; SCDHEC, South Carolina Department of Health and Environmental Control; CMC, criteria maximum concentration; CCC, criteria continuous concentration]

SCDHEC water-quality criterion	Total cadmium	Total copper	Total lead	Total nickel	Total zinc
Freshwater aquatic-life criteria					
CMC	0.53	3.8	14	150	75
CCC	0.10	2.9	0.54	16	8.3
Saltwater aquatic-life criteria					
CMC	43	5.8	220	37	95
CCC	9.3	3.7	8.5	37	86

all samples collected at all four BMPs was 25 mg/L, and the computed CMC for that hardness was used for the “screening level” for freshwater and saltwater aquatic life. The freshwater CMC was selected because stormwater contributions of metals to receiving water represented more of an acute or maximum contribution than the CCC for freshwater.

Concentration ranges of the targeted trace metals in the stormwater entering the inlet of BMP1 varied by 4 orders of magnitude (figs. 18–20), and are listed in order of increasing concentration: total cadmium (median, 0.32 µg/L), total nickel (median, 6.17 µg/L), total lead (median, 14.3 µg/L), total copper (median, 19.8 µg/L), and total zinc (median, 128 µg/L). Concentration ranges of the targeted trace metals in the stormwater leaving the outlet of BMP1 varied by 3 orders of magnitude, but were in the same order of increasing concentration: total cadmium (median, 0.17 µg/L), total nickel (median, 4 µg/L), total lead (median, 11 µg/L), total copper (median, 13.5 µg/L), and total zinc (median, 77 µg/L). Lead was mostly in the particulate form in inlet and outlet water samples (fig. 19). Cadmium was mainly in particulate forms of the metal, especially in the outlet water (fig. 18). In general, copper, nickel, and zinc were distributed fairly evenly between particulate and dissolved forms.

Total cadmium and nickel EMCs in the stormwater entering the inlet and leaving the outlet of BMP1 were well below the SCDHEC-established CMCs for freshwater aquatic life (table 8; figs. 18 and 19). However, the reverse was true for total copper; all copper EMCs in the inlet and outlet waters

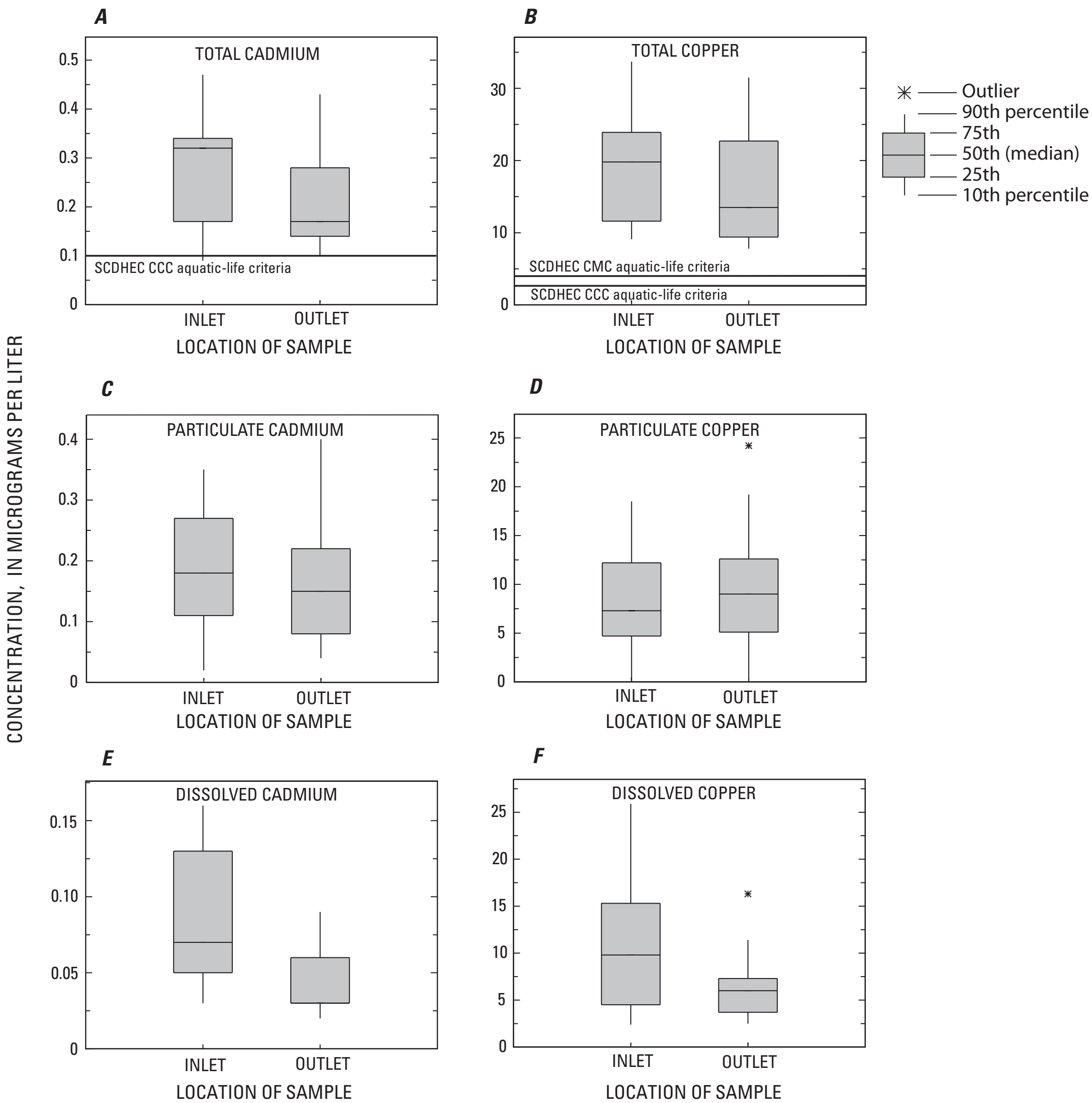

Figure 18. Event-mean concentrations of total *(A)* cadmium and *(B)* copper; particulate *(C)* cadmium and *(D)* copper; and dissolved *(E)* cadmium and *(F)* copper at best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration]

of BMP1 were greater than the freshwater CMC of 3.8 µg/L (table 8; fig. 18). For total lead EMCs in the stormwater, about 50 percent of the EMCs entering the inlet of BMP1 were greater than the SCDHEC-established CMC for freshwater aquatic life of 14 µg/L (fig. 19). However, less than 25 percent of the samples were greater than 14 µg/L in the stormwater leaving BMP1. Similarly, more than 75 percent of total zinc EMCs entering the inlet of BMP1 were greater than the SCDHEC-established CMC for freshwater aquatic life (75 µg/L); about 50 percent of the total EMCs leaving BMP1 were greater than the CMC (table 8; fig. 20).

The trace-metal loads had a similar pattern to that of the trace-metal concentrations (figs. 21–23) indicating no overall changes in trace-metal loads between inlet and outlet waters. Inlet loads were: total cadmium (median, 0.01 g/event), total nickel (median, 0.34 g/event), total copper (median, 1.09 g/event), total lead (median, 0.92 g/event), and total zinc (median, 6.21 g/event; table 6). Outlet loads were: total cadmium (median, 0.01 g/event), total nickel (median, 0.29 g/event), total lead (median, 0.61 g/event), total copper (median, 0.91 g/event), and total zinc (median, 4.20 g/event). The statistical analysis indicated total and dissolved cadmium loads (Z-scores = 1.7861 and 1.7955, respectively; p-values = 0.0370 and 0.0363, respectively), total and particulate lead loads (V-statistics = 46 and 46, respectively; p-values = 0.0322 and 0.0322, respectively), dissolved copper loads (V-statistic = 50; p-value = 0.0098), and particulate nickel loads (Z-score = 1.6840; p-value = 0.0461) for BMP1 were statistically

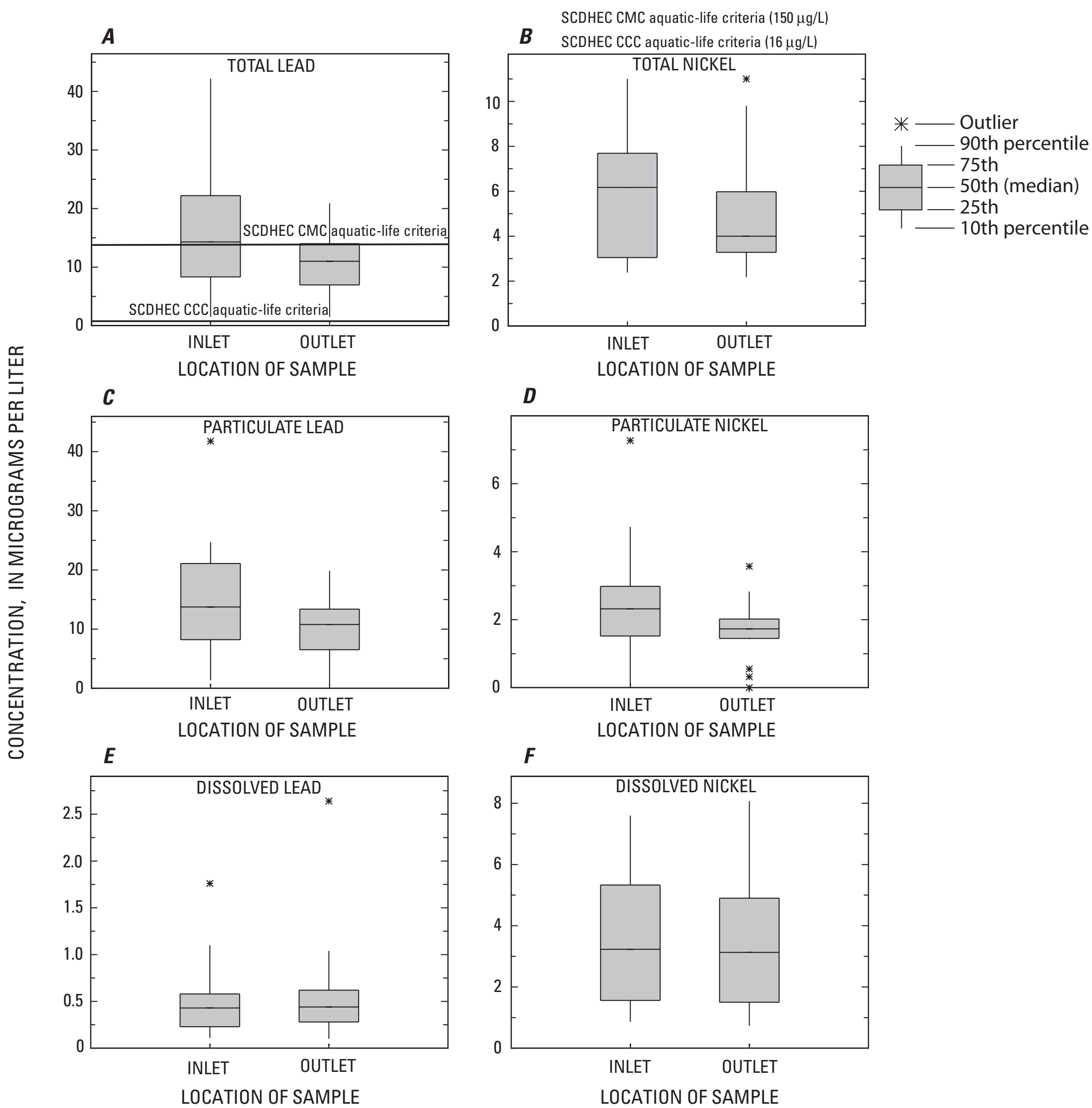

Figure 19. Event-mean concentrations of total *(A)* lead and *(B)* nickel; particulate *(C)* lead and *(D)* nickel; and dissolved *(E)* lead and *(F)* nickel at best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration]

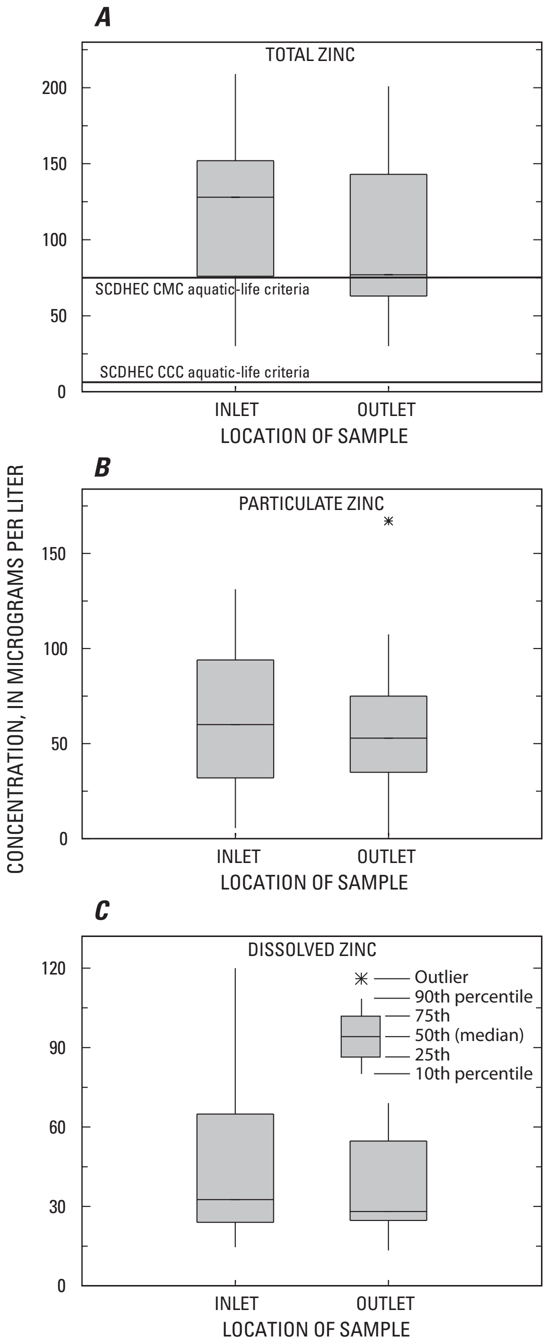

Figure 20. Event-mean concentrations of *(A)* total zinc, *(B)* particulate zinc, and *(C)* dissolved zinc at best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration]

different between inlet and outlet water for this study. These findings indicated that BMP1 was efficient at reducing trace-metal loads in stormwater.

Significant changes in trace-metal concentrations between inlet and outlet waters were identified (table 5; fig. 24). Total cadmium concentrations were significantly reduced in the outlet water (p-value = 0.0025). Total and dissolved copper concentrations (p-scores, 0.0048 and 0.0009, respectively), total and particulate lead concentrations (p-scores, 0.0017 and 0.0009, respectively), total nickel concentrations (p-score, 0.0433) and total and dissolved zinc concentrations (p-scores, 0.0078 and 0.0239, respectively) for BMP1 were statistically different between inlet and outlet water for this study. These findings indicated that BMP1 was efficient at reducing trace-metal concentrations in stormwater.

For the sampled storm events, the average amount of trace-metal load that was reduced by BMP1 during the storm events sampled for this study were, in order from least to greatest loads: total cadmium (0.003 +/- 0.002 g/event), total nickel (0.05 +/- 0.04 g/event), total copper (0.11 +/- 0.07 g/event), total lead (0.29 +/- 0.17 g/event), and total zinc (0.87 +/- 0.56 g/event; fig. 24; Appendix D-1). The average percentages of trace-metal concentrations and loads removed by BMP1 were similar and are listed in order of least to greatest: total nickel (6.36 +/- 6.35 percent), total zinc (6.77 +/- 7.49 percent), total copper (8.79 +/- 5.18 percent), total cadmium (13.1 +/- 6.19 percent), and total lead (15.8 +/- 7.52 percent). Except for copper, the particulate form of each of the trace metals appeared to have greater reductions in load than in the dissolved form. For the sampled storm events at BMP1, stormwater entering the BMP had the following cumulative loads: 0.16 g of total cadmium, of which 0.03 g were removed; 3.32 g of total nickel, of which 0.48 g were removed; 10.9 g of total copper, of which 1.13 g were removed; 10.5 g of total lead, of which 2.96 g were removed; and 67.7 g of total zinc, of which 8.72 g were removed by BMP1 (Appendix D-2).

As mentioned previously, trace-metal concentrations were measured in the retained coarser-grained sediment and were lead, zinc, copper, nickel, and cadmium, in order from greatest to least concentration (fig. 8). Similar retention or mobility characteristics of these metals in sediment have been previously reported (Ellis and Revitt, 1982; McBride, 1989; Stumm and Morgan, 1996; Burton and others, 2005; Morrison and Benoit, 2005; Knox and others, 2006). The trace-metal loads removed between the inlet and outlet water of BMP1 were: zinc, lead, copper, nickel, and cadmium in order from greatest to least.

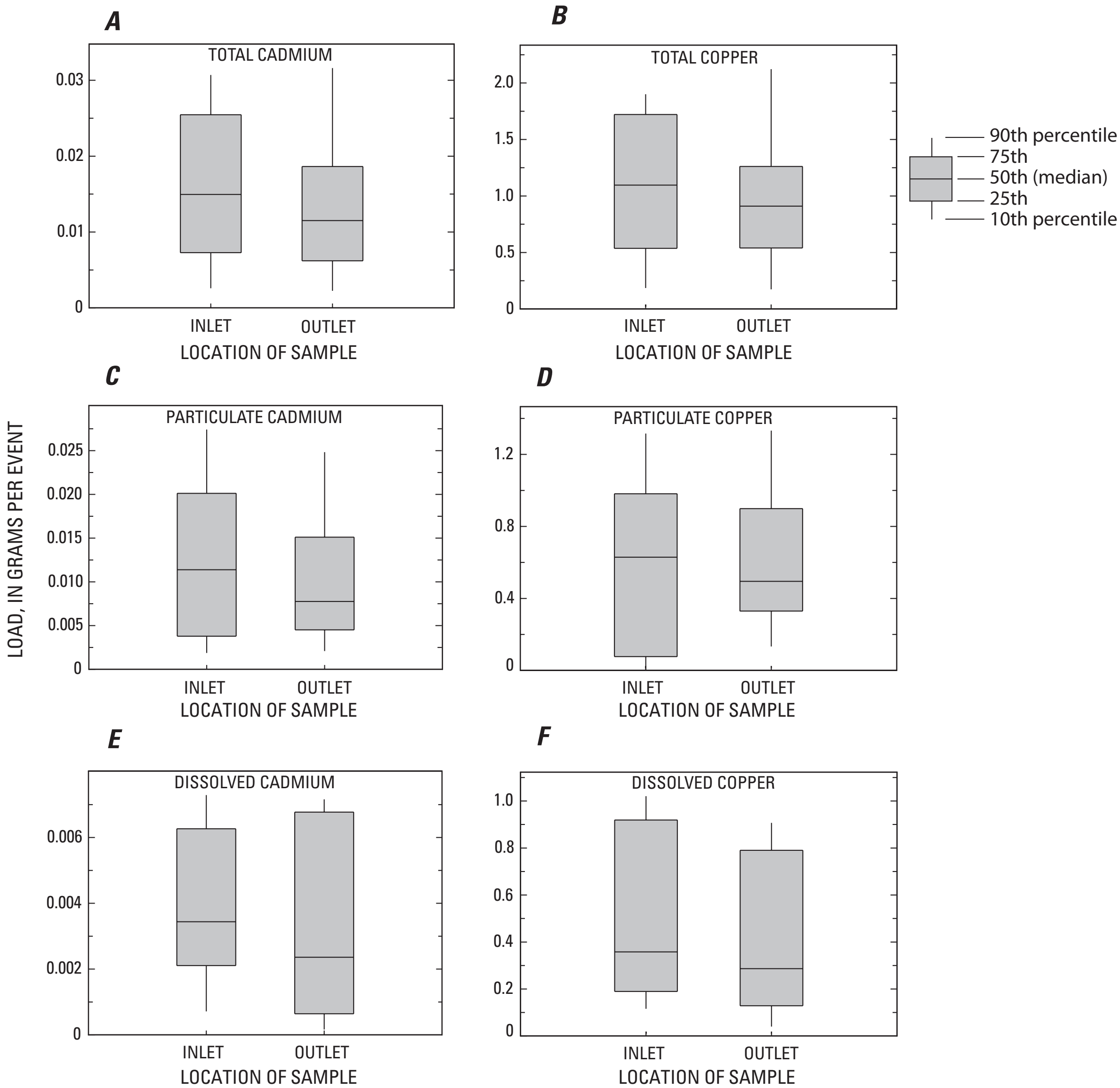

Figure 21. Event-mean loads of total *(A)* cadmium and *(B)* copper; particulate *(C)* cadmium and *(D)* copper; and dissolved *(E)* cadmium and *(F)* copper at best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

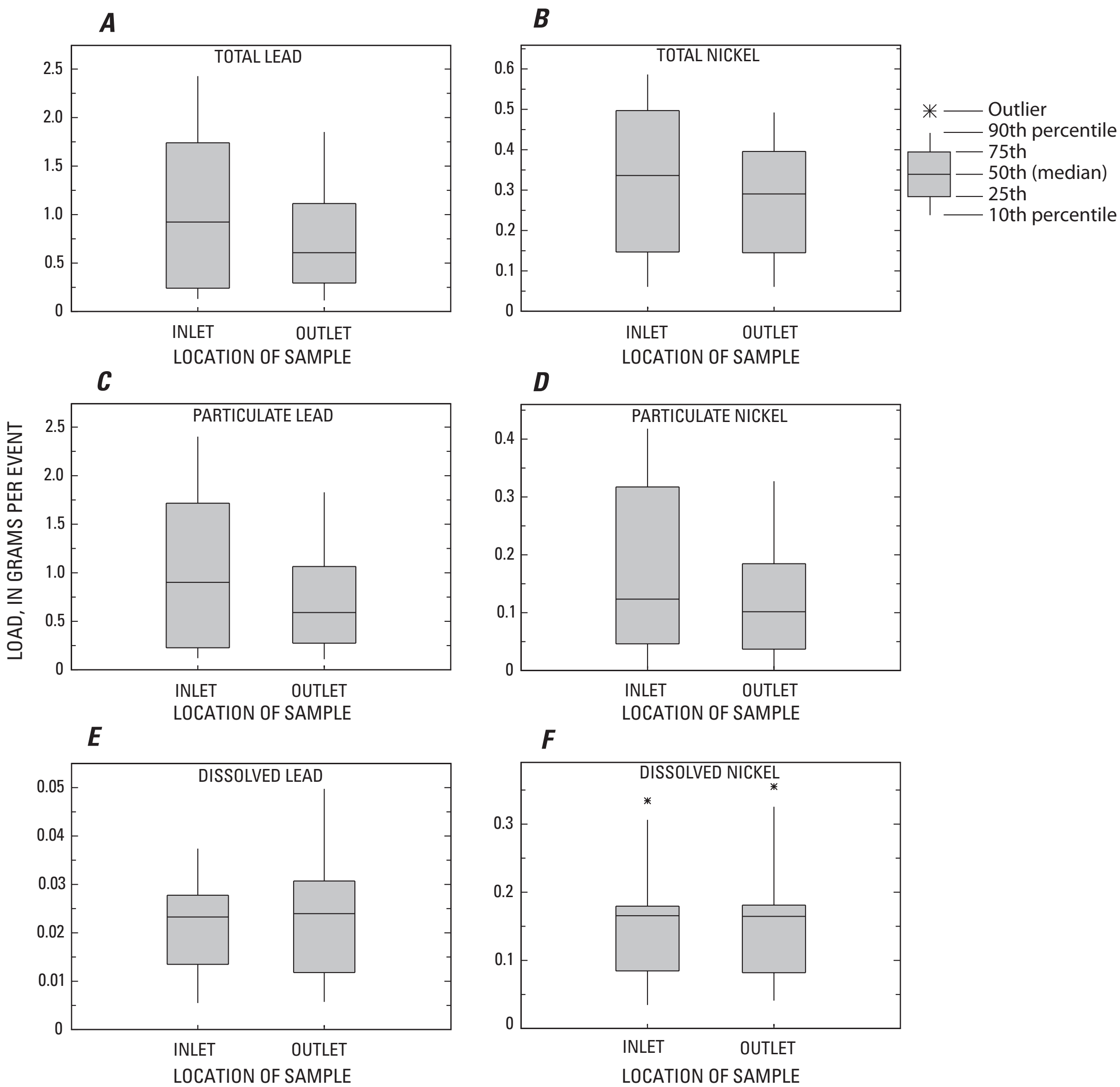

Figure 22. Event-mean loads of total *(A)* lead and *(B)* nickel; particulate *(C)* lead and *(D)* nickel; and dissolved *(E)* lead and *(F)* nickel at best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

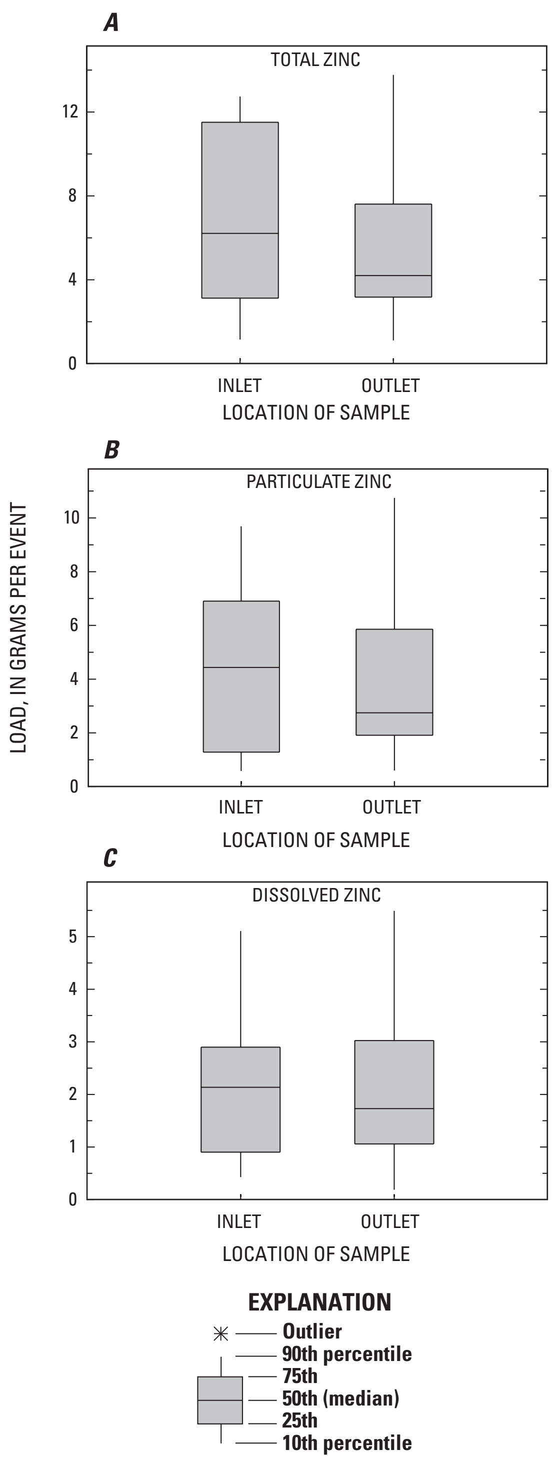

Figure 23. Event-mean loads of *(A)* total zinc, *(B)* particulate zinc, and *(C)* dissolved zinc at best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

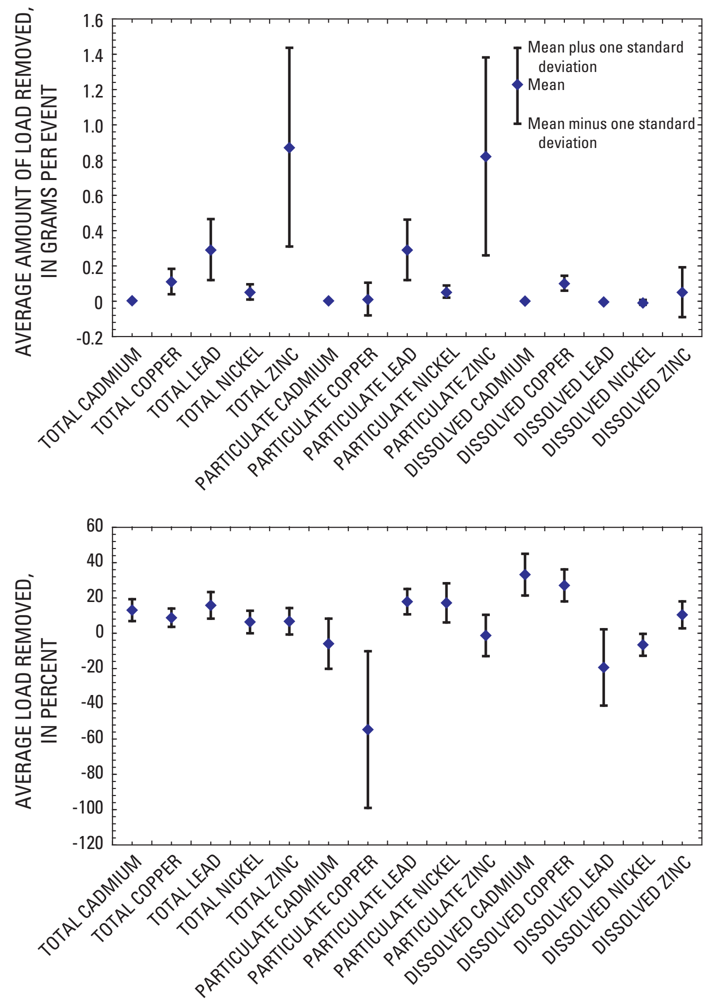

Figure 24. Average amounts and percentages of event-mean loads of selected trace metals removed by best management practice 1 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

BMP2 Performance Assessment

BMP2 is located along the southbound lane of U.S. Highway 21 near the Woods Memorial Bridge in Beaufort, S.C. (fig. 2). The drainage area for this BMP is 1.11 acres, with a curb and gutter system for highway runoff (table 1). For BMP2, stormwater and contaminants enter the system and are introduced tangentially inside the separation screen forming a vortex. Flows in excess of the BMP treatment capacity bypass the screen chamber. Floating debris and suspended solids are diverted to the center of the vortex. Negatively buoyant solids settle out to an undisturbed sump chamber below, while the water passes counter-currently through the separation screen. Floating debris remains at the water surface trapped within the screen (CDS, 2008).

The event-mean concentrations and loads of the following water-quality constituents are summarized in this section for BMP2: (1) SSC and TSS; (2) oil and grease; (3) bacteria; (4) nutrients (TKN and TP); and (5) metals. As described earlier, the design of BMP2 is conducive for the removal of suspended sediments and oil and grease; however, removal of the total and particulate forms of other water-quality constituents also were considered in this assessment.

Suspended Sediment, Total Suspended Solids, and Sediment

Analytical methods to determine SSC and TSS were used to quantify concentrations of suspended organic and inorganic particles in surface waters. A monotonic correlation between TSS and SSC in the inlet and outlet waters at BMP2 was statistically significant (rho = 0.66900, p-value = 0.0174; and rho = 0.72353, p-value = 0.0118, respectively), but not one-to-one as would be expected for measurements of suspended particles. Comparison of the SSC and TSS concentrations from the BMP2 sampling events demonstrated a positive bias for the range in SSC concentrations, with the exception of one measurement (fig. 25). The greatest difference was observed at the maximum inlet SSC concentration of 6,550 mg/L that had a corresponding TSS concentration of only 1,160 mg/L. Further evaluation of grain size indicated the bias between SSC and TSS concentrations tended to increase as the percentage of the sediment finer than 63 microns (finer than sand) decreased below 20 percent.

This bias is important to note because different statistical findings were identified between TSS and SSC when comparisons were made among other constituents and between inlet and outlet waters. Because the SSC analytical method is reported to produce more reliable results than the TSS method (Gray and others, 2000), statistical findings based on SSC results are considered more indicative of the BMP performance. However, because the TSS method is often the method adopted for regulatory monitoring, statistical findings based on TSS results also are discussed.

Event-mean concentrations of SSC in the inlet water of BMP2 ranged from 22 to 6,550 mg/L, with a median value of 92.5 mg/L (fig. 26, table 9, Appendix C). The SSC EMCs in the outlet water were an order of magnitude lower and less variable than in the inlet water (11 to 109 mg/L), with a median of 38 mg/L (fig. 26, table 9). Suspended-sediment EMCs were reduced significantly by BMP2 in the outlet water as compared to the inlet water during the period of study (table 9; V-statistic = 66, p-value = 0.0005). This statistical finding indicated that BMP2 performed efficiently at reducing EMCs for SSC in stormwater.

Median EMCs of TSS of 76.0 and 35.0 mg/L for inlet and outlet water, respectively, were less than the median SSC concentrations for BMP2 (fig. 27, table 9). The less variable EMCs for TSS also were significantly different between inlet and outlet waters (Z-score = 2.6785, p-value = 0.0037), which reproduced the same findings as SSC on the efficiency of BMP2 at removing suspended particles.

For BMP2, turbidity was identified as a potential surrogate for SSC. The event-mean turbidity values were correlated positively with EMCs for SSC for the period of study for water entering the inlet (rho = 0.72727, p-value = 0.0074), but not for water leaving the outlet (rho = 0.25513, p-value = 0.4490). Turbidity was not correlated to EMCs for TSS in the water entering the inlet (rho = 0.56342, p-value = 0.0620). Although median turbidity values were similar between inlet and outlet waters (24.0 and 21.0 NTU, respectively; table 9; fig. 27), reduction in turbidity in stormwater by BMP2 was identified for the period of study.

As observed in the BMP1 assessment, the percentage of the suspended sediment finer than sand (grain sizes smaller than 63 microns), such as silt and clay was highly variable in the inlet water of BMP2, with a median of 55 percent (fig. 26, table 9). The predominant size fraction of suspended sediment in outlet water was finer than sand (80 percent) and significantly finer than the inlet waters (Z-score = –2.8480, p-value = 0.0022). The change in the character of the SSC indicated that BMP2 was more efficient at capturing the sand-sized fractions of the suspended sediment than the silt- and clay-sized fractions. This retention of coarser grained sediment also could influence the lack of retention of certain nutrients (such as phosphorus), bacteria, and trace metals (such as lead and zinc) because of their tendency to adsorb preferentially to the smaller sized sediment.

Examination of the grain-sized fractions of the accumulated sediment within BMP2 in May 2006 further verified this preferential retention of the larger sized fractions. None of the sediment within BMP2 was finer than 63 microns (fig. 28), even though 55 percent of the suspended sediment from the inlet waters were finer than 63 microns (fig. 26). Nonetheless, the trace metal concentrations measured in the retained coarser grained sediment were: zinc, lead, copper, nickel, and cadmium, in order from greatest to least concentration (fig. 29).

Event-mean loads for individual storm events were computed for inlet and outlet waters. Stormwater reaching the inlet of BMP2 had suspended sediment loads that

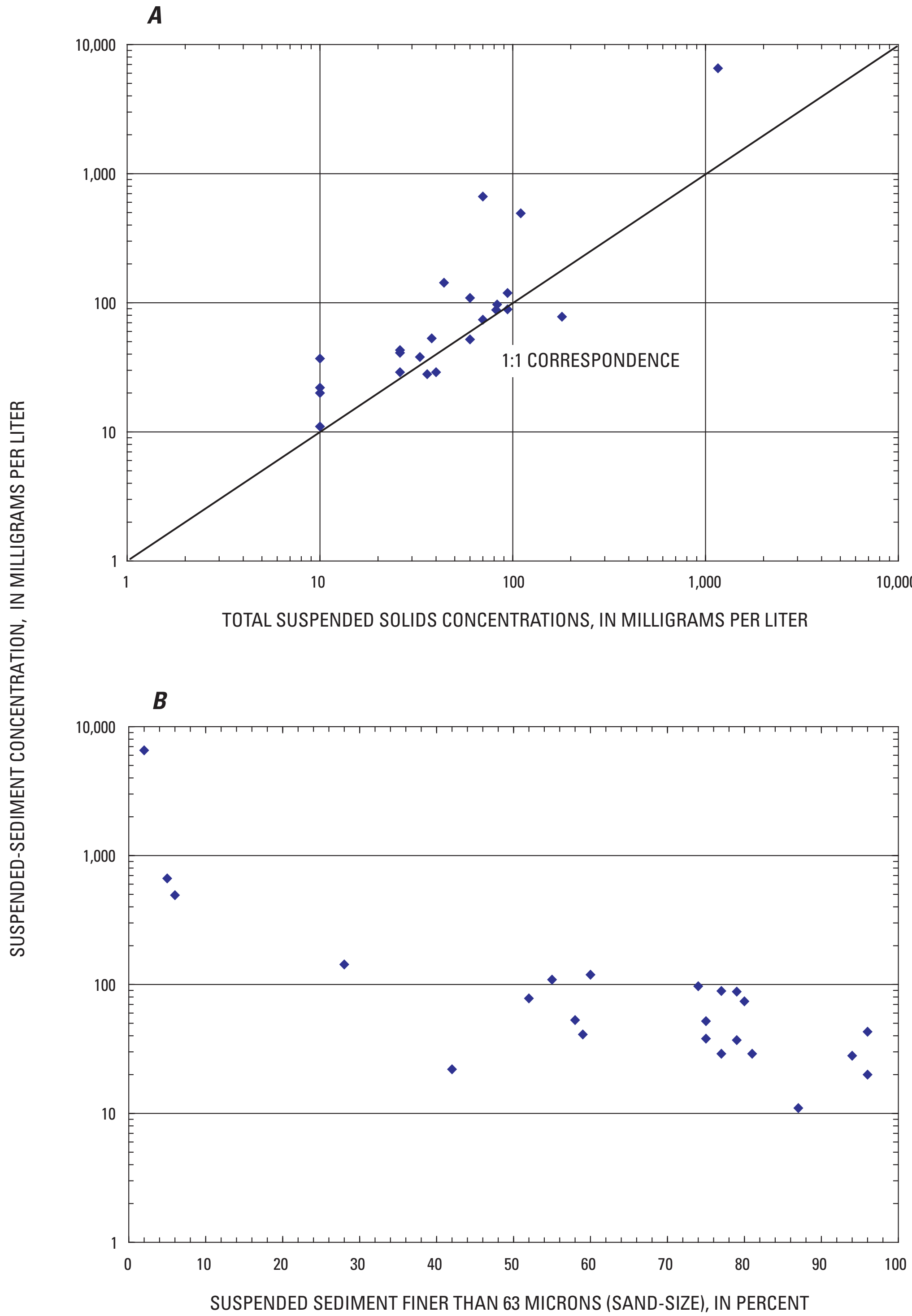

Figure 25. Relation between *(A)* suspended-sediment and total suspended solids concentrations and between *(B)* suspended-sediment concentrations and percentage of sediment finer than sand measured at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

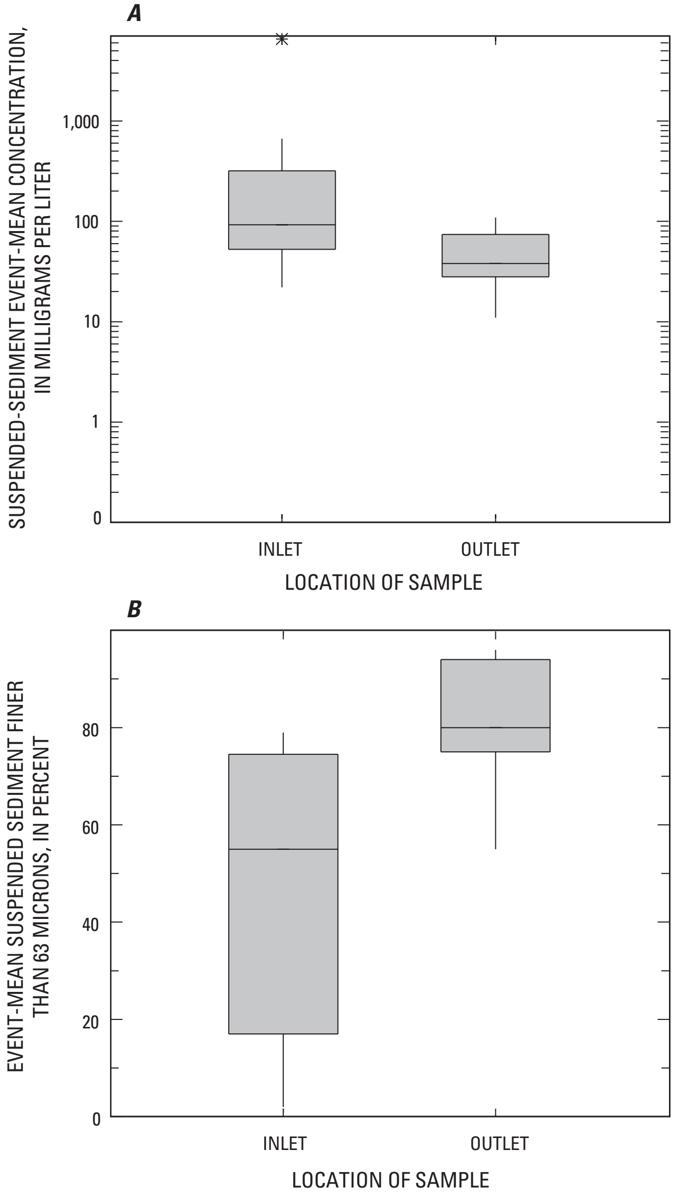

Figure 26. Event-mean *(A)* concentrations of suspended sediment, in milligrams per liter, and *(B)* percentages of suspended sediment finer than 63 microns, at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

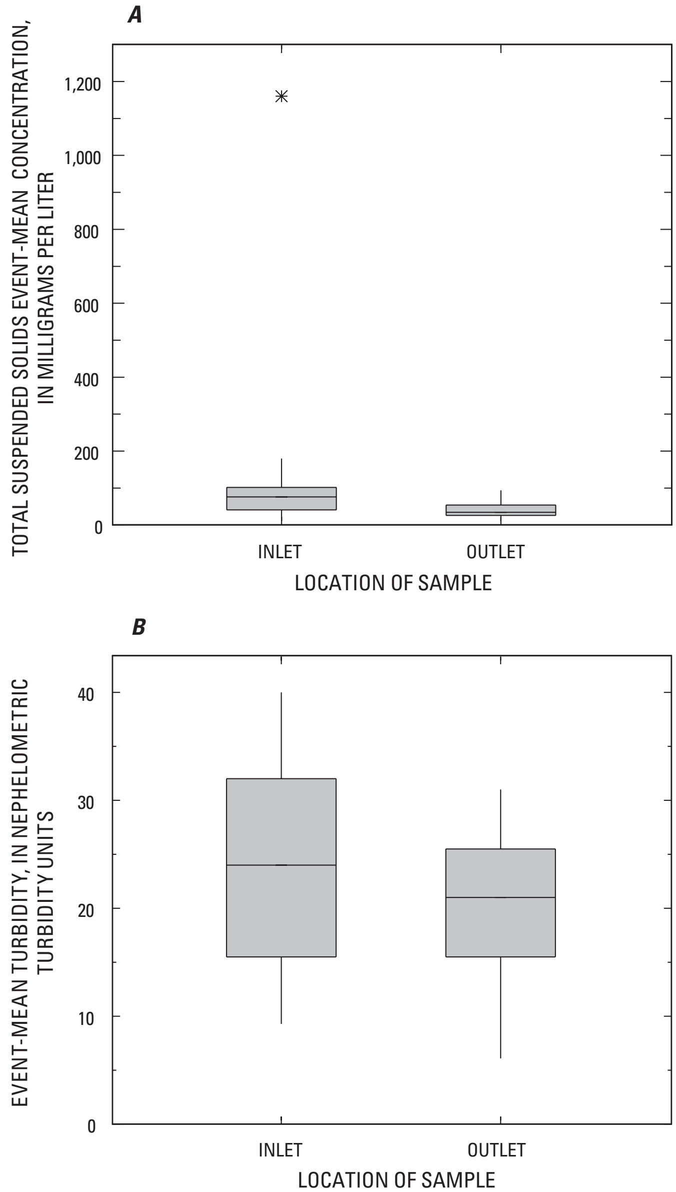

Figure 27. Event-mean concentrations of *(A)* total suspended solids and *(B)* turbidity at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

Table 9. Summary statistics describing the comparison among event-mean concentrations in inlet and outlet waters of best management practice 2 (BMP2), Beaufort County, South Carolina, 2005–2006.

[>, greater than; µg/L, micrograms per liter; mg/L, milligrams per liter; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters]

Constituent	Units	Location	Median	Mean	Standard deviation	Comparison among event-mean concentrations in inlet and outlet waters of BMP2		Wilcoxon signed-rank test		
						Number	[1]Inlet > outlet	V-statistic	Z-score	Probability value
Dissolved cadmium	µg/L	Inlet	0.05	0.06	0.04	12	No		0.042	0.483
	µg/L	Outlet	0.04	0.06	0.04	12				
Total cadmium	µg/L	Inlet	0.19	0.28	0.31	12	Yes		2.984	0.001
	µg/L	Outlet	0.13	0.16	0.08	12				
Particulate cadmium	µg/L	Inlet	0.13	0.22	0.30	12	Yes		2.472	0.007
	µg/L	Outlet	0.08	0.11	0.06	12				
Dissolved copper	µg/L	Inlet	9.35	10.4	5.78	12	Yes		1.963	0.025
	µg/L	Outlet	7.45	8.23	4.79	12				
Total copper	µg/L	Inlet	15.8	19.0	10.4	12	Yes	78		0.000
	µg/L	Outlet	14.0	14.8	6.25	12				
Particulate copper	µg/L	Inlet	6.15	8.63	8.59	12	No	45		0.339
	µg/L	Outlet	5.25	6.55	3.58	12				
Dissolved lead	µg/L	Inlet	0.73	0.81	0.55	12	No		0.824	0.205
	µg/L	Outlet	0.60	0.63	0.37	12				
Total lead	µg/L	Inlet	14.1	18.5	19.6	12	Yes	78		0.000
	µg/L	Outlet	9.77	10.6	4.73	12				
Particulate lead	µg/L	Inlet	13.4	17.7	19.7	12	Yes	77		0.001
	µg/L	Outlet	9.36	9.96	4.68	12				
Dissolved nickel	µg/L	Inlet	2.09	2.50	1.55	12	No		1.496	0.933
	µg/L	Outlet	2.34	2.72	1.79	12				
Total nickel	µg/L	Inlet	3.44	5.44	5.35	12	Yes	76		0.001
	µg/L	Outlet	2.82	3.71	1.79	12				
Particulate nickel	µg/L	Inlet	1.67	2.93	4.73	12	Yes	78		0.000
	µg/L	Outlet	0.99	0.99	0.61	12				
Dissolved zinc	µg/L	Inlet	31.5	39.8	26.8	12	No	42		0.425
	µg/L	Outlet	25.1	41.0	29.4	12				
Total zinc	µg/L	Inlet	79.5	110	82.7	12	Yes	78		0.000
	µg/L	Outlet	53.5	77.8	42.9	12				
Particulate zinc	µg/L	Inlet	49.3	69.8	75.7	12	Yes	74		0.002
	µg/L	Outlet	33.8	36.9	22.1	12				
Total ammonia plus organic nitrogen	mg/L	Inlet	1.85	2.05	1.36	12	No		0.511	0.695
	mg/L	Outlet	1.70	2.04	1.30	12				
Total phosphorus	mg/L	Inlet	0.34	0.51	0.56	12	No		0.788	0.216
	mg/L	Outlet	0.33	0.40	0.17	12				
Turbidity	NTU	Inlet	24.0	24.3	10.0	12	Yes		2.358	0.009
	NTU	Outlet	21.0	20.3	8.00	12				
Total organic carbon	mg/L	Inlet	30.0	29.0	14.1	12	No		0.628	0.265
	mg/L	Outlet	31.0	28.0	14.3	12				
Total suspended solids as residue	mg/L	Inlet	76.0	162	318	12	Yes		2.679	0.004
	mg/L	Outlet	35.0	40.0	25.0	12				
Biochemical oxygen demand	mg/L	Inlet	27.0	43.2	48.4	12	No	37		0.575
	mg/L	Outlet	18.0	40.0	51.0	12				
Chemical oxygen demand	mg/L	Inlet	90.0	105	60.0	12	No		–0.394	0.653
	mg/L	Outlet	90.0	110	55.0	12				
Enterococci	col/100 mL	Inlet	3,870	6,440	7,900	12			0.979	0.164
	col/100 mL	Outlet	2,490	5,448	6,260	12				
Escherichia coli	col/100 mL	Inlet	2,910	3,720	3,320	12	No		–0.089	0.536
	col/100 mL	Outlet	1,800	3,470	3,800	12				
Suspended sediment finer than sand	percent	Inlet	55.0	47.0	30.0	12	[2]Yes		–2.848	0.002
	percent	Outlet	80.0	80.0	14.0	12				
Suspended sediment	mg/L	Inlet	92.5	700	1853	12	Yes	66		0.001
	mg/L	Outlet	38.0	47.0	31.0	12				
Oil and grease	mg/L	Inlet	8.00	9.00	3.30	12	Yes		2.546	0.005
	mg/L	Outlet	5.00	5.33	2.30	12				

[1] Probability that the hypothesis that the input and output concentrations are the same versus the alternative one-sided hypothesis that the concentration is greater in the input than the output.

[2] One-sided test such that the alternative hypothesis is that the percentage of suspended sediment finer than 63 micron is greater in the output than the input.

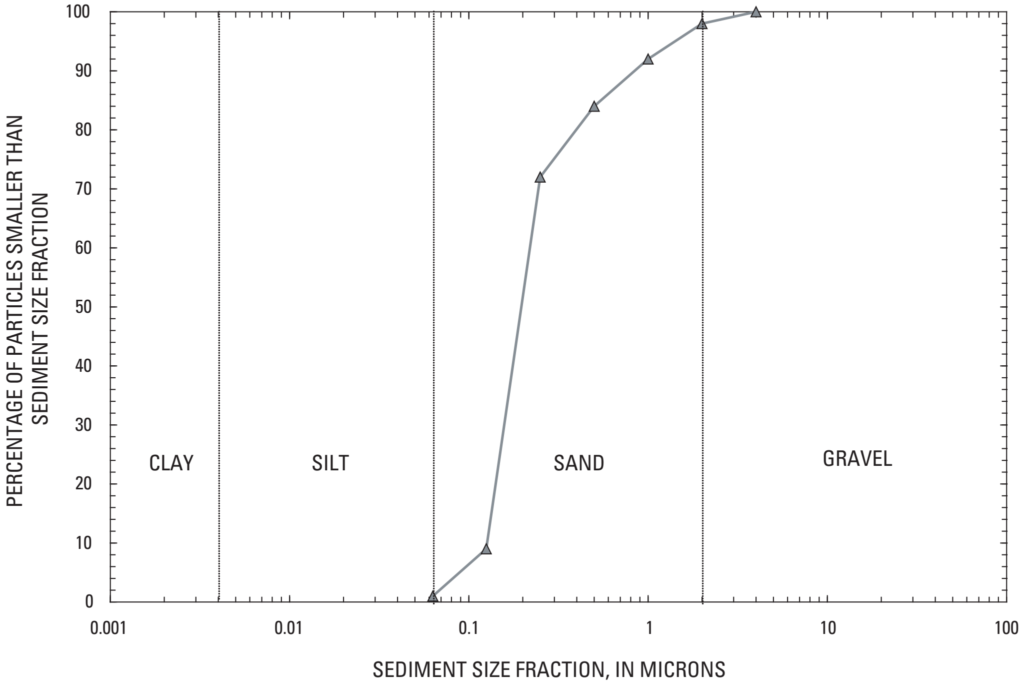

Figure 28. Particle-size distribution of sediment collected from within structural best management practice 2 at U.S. Highway 21 near Beaufort, S.C., May 2006.

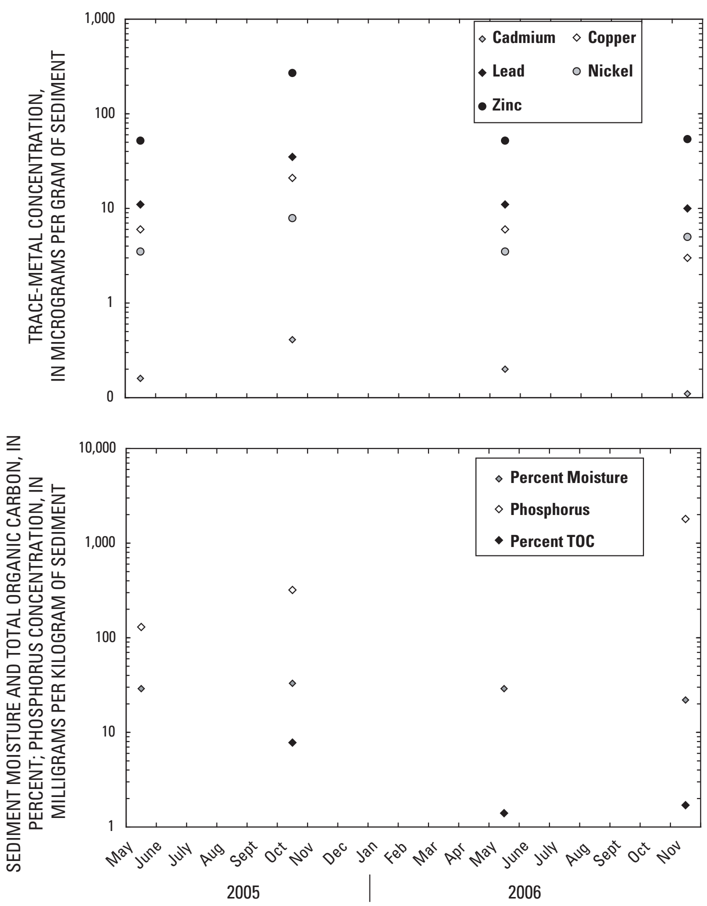

Figure 29. Sediment chemistry from samples collected from within best management practice 2 in Beaufort County, S.C., May 2005, October 2005, May 2006, and October 2006.

ranged from 0.08 to 44.5 kg/event (median of 6.23 kg/event) (fig. 30, table 10). The maximum SSC load for the inlet of BMP2 of 44.5 kg/event was an outlier value, and the majority of the sampled storms had SSC loads near the median of 6.23 kg/event. Stormwater leaving the outlet of BMP2 had SSC loads that ranged from 0.04 to 13.7 kg/event with a median of 1.43 kg/event. The SSC loads were statistically different between inlet and outlet waters (V-statistic = 66, p-value = 0.0005; table 10). This finding indicated that BMP2 was efficient at removing SSC loads in stormwater.

Computation of the average reduction of SSC loads by BMP2 for the sampled storm events indicated SSC loads were reduced by 8.62 +/- 3.97 kg/event, or 58.6 +/- 9.61 percent (fig. 31; Appendix D-1). For the storm events, a cumulative load of 141 kg of sediment entered BMP2, and BMP2 was able to remove 103 kg of that load (Appendix D-2).

In relation to other environmental and chemical factors, the EMCs for SSC and TSS in the inlet of BMP2 were not correlated significantly with hydrologic variables, such as rainfall, rainfall intensity, or stormflow; however, the EMCs for SSC in the outlet were correlated with rainfall intensity and rainfall (rho = 0.71526, p-value = 0.0133 and rho = 0.71854, p-value = 0.0127, respectively). In general, particulate and total forms of cadmium, lead, and zinc were correlated with SSC and TSS for the inlet and outlet of BMP2, indicating particulate forms of most metals had similar transport as suspended sediment through the structural BMP.

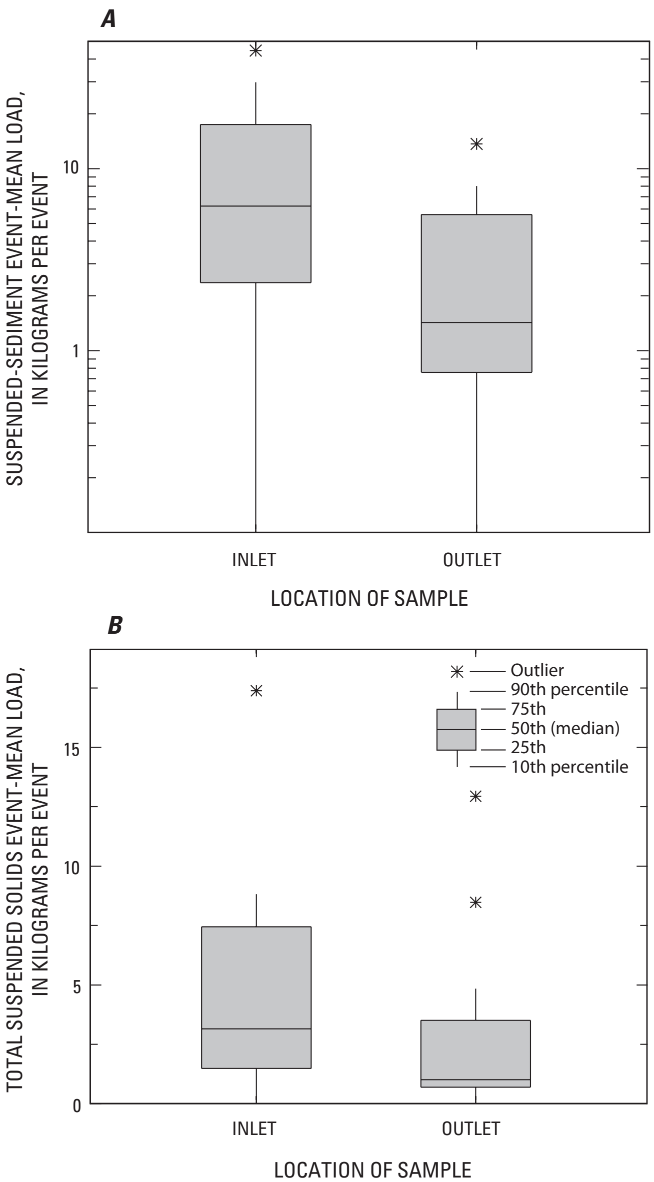

Figure 30. Event-mean loads of *(A)* suspended sediment and *(B)* total suspended solids, in kilograms per event, at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

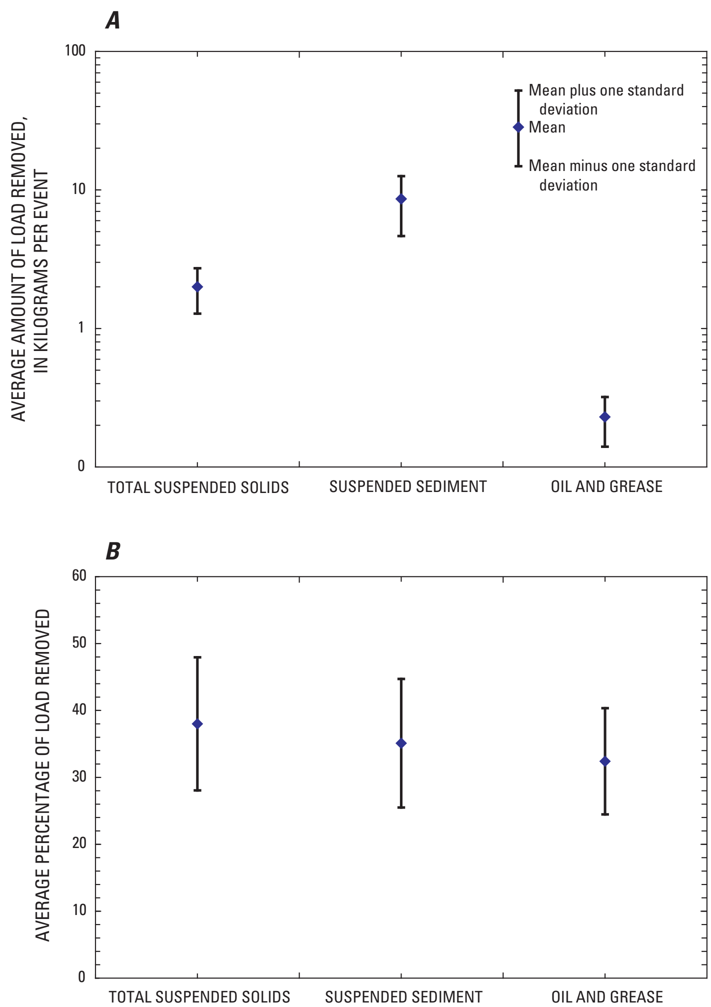

Figure 31. Total loads removed and average percentages of loads removed for total suspended solids, suspended sediment, and oil and grease at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

Table 10. Summary statistics describing the comparison among event-mean loads in inlet and outlet waters of best management practice 2 (BMP2), Beaufort County, South Carolina, 2005–2006.

[>, greater than; g/event; grams per event; kg/event, kilograms per event]

Constituent	Units	Location	Median	Mean	Standard deviation	Comparison among event-mean loads in inlet and outlet waters of BMP2		Wilcoxon signed-rank test		
						Number	[1]Inlet > outlet	V-statistic	Z-score	Probability value
Dissolved cadmium	g/event	Inlet	0.002	0.003	0.005	12	No		–0.753	0.774
	g/event	Outlet	0.002	0.003	0.004	12				
Total cadmium	g/event	Inlet	0.01	0.01	0.01	12	Yes	72		0.003
	g/event	Outlet	0.01	0.01	0.01	12				
Particulate cadmium	g/event	Inlet	0.01	0.01	0.01	12	No	1		1.000
	g/event	Outlet	0.004	0.01	0.01	12				
Dissolved copper	g/event	Inlet	0.31	0.65	1.03	12	Yes		1.963	0.025
	g/event	Outlet	0.26	0.47	0.68	12				
Total copper	g/event	Inlet	0.59	1.01	1.19	12	Yes	72		0.003
	g/event	Outlet	0.50	0.88	1.09	12				
Particulate copper	g/event	Inlet	0.25	0.36	0.27	12	No	39		0.515
	g/event	Outlet	0.28	0.41	0.45	12				
Dissolved lead	g/event	Inlet	0.02	0.05	0.06	12	No	50		0.212
	g/event	Outlet	0.02	0.04	0.04	12				
Total lead	g/event	Inlet	0.57	0.87	0.92	12	Yes	76		0.001
	g/event	Outlet	0.49	0.69	0.79	12				
Particulate lead	g/event	Inlet	0.54	0.82	0.86	12	Yes	75		0.001
	g/event	Outlet	0.42	0.65	0.77	12				
Dissolved nickel	g/event	Inlet	0.09	0.14	0.18	12	No		–1.260	0.896
	g/event	Outlet	0.09	0.14	0.19	12				
Total nickel	g/event	Inlet	0.15	0.24	0.25	12	Yes	70		0.006
	g/event	Outlet	0.13	0.21	0.25	12				
Particulate nickel	g/event	Inlet	0.08	0.1	0.08	12	Yes	78		0.000
	g/event	Outlet	0.04	0.07	0.07	12				
Dissolved zinc	g/event	Inlet	1.37	2.69	4.84	12	No	46		0.311
	g/event	Outlet	1.45	2.38	3.89	12				
Total zinc	g/event	Inlet	3.81	6.06	7.83	12	Yes	78		0.000
	g/event	Outlet	2.73	4.99	6.9	12				
Particulate zinc	g/event	Inlet	2.11	3.36	3.3	12	Yes	76		0.001
	g/event	Outlet	1.35	2.61	3.26	12				
Total ammonia plus organic nitrogen	kg/event	Inlet	0.09	0.12	0.17	12	No		–0.785	0.784
	kg/event	Outlet	0.08	0.12	0.17	12				
Total phosphorus	kg/event	Inlet	0.02	0.02	0.03	12	No	40		0.485
	kg/event	Outlet	0.01	0.02	0.03	12				
Total organic carbon	kg/event	Inlet	0.92	1.57	1.91	12	No	49		0.235
	kg/event	Outlet	0.95	1.52	1.94	12				
Total suspended solids as residue	kg/event	Inlet	3.15	4.9	4.85	12	Yes		2.441	0.007
	kg/event	Outlet	1.01	2.89	3.97	12				
Biochemical oxygen demand	kg/event	Inlet	1.51	2.04	2.13	12	No	27		0.830
	kg/event	Outlet	0.95	2.18	3.32	12				
Chemical oxygen demand	kg/event	Inlet	4.01	5.99	8.32	12	No		–0.246	0.597
	kg/event	Outlet	2.98	5.66	9.02	12				
Suspended sediment	kg/event	Inlet	6.23	11.7	13.7	12	Yes	66		0.001
	kg/event	Outlet	1.43	3.39	4.19	12				
Oil and grease	kg/event	Inlet	0.36	0.52	0.48	12	Yes		2.815	0.002
	kg/event	Outlet	0.24	0.29	0.21	12				

[1] Probability that the hypothesis that the input and output concentrations are the same versus the alternative one-sided hypothesis that the concentration is greater in the input than in the output.

Oil and Grease

For the period of study, stormwater entering the inlet of BMP2 had a median oil and grease concentration of 8.00 mg/L and concentration range of 5 to 15 mg/L (fig. 32; table 9). Oil and grease concentrations in the stormwater leaving the outlet of BMP2 were reduced significantly (Z-score = 2.5460, p-value = 0.0054) more than 75 percent of the oil and grease concentrations were less than the LRL of 7 mg/L. Consequently, outlet water had a median oil and grease concentration of 5.00 mg/L. The statistical results indicated that BMP2 was efficient at reducing oil and grease concentrations in the stormwater entering the BMP to levels less than the LRL of 7 mg/L in the outlet water.

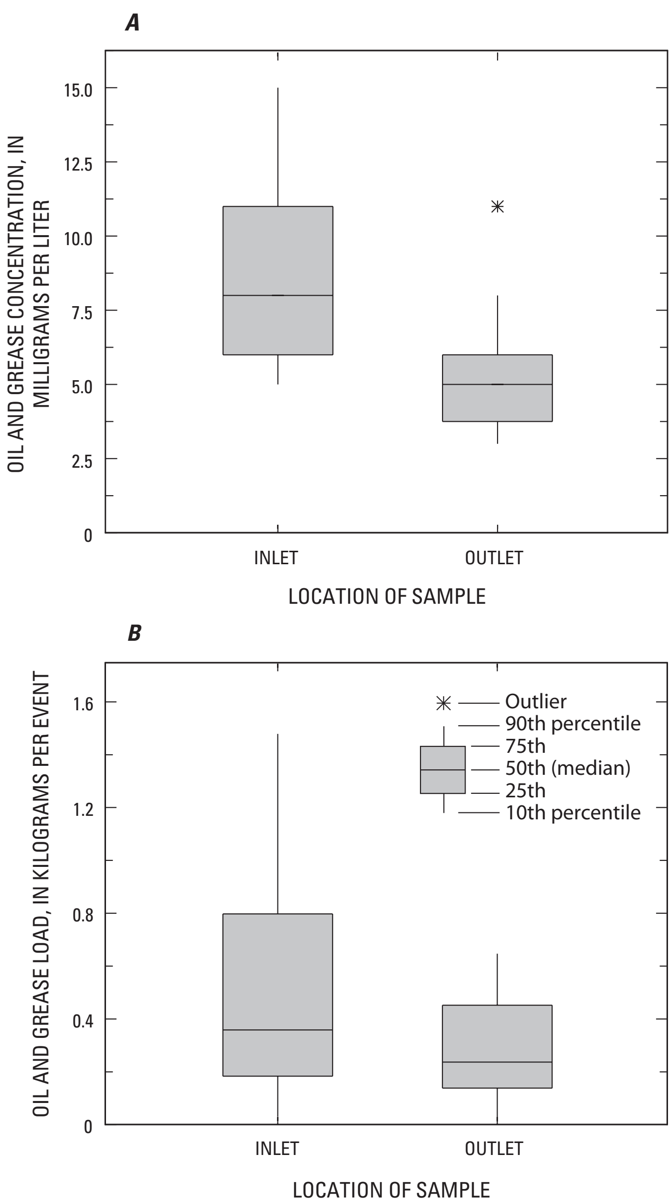

Figure 32. Oil and grease *(A)* concentrations in grab samples and *(B)* loads from best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

The total PAH concentration in stormwater entering the inlet and leaving the outlet of BMP2 ranged from 0.33 to 2.48 µg/L and from 0.09 to 1.88 µg/L, respectively (table 11). Oil and grease and total PAH concentrations did not appear to be related. The lower total inlet PAH concentrations of 0.33, 0.54, and 0.64 µg/L occurred with the higher oil and grease concentrations of 7, 8, and 10 mg/L, respectively.

Oil and grease loads in the stormwater entering the inlet of BMP2 had a median value of 0.36 kg/event (table 10) and a range of 0.03 to 1.48 kg/event for the study period (fig. 32*B*). The stormwater leaving the outlet of BMP2 had oil and grease loads that were less than those of the inlet water (median of 0.24 kg/event; range of 0.01 to 0.65 kg/event). As with the SSC and oil and grease concentrations, BMP2 was effective at significantly reducing the oil and grease loads that entered the BMP (Z-score = 2.8153, p-value = 0.0024).

For the sampled storm events, the average reduction in the oil and grease loads in stormwater by BMP2 was 0.23 +/- 0.09 kg/event, or 32.4 +/- 7.94 percent (fig. 31*B*; Appendix D-1). Cumulative oil and grease loads entering the inlet of BMP2 were 6.23 kg, and load removed was 2.77 kg (Appendix D-2).

Table 11. Comparison of oil and grease concentrations with total polycyclic aromatic hydrocarbon (PAH) concentrations in the water of selected storms at best management practice 2, Beaufort County, South Carolina, 2006.

[mg/L, milligrams per liter; µg/L, micrograms per liter]

Date of sample	Oil and grease (inlet [mg/L])	Oil and grease (outlet [mg/L])	Total PAH (inlet [µg/L])	Total PAH (outlet [µg/L])
February 2, 2006	6	6.0	2.48	1.23
July 6, 2006	5	5.0		1.88
August 31, 2006	7	5.0	0.33	0.14
September 7, 2006	5	5.0	1.13	0.95
September 19, 2006	6	4.0	0.92	1.40
October 27, 2006	10	3.5	0.64	0.35
November 7, 2006	8	3.0	0.54	0.09

Nutrients

For the period of study, EMCs of TKN and TP were correlated significantly with each other in the inlet and outlet waters of BMP2. Stormwater entering the inlet of BMP2 had nutrient EMCs similar to those in the stormwater leaving the outlet of BMP2 (fig. 33). Inlet and outlet waters had similar median EMCs for TKN (1.85 and 1.70 mg/L, respectively) and TP (0.34 and 0.33 mg/L, respectively; table 9). Outlet water had median TKN and TP concentrations that were reduced only slightly from concentrations in the inlet water. Not only were the median values similar; ranges of the TKN and TP concentrations in the inlet and outlet waters had considerable overlap. Significant reductions in TKN and TP concentrations between the stormwater entering the inlet and leaving the outlet at BMP2 were not identified by statistical tests (p-values = 0.6952 and 0.2155, respectively). These findings indicated that BMP2 was not efficient at reducing nutrient concentrations in stormwater.

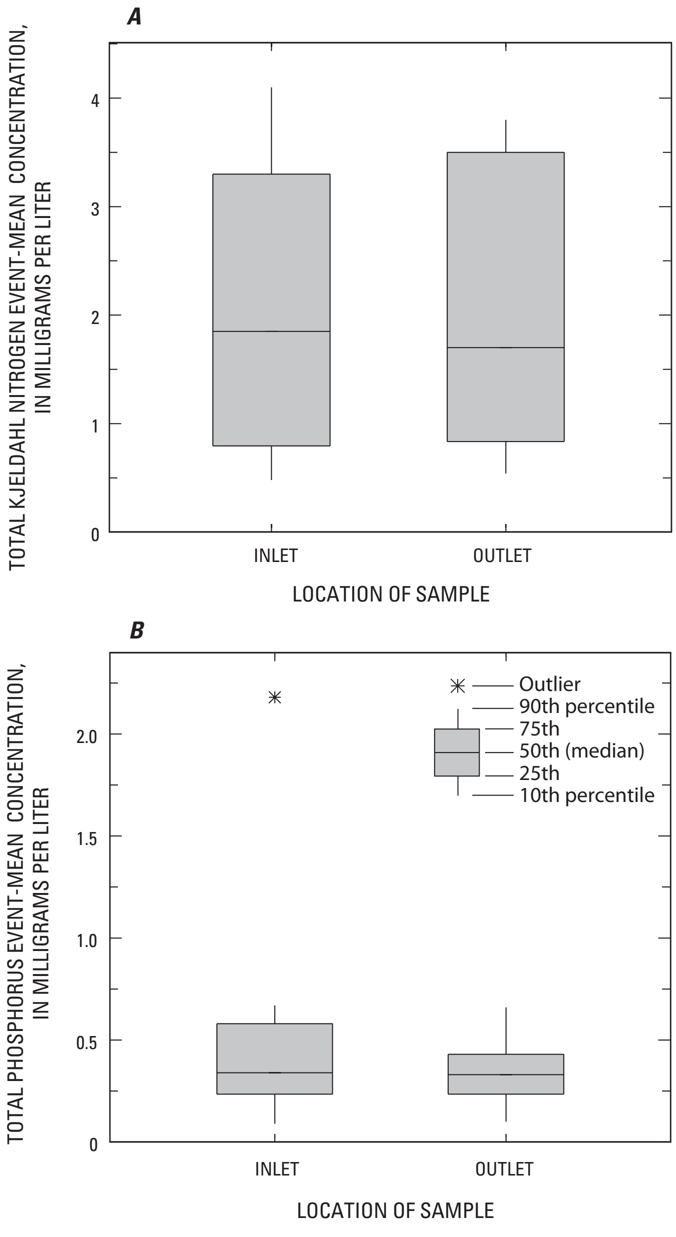

Figure 33. Event-mean concentrations of *(A)* total Kjeldahl nitrogen and *(B)* total phosphorus at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

Median EMCs for TOC, BOD_5, and COD in the stormwater entering the inlet in BMP2 were 30.0, 27.0, and 90.0 mg/L, respectively (table 9). The much larger COD, in comparison with BOD_5, indicated organic decay processes were playing less of a role in oxygen consumption than other biological and chemical processes. Median EMCs for TOC, BOD_5, and COD in the stormwater leaving the outlet of BMP2 were 31.0, 18.0, and 90.0 mg/L, respectively. No statistical differences for EMCs for TOC, BOD_5, or COD between inlet and outlet waters for BMP2 were identified (for TOC, Z-score = 0.6278, p-value = 0.2651; for BOD_5, V-statistic = 37, p-value = 0.5750; for COD, Z-score = –0.3937, p-value = 0.6531). This finding indicated that BMP2 was not reducing EMCs for TOC, BOD_5, and COD in stormwater.

A great amount of overlap also was observed for the TKN loads entering and leaving BMP2; the ranges in TKN loads in the inlet and outlet waters were nearly identical (fig. 34). The median TKN load for the inlet of BMP2 was 0.09 kg/event, and the median TKN load for the outlet was 0.08 kg/event. The median TP load for the inlet of BMP2 was 0.02 kg/event, and the median TP load for the outlet was 0.01 kg/event. The TKN and TP loads for BMP2 were not statistically different between inlet and outlet waters for this study (p-values, 0.7838 and 0.4849, respectively; table 10). This finding indicated that BMP2 was not efficient at reducing nutrient loads in stormwater.

Median TOC, BOD_5, and COD loads in the stormwater entering the inlet in BMP2 were 0.92, 1.51, and 4.01 kg/event, respectively (table 10). Median TOC, BOD_5, and COD loads in the stormwater leaving the outlet of BMP2 were 0.95, 0.95, and 2.98 kg/event, respectively. No statistical difference in TOC, BOD_5, and COD loads between inlet and outlet waters for BMP2 were identified (for TOC, V-statistic = 49, p-value = 0.2349; for BOD_5, V-statistic = 27, p-value = 0.8303; and for COD, Z-score = –0.2460, p-value = 0.5971). This finding indicated that BMP2 was not reducing TOC, BOD_5, or COD loads in stormwater.

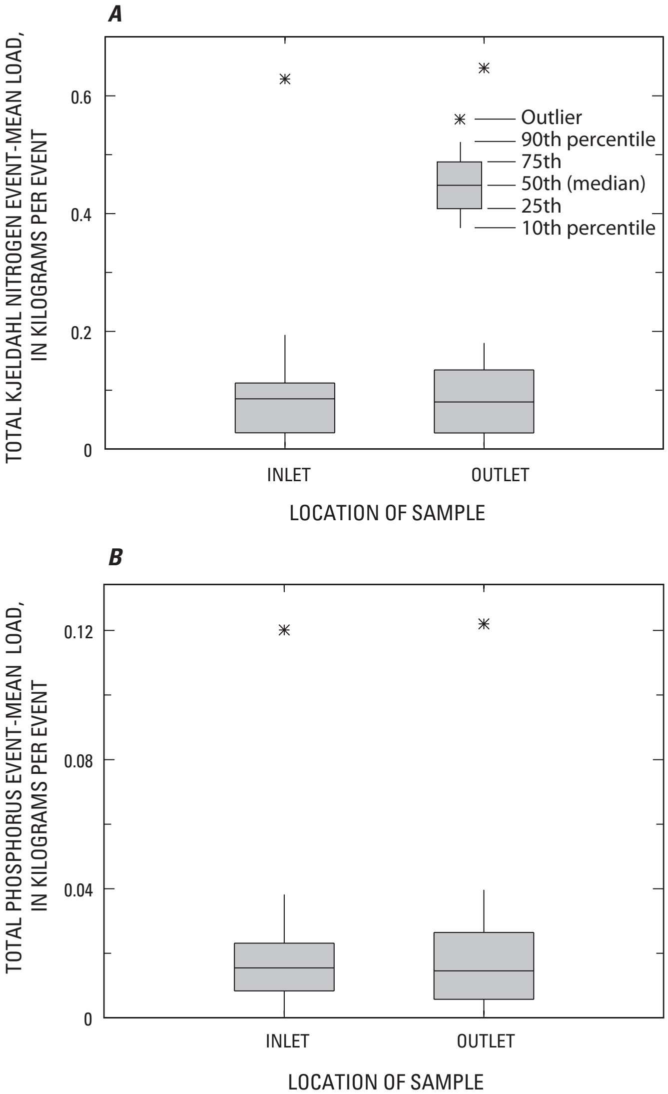

Figure 34. Event-mean loads of *(A)* total Kjeldahl nitrogen and *(B)* total phosphorus at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

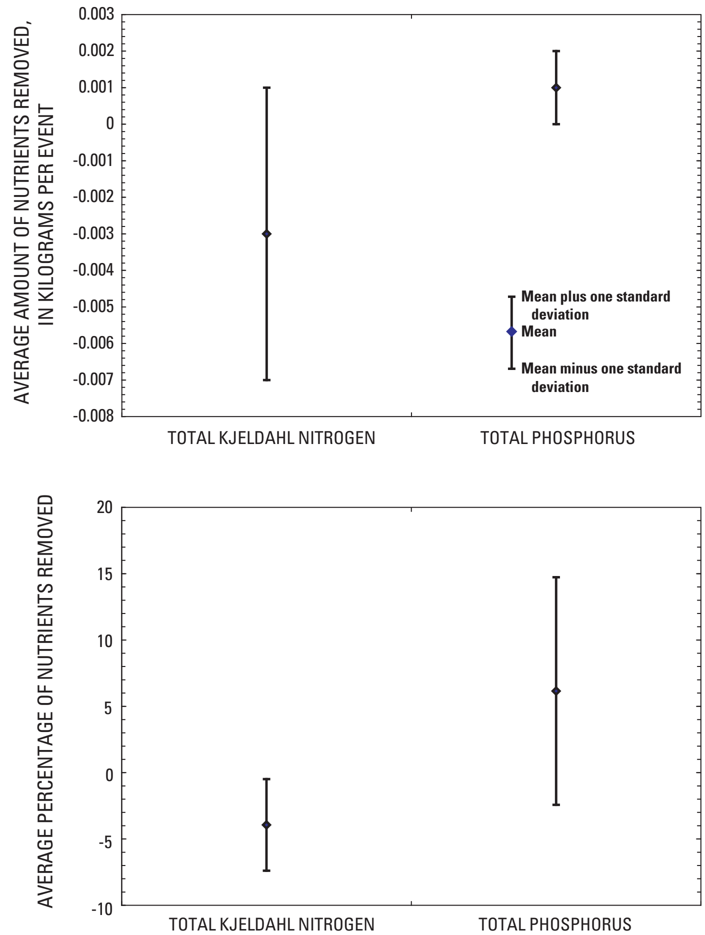

Figure 35. Average amounts and percentages of total Kjeldahl nitrogen and total phosphorus removed by best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

The TKN loads at BMP2 during the storm events sampled for this study appeared to increase slightly between the inlet and outlet waters by an average of –0.003 +/- 0.004 kg/event, or about –3.94 +/- 3.45 percent (fig. 35; Appendix D-1). The TP loads appeared to decrease slightly by an average of 0.001 +/- 0.001 kg/event, or about 6.15 +/- 8.58 percent. Cumulatively, negligible changes of –0.04 and 0.01 kg of TKN and TP loads, respectively, leaving the respective devices were observed for BMP2 (Appendix D-2).

In relation to environmental and chemical factors, TKN and TP were not correlated significantly with hydrologic variables, such as rainfall intensity and mean stormflow. However, TOC, total forms of the trace metals, and COD were correlated with TKN and TP, suggesting that nutrients had similar fate and transport as organics and total trace metals through the structural BMP. Although SSC did not correlate with nutrients, TSS and TP were significantly correlated.

Indicator Bacteria

The *E. coli* and enterococci concentrations in samples collected from stormwater entering BMP2 were not correlated for the period of study (rho = 0.62424, p-value = 0.0537), but were correlated for stormwater leaving BMP2 (rho = 0.71733; p-value = 0.0195). Both fecal indicator bacteria ranged more than 4 orders of magnitude in concentrations during the period of study (fig. 36). Median concentrations of enterococci of 3,870 col/100 mL for inlet water and 2,490 col/100 mL for outlet water at BMP2 indicated an overall decrease in fecal indicator bacterial concentrations. Median concentrations of *E. coli* of 2,910 col/100 mL for inlet water and 1,800 col/100 mL for outlet water indicated a decrease in fecal indicator bacterial concentrations. However, statistical tests of the *E. coli* and enterococci concentrations between inlet and outlet waters indicated no significant change in these concentrations (p-values = 0.5355 and 0.1638, respectively; table 9).

No significant relations between *E. coli* and hydrologic variables were determined for the stormwater entering BMP2. Enterococci concentrations also had no significant correlation with hydrologic variables. Several environmental factors potentially could influence fecal indicator bacterial concentrations. One such factor is the accumulated sediment and organic matter in the bottom of the BMP devices that could serve as an additional source of bacteria in the BMP. That survival, or growth, and then re-suspension process of enterococci and *E. coli* bacteria also could explain outlet water concentrations that were periodically equal to or greater than the inlet water concentrations (figs. 37 and 38).

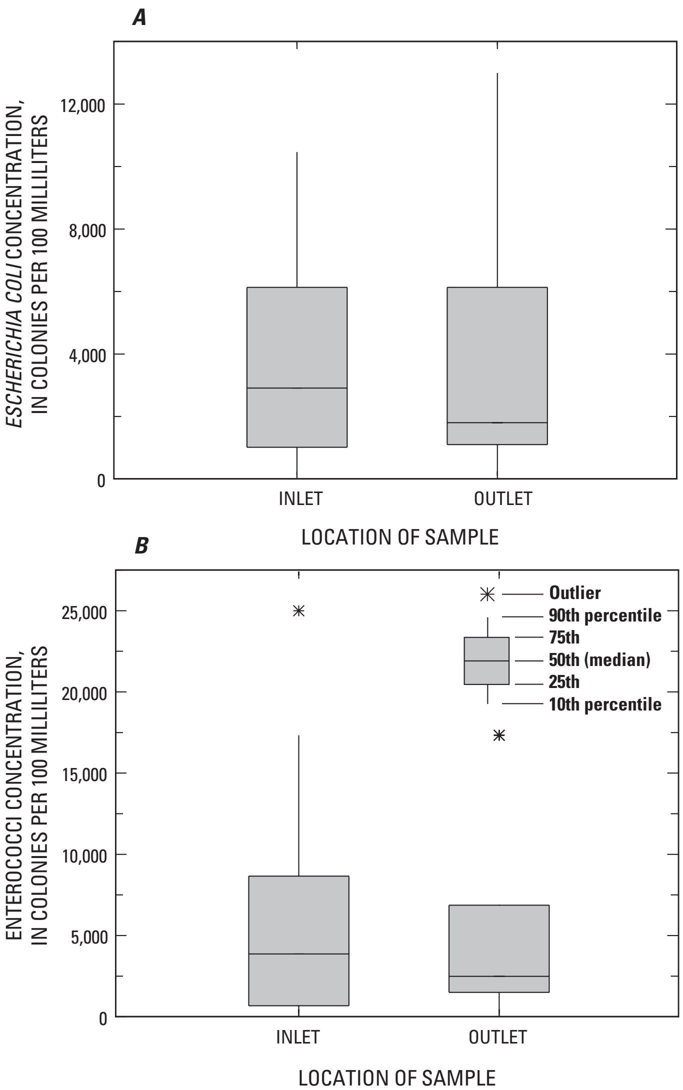

Figure 36. Concentrations of *(A) Escherichia coli* and *(B)* enterococci in grab samples collected from best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

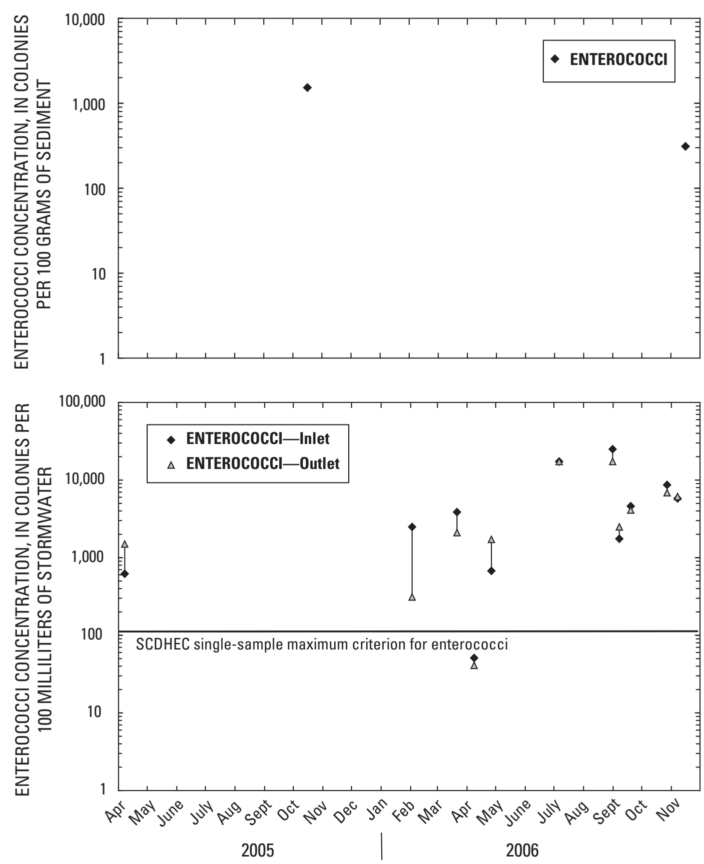

Figure 37. Time-series plots of enterococci concentrations in sediment and stormwater at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control]

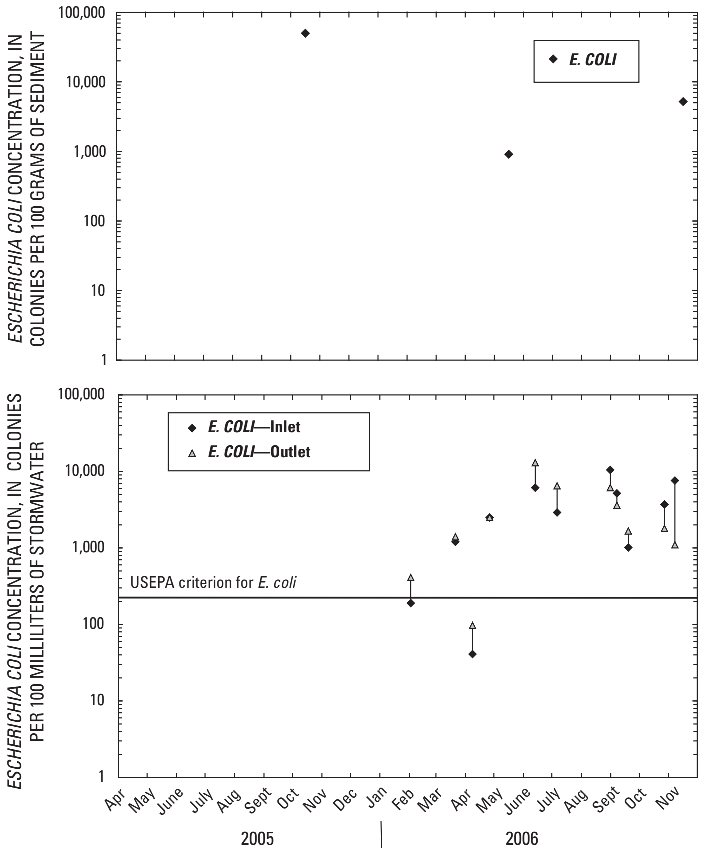

Figure 38. Time-series plots of *Escherichia coli* (*E. coli*) concentrations in sediment and stormwater for best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006. [USEPA, U.S. Environmental Protection Agency]

Sediments removed from BMP2 during clean-out periods were analyzed for viable colonies of enterococci and *E. coli* during October 2005, May 2006 (*E. coli* only), and November 2006. Enterococci concentrations varied from 311 to 1,530 colonies per 100 grams of sediment for November 2006 and October 2005, respectively (fig. 37). Because the sediment data were limited, no strong pattern between sediment and water concentrations was observed for enterococci; higher sediment concentrations did not reflect higher water concentrations. The *E. coli* concentrations were much more variable than enterococci concentrations, ranging from 910 to 50,000 colonies per 100 grams of sediment (fig. 38). Again, no pattern between sediment and water concentrations was observed for *E. coli*.

Only one storm had stormwater entering the inlet and leaving the outlet water at BMP2 at *E. coli* and enterococci concentrations below the recommended USEPA-criterion of 235 col/100 mL and the SCDHEC-established one-time maximum concentration of 104 col/100 mL, respectively. That storm occurred in April 2006, 1 month before BMP2 was cleaned in May 2006.

Metals

Concentration ranges of the targeted trace metals in the stormwater entering the inlet of BMP2 varied by 3 orders of magnitude (figs. 39–41), and are listed in order of increasing concentration: total cadmium (median, 0.19 µg/L), total nickel (median, 3.44 µg/L), total lead (median, 14.1 µg/L), total copper (median, 15.8 µg/L), and total zinc (median, 79.5 µg/L; table 9). Concentration ranges of the targeted trace metals in the stormwater leaving the outlet of BMP2 had similar variabilities and were in the same order of increasing concentration: total cadmium (median, 0.13 µg/L), total nickel (median, 2.82 µg/L), total lead (median, 9.77 µg/L), total copper (median, 14.0 µg/L), and total zinc (median, 53.5 µg/L). Lead and cadmium were predominantly in particulate form in both inlet and outlet water samples, and copper was mainly in dissolved form. In general, nickel and zinc were distributed fairly evenly between particulate and dissolved forms. These findings are similar to the findings for BMP1.

Significant changes in trace-metal concentrations from inlet to outlet waters were identified (table 9; fig. 42). Total and dissolved copper concentrations (p-scores, 0.0002 and 0.0248, respectively), total and particulate lead concentrations (p-scores, 0.0002 and 0.0005, respectively), total and particulate nickel concentrations (p-scores, 0.0007 and 0.0002, respectively), and total and particulate zinc concentrations (p-scores, 0.0002 and 0.0017, respectively) for BMP2 were statistically different between inlet and outlet waters for this study. These findings indicated that BMP2 was efficient at reducing trace-metal concentrations in stormwater.

Total cadmium and total nickel EMCs in the stormwater entering the inlet and leaving the outlet of BMP2 were less than the SCDHEC-established CMCs for freshwater aquatic life (table 8; figs. 39 and 40). The reverse was true for total copper; all EMCs in the inlet and outlet waters of BMP2 were greater than the CMC for total copper of 3.8 µg/L (fig. 39). For total lead and total zinc EMCs in the stormwater, about 50 percent of the EMCs entering the inlet of BMP2 were greater than the SCDHEC-established CMCs for freshwater aquatic life of 14 and 75 µg/L, respectively (figs. 40 and 41). In the stormwater leaving the outlet of BMP2, almost 70 and 60 percent of the samples were less than the same criteria for total lead and zinc, respectively.

The trace-metal loads had a similar pattern to that of the trace-metal concentrations, and are listed in order of increasing median load: total cadmium (0.01 g/event), total nickel (0.15 g/event), total lead (0.57 g/event), total copper (0.59 g/event), and total zinc (3.81 g/event) for inlet water (table 10; figs. 42–44). Outlet loads were: total cadmium (0.01 g/event), total nickel (0.13 g/event), total lead (0.49 g/event), total copper (0.50 g/event), and total zinc (2.73 g/event). The statistical tests indicated significant changes in trace-metal loads between inlet and outlet waters. The following concentrations were statistically significant: total cadmium (V-statistic = 72, p-value = 0.0034), dissolved and total copper (Z-score = 1.9627, V-statistic = 72,

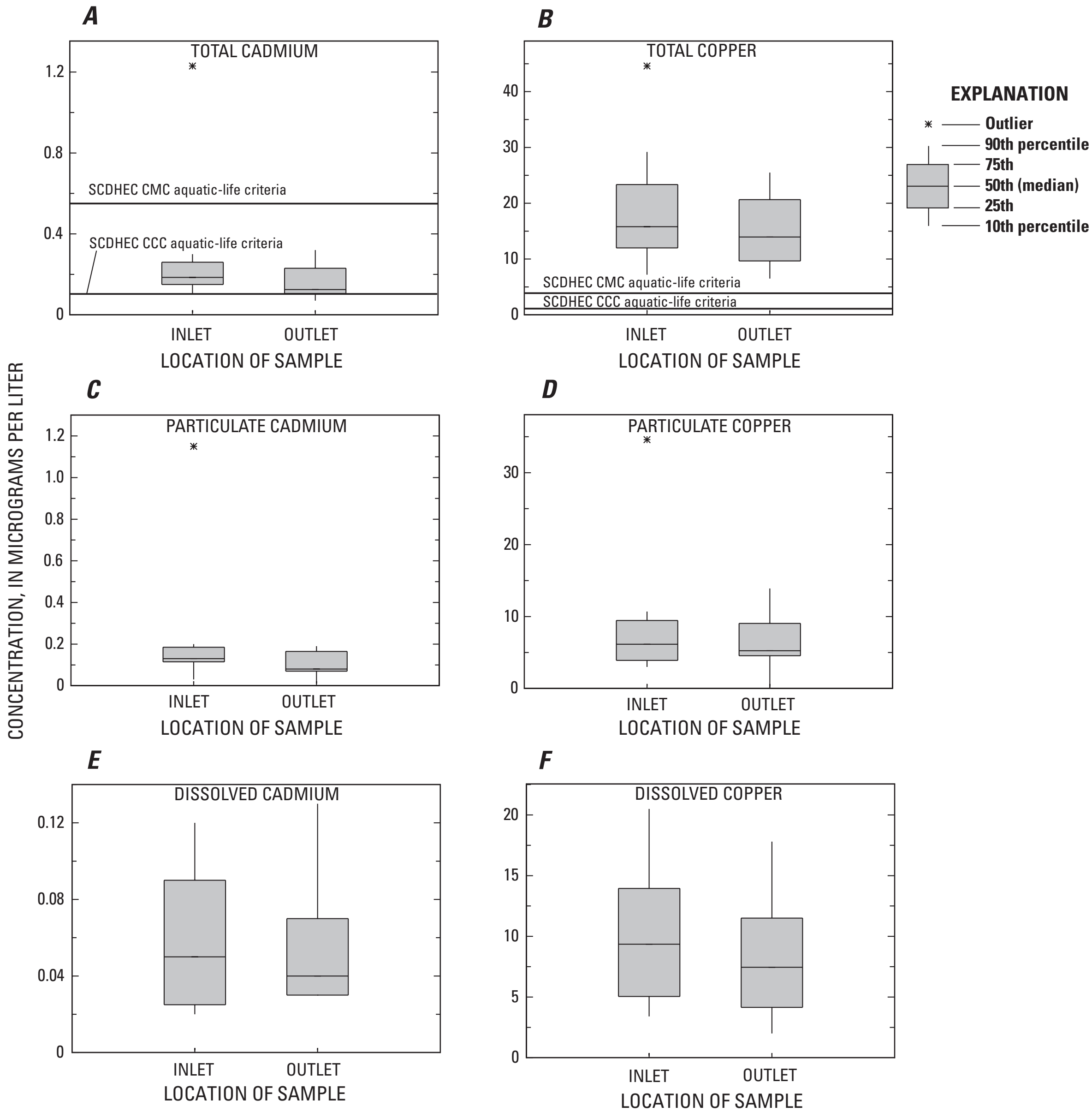

Figure 39. Event-mean concentrations of total *(A)* cadmium and *(B)* copper; particulate *(C)* cadmium and *(D)* copper; and dissolved *(E)* cadmium and *(F)* copper at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration]

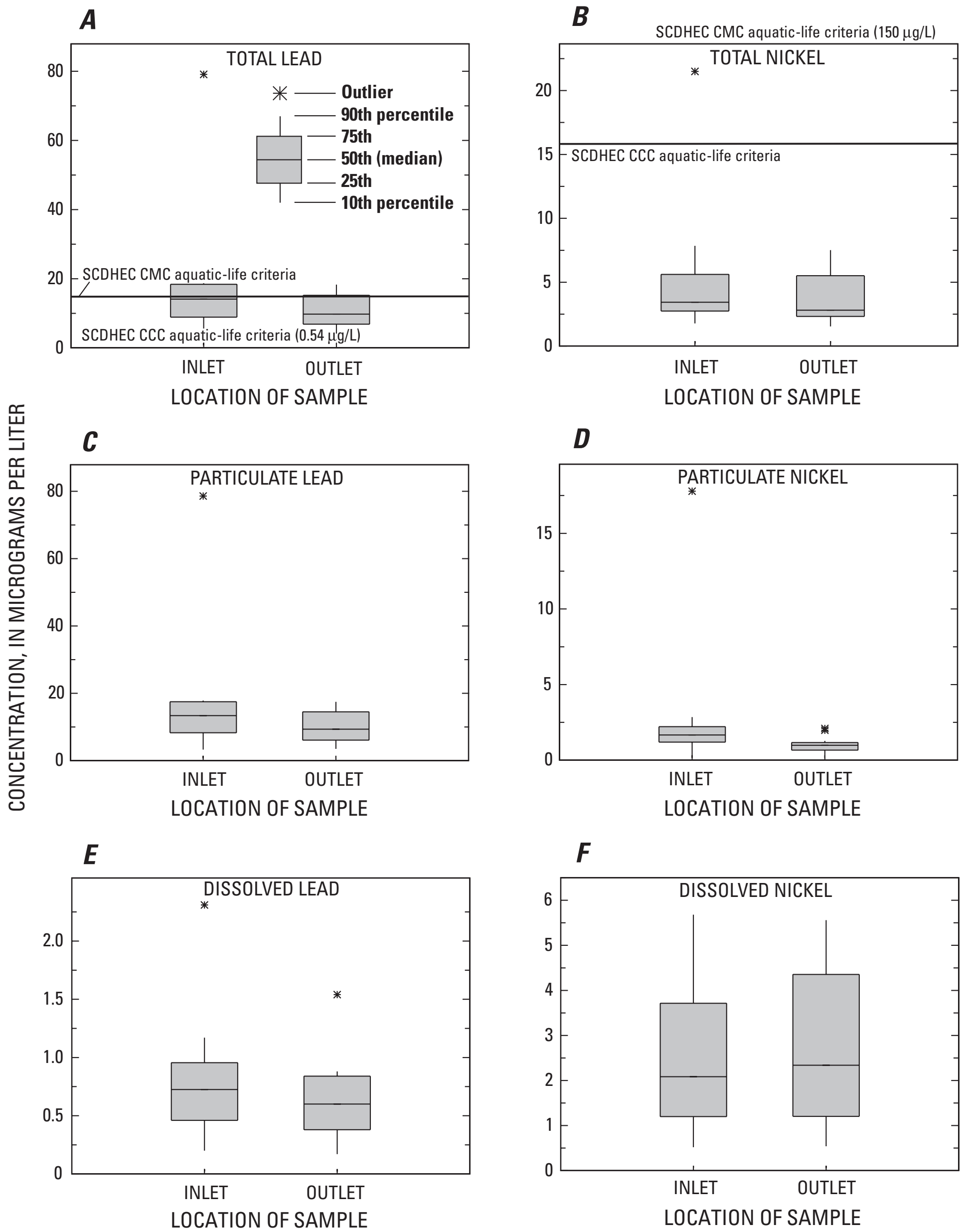

Figure 40. Event-mean concentrations of total *(A)* lead and *(B)* nickel; particulate *(C)* lead and *(D)* nickel; and dissolved *(E)* lead and *(F)* nickel at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration]

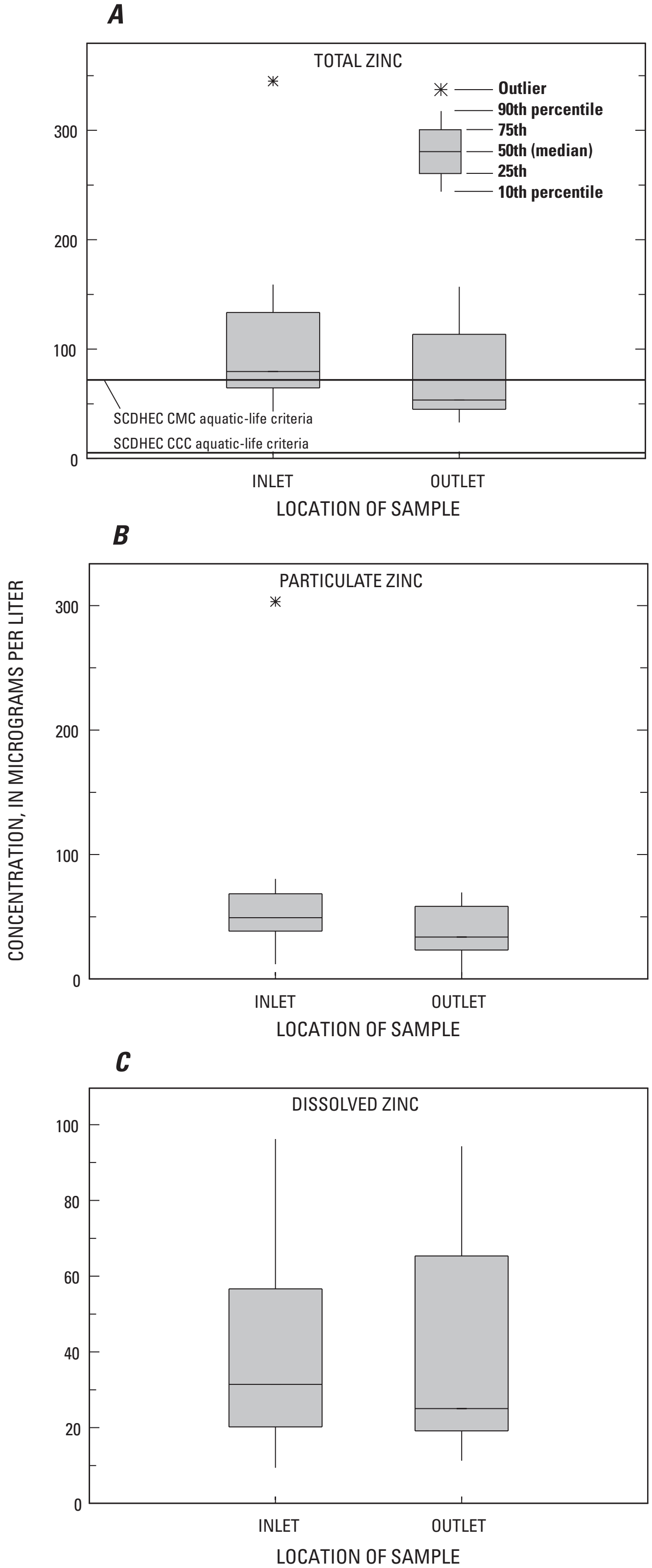

Figure 41. Event-mean concentrations of *(A)* total zinc, *(B)* particulate zinc, and *(C)* dissolved zinc at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration]

respectively; p-values = 0.0248 and 0.0034, respectively), total and particulate lead (V-statistics = 76 and 75, respectively; p-values = 0.0007 and 0.0012, respectively), total and particulate nickel (V-statistics = 70 and 78, respectively; p-values = 0.0061 and 0.0002, respectively), and total and particulate zinc (V-statistics = 78 and 76, respectively; p-values = 0.0002 and 0.0007, respectively). This finding indicated that BMP2 was efficient at reducing trace-metal loads in stormwater.

The average amounts of trace-metal loads that were reduced by BMP2 for the sampled storm events sampled for this study were, in order from least to greatest: total cadmium (0.003 +/- 0.001 g/event), total nickel (0.03 +/- 0.01 g/event), total copper (0.13 +/- 0.05 g/event), total lead (0.18 +/- 0.05 g/event), and total zinc (1.07 +/- 0.33 g/event; fig. 45; Appendix D-1). The average percentages of trace metal concentrations and loads removed by BMP2 were similar, and are listed in order from least to greatest: total copper (16.8 +/- 4.39 percent), total nickel (17.3 +/- 6.72 percent), total zinc (23.2 +/- 4.33 percent), total cadmium (26.2 +/- 5.99 percent), and total lead (27.5 +/- 6.22 percent). For the sampled storm events at BMP2, stormwater entering the BMP had the following cumulative loads: 0.15 g of total cadmium, of which 0.03 g were removed; 2.85 g of total nickel, of which 0.35 g were removed; 12.1 g of total copper, of which 1.57 g were removed; 10.4 g of total lead, of which 2.21 g were removed; and 72.7 g of total zinc, of which 12.8 g were removed by BMP2 (Appendix D-2).

As mentioned previously, trace-metal concentrations were measured in the retained coarser grained sediment and were zinc, lead, copper, nickel, and cadmium, in order from greatest to least concentration in micrograms per gram (fig. 29). The sequence for the amount of trace-metal loads removed between the inlet and outlet water of BMP2 was the same as for BMP1, in order from greatest to least loads (grams per event): zinc, lead, copper, nickel, and cadmium.

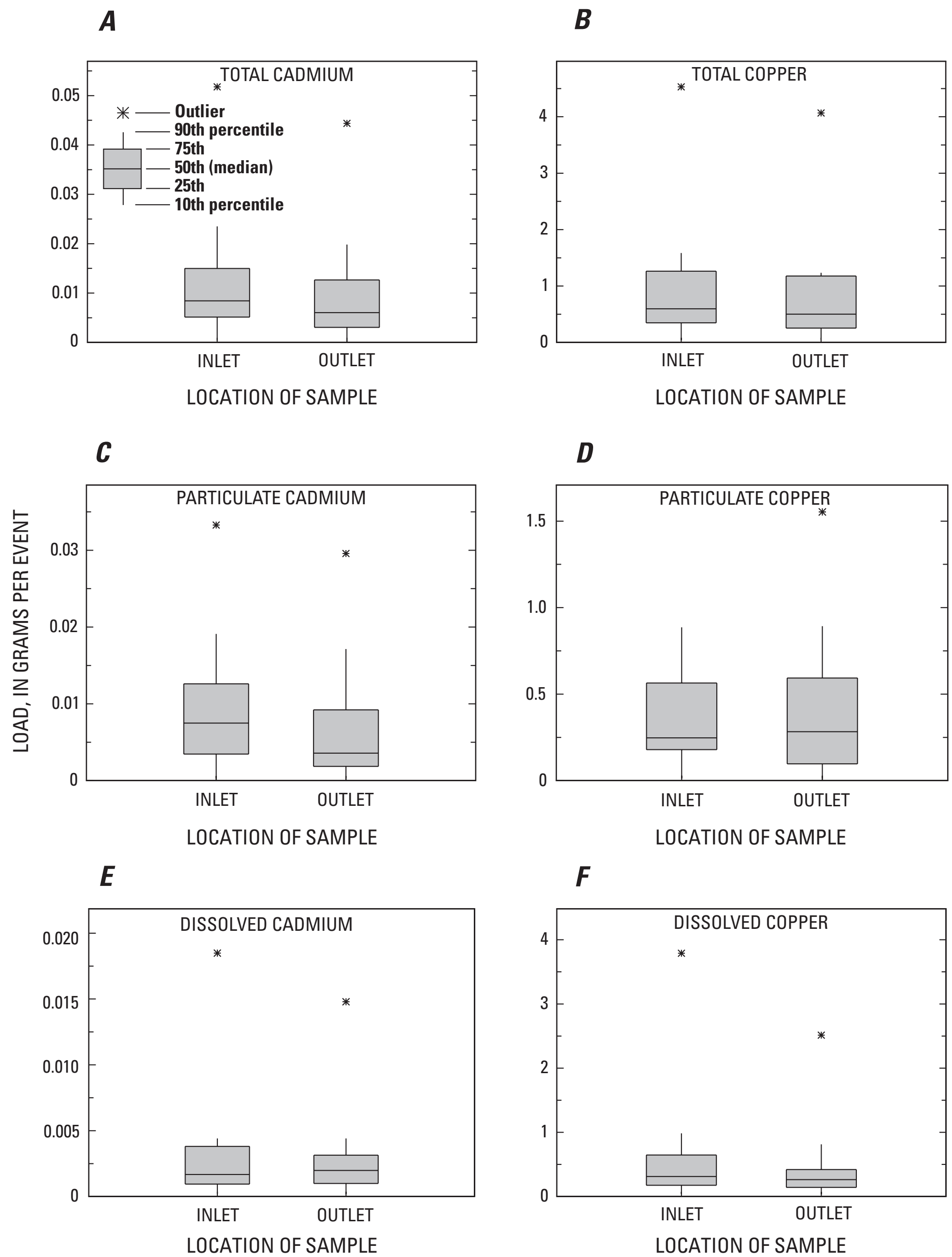

Figure 42. Event-mean loads of total *(A)* cadmium and *(B)* copper; particulate *(C)* cadmium and *(D)* copper; and dissolved *(E)* cadmium and *(F)* copper at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

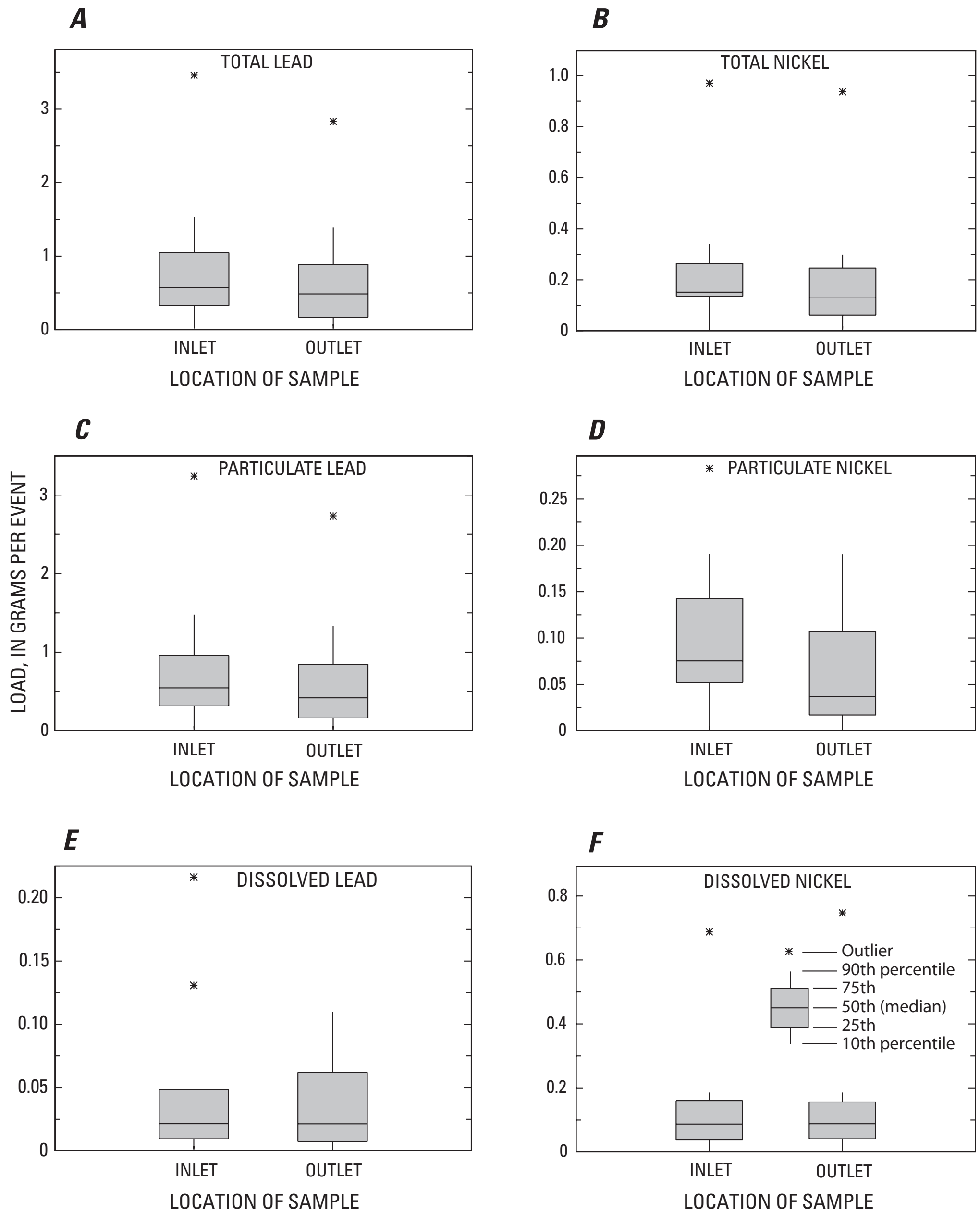

Figure 43. Event-mean loads of total *(A)* lead and *(B)* nickel; particulate *(C)* lead and *(D)* nickel; and dissolved *(E)* lead and *(F)* nickel at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

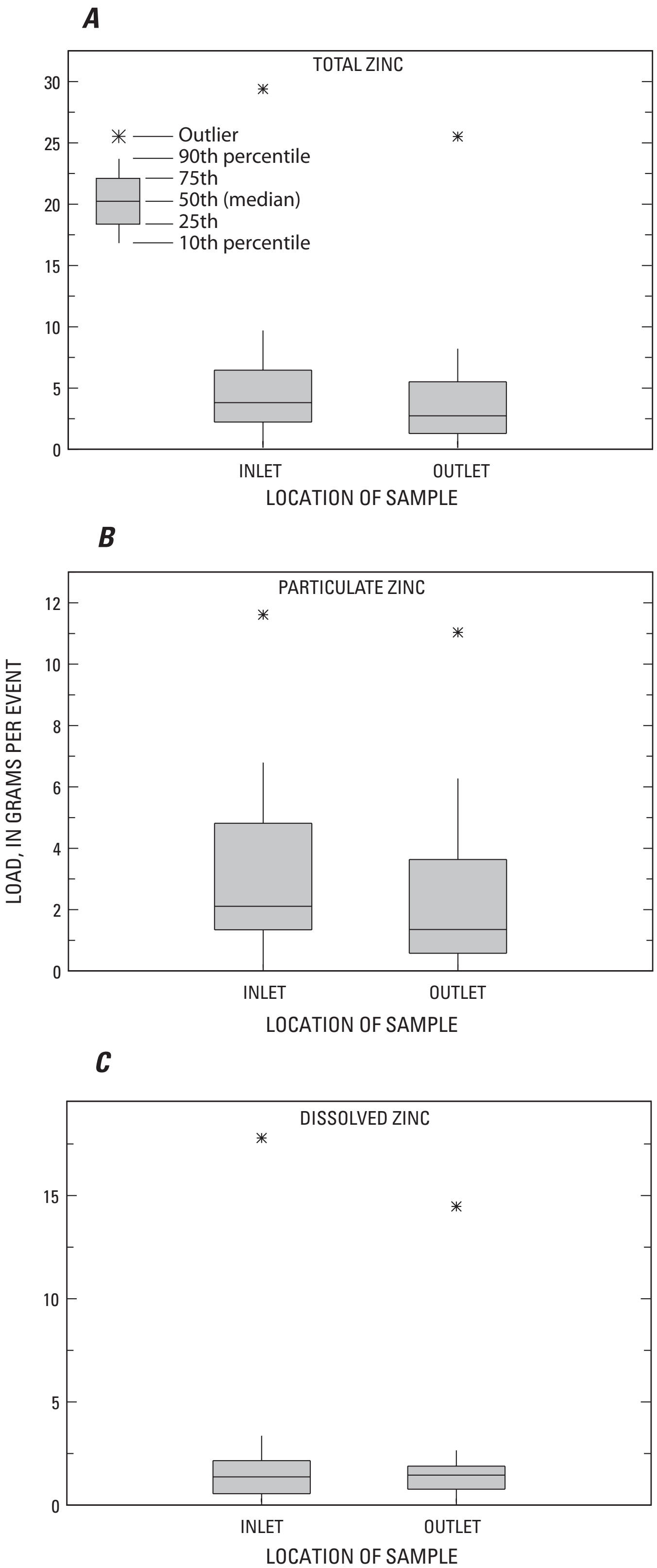

Figure 44. Event-mean loads of *(A)* total zinc, *(B)* particulate zinc, and *(C)* dissolved zinc at best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

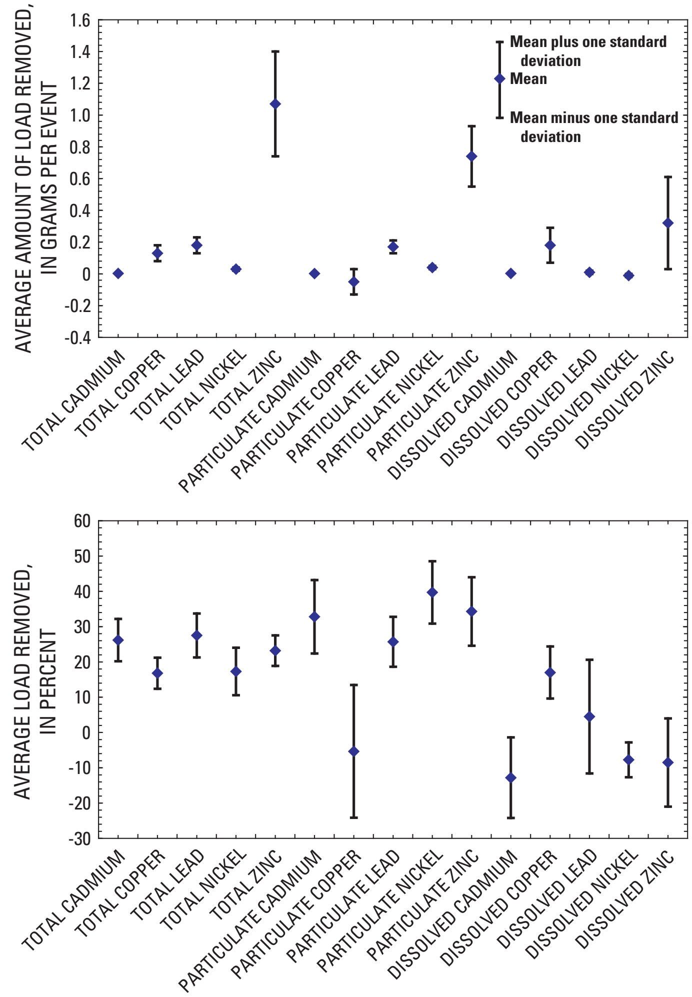

Figure 45. Average amounts and percentages of event-mean loads of selected trace metals removed by best management practice 2 at U.S. Highway 21 near Beaufort, S.C., 2005–2006.

BMP3 Performance Assessment

BMP3 is located along the westbound lane of S.C. Highway 802, approximately 2 miles northeast of the intersection of S.C. 802 and U.S. 21, in Beaufort, S.C. (fig. 2). The drainage area for this BMP is 5.90 acres with a curb and gutter system for highway runoff (table 1). This BMP consists of a grit chamber, an oil baffle wall, and low- and high-flow controls. During runoff, stormwater enters the system and circulates around the grit chamber in a swirling motion before entering the area between the grit chamber and the oil baffle wall. Flow is forced under the baffle wall, where BMP3 retains floating debris and oily contaminants. Flow then passes through the low- or high-flow control. To accommodate large, infrequent storms, the device is constructed with a peak-flow bypass (Vortechs, 2008).

The EMCs and loads of the following water-quality constituents are summarized for BMP3: (1) SSC and TSS; (2) oil and grease; (3) bacteria; (4) nutrients (such as TKN and TP); and (5) metals. As described earlier, the design of BMP3 is conducive for the removal of suspended sediments and oil and grease; however, removal of the total and particulate forms of other water-quality constituents also were considered in this assessment.

Suspended Sediment, Total Suspended Solids, and Sediment

As mentioned previously, analytical methods to determine SSC and TSS were used to quantify concentrations of suspended organic and inorganic particles in surface waters. A monotonic correlation between TSS and SSC in the inlet and outlet waters at BMP3 was statistically significant (rho = 0.81818, p-value = 0.0011 and rho = 0.86302, p-value = 0.0006, respectively) (fig. 46), but not one-to-one as would be expected for measurements of the same substance (suspended particles). Comparison of the SSC and TSS concentrations from the BMP3 sampling events demonstrated a positive bias, especially for SSC concentrations greater than 100 mg/L. The greatest difference was observed at the maximum inlet SSC concentration of 255 mg/L, which had a corresponding TSS concentration of only 90 mg/L. Further evaluation of grain size did not indicate a strong bias between SSC and TSS concentrations, which tended to increase as the percentage of the sediment finer than 63 microns (finer than sand) decreased.

Because the SSC analytical method is reported to produce more reliable results than the TSS method (Gray and others, 2000), statistical findings based on SSC results are considered more indicative of the BMP performance. However, because the TSS method is often the method adopted for regulatory monitoring, statistical findings based on TSS results also are discussed.

Suspended-sediment EMCs in the inlet water of BMP3 ranged from 47 to 255 mg/L, with a median value of 94 mg/L (fig. 47, table 12). The EMCs for SSC in the outlet water were smaller and less variable than those in the inlet water, with a median of 54 mg/L. Suspended-sediment concentrations were reduced significantly by BMP3 during the period of study (V-statistic = 60, p-value = 0.0068). This statistical finding indicated that BMP3 performed efficiently at reducing EMCs for SSC in stormwater. Median EMCs of TSS of 85 and 46 mg/L for inlet and outlet water, respectively, were slightly less than the median SSC concentrations for BMP3 (fig. 48). The TSS concentrations also were different significantly between inlet and outlet waters (Z-score = 2.6703, p-value = 0.0038).

Turbidity has been used as a surrogate measure of the suspended sediment or particulates in water. However, for BMP3, turbidity values were not correlated to TSS in the inlet and outlet waters (rho = 0.50539, p-value = 0.0794 and rho = 0.52290, p-value = 0.0771, respectively) or SSC (rho = 0.36073, p-value = 0.2493 and rho = 0.35160, p-value = 0.2890, respectively) for the period of study. For BMP3, the median event-mean turbidities in the inlet and outlet waters were similar (31.0 and 27.0 NTU, respectively) (fig. 48; table 12). Significant difference in turbidity was identified between inlet and outlet waters (Z-score = 2.3954, p-value = 0.0083), indicating that BMP3 was efficient at reducing turbidity in stormwater.

The character, as well as concentration, of the SSC also changed between the inlet and outlet waters in BMP3 (fig. 47*B*). The percentage of the suspended sediment finer than sand (grain sizes smaller than 63 microns), such as silt and clay, was more variable in the inlet water of BMP3, with a median of 73.0 percent (fig. 47*B*, table 12). The predominant size fraction of suspended sediment in outlet water was finer than sand (median of 92 percent) and was significantly finer than in the inlet waters (V-statistic = 2.6086, p-value = 0.0045). The change in the character of the SSC indicated that BMP3 was more efficient at capturing the sand-sized fractions of the suspended sediment than the silt- and clay-sized fractions. This retention of coarser grained sediment also could influence the lack of retention of certain nutrients (such as phosphorus), bacteria, and trace metals (such as lead and zinc) because of their tendency to adsorb preferentially to the smaller grained sediment.

Examination of the grain-sized fractions of the accumulated sediment within BMP3 in May 2006 further verified this preferential retention of the larger grained fractions. No sediment within BMP3 was finer than 63 microns (fig. 49), even though about 69 percent of the suspended sediment from the inlet waters finer than 63 microns (fig. 47). Trace-metal concentrations measured in the retained coarser grained sediment were zinc, lead, copper, nickel, and cadmium, in order from greatest to least concentration, in micrograms per gram (fig. 50).

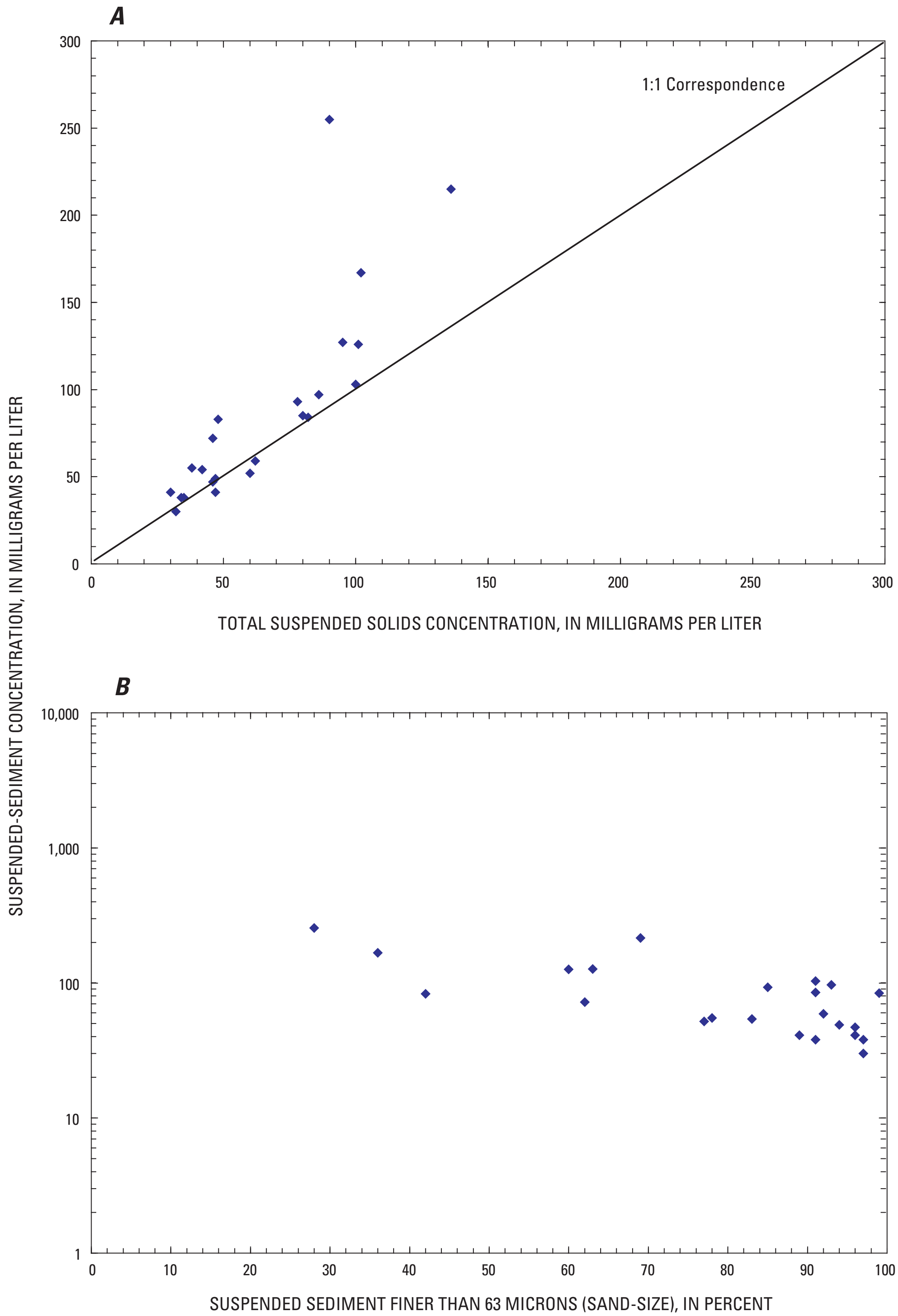

Figure 46. Relation between *(A)* suspended-sediment and total suspended solids concentrations and between *(B)* suspended-sediment concentrations and percentage of sediment finer than sand measured at best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

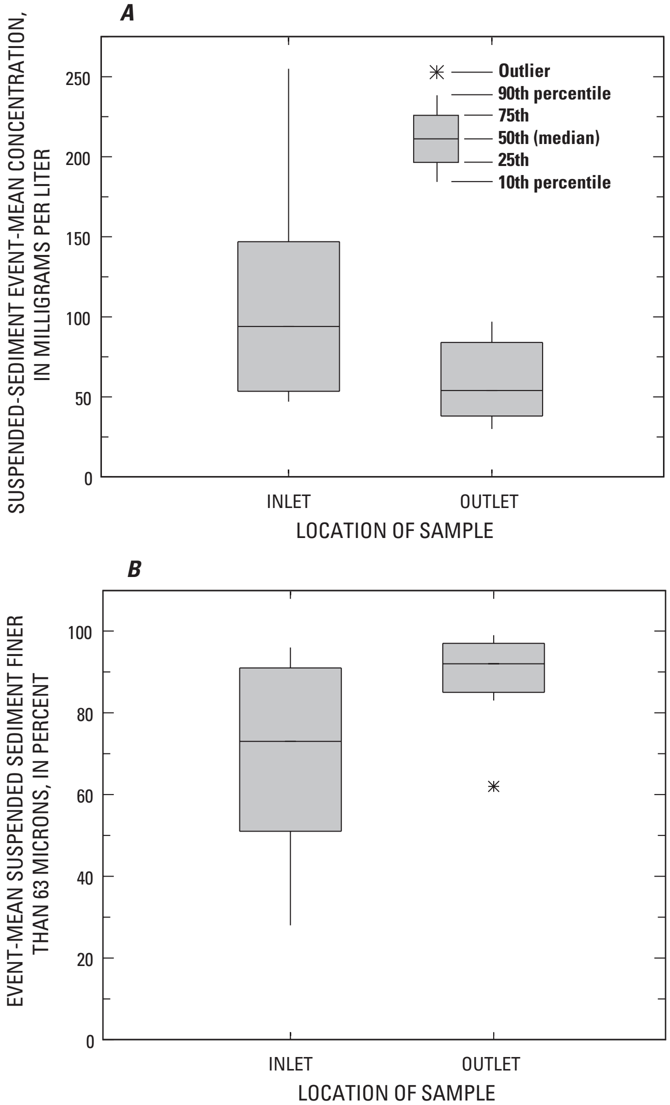

Figure 47. Event-mean *(A)* concentrations of suspended sediment, in milligrams per liter, and *(B)* percentages of suspended sediment finer than 63 microns, at best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

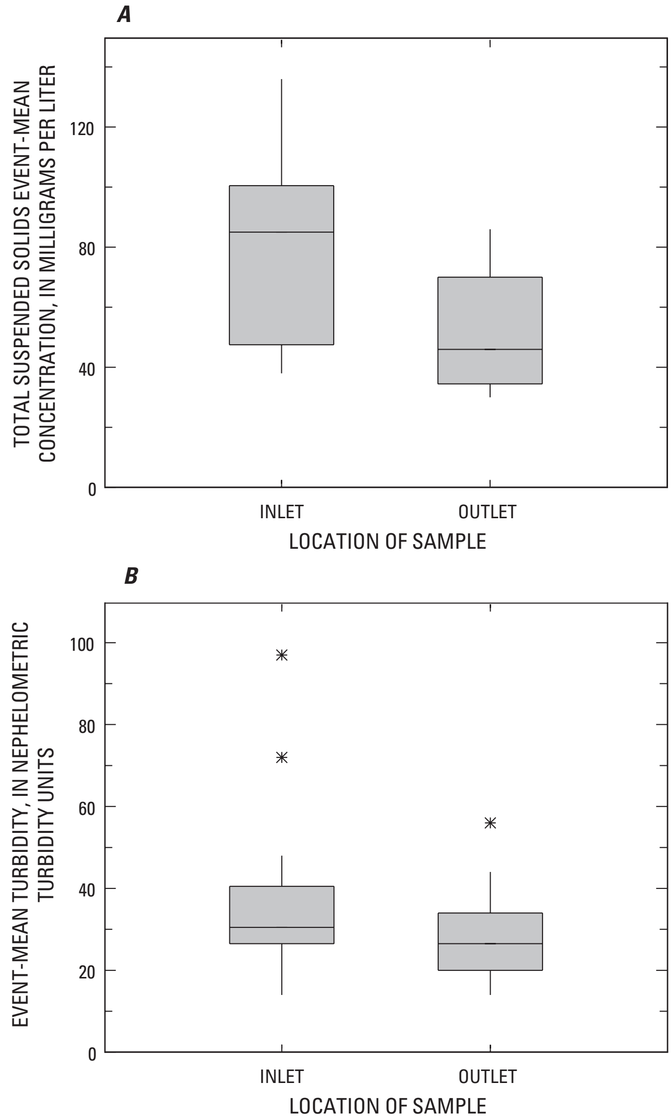

Figure 48. Event means of *(A)* total suspended solids concentrations and *(B)* turbidity for best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

Table 12. Summary statistics describing the comparison among event-mean concentrations in inlet and outlet waters of best management practice 3 (BMP3), Beaufort County, South Carolina, 2005–2006.

[>, greater than; µg/L, micrograms per liter; mg/L, milligrams per liter; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters]

Constituent	Units	Location	Median	Mean	Standard deviation	Comparison among event-mean concentrations in inlet and outlet waters of BMP3		Wilcoxon signed-rank test		
						Number	[1]Inlet > outlet	V-statistic	Z-score	Probability value
Dissolved cadmium	µg/L	Inlet	0.04	0.05	0.03	12	No		–0.443	0.671
	µg/L	Outlet	0.05	0.05	0.04	12				
Total cadmium	µg/L	Inlet	0.20	0.21	0.08	12	Yes		2.632	0.004
	µg/L	Outlet	0.15	0.16	0.06	12				
Particulate cadmium	µg/L	Inlet	0.15	0.16	0.07	12	Yes	74		0.002
	µg/L	Outlet	0.10	0.11	0.06	12				
Dissolved copper	µg/L	Inlet	5.85	7.87	5.46	12	No		0.314	0.377
	µg/L	Outlet	6.85	7.83	4.92	12				
Total copper	µg/L	Inlet	15.3	17.0	8.78	12	Yes	66		0.017
	µg/L	Outlet	12.3	14.2	6.20	12				
Particulate copper	µg/L	Inlet	9.00	9.37	6.07	12	Yes		1.884	0.030
	µg/L	Outlet	6.65	6.87	4.43	12				
Dissolved lead	µg/L	Inlet	0.54	0.60	0.46	12	No		–0.707	0.760
	µg/L	Outlet	0.56	0.71	0.53	12				
Total lead	µg/L	Inlet	16.6	16.7	8.36	12	Yes	69		0.008
	µg/L	Outlet	12.2	14.1	5.16	12				
Particulate lead	µg/L	Inlet	16.1	16.7	8.27	12	Yes	73		0.002
	µg/L	Outlet	11.7	13.4	5.28	12				
Dissolved nickel	µg/L	Inlet	2.54	3.13	2.53	12	No		–0.315	0.623
	µg/L	Outlet	2.57	2.94	2.01	12				
Total nickel	µg/L	Inlet	4.42	5.46	3.61	12	Yes	62		0.039
	µg/L	Outlet	3.87	4.61	2.33	12				
Particulate nickel	µg/L	Inlet	1.93	2.33	1.54	12	Yes	66		0.017
	µg/L	Outlet	1.41	1.67	0.77	12				
Dissolved zinc	µg/L	Inlet	15.2	28.1	25.0	12	No	35		0.633
	µg/L	Outlet	17.2	27.9	20.7	12				
Total zinc	µg/L	Inlet	82.0	88.8	41.7	12	Yes		2.197	0.014
	µg/L	Outlet	65.0	71.1	31.8	12				
Particulate zinc	µg/L	Inlet	59.9	60.7	38.7	12	Yes	60		0.007
	µg/L	Outlet	40.0	48.1	22.1	12				
Total ammonia plus organic nitrogen	mg/L	Inlet	1.60	1.86	1.07	12	No		0.401	0.344
	mg/L	Outlet	1.45	1.78	1.01	12				
Total phosphorus	mg/L	Inlet	0.28	0.28	0.11	12	No		0.445	0.328
	mg/L	Outlet	0.24	0.25	0.09	12				
Turbidity	NTU	Inlet	31.0	38.1	24.0	12	Yes		2.395	0.008
	NTU	Outlet	27.0	29.0	12.1	12				
Total organic carbon	mg/L	Inlet	26.0	28.0	17.0	12	No	46		0.139
	mg/L	Outlet	23.0	26.0	13.2	12				
Total suspended solids as residue	mg/L	Inlet	85.0	79.0	30.4	12	Yes		2.670	0.004
	mg/L	Outlet	46.0	52.0	20.3	12				
Biochemical oxygen demand	mg/L	Inlet	14.1	20.0	19.0	12	No	60		0.055
	mg/L	Outlet	12.0	18.4	17.0	12				
Chemical oxygen demand	mg/L	Inlet	100	116	58.0	12	Yes		2.218	0.013
	mg/L	Outlet	90.0	99.2	51.3	12				
Enterococci	col/100 mL	Inlet	2,260	6,290	7,430	10	Yes	45		0.042
	col/100 mL	Outlet	1,240	3,540	3,960	10				
Escherichia coli	col/100 mL	Inlet	5,200	5,780	5,600	11	No	43		0.207
	col/100 mL	Outlet	1,700	4,920	7,170	11				
Suspended sediment finer than sand	percent	Inlet	73.0	69.0	24.0	12	[2]Yes	2.609		0.005
	percent	Outlet	92.0	90.0	10.4	12				
Suspended sediment	mg/L	Inlet	94.0	114	68.2	11	Yes	60		0.007
	mg/L	Outlet	54.0	58.8	24.1	11				
Oil and grease	mg/L	Inlet	5.00	5.59	2.58	12	No		0.178	0.429
	mg/L	Outlet	4.00	5.91	5.94	12				

[1] Probability that the hypothesis that the input and output concentrations are the same versus the alternative one-sided hypothesis that the concentration is greater in the input than the output.

[2] One-sided test such that the alternative hypothesis is that the percentage of suspended sediment finer than 63 micron is greater in the output than the input.

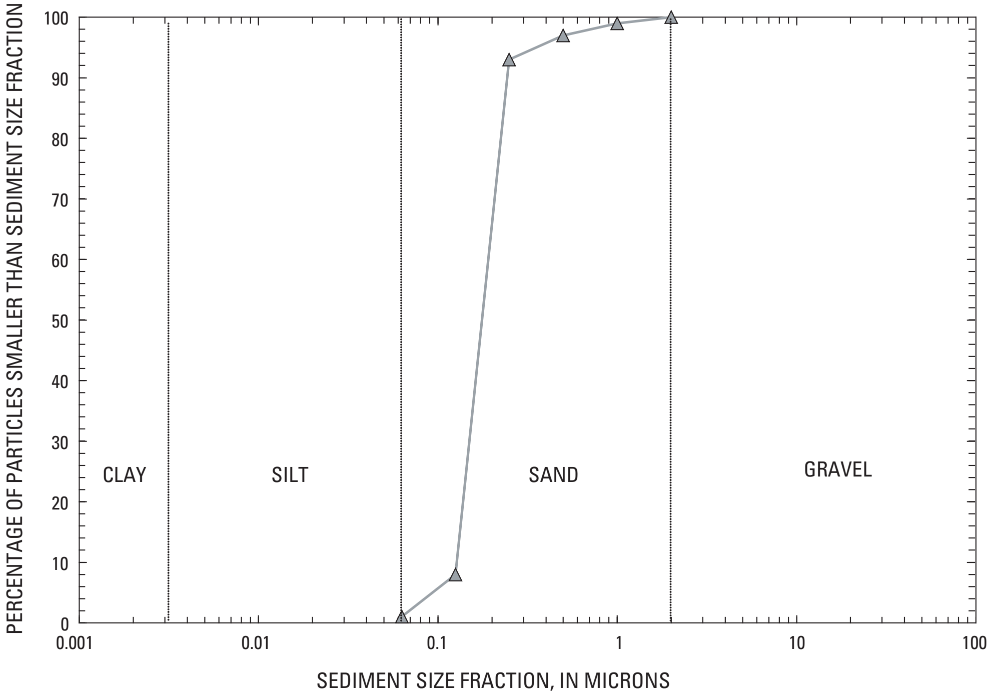

Figure 49. Particle-size distribution of sediment collected from within structural best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

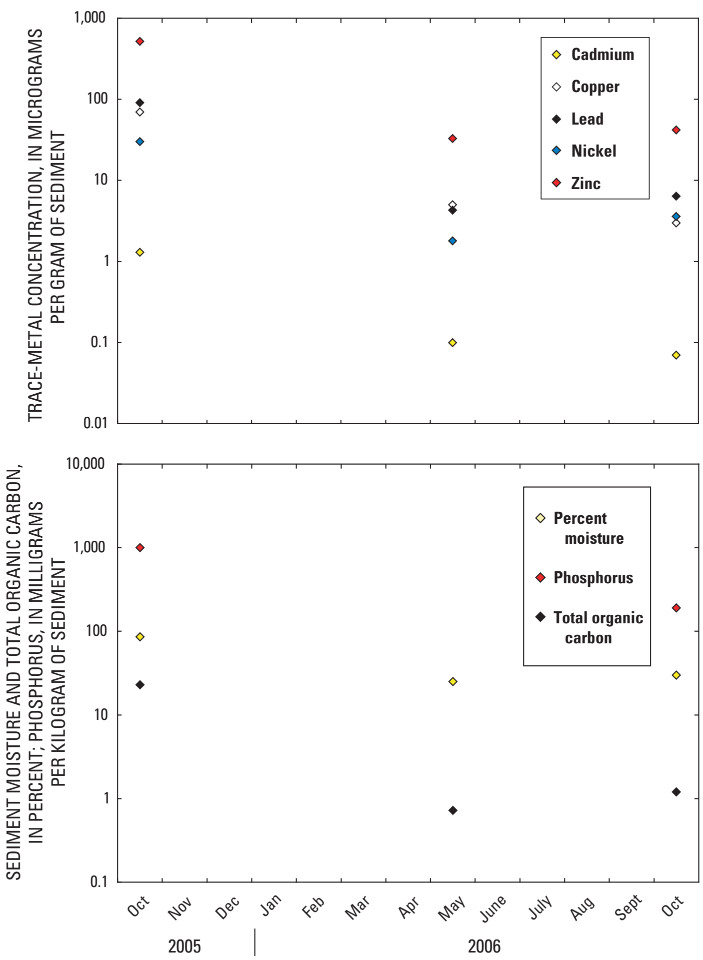

Figure 50. Sediment chemistry determined from samples collected from within best management practice 3 at S.C. Highway 802 near Beaufort County, S.C., May 2005, October 2005, May 2006, and October 2006.

Event-mean loads of SSC for individual storm events were computed for inlet and outlet waters. Stormwater reaching the inlet of BMP3 had SSC loads that ranged from 2.53 to 157 kg/event (median of 18.6 kg/event) (fig. 51; table 13). Stormwater leaving the outlet of BMP3 had SSC loads ranging from 1.39 to 136 kg/event (median of 10.6 kg/event). The SSC loads were statistically different between inlet and outlet waters (V-statistic = 58, p-value = 0.0122), which indicated that BMP3 was efficient at reducing SSC concentrations in stormwater.

Computation of this reduction for the sampled storm events indicated that BMP3 reduced SSC loads from stormwater an average of 12.7 +/- 5.66 kg/event or an average of 39.0 +/- 10.6 percent (fig. 52; Appendix D-1). The larger watershed and higher mean stormflows at BMP3 delivered larger cumulative SSC loads (summed from the sampled storm events from 2005 to 2006) than the flows at the other BMP sites. The cumulative SSC load entering BMP3 was 469 kg during the period of study; BMP3 removed 153 kg of that load (Appendix D-2).

In relation to other environmental and chemical factors, EMCs for SSC in the inlet and outlet waters were not correlated significantly with hydrologic variables, such as rainfall, rainfall intensity, or stormflow, with only one exception of a correlation with SSC and rainfall intensity for outlet water (rho = 0.66211, p-value = 0.0265). Additionally, particulate EMCs of cadmium, nickel, and zinc were correlated with EMCs for SSC, indicating that these particulate metals had similar transport as suspended sediment through the structural BMP. EMCs for TSS had significant correlation with all particulate metal EMCs.

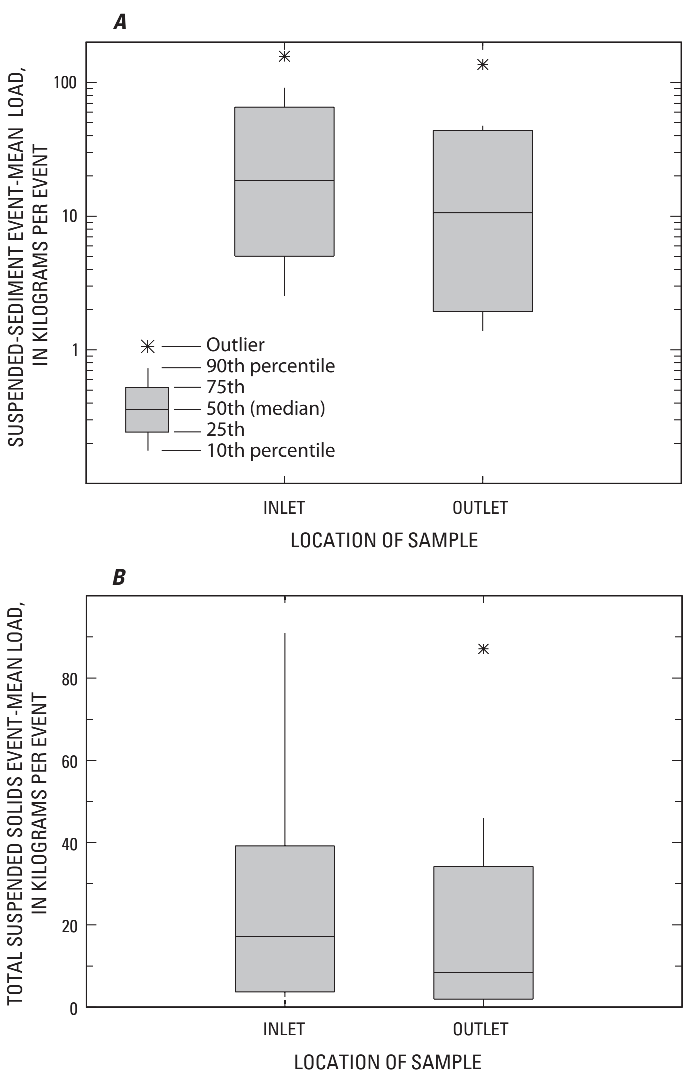

Figure 51. Event-mean loads of *(A)* suspended sediment and *(B)* total suspended solids, in kilograms per event, at best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

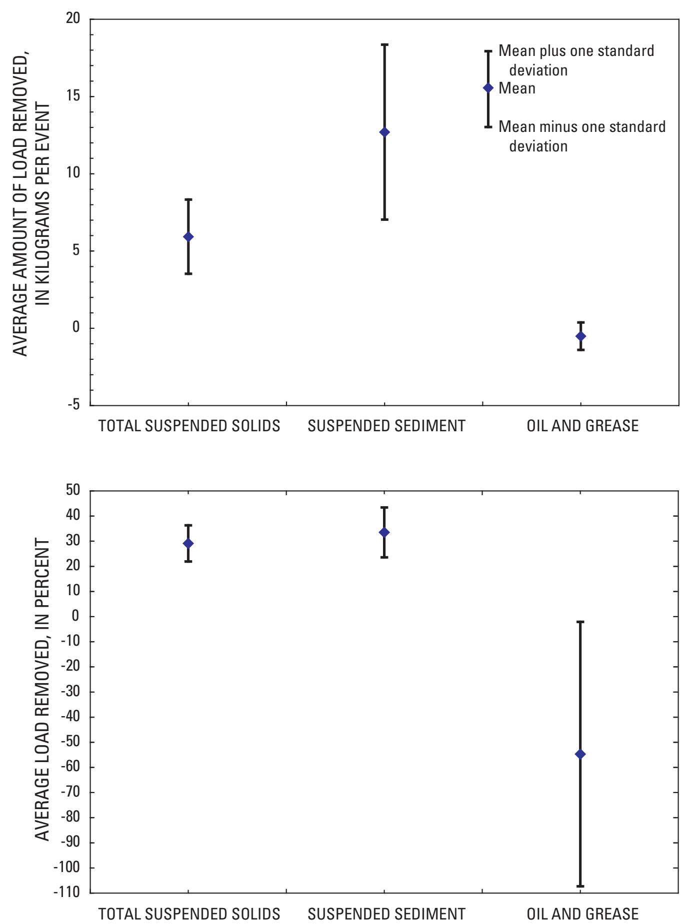

Figure 52. Average loads of total suspended solids, suspended sediment, and oil and grease removed by best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

Table 13. Summary statistics describing the comparison among event-mean loads in inlet and outlet waters of best management practice 3 (BMP3), Beaufort County, South Carolina, 2005–2006.

[>, greater than; g/event; grams per event; kg/event, kilograms per event]

Constituent	Units	Location	Median	Mean	Standard deviation	Comparison among event-mean loads in inlet and outlet waters of BMP3		Wilcoxon signed-rank test		
						Number	[1]Inlet > outlet	V-statistic	Z-score	Probability value
Dissolved cadmium	g/event	Inlet	0.01	0.01	0.01	12	No		–0.393	0.653
	g/event	Outlet	0.01	0.01	0.01	12				
Total cadmium	g/event	Inlet	0.05	0.06	0.05	12	Yes	61		0.046
	g/event	Outlet	0.03	0.05	0.06	12				
Particulate cadmium	g/event	Inlet	0.03	0.05	0.04	12	Yes	65		0.021
	g/event	Outlet	0.01	0.04	0.05	12				
Dissolved copper	g/event	Inlet	1.52	1.80	1.53	12	No	34		0.661
	g/event	Outlet	1.84	2.83	4.14	12				
Total copper	g/event	Inlet	3.63	4.35	3.84	12	No	48		0.259
	g/event	Outlet	3.72	4.26	4.15	12				
Particulate copper	g/event	Inlet	1.08	2.61	3.09	12	No		1.178	0.120
	g/event	Outlet	0.54	1.62	1.91	12				
Dissolved lead	g/event	Inlet	0.10	0.15	0.14	12	No		–0.942	0.827
	g/event	Outlet	0.15	0.41	0.95	12				
Total lead	g/event	Inlet	3.82	4.77	4.52	12	No	57		0.088
	g/event	Outlet	3.37	4.66	5.03	12				
Particulate lead	g/event	Inlet	3.57	4.62	4.43	12	Yes	68		0.011
	g/event	Outlet	3.07	4.25	4.28	12				
Dissolved nickel	g/event	Inlet	0.49	0.64	0.59	12	No		–1.335	0.909
	g/event	Outlet	0.66	0.69	0.63	12				
Total nickel	g/event	Inlet	1.16	1.36	1.15	12	No	53		0.151
	g/event	Outlet	1.08	1.29	1.15	12				
Particulate nickel	g/event	Inlet	0.41	0.72	0.84	12	No	60		0.055
	g/event	Outlet	0.27	0.60	0.78	12				
Dissolved zinc	g/event	Inlet	5.96	7.29	7.40	12	No	33		0.689
	g/event	Outlet	6.69	9.09	10.6	12				
Total zinc	g/event	Inlet	21.3	24.0	21.8	12	No	50		0.212
	g/event	Outlet	16.2	23.1	23.8	12				
Particulate zinc	g/event	Inlet	7.37	16.7	19.0	12	Yes	54		0.034
	g/event	Outlet	9.18	15.5	15.5	12				
Total ammonia plus organic nitrogen	kg/event	Inlet	0.39	0.47	0.42	12	No	24		0.794
	kg/event	Outlet	0.42	0.54	0.55	12				
Total phosphorus	kg/event	Inlet	0.07	0.08	0.09	12	No		–0.267	0.605
	kg/event	Outlet	0.06	0.09	0.11	12				
Total organic carbon	kg/event	Inlet	7.09	6.50	5.32	12	No	31		0.585
	kg/event	Outlet	6.54	6.71	5.69	12				
Total suspended solids as residue	kg/event	Inlet	17.2	26.7	29.8	12	Yes	73		0.002
	kg/event	Outlet	8.43	20.8	26.1	12				
Biochemical oxygen demand	kg/event	Inlet	3.94	4.41	3.59	11	No	48		0.103
	kg/event	Outlet	4.67	4.58	3.67	11				
Chemical oxygen demand	kg/event	Inlet	26.6	30.6	26.2	12	No		1.418	0.078
	kg/event	Outlet	24.1	29.3	28.6	12				
Suspended sediment	kg/event	Inlet	18.6	39.1	47.7	11	Yes	58		0.012
	kg/event	Outlet	10.6	28.7	39.6	11				
Oil and grease	kg/event	Inlet	0.77	1.73	2.28	11	No	37		0.382
	kg/event	Outlet	0.69	2.10	2.98	11				

[1] Probability that the hypothesis that the input and output concentrations are the same versus the alternative one-sided hypothesis that the concentration is greater in the input than the output.

Oil and Grease

For the period of study, stormwater entering the inlet of BMP3 had a median oil and grease concentration of 5.00 mg/L. Concentrations ranged from 1.5 (substituted for the censor level of less than 7) to 11 mg/L (fig. 53). Oil and grease concentrations in the stormwater leaving the outlet of BMP3 were not reduced significantly from the inlet concentrations (Z-score = 0.1783, p-value = 0.4293; table 12). More than 75 percent of the oil and grease concentrations were less than the LRL of 7 mg/L (fig. 53). Consequently, outlet water had a median oil and grease concentration of 4.00 mg/L. These results indicated BMP3 was not efficient at reducing oil and grease concentrations in the stormwater entering the BMP.

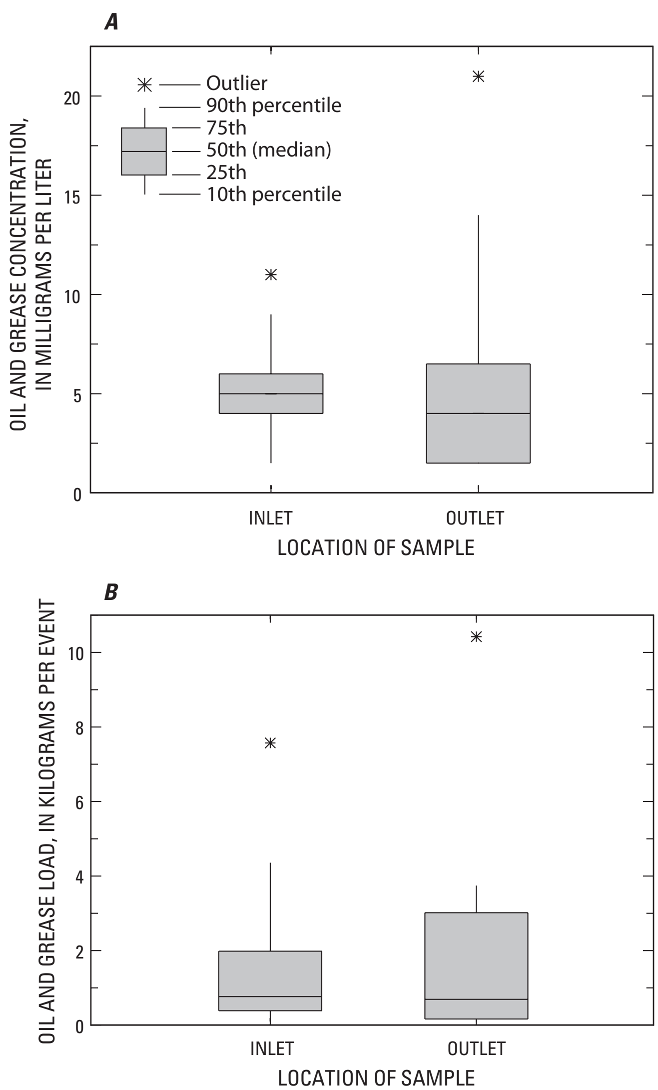

Figure 53. Oil and grease *(A)* concentrations in grab samples and *(B)* loads at best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

The total PAH concentrations during selected storm events ranged from 0.34 to 1.06 g/L in stormwater entering the inlet of BMP3 (table 14). Minimal relation between total PAH and oil and grease concentrations was observed. The maximum total PAH concentration did not co-occur with the highest oil and grease concentrations for the same storm events.

Oil and grease loads in the stormwater entering the inlet of BMP3 had a median value of 0.77 kg/event and a range of 0.11 to 7.58 kg/event for the study period (fig. 53). The stormwater leaving the outlet of BMP3 had oil and grease loads that were similar to those of the inlet water (median of 0.69 kg/event; range of 0.06 to 10.4 kg/event). As was determined for oil and grease concentrations, BMP3 was not effective at significantly reducing the oil and grease loads that entered the BMP (V-statistic = 37, p-value = 0.3823; table 13). In fact, differences in the oil and grease loads in the inlet and outlet waters for individual storms averaged –0.51 +/- 0.89 kg/event or –54.7 +/- 52.6 percent (fig. 52; Appendix D-1), indicating increases in oil and grease loads as the stormwater passes through the BMP. For the sampled storm events, BMP3 exhibited similar behavior in cumulative loads of oil and grease. A cumulative load of 19.0 kg of oil and grease entered BMP3 in stormwater from the individual storms that were sampled, and, rather than removing a portion of that load, 6.18 kg were added to the cumulative load leaving BMP3 (Appendix D-2). These results indicated BMP3 was not efficient at reducing oil and grease loads in the stormwater entering the BMP.

Table 14. Comparison of oil and grease concentrations and total polycyclic aromatic hydrocarbon (PAH) concentrations in the water from selected storms at best management practice 3, Beaufort County, South Carolina, 2006.

[mg/L, milligrams per liter; µg/L, micrograms per liter]

Date of sample	Oil and grease (inlet [mg/L])	Oil and grease (outlet [mg/L])	Total PAH (inlet [µg/L])	Total PAH (outlet [µg/L])
July 6, 2006		1.5	0.56	0.23
August 24, 2006	4	1.5	0.44	0.69
August 31, 2006	9	1.5	0.34	0.09
September 7, 2006	6	1.5	1.06	0.79
September 19, 2006	4	21	0.74	0.96

Nutrients

Stormwater entering the inlet of BMP3 had nutrient EMCs similar to the nutrient EMCs in stormwater leaving the outlet of BMP3 (fig. 54). Inlet water had a median TKN concentration of 1.60 mg/L and a median TP concentration of 0.28 mg/L (table 12; fig. 54). Outlet water had median TKN and TP concentrations of 1.45 and 0.24 mg/L, respectively; these amounts were reduced only slightly from those in the inlet water. Not only were the median values similar; ranges in the TKN concentrations in the inlet and outlet waters were almost identical, and ranges in TP concentrations had considerable overlap. The TKN and TP concentrations in the inlet and outlet waters at BMP3 were not statistically significant (for TKN, Z-score = 0.4007 and p-value = 0.3443; for TP, Z-score = 0.4452 and p-value = 0.3281). This finding indicated that BMP3 was not efficient at reducing nutrient concentrations in stormwater.

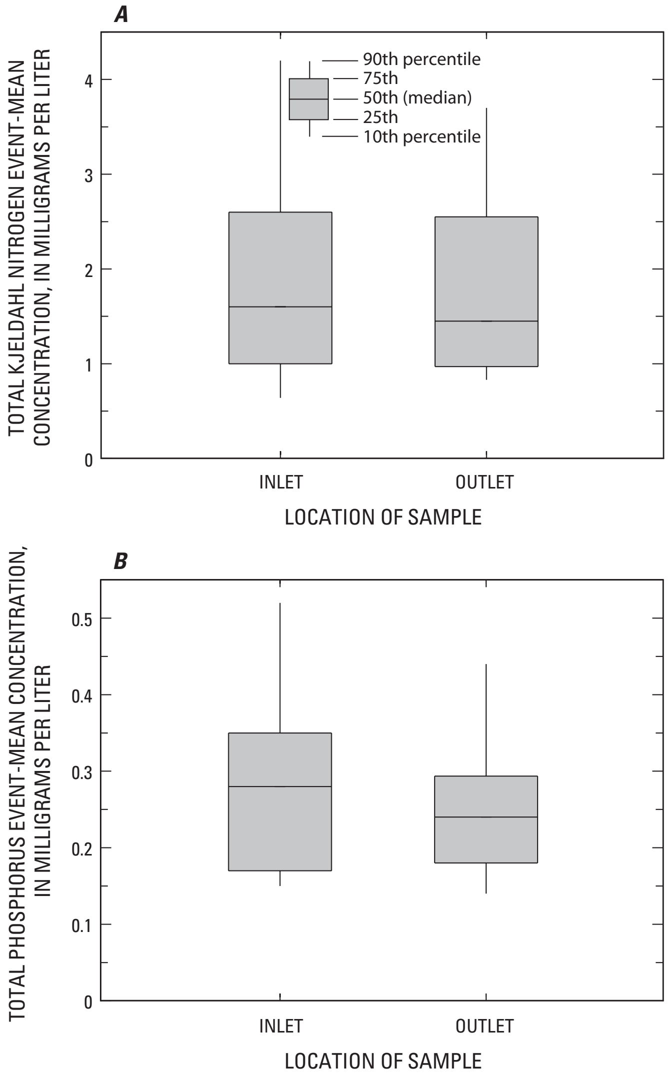

Figure 54. Event-mean concentrations of *(A)* total Kjeldahl nitrogen and *(B)* total phosphorus at best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

Median EMCs for TOC, BOD_5, and COD in the stormwater entering the inlet of BMP3 were 26.0, 14.1, and 100 mg/L, respectively (table 12). The much higher COD concentration, compared with the BOD_5 concentration suggested that organic decay processes were playing less of a role in oxygen consumption than other biological and chemical processes. Median EMCs for TOC, BOD_5, and COD in the stormwater leaving the outlet of BMP3 were 23.0, 12.0, and 90.0 mg/L, respectively. No statistical difference in TOC and BOD_5 loads between inlet and outlet waters for BMP3 were identified (for TOC, V-statistic = 46 and p-value = 0.1392; for BOD_5, V-statistic = 60 and p-value = 0.0549). COD concentrations were significantly reduced in the outlet water (Z-score = 2.2179, p-value = 0.0133). This finding indicated that BMP3 was not reducing TOC and BOD_5, but was efficient at reducing COD in the stormwater entering the BMP.

In relation to environmental and chemical factors, EMCs for TKN in the inlet and outlet waters of BMP3 were not correlated significantly with hydrologic variables of rainfall intensity and mean stormflow. Only EMCs for TP in the inlet water had a significant correlation with peak discharge (rho = –0.60275, p-value = 0.0497). Additionally, most dissolved (inlet only) and total forms of the trace metals, TOC, BOD, and COD were correlated with EMCs for TKN and TP in the inlet and outlet waters, indicating that nutrients had similar transport as dissolved and total trace metals through the structural BMP.

Slightly greater variability was observed for the TKN and TP loads leaving BMP3; the inlet and outlet waters had similar median values (table 13; fig. 55). Median TKN loads in the inlet and outlet waters were 0.39 and 0.42 kg/event, respectively. Median TP load in the inlet water (0.07 kg/event) was similar to the median TP load of the outlet water (0.06 kg/event). As determined for nutrient EMCs, the TKN and TP loads for BMP3 were not statistically different between inlet and outlet waters for this study (for TKN, V-statistic = 24 and p-value = 0.7935; for TP, Z-score = –0.267 and p-value = 0.6053). This finding indicated that BMP3 was not efficient at reducing nutrient loads in stormwater. In fact, the average difference between TKN loads in the water entering the inlet and in the water leaving the outlet of BMP3 for the individual storm events sampled for this study averaged –0.08 +/- 0.06 kg/event, or about –0.30 +/- 7.59 percent (fig. 56*B*; Appendix D-1). The difference in TP loads for the same storm events averaged –0.01 +/- 0.01 kg/event, or about

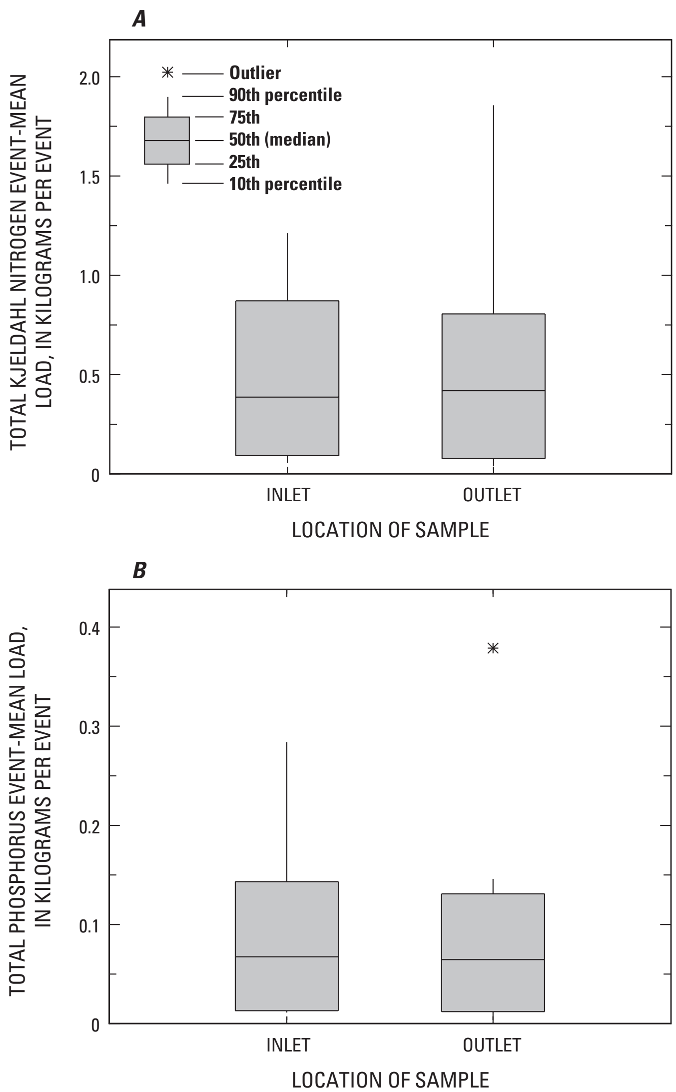

Figure 55. Event-mean loads of *(A)* total Kjeldahl nitrogen and *(B)* total phosphorus at best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

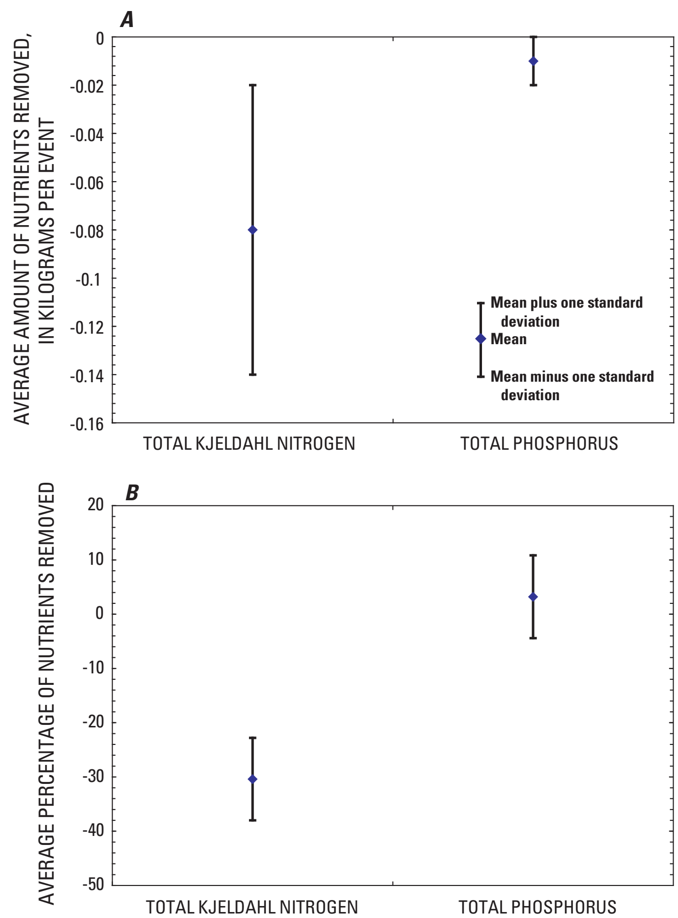

Figure 56. Average amounts and percentages of total Kjeldahl nitrogen and total phosphorus removed by best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

3.21 +/- 7.63 percent. These findings indicated a potential net gain of nutrients. Cumulative TKN and TP loads of 5.25 kg and 0.91 kg, respectively, entered BMP3 during the sampled storms and had additions of 0.83 and 0.10 kg, respectively, in the water leaving BMP3 (Appendix D-2).

Median TOC, BOD_5, and COD loads in the stormwater entering the inlet of BMP3 were 7.09, 3.94, and 26.6 kg/event, respectively (table 13). Median TOC, BOD_5, and COD loads in the stormwater leaving the outlet of BMP3 were 6.54, 4.67, and 24.1 kg/event, respectively. No statistical difference in TOC, BOD_5, and COD loads between inlet and outlet waters for BMP3 were identified (for TOC, V-statistic = 31 and p-value = 0.5845; for BOD_5, V-statistic = 48 and p-value = 0.1030; for COD, Z-score = 1.4175 and p-value = 0.0782). These findings indicated that BMP3 was not reducing TOC, BOD_5, and COD loads in stormwater.

Indicator Bacteria

The *E. coli* and enterococci concentrations in samples collected from stormwater entering the inlet and leaving the outlet of BMP3 had no relation to each other for the period of study (inlet: rho = –0.13333 and p-value = 0.7324; outlet: rho = 0.03333 and p-value = 0.9322). However, both fecal indicator bacteria ranged 3 orders of magnitude in concentrations during the period of study. Median concentrations of 5,200 and 2,260 col/100 mL for *E. coli* and enterococci, respectively, for inlet water and 1,700 and 1,240 col/100 mL, respectively, for outlet water indicated an overall reduction in fecal indicator bacterial concentrations by BMP3 (table 12; fig. 57). Statistical differences in enterococci concentrations between inlet and outlet waters of BMP3 were identified (V-statistic = 45, p-value = 0.0420). However, statistical tests comparing the *E. coli* concentrations in the inlet and outlet waters indicated no significant change in these concentrations (V-statistic = 43, p-value = 0.2065). These tests indicated that BMP3 was not effective at reducing *E. coli* concentrations but was effective in reducing enterococci concentrations.

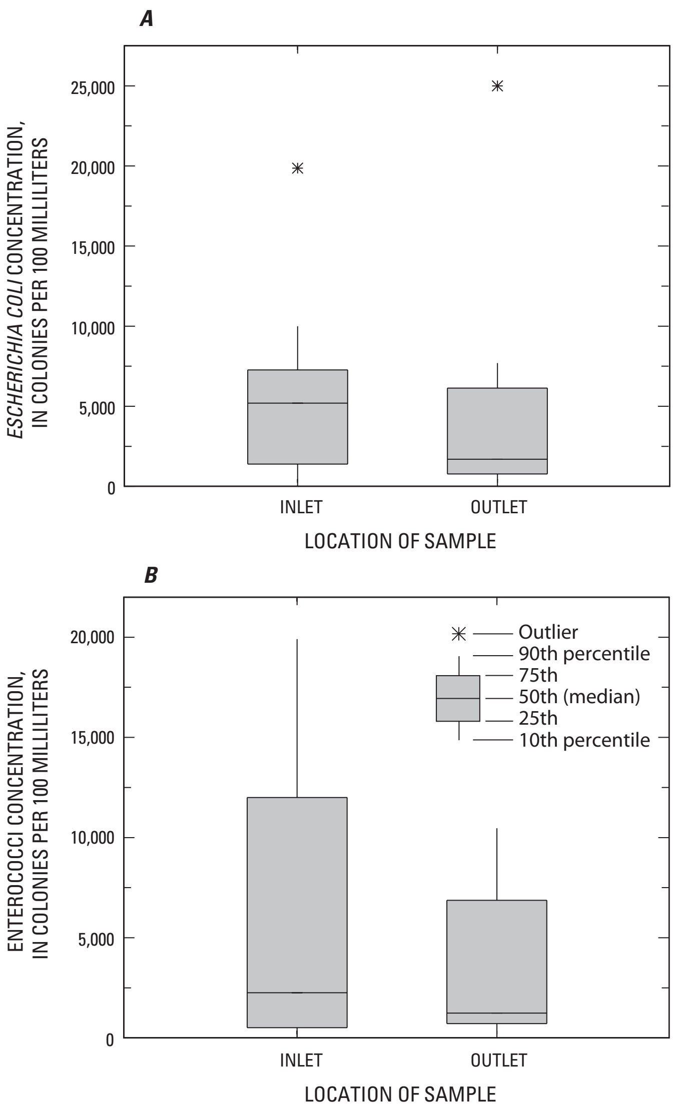

Figure 57. Concentrations of *(A) Escherichia coli* and *(B)* enterococci in grab samples collected from best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

No significant relations existed between *E. coli* and hydrologic variables, nutrients, BOD, TOC, or metals. Enterococci also had a similar lack of correlation with potential environmental variables. The lack of correlation between hydrologic variables and bacterial concentrations indicated that factors other than hydrology influenced the fate and transport of fecal indicator bacteria in the BMP. Although several factors could potentially influence fecal indicator bacterial concentrations, one such factor is the potential for the accumulated sediment and organic matter in the bottom of the BMP devices to serve as an additional source of bacteria. That survival or growth and then re-suspension process of enterococci and *E. coli* bacteria also could explain outlet water concentrations that were periodically equal to or higher than inlet water concentrations (figs. 58 and 59).

Only one sample of stormwater at BMP3 had a fecal bacteria concentration less than the established criteria. The stormwater entering the inlet of BMP3 in July 2006 had an enterococci concentration less than the recommended USEPA criteria of 104 col/100 mL source. All other samples, including the stormwater leaving the outlet of BMP3 for that July 2006 sample, had concentrations that exceeded both the SCDHEC-established one-time maximum concentration criterion of 235 col/100 mL for *E. coli* and the USEPA criteria for enterococci.

Sediments removed from BMP3 during clean-out periods were analyzed for viable colonies of enterococci and *E. coli* in October 2005, May 2006 (*E. coli* only), and October 2006. Enterococci concentrations were highly variable at 311 and 1,530 colonies per 100 grams of sediment for October 2006 and 2005, respectively (fig. 58). Because the sediment data were limited, no strong pattern between enterococci concentrations in sediment and water was observed; higher concentrations in sediment did not correlate with higher concentrations in water. The *E. coli* concentrations in the sediment were more variable than enterococci, ranging from 560 to 4,600 colonies per 100 grams of sediment (fig. 59). Again, no pattern between *E. coli* concentrations in sediment and in water was observed for *E. coli*.

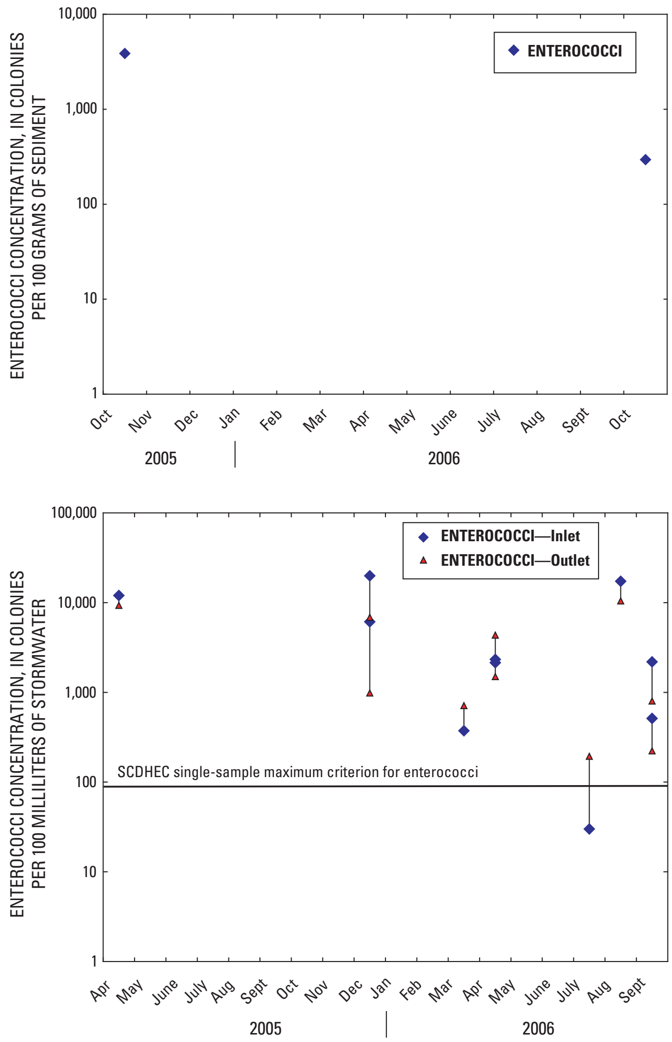

Figure 58. Time-series plots of enterococci concentrations in sediment and stormwater at best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control]

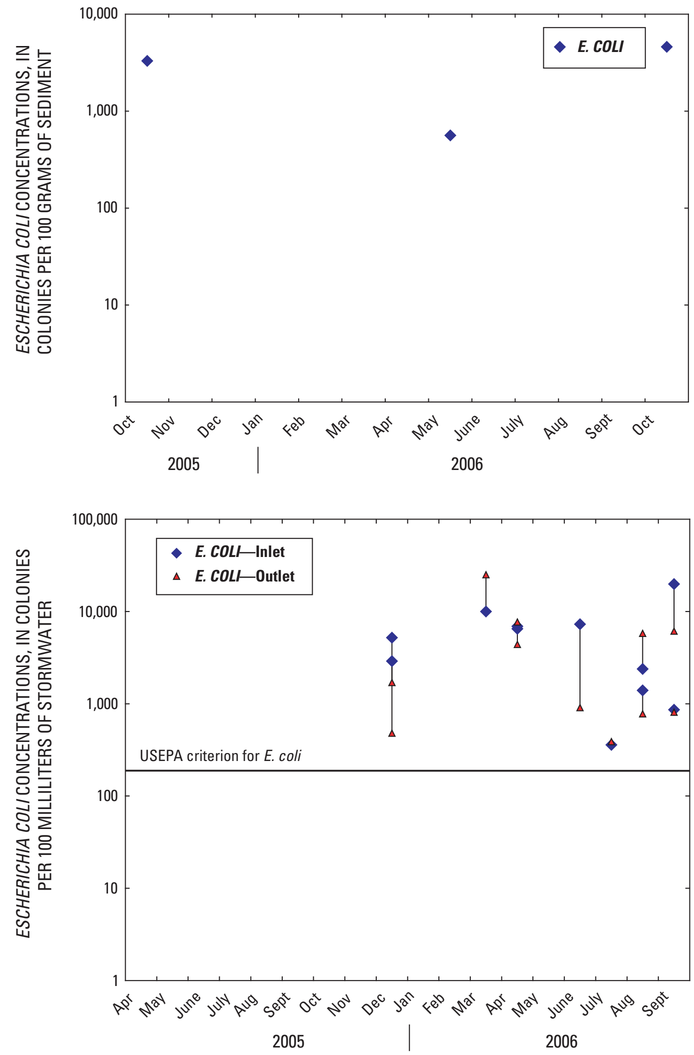

Figure 59. Time-series plots of *Escherichia coli* (*E. coli*) concentrations in sediment and stormwater for best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006. [USEPA, U.S. Environmental Protection Agency]

Metals

Concentration ranges of the targeted trace metals in the stormwater entering the inlet of BMP3 varied by 3 orders of magnitude (figs. 60–62), and are listed in order of increasing median concentrations: total cadmium (0.20 µg/L), total nickel (4.42 µg/L), total copper (15.3 µg/L), total lead (16.6 µg/L), and total zinc (82.0 µg/L; table 12). Concentration ranges of targeted trace metals in stormwater leaving the outlet of BMP3 also varied by 3 orders of magnitude, but were in the same order of increasing median concentration: total cadmium (0.15 µg/L), total nickel (3.87 µg/L), total copper (12.3 µg/L), total lead (12.2 µg/L), and total zinc (65.0 µg/L). Lead was predominantly in particulate form in inlet and outlet water samples (fig. 61). Cadmium, zinc, and copper were mainly in particulate forms in inlet and outlet water samples (figs. 60 and 62). In general, nickel was distributed fairly evenly between particulate and dissolved forms (fig. 61).

Total cadmium and nickel EMCs in the stormwater entering the inlet and leaving the outlet of BMP3 were less than the SCDHEC-established CMCs for freshwater aquatic life (table 8; figs. 60 and 61). The reverse was true for total copper; all EMCs in the inlet and outlet waters of BMP3 were greater than the copper CMC of 3.8 µg/L (table 8; fig. 60). For total lead and total zinc EMCs in the stormwater, about 35 and 40 percent, respectively, of the EMCs entering the inlet of BMP3 were greater than the SCDHEC-established CMCs for freshwater aquatic life of 14 and 75 µg/L, respectively (table 8; figs. 60 and 62). In the stormwater leaving the outlet of BMP3, almost 65 and 60 percent of the samples had concentrations that were less than the same criterion for total lead and zinc, respectively (figs. 61 and 62).

Significant changes in trace-metal concentrations from inlet to outlet waters were identified (table 12; fig. 63). Total and particulate cadmium concentrations were significantly reduced in the outlet water (p-values = 0.0042 and 0.0017, respectively; table 12). Total and particulate copper concentrations (p-values = 0.0171 and 0.0298, respectively), total and particulate lead concentrations (p-values = 0.0081 and 0.0024, respectively), total and particulate nickel concentrations (p-values = 0.0386 and 0.0171, respectively), and total and dissolved zinc concentrations (p-values = 0.0140 and 0.0068, respectively) for BMP3 were statistically different between inlet and outlet waters for this study. These findings indicated that BMP3 was efficient at reducing trace-metal concentrations in stormwater.

The trace-metal loads had a similar pattern to that of the trace-metal concentrations, and are listed in order of increasing median load: total cadmium (0.05 g/event), total nickel (1.16 g/event), total lead (3.82 g/event), total copper (3.63 g/event), and total zinc (21.3 g/event) for inlet water (table 13; figs. 64–66). Outlet median loads were: total cadmium (0.03 g/event), total nickel (1.08 g/event), total lead (3.37 g/event), total copper (3.72 g/event), and total zinc (16.2 g/event). Only minor reductions in trace-metal loads were observed between water entering the inlet and leaving the outlet of BMP3. Significant changes in trace-metal loads from inlet to outlet waters were identified (table 13). Total and particulate cadmium loads were significantly reduced in the outlet water (p-values = 0.0461 and 0.0212, respectively). Particulate lead loads (p-value = 0.0105) and particulate zinc loads (p-value = 0.0337) for BMP3 were statistically different between inlet and outlet waters for this study.

The average difference between the trace-metal loads in the inlet and outlet waters of BMP3 for the storm events sampled for this study were, in order from least to greatest loads: total cadmium (0.01+/- 0.01 g/event), total nickel (0.07 +/- 0.09 g/event), total copper (0.08 +/- 0.26 g/event), total lead (0.11 +/- 0.36 g/event), and total zinc (0.94 +/- 1.79 g/event) (fig. 63; Appendix D-1). The least-to-greatest listing of the average percentage of trace-metal loads removed by BMP3 is in a different order: total nickel (7.92 +/- 6.35 percent), total copper (11.4 +/- 5.31 percent), total zinc (15.9 +/- 6.55 percent), total cadmium (20.9 +/- 5.89 percent), and total lead (12.7 +/- 5.83 percent). With the exception of nickel, particulate forms of the trace metals appeared to have greater reductions by BMP3 than did the dissolved forms; particulate cadmium, lead, and zinc reductions were statistically significant. Additionally, dissolved forms of the trace metals appeared to have negative differences in the amount of loads removed, suggesting an overall increase, rather than reduction, in these constituents. For the sampled storm events at BMP3, stormwater entering the BMP had the following cumulative loads: 0.71 g of total cadmium, of which 0.09 g were removed; 16.4 g of total nickel, of which 0.87 g were removed; 52.2 g of total copper, of which 1.01 g were removed; 57.2 g of total lead, of which 1.31 g were removed; and 288 g of total zinc, of which 11.3 g were removed (Appendix D-2).

As mentioned previously, trace-metal concentrations were measured in the retained coarser grained sediment and were zinc, lead, copper, nickel, and cadmium, in order from greatest to least concentration, in micrograms per gram (fig. 50). The sequence for the amount of trace-metal loads removed between the inlet and outlet waters of BMP3 was the same as for BMP1 and BMP2, in order from greatest to least: zinc, lead, copper, nickel, and cadmium.

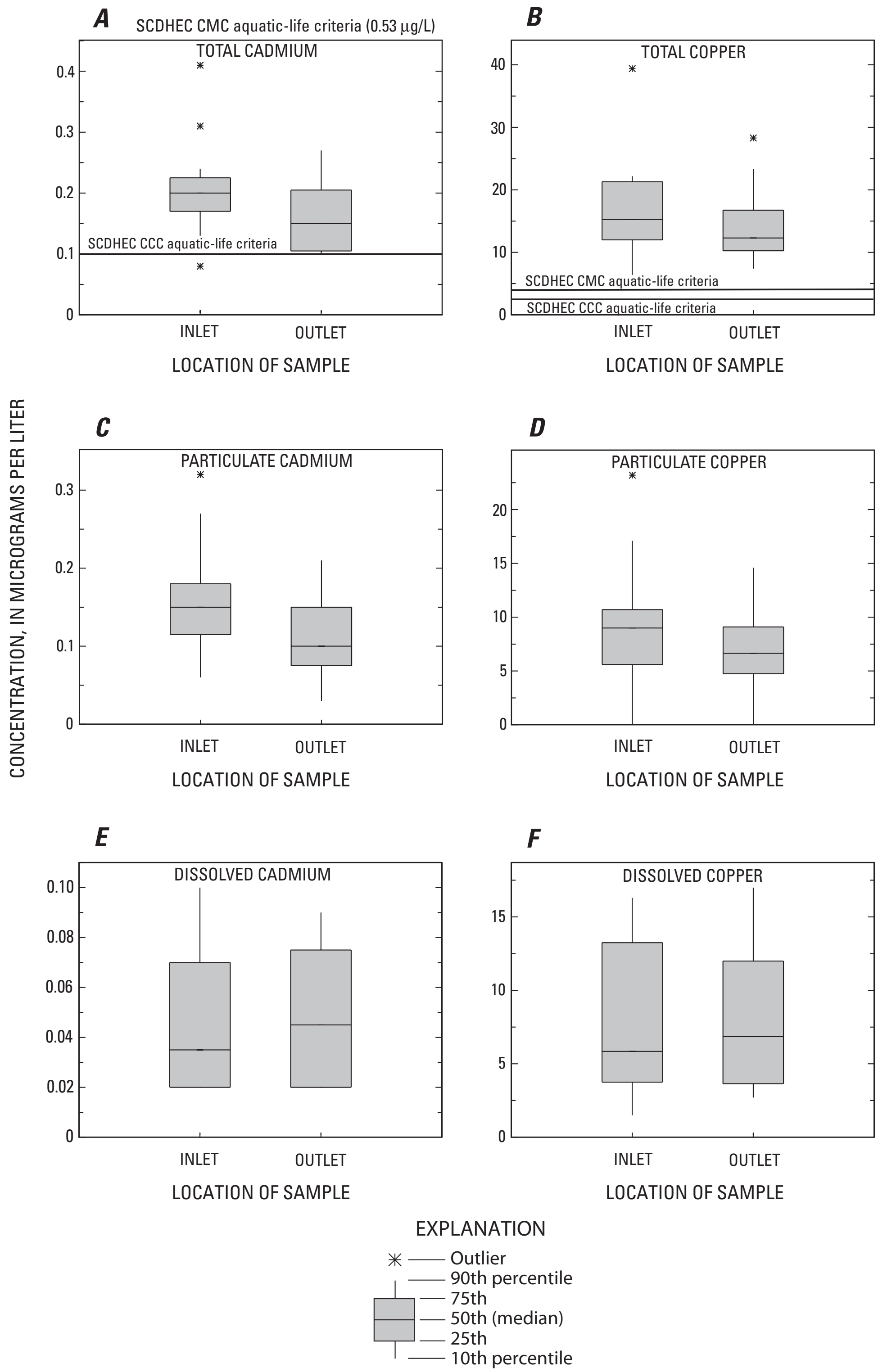

Figure 60. Event-mean concentrations of total *(A)* cadmium and *(B)* copper; particulate *(C)* cadmium and *(D)* copper; and dissolved *(E)* cadmium and *(F)* copper at best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration]

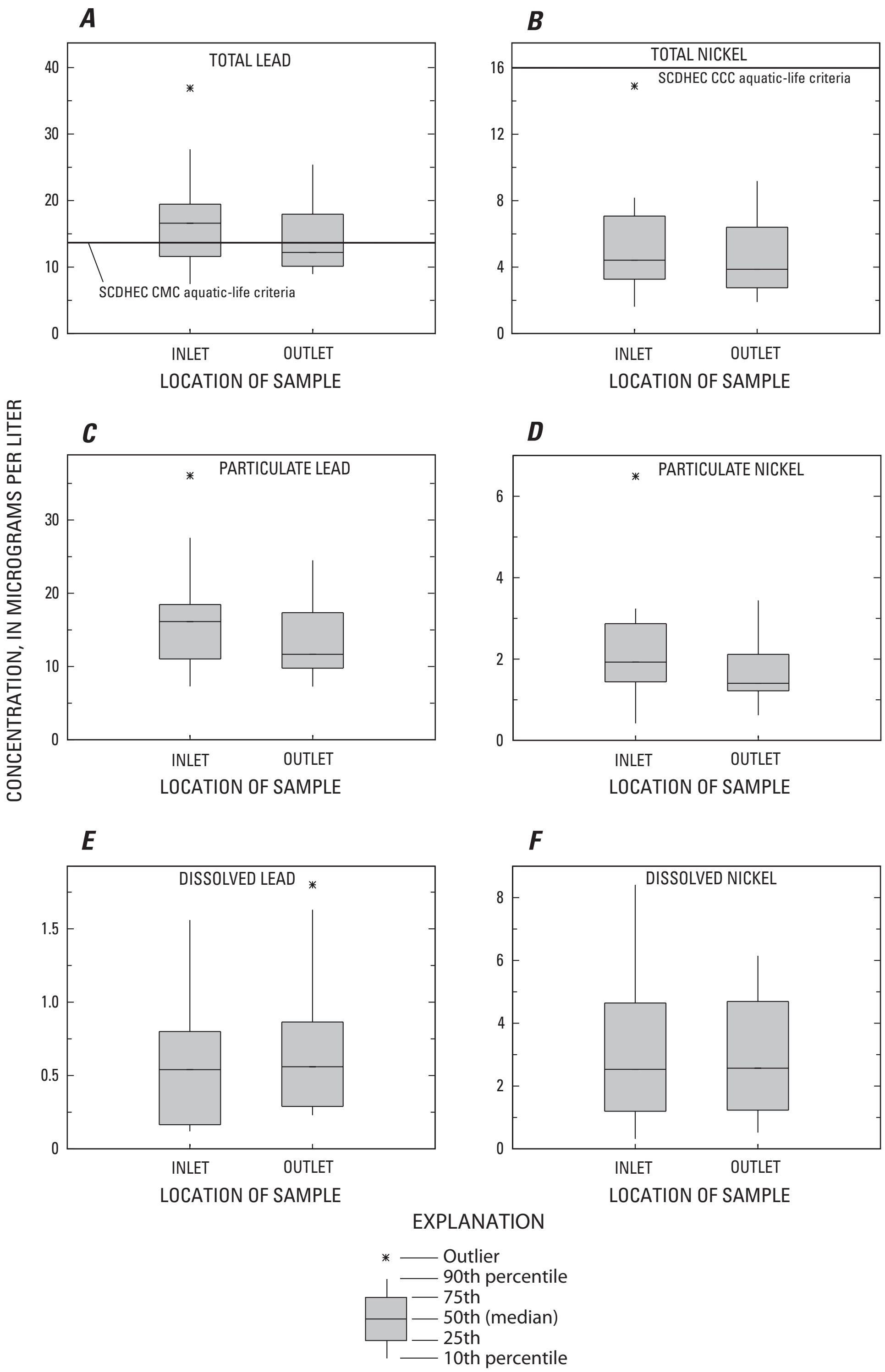

Figure 61. Event-mean concentrations of total *(A)* lead and *(B)* nickel; particulate *(C)* lead and *(D)* nickel; and dissolved *(E)* lead and *(F)* nickel at best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration]

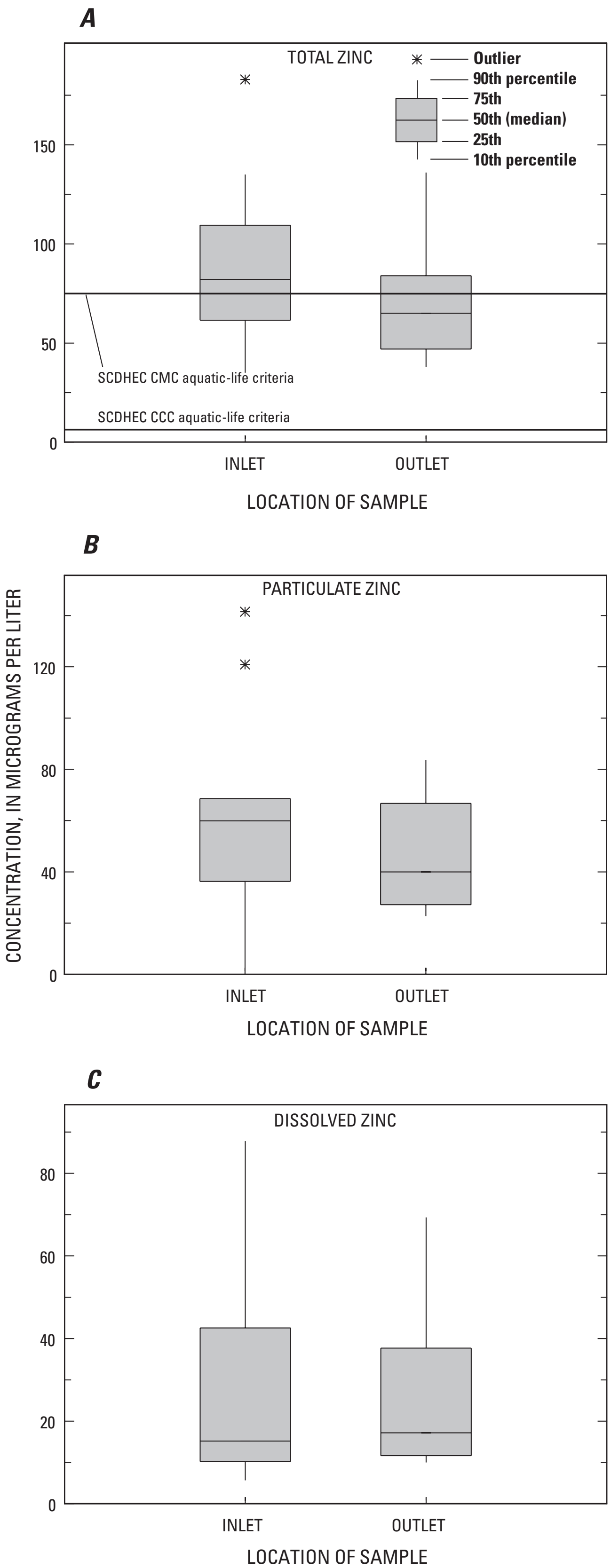

Figure 62. Event-mean concentrations of *(A)* total zinc, *(B)* particulate zinc, and *(C)* dissolved zinc at best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration]

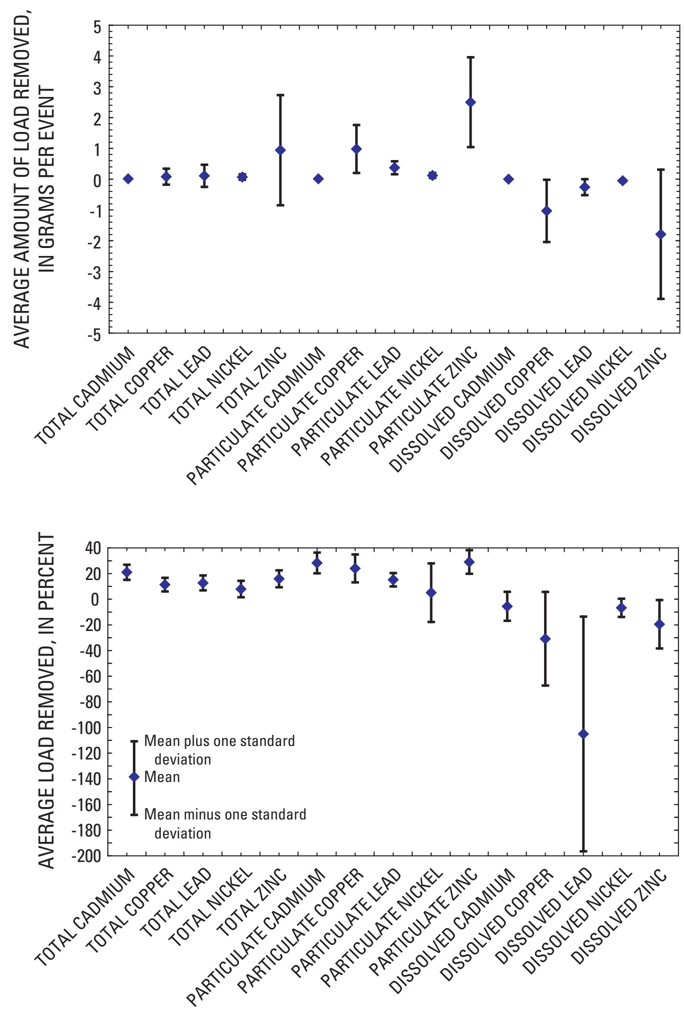

Figure 63. Average amounts and percentages of event-mean loads of selected trace metals removed by best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

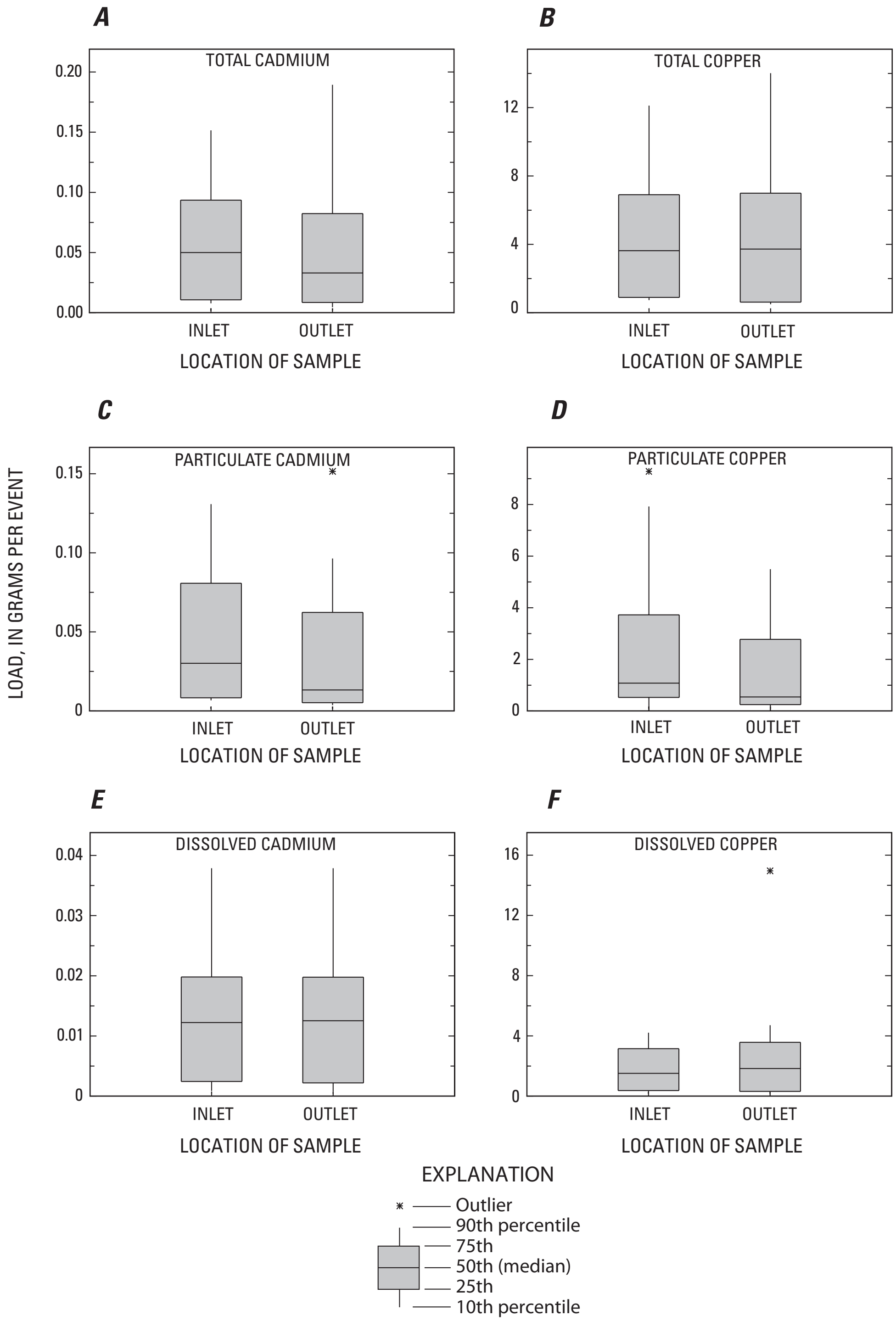

Figure 64. Event-mean loads of total *(A)* cadmium and *(B)* copper; particulate *(C)* cadmium and *(D)* copper; and dissolved *(E)* cadmium and *(F)* copper at best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

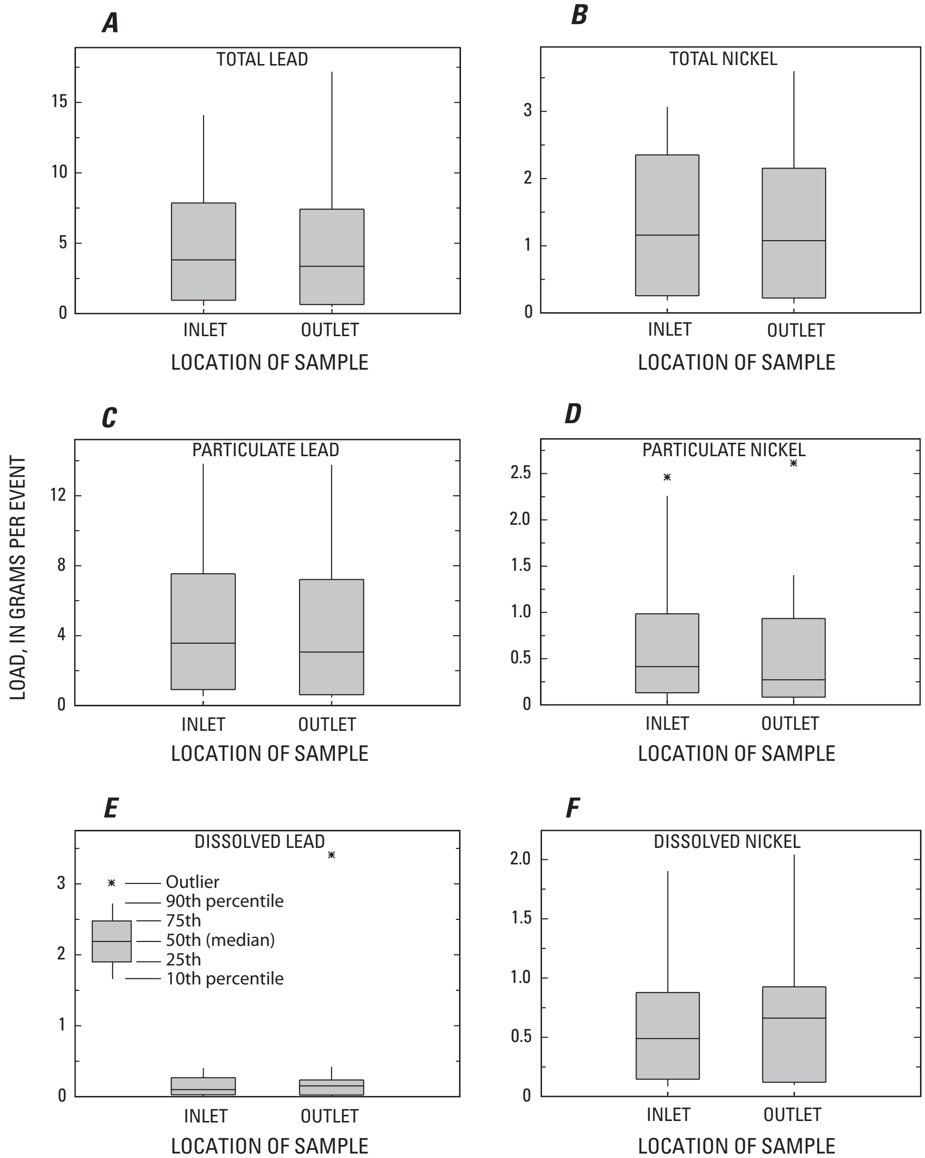

Figure 65. Event-mean loads of total *(A)* lead and *(B)* nickel; particulate *(C)* lead and *(D)* nickel; and dissolved *(E)* lead and *(F)* nickel at best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

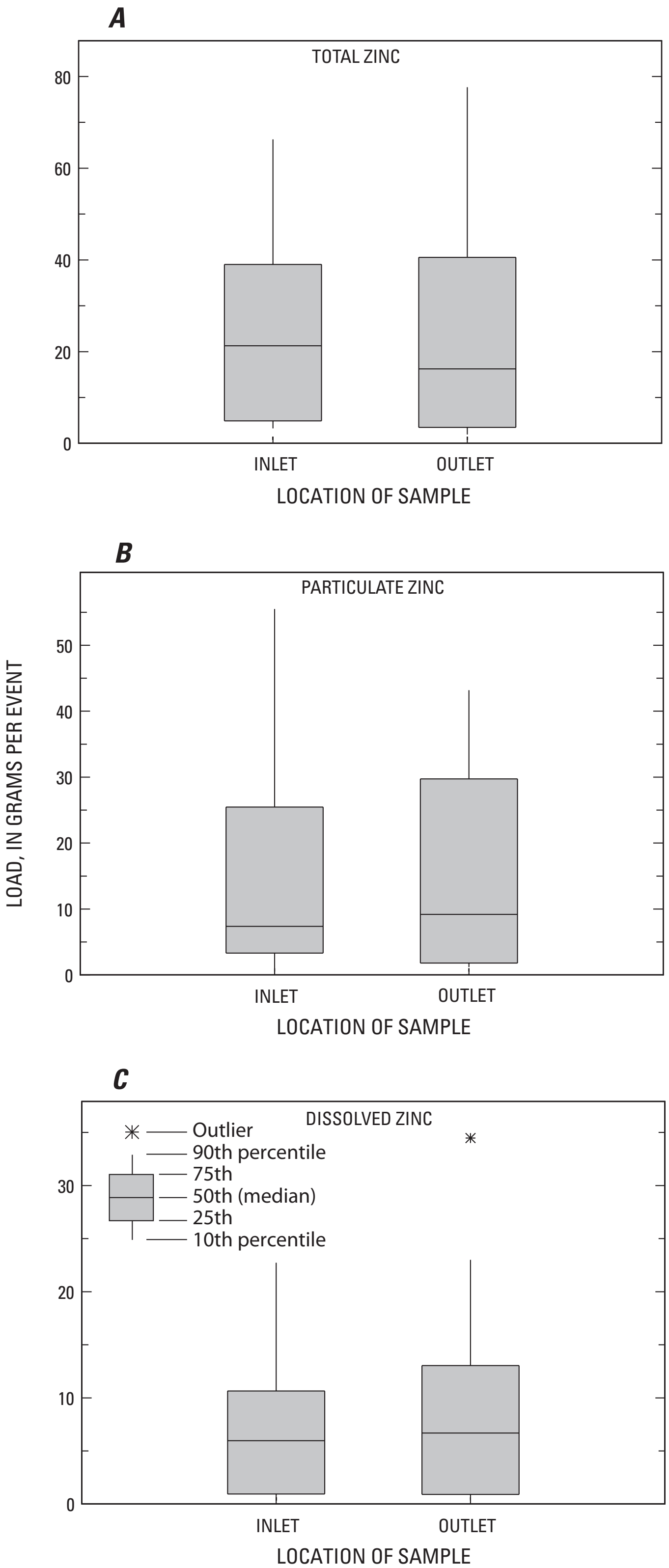

Figure 66. Event-mean loads of *(A)* total zinc, *(B)* particulate zinc, and *(C)* dissolved zinc at best management practice 3 at S.C. Highway 802 near Beaufort, S.C., 2005–2006.

BMP4 Performance Assessment

BMP4 is located at the I-95 southbound rest area in Colleton County, south of Walterboro, S.C. (fig. 3). The drainage area for this BMP is 2.77 acres, and this BMP includes a curb and gutter system for roadway runoff and some overland flow (table 1). BMP4 consists of a trash basket, baffles, an oil and hydrocarbon reservoir, a sediment chamber, and a fiber mesh filter. Incoming flow passes through a fine mesh in the trash basket, which captures floating debris and vegetative matter. The water proceeds around baffles slowing and spreading the flow and ensuring that the oil gathers at the top of the water. As the water level rises, the oil flows over the edge of the oil and hydrocarbon reservoir, and the water flows under the reservoir into the sediment chamber. As the water rises out of the unit in the back chamber it passes through a ¾-in. coconut fiber filter, designed to remove small floating or suspended materials (CrystalStream, 2008).

The event-mean concentrations and loads of the following water-quality constituents are summarized for BMP4: (1) SSC and TSS; (2) oil and grease concentrations; (3) bacteria; (4) nutrients, such as TKN and TP; and (5) metals. As described earlier, the design of BMP4 is conducive for the removal of suspended sediments and oil and grease; however, removal of the total and particulate forms of other water-quality constituents also were assessed.

Suspended Sediment, Total Suspended Solids, and Sediment

Analytical methods to determine SSC and TSS were used to quantify concentrations of suspended organic and inorganic particles in surface waters. A monotonic correlation between TSS and SSC in the inlet and outlet waters at BMP4 was statistically significant (inlet: rho = 0.93007, p-value < 0.0001; outlet: rho = 0.99650, p-value < 0.0001) (fig. 67), but not one-to-one as would be expected for measurements of the same substance (suspended particles). Comparison of the SSC and TSS concentrations from the BMP4 sampling events demonstrated a positive bias, especially for SSC concentrations greater than 80 mg/L The greatest difference was observed at the maximum inlet SSC concentration of 437 mg/L which had a corresponding TSS concentration of only 280 mg/L. Further evaluation of grain size indicated that the bias between SSC and TSS concentrations tended to increase as the percentage of the sediment finer than 63 microns (finer than sand) decreased to less than 30 percent.

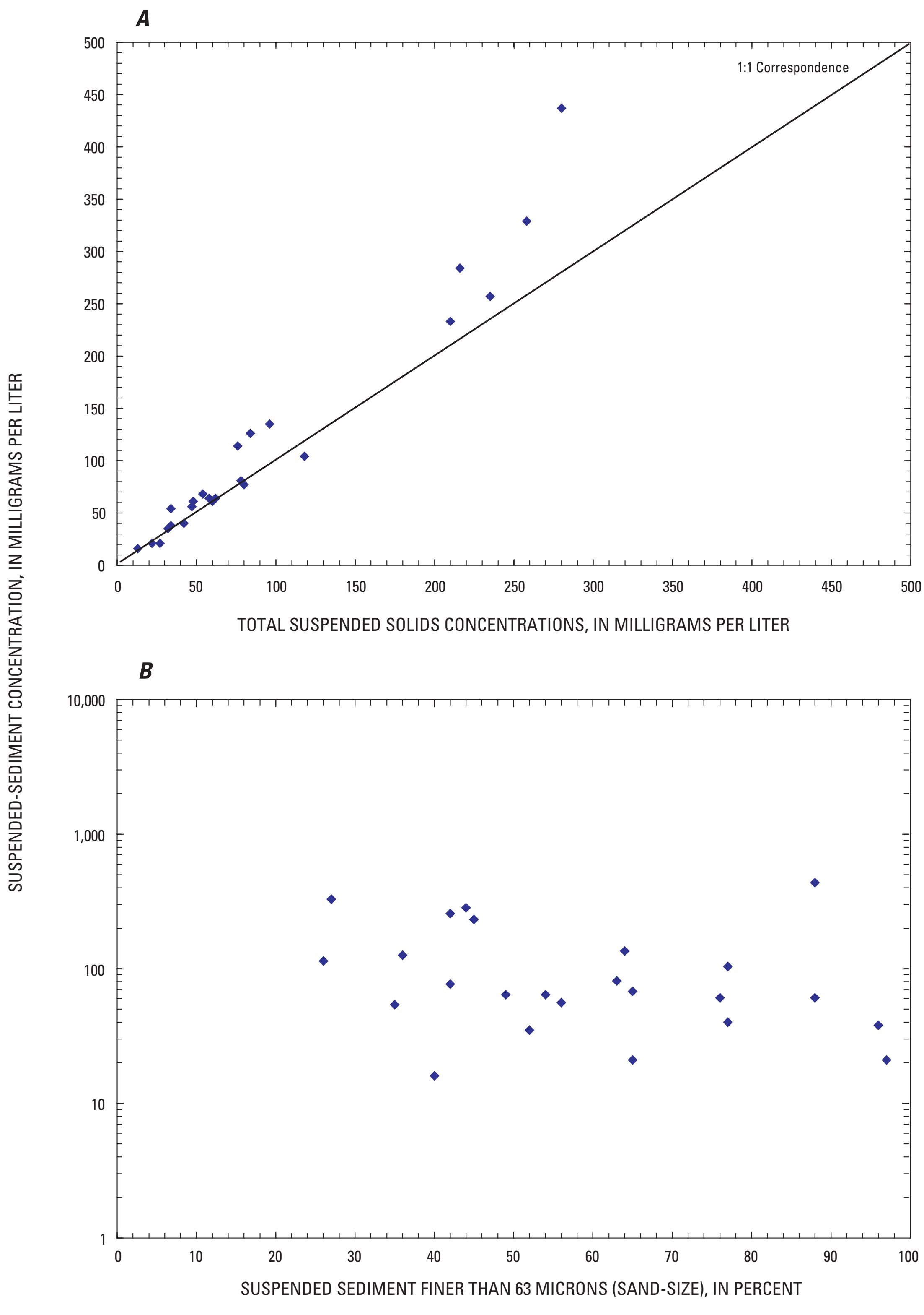

Figure 67. Relation between *(A)* suspended-sediment and total suspended solids concentrations and between *(B)* suspended-sediment concentrations and percentage of sediment finer than sand measured at best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

This bias is important to note because different statistical findings were identified between TSS and SSC when comparisons were made among other constituents and between inlet and outlet waters. Because the SSC analytical method is reported to produce more reliable results (Gray and others, 2000), statistical findings based on SSC results are considered more indicative of the BMP4 performance than TSS results. However, because the TSS method is often the method adopted for regulatory monitoring, statistical findings based on TSS results also are discussed.

Suspended-sediment EMCs in the inlet water of BMP4 ranged from 54.0 to 437 mg/L, with a median value of 120 mg/L (fig. 68, table 15). The EMCs for SSC in the outlet water were lower and less variable than those in the inlet water, with a median of 48.0 mg/L. Suspended-sediment EMCs were reduced significantly by BMP4 in the outlet water as compared to the inlet water during the period of study (Z-score = 2.9833, p-value = 0.0014; table 15). This statistical finding indicated that BMP4 performed efficiently at reducing SSC in stormwater. Median EMCs of TSS of 90.0 and 44.5 mg/L for inlet and outlet waters, respectively, were about half of the median SSC concentrations for BMP4 (fig. 69). Lower median EMCs for TSS, when compared with median EMCs for SSC, could be explained by the underestimation

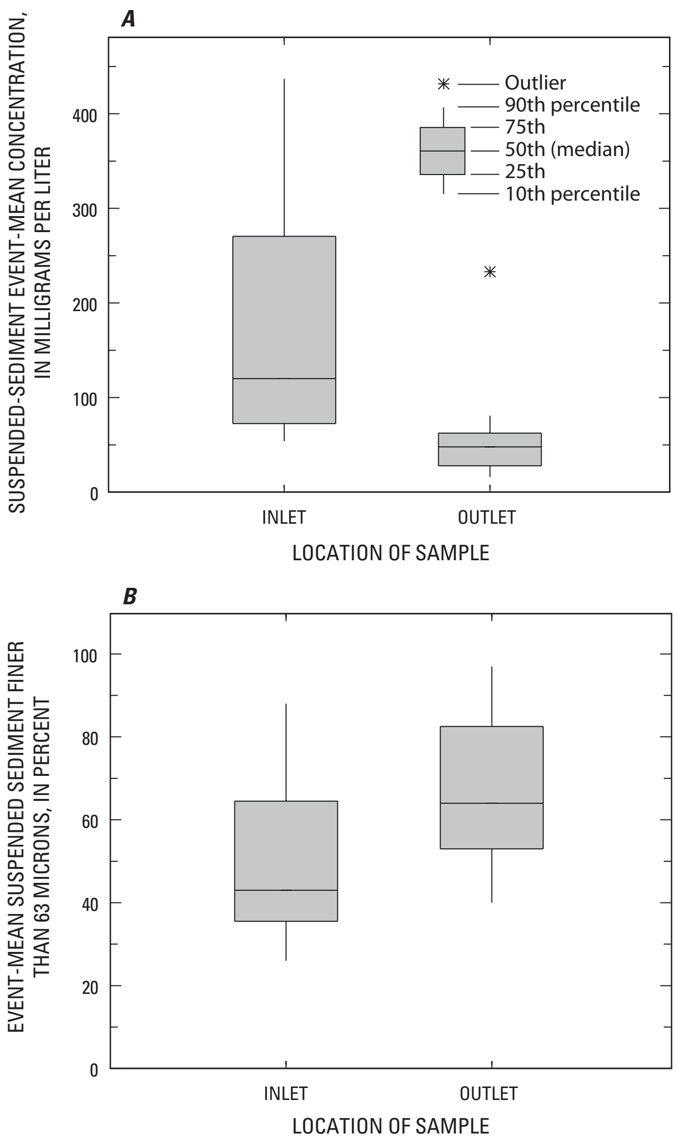

Figure 68. Event-mean *(A)* concentrations of suspended sediment, in milligrams per liter, and *(B)* percentages of suspended sediment finer than 63 microns, at best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

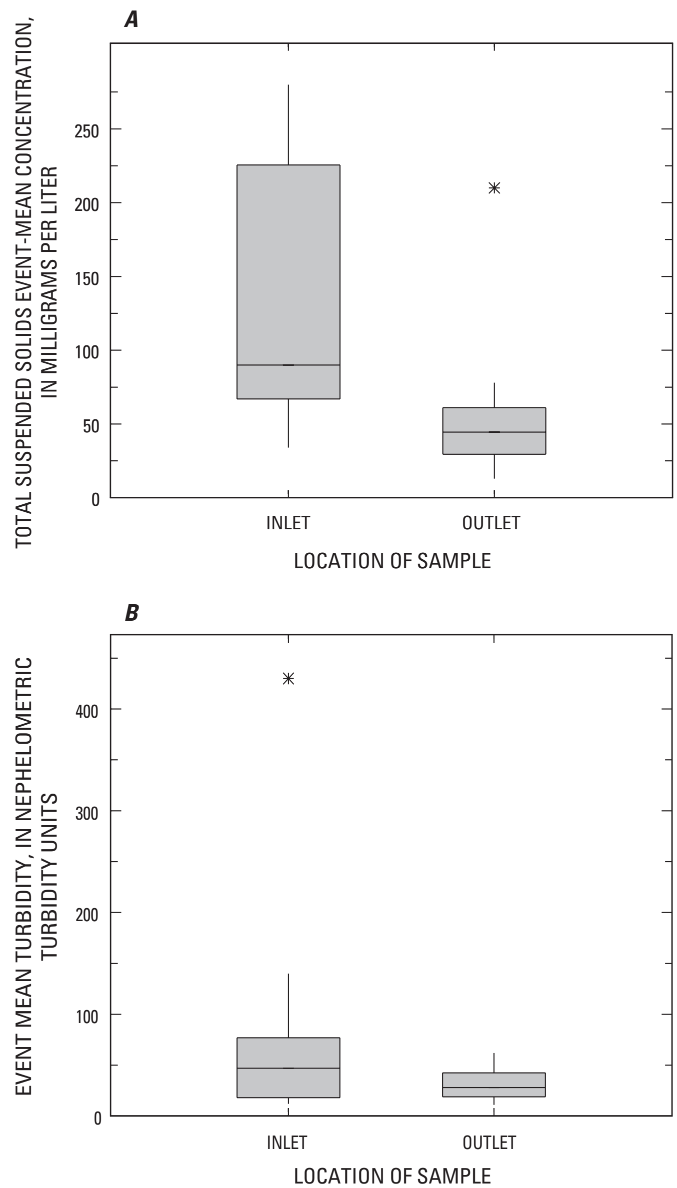

Figure 69. Event means of *(A)* total suspended solids concentrations and *(B)* turbidity for best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

Table 15. Summary statistics describing the comparison among event-mean concentrations in inlet and outlet waters of best management practice 4 (BMP4), Colleton County, South Carolina, 2005–2006.

[>, greater than; µg/L, micrograms per liter; mg/L, milligrams per liter; NTU, nephelometric turbidity units; col/100 mL, colonies per 100 milliliters]

Constituent	Units	Location	Median	Mean	Standard deviation	Comparison among event-mean concentrations in inlet and outlet waters of BMP4		Wilcoxon signed-rank test		
						Number	[1]Inlet > outlet	V-statistic	Z-score	Probability value
Dissolved cadmium	µg/L	Inlet	0.05	0.08	0.05	12	No		1.353	0.088
	µg/L	Outlet	0.05	0.06	0.04	12				
Total cadmium	µg/L	Inlet	0.51	0.57	0.23	12	Yes	76		0.001
	µg/L	Outlet	0.26	0.32	0.25	12				
Particulate cadmium	µg/L	Inlet	0.41	0.49	0.25	12	Yes	75		0.001
	µg/L	Outlet	0.17	0.26	0.25	12				
Dissolved copper	µg/L	Inlet	9.55	13.8	11.5	12	Yes	61		0.046
	µg/L	Outlet	7.55	8.97	4.76	12				
Total copper	µg/L	Inlet	34.1	40.4	20.7	12	Yes	76		0.001
	µg/L	Outlet	18.0	21.2	12.5	12				
Particulate copper	µg/L	Inlet	20.8	26.7	15.4	12	Yes	78		0.000
	µg/L	Outlet	9.70	12.2	9.57	12				
Dissolved lead	µg/L	Inlet	0.17	0.19	0.13	12	No		0.197	0.578
	µg/L	Outlet	0.17	0.39	0.80	12				
Total lead	µg/L	Inlet	11.6	14.4	8.26	12	Yes	78		0.000
	µg/L	Outlet	4.69	6.99	7.01	12				
Particulate lead	µg/L	Inlet	11.2	14.3	8.27	12	Yes	78		0.000
	µg/L	Outlet	4.52	6.59	6.27	12				
Dissolved nickel	µg/L	Inlet	2.10	3.69	3.23	12	Yes		2.355	0.009
	µg/L	Outlet	1.84	2.31	1.33	12				
Total nickel	µg/L	Inlet	6.47	6.27	3.37	12	Yes	77		0.001
	µg/L	Outlet	3.04	3.52	1.53	12				
Particulate nickel	µg/L	Inlet	1.84	2.58	1.71	12	Yes		2.943	0.002
	µg/L	Outlet	0.85	1.22	1.44	12				
Dissolved zinc	µg/L	Inlet	30.7	38.3	23.6	12	No		1.373	0.085
	µg/L	Outlet	28.0	32.7	14.9	12				
Total zinc	µg/L	Inlet	404	527	345	12	Yes	75		0.001
	µg/L	Outlet	176	263	315	12				
Particulate zinc	µg/L	Inlet	359	489	349	12	Yes	75		0.001
	µg/L	Outlet	137	231	310	12				
Total ammonia plus organic nitrogen	mg/L	Inlet	6.70	14.0	16.3	12	Yes		2.914	0.002
	mg/L	Outlet	5.00	7.38	7.45	12				
Total phosphorus	mg/L	Inlet	1.03	1.19	0.88	12	Yes		2.943	0.002
	mg/L	Outlet	0.65	0.73	0.53	12				
Turbidity	NTU	Inlet	47.0	80.1	116	12	Yes		2.119	0.017
	NTU	Outlet	28.0	30.9	15.5	12				
Total organic carbon	mg/L	Inlet	38.0	43.3	35.0	12	Yes	77		0.001
	mg/L	Outlet	23.3	23.1	11.9	12				
Total suspended solids as residue	mg/L	Inlet	90.0	132	88.5	12	Yes		2.747	0.003
	mg/L	Outlet	44.5	56.3	51.8	12				
Biochemical oxygen demand	mg/L	Inlet	78.1	90.7	85.0	12	Yes	61		0.005
	mg/L	Outlet	24.6	38.8	53.4	12				
Chemical oxygen demand	mg/L	Inlet	140	174	133	12	Yes		2.832	0.002
	mg/L	Outlet	95.0	90.8	53.5	12				
Enterococci	col/100 mL	Inlet	11,700	12,000	8,700	12	Yes		1.887	0.030
	col/100 mL	Outlet	2,820	8,510	10,400	12				
Escherichia coli	col/100 mL	Inlet	1,500	9,940	12,000	12	No		1.430	0.076
	col/100 mL	Outlet	700	4,140	7,740	12				
Suspended sediment finer than sand	percent	Inlet	43.0	49.6	19.7	12	[2]Yes		–3.023	0.001
	percent	Outlet	64.0	67.4	19.3	12				
Suspended sediment	mg/L	Inlet	120	171	125	12	Yes		2.983	0.001
	mg/L	Outlet	48.0	60.6	57.9	12				
Oil and grease	mg/L	Inlet	16.0	23.0	16.6	12	Yes		2.786	0.003
	mg/L	Outlet	5.00	6.79	6.04	12				

[1] Probability that the hypothesis that the input and output concentrations are the same versus the alternative one-sided hypothesis that the concentration is greater in the input than the output.

[2] One-sided test such that the alternative hypothesis is that the percentage of suspended sediment finer than 63 micron is greater in the output than in the input.

of suspended sediment discussed earlier (fig. 67). The less variable EMCs for TSS were significantly different between inlet and outlet waters (Z-score = 2.7467, p-value = 0.0030; table 15), which relates to the findings based on SSC.

Turbidity has been used as a surrogate measure of the suspended sediment or particulates in water. For BMP4, turbidity values were correlated to TSS (rho = 0.76923, p-value = 0.0034) and SSC (rho = 0.70629, p-value = 0.0102) for the period of study. For BMP4, the median event-mean turbidities in the inlet and outlet waters were very different (47.0 and 28.0 NTU, respectively, table 15). As observed with TSS, a significant difference in turbidity was identified between inlet and outlet waters, indicating that BMP4 was efficient at reducing EMCs for TSS and turbidity in stormwater.

The character, as well as concentration, of the SSC also changed between the inlet and outlet waters in BMP4 (fig. 68). The percentage of the suspended sediment finer than sand (grain sizes less than 63 microns, such as silt and clay) was highly variable in the inlet water of BMP4, with a median of about 43 percent. This conversely indicates that about 57 percent of the sediment was sand-sized particles (fig. 68; table 15). The predominant size fraction of suspended sediment in outlet water was finer than sand (median of 64 percent) and significantly finer than the inlet waters (table 15; Z-score = –3.0225, p-value = 0.0013). The change in the character of the SSC indicated that BMP4 was more efficient at capturing the sand-sized fractions of the suspended sediment than the silt- and clay-sized fractions. This preferential retention of coarser grained sediment also could influence the lack of retention of certain nutrients (such as phosphorus), bacteria, and trace metals (such as lead and zinc) because of their tendency to adsorb preferentially to the smaller grained sediment.

Examination of the grain-sized fractions of the accumulated sediment within BMP4 in May 2006 further verified this preferential retention of the larger grain-sized fractions. Only about 3 percent of the sediment that accumulated in BMP4 was finer than 63 microns (clay and silt) (fig. 70), even though an average of 50 percent of the suspended sediment from the inlet waters was finer than 63 microns (fig. 68*B*). Additionally, trace-metal concentrations were measured in the retained coarser grained sediment and were zinc, copper, lead, nickel, and cadmium, in order from greatest to least concentration, in micrograms per gram (fig. 71*A*).

Event-mean loads for individual storm events were computed for inlet and outlet waters. Stormwater reaching the inlet of BMP4 had suspended-sediment loads that ranged from 0.21 to 84.2 kg/event (median of 6.64 kg/event) (fig. 72; table 16). Stormwater leaving the outlet of BMP4 had SSC loads ranging from 0.06 to 23.5 kg/event (median of 3.49 kg/event).

SSC loads were statistically different between inlet and outlet waters (Z-score = 2.9833, p-value = 0.0014; table 16). Computation of that reduction indicated that BMP4, on average for the sampled storm events, reduced SSC loads from stormwater by 10.6 +/- 6.31 kg/event, or an average of 55.4 +/- 8.98 percent (fig. 73; Appendix D-1). Cumulatively, BMP4 received 207 kilograms of suspended sediment during the sampled storm events from 2005 to 2006. Of that 207 kg, BMP4 was able to remove 127 kg (Appendix D-2).

In relation to other environmental and chemical factors, SSC was not correlated significantly with hydrologic variables, such as rainfall, rainfall intensity, or stormflow. However, particulate forms of the trace metals were correlated with SSC, suggesting particulate metals had similar transport as suspended sediment through the structural BMP.

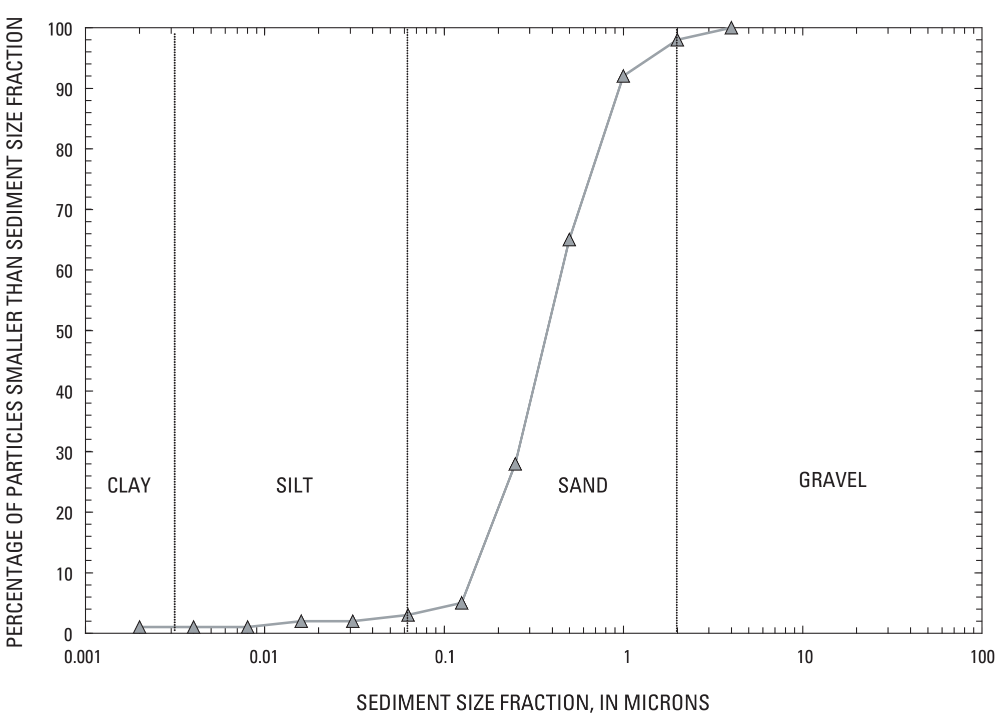

Figure 70. Particle-size distribution of sediment collected from within structural best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

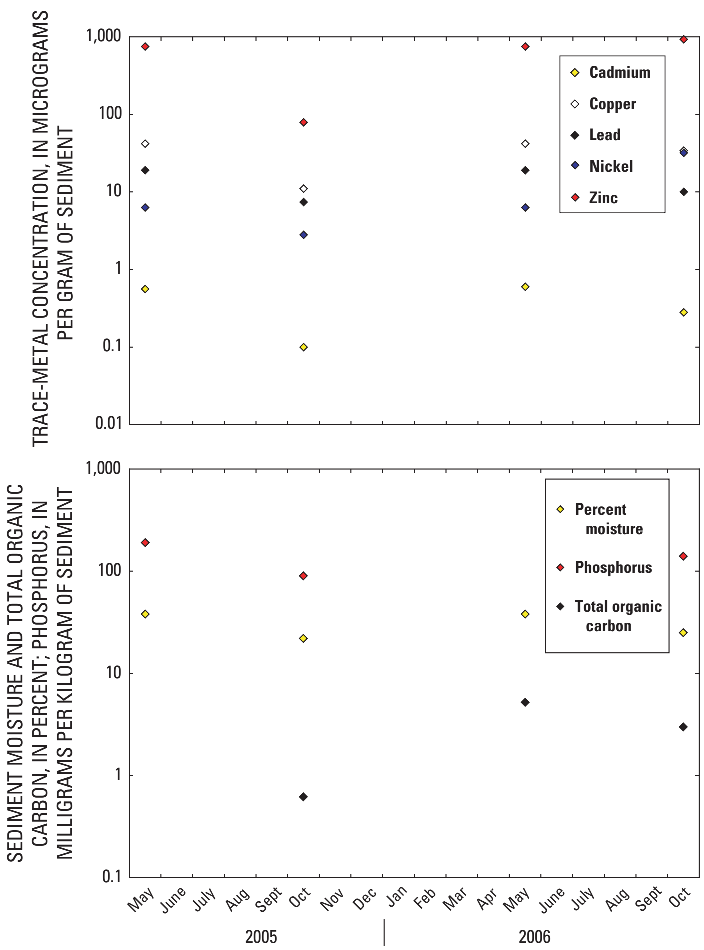

Figure 71. Sediment chemistry determined from samples collected from within best management practice 4 at the south side of I-95 near Walterboro, S.C., May 2005, October 2005, May 2006, and October 2006.

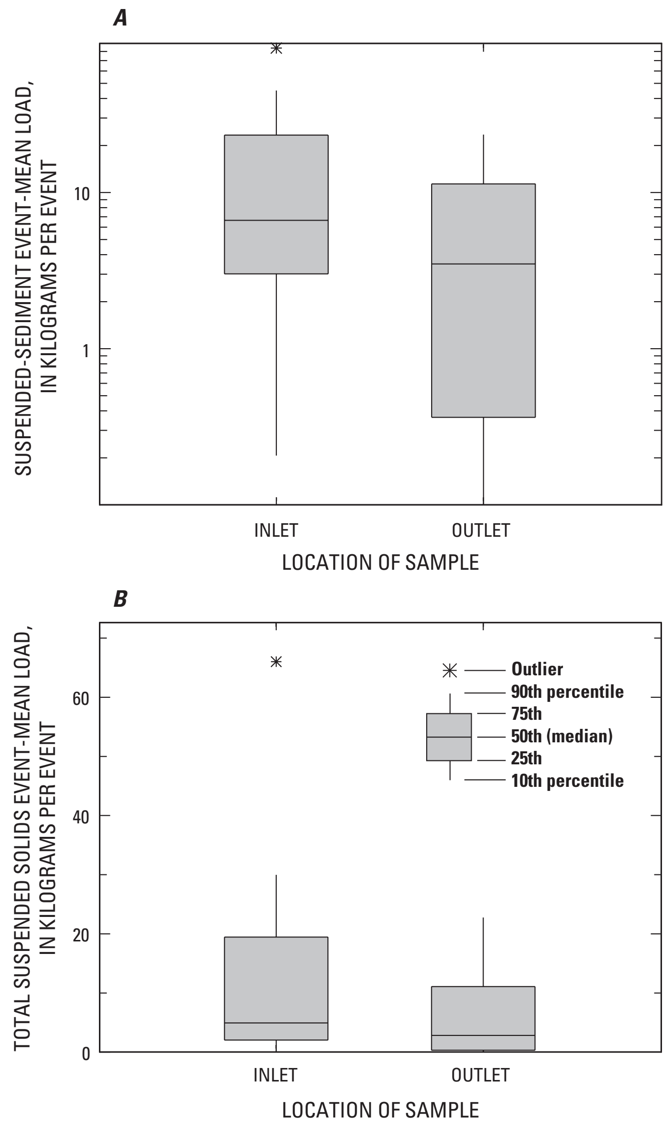

Figure 72. Event-mean loads of *(A)* suspended sediment and *(B)* total suspended solids, in kilograms per event, at best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

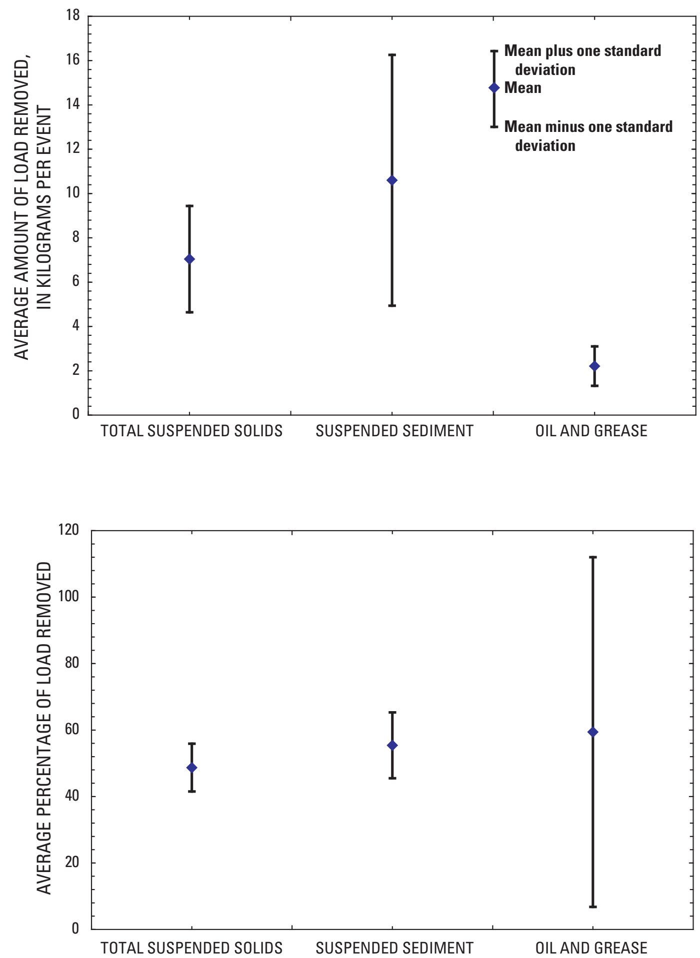

Figure 73. Average loads of total suspended solids, suspended sediment, and oil and grease removed by best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

Table 16. Summary statistics describing the comparison among event-mean loads in inlet and outlet waters of best management practice 4 (BMP4), Colleton County, South Carolina, 2005–2006.

[>, greater than; g/event, grams per event; kg/event, kilograms per event]

Constituent	Units	Location	Median	Mean	Standard deviation	Comparison among event-mean loads in inlet and outlet waters of BMP4		Wilcoxon signed-rank test		
						Number	[1]Inlet > outlet	V-statistic	Z-score	Probability value
Dissolved cadmium	g/event	Inlet	0.01	0.01	0.01	12	No		1.312	0.095
	g/event	Outlet	0.01	0.01	0.01	12				
Total cadmium	g/event	Inlet	0.03	0.06	0.07	12	Yes	75		0.001
	g/event	Outlet	0.02	0.03	0.04	12				
Particulate cadmium	g/event	Inlet	0.02	0.05	0.06	12	Yes	70		0.006
	g/event	Outlet	0.01	0.03	0.04	12				
Dissolved copper	g/event	Inlet	0.48	1.16	1.25	12	No	54		0.133
	g/event	Outlet	0.84	0.89	0.83	12				
Total copper	g/event	Inlet	2.26	3.90	4.58	12	No		neg. infinity	1.000
	g/event	Outlet	1.59	2.23	2.25	12				
Particulate copper	g/event	Inlet	1.02	2.74	3.75	12	Yes	78		0.000
	g/event	Outlet	0.71	1.33	1.56	12				
Dissolved lead	g/event	Inlet	0.01	0.03	0.06	12	No	44		0.367
	g/event	Outlet	0.01	0.05	0.07	12				
Total lead	g/event	Inlet	0.53	1.65	2.31	12	Yes	78		0.000
	g/event	Outlet	0.29	0.78	0.99	12				
Particulate lead	g/event	Inlet	0.52	1.61	2.27	12	Yes	78		0.000
	g/event	Outlet	0.28	0.74	0.93	12				
Dissolved nickel	g/event	Inlet	0.13	0.27	0.25	12	Yes		2.120	0.017
	g/event	Outlet	0.12	0.2	0.19	12				
Total nickel	g/event	Inlet	0.38	0.55	0.55	12	Yes	73		0.002
	g/event	Outlet	0.25	0.35	0.35	12				
Particulate nickel	g/event	Inlet	0.07	0.28	0.39	12	Yes	74		0.002
	g/event	Outlet	0.04	0.14	0.21	12				
Dissolved zinc	g/event	Inlet	2.10	4.13	4.39	12	Yes	65		0.021
	g/event	Outlet	2.75	3.37	3.26	12				
Total zinc	g/event	Inlet	21.8	62.7	89.1	12	Yes	72		0.003
	g/event	Outlet	11.9	29.5	38.1	12				
Particulate zinc	g/event	Inlet	17.6	58.6	85.8	12	Yes	73		0.002
	g/event	Outlet	8.89	26.1	35.9	12				
Total ammonia plus organic nitrogen	kg/event	Inlet	0.48	0.99	1.09	12	Yes		2.914	0.002
	kg/event	Outlet	0.39	0.66	0.68	12				
Total phosphorus	kg/event	Inlet	0.06	0.11	0.11	12	Yes	74		0.002
	kg/event	Outlet	0.06	0.08	0.08	12				
Total organic carbon	kg/event	Inlet	2.33	3.44	3.19	12	Yes	75		0.001
	kg/event	Outlet	1.88	2.31	2.25	12				
Total suspended solids as residue	kg/event	Inlet	4.93	13.3	19.1	12	Yes	68		0.011
	kg/event	Outlet	2.83	6.31	7.60	12				
Biochemical oxygen demand	kg/event	Inlet	2.63	9.13	11.1	12	Yes	61		0.005
	kg/event	Outlet	1.34	4.51	6.43	12				
Chemical oxygen demand	kg/event	Inlet	10.1	15.1	15.5	12	Yes		2.355	0.009
	kg/event	Outlet	4.58	9.08	10.7	12				
Suspended sediment	kg/event	Inlet	6.64	17.3	24.9	12	Yes		2.983	0.001
	kg/event	Outlet	3.49	6.71	7.98	12				
Oil and grease	kg/event	Inlet	0.89	2.84	5.38	12	Yes	70		0.006
	kg/event	Outlet	0.15	0.64	1.29	12				

[1] Probability that the hypothesis that the input and output concentrations are the same versus the alternative one-sided hypothesis that the concentration is greater in the input than the output.

Oil and Grease

Oil and grease concentrations in the stormwater leaving BMP4 were frequently less than the LRL of 7 mg/L and are reported as estimated or as < 7 mg/L (Appendix B). A greater uncertainty in the results of the statistical analysis of oil and grease concentrations existed because of the semi-quantitative nature of the estimated values that were retained as actual values for this study. Additionally, censored values were reported as 1.5 mg/L for the statistical analysis to represent half the LT-MDL of 3 mg/L.

For the period of study, stormwater in the inlet of BMP4 had a median oil and grease concentration of 16.0 mg/L and range of 9 to 59 mg/L (fig. 74; table 15). Oil and grease concentrations in the stormwater in the outlet of BMP4 were reduced significantly (Z-score = 2.7859, p-value = 0.0027) from the inlet; more than 50 percent of the oil and grease concentrations were below the LRL of 7 mg/L. Consequently, outlet water had a median oil and grease concentration of only 5.00 mg/L. These results indicated that BMP4 was efficient at reducing oil and grease concentrations in the stormwater entering the BMP from above quantifiable levels to below the LRL.

Grab samples also were collected periodically for analysis for PAHs. The PAH concentrations represented a group of organic compounds derived from the combustion of fuels and leaching of asphalt. The oil and grease concentrations include the PAHs as just one component of all compounds derived from oil and grease. The concentrations of all uncensored individual PAH concentrations were summed to obtain the total PAH concentrations for the inlet and outlet waters at BMP4 (table 17). The total PAH concentrations in stormwater entering the inlet and leaving the outlet of BMP4 ranged from 0.00 to 12.2 µg/L and from 0.00 to 3.29 µg/L, respectively.

Oil and grease loads in the stormwater entering the inlet of BMP4 had a median value of 0.89 kg/event and a range of 0.02 to 19.1 kg/event for the study period (fig. 74; table 16). The stormwater leaving the outlet of BMP4 had oil and grease loads that were more than half that of the inlet water (median of 0.15 kg/event; range of 0.02 to 4.64 kg/event). As was determined for SSC and oil and grease concentrations, BMP4 was also effective at significantly reducing the oil and grease loads that entered the BMP (V-statistic = 70, p-value = 0.0061). In fact, BMP4 reduced the oil and grease loads in stormwater by an average of 2.21 +/- 1.54 kg/event, or 59.4 +/- 11.3 percent (fig. 73; Appendix D-1). These results indicated BMP4 was efficient at reducing oil and grease loads in the stormwater entering the BMP.

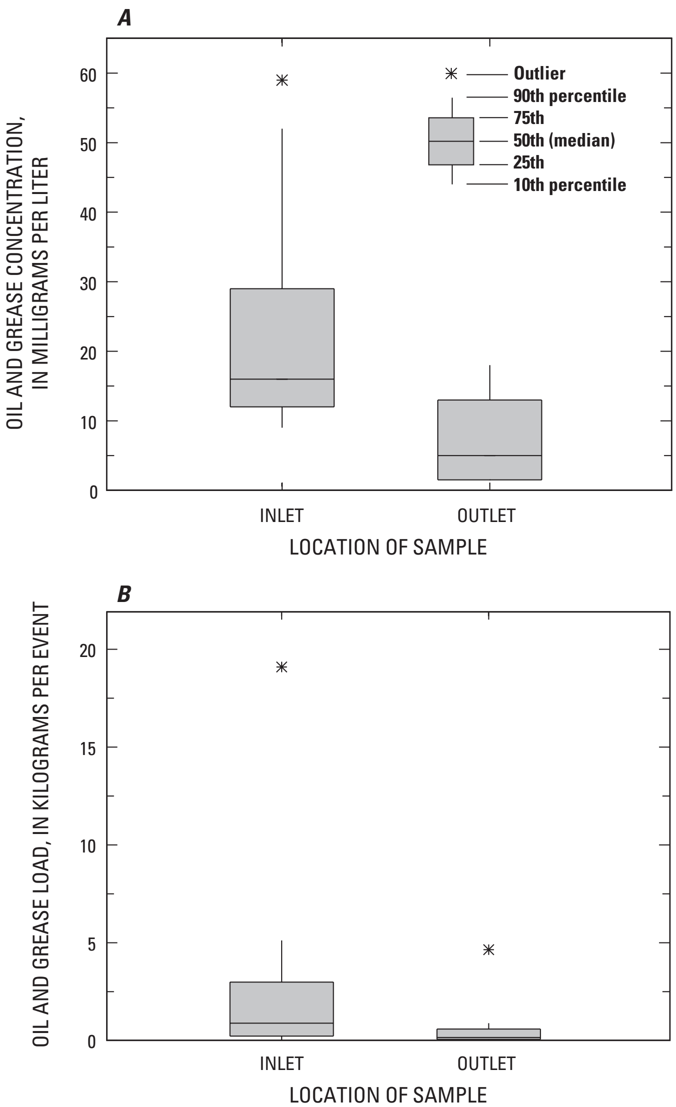

Figure 74. Oil and grease *(A)* concentrations in grab samples and *(B)* loads at best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

Table 17. Comparison of oil and grease concentrations and total polycyclic aromatic hydrocarbon (PAH) concentrations in the water from selected storms at BMP4, Colleton County, South Carolina, 2006.

[mg/L, milligrams per liter; µg/L, micrograms per liter]

Date of sample	Oil and grease (inlet [mg/L])	Oil and grease (outlet [mg/L])	Total PAH (inlet [µg/L])	Total PAH (outlet [µg/L])
April 26, 2006	52	1.5	3.68	3.27
August 31, 2006	16	1.5	0.00	0.00
September 19, 2006	28	18	12.2	3.29

Nutrients

Stormwater entering the inlet of BMP4 had nutrient EMCs similar to nutrient EMCs in the stormwater leaving the outlet of BMP4 (fig. 75). Inlet water had a median TKN concentration of 6.70 mg/L and a median TP concentration of 1.03 mg/L (table 15). Outlet water had median TKN and TP concentrations of 5.00 and 0.65 mg/L, respectively, which were slight reductions from the inlet water concentrations. Not only were the median values similar, ranges in the TKN and TP concentrations in the inlet and outlet waters had considerable overlap. The TKN and TP concentrations in the inlet and outlet waters at BMP4 were statistically significant (Z-scores = 2.9137 and 2.9429, respectively; p-values = 0.0018 and 0.0016, respectively). This finding indicated that BMP4 was efficient at reducing nutrient concentrations in stormwater.

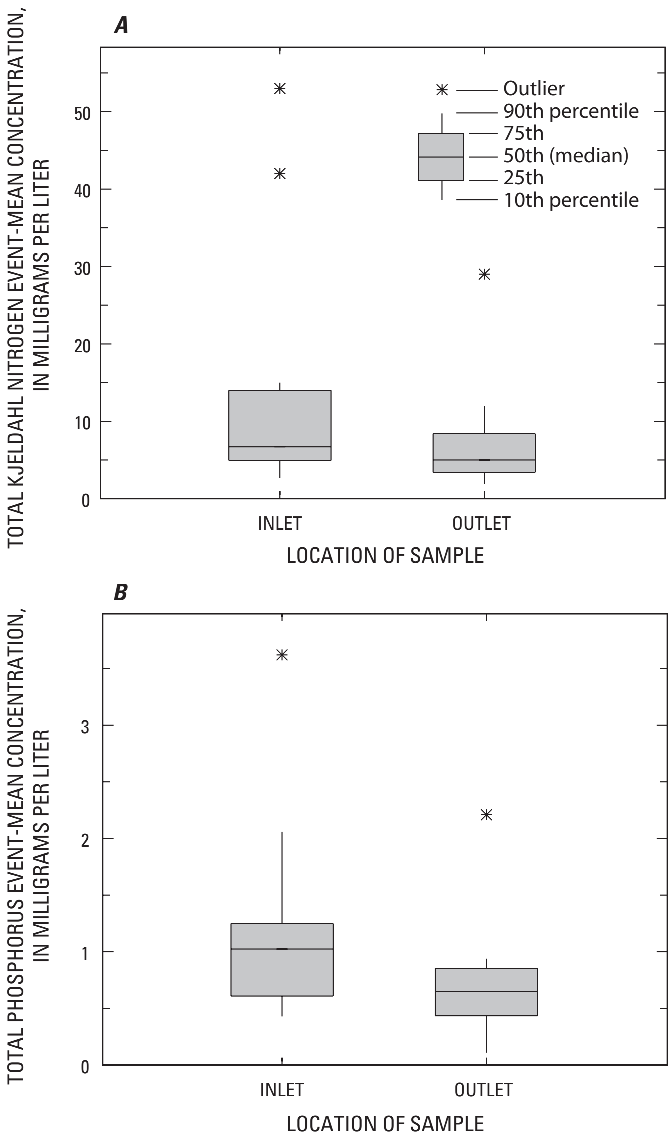

Figure 75. Event-mean concentrations of *(A)* total Kjeldahl nitrogen and *(B)* total phosphorus at best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

Median EMCs for TOC, BOD_5, and COD in the stormwater entering the inlet of BMP4 were 38.0, 78.1, and 140 mg/L, respectively (table 15). The much higher EMC for COD in comparison to the EMC for BOD_5 indicated that organic decay processes were playing less of a role in oxygen consumption than other biological and chemical processes. Median EMCs for TOC, BOD_5, and COD in the stormwater leaving the outlet of BMP4 were 23.3, 24.6, and 95.0 mg/L, respectively. Median EMCs for TOC, BOD_5, and COD did show a reduction between inlet and outlet waters of BMP4, and statistical changes in concentrations were determined (for TOC, V-statistic = 77 and p-value = 0.0005; for BOD_5, V-statistic = 61 and p-value = 0.0049; and for COD, Z-score = 2.8317 and p-value = 0.0023). These statistical changes indicated that BMP4 was reducing EMCs for TOC, BOD_5, and COD in stormwater.

In relation to environmental and chemical factors, EMCs for TKN and TP entering and leaving BMP4 were correlated significantly with hydrologic variables of rainfall intensity and mean stormflow. Commonly associated constituents, EMCs for TOC, COD, and BOD_5 were correlated with EMCs for TKN in the stormwater entering the inlet (exception of BOD_5) and leaving the outlet of BMP4. However, EMCs for TP were correlated only with TOC and COD in the inlet waters, but were correlated significantly with TOC, COD, and BOD_5 in the outlet water. Additionally, most dissolved and total forms of the trace metals were correlated with TKN and TP, indicating that nutrients had similar transport as organic carbon and other oxygen consuming compounds and trace metals through the structural BMP.

Overlap also was observed for the TP loads entering and leaving BMP4; the inlet and outlet waters had the same median TP load of 0.06 kg/event (fig. 76; table 16). Median TKN loads of the inlet and outlet waters of 0.48 and 0.39 kg/event, respectively, were almost identical; however, the range in TP and TKN loads for the outlet water appeared slightly reduced when compared to loads in the inlet water. The TKN and TP loads for BMP4 were statistically different between inlet and outlet waters for this study (for TKN, Z-score = 2.9137 and p-value = 0.0018; for TP, V-statistic = 74 and p-value = 0.0017). These statistics indicated that BMP4 was efficient at reducing nutrient loads in stormwater.

Median TOC, BOD_5, and COD loads in the stormwater entering the inlet of BMP4 were 2.33, 2.63, and 10.1 kg/event, respectively (table 16). Median TOC, BOD_5, and COD loads in the stormwater leaving the outlet of BMP4 were 1.88, 1.34, and 4.58 kg/event, respectively. Statistical differences in TOC, BOD_5, and COD loads between inlet and outlet waters for BMP4 were identified (for TOC, V-statistic = 75 and p-value = 0.0012; for BOD_5, V-statistic = 61 and p-value = 0.0049; and for COD, Z-score = 2.3552 and p-value = 0.0093). These statistics indicated that BMP4 was reducing TOC, BOD_5, and COD loads in stormwater.

For the sampled storm events from 2005 to 2006, the average amount of TKN load that was reduced by BMP4 was 0.34 +/- 0.15 kg/event, or about 31.3 +/- 7.89 percent (fig. 77; Appendix D-1). The TP loads were reduced an average of 0.03 +/- 0.01 kg/event, or about 31.4 +/- 7.43 percent. Cumulatively for the sampled storm events, BMP4 received 11.9 kg of TKN load and removed 4.02 kg (Appendix D-2). BMP4 received 1.26 kg of TP load and removed 0.36 kg of that load.

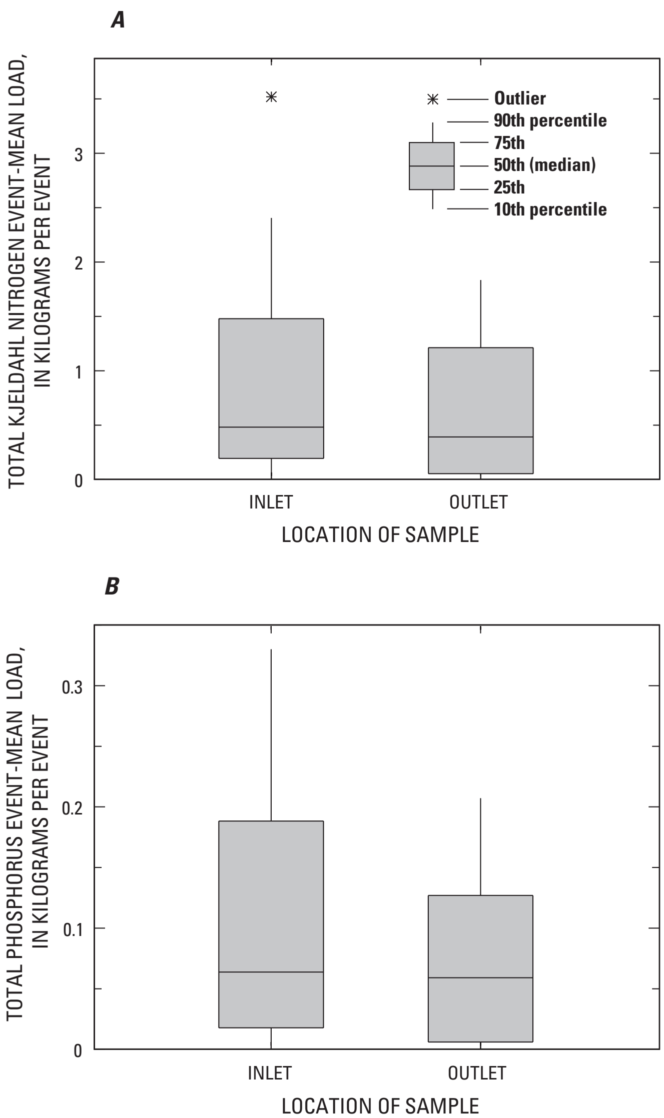

Figure 76. Event-mean loads of *(A)* total Kjeldahl nitrogen and *(B)* total phosphorus at best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

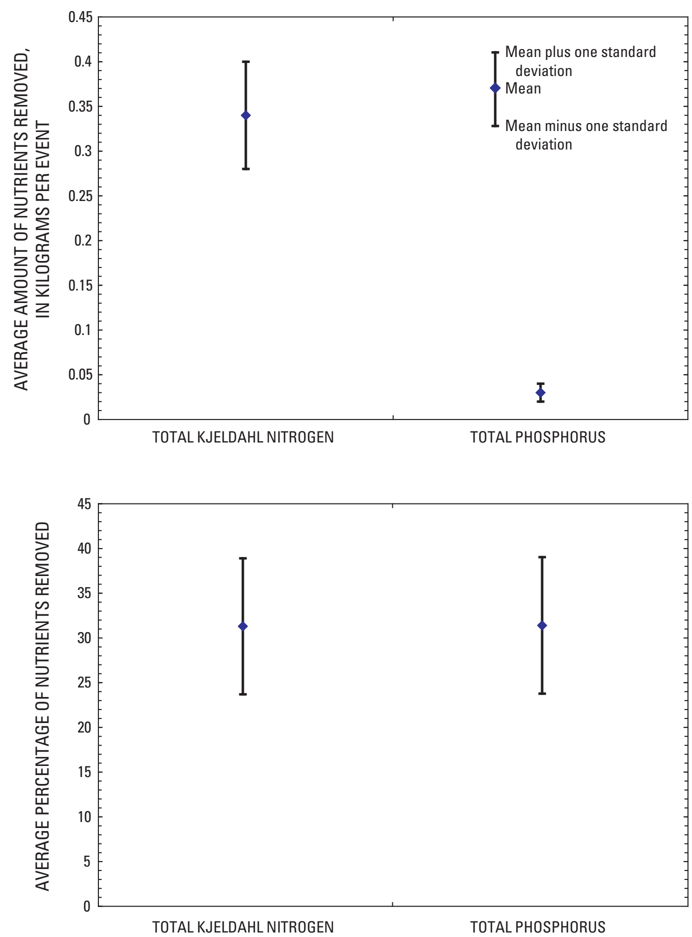

Figure 77. Average amounts and percentages of total Kjeldahl nitrogen and total phosphorus removed by best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

Indicator Bacteria

The *E. coli* and enterococci concentrations in samples collected from stormwater entering and leaving BMP4 were not correlated in the inlet waters (rho = 0.37555, p-value = 0.2849), but were for the outlet waters (rho = 0.826675; p-value = 0.0032) for the period of study. However, both fecal indicator bacteria ranged more than 4 orders of magnitude in concentrations during the period of study. Median concentrations of 1,500 and 11,700 col/100 mL for *E. coli* and enterococci, respectively, for inlet water and 700 and 2,820 col/100 mL, respectively, for outlet water indicated an overall decrease in fecal indicator bacterial concentrations (fig. 78; table 15). A statistical difference in enterococci concentrations between inlet and outlet waters for BMP4 was identified (Z-score = 1.8869, p-value = 0.0296), indicating that BMP4 was efficient at removing enterococci from stormwater. However, statistical tests of the *E. coli* concentrations between inlet and outlet waters indicated no significant change in these concentrations (Z-score = 1.4297, p-value = 0.0764).

No significant relations between *E. coli* and hydrologic variables were determined for the stormwater entering BMP4. Enterococci concentrations also had no significant correlation with hydrologic variables. Several environmental factors potentially could influence fecal indicator bacterial concentrations; one such factor is the accumulated sediment and organic matter in the bottom of BMP4 that could serve as an additional source of bacteria during storm events. That survival or growth and then re-suspension process of enterococci and *E. coli* bacteria also could explain outlet water concentrations that were periodically equal to or higher than the inlet water concentrations (figs. 79 and 80).

Sediments removed from BMP4 during clean-out periods were analyzed for viable colonies of enterococci and *E. coli* in May 2005, October 2005 (*E. coli* only), and May 2006. Enterococci concentrations were highly variable at 31 and 6,490 colonies per 100 grams of sediment for May 2005 and 2006, respectively (fig. 79). Although the sediment data were limited, no strong correlation between sediment and water concentrations was observed for enterococci; higher sediment concentrations did not reflect higher water concentrations. The *E. coli* concentrations were slightly less variable than enterocooci concentrations, ranging from 96 to 8,200 colonies per 100 grams of sediment (fig. 80). Again, no pattern between sediment and water concentrations was observed for *E. coli*.

Escherichia coli concentrations in all but one inlet water sample were greater than the SCDHEC-established one-time maximum concentration of 104 col/100 mL. Enterococci and *E. coli* concentrations in all inlet samples were greater than the USEPA recommended criterion of 235 col/100 mL.

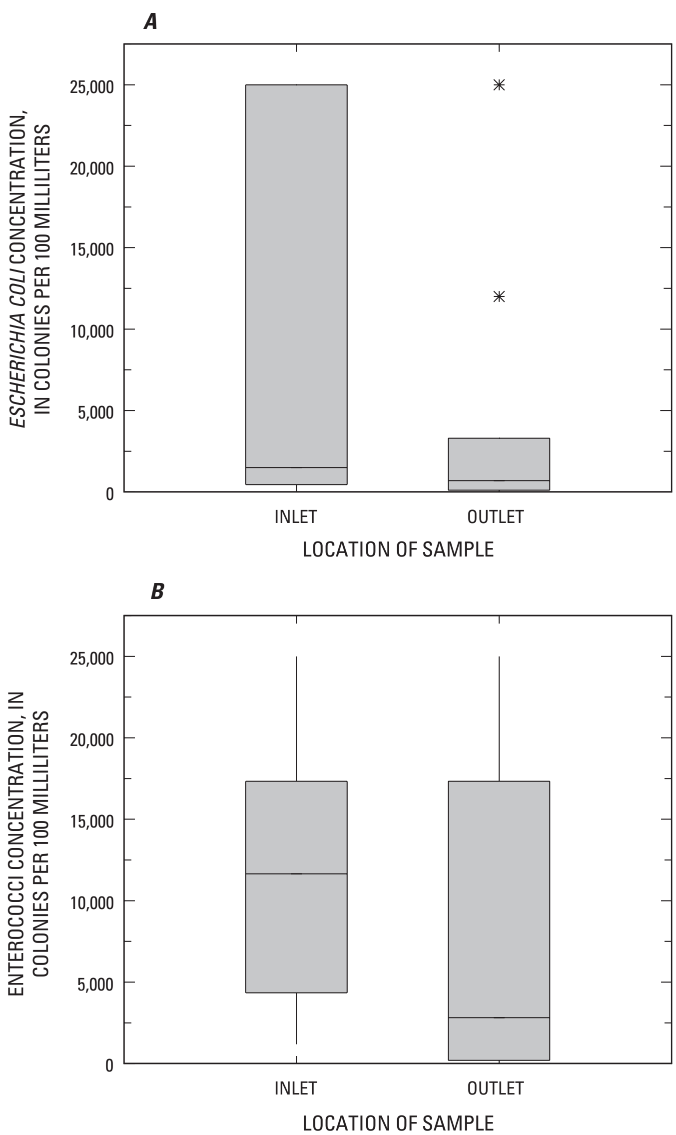

Figure 78. Concentrations of *(A) Escherichia coli* and *(B)* enterococci in grab samples collected from best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

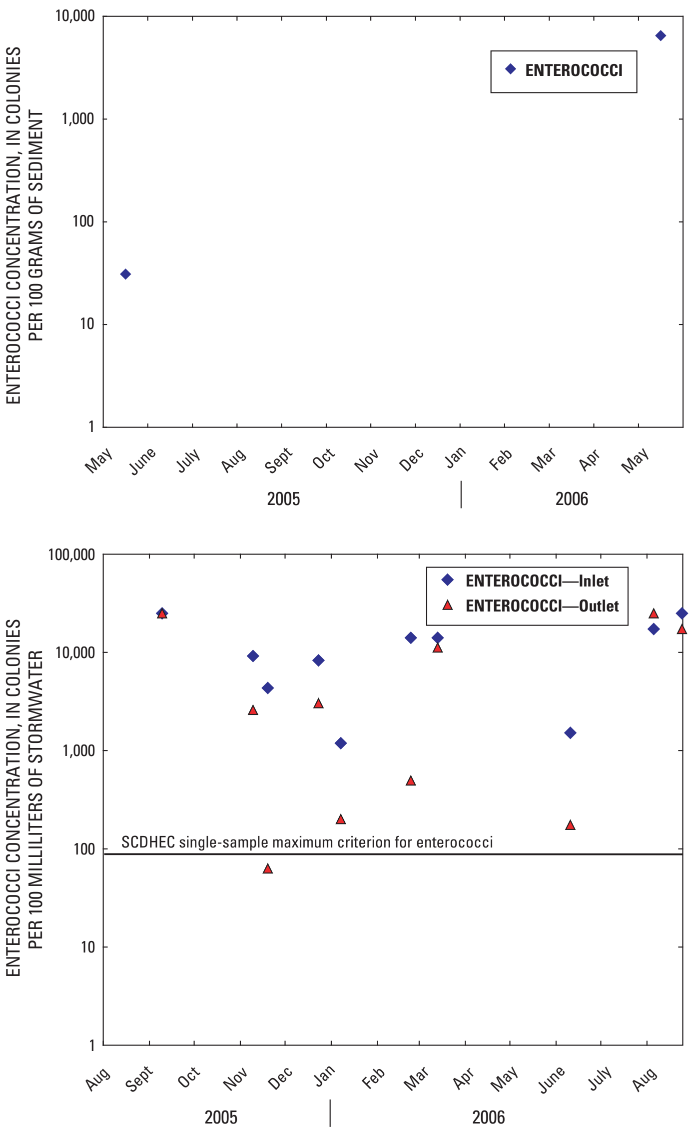

Figure 79. Time-series plots of enterococci concentrations in sediment and stormwater at best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control]

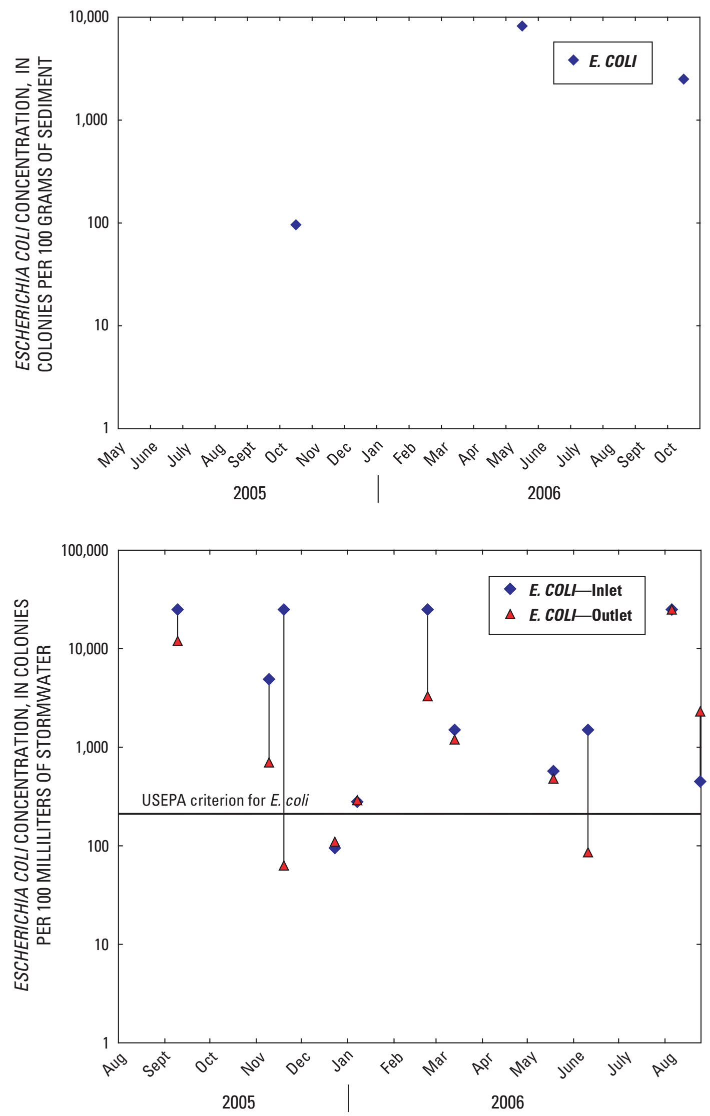

Figure 80. Time-series plots of *Escherichia coli* (*E. coli*) concentrations in sediment and stormwater for best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006. [USEPA, U.S. Environmental Protection Agency]

Metals

Concentration ranges of the targeted trace metals in stormwater entering the inlet of BMP4 varied by 3 orders of magnitude (figs. 81–83), and are listed in order of increasing median concentration: total cadmium (0.51 µg/L), total nickel (6.47 µg/L), total lead (11.6 µg/L), total copper (34.1 µg/L), and total zinc (404 µg/L). Concentration ranges of the targeted trace metals in the stormwater leaving the outlet of BMP4 had similar variabilities and were in the same order of increasing median concentration: total cadmium (0.26 µg/L), total nickel (3.04 µg/L), total lead (4.69 µg/L), total copper (18.0 µg/L), and total zinc (176 µg/L). Lead and zinc were predominantly in particulate form in both inlet and outlet water samples (figs. 82 and 83). Cadmium was mainly in the particulate form (fig. 81). In general, the copper and nickel concentrations were distributed fairly evenly between particulate and dissolved forms (figs. 81 and 82, respectively).

Significant changes in trace-metal concentrations from inlet to outlet waters were identified (table 15). The following concentrations were statistically significant: total and particulate cadmium (V-statistics = 76 and 75, respectively; p-values = 0.0007 and 0.0012, respectively); dissolved, total, and particulate copper (V-statistics = 61, 76, and 78, respectively; p-values = 0.0461, 0.0007, and 0.0002, respectively); total and particulate lead (V-statistics = 78 and 78, respectively; p-values = 0.0002 and 0.0002, respectively); dissolved, total, and particulate nickel (for dissolved nickel, Z-score = 2.3552 and p-value = 0.0093; for total nickel, V-statistic = 77 and p-value = 0.0005; for particulate nickel, Z-score = 2.9429 and p-value = 0.0016); and total and particulate zinc (V-statistics = 75 and 75, respectively; p-values = 0.0012 and 0.0012, respectively). These statistics indicated that BMP4 was efficient at reducing trace-metal concentrations in stormwater.

Total nickel EMCs in the stormwater entering the inlet and leaving the outlet of BMP4 were less than the SCDHEC-established CMCs for freshwater aquatic life (table 8; fig. 82). However, all EMCs for total copper in the inlet and outlet waters of BMP4 were above the CMC of 3.8 µg/L (table 8; fig. 81). For total lead and total cadmium EMCs in the stormwater, about 50 to 60 percent of the EMCs entering the inlet of BMP4 were greater than the SCDHEC-established CMCs for freshwater aquatic life of 14 and 0.53 µg/L, respectively (table 8; figs. 81 and 82). In the stormwater leaving the outlet of BMP4, almost 90 percent of the samples had concentrations of total lead and total cadmium that were less than their CMCs, the same criterion for total lead and cadmium.

The trace-metal loads had a similar pattern to that of the trace-metal concentrations and are listed in order of increasing median load: total cadmium (0.03 g/event), total nickel (0.38 g/event), total lead (0.53 g/event), total copper (2.26 g/event), and total zinc (21.8 g/event) for inlet water (figs. 84–86; table 16). Outlet median loads were: total cadmium (0.02 g/event), total nickel (0.25 g/event), total lead (0.29 g/event), total copper (1.59 g/event), and total zinc (11.9 g/event). Significant changes in trace-metal loads from inlet to outlet waters were identified (table 16; fig. 87). Total and particulate cadmium loads were significantly reduced in the outlet water (p-values, 0.0012 and 0.0061, respectively). The following loads for BMP4 were statistically different between inlet and outlet waters for this study: particulate copper (p-score, 0.0002); total and particulate lead (p-scores = 0.0002 and 0.0002, respectively); dissolved, total, and particulate nickel (p-scores = 0.0170, 0.0024, and 0.0017, respectively); and dissolved, total, and particulate zinc (p-scores = 0.0212, 0.0034, and 0.0024, respectively). These statistics indicated that BMP4 was efficient at reducing trace-metal loads in stormwater.

For the sampled storm events, the average amounts of trace-metal loads that were reduced by BMP4 are listed in order from least to greatest loads: total cadmium (0.02 +/- 0.01 g/event), total nickel (0.20 +/- 0.09 g/event), total lead (0.86 +/- 0.54 g/event), total copper (1.68 +/- 0.89 g/event), and total zinc (33.2 +/- 21.4 g/event) (fig. 87; Appendix D-1). The average percentages of trace-metal concentrations and loads removed by BMP4 were similar. The percentages of loads removed are listed in order from least to greatest: total nickel (36.2 +/- 7.43 percent), total copper (40.1 +/- 8.04 percent), total cadmium (42.7 +/- 8.29 percent), total lead (49.6 +/- 9.3 percent), and total zinc (50.6 +/- 9.13 percent).

For the sampled storm events at BMP4, stormwater entering the BMP had the following cumulative loads: 0.70 g of total cadmium, of which 0.28 g were removed; 6.62 g of total nickel, of which 2.40 g were removed; 46.8 g of total copper, of which 20.1 g were removed; 19.7 g of total lead, of which 10.3 g were removed; and 752 g of total zinc, of which 398 g were removed (Appendix D-2).

As mentioned previously, trace-metal concentrations were measured in the retained coarser grained sediment and were zinc, copper, lead, nickel, and cadmium, in order from greatest to least concentration (units in microgram per gram) (fig. 71). The sequence for the amount of trace-metal loads removed between the inlet and outlet waters of BMP4 was: zinc, copper, lead, nickel, and cadmium, in order from greatest to least load.

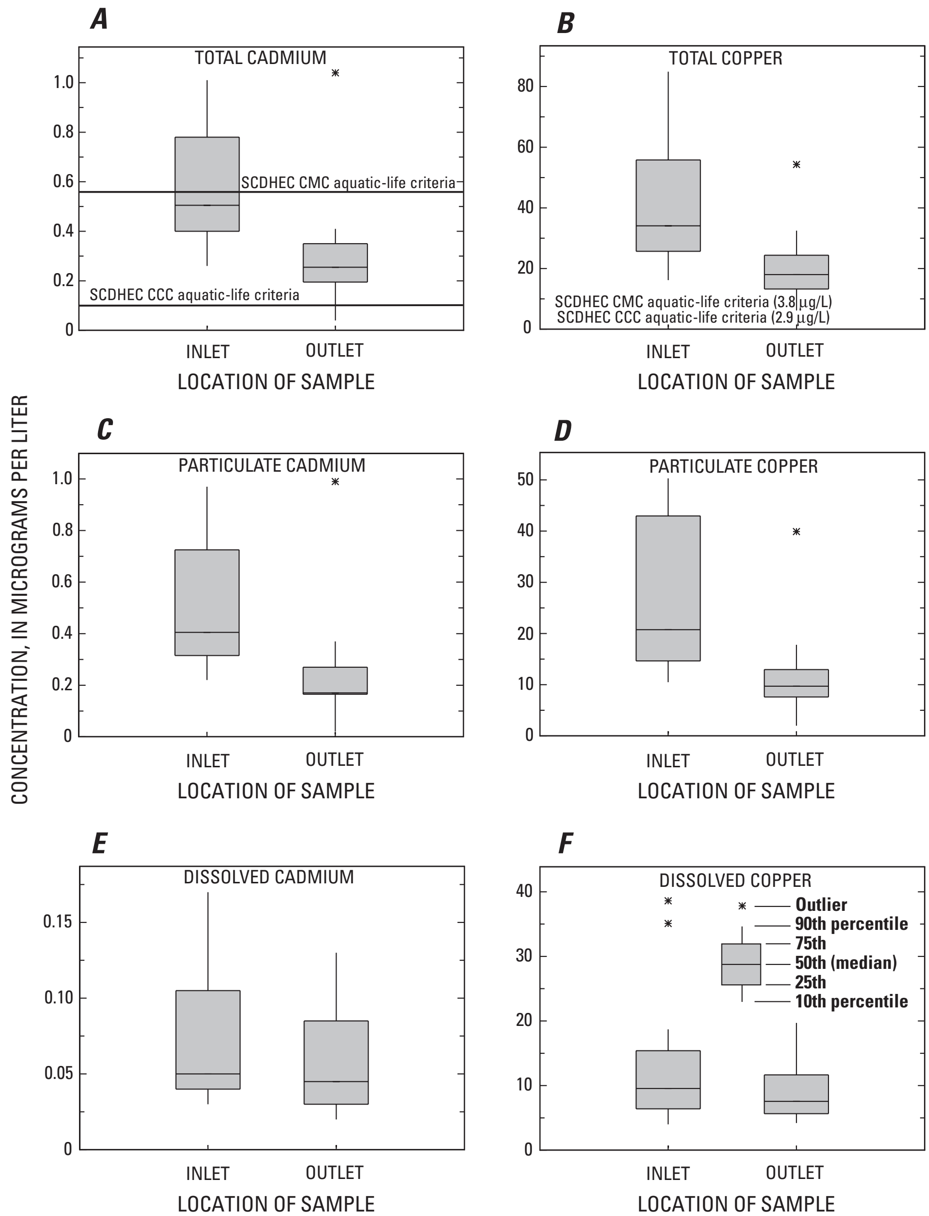

Figure 81. Event-mean concentrations of total *(A)* cadmium and *(B)* copper; particulate *(C)* cadmium and *(D)* copper; and dissolved *(E)* cadmium and *(F)* copper at best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration]

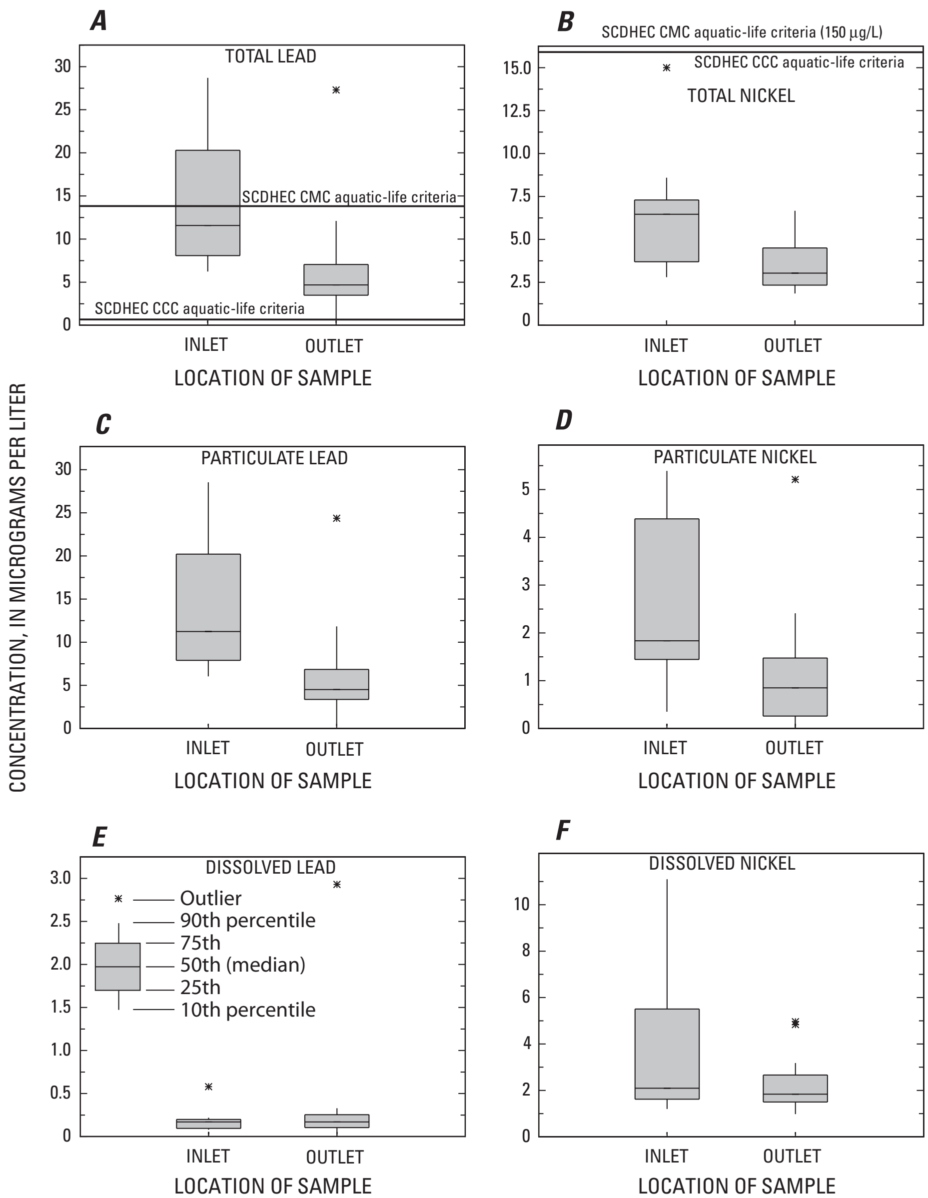

Figure 82. Event-mean concentrations of total *(A)* lead and *(B)* nickel; particulate *(C)* lead and *(D)* nickel; and dissolved *(E)* lead and *(F)* nickel at best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration]

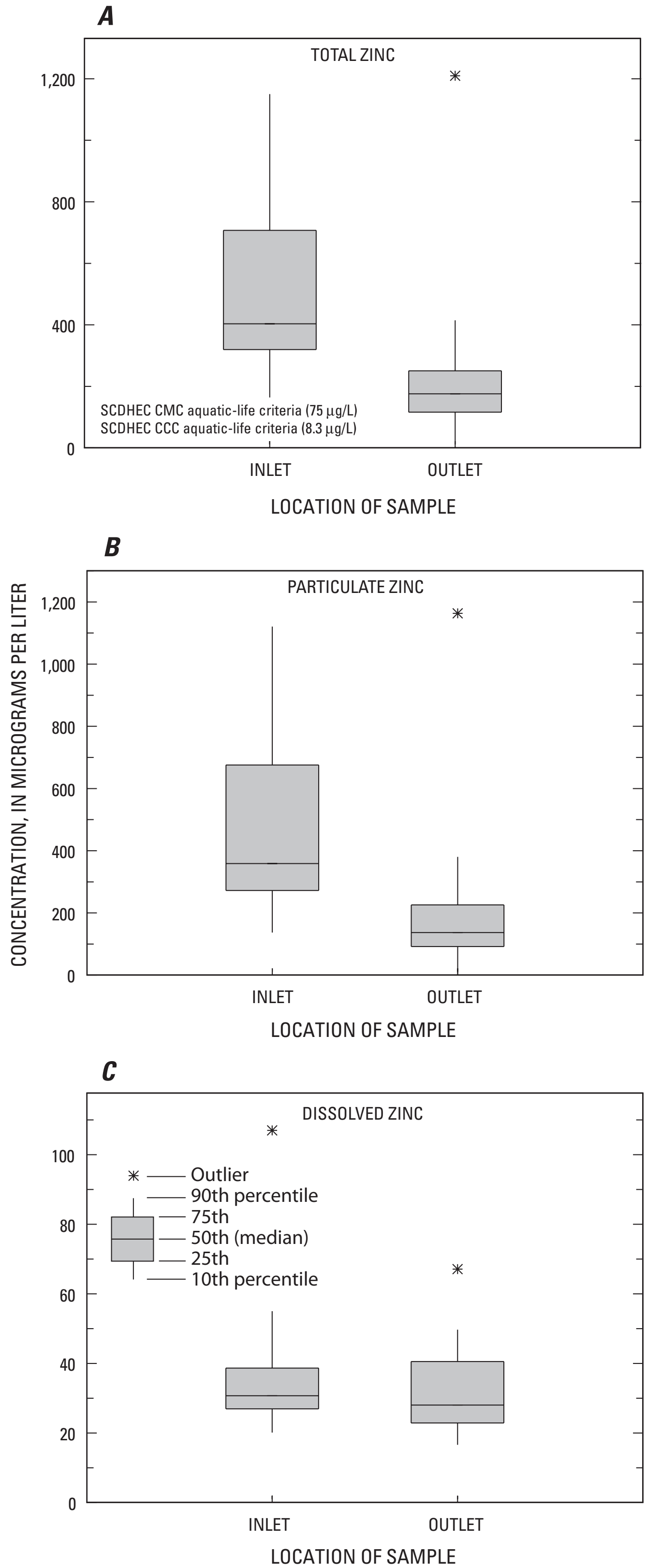

Figure 83. Event-mean concentrations of *(A)* total zinc, *(B)* particulate zinc, and *(C)* dissolved zinc at best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006. [SCDHEC, South Carolina Department of Health and Environmental Control; CCC, criteria continuous concentration; CMC, criteria maximum concentration]

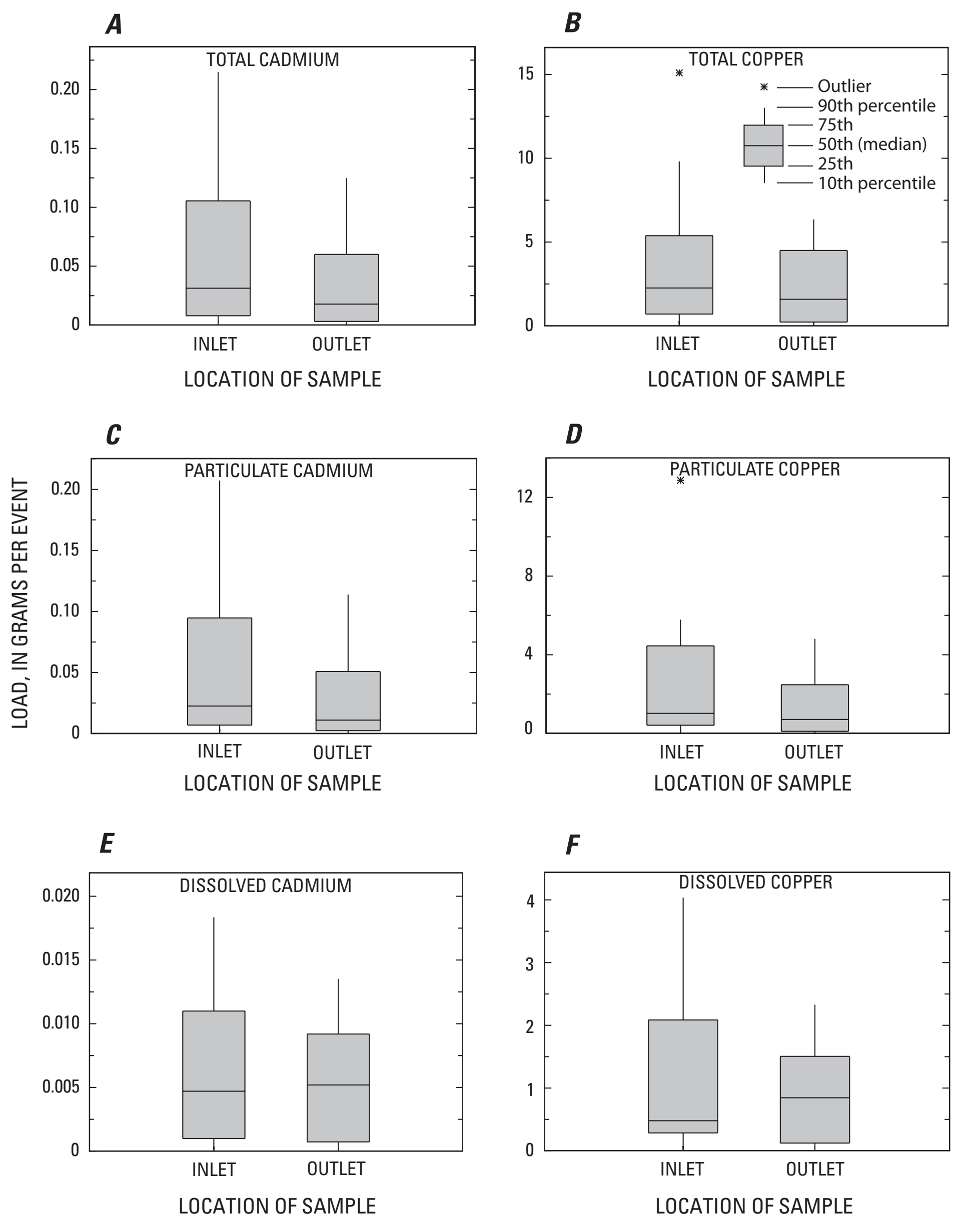

Figure 84. Event-mean loads of total *(A)* cadmium and *(B)* copper; particulate *(C)* cadmium and *(D)* copper; and dissolved *(E)* cadmium and *(F)* copper at best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

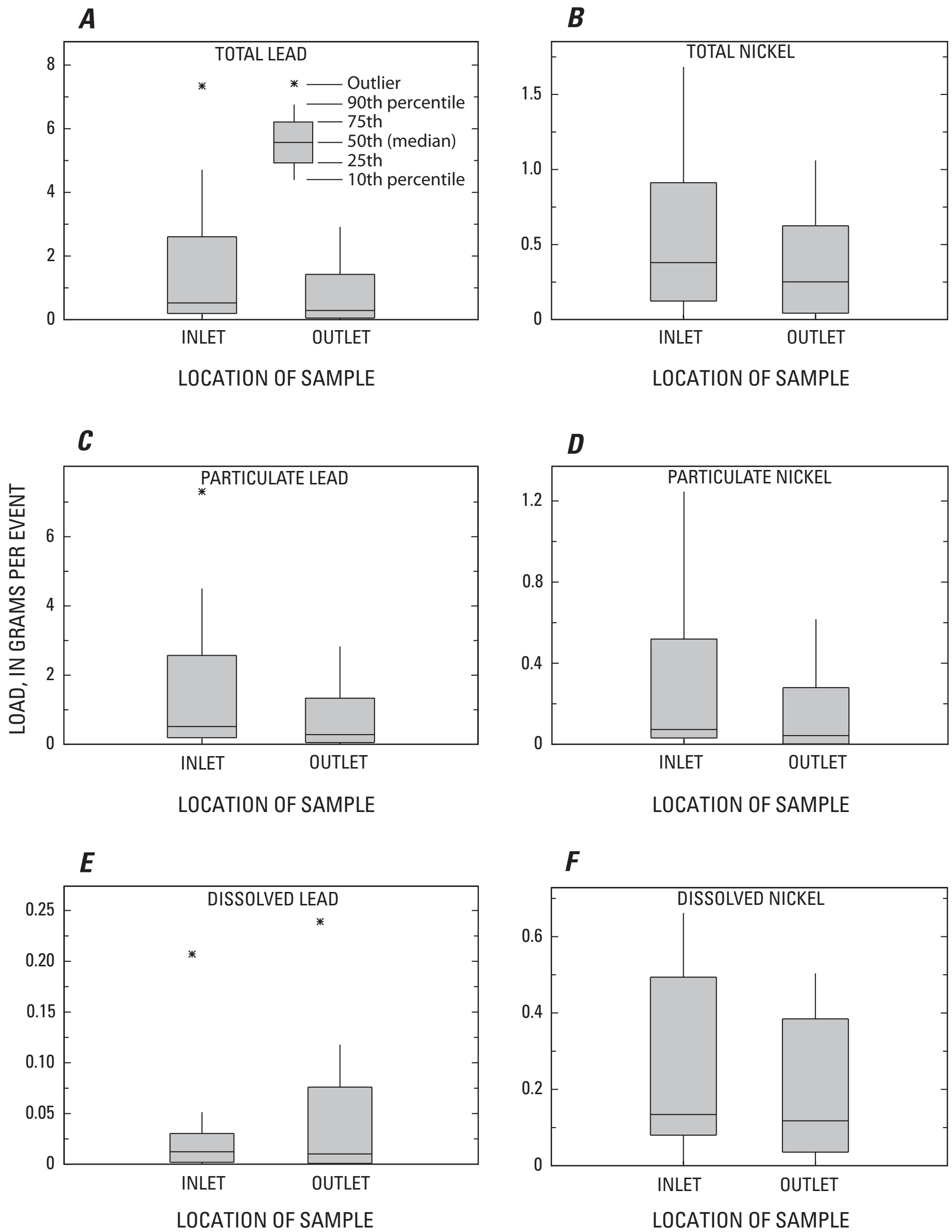

Figure 85. Event-mean loads of total *(A)* lead and *(B)* nickel; particulate *(C)* lead and *(D)* nickel; and dissolved *(E)* lead and *(F)* nickel at best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

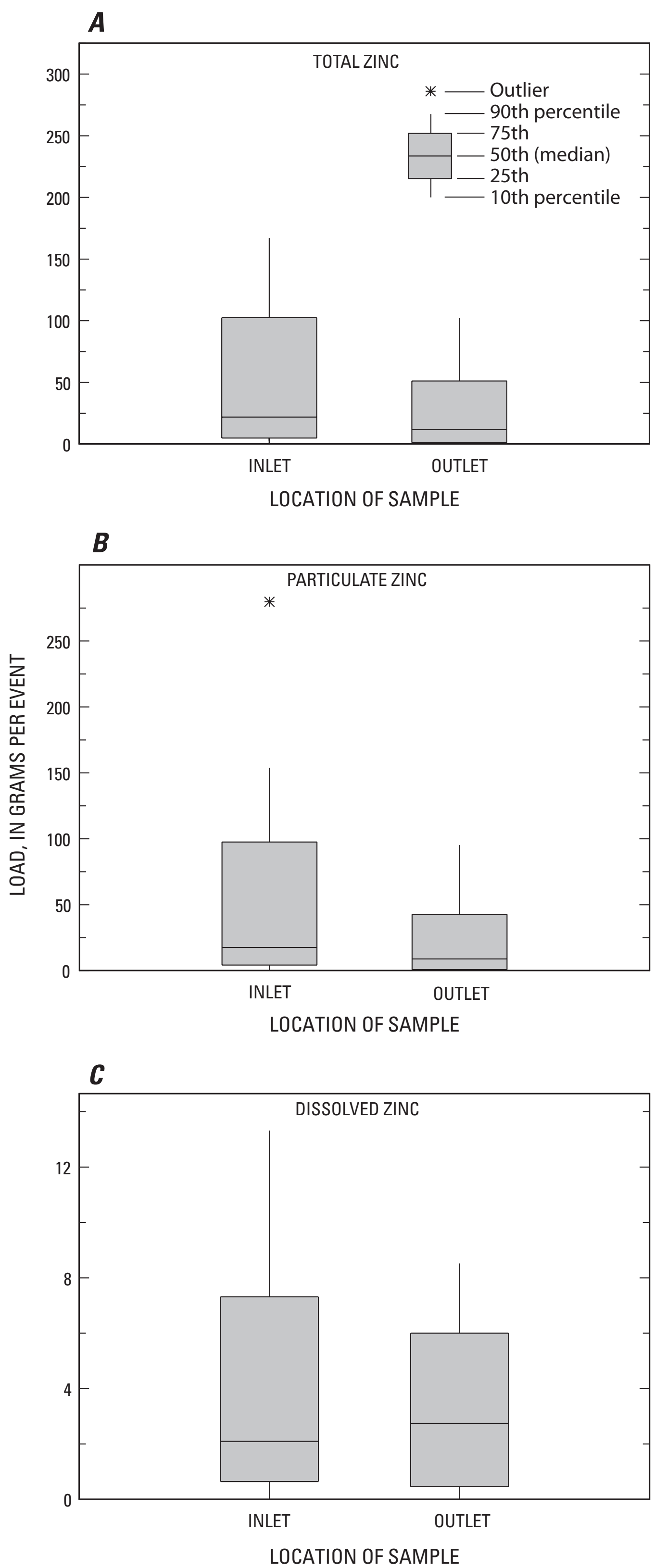

Figure 86. Event-mean loads of *(A)* total zinc, *(B)* particulate zinc, and *(C)* dissolved zinc at best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

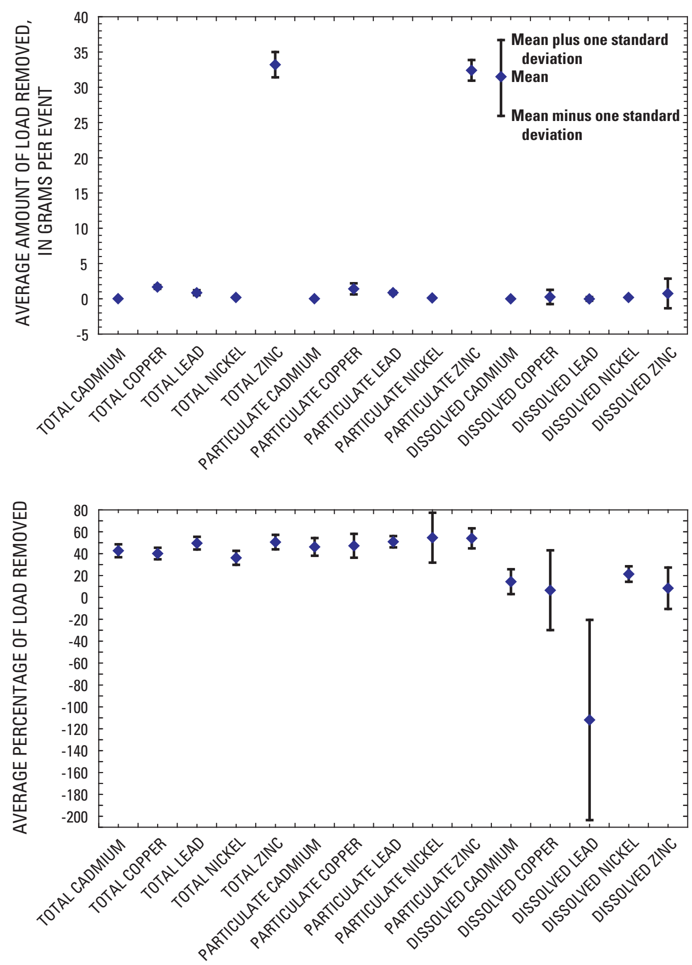

Figure 87. Average amounts and percentages of event-mean loads of selected trace metals removed by best management practice 4 at the south side of I-95 near Walterboro, S.C., 2005–2006.

Relation of Daily Traffic Counts to Inlet Event-Mean Concentrations and Loads

The total traffic counts at BMP1, BMP2, and BMP3 had minimal variability among seasons and among sites, ranging from 61,599 at BMP1 for the fall season to 68,489 at BMP1 for the summer season (table 18). The greatest difference in counts was observed at BMP4 when compared among sites and between seasons; traffic counts ranged from only 6,210 in the fall season to 16,269 in the summer season. Cars were the most frequently counted vehicle (more than 50 percent of the total) at all four sites, followed by pick-up or van at BMP1, BMP2, and BMP3, and trucks at BMP4.

The lack of spread of the traffic count data among BMP1, BMP2, and BMP3 and among seasons for each site prevented analysis of the effect of traffic counts on loads at those sites. The suspended-sediment and trace-metal loads at BMP4 were compared to the suspended-sediment and trace-metal loads at the other three BMP sites with higher traffic counts. Trace-metal and suspended-sediment loads at BMP4 were equal to or greater than loads at the other three sites, implying no direct effect on traffic counts.

Comparison of Removal Efficiency among BMPs

Individual BMP performance assessments from previous sections determined the constituents in stormwater that were significantly reduced between the time they entered the inlet and left the outlet of each BMP (table 19). If an EMC or load in water entering the inlet of a BMP was statistically greater than the EMC or load leaving the outlet of the BMP (designated by a greater-than sign in table 19), the BMP was considered successful at removing some amount of the EMC or load. If no statistical difference was identified, then negligible removal by the BMP was indicated (designated by an equal sign in table 19). If the EMC or load in water entering the inlet of a BMP was statistically less than the EMC or load leaving the outlet of the BMP (designated by a less-than sign in table 19), the BMP actually contributed some amount of load to the stormwater that left the BMP during a storm event.

Only EMCs for SSC and TSS were reduced significantly by all four BMPs. BMP1, BMP2, and BMP4 also reduced oil and grease EMCs significantly. Increases in the percentages of suspended sediment that was finer than 63 microns (representative of the silt and clay fraction of sediment) leaving the BMPs indicated that all four BMPs tended to retain the sand-sized and coarser fraction in the BMP but released additional silt- and clay-sized sediment during storm events. BMP4 had the greatest number of significant reductions, including all total and particulate metal concentrations. BMP1 and BMP2 were unable to significantly reduce nutrient (except for TP for BMP1) and fecal indicator bacterial concentrations significantly in stormwater. BMP3 reduced enterococci bacteria, and BMP4 reduced nutrient and enterococci bacterial concentrations.

Reductions in event-mean loads showed trends similar to those of the EMCs. The SSC and TSS loads were reduced significantly by all four BMPs. BMP1, BMP2, and BMP4

Table 18. Average daily traffic counts and vehicle classification at four structural best management practice (BMP) sites in Beaufort and Colleton Counties, South Carolina.

[Due to rounding, percentage totals may not equal 100 percent]

BMP site	Date	Counts or percentages	Vehicle classification and counts (percentage of total)						Total counts
			Motorcycle	Car	Pick-up; van	Bus	Truck	Other	
1	8/7/2006 – 8/14/2006	Counts	370	54,144	11,192	90.0	2,443	250	68,489
		Percentage	0.54	79.06	16.3	0.13	3.56	0.37	
	10/16/2006 – 10/23/2006	Counts	286	49,648	8,465	66.0	2,442	692	61,599
		Percentage	0.46	80.6	13.7	0.11	3.97	1.12	
2	8/7/2006 – 8/14/2006	Counts	343	49,904	14,733	159	2,921	59.0	68,119
		Percentage	0.50	73.3	21.6	0.23	4.29	0.09	
	10/16/2006 – 10/23/2006	Counts	279	49,334	13,827	128	3,437	207	67,212
		Percentage	0.42	73.4	20.6	0.19	5.11	0.31	
3	8/2/2006 – 8/9/2006	Counts	344	47,930	14,206	230	3,546	10.0	66,266
		Percentage	0.52	72.3	21.4	0.35	5.34	0.02	
	10/16/2006 – 10/23/2006	Counts	214	44,981	14,389	251	6,266	96.0	66,197
		Percentage	0.32	67.9	21.7	0.38	9.46	0.15	
4	8/03/2006 – 8/10/2006	Counts	892	9,373	2,062	281	3,659	2.00	16,269
		Percentage	5.49	57.5	12.7	1.73	22.5	0.01	
	10/16/2006 – 10/23/2006	Counts	379	3,250	745	119	1,711	6.00	6,210
		Percentage	6.10	52.3	12.0	1.92	27.6	0.10	

Table 19. Summary of the Wilcoxon signed-rank tests used to evaluate the differences between event-mean concentrations and loads of selected parameters in water entering the inlet and water leaving the outlet of four structural best management practices, Beaufort and Colleton Counties, South Carolina, 2005–2006 (summarized from tables 5, 6, 9, 10, 12, 13, 15, and 16).

[SSC, suspended sediment concentration; SSC < 63 m, suspended sediment smaller than 63 microns; TSS, total suspended solids; TKN, total Kjeldahl nitrogen; TP, total phosphorus; BOD_5, biochemical oxygen demand; COD, chemical oxygen demand; >, concentration or load in inlet water greater than in outlet water; <, concentration or load in inlet water less than in outlet water; =, no significant difference between concentration or load in inlet and outlet waters; chemical abbreviation for metal or abbreviation for constituent having the significant difference—Cd, cadmium; Cu, copper; Entero, enterococci; Ni, nickel; Pb, lead; Zn, zinc; NA, not applicable]

Site	SSC	SSC < 63 µm	TSS	Oil and grease	TKN, TP	BOD_5, COD	Fecal bacteria	Dissolved metals	Total metals	Particulate metals
					[1]Event-mean concentrations					
BMP1	>	<	>	>	> (TP)	=	=	> (Cd, Cu, Zn)	> (all)	> (Pb)
BMP2	>	<	>	>	=	=	=	> (Cu)	> (all)	> (Cd, Pb, Ni, Zn)
BMP3	>	<	>	=	=	> (COD)	> (Entero)	=	> (all)	> (all)
BMP4	>	<	>	>	>	>	> (Entero)	> (Cu, Ni)	> (all)	> (all)
					[1]Event-mean loads					
BMP1	>	NA	>	>	> (TP)	=	NA	> (Cd, Cu)	> (Cd, Pb, Zn)	> (Pb, Ni)
BMP2	>	NA	>	>	=	=	NA	> (Cu)	> (all)	> (Pb, Ni, Zn)
BMP3	>	NA	>	=	=	=	NA	=	> (Cd)	> (Cd, Pb, Zn)
BMP4	>	NA	>	>	>	>	NA	> (Ni, Zn)	> (Cd, Pb, Ni, Zn)	> (all)

[1] Results for fecal bacteria and oil and grease concentrations are from a "first flush" grab sample.

significantly reduced oil and grease loads. Only BMP4 was able to reduce nutrient loads significantly. An exception was BMP1, which reduced the total phosphorus load.

Different environmental conditions can influence the performance of structural BMPs, thereby contributing some bias to the overall assessment for the BMPs. The investigation attempted to control as many of the conditions as possible. However, two factors that may have some influence on the performance evaluation included different environmental conditions related to the larger watershed size of BMP3 and greater inlet concentrations of constituents at BMP4. As mentioned earlier, statistical comparison of hydrologic conditions of the sampled storm events among the four BMPs indicated that rainfall amounts and rainfall intensities were similar (table 4). However, BMP3 had significantly greater event-mean stormflow than the other BMPs. These findings about the hydrologic conditions need to be kept in mind when evaluating loads among these BMPs.

Secondly, a significant relation was determined among all four BMPs between the inlet water concentrations for several constituents (mainly metals, such as zinc and nickel) and the percentage reduction for those constituents. The relation identified a tendency for the BMP devices to exhibit greater reduction at the greater inlet water concentrations and to exhibit lower reductions at the lower inlet water concentrations. A reported explanation for this is that there appears to be a limit to which any BMP can reduce a concentration—often referred to as its "irreducible concentration" (U.S. Environmental Protection Agency, 2002b). Because the quantification of efficiency for this study was based on reduction percentages of these constituents between the stormwater entering the inlet and leaving the outlet of the BMP, a BMP receiving stormwater with larger inlet concentrations would appear to have better efficiency than a similarly capable BMP receiving stormwater with inlet concentrations near the irreducible concentration. To evaluate if this potential bias may have existed, a statistical comparison of event-mean concentrations and loads of constituents in the stormwater entering the inlet of the four BMPs was conducted to identify which BMPs may have introduced this bias (table 20). Final results of the statistical comparison are summarized in table 20 with letters that identify differences among BMPs. BMPs that have no letters in common with other BMPs are statistically different from the other BMPs. If BMPs share at least one letter, those BMPs are statistically similar. If one BMP has the letter "A" and another BMP has the letter "B," the BMP with the letter "A" is statistically greater than the BMP with the letter "B."

No significant differences in inlet water EMCs were identified among the four BMPs for total suspended solids or suspended sediment (table 20). However, BMP4 had larger oil and grease concentrations and larger total and particulate copper, total and particulate cadmium, and total and particulate zinc EMCs than the other three BMPs (tables 5, 9, 12, and 15). Therefore, some bias can be expected when comparing performances in reducing metal EMCs among the four BMPs.

Table 20. Statistical summary of the comparison of inlet water event-mean concentrations and loads at selected best management practices (BMPs) in Beaufort and Colleton Counties, South Carolina, 2005–2006.

Constituent	Kruskal-Wallis test statistics				Comparison of difference among inlet waters—Tukey test results				
	Chi-squared	Degrees of freedom	R-squared	Probability value		BMP1	BMP2	BMP3	BMP4
Event-mean concentrations									
Dissolved cadmium	10.071	3	0.243	0.018	Group	**A**	B	B	AB
					N	13	12	12	12
Total cadmium	8.675	3	0.182	0.034	Group	AB	AB	B	A
					N	13	12	12	12
Particulate cadmium	11.216	3	0.187	0.011	Group	B	AB	AB	A
					N	13	12	12	12
Dissolved copper	5.027	3	0.082	0.170	Group	A	A	A	A
					N	13	12	12	12
Total copper	8.965	3	0.269	0.030	Group	B	B	B	**A**
					N	13	12	12	12
Particulate copper	16.318	3	0.322	0.001	Group	B	B	B	**A**
					N	13	12	12	12
Dissolved lead	2.046	3	0.050	0.563	Group	A	A	A	A
					N	13	12	12	12
Total lead	2.889	3	0.037	0.409	Group	A	A	A	A
					N	13	12	12	12
Particulate lead	3.967	3	0.035	0.265	Group	A	A	A	A
					N	13	12	12	12
Dissolved nickel	8.351	3	0.157	0.039	Group	AB	B	AB	**A**
					N	13	12	12	12
Total nickel	5.765	3	0.062	0.124	Group	A	A	A	A
					N	13	12	12	12
Particulate nickel	1.894	3	0.037	0.595	Group	A	A	A	A
					N	13	12	12	12
Dissolved zinc	3.133	3	0.115	0.372	Group	A	A	A	A
					N	13	12	12	12
Total zinc	14.405	3	0.365	0.002	Group	B	B	B	**A**
					N	13	12	12	12
Particulate zinc	14.600	3	0.361	0.002	Group	B	B	B	**A**
					N	13	12	12	12
Total Kjeldahl nitrogen	16.527	3	0.195	0.001	Group	AB	B	AB	**A**
					N	13	12	12	12
Total phosphorus	13.832	3	0.165	0.003	Group	INCONCLUSIVE			
					N	13	12	12	12
Turbidity	3.150	3	0.108	0.369	Group	A	A	A	A
					N	13	12	12	12
Total organic carbon	10.850	3	0.176	0.013	Group	AB	B	AB	**A**
					N	13	12	12	12
Total suspended solids as residue	3.131	3	0.060	0.372	Group	A	A	A	A
					N	13	12	12	12
Biochemical oxygen demand	16.480	3	0.352	0.001	Group	B	B	B	**A**
					N	13	12	12	12
Chemical oxygen demand	11.556	3	0.212	0.009	Group	B	B	AB	A
					N	13	12	12	12
Enterococci	5.271	3	0.145	0.153	Group	A	A	A	A
					N	12	11	12	10
Escherichia coli	8.383	3	0.169	0.039	Group	B	AB	AB	**A**
					N	11	11	11	11
Suspended sediment finer than sand	3.481	3	0.109	0.323	Group	A	A	A	A
					N	12	11	12	12
Suspended sediment	1.478	3	0.067	0.687	Group	A	A	A	A
					N	13	11	12	12
Oil and grease	11.606	3	0.325	0.009	Group	B	B	B	A
					N	13	12	12	12

Table 20. Statistical summary of the comparison of inlet water event-mean concentrations and loads at selected best management practices (BMPs) in Beaufort and Colleton Counties, South Carolina, 2005–2006.—Continued

Constituent	Kruskal-Wallis test statistics				Comparison of difference among inlet waters—Tukey test results				
	Chi-squared	Degrees of freedom	R-squared	Probability value		BMP1	BMP2	BMP3	BMP4
Event-mean loads									
Dissolved cadmium	2.765	3	0.105	0.429	Group N	**A** 10	A 12	A 12	A 12
Total cadmium	4.419	3	0.105	0.220	Group N	A 10	A 12	A 12	A 12
Particulate cadmium	4.394	3	0.094	0.222	Group N	A 10	A 12	A 12	A 12
Dissolved copper	2.207	3	0.085	0.531	Group N	A 10	A 12	A 12	A 12
Total copper	4.179	3	0.158	0.243	Group N	A 10	A 12	A 12	A 12
Particulate copper	10.415	3	0.091	0.015	Group N	INCONCLUSIVE 10	12	12	12
Dissolved lead	1.977	3	0.060	0.577	Group N	A 10	A 12	A 12	A 12
Total lead	1.051	3	0.067	0.789	Group N	A 10	A 12	A 12	A 12
Particulate lead	1.782	3	0.068	0.619	Group N	A 10	A 12	A 12	A 12
Dissolved nickel	8.039	3	0.219	0.045	Group N	AB 10	AB 12	B 12	**A** 12
Total nickel	3.745	3	0.085	0.290	Group N	A 10	A 12	A 12	A 12
Particulate nickel	1.251	3	0.043	0.741	Group N	A 10	A 12	A 12	A 12
Dissolved zinc	3.772	3	0.068	0.287	Group N	A 10	A 12	A 12	A 12
Total zinc	9.065	3	0.132	0.028	Group N	INCONCLUSIVE 10	12	12	12
Particulate Zinc	8.811	3	0.126	0.032	Group N	INCONCLUSIVE 10	12	12	12
Total Kjeldahl nitrogen	11.763	3	0.256	0.008	Group N	AB 10	B 12	B 11	**A** 12
Total phosphorus	9.338	3	0.240	0.025	Group N	AB 10	AB 12	B 11	**A** 12
Total organic carbon	8.053	3	0.203	0.045	Group N	AB 10	AB 12	B 11	**A** 12
Total suspended solids as residue	2.803	3	0.054	0.423	Group N	A 10	A 12	A 12	A 12
Biochemical oxygen demand	13.592	3	0.233	0.004	Group N	B 10	B 12	AB 11	**A** 11
Chemical oxygen demand	9.457	3	0.122	0.024	Group N	INCONCLUSIVE 10	12	12	12
Suspended sediment	0.259	3	0.018	0.968	Group N	A 10	A 12	A 12	A 12
Oil and grease	2.225	3	0.103	0.527	Group N	A 10	A 12	A 12	A 12

For constituents listed in table 19 that demonstrated significant reductions by the BMPs, mean and geometric mean efficiency ratios were computed to quantify the removal efficiency of each BMP (U.S. Environmental Protection Agency, 2002b; table 21). Efficiency ratios are unitless—units designated in table 21 represent the original units of the properties used to compute the ratio. The greater the efficiency ratio (ER), the greater the amount of EMC or load reduced by the BMP. In other words, as the ER approaches 1, the amount of EMC or load reduced by the BMP from the original storm EMC or load approaches 100 percent. Computed ERs were not sufficiently diagnostic to determine statistical differences among BMPs, so subsequent rankings of the BMPs may not have represented statistically significant differences.

Mean ERs for EMCs of SSC varied among the four BMPs, listed in order from greatest to least: BMP2 (0.93), BMP1 (0.83), BMP4 (0.65), and BMP3 (0.48; table 21). Geometric mean ERs were similarly ranked. BMP2 had the greatest efficiency ratios for EMCs of TSS (0.75), followed by BMP4 (0.58), then by BMP1 (0.42).

For oil and grease concentrations, a simple comparison of the ERs was not sufficient because (1) oil and grease concentrations are not event-mean concentrations (they are from “first flush” grab samples); (2) oil and grease concentrations frequently were present at estimated or censored values at BMP1, BMP2, and BMP3, preventing accurate computations of means and geometric means; and (3) the inlet concentrations were found to be higher at BMP4. Computed mean ERs for oil and grease were ranked from greatest to least: BMP4 (0.70), BMP1 (0.43), and BMP2 (0.38). BMP3 was not ranked because BMP3 did not demonstrate statistically significant removal of oil and grease concentrations (table 19).

Trace-metal EMCs and loads also required more than a simple comparison of the ERs because of the significantly larger inlet concentrations at BMP4. BMP4 consistently had significant reductions in total and particulate trace-metal EMCs (table 19). Computed mean ERs for the total and particulate metals at BMP4 were relatively consistent and ranged from 0.44 to 0.54. For particulate nickel EMCs, the mean ER for BMP2 (0.66) was greater than the mean for BMP4 (0.53; table 21). Further evaluation of the BMP data, however, identified that the trace-metal EMCs in the outlet water were relatively similar among the BMPs, again, suggesting that all BMPs were able to reduce the trace-metal EMCs to a certain irreducible concentration.

As mentioned previously, differences among mean and geometric mean ERs of the BMPs did not indicate conclusively statistically significant differences among BMPs. Consequently, a modified ISL method also was applied such that reduction percentages for constituents whose EMCs and loads were significantly different (table 19) were computed for individual storms and used as input into a multiple comparison test to determine if differences existed among BMPs (table 22). Mean reduction percentages determined from the ISL method also have been previously provided in the text and figures in the individual BMP assessment sections. No statistical differences among the removal efficiency percentages for the four BMPs were determined for EMCs of suspended-sediment, EMCs of TSS, or oil and grease concentrations. These statistical findings indicated that the BMP rankings by mean ERs were not significant and that no statistical differences existed among the BMPs for EMCs of suspended-sediment, EMCs of TSS, or oil and grease concentrations. Additionally, BMP4 generally had statistically greater removal efficiency for total lead and total zinc than BMP1 and BMP3, but the removal efficiency of BMP2 was often equal to that of BMP4.

Table 21. Mean and geometric mean efficiency ratios for four structural best management practices (BMP), Beaufort and Colleton Counties, South Carolina, 2005–2006.

[Note: Ratios are unitless. Designated units are for the parameter's original concentration or load. Ratios that are significant are in bold; —, zero values in the original data; mg/L, milligrams per liter; col/100 mL, colonies per 100 milliliters; µg/L, micrograms per liter; kg/event, kilogram per event; g/event, gram per event]

Constituent	Unit	Mean				Geometric mean			
		BMP1	BMP2	BMP3	BMP4	BMP1	BMP2	BMP3	BMP4
Event-mean concentrations									
Total suspended solids	mg/L	0.42	0.75	0.34	0.58	0.33	0.52	0.34	0.59
Total Kjeldahl nitrogen	mg/L	0.13	0.00	0.04	**0.47**	0.16	-0.02	0.03	**0.39**
Total phosphorus	mg/L	0.22	0.32	0.09	0.39	0.22	0.15	0.08	0.41
Total organic carbon	mg/L	0.19	0.03	0.08	0.47	0.18	0.05	0.05	0.39
Biochemical oxygen demand	mg/L	–0.28	0.08	0.08	**0.57**	–0.49	0.06	0.10	**0.68**
Chemcial oxygen demand	mg/L	0.07	–0.05	**0.14**	**0.48**	0.07	–0.08	**0.14**	**0.47**
Enterococci	col/100 mL	–0.73	0.15	0.44	0.29	–1.72	0.12	0.24	0.75
Escherichia coli	col/100 mL	–0.92	0.07	0.15	0.58	–0.89	–0.03	0.38	0.67
Total coliform	col/100 mL	–0.32	0.01	–0.01	0.08	–0.69	–0.16	–0.00	0.08
Dissolved cadmium	µg/L	**0.50**	0.01	0.00	0.20	**0.48**	–0.02	0.01	0.19
Total cadmium	µg/L	0.24	0.41	0.24	0.44	0.24	0.31	0.23	0.52
Particulate cadmium	µg/L	0.12	0.52	0.31	0.48	0.15	0.42	0.34	0.58
Dissolved copper	µg/L	0.40	0.21	0.01	0.35	0.34	0.22	–0.07	0.25
Total copper	µg/L	0.17	0.22	0.16	0.48	0.18	0.19	0.13	0.48
Particulate copper	µg/L	–0.15	0.24	0.27	0.54	—	—	—	0.57
Dissolved lead	µg/L	–0.25	0.22	–0.19	–1.16	–0.21	0.19	–0.30	–0.10
Total lead	µg/L	**0.31**	**0.43**	**0.18**	**0.52**	**0.25**	**0.33**	**0.15**	**0.61**
Particulate lead	µg/L	0.33	0.44	0.20	0.54	0.39	0.32	0.17	0.62
Dissolved nickel	µg/L	0.04	–0.09	0.06	**0.37**	0.04	–0.05	–0.04	**0.26**
Total nickel	µg/L	0.17	0.32	0.16	0.44	0.17	0.22	0.10	0.42
Particulate nickel	µg/L	0.35	0.66	0.28	0.53	—	0.56	0.21	—
Dissolved zinc	µg/L	0.27	–0.03	0.01	0.15	0.19	–0.01	–0.10	0.12
Total zinc	µg/L	**0.18**	**0.29**	**0.20**	**0.50**	**0.17**	**0.26**	**0.19**	**0.61**
Particulate zinc	µg/L	0.11	**0.47**	**0.21**	**0.53**	0.31	—	**–0.19**	**0.69**
Oil and grease	mg/L	0.43	0.38	–0.06	0.70	0.44	0.39	0.20	0.77
Suspended sediment finer than 63 microns	percent	–0.54	–0.71	–0.30	–0.36	–0.75	–1.66	–0.38	–0.40
Suspended sediment	mg/L	0.83	0.93	0.48	0.65	0.58	0.73	0.44	0.66
Storm-event loads									
Total suspended solids	kg/event	0.44	0.41	0.22	0.53	0.22	0.51	0.34	0.60
Total Kjeldahl nitrogen	kg/event	0.12	–0.03	–0.13	0.34	0.13	–0.03	0.00	0.40
Total phosphorus	kg/event	0.20	0.02	–0.07	0.28	0.20	0.14	0.05	0.42
Total organic carbon	kg/event	0.23	0.03	–0.03	0.33	0.11	0.04	0.01	0.40
Biochemical oxygen demand	kg/event	–0.52	–0.07	–0.04	**0.51**	–0.61	0.04	–0.05	**0.68**
Chemcial oxygen demand	kg/event	–0.06	0.05	0.04	**0.40**	–0.00	—	0.14	**0.48**
Dissolved cadmium	g/event	0.17	0.30	–0.03	0.20	0.40	0.18	0.01	0.20
Total cadmium	g/event	**0.18**	**0.21**	**0.13**	**0.40**	**0.17**	**0.30**	**0.23**	**0.53**
Particulate cadmium	g/event	0.18	0.25	**0.17**	**0.43**	0.06	0.41	**0.34**	**0.58**
Dissolved copper	g/event	0.21	0.28	–0.57	0.23	0.31	0.21	–0.07	0.26
Total copper	g/event	0.10	0.13	0.02	0.43	0.11	0.18	0.13	0.49
Particulate copper	g/event	0.02	–0.14	0.38	0.51	—	—	—	0.58
Dissolved lead	g/event	–0.18	0.24	**–1.69**	–0.48	–0.08	0.18	–0.30	–0.09
Total lead	g/event	0.28	0.21	0.02	0.52	0.21	0.32	0.15	0.62
Particulate lead	g/event	0.29	0.21	0.08	0.54	0.23	0.31	0.17	0.63
Dissolved nickel	g/event	–0.04	–0.05	–0.07	0.25	–0.05	–0.07	–0.04	0.27
Total nickel	g/event	0.14	0.12	0.05	0.36	0.10	0.21	0.10	0.43
Particulate nickel	g/event	0.31	0.35	0.17	0.47	—	0.56	0.21	—
Dissolved zinc	g/event	0.02	0.12	–0.25	0.18	0.12	–0.02	–0.10	0.13
Total zinc	g/event	**0.13**	**0.18**	0.04	**0.53**	**0.10**	**0.25**	0.19	**0.62**
Particulate zinc	g/event	0.18	**0.22**	**0.07**	**0.55**	0.07	—	**–0.15**	**0.69**
Oil and grease	kg/event	0.62	0.45	–0.21	0.78	—	0.38	0.17	0.77
Suspended sediment	kg/event	0.84	0.71	0.26	0.61	0.62	0.70	0.35	0.66

Table 22. Statistical summary of the comparison of percent efficiencies at selected best management practices (BMPs) in Beaufort and Colleton Counties, South Carolina, 2005–2006.

Constituent	Kruskal-Wallis test statistics				Comparison of percent reduction between inlet and outlet waters—Tukey test results				
	Chi-squared	Degrees of freedom	R-squared	Probability value		BMP1	BMP2	BMP3	BMP4
Event-mean concentrations									
Dissolved cadmium	10.920	3	0.247	0.012	Group	A	B	B	AB
					N	13	12	12	12
Total cadmium	5.362	3	0.136	0.147	Group	A	A	A	A
					N	13	12	12	12
Particulate cadmium	7.664	3	–0.175	0.054	Group	A	A	A	A
					N	13	12	12	12
Dissolved copper	4.742	3	0.089	0.192	Group	A	A	A	A
					N	13	12	12	12
Total copper	7.499	3	0.231	0.058	Group	A	A	A	A
					N	13	12	12	12
Particulate copper	8.430	3	0.150	0.038	Group	INCONCLUSIVE			
					N	13	12	12	12
Dissolved lead	3.117	3	0.036	0.374	Group	A	A	A	A
					N	13	12	12	12
Total lead	8.096	3	0.245	0.044	Group	B	AB	B	A
					N	13	12	12	12
Particulate lead	7.522	3	0.198	0.057	Group	A	A	A	A
					N	13	12	12	12
Dissolved nickel	9.710	3	0.195	0.021	Group	AB	B	B	A
					N	13	12	12	12
Total nickel	6.628	3	0.172	0.085	Group	A	A	A	A
					N	13	12	12	12
Particulate nickel	6.930	3	0.127	0.074	Group	A	A	A	A
					N	13	12	12	12
Dissolved zinc	3.985	3	0.095	0.263	Group	A	A	A	A
					N	13	12	12	12
Total zinc	10.398	3	0.277	0.016	Group	B	AB	B	A
					N	13	12	12	12
Particulate zinc	6.212	3	0.151	0.102	Group	B	AB	AB	A
					N	13	12	12	12
Total Kjeldahl nitrogen	13.328	3	0.292	0.004	Group	AB	B	B	A
					N	13	12	11	12
Total phosphorus	7.772	3	0.145	0.051	Group	A	A	A	A
					N	13	12	11	12
Turbidity	1.201	3	0.052	0.753	Group	A	A	A	A
					N	13	12	12	12
Total organic carbon	13.314	3	0.255	0.004	Group	AB	B	B	A
					N	13	12	11	12
Total suspended solids as residue	2.482	3	0.080	0.479	Group	A	A	A	A
					N	13	12	12	12
Biochemical oxygen demand	16.125	3	0.276	0.001	Group	B	AB	A	A
					N	13	12	12	11
Chemical oxygen demand	9.186	3	0.176	0.027	Group	B	AB	AB	A
					N	13	12	12	12
Enterococci	7.462	3	0.074	0.059	Group	A	A	A	A
					N	12	11	10	10
Escherichia coli	10.323	3	0.194	0.016	Group	B	AB	A	AB
					N	11	11	11	11
Suspended sediment finer than sand	3.151	3	0.192	0.369	Group	A	A	A	A
					N	12	11	12	12
Suspended sediment	1.633	3	0.045	0.652	Group	A	A	A	A
					N	13	11	12	12
Oil and grease	6.180	3	0.163	0.103	Group	A	A	A	A
					N	13	12	11	12

Table 22. Statistical summary of the comparison of percent efficiencies at selected best management practices (BMPs) in Beaufort and Colleton Counties, South Carolina, 2005–2006.—Continued

Constituent	Kruskal-Wallis test statistics				Comparison of percent reduction between inlet and outlet waters—Tukey test results				
	Chi-squared	Degrees of freedom	R-squared	Probability value		BMP1	BMP2	BMP3	BMP4
Event-mean loads									
Dissolved cadmium	7.465	3	0.202	0.059	Group	A	A	A	A
					N	11	12	12	12
Total cadmium	8.477	3	0.195	0.037	Group	B	AB	AB	A
					N	11	12	12	12
Particulate cadmium	10.440	3	0.232	0.015	Group	B	AB	AB	A
					N	11	12	12	12
Dissolved copper	3.901	3	0.088	0.272	Group	A	A	A	A
					N	11	12	12	12
Total copper	9.710	3	0.289	0.212	Group	B	B	B	A
					N	11	12	12	12
Particulate copper	11.477	3	0.202	0.009	Group	B	AB	AB	A
					N	10	12	11	12
Dissolved lead	2.23	3	0.043	0.526	Group	A	A	A	A
					N	11	12	12	12
Total lead	8.785	3	0.267	0.032	Group	B	AB	B	A
					N	11	12	12	12
Particulate lead	8.921	3	0.262	0.030	Group	B	AB	B	A
					N	11	12	12	12
Dissolved nickel	11.149	3	0.252	0.011	Group	B	B	B	A
					N	11	12	12	12
Total nickel	9.059	3	0.225	0.029	Group	B	AB	B	A
					N	11	12	12	12
Particulate nickel	7.168	3	0.143	0.067	Group	A	A	A	A
					N	11	12	12	12
Dissolved zinc	2.544	3	0.078	0.468	Group	A	A	A	A
					N	11	12	12	12
Total zinc	12.005	3	0.332	0.007	Group	B	B	B	A
					N	11	12	12	12
Particulate zinc	10.754	3	0.261	0.013	Group	B	AB	AB	A
					N	11	12	12	12
Total Kjeldahl nitrogen	12.4	3	0.308	0.006	Group	AB	B	B	A
					N	11	12	11	12
Total phosphorus	8.249	3	0.158	0.041	Group	INCONCLUSIVE			
					N	11	12	11	12
Total organic carbon	15.581	3	0.321	0.001	Group	B	B	B	A
					N	11	12	11	12
Total suspended solids as residue	4.256	3	0.126	0.235	Group	A	A	A	A
					N	11	12	12	12
Biochemical oxygen demand	14.333	3	0.288	0.003	Group	B	AB	A	A
					N	11	12	11	11
Chemical oxygen demand	10.979	3	0.176	0.0118	Group	B	AB	AB	A
					N	11	12	12	12
Suspended sediment	2.178	3	0.058	0.536	Group	A	A	A	A
					N	11	12	12	12
Oil and grease	6.357	3	0.164	0.096	Group	A	A	A	A
					N	11	12	11	12

Summary

From 2005 to 2006, the U.S. Geological Survey worked cooperatively with the South Carolina Department of Transportation in Beaufort and Colleton Counties, South Carolina, to assess the performance of four different structural devices that served as best management practices (BMPs). These structural devices were installed to mitigate the effects of stormwater runoff on waterways near State roads. The South Carolina Department of Transportation is required to address the quality of stormwater runoff from State-maintained roadways as part of the National Pollutant Discharge Elimination System stormwater program mandated in the Clean Water Act.

The performance assessment of the four structural BMP devices (identified as BMP1, BMP2, BMP3, and BMP4) was based on stormflow measurements and chemical analyses of stormwater-quality samples collected during a 20-month period from March 2005 through October 2006 that represented a range of seasons and rainfall intensities. A total of 49 sample sets that included stormwater from the inlet and outlet of each of the four structural devices were collected as flow-weighted composites to provide event-mean concentrations of suspended sediment, nutrients, and trace metals. Grab samples were collected to provide the first flush concentrations of oil and grease and fecal indicator bacteria.

A tiered statistical approach was used in the data analyses. Performances of the four structural BMPs were assessed individually based on how well the BMPs were able to reduce selected constituents. Descriptive statistics and nonparametric Wilcoxon signed-rank tests were applied to event-mean concentrations and loads in the water entering the inlet and in the water leaving the outlet of each BMP for each constituent to identify if significant reductions occurred. If significant reductions occurred, the BMP was considered efficient at reducing the constituent. To quantify efficiency, a simplistic approach was applied that computed mean and geometric mean efficiency ratios for the significantly reduced constituents at each BMP. Each BMP performance was ranked based on its computed efficiency ratios; however, the computed efficiency ratios were not sufficient to determine if statistical differences occurred in the performances of the four BMPs. Consequently, a more complex approach also applied statistical comparison tests to reduction percentages computed for individual storms (a modified approach to determine removal efficiency of individual storm loads) to determine if differences in event-mean concentrations, loads, and reduction percentages for significantly reduced constituents occurred among the four structural BMPs.

In some cases, the four BMPs had similar performance characteristics. Overall, the four BMPs were efficient at reducing suspended-sediment event-mean concentrations and loads in the stormwater entering the inlets of the BMPs to significantly lower event-mean concentrations and loads before discharging the stormwater from their outlet. The cumulative suspended-sediment event-mean loads in stormwater entering the inlet of each BMP from the sampled storms were 209 kilograms (kg) for BMP1, 141 kg for BMP2, 469 kg for BMP3, and 207 kg for BMP4 (a total of 1,026 kg or 1.13 tons). The amount of load that BMPs removed is operationally defined as the difference between the event-mean loads in the inlet water and in the outlet water for each storm event. The following cumulative suspended-sediment loads were removed: 175 kg by BMP1, 103 kg by BMP2, 153 kg by BMP3, and 127 kg by BMP4 (a total of 558 kg or 0.62 ton).

Additionally, all four BMPs tended to preferentially trap the sand-sized fraction of the sediment, thereby releasing a greater percentage of fine-grained (silt- and clay-sized fractions) sediment in the water discharging from the outlet. This preferential trapping of fine-grained sediment by the BMPs could explain, at least in part, why some of the BMPs were not successful at significantly reducing fecal bacteria, nutrients, and total organic carbon, including associated constituents of biochemical oxygen demand and chemical oxygen demand. These constituents have a tendency to attach to the fine-grained fractions of sediment. Bacterial analysis of the sediment identified residual pools of fecal bacterial colonies in all four BMPs, which could have been re-suspended during storm events and detected as an additional source of bacteria in water leaving the BMP outlets. The fecal indicator concentrations in the sediment and in the stormwater entering the inlet and leaving outlet of all four BMPs were consistently greater than established criteria (based on the South Carolina Department of Health and Environmental Control single-sample maximum level for enterococci or the U.S. Environmental Protection Agency recommended levels for *Escherichia coli*.

BMP1, BMP2, and BMP4 significantly lowered oil and grease concentrations in the stormwater before the water was discharged to the outlet. However, for BMP1, BMP2, and BMP3, oil and grease concentrations frequently were equal to or less than the laboratory reporting level and were reported as estimated or as less than 7 mg/L. Further evaluation assumed that an “irreducible concentration” for these oil and grease concentrations was the censoring level of 7 mg/L because all values measured and reported less than this were only semi-quantitative. Thus, the apparent poor performance of BMP3 could be attributed to oil and grease concentrations in stormwater that entered the inlet and exited the outlet being less than the irreducible concentration, which means that no further reductions were possible.

Overall, all four BMPs were efficient at significantly reducing total trace-metal event-mean concentrations. BMP3 and BMP4 were effective at reducing all particulate trace-metal event-mean concentrations in stormwater entering the inlet, and BMP4 was effective at reducing all particulate trace-metal event-mean loads.

Because hardness-dependent aquatic-life criteria have been established by the South Carolina Department of Health and Environmental Control, the event-mean concentrations of total metals in stormwater entering the inlet and leaving the outlet of each BMP were compared with the freshwater criteria for water with a hardness of 25 mg/L. For all four BMPs, total nickel event-mean concentrations in the inlet and outlet waters did not exceed the established criteria of 150 µg/L. For all four BMPs, total copper event-mean concentrations in the inlet and outlet waters did exceed the established criteria of 3.8 µg/L. Total cadmium event-mean concentrations in the inlet and outlet waters did not exceed the established criteria of 0.53 µg/L for BMP1, BMP2, and BMP3. For all four BMPs, a large percentage of the total lead and total zinc event-mean concentrations in the inlet waters exceeded the established criteria of 14 and 75 µg/L, respectively, but that percentage was reduced in the outlet water by each BMP.

A significant relation was determined among all four BMPs between the inlet water concentrations for several constituents (mainly trace metals such as zinc and nickel) and the reduction percentage. The relation identified a tendency for the BMP devices to exhibit greater reduction when the inlet water concentrations were larger and to exhibit less reductions when the inlet water concentrations were smaller—previously referred to as the irreducible concentration by the U.S. Environmental Protection Agency. Because the quantification of efficiency in this study was based on reduction percentages of the constituents between the stormwater entering the BMP inlet and leaving the outlet, a BMP receiving stormwater with greater inlet concentrations would appear to have better efficiency than a similarly capable BMP receiving stormwater with inlet concentrations near the irreducible concentration. Statistical assessments indicated that BMP4 had larger oil and grease concentrations, total and particulate copper, total and particulate cadmium, and total and particulate zinc event-mean concentrations than the other three BMPs. Therefore, some bias can be expected when comparing BMP performances in reducing trace-metal event-mean concentrations among the four BMPs.

For the significantly reduced constituents, dimensionless efficiency ratios were computed to quantify the removal efficiency of each BMP. Mean efficiency ratios for suspended-sediment event-mean concentrations varied among the four BMPs, and are listed from greatest to least: BMP2 (0.93), BMP1 (0.83), BMP4 (0.65), and BMP3 (0.48). Geometric mean efficiency ratios were similarly ranked. BMP2 had the greatest efficiency ratio (0.75) for total suspended solids event-mean concentrations, followed by BMP4 (0.58), then by BMP1 (0.42).

For oil and grease concentrations, simple comparison of the efficiency ratios was not sufficient because (1) oil and grease concentrations are not event-mean concentrations but rather were obtained from first flush grab samples; (2) oil and grease concentrations frequently were present at estimated or censored values in BMP1, BMP2, and BMP3, preventing accurate computations of means and geometric means; and (3) the inlet concentrations were found to be statistically larger at BMP4. Computed mean efficiency ratios for oil and grease are listed from greatest to least: BMP4 (0.70), BMP1 (0.43), and BMP2 (0.38).

Trace-metal event-mean concentrations and loads also required more than a simple comparison of the efficiency ratios because of the significantly higher inlet concentrations at BMP4. BMP4 consistently had significant reductions in total and particulate trace-metal event-mean concentrations. Computed mean efficiency ratios for the total and particulate metals at BMP4 were relatively consistent and ranged from 0.44 to 0.54. For particulate nickel, the mean efficiency ratio for BMP2 (0.66) was higher than that for BMP4 (0.53). Further evaluation of the BMP data, however, identified that the trace-metal event-mean concentrations in the outlet water were relatively similar among the BMPs, again in dictating that all BMPs were able to reduce the trace-metal event-mean concentrations to a certain irreducible level and that the BMPs with the lower inlet concentrations and lower efficiency ratios did not have significant reductions because the differences between the inlet and outlet concentrations were similar.

Differences among mean and geometric mean efficiency ratios of the BMPs did not conclusively indicate statistically significant differences among the BMPs. Consequently, a modified ISL method also was applied such that reduction percentages for constituents with EMCs and loads that were significantly different were computed for individual storms and used as input into a multiple comparison test to determine if differences occurred among BMPs. No statistical differences among the removal efficiency percentages for the four BMPs were determined for suspended-sediment event-mean concentrations, total suspended solids event-mean concentrations, or oil and grease concentrations. These statistical findings indicate that the BMP rankings by mean efficiency ratio were not significant and that no statistical differences occurred among the BMPs for these constituents. Additionally, BMP4 generally had statistically greater removal efficiency for total and particulate cadmium, copper, lead, and zinc than did BMP1, BMP2, and BMP3.

Statistical correlation tests were unable to identify a single major factor that could explain the large variability in inlet and outlet water concentrations and in removal efficiencies estimated by reduction percentage. Highly variable inlet and outlet concentrations for each BMP that produced highly variable reduction percentages were probably the result of multiple interacting factors, particularly rainfall intensity, the amount of rainfall between sampling events, traffic density, and the period of time since the last maintenance (clean out) of the BMP device.

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Appendixes A–D

Appendix A. Sample dates and times and rainfall conditions at four structural best management practice (BMP) sites in Beaufort and Colleton Counties, South Carolina.

[EST, Eastern Standard Time; ft³/s, cubic feet per second; in/hr, inch per hour; hr, hour; <, less than; >, greater than; E, estimated; —, no data]

Date	Season	BMP site	Time sampled (EST)	Inlet peak flow (ft³/s)	Inlet event mean flow (ft³/s)	Rainfall started (EST)	Amount of rainfall (inch)	Rainfall intensity (in/hr)	Rainfall duration (minutes)	Rainfall duration (hr)	72 Hours criteria (<, >)
4/7/2005	Spring	1	1259–1345	0.71	0.31	1225	0.12	0.09	80	1.33	>72
		2	1255–1340	0.52	0.21	1225	0.12	0.10	75	1.25	>72
		3	1157–1303	1.20	0.80	1225	0.12	0.19	38	0.63	>72
4/26/2005	Spring	1	1556–1630	0.25	0.13	—	—	—	—	—	—
8/27/2005	Summer	4	1305–1330	1.70	0.41	1245	0.31	0.41	45	0.75	>72
10/5/2005	Fall	4	1305–1419	0.03	0.02	1300	0.29	0.22	79	1.32	>72
12/5/2005	Fall	1	1524–1800	0.94	0.43	1530	1.19	0.48	150	2.50	<72 >24
		3	1627–1800	5.91	2.85	1530	1.19	0.48	150	2.50	<72 >24
		4	1400–1435	1.70	0.94	1400	0.14	0.24	35	0.58	<72 >24
12/15/2005	Fall	1	1428–1547	0.42	0.20	1430	0.13	0.10	77	1.28	>72
		3	1500–1610	E 0.43	E 0.22	1430	0.13	0.08	100	1.67	>72
		4	1325–1455	0.25	0.21	1315	0.1	0.07	90	1.50	>72
1/18/2006	Winter	1	0150–0410	0.70	0.35	115	0.41	0.14	175	2.92	>72
		4	2250–0150	0.80	0.34	2245	0.15	0.05	180	3.00	>72
2/2/2006	Winter	1	1547–1816	1.29	0.74	1530	1.5	0.54	166	2.77	<72 >24
		2	1539–1825	0.87	0.28	1530	1.51	0.52	175	2.92	<72 >24
		4	1510–1810	2.80	1.20	1515	1.12	0.37	180	3.00	<72 >24
3/21/2006	Winter	1	0834–1003	0.12	0.03	815	0.15	0.08	108	1.80	>72
		2	0902–0944	0.20	0.12	815	0.15	0.10	89	1.48	>72
		3	0902–1012	0.20	0.11	815	0.15	0.08	117	1.95	>72
		4	0820–0940	3.80	0.60	805	0.32	0.24	80	1.33	>72
4/8/2006	Spring	1	1536–1806	0.80	0.30	1530	0.77	0.30	156	2.60	>72
		2	1535–1755	1.50	0.75	1530	0.76	0.31	145	2.42	>72
		3	1549–1732	2.80	1.60	1530	0.73	0.36	122	2.03	>72
		4	1532–1756	0.54	0.21	1450	0.63	0.20	186	3.10	>72
4/26/2006	Spring	1	1725–1859	1.44	0.38	1730	0.78	0.53	89	1.48	>72
		2	1725–1838	1.50	0.73	1730	0.76	0.67	68	1.13	>72
		3	1725–1858	5.40	3.42	1730	0.78	0.53	88	1.47	>72
6/13/2006	Spring	1	0750–1045	E 0.20	E 0.07	745	0.13	0.04	180	3.00	>72
		2	0750–1045	0.41	0.11	745	0.13	0.04	180	3.00	>72
		3	0817–1130	E 0.92	E 0.63	745	0.26	0.07	225	3.75	>72
		4	1010–1310	1.40	0.70	935	0.61	0.17	215	3.58	>72
7/6/2006	Summer	1	1820–2031	—	—	1815	0.55	0.24	136	2.27	>72
		2	1822–1855	0.16	0.10	1815	0.54	0.81	40	0.67	>72
		3	1827–2000	E 2.50	E 1.45	1815	0.54	0.31	105	1.75	>72
		4	1800–1855	0.15	0.07	1725	0.06	0.04	90	1.50	>72
8/9/2006	Summer	1	1905–2006	2.43	0.64	1815	0.68	0.37	111	1.85	<72 >24
8/24/2006	Summer	3	1535–1838	11.64	5.11	1500	2.7	0.74	218	3.63	>72
8/31/2006	Summer	1	0145–0210	—	—	0:30	0.09	0.05	100	1.67	>72
		2	1020–1205	0.30	0.17	9:30	0.19	0.07	155	2.58	>72
		3	0957–1220	E 0.26	E 0.15	9:30	0.19	0.07	170	2.83	>72
		4	0211–0320	E 6.40	E 2.00	135	0.45	0.26	105	1.75	>72
9/7/2006	Summer	2	1615–1855	0.20	0.07	1515	0.37	0.10	220	3.67	<72 >24
		3	1620–1825	0.69	0.30	1515	0.26	0.08	190	3.17	<72 >24
9/19/2006	Summer	2	1540–1645	E 2.11	E 1.33	1540	0.58	0.54	65	1.08	<72 >24
		3	1550–1710	7.61	3.65	1540	0.59	0.44	80	1.33	<72 >24
		4	1640–1705	0.03	0.02	1640	0.16	0.38	25	0.42	>72
10/27/2006	Fall	2	0720–0900	E 0.47	E 0.42	715	0.07	0.04	100	1.67	>72
11/7/2006	Fall	2	0435–0530	0.06	0.04	300	0.07	0.08	55	0.92	>72

Appendix B. Constituents, reporting limits, and long-term detection limits for selected analyses used in the study.

Lab Code 2144
Description: COD-HACH (Chemical Oxygen Demand)
Analyzing Laboratory: USGS-National Water Quality Lab, Denver, CO

Parameter name	Lab code	Parameter code	M	CAS number	LT-MDL	RL	Unit	RL code
Chemical oxygen demand (COD)	2144	00340	OX004		N/A	10	mg/L	mrl

Container Requirements
125mL COD
Description: 125 mL Glass bottle, Bottle baked at 450 deg C by laboratory. Use unfiltered sample.
Treatment and Preservation: DO NOT RINSE BOTTLE. Prepare each sample to pH<2 with sulfuric acid (H2SO4), chill and maintain at 4 deg C: ship immediately
References
TWRI B5-A1/89

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Method ID: I-3561-89

Lab Code 2187
Description: Turbidity, broad band light (400-680 nm), detectors at angles including 90+/-30 degs, NTRU
Analyzing Laboratory: USGS-National Water Quality Lab, Denver, CO

Parameter name	Lab code	Parameter code	M	CAS number	LT-MDL	RL	Unit	RL code
Turbidity	2187	63676	TS098		N/A	2	NTRU	mrl

Container Requirements
500mL TBY
Description: 500 mL Polyethylene bottle. Use unfiltered sample to rinse bottles, chill collected sample
Treatment and Preservation: maintain at 4 deg.C, ship immediately. Dedicated bottle for lab code 2187
References
Std Meth 2130

Standard methods for the examination of water and wastewater (20th edition), 1998; Washington, D.C., American Public Health Association, American Water Works Association, and Water Environment Federation, 2130, p. 2-8 to 2-11.

Method ID: 2130

Lab Code 2125
Description: EPA Method 1664, Oil & Grease
Analyzing Laboratory: USGS-National Water Quality Lab, Denver, CO

Parameter name	Lab code	Parameter code	M	CAS number	LT-MDL	RL	Unit	RL code
Oil and grease	2125	00556	101		3	7	mg/L	lrl

Container Requirements
1L OAG - This test consumes the entire container.
Description: 1 L Glass bottle, amber
Treatment and Preservation: Bottle baked at 450 deg C by laboratory. DO NOT RINSE BOTTLE. Do not fill bottle beyond shoulder, add 2 mL of concentrated or 4 mL of 1:1 sulfuric acid (H2SO4) and mix, to adjust pH to <2. Chill sample and maintain at 4 deg C, ship immediately

References

EPA 1664A

N-Hexane Extractable Material (HEM; Oil and Grease) and Silica Gel Treated by N-Hexane Extractable Material (SGT-HEM; Non-polar Material) by Extraction and Gravimetry - Revision A (Approved at 40 CFR Parts 136 and 260, Not Approved at 40 CFR Part 141)
NWQL TM 96.08
Implementation of EPA Method 1664 for the Analysis of Oil and Grease or Total Petroleum Hydrocarbons in water, May 22, 1996

Appendix B. Constituents, reporting limits, and long-term detection limits for selected analyses used in the study.—Continued

Schedule 1995
Description: BMP metals, SC District
Analyzing Laboratory(s): USGS - National Water Quality Laboratory, Denver, CO

Analyte	Lab Code	Parameter Code	M	CAS Number	until 9/20/2006		after 10/1/2006		Unit	RL Type	Container
					LT-MDL	RL	LT-MDL	RL			
cadmium, dissolved	1788	01025	G	7440-43-9	0.02	0.04			µg/L	lrl	FA
cadmium, total	2376	01027	I	7440-43-9	0.02	0.04	0.009	0.018	µg/L	lrl	RA
copper, dissolved	3128	01040	G	7440-50-8	0.2	0.4			µg/L	lrl	FA
copper, total	3129	01042	H	7440-50-8	0.3	0.6	0.6	1.2	µg/L	lrl	RA
lead, dissolved	1792	01049	G	7439-92-1	0.04	0.08	0.06	1.2	µg/L	lrl	FA
lead, total	2380	01051	I	7439-92-1	0.03	0.06			µg/L	lrl	RA
nickel, dissolved	3130	01065	G	7440-02-0	0.03	0.06			µg/L	lrl	FA
nickel, total	3131	01067	I	7440-02-0	0.08	0.16			µg/L	lrl	RA
pH, laboratory	68	00403	A			0.1			pH	mrl	RU
specific conductance, laboratory	69	90095	A			2.6			µS/cm	mrl	RU
zinc, dissolved	3138	01090	G	7440-66-6	0.3	0.6			µg/L	lrl	FA
zinc, total	3139	01092	D	7440-66-6	1.0	2			µg/L	lrl	RA

Container Requirements

Quantity	Bottle
1	250mL FA Description: 250 mL Polyethylene bottle, acid-rinsed Treatment and Preservation: Filter through 0.45-um filter, use filtered sample to rinse containers and acidify sample with nitric acid (HNO3) to pH < 2
1	250mL RA Description: 250 mL Polyethylene bottle, acid-rinsed Treatment and Preservation: Use unfiltered sample to rinse bottles, then acidify collected sample with nitric acid (HNO3) to pH < 2
1	50mL RU Description: Treatment and Preservation: 250 or 500 mL Polyethylene bottle, Use unfiltered sample to rinse bottles

References

1. OFR 92-634

Faires, L.M., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of metals in water by inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 92-634, 28 p.

Method ID: I-2477-92

2. OFR 96-225

Hoffman, G.L., Fishman, M.J., and Garbarino, J.R., 1996, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—In-bottle acid digestion of whole-water samples: U.S. Geological Survey Open-File Report 96-225, 28 p.

Method ID: I-3486-95

3. OFR 98-165

Garbarino, J.R., and Struzeski, T.M., 1998, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory -- Determination of elements in whole-water digests using inductively coupled plasma- optical emission spectrometry and inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 98-165, 101 p.

Method ID: I-4471-97

4. TWRI B5-A1/89

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Method ID: I-2587-89 , I-2781-89

Appendix B. Constituents, reporting limits, and long-term detection limits for selected analyses used in the study.—Continued

Schedule 1040
Description: S1040 (NWQL schedule 1040)
Owner: CL
Analyzing Laboratory(s):
USGS-National Water Quality Lab, Denver, CO

Analyte	Lab Code	Parameter Code	M	CAS Number	LT-MDL	RL	Unit	RL Type	Container
Nitrogen, total ammonia + organic nitrogen	1986	00625	KJ008	17778-88-0	0.05	0.1	mg/L	lrl	WCA
Phosphorus, total	1984	00665	KJ009	7723-14-0	0.02	0.04	mg/L	lrl	WCA

CAS Registry Number® is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS Client Services.

Container Requirements

Quantity	Bottle
1	125mL WCA

Description: 125 mL Plain (translucent) polyethylene bottle, Use unfiltered sample to rinse bottles

Treatment and Preservation: acidify with 1 mL of 4.5N (4.5 normal) sulfuric acid (H2S04), chill and maintain at 4 deg C, ship immediately.

References

OFR 00-170

Patton, C.J., amd Truitt, E.P., 2000, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of ammonium plus organic nitrogen by a Kjeldahl digestion method and an automated photometric finish that includes digest cleanup by gas diffusion: U.S. Geological Survey Open-File Report 00-170, 31 p.

Method ID: I-4515-91

OFR 92-146

Patton, C.J., and Truitt, E.P., 1992, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of total phosphorus by a Kjeldahl digestion method and an automated colorimetric finish that includes dialysis: U.S. Geological Survey Open-File Report 92-146, 39 p.

Method ID: I-4610-91

Appendix C

Explanation

>	greater than
<	less than
%	percent
BMP1 intake	U.S. Geological Survey (USGS) station identification number (STAID), 322518808039571; station name, BMP1 intake upstream side US Hwy 21 near Beaufort, SC.
BMP1 outflow	USGS STAID, 322518808039572; station name, BMP1 outflow upstream side US Hwy 21 near Beaufort, SC.
BMP2 intake	USGS STAID, 322517008039551; station name, BMP2 intake D/S side US Hwy 21 near Beaufort, S.C.
BMP2 outflow	USGS STAID, 322517008039552; station name, BMP2 outflow D/S side US Hwy 21 near Beaufort, S.C.
BMP3 intake	USGS STAID, 322525908038381; station name, BMP3 intake east corner SC Hwy 802 near Beaufort, S.C.
BMP3 outflow	USGS STAID, 322525908038382; station name, BMP3 outflow east corner SC Hwy 802 near Beaufort, S.C.
BMP4 intake	USGS STAID, 324756508046271; station name, BMP4 intake S side I-95 Rest Area near Yemassee, SC.
BMP4 outflow	USGS STAID, 324756508046272; station name, BMP4 outflow S side I-95 Rest Area near Yemassee, SC.
°C	degrees Celsius
col/100 mL	colonies per 100 milliliters
E	estimated
ft^3/s	cubic feet per second
g/kg	grams per kilogram
M	detected value was below the minimum reporting level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mL	milliliters
mm	millimeters
µg/g	micrograms per gram
µg/L	micrograms per liter
µS/cm at 25 °C	microsiemens per centimeter at 25 degrees Celsius
NTRU	nephelometric turbidity units

Turbidity is from water, unfiltered, broad band light source (400–680 nm), detectors at multiple angles including 90 +/– 30 degrees, ratiometric correction.

Appendix C-1. Water-quality data from four structural best management practice sites, January 2005 through November 2006.

Date:	Apr 7 2005	Apr 26 2005	Dec 5 2005	Dec 15 2005	Jan 18 2006	Feb 2 2006	Mar 21 2006	Apr 8 2006	Apr 26 2006	Jun 13 2006	Jul 6 2006	Aug 9 2006	Aug 31 2006
Site:	BMP1 intake	BMP1 intake	BMP1 intake	BMP1 intake	BMP1 intake	BMP1 intake	BMP1 intake	BMP1 intake	BMP1 intake	BMP1 intake	BMP1 intake	BMP1 intake	BMP1 intake
Time:	1225	1610	1600	1500	0300	1650	0834	1651	1905	0917	2000	1835	0100
Parameter													
Discharge, mean for storm event, ft^3/s	0	0	0	0	0	0	0	0	0	E.0		0	
Discharge, peak for storm event, ft^3/s	0.71	0.25	0.94	0.42	0.7	1.3	0.12	0.8	1.4	E.20		2.4	
Precipitation total, inches per storm	0.12		1.2	0.13	0.41	1.5	0.15	0.77	0.78	0.13	0.55	0.68	0.09
Precipitation, duration of storm event, minutes	80		150	77	175	166	108	156	89	180	136	111	100
Sampling method, code	55	55	55	55		55		55	55				
Turbidity, NTRU	16	48	26	50	6.7	14	48	12	28	33	21	11	9.8
pH, water, unfiltered, field, standard units	7.1	6.7		7.2		6.3	6.2	6.5	7.6		6.4	5.9	6.8
pH, water, unfiltered, laboratory, standard units	6.2	6.5	7.8	6.9	7.7	7	7	7.1	6.7	6.7	6.8	7.4	6.7
Specific conductance, water, unfiltered, laboratory, µS/cm at 25 °C	44	113	46	90	93	32	162	60	70	184	121	43	221
Specific conductance, water, unfiltered, µS/cm at 25 °C	91	121		108		31	169	60	60		128	41	217
Temperature, air, °C	18.8	19.6							23.2				
Temperature, water, °C	18.4	20.4				11.9		18.8	10.2				
Hardness, water, mg/L as calcium carbonate	12	39	13	28	33	10	43	17	15	40	28	9	49
Calcium, water, filtered, mg/L	4.44	14.1	4.61	10.3	12	3.69	15.7	6.11	5.16	13.3	9.12	3.07	16.6
Magnesium, water, filtered, mg/L	0.289	0.885	0.34	0.685	0.727	0.214	1.02	0.433	0.392	1.51	1.38	0.385	1.93
Residue, total nonfilterable, mg/L	11	40	142	34	11	38	64	80	204	46	67	86	22
Ammonia plus organic nitrogen, water, unfiltered, mg/L as nitrogen	1.4	2.7	1.1	1.7	1.1	1.4	5.5	2.3	1.7	5.6	2	0.92	2.6
Phosphorus, water, unfiltered, mg/L	0.18	0.28	0.2	0.25	0.09	0.16	0.6	0.37	0.36	0.34	0.4	0.16	0.31
Organic carbon, water, unfiltered, mg/L	9.3	38.3	46.7	42.3	19.5	9.4	46	21.6	15.2	47.6	38	11.1	49.4
Biochemical oxygen demand, water, unfiltered, 5 days at 20 °C, mg/L	66.1	37.1	12.1	77.3	6.8	3.7	20.6	53.9	4.5	24	8.9	4.7	15.2
Chemical oxygen demand, high level, water, unfiltered, mg/L	60	150	70	150	60	30	200	120	80	170	130	50	140
Enterococci, mEI MF method, water, col/100 mL	14,000	9,300	1,500	4,610	332	454	886	8,160	464		<10	6,870	630
Escherichia coli, Defined Substrate Technology, water, most probable number per 100 mL			1,300	2,300	860	75	440	370	30	20,000	3,400	190	820
Fecal coliform, M-FC MF (0.7 micron) method, water, col/100 mL	6,000	36,000											
Total coliform, Defined Substrate Technology, water, most probable number per 100 mL			>24,000	17,000	7,700	1,300	7,700	13,000	2,600	24,000	>24,000	24,000	>24,000
Cadmium, water, filtered, µg/L	0.05	0.15	E.03	0.07	0.07	E.03	0.13	0.09	0.06	0.16	0.16	0.04	0.11
Cadmium, water, unfiltered, µg/L	0.14	0.44	0.28	0.34	0.09	0.14	0.47	0.32	0.41	0.34	0.32	0.17	0.2
Copper, water, filtered, µg/L	4.5	15.3	3.7	6.1	9.8	4.4	21	11.6	5.4	25.9	10.6	2.4	19.8
Copper, water, unfiltered, recoverable, µg/L	11.6	26.4	15.7	20.5	9.8	9.1	33.7	23.8	23.9	29.5	17	9.7	19.8
Lead, water, filtered, µg/L	0.32	0.64	0.26	0.21	0.15	0.11	1.76	0.47	0.43	1.1	0.58	0.23	0.47
Lead, water, unfiltered, recoverable, µg/L	5.71	14.3	14	24.9	1.52	8.33	23.6	15	42.2	22.2	14	15.7	3.52
Nickel, water, filtered, µg/L	1.5	4.71	1.56	3.23	3.21	0.86	6.27	3.85	2.93	7.6	5.33	0.93	6.2
Nickel, water, unfiltered, recoverable, µg/L	2.73	7.69	4.96	5.61	3.05	2.38	11	6.17	10.2	9.76	7.68	2.94	6.49
Zinc, water, filtered, µg/L	21.4	52	16.9	29.1	24.4	14.6	77.8	64.2	32.6	112	120	24	64.9
Zinc, water, unfiltered, recoverable, µg/L	52	146	105	128	30	61	209	151	152	172	152	76	77
Oil and grease, water, unfiltered, freon extraction, gravimetric, recoverable, mg/L	12	15	8	11	7	8	E7	11	9	E5	<7	<7	E4
9H-Fluorene, water, unfiltered, recoverable, µg/L						M					<.33		<.33
Acenaphthene, water, unfiltered, recoverable, µg/L						M					<.28		<.28
Acenaphthylene, water, unfiltered, recoverable, µg/L						<2					<.30		<.30
Anthracene, water, unfiltered, recoverable, µg/L						<2					<.39		<.39
Benzo[a]anthracene, water, unfiltered, recoverable, µg/L						M					<.26		<.26
Benzo[a]pyrene, water, unfiltered, recoverable, µg/L						M					M		<.33
Benzo[b]fluoranthene, water, unfiltered, recoverable, µg/L						M					<.40		<.40
Benzo[ghi]perylene, water, unfiltered, recoverable, µg/L						M					M		<.64
Benzo[k]fluoranthene, water, unfiltered, recoverable, µg/L						M					<.45		<.45
Chrysene, water, unfiltered, recoverable, µg/L						M					<.33		<.33
Dibenzo[a,h]anthracene, water, unfiltered, recoverable, µg/L						<3					<.70		<.70
Fluoranthene, water, unfiltered, recoverable, µg/L						M					M		<.30
Indeno[1,2,3-cd]pyrene, water, unfiltered, recoverable, µg/L						M					M		<.56
Nitrobenzene, water, unfiltered, recoverable, µg/L						<2					<.21		<.21
Phenanthrene, water, unfiltered, recoverable, µg/L						M					M		<.32
Pyrene, water, unfiltered, recoverable, µg/L						M					M		<.35
Trihalomethanes, water, unfiltered, calculated, µg/L													
Naphthalene, water, unfiltered, recoverable, µg/L						M					<.32		M
Suspended sediment, sieve diameter, percent smaller than 0.063 mm	49	91	23	58	68	62	87	45	12	87	54	29	95
Suspended sediment concentration, mg/L	43	51	204	96	10	51	104	148	2390	65	92	158	15

Appendix C-1. Water-quality data from four structural best management practice sites, January 2005 through November 2006.—Continued

Date:	Apr 7 2005	Apr 26 2005	Dec 5 2005	Dec 15 2005	Jan 18 2006	Feb 2 2006	Mar 21 2006	Apr 8 2006	Apr 26 2006	Jun 13 2006	Jul 6 2006	Aug 9 2006	Aug 31 2006
Site:	BMP1 outflow	BMP1 outflow	BMP1 outflow	BMP1 outflow	BMP1 outflow	BMP1 outflow	BMP1 outflow	BMP1 outflow	BMP1 outflow	BMP1 outflow	BMP1 outflow	BMP1 outflow	BMP1 outflow
Time:	1230	1610	1605	1510	0310	1650	0835	1652	1910	0918	2001	1836	0101
Parameter													
Discharge, mean for storm event, ft^3/s	0	0	0	0	0	0	0	0	0	E.0		0	
Discharge, peak for storm event, ft^3/s	0.71	0.25	0.94	0.42	0.7	1.3	0.12	0.8	1.4	E.20		2.4	
Precipitation total, inches per storm	0.12		1.2	0.13	0.41	1.5	0.15	0.77	0.78	0.13	0.55	0.68	0.09
Precipitation, duration of storm event, minutes	80		150	77	175	166	108	156	89	180	136	111	100
Sampling method, code	55	55	55	55		55		55	55				
Turbidity, NTRU	13	28	22	44	5.2	16	25	13	43	29	12	25	8.2
pH, water, unfiltered, field, standard units	7	6.4		7.7	6	6.4	6.5	6.6	8.2		6.5	6	6.5
pH, water, unfiltered, laboratory, standard units	6.5	6.3	7.8	7	7.3	7	7	6.9	6.9	6.7	6.9	7.2	6.6
Specific conductance, water, unfiltered, laboratory, µS/cm at 25 ºC	51	132	52	106	103	34	203	67	49	252	109	54	174
Specific conductance, water, unfiltered, µS/cm at 25 ºC	51	139		108	105	33	139	54	59		112	54	174
Temperature, air, ºC	19	19.6							22.6				
Temperature, water, ºC	19.2	20.1				10.5		15.8	10.8				
Hardness, water, mg/L as calcium carbonate	12	51	14	35	37	11	60	19	10	57	28	11	45
Calcium, water, filtered, mg/L	4.24	18.5	4.64	12.2	13.5	3.92	21.7	6.81	3.57	19.1	9.17	3.53	15.6
Magnesium, water, filtered, mg/L	0.355	1.13	0.51	1.02	0.883	0.241	1.45	0.514	0.37	2.28	1.18	0.529	1.56
Residue, total nonfilterable, mg/L	24	26	45	52	<10	32	46	80	71	40	22	30	<20
Ammonia plus organic nitrogen, water, unfiltered, mg/L as nitrogen	1.4	3.2	0.79	1.3	1.2	0.82	3.7	2.4	1.3	5.8	1.3	0.88	1.9
Phosphorus, water, unfiltered, mg/L	0.176	0.37	0.12	0.21	0.1	0.12	0.35	0.36	0.19	0.38	0.18	0.1	0.24
Organic carbon, water, unfiltered, mg/L	11.5	41.6	12.3	31.2	17.7	9.2	47.2	23.8	12.8	51.4	16.5	11.5	34.3
Biochemical oxygen demand, water, unfiltered, 5 days at 20 ºC, mg/L	99.4	46.5	8.3	59	20	18.7	28.6	60.8	10.2	40.1	11.2	5.8	20.5
Chemical oxygen demand, high level, water, unfiltered, mg/L	50	180	60	130	70	50	190	110	60	170	80	50	100
Enterococci, mEI MF method, water, col/100 mL	3,800	2,000	2,050	3,260	281	24,200	5,480	24,200	324		3,650	3,450	8,660
Escherichia coli, Defined Substrate Technology, water, most probable number per 100 mL			1,700	1,100	2,500	330	1,200	500	110	24,000	>24,000	310	570
Fecal coliform, M-FC MF (0.7 micron) method, water, col/100 mL	8,100	25,000											
Total coliform, Defined Substrate Technology, water, most probable number per 100 mL			>24,000	>24,000	12,000	8,200	>24,000	>24,000	24,000	24,000	9,800	24,000	>24,000
Cadmium, water, filtered, µg/L	0.06	E.03	<.04	E.02	0.06	E.03	E.03	0.09	E.03	E.03	0.08	0.04	0.05
Cadmium, water, unfiltered, µg/L	0.14	0.43	0.17	0.24	0.1	0.14	0.41	0.28	0.18	0.29	0.12	0.15	0.13
Copper, water, filtered, µg/L	4.6	6.2	2.5	3.7	7.2	3.5	7.3	11.4	4.6	6	8.5	2.7	16.3
Copper, water, unfiltered, recoverable, µg/L	14.3	25.1	11.5	16.3	9.2	9.4	31.5	22.7	13.5	25.2	8.1	7.8	13.5
Lead, water, filtered, µg/L	0.43	0.55	0.28	0.27	0.44	0.1	1.04	0.62	0.41	0.55	0.86	0.21	2.64
Lead, water, unfiltered, recoverable, µg/L	6.96	13.4	9.47	17.3	1.51	8.2	20.9	14	11.7	16.9	6.53	11	2.9
Nickel, water, filtered, µg/L	1.42	5.2	1.5	3.13	3.14	0.73	7.43	4.09	2.18	8.07	2.96	1.5	4.9
Nickel, water, unfiltered, recoverable, µg/L	3.44	8.03	3.61	4.6	2.84	2.18	11	5.98	4	9.8	3.28	3.03	5.45
Zinc, water, filtered, µg/L	25.1	35.5	15.6	24.7	24.7	13.4	33.9	69	26.9	58.7	65.1	28.1	54.7
Zinc, water, unfiltered, recoverable, µg/L	78	143	69	99	30	61	201	144	77	148	67	63	59
Oil and grease, water, unfiltered, freon extraction, gravimetric, recoverable, mg/L	E3	8	E3	9	<7		7	E6	<7	E6	<7	E5	<7
9H-Fluorene, water, unfiltered, recoverable, µg/L						M					<.33		<.33
Acenaphthene, water, unfiltered, recoverable, µg/L						<2					<.28		<.28
Acenaphthylene, water, unfiltered, recoverable, µg/L						<2					<.30		<.30
Anthracene, water, unfiltered, recoverable, µg/L						<2					<.39		<.39
Benzo[a]anthracene, water, unfiltered, recoverable, µg/L						M					<.26		<.26
Benzo[a]pyrene, water, unfiltered, recoverable, µg/L						M					<.33		<.33
Benzo[b]fluoranthene, water, unfiltered, recoverable, µg/L						M					<.40		<.40
Benzo[ghi]perylene, water, unfiltered, recoverable, µg/L						M					<.64		<.64
Benzo[k]fluoranthene, water, unfiltered, recoverable, µg/L						M					<.45		<.45
Chrysene, water, unfiltered, recoverable, µg/L						M					<.33		<.33
Dibenzo[a,h]anthracene, water, unfiltered, recoverable, µg/L						<3					<.70		<.70
Fluoranthene, water, unfiltered, recoverable, µg/L						M					<.30		<.30
Indeno[1,2,3-cd]pyrene, water, unfiltered, recoverable, µg/L						M					<.56		<.56
Nitrobenzene, water, unfiltered, recoverable, µg/L						<2					<.21		M
Phenanthrene, water, unfiltered, recoverable, µg/L						M					<.32		<.32
Pyrene, water, unfiltered, recoverable, µg/L						M					<.35		<.35
Trihalomethanes, water, unfiltered, calculated, µg/L													
Naphthalene, water, unfiltered, recoverable, µg/L						M					<.32		M
Suspended sediment, sieve diameter, percent smaller than 0.063 mm	93	98	80	98	94	97	99	89	61	99		81	90
Suspended sediment concentration, mg/L	19	43	47	46	5	31	76	71	97	44		47	14

Appendix C-1. Water-quality data from four structural best management practice sites, January 2005 through November 2006.—Continued

Date: Site: Time: Parameter	Apr 7 2005 BMP2 intake 1210	Feb 2 2006 BMP2 intake 1700	Mar 21 2006 BMP2 intake 0920	Apr 8 2006 BMP2 intake 1730	Apr 26 2006 BMP2 intake 1900	Jun 13 2006 BMP2 intake 0920	Jul 6 2006 BMP2 intake 1936	Aug 9 2006 BMP2 intake 1914	Aug 31 2006 BMP2 intake 1112	Sep 7 2006 BMP2 intake 1735	Sep 19 2006 BMP2 intake 1612	Oct 27 2006 BMP2 intake 0810	Nov 7 2006 BMP2 intake 0505
Discharge, mean for storm event, ft^3/s	0	0	0	0	0	0	0		0	0	E1	E.0	0
Discharge, peak for storm event, ft^3/s	0.52	0.87	0.2	1.5	1.5	0.41	0.16		0.3	0.2	E2.1	E.47	0.06
Precipitation total, inches per storm	0.12	1.5	0.15	0.76	0.76	0.13	0.54		0.19	0.37	E.58	0.07	0.07
Precipitation, duration of storm event, minutes	75	175	89	145	68	180	40		155	220	E65.0	100	55
Sampling method, code	55	55	55	55	55							55	
Turbidity, NTRU	17	13	37	23	27	22	40		34	30	14	25	9.3
pH, water, unfiltered, field, standard units	6.9	5.8	6.8	6.9	8.5		5.6		6.6	7.2	6.3	6.9	7.3
pH, water, unfiltered, laboratory, standard units	6	7.2	7.2	6	6.7	7	7.1		7.4	7.3	7.2	7.3	7.7
Specific conductance, water, unfiltered, laboratory, µS/cm at 25 ºC	88	28	244	150	68	308	164		82	71	49	324	306
Specific conductance, water, unfiltered, µS/cm at 25 ºC	96	27	255	152	411		118		80	68	45	486	349
Temperature, air, ºC	19		12.6	20.3	20.2								
Temperature, water, ºC	19.2	9.6	14.7	8.4	9.6								
Hardness, water, mg/L as calcium carbonate	19	9	59	26	11	48	34		20	19	11	62	64
Calcium, water, filtered, mg/L	6.11	3.21	20.2	7.96	3.43	13.6	11.3		6.33	6.23	3.53	19.2	20.1
Magnesium, water, filtered, mg/L	0.822	0.179	2.06	1.6	0.631	3.49	1.46		0.911	0.76	0.456	3.37	3.36
Residue, total nonfilterable, mg/L	180	38	82	94	83	44	1160		70	110	60	<20	<10
Ammonia plus organic nitrogen, water, unfiltered, mg/L as nitrogen	4.1	0.48	3.9	3.4	2.3	3.2	2.6		0.81	0.73	0.78	1.4	0.87
Phosphorus, water, unfiltered, mg/L	0.67	0.09	0.51	0.65	0.32	0.39	2.18		0.36	0.21	0.26	0.27	0.18
Organic carbon, water, unfiltered, mg/L	35.5	7.1	46	38.9	23.9	40.1	51.4		19.8	13.3	12.3	33.6	25.9
Biochemical oxygen demand, water, unfiltered, 5 days at 20 ºC, mg/L	160	45.8	113	38.2	29.2	66.1	24.4		7.3	8.3	6.5	12	7
Chemical oxygen demand, high level, water, unfiltered, mg/L	150	30	220	170	90	140	150		60	50	40	90	70
Enterococci, mEI MF method, water, col/100 mL	620	2490	3870	51	676		17300		25000	1750	4610	8660	5790
Escherichia coli, Defined Substrate Technology, water, most probable number per 100 mL		190	1200	41	2500	6100	2900		10000	5200	1000	3700	7600
Fecal coliform, M-FC MF (0.7 micron) method, water, col/100 mL	>6000												
Total coliform, Defined Substrate Technology, water, most probable number per 100 mL		12000	>24000	370	24000	25000	25000			25000	25000	>24000	>24000
Cadmium, water, filtered, µg/L	0.05	<.04	0.11	0.1	<.04	0.12	0.08		E.03	<.04	E.03	0.05	0.07
Cadmium, water, unfiltered, µg/L	0.18	0.12	0.3	0.28	0.22	0.24	1.23		0.19	0.14	0.16	0.16	0.1
Copper, water, filtered, µg/L	8.7	3.4	18.5	20.5	3.4	14	10		8.3	4.5	5.6	13.8	13.9
Copper, water, unfiltered, recoverable, µg/L	14.7	7.2	29.2	24.5	13.9	21.7	44.6		13.2	10.8	9.2	22.2	16.9
Lead, water, filtered, µg/L	0.31	0.2	0.85	1.17	0.58	0.78	0.52		1.02	0.4	0.89	0.67	2.31
Lead, water, unfiltered, recoverable, µg/L	11.5	8.31	18.7	18.7	18.1	16.1	79.1		16.1	12.1	9.34	8.42	5.61
Nickel, water, filtered, µg/L	1.97	0.52	5.68	3.72	1.12	4.3	3.71		1.8	1.2	1.2	2.6	2.2
Nickel, water, unfiltered, recoverable, µg/L	4.82	1.78	7.85	5.25	3.38	5.97	21.5		3.46	3.02	2.32	3.41	2.47
Zinc, water, filtered, µg/L	43.6	9.4	72.8	96.2	17.5	69.7	41.8		31.8	12.7	22.9	27.7	31.1
Zinc, water, unfiltered, recoverable, µg/L	79	49	147	159	98	120	345		80	64	66	65	43
Oil and grease, water, unfiltered, freon extraction, gravimetric, recoverable, mg/L	9	E6	13	8	15	12	E5	E5	7	E5	E6	10	8
9H-Fluorene, water, unfiltered, recoverable, µg/L		M							<.33	<.33	<.33	<.33	<.33
Acenaphthene, water, unfiltered, recoverable, µg/L		<2							<.28	<.28	<.28	<.28	<.28
Acenaphthylene, water, unfiltered, recoverable, µg/L		<2							<.30	<.30	<.30	<.30	<.30
Anthracene, water, unfiltered, recoverable, µg/L		<2							M	<.39	<.39	<.39	M
Benzo[a]anthracene, water, unfiltered, recoverable, µg/L		<2							<.26	M	M	M	<.26
Benzo[a]pyrene, water, unfiltered, recoverable, µg/L		M							<.33	M	M	M	M
Benzo[b]fluoranthene, water, unfiltered, recoverable, µg/L		M							<.40	M	M	M	M
Benzo[ghi]perylene, water, unfiltered, recoverable, µg/L		M							<.64	M	M	M	<.64
Benzo[k]fluoranthene, water, unfiltered, recoverable, µg/L		M							<.45	M	M	M	<.45
Chrysene, water, unfiltered, recoverable, µg/L		<3							<.33	M	M	M	<.33
Dibenzo[a,h]anthracene, water, unfiltered, recoverable, µg/L		<3							<.70	<.70	<.70	<.70	<.70
Fluoranthene, water, unfiltered, recoverable, µg/L		M							M	M	M	M	M
Indeno[1,2,3-cd]pyrene, water, unfiltered, recoverable, µg/L		M							<.56	M	M	M	<.56
Nitrobenzene, water, unfiltered, recoverable, µg/L		<2							<.21	<.21	<.21	<.21	<.21
Phenanthrene, water, unfiltered, recoverable, µg/L		M							M	M	M	M	M
Pyrene, water, unfiltered, recoverable, µg/L		M							M	M	M	M	M
Trihalomethanes, water, unfiltered, calculated, µg/L													
Naphthalene, water, unfiltered, recoverable, µg/L		M							M	M	M	M	M
Suspended sediment, sieve diameter, percent smaller than 0.063 mm	52	58	79	60	74	28	2		5	6	75	79	42
Suspended sediment concentration, mg/L	78	53	88	119	97	143	6550		665	493	52	37	22

Appendix C-1. Water-quality data from four structural best management practice sites, January 2005 through November 2006.—Continued

Date: / Site: / Time: / Parameter	Apr 7 2005 BMP2 outflow 1215	Feb 2 2006 BMP2 outflow 1700	Mar 21 2006 BMP2 outflow 0923	Apr 8 2006 BMP2 outflow 1740	Apr 26 2006 BMP2 outflow 1905	Jun 13 2006 BMP2 outflow 0923	Jul 6 2006 BMP2 outflow 1937	Aug 9 2006 BMP2 outflow 1915	Aug 31 2006 BMP2 outflow 1113	Sep 7 2006 BMP2 outflow 1736	Sep 19 2006 BMP2 outflow 1613	Oct 27 2006 BMP2 outflow 0811	Nov 7 2006 BMP2 outflow 0510
Discharge, mean for storm event, ft^3/s	0	0	0	0	0	0	0		0	0	E1	E.0	0
Discharge, peak for storm event, ft^3/s	0.52	0.87	0.2	1.5	1.5	0.41	0.16		0.3	0.2	E2.1	E.47	0.06
Precipitation total, inches per storm	0.12	1.5	0.15	0.76	0.76	0.13	0.54		0.19	0.37	0.58	0.07	0.07
Precipitation, duration of storm event, minutes	75	175	89	145	68	180	40		155	220	65	100	55
Sampling method, code	55	55	55	55	55							55	
Turbidity, NTRU	22	9.4	30	20	24	18	26		31	25	13	19	6.1
pH, water, unfiltered, field, standard units	6.6	6	6.7	7.8	7.4		6.4			7.2	6.2	6.9	7.1
pH, water, unfiltered, laboratory, standard units	6	7.2	6.8	7	6.4	7	6.7		7.4	7.4	7.6	7.1	7.3
Specific conductance, water, unfiltered, laboratory, µS/cm at 25 ºC	104	31	250	152	72	511	185		90	84	56	337	297
Specific conductance, water, unfiltered, µS/cm at 25 ºC	116	29	251	160	71		169			80	53	339	286
Temperature, air, ºC	18.9		9.7	17.1									
Temperature, water, ºC	19.2	11.2	13	9.5	14.5								
Hardness, water, mg/L as calcium carbonate	26	10	64	29	13	79	47		21	22	15	80	65
Calcium, water, filtered, mg/L	8.66	3.6	22.3	8.95	4.08	22	15.3		6.91	7.16	4.96	25.7	20.7
Magnesium, water, filtered, mg/L	1.16	0.234	2.07	1.7	0.607	5.74	2.19		1.03	0.91	0.556	3.8	3.13
Residue, total nonfilterable, mg/L	40	26	48	70	94	26	60		36	26	33	<19	<10
Ammonia plus organic nitrogen, water, unfiltered, mg/L as nitrogen	3.6	0.54	3.5	3.5	2	3.8	2.7		0.79	0.75	0.88	1.4	1
Phosphorus, water, unfiltered, mg/L	0.61	0.1	0.42	0.66	0.31	0.44	0.37		0.29	0.15	0.27	0.35	0.2
Organic carbon, water, unfiltered, mg/L	39.5	6.5	38.6	39.6	15.3	48.5	43.3		18.9	13.9	10.6	32.3	28.8
Biochemical oxygen demand, water, unfiltered, 5 days at 20 ºC, mg/L	186	11.5	51.8	63.5	29.4	60.3	20.7		7.2	10.1	6.7	13	15
Chemical oxygen demand, high level, water, unfiltered, mg/L	150	30	180	180	80	160	150		60	50		90	80
Enterococci, mEI MF method, water, col/100 mL	1500	311	2100	41	1720		17300		17300	2490	4110	6870	6130
Escherichia coli, Defined Substrate Technology, water, most probable number per 100 mL		410	1400	97	2500	13000	6500		6100	3600	1700	1800	1100
Fecal coliform, M-FC MF (0.7 micron) method, water, col/100 mL	1700												
Total coliform, Defined Substrate Technology, water, most probable number per 100 mL		6600	>24000	2900	24000	25000	25000			25000	25000	>24000	>24000
Cadmium, water, filtered, µg/L	0.06	E.03	0.13	0.08	E.03	E.03	0.13		E.03	E.03	E.03	0.05	0.06
Cadmium, water, unfiltered, µg/L	0.14	0.11	0.25	0.24	0.22	0.2	0.32		0.11	0.09	0.11	0.1	0.07
Copper, water, filtered, µg/L	10.1	2	17.8	13.6	3.8	6.1	11.6		5.7	4.5	3.4	11.4	8.8
Copper, water, unfiltered, recoverable, µg/L	9.9	6.5	25.5	22	13.7	20	21.3		10.2	9.4	8	16.5	14.2
Lead, water, filtered, µg/L	0.26	0.17	0.88	0.51	0.61	0.87	0.81		0.6	0.29	0.47	1.54	0.6
Lead, water, unfiltered, recoverable, µg/L	5.26	7.68	12.7	15.3	15.4	15.1	18.3		11.8	7.5	7.73	6.23	4.13
Nickel, water, filtered, µg/L	2.28	0.54	5.53	4.04	1.21	4.67	5.56		1.7	1.2	0.96	2.6	2.4
Nickel, water, unfiltered, recoverable, µg/L	2.4	1.54	7.51	5.07	3.31	5.95	6.53		2.54	2.25	1.85	3.09	2.52
Zinc, water, filtered, µg/L	52.4	11.3	83	78.3	21.4	46.8	94.3		20.2	15.6	18.1	25.9	24.2
Zinc, water, unfiltered, recoverable, µg/L	52	44	123	138	91	104	157		55	46	49	42	33
Oil and grease, water, unfiltered, freon extraction, gravimetric, recoverable, mg/L	E6	E6	8	<7	E4	11	E5	E6	E5	E5	E4	<7	E3
9H-Fluorene, water, unfiltered, recoverable, µg/L		M					<.33		<.33	<.33	<.33	<.33	<.33
Acenaphthene, water, unfiltered, recoverable, µg/L		<2					<.28		<.28	<.28	<.28	<.28	<.28
Acenaphthylene, water, unfiltered, recoverable, µg/L		<2					<.30		<.30	<.30	<.30	<.30	<.30
Anthracene, water, unfiltered, recoverable, µg/L		<2					M		<.39	<.39	M	<.39	<.39
Benzo[a]anthracene, water, unfiltered, recoverable, µg/L		M					M		<.26	M	M	<.26	<.26
Benzo[a]pyrene, water, unfiltered, recoverable, µg/L		M					M		<.33	M	M	<.33	<.33
Benzo[b]fluoranthene, water, unfiltered, recoverable, µg/L		M					M		<.40	M	M	M	M
Benzo[ghi]perylene, water, unfiltered, recoverable, µg/L		M					<.64		<.64	M	M	M	<.64
Benzo[k]fluoranthene, water, unfiltered, recoverable, µg/L		M					M		<.45	M	M	M	<.45
Chrysene, water, unfiltered, recoverable, µg/L		M					M		<.33	M	M	<.33	<.33
Dibenzo[a,h]anthracene, water, unfiltered, recoverable, µg/L		<3					<.70		<.70	<.70	<.70	<.70	<.70
Fluoranthene, water, unfiltered, recoverable, µg/L		M					M		M	M	M	M	<.30
Indeno[1,2,3-cd]pyrene, water, unfiltered, recoverable, µg/L		M					<.56		<.56	M	M	M	<.56
Nitrobenzene, water, unfiltered, recoverable, µg/L		<2					<.21		<.21	<.21	<.21	M	<.21
Phenanthrene, water, unfiltered, recoverable, µg/L		M					M		<.32	M	M	<.32	<.32
Pyrene, water, unfiltered, recoverable, µg/L		M					M		M	M	M	M	<.35
Trihalomethanes, water, unfiltered, calculated, µg/L													
Naphthalene, water, unfiltered, recoverable, µg/L		M					<.32		M	M	M	M	M
Suspended sediment, sieve diameter, percent smaller than 0.063 mm	81	59		80	77	96	55		94	77	75	96	87
Suspended sediment concentration, mg/L	29	41		74	89	43	109		28	29	38	20	11

Appendix C-1. Water-quality data from four structural best management practice sites, January 2005 through November 2006.—Continued

Date: Site: Time: Parameter	Apr 7 2005 BMP3 intake 1230	May 4 2005 BMP3 intake 1230	Dec 5 2005 BMP3 intake 1700	Dec 15 2005 BMP3 intake 1535	Mar 21 2006 BMP3 intake 0933	Apr 8 2006 BMP3 intake 1730	Apr 26 2006 BMP3 intake 1801	Jun 13 2006 BMP3 intake 0948	Jul 6 2006 BMP3 intake 1908	Jul 6 2006 BMP3 intake 1910	Aug 9 2006 BMP3 intake 1912	Aug 24 2006 BMP3 intake 1708	Aug 31 2006 BMP3 intake 1106	Aug 31 2006 BMP3 intake 1108	Sep 7 2006 BMP3 intake 1722
Discharge, mean for storm event, ft³/s	0		3	E.0	0	2	3	E.0	E1			5	E.0		0
Discharge, peak for storm event, ft³/s	1.2		5.9	E.43	0.2	2.8	5.4	E.92	E2.5			12	E.26		0.69
Precipitation total, inches per storm	0.12		1.2	0.13	0.15	0.73	0.78	0.26	0.54			2.7	0.19		0.26
Precipitation, duration of storm event, minutes	38		150	100	117	122	88	225	105			218	170		190
Sampling method, code	55		55	55	55	55	55								
Turbidity, NTRU	31		30	97	72	28	33	28	25			14	48		32
pH, water, unfiltered, field, standard units	6.8			4.5	7.1	7.4	6.8		6.9				7.1		9.4
pH, water, unfiltered, laboratory, standard units	6.3		7.8	7.6	6.7	6.8	6.3	6.9	6.6			7.7	7.4		6.9
Specific conductance, water, unfiltered, laboratory, µS/cm at 25 °C	78		31	95	152	69	41	113	66			19	73		55
Specific conductance, water, unfiltered, µS/cm at 25 °C	83			97	148	86	34		64				71		144
Temperature, air, °C	19.5				9.2	13									
Temperature, water, °C	19.5				11.8	10									
Hardness, water, mg/L as calcium carbonate	28		10	35	52	24	11	41	20			6	26		19
Calcium, water, filtered, mg/L	10.5		3.68	13	19.1	8.98	3.94	15.2	7.2			2.06	9.42		7.22
Magnesium, water, filtered, mg/L	0.53		0.21	0.703	0.901	0.427	0.193	0.736	0.383			0.103	0.487		0.327
Residue, total nonfilterable, mg/L	47		101	100	136	80	95	46	90			48	102		38
Ammonia plus organic nitrogen, water, unfiltered, mg/L as nitrogen	2.6		1.2	1.9	4.2	2.8	1.6	2.4				0.64	1.3		1
Phosphorus, water, unfiltered, mg/L	0.293		0.21	0.35	0.52	0.37	0.28	0.28				0.15	0.26		0.17
Organic carbon, water, unfiltered, mg/L	32.6		13.2	34.1	59	37.2	16.5	50.6				7.9	25.7		15.9
Biochemical oxygen demand, water, unfiltered, 5 days at 20 °C, mg/L	68.5		12.1	13.2	23	21.9	15	43.9	21.3			2	5.5		5
Chemical oxygen demand, high level, water, unfiltered, mg/L	140		90	140	230	170	90	180	110			40	90		60
Enterococci, mEI MF method, water, col/100 mL	12000		19900	6130	373	2140	2330		30			17300			512
Escherichia coli, Defined Substrate Technology, water, most probable number per 100 mL			5200	2900	10000	6500	6900	7300	360			1400	2400		20000
Fecal coliform, M-FC MF (0.7 micron) method, water, col/100 mL	36000														
Total coliform, Defined Substrate Technology, water, most probable number per 100 mL			>24000	>24000	24000	20000	>24000	25000	25000			25000	24000		25000
Cadmium, water, filtered, µg/L	0.06		<.04	0.04	0.09	0.08	E.03	0.1	0.06			<.04	E.02		E.03
Cadmium, water, unfiltered, µg/L	0.19		0.2	0.31	0.41	0.24	0.21	0.2	0.2			0.08	0.18		0.13
Copper, water, filtered, µg/L	7.7		2.2	5.1	16.2	12.1	4.6	14.4	16.3			1.5	6.6		4.8
Copper, water, unfiltered, recoverable, µg/L	18.2		13.1	22.2	39.4	21.9	12.8	20.7	13.5			6.4	17		11.2
Lead, water, filtered, µg/L	0.37		0.16	0.12	0.84	0.76	0.75	0.7	1.56			0.15	1.21		0.38
Lead, water, unfiltered, recoverable, µg/L	10.8		14.8	27.7	36.9	19	18.4	18.9	13.2			7.45	19.9		12.4
Nickel, water, filtered, µg/L	3.23		1.1	3.07	8.41	5.73	1.63	6.44	3.56			0.32	2		1.3
Nickel, water, unfiltered, recoverable, µg/L	3.65		4.21	6.31	14.9	7.84	4.11	8.18	5.14			1.62	4.63		2.9
Zinc, water, filtered, µg/L	29.5		9.3	14.1	41.5	56.5	16.3	43.6	87.8			5.7	12.9		10.1
Zinc, water, unfiltered, recoverable, µg/L	98		78	135	183	121	74	86	88			35	75		49
Oil and grease, water, unfiltered, freon extraction, gravimetric, recoverable, mg/L	E6		E6	11	E5	E4	<7	E5			E5	E4	9		E6
9H-Fluorene, water, unfiltered, recoverable, µg/L												<.33	<.33		<.33
Acenaphthene, water, unfiltered, recoverable, µg/L												M	<.28		<.28
Acenaphthylene, water, unfiltered, recoverable, µg/L												M	<.30		<.30
Anthracene, water, unfiltered, recoverable, µg/L												M	<.39		<.39
Benzo[a]anthracene, water, unfiltered, recoverable, µg/L												M	<.26		M
Benzo[a]pyrene, water, unfiltered, recoverable, µg/L												M	<.33		M
Benzo[b]fluoranthene, water, unfiltered, recoverable, µg/L												M	<.40		M
Benzo[ghi]perylene, water, unfiltered, recoverable, µg/L												M	M		M
Benzo[k]fluoranthene, water, unfiltered, recoverable, µg/L												M	<.45		M
Chrysene, water, unfiltered, recoverable, µg/L												M	<.33		M
Dibenzo[a,h]anthracene, water, unfiltered, recoverable, µg/L												<.70	<.70		<.70
Fluoranthene, water, unfiltered, recoverable, µg/L												M	M		M
Indeno[1,2,3-cd]pyrene, water, unfiltered, recoverable, µg/L												M	<.56		M
Nitrobenzene, water, unfiltered, recoverable, µg/L												<.21	<.21		<.21
Phenanthrene, water, unfiltered, recoverable, µg/L												M	<.32		M
Pyrene, water, unfiltered, recoverable, µg/L												M	M		M
Trihalomethanes, water, unfiltered, calculated, µg/L															
Naphthalene, water, unfiltered, recoverable, µg/L												<.32	<.32		M
Suspended sediment, sieve diameter, percent smaller than 0.063 mm	94		60	91	69	91	63	96	28	30		42		36	78
Suspended sediment concentration, mg/L	49		126	103	215	85	127	47	255	215		83		167	55

Appendix C-1. Water-quality data from four structural best management practice sites, January 2005 through November 2006.—Continued

Date: Site: Time: Parameter	Sep 19 2006 BMP3 intake 1630	Apr 7 2005 BMP3 outflow 1235	Dec 5 2005 BMP3 outflow 1705	Dec 15 2005 BMP3 outflow 1536	Mar 21 2006 BMP3 outflow 0945	Apr 8 2006 BMP3 outflow 1740	Apr 26 2006 BMP3 outflow 1802	Jun 13 2006 BMP3 outflow 0958	Jul 6 2006 BMP3 outflow 1918	Aug 9 2006 BMP3 outflow 1913	Aug 24 2006 BMP3 outflow 1709	Aug 31 2006 BMP3 outflow 1115	Sep 7 2006 BMP3 outflow 1724	Sep 19 2006 BMP3 outflow 1631	Sep 19 2006 BMP3 outflow 1710
Discharge, mean for storm event, ft³/s	4	0	3	E.0	0	2	3	E.0	E1		5	E.0	0	4	
Discharge, peak for storm event, ft³/s	7.6	1.2	5.9	E.43	0.2	2.8	5.4	E.92	E2.5		12	E.26	0.69	7.6	
Precipitation total, inches per storm	0.59	0.12	1.2	0.13	0.15	0.73	0.78	0.26	0.54		2.7	0.19	0.26	0.59	
Precipitation, duration of storm event, minutes	80	38	150	100	117	122	88	225	105		218	170	190	80	
Sampling method, code		55	55	55	55	55	55								
Turbidity, NTRU	19	25	23	56	44	33	35	22	16		18	29	28	14	
pH, water, unfiltered, field, standard units	6.4	6.8		6.7	7.2	7	6.9		6.8		6.6	6.9	6.9	6.1	
pH, water, unfiltered, laboratory, standard units	6.8	6.3	7.8	7.5	6.8	7.3	6.5	7.2	6.7		7.4	7.7	6.7	6.6	
Specific conductance, water, unfiltered, laboratory, µS/cm at 25 °C	33	85	34	104	152	92	43	119	61		21	74	57	34	
Specific conductance, water, unfiltered, µS/cm at 25 °C	29			106	150	86	39		62		25	89	53	34	
Temperature, air, °C		19.5			8.6	17.8									
Temperature, water, °C		19.4			10.7	9.3									
Hardness, water, mg/L as calcium carbonate	10	32	11	40	55	35	13	46	20		6	25	20	10	
Calcium, water, filtered, mg/L	3.6	11.9	4.01	14.7	20.6	13	4.83	17.1	7.34		2.25	9.37	7.44	3.8	
Magnesium, water, filtered, mg/L	0.208	0.581	0.236	0.789	0.895	0.555	0.233	0.737	0.379		0.115	0.5	0.326	0.212	
Residue, total nonfilterable, mg/L	60	47	62	46	82	86	78	34	30		46	32	35	42	
Ammonia plus organic nitrogen, water, unfiltered, mg/L as nitrogen	0.78	2.6	1	1.5	3.7	3.3	1.7	2.5	1.4		0.98	0.84	0.83	0.96	
Phosphorus, water, unfiltered, mg/L	0.15	0.297	0.16	0.29	0.36	0.44	0.28	0.29	0.2		0.2	0.16	0.14	0.2	
Organic carbon, water, unfiltered, mg/L	14.3	36.1	13.5	26.4	50	39.3	18.3	41.3	25.4		9.5	20.4	13.6	13.1	
Biochemical oxygen demand, water, unfiltered, 5 days at 20 °C, mg/L	8.1	60	8.9	8.5	22.7	33.6	14.3	33.7	18.9		1.6	5.4	4.2	9.4	
Chemical oxygen demand, high level, water, unfiltered, mg/L	50	130	60	110	190	180	90	140	90		50	50	50	50	
Enterococci, mEI MF method, water, col/100 mL	2190	9300	6870	985	712	1500	4350		194		10500		223	801	
Escherichia coli, Defined Substrate Technology, water, most probable number per 100 mL	860		1700	480	>24000	4400	7700	910	390		780	5800	6100	810	
Fecal coliform, M-FC MF (0.7 micron) method, water, col/100 mL		28000													
Total coliform, Defined Substrate Technology, water, most probable number per 100 mL	25000		>24000	20000	>24000	>24000	>24000	25000	25000		25000		25000	25000	
Cadmium, water, filtered, µg/L	E.02	0.06	E.02	E.02	0.08	0.09	<.04	0.08	0.07		E.02	E.02	0.06	E.03	
Cadmium, water, unfiltered, µg/L	0.16	0.18	0.15	0.23	0.27	0.25	0.16	0.15	0.1		0.1	0.1	0.11	0.11	
Copper, water, filtered, µg/L	2.9	7.4	2.7	2.8	13.7	14.2	3.6	10.3	17		7.9	6.3	4.3	3.7	
Copper, water, unfiltered, recoverable, µg/L	7.6	13.6	10.1	16.1	28.3	23.3	12.7	17.4	11.9		7.4	10.7	10.4	8.8	
Lead, water, filtered, µg/L	0.17	0.4	0.23	0.28	0.89	0.76	0.43	0.69	1.63		1.8	0.84	0.3	0.27	
Lead, water, unfiltered, recoverable, µg/L	8.5	10.3	11.6	18.9	25.4	18.8	17.1	16.5	8.96		9.07	12.8	9.95	10.4	
Nickel, water, filtered, µg/L	0.75	3.65	1.17	3.04	5.74	6.15	1.64	5.79	3.14		0.52	2.1	1.3	1.03	
Nickel, water, unfiltered, recoverable, µg/L	1.99	5.19	3.06	5.59	9.18	7.44	3.98	7.22	3.76		1.9	3.13	2.45	2.38	
Zinc, water, filtered, µg/L	10.4	33.8	10	11.3	38.7	69.3	14.9	36.7	62.8		18.2	16.2	10.8	12	
Zinc, water, unfiltered, recoverable, µg/L	44	72	59	95	122	136	73	71	52		41	42	38	52	
Oil and grease, water, unfiltered, freon extraction, gravimetric, recoverable, mg/L	E4	E4	E4	E6	E7	E3	E6	14	<7	<7	<7	<7	<7	21	
9H-Fluorene, water, unfiltered, recoverable, µg/L	<.33								<.33		M	<.33	<.33	<.33	
Acenaphthene, water, unfiltered, recoverable, µg/L	<.28								<.28		M	<.28	<.28	<.28	
Acenaphthylene, water, unfiltered, recoverable, µg/L	<.30								<.30		<.30	<.30	<.30	<.30	
Anthracene, water, unfiltered, recoverable, µg/L	<.39								<.39		M	<.39	<.39	<.39	
Benzo[a]anthracene, water, unfiltered, recoverable, µg/L	M								<.26		M	<.26	M	M	
Benzo[a]pyrene, water, unfiltered, recoverable, µg/L	M								<.33		M	<.33	M	M	
Benzo[b]fluoranthene, water, unfiltered, recoverable, µg/L	M								<.40		M	<.40	M	M	
Benzo[ghi]perylene, water, unfiltered, recoverable, µg/L	M								<.64		M	<.64	M	M	
Benzo[k]fluoranthene, water, unfiltered, recoverable, µg/L	M								<.45		M	<.45	M	M	
Chrysene, water, unfiltered, recoverable, µg/L	M								M		M	<.33	M	M	
Dibenzo[a,h]anthracene, water, unfiltered, recoverable, µg/L	<.70								<.70		<.70	<.70	<.70	<.70	
Fluoranthene, water, unfiltered, recoverable, µg/L	M								M		M	M	M	M	
Indeno[1,2,3-cd]pyrene, water, unfiltered, recoverable, µg/L	M								<.56		M	<.56	M	M	
Nitrobenzene, water, unfiltered, recoverable, µg/L	<.21								<.21		<.21	<.21	<.21	<.21	
Phenanthrene, water, unfiltered, recoverable, µg/L	M								<.32		M	<.32	M	M	
Pyrene, water, unfiltered, recoverable, µg/L	M								M		M	M	M	M	
Trihalomethanes, water, unfiltered, calculated, µg/L															
Naphthalene, water, unfiltered, recoverable, µg/L	<.32								<.32		M	<.32	M	M	
Suspended sediment, sieve diameter, percent smaller than 0.063 mm	77	96	92		99	93	85	97	89		62	97	91		83
Suspended sediment concentration, mg/L	52	41	59		84	97	93	38	41		72	30	38		54

Appendix C-1. Water-quality data from four structural best management practice sites, January 2005 through November 2006.—Continued

Date: / Site: / Time: / Parameter	Aug 27 2005 BMP4 intake 1515	Oct 5 2005 BMP4 intake 1440	Dec 5 2005 BMP4 intake 1430	Dec 15 2005 BMP4 intake 1415	Jan 18 2006 BMP4 intake 0020	Feb 2 2006 BMP4 intake 1640	Mar 21 2006 BMP4 intake 0900	Apr 8 2006 BMP4 intake 1644	Jun 13 2006 BMP4 intake 1140	Jul 6 2006 BMP4 intake 1915	Aug 31 2006 BMP4 intake 0240	Sep 19 2006 BMP4 intake 1652
Discharge, mean for storm event, ft³/s	0	0	0	0	0	1	0		0	0	E2	0
Discharge, peak for storm event, ft³/s	1.7	0.03	1.7	0.25	0.8	2.8	3.8	0.54	1.4	0.15	E6.4	0.03
Precipitation total, inches per storm	0.31	0.29	0.14	0.1	0.15	1.1	0.32	0.63	0.61	0.06	0.45	0.16
Precipitation, duration of storm event, minutes	45	79	35	90	180	180	80	186	215	90	105	25
Sampling method, code	55		55	55	55			55				
Turbidity, NTRU	12	19	17	140	48	16	46	84	70	430	24	55
pH, water, unfiltered, field, standard units	6.7			7.3	6.7	5.8	6.6	6.1		6.6	7	6.9
pH, water, unfiltered, laboratory, standard units	7.4	8	7.5	7.5	6.8	6.9	7.4	7.1	7.1	6.6	6.6	7.3
Specific conductance, water, unfiltered, laboratory, µS/cm at 25 ºC	80	102	101	284	220	70	89	560	110	373	93	101
Specific conductance, water, unfiltered, µS/cm at 25 ºC	69			317	233	67	75	332		374	81	93
Temperature, air, ºC												
Temperature, water, ºC	18.4							14.4			14.9	
Hardness, water, mg/L as calcium carbonate	23	27	23	58	47	15	17	69	30	110	24	24
Calcium, water, filtered, mg/L	8.64	10.2	8.57	21.9	17.4	5.77	6.24	25.7	11.5	39.6	9.07	9.14
Magnesium, water, filtered, mg/L	0.264	0.366	0.38	0.882	0.768	0.214	0.232	1.15	0.391	1.6	0.345	0.331
Residue, total nonfilterable, mg/L	34	80	76	96	54	58	216	118	258	280	84	235
Ammonia plus organic nitrogen, water, unfiltered, mg/L as nitrogen	2.7	6.3	5.4	15	13	3.3	5.9	53	9.4	42	4.5	7.1
Phosphorus, water, unfiltered, mg/L	0.43	0.7	0.82	1.21	1.05	0.52	1	3.62	1.29	2.06	0.52	1.06
Organic carbon, water, unfiltered, mg/L	15.1	13.2	27.8	44.5	40.6	15.8	38.1	96.1	37.9	129	20	41.1
Biochemical oxygen demand, water, unfiltered, 5 days at 20 ºC, mg/L		28.9	42.4	81.8	51.6	90.4	178	297	78.1	127	3.2	19
Chemical oxygen demand, high level, water, unfiltered, mg/L	20	100	120	150	130	80	180	370	190	500	90	160
Enterococci, mEI MF method, water, col/100 mL		25000	9210	4350	8300	1190	14100	14100		1520	17300	25000
Escherichia coli, Defined Substrate Technology, water, most probable number per 100 mL		12000	4900	>24000	95	280	>24000	1500	570	1500	25000	450
Fecal coliform, M-FC MF (0.7 micron) method, water, col/100 mL												
Total coliform, Defined Substrate Technology, water, most probable number per 100 mL		25000	>24000	>24000	>24000	5800	>24000	>24000	25000	>24000	25000	25000
Cadmium, water, filtered, µg/L	0.04	0.05	0.11	0.1	0.17	0.05	0.04	0.17	E.03	0.07	E.03	0.04
Cadmium, water, unfiltered, µg/L	0.26	0.46	0.44	0.55	0.46	0.35	1.01	0.57	0.84	0.72	0.36	0.84
Copper, water, filtered, µg/L	5.7	7.1	9.7	12.1	18.7	4	4.8	35.1	8.7	38.6	11.3	9.4
Copper, water, unfiltered, recoverable, µg/L	16.2	25.8	25.6	38.5	29.7	17.4	53.7	57.9	59	84.9	27.5	49
Lead, water, filtered, µg/L	0.18	E.08	0.18	0.09	0.19	0.14	0.21	0.22	0.16	0.09	0.58	0.1
Lead, water, unfiltered, recoverable, µg/L	7.59	14.5	9.29	9.96	6.23	8.1	27.4	8.07	28.7	14.2	13.2	26.1
Nickel, water, filtered, µg/L	1.54	2.21	2.09	4.65	6.36	1.2	1.37	8.24	1.71	11.1	1.7	2.1
Nickel, water, unfiltered, recoverable, µg/L	2.8	4.38	3.73	6.35	7.55	2.83	6.76	8.59	6.58	15	3.67	7.04
Zinc, water, filtered, µg/L	27.3	20.1	31.9	28	55	20.5	29.5	107	36.8	40	37.3	26.6
Zinc, water, unfiltered, recoverable, µg/L	164	441	351	336	232	303	1150	369	1130	438	468	947
Oil and grease, water, unfiltered, freon extraction, gravimetric, recoverable, mg/L	9	59	30	16	10	52	12	12	20	16	12	28
9H-Fluorene, water, unfiltered, recoverable, µg/L						M				<.33		<.33
Acenaphthene, water, unfiltered, recoverable, µg/L						<2				<.28		<.28
Acenaphthylene, water, unfiltered, recoverable, µg/L						<2				<.30		M
Anthracene, water, unfiltered, recoverable, µg/L						<2				<.39		M
Benzo[a]anthracene, water, unfiltered, recoverable, µg/L						M				<.26		M
Benzo[a]pyrene, water, unfiltered, recoverable, µg/L						M				<.33		M
Benzo[b]fluoranthene, water, unfiltered, recoverable, µg/L						M				<.40		2
Benzo[ghi]perylene, water, unfiltered, recoverable, µg/L						M				<.64		M
Benzo[k]fluoranthene, water, unfiltered, recoverable, µg/L						M				<.45		M
Chrysene, water, unfiltered, recoverable, µg/L						M				<.33		2
Dibenzo[a,h]anthracene, water, unfiltered, recoverable, µg/L						<3				<.70		<.70
Fluoranthene, water, unfiltered, recoverable, µg/L						M				<.30		1
Indeno[1,2,3-cd]pyrene, water, unfiltered, recoverable, µg/L						M				<.56		M
Nitrobenzene, water, unfiltered, recoverable, µg/L						<2				<.21		M
Phenanthrene, water, unfiltered, recoverable, µg/L						M				<.32		M
Pyrene, water, unfiltered, recoverable, µg/L						M				<.35		3
Trihalomethanes, water, unfiltered, calculated, µg/L												
Naphthalene, water, unfiltered, recoverable, µg/L						M				<.32		M
Suspended sediment, sieve diameter, percent smaller than 0.063 mm	35	42	26	64	65	49	44	77	27	88	36	42
Suspended sediment concentration, mg/L	54	77	114	135	68	64	284	104	329	437	126	257

Appendix C-1. Water-quality data from four structural best management practice sites, January 2005 through November 2006.—Continued

Date: Site: Time: Parameter	Aug 27 2005 BMP4 outflow 1515	Oct 5 2005 BMP4 outflow 1440	Dec 5 2005 BMP4 outflow 1435	Dec 15 2005 BMP4 outflow 1416	Jan 18 2006 BMP4 outflow 0021	Feb 2 2006 BMP4 outflow 1641	Mar 21 2006 BMP4 outflow 0901	Apr 8 2006 BMP4 outflow 1645	Jun 13 2006 BMP4 outflow 1141	Jul 6 2006 BMP4 outflow 1920	Aug 31 2006 BMP4 outflow 0245	Sep 19 2006 BMP4 outflow 1653
Discharge, mean for storm event, ft³/s	0	0	0	0	0	1	0	0	0	0	E2	0
Discharge, peak for storm event, ft³/s	1.7	0.03	1.7	0.25	0.8	2.8	3.8	0.54	1.4	0.15	E6.4	0.03
Precipitation total, inches per storm	0.31	0.29	0.14	0.1	0.15	1.1	0.32	0.63	0.61	0.06	0.45	0.16
Precipitation, duration of storm event, minutes	45	79	35	90	180	180	80	186	215	90	105	25
Sampling method, code	55	55	55	55	55			55				
Turbidity, NTRU	14	17	21	50	42	25	43	62	26	30	11	30
pH, water, unfiltered, field, standard units	6.5	6.7		7.6	6.6	6.2	6.9	6.3		6.7	7	6.5
pH, water, unfiltered, laboratory, standard units	7.2	7.3	7.3	7.4	7	6.9	7.3	6.8	6.9	6.9	7	7
Specific conductance, water, unfiltered, laboratory, µS/cm at 25 ºC	79	90	103	214	189	71	89	286	110	137	75	98
Specific conductance, water, unfiltered, µS/cm at 25 ºC	73	88		218	202	66	75	233		141	67	93
Temperature, air, ºC												
Temperature, water, ºC	19.1	22.8						11.4			16.5	
Hardness, water, mg/L as calcium carbonate	21	25	23	46	44	16	17	50	32	41	19	25
Calcium, water, filtered, mg/L	8.1	9.33	8.71	17.2	16.5	6.03	6.31	18.4	11.9	15.1	7	9.2
Magnesium, water, filtered, mg/L	0.254	0.397	0.414	0.831	0.781	0.232	0.248	0.925	0.436	0.889	0.306	0.402
Residue, total nonfilterable, mg/L	13	27	47	34	60	62	210	48	42	22	32	78
Ammonia plus organic nitrogen, water, unfiltered, mg/L as nitrogen	2	4.6	5.4	9.9	12	3.2	5.9	29	6.9	4.2	1.9	3.6
Phosphorus, water, unfiltered, mg/L	0.34	0.53	0.74	0.73	0.9	0.53	0.94	2.21	0.81	0.11	0.32	0.57
Organic carbon, water, unfiltered, mg/L	11	10.3	23.5	26.9	33	16.1	30	51.8	24.9	16.7	10.1	23.1
Biochemical oxygen demand, water, unfiltered, 5 days at 20 ºC, mg/L		13.1	39.7	7.9	37.8	26.5	9.8	186	76.3	1.1	3.8	24.6
Chemical oxygen demand, high level, water, unfiltered, mg/L	20	60	100	90	110	90	160	200	100	50	10	100
Enterococci, mEI MF method, water, col/100 mL		>24200	2600	63	3040	201	496	11200		175	25000	17300
Escherichia coli, Defined Substrate Technology, water, most probable number per 100 mL		12000	700	63	110	290	3300	1200	480	86	25000	2300
Fecal coliform, M-FC MF (0.7 micron) method, water, col/100 mL												
Total coliform, Defined Substrate Technology, water, most probable number per 100 mL		>24000	>24000	24000	>24000	20000	7300	>24000	25000	10000	25000	25000
Cadmium, water, filtered, µg/L	0.04	0.05	0.13	0.07	0.13	E.03	0.05	0.1	E.03	E.02	E.03	0.04
Cadmium, water, unfiltered, µg/L	0.18	0.22	0.33	0.24	0.36	0.34	1.04	0.27	0.19	E.04	0.2	0.41
Copper, water, filtered, µg/L	6.3	5.7	9.2	7.6	14.1	4.2	14.4	19.7	9.1	4.2	5.6	7.5
Copper, water, unfiltered, recoverable, µg/L	12.4	13.7	20.1	17.6	23.5	17.3	54.3	32.5	18.4	6.2	12.8	25.3
Lead, water, filtered, µg/L	0.16	0.09	0.16	E.05	0.12	0.24	2.93	0.18	0.25	<.08	0.33	0.26
Lead, water, unfiltered, recoverable, µg/L	2.93	4.72	6.16	3.23	5.92	7.94	27.3	3.75	4.65	0.54	4.65	12.1
Nickel, water, filtered, µg/L	1.54	2.04	2.08	3.18	4.84	1.21	1.46	4.96	1.64	2.15	0.98	1.6
Nickel, water, unfiltered, recoverable, µg/L	2.03	2.87	3.35	3.18	5.67	2.89	6.67	4.99	2.61	2.06	1.85	4.01
Zinc, water, filtered, µg/L	23.8	22.1	30.3	25.7	49.7	18.6	46.6	67.1	33.3	16.6	23.6	34.5
Zinc, water, unfiltered, recoverable, µg/L	67	133	223	99	205	278	1210	178	157	22	174	415
Oil and grease, water, unfiltered, freon extraction, gravimetric, recoverable, mg/L	E5	13	<7	E5	E6	<7	<7	14	<7	<7	13	18
9H-Fluorene, water, unfiltered, recoverable, µg/L						M				<.33		<.33
Acenaphthene, water, unfiltered, recoverable, µg/L						<2				<.28		<.28
Acenaphthylene, water, unfiltered, recoverable, µg/L						<2				<.30		M
Anthracene, water, unfiltered, recoverable, µg/L						<2				<.39		M
Benzo[a]anthracene, water, unfiltered, recoverable, µg/L						M				<.26		M
Benzo[a]pyrene, water, unfiltered, recoverable, µg/L						M				<.33		M
Benzo[b]fluoranthene, water, unfiltered, recoverable, µg/L						M				<.40		M
Benzo[ghi]perylene, water, unfiltered, recoverable, µg/L						M				<.64		M
Benzo[k]fluoranthene, water, unfiltered, recoverable, µg/L						M				<.45		M
Chrysene, water, unfiltered, recoverable, µg/L						M				<.33		M
Dibenzo[a,h]anthracene, water, unfiltered, recoverable, µg/L						<3				<.70		<.70
Fluoranthene, water, unfiltered, recoverable, µg/L						M				<.30		M
Indeno[1,2,3-cd]pyrene, water, unfiltered, recoverable, µg/L						M				<.56		M
Nitrobenzene, water, unfiltered, recoverable, µg/L						<2				<.21		M
Phenanthrene, water, unfiltered, recoverable, µg/L						M				<.32		M
Pyrene, water, unfiltered, recoverable, µg/L						M				<.35		M
Trihalomethanes, water, unfiltered, calculated, µg/L												
Naphthalene, water, unfiltered, recoverable, µg/L						M				<.32		M
Suspended sediment, sieve diameter, percent smaller than 0.063 mm	40	65	56	96	76	54	45	88	77	97	52	63
Suspended sediment concentration, mg/L	16	21	56	38	61	64	233	61	40	21	35	81

Appendix C-2. Sediment-quality data from four structural best management practice sites, January 2005 through November 2006.

Date:	**May 4 2005**	**Oct 11 2005**	**May 4 2006**	**Nov 28 2006**	**May 4 2005**	**Oct 11 2005**	**May 4 2006**
Site:	**BMP2 intake**	**BMP2 intake**	**BMP2 intake**	**BMP2 intake**	**BMP1 intake**	**BMP1 intake**	**BMP1 intake**
Time:	**1130**	**1300**	**1130**	**1130**	**1310**	**1530**	**1310**
Sample type:	**Sediment**	**Sediment**	**Sediment**	**Sediment**	**Sediment**	**Sediment**	**Sediment**
Parameter							
Moisture content, fraction of dry weight, %	29	33	29	22	5.7	32	6
Sampling method, code		55				55	
Phosphorus, bed sediment, total, dry weight, mg/kg	130	320		1800	160	220	
Carbon (inorganic plus organic), bed sediment, dry weight, %		8.2	1.8	2.3		2.6	2.8
Inorganic carbon, bed sediment, dry weight, %		0.4	0.39	0.58		0.7	0.3
Organic carbon, bed sediment, dry weight, %		7.8	1.4	1.7		1.9	2.5
Organic carbon, bed sediment, total, dry weight, g/kg							
Enterococci, mEI MF method, water, col/100 mL		1530		311		14100	
Escherichia coli, Defined Substrate Technology, water, most probable number per 100 mL		50000	910	5200		3900	180
Total coliform, Defined Substrate Technology, water, most probable number per 100 mL		>24000	>24000	>24000		>24000	>24000
Cadmium, bed sediment, recoverable, dry weight, µg/g	0.16	0.41	0.2	0.11	0.17	0.22	0.2
Chromium, bed sediment, recoverable, dry weight, µg/g	4.4	13	4.4	5.5	6.6	8	6.6
Cobalt, bed sediment, recoverable, dry weight, µg/g	0.5	1.2	0.5	0.9	0.78	0.67	0.8
Copper, bed sediment, recoverable, dry weight, µg/g	6	21	6	<6	59	7	59
Iron, bed sediment, total, dry weight, µg/g	1800	4200	1800	3200	2600	2100	2600
Lead, bed sediment, recoverable, dry weight, µg/g	11	35	11	10	150	19	150
Manganese, bed sediment, recoverable, dry weight, µg/g	36	82	36	66	49	30	49
Mercury, bed sediment, recoverable, dry weight, µg/g			0.011	<.007			0.008
Nickel, bed sediment, recoverable, dry weight, µg/g	3.5	7.9	3.5	5	3.6	4.5	3.6
Zinc, bed sediment, recoverable, dry weight, µg/g	52	270	52	54	74	70	74
Bed sediment, dry sieved, sieve diameter, percent smaller than 0.063 mm			1				1
Bed sediment, dry sieved, sieve diameter, percent smaller than 0.125 mm			9				9
Bed sediment, dry sieved, sieve diameter, percent smaller than 0.25 mm			72				64
Bed sediment, dry sieved, sieve diameter, percent smaller than 0.5 mm			84				75
Bed sediment, dry sieved, sieve diameter, percent smaller than 1 mm			92				85
Bed sediment, dry sieved, sieve diameter, percent smaller than 2 mm			98				92
Bed sediment, dry sieved, sieve diameter, percent smaller than 4 mm			100				94
Bed sediment, dry sieved, sieve diameter, percent smaller than 8 mm							94
Bed sediment, dry sieved, sieve diameter, percent smaller than 16 mm							95
Bed sediment, dry sieved, sieve diameter, percent smaller than 63 mm							100
Bed sediment, fall diameter (deionized water), percent smaller than 0.002 mm							0
Bed sediment, fall diameter (deionized water), percent smaller than 0.004 mm							0
Bed sediment, fall diameter (deionized water), percent smaller than 0.008 mm							0
Bed sediment, fall diameter (deionized water), percent smaller than 0.016 mm							1
Bed sediment, fall diameter (deionized water), percent smaller than 0.031 mm							1

Appendix C-2. Sediment-quality data from four structural best management practice sites, January 2005 through November 2006.—Continued

Date:	Oct 25 2006	Oct 11 2005	May 4 2006	Oct 25 2006	Oct 11 2005	May 4 2006	Oct 25 2006	May 4 2005
Site:	BMP1 intake	BMP3 intake	BMP3 intake	BMP3 intake	BMP4 intake	BMP4 intake	BMP4 intake	BMP4 outflow
Time:	1320	1400	1230	1210	1000	0900	0945	0930
Sample type:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Parameter								
Moisture content, fraction of dry weight, %	31	86	25	30	22	38	25	38
Sampling method, code		55			55			
Phosphorus, bed sediment, total, dry weight, mg/kg	230	1000		190	90		140	190
Carbon (inorganic plus organic), bed sediment, dry weight, %	2.6	23	0.74	1.2	0.7	5.2	3.1	
Inorganic carbon, bed sediment, dry weight, %	0.46	0.06	0.02	0.03	0.08	0.02	0.12	
Organic carbon, bed sediment, dry weight, %	2.2	23	0.72	1.2	0.62	5.2	3	
Organic carbon, bed sediment, total, dry weight, g/kg								
Enterococci, mEI MF method, water, col/100 mL	256	3870		295	31		6490	
Escherichia coli, Defined Substrate Technology, water, most probable number per 100 mL	98	3300	560	4600	96	8200	2500	
Total coliform, Defined Substrate Technology, water, most probable number per 100 mL	2200	>24000	24000	>24000	5500	>24000	>24000	
Cadmium, bed sediment, recoverable, dry weight, µg/g	0.2	1.3	0.1	0.07	0.1	0.6	0.28	0.56
Chromium, bed sediment, recoverable, dry weight, µg/g	11	37	2.5	5.6	7.2	17	50	17
Cobalt, bed sediment, recoverable, dry weight, µg/g	0.8	3.7	0.3	0.4	0.81	1.6	2.1	1.6
Copper, bed sediment, recoverable, dry weight, µg/g	11	70	5	3	11	42	34	42
Iron, bed sediment, total, dry weight, µg/g	2900	9900	900	1400	3900	6200	16000	6200
Lead, bed sediment, recoverable, dry weight, µg/g	41	91	4.3	6.4	7.4	19	10	19
Manganese, bed sediment, recoverable, dry weight, µg/g	45	150	12	21	31	44	100	44
Mercury, bed sediment, recoverable, dry weight, µg/g	0.016		0.007	0.013		0.018	0.008	
Nickel, bed sediment, recoverable, dry weight, µg/g	3.9	30	1.8	3.6	2.8	6.3	32	6.3
Zinc, bed sediment, recoverable, dry weight, µg/g	68	520	33	42	79	750	930	750
Bed sediment, dry sieved, sieve diameter, percent smaller than 0.063 mm			1			3		
Bed sediment, dry sieved, sieve diameter, percent smaller than 0.125 mm			8			5		
Bed sediment, dry sieved, sieve diameter, percent smaller than 0.25 mm			93			28		
Bed sediment, dry sieved, sieve diameter, percent smaller than 0.5 mm			97			65		
Bed sediment, dry sieved, sieve diameter, percent smaller than 1 mm			99			92		
Bed sediment, dry sieved, sieve diameter, percent smaller than 2 mm			100			98		
Bed sediment, dry sieved, sieve diameter, percent smaller than 4 mm						100		
Bed sediment, dry sieved, sieve diameter, percent smaller than 8 mm								
Bed sediment, dry sieved, sieve diameter, percent smaller than 16 mm								
Bed sediment, dry sieved, sieve diameter, percent smaller than 63 mm								
Bed sediment, fall diameter (deionized water), percent smaller than 0.002 mm						1		
Bed sediment, fall diameter (deionized water), percent smaller than 0.004 mm						1		
Bed sediment, fall diameter (deionized water), percent smaller than 0.008 mm						1		
Bed sediment, fall diameter (deionized water), percent smaller than 0.016 mm						2		
Bed sediment, fall diameter (deionized water), percent smaller than 0.031 mm						2		

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